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Aquatic Plant Control Research Program

Framework Development for Rapid Assessment and Economic Valuation of Feral Swine Damage to Wetland Terrain

A Pilot Study at US Army Corps of Engineers–Somerville Lake, Texas

Nathan R. Beane, Nicole M. Didero, Sophie McKee,
Jeremiah L. Psiropoulos, Stephanie Shwiff,
William Tomlinson, Jaybus Price, and Heather Theel

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Nathan R. Beane, William Tomlinson,
Jaybus Price, and Heather Theel

*US Army Engineer Research and Development
Center (ERDC)
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199*

Stephanie Shwiff

*US Department of Agriculture (USDA)–Animal and
Plant Health Inspection Service (APHIS)
Wildlife Services (WS)
National Wildlife Research Center (NWRC)
4101 LaPorte Avenue
Fort Collins, CO 80521*

Nicole M. Didero and Sophie McKee

*US Department of Agriculture (USDA)–Animal and
Plant Health Inspection Service (APHIS)
Wildlife Services (WS)
National Wildlife Research Center (NWRC)
4101 LaPorte Avenue
Fort Collins, CO 80521*

Jeremiah L. Psiropoulos

*US Department of Agriculture (USDA)–Animal and
Plant Health Inspection Service (APHIS)
Wildlife Services (WS)
National Feral Swine Damage Management
Program (NFSDMP)
4101 LaPorte Avenue
Fort Collins, CO 80521*

*Colorado State University (CSU)
College of Liberal Arts
Department of Economics
C306 Clark Building
1771 Campus Delivery
Fort Collins, CO 80523-1771*

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Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Abstract

The increased spread and presence of feral swine on sensitive natural resources landscapes like wetlands has become a considerable concern on lands managed by the US Army Corps of Engineers. In August 2021 a pilot study was carried out at Somerville Lake, Texas, as the first step in a three-year research plan to develop an ecological-economic framework for feral swine damage assessments (FSDA) and valuation. The study sought to quantify and value soil disturbance caused by feral swine trampling, rooting, and wallowing on wetland soils. The primary objective—to develop and test a rapid FSDA prototype—was achieved and represents an important first step to creating a quick and user-friendly damage-assessment framework that also estimates the economic value of the damage observed. With continued testing and development, this rapid FSDA protocol will be of use to all who manage feral swine impacts on landscapes with wetland ecosystems, and findings from this information will be of use for scientifically informed cost-benefit analysis and management decision-making.

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Preface

This study was conducted for the US Army Engineer Research and Development Center–Environmental Laboratory (ERDC-EL) under Funding Account Code 4FH684, AMSCO Code 075098, in partnership with the US Department of Agriculture–Animal and Plant Health Inspection Service’s (USDA-APHIS) Wildlife Services (WS) program, National Wildlife Research Center (NWRC), in Fort Collins, Colorado. The technical monitor was Mr. Jeremy Crossland of ERDC-EL.

The work was performed by ERDC-EL’s Aquatic Plant Control Research Program (APCRP). At the time of publication, Ms. Patricia M. Tolley was the branch chief, Wetlands and Coastal Ecology Branch, and Mr. Mark D. Farr was division chief, Ecosystem Evaluation and Engineering Division. The deputy director of ERDC-EL was Dr. Brandon J. Lafferty, and the director was Dr. Edmond J. Russo Jr.

The mission of the APCRP is to develop new technologies to manage invasive species, study invasive species biology and impacts, and support improved science and management of invasive species issues through research and science. This research supports better management and reduction of costs and impacts to the US Army Corps of Engineers’ (USACE), US Army Engineer Research and Development Center’s (ERDC), and others’ missions. This research collaboration combines ERDC-EL and USDA-APHIS WS expertise to measure and evaluate economic impacts of feral swine disturbance on wetlands at USACE projects. Economic estimations of feral swine damage are important information for decision-making regarding management actions and investment.

Research and data collection were provided by Dr. Nathan R. Beane, Ms. Nicole M. Didero, Mr. William Tomlinson, Mr. Jaybus Price, Ms. Heather Theel, Ms. Amber Owen (USACE Park Ranger at Somerville Lake), Mr. Jeremiah L. Psiropoulos, Mr. Jacob Hetzel (USDA-APHIS WS Wildlife Biologist and Texas A&M Extension Service), Ms. Linda Tschirhart-Hejl (USDA-APHIS WS District Supervisor, College Station, Texas) and Mr. Mike Bodenchuk (USDA-APHIS WS State Director, Texas).

Thank you to Mr. Travis Schoppe and staff at the Texas Parks and Wildlife Service State Parks Division for their support of this research effort

involving Lake Somerville State Park areas. Sincere thanks are also extended to various experts in the agencies and organizations listed above for their knowledge regarding the biology, ecology, and history of the Somerville Lake area.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

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1 Introduction

1.1 Background

Feral swine (*Sus scrofa*) were first brought to the United States by Europeans in the 1500s as a food source. Repeated introductions via escape or intended or accidental release have occurred thereafter, resulting in shared genetic lineage with commercial farm pigs. This pervasive and invasive species has swiftly expanded its range, doubling it in the past 30 years, and is currently documented in at least 38 states (Barrios-García and Ballari 2012; Bevins et al. 2014).

Primary impacts of feral swine include significant damage to agricultural crops, property, natural resources, and ecosystems, presenting substantial risk to domestic animals and human health (USDA-APHIS 2020). Feral swine are detrimental to ecosystems largely because of their soil disturbance behavior or rooting techniques (Crooks 2002; Gray et al. 2020). Scientific results have indicated their feeding habits (primarily rooting) are destructive and can negatively affect plant and animal communities (Barrios-García and Ballari 2012). Of ecological concern are feral swine impacts to sensitive wetland ecosystems (for example, Engeman et al. 2003; Thomas et al. 2013; Felix et al. 2014; Engeman et al., “Steephead Ravine,” 2019). Although previous research has not yet provided conclusive evidence for all effects feral swine can have on wetland habitats (for example, Barrios-García and Ballari 2012), there exists substantial evidence pointing directly and indirectly to negative impacts of concern for feral swine on wetland landscapes, including destruction of vegetation (Arrington et al. 1999; Mayer et al. 2000; Engeman et al. 2003; Engeman et al., “Damage Reduction,” 2004; Engeman et al., “Extraordinary Patch,” 2007; Seward et al. 2004; Doupé et al. 2010; Gray et al. 2020); soil structure disturbance (Doupé et al. 2010; Gray et al. 2020); depredation of animal species (for example, Giménez-Anaya et al. 2008 [birds]; Elsey et al. 2012 [alligators]; Engeman et al. 2014 [marine turtles]); and competition for resources among native animal species (including endangered species) (for example, Sicuro and Oliveira 2002; Jones et al. 2018).

As of 2022, no standardized protocol exists to assess feral swine damage impacts to federal assets. At the same time, millions of dollars are spent each year across US Army Corps of Engineers (USACE) projects, managing

stewardship for approximately 12 million ac¹ of land and water, to manage feral swine populations. This issue is underscored by the difficulty of observing and tracking feral swine because of their spatiotemporal nomadic behavior and their rapid range expansion in recent decades (for example, Bevins et al. 2014). Because of inherent foraging behavior of feral swine, quantifying impacts to soil disturbance in the form of rooting, trampling, and wallowing is at the forefront of damage assessment techniques. Feral swine damage assessments (FSDA) have largely been performed for quantifying damage to agricultural products, with some carrying out field measurements (for example, Higginbotham and Bodenchuk 2014; Bankovich et al. 2016; Engeman et al. 2013; Engeman et al. 2018; Boyer et al. 2020) and others based on survey-questionnaire responses (for example, Anderson et al. 2019; Anderson et al. 2016; McKee et al. 2020). The common thread among all the studies previously listed is the additional use of vetted methods to then estimate the economic value of the agricultural damage observed. This technique is largely lacking in the realm of natural resource damage because of the inherent challenges for both quantification and economic valuation of natural-resource and environmental damage. The research presented here attempts to address this difficulty through the development of a framework to assess ecological and economic wetland damage impacts caused by feral swine presence on USACE project lands.

Several previous studies have specifically addressed the concern of accurately estimating feral swine rooting damage on a landscape (Cushman et al. 2004; Engeman et al., “Extraordinary Patch,” 2007; Engeman et al., “Management Methods,” 2007; Chavarria et al. 2007). These studies do not account for all incidences of rooting within an entire survey site (Felix et al. 2014) because of the need for balancing the trade-offs between sampling effort, cost, and labor efficiency (for example, Engeman et al. 2003; Engeman et al., “Damage Reduction,” 2004; Engeman et al., “Feral Swine,” 2007; Thomas et al. 2013; Felix et al. 2014). To the authors’ knowledge, the most current research investigating improved feral swine damage quantification methods come from Thomas et al. (2013) and Felix et al. (2014). Thomas et al. (2013) compared transect sampling approaches using simulation techniques to optimize a

1. For a full list of the spelled-out forms of the units of measure used in this document and their conversions, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52 and 345–47, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

line-intercept sampling approach for the purpose of “practical, logistical, [and] economic considerations determining final design details” (1503). Felix et al. (2014) built on the work done by Chavarria et al. (2007) to map an entire population of rooted areas in a survey site including capturing categorical data about rooting age and severity. However, these studies did not attempt to estimate the economic value of the feral swine rooting damage observed.

Alternatively, other research has estimated the economic value of natural resource damage quantified in the field (Engeman et al. 2003; Engeman et al., “Damage Reduction,” 2004; Engeman et al., “Economic Cost,” 2004; Engeman et al., “Management Methods,” 2007; Engeman et al., “Extraordinary Patch,” 2007; Engeman et al. 2014; Engeman et al., “Sea Turtle,” 2019; Engeman et al. “Steephead Ravine,” 2019); however, they lack the updated field methods and use economic valuation techniques for which there are arguably better substitutes (see Section 2.3). The bulk of these studies focus on feral swine damage to wetlands (Engeman et al. 2003; Engeman et al., “Damage Reduction,” 2004; Engeman et al., “Economic Cost,” 2004; Engeman et al., “Management Methods,” 2007; Engeman et al., “Extraordinary Patch,” 2007; Engeman et al. 2014; Engeman et al., “Sea Turtle,” 2019; Engeman et al., “Steephead Ravine,” 2019) occurring on US Air Force bases or Florida state parks, including the following: wet-pine flatwoods (Engeman et al. 2003), a basin-marsh system and associated ecotones (Engeman et al., “Damage Reduction,” 2004; Engeman et al., “Economic Cost,” 2004), seepage slopes (Engeman et al., “Management Methods,” 2007; Engeman et al., “Extraordinary Patch,” 2007), and steephead ravines (Engeman et al., “Steephead Ravine,” 2019). Though these studies form an important foundation for feral swine wetland-damage assessment and valuation research, the research available lacks consideration for ecological-economic relationships. Therefore, the field requires a framework for both quantifying and valuing damage or disturbance to natural resource ecosystems.

1.2 Objective

The methods and results of the pilot study presented in this technical report represent the first step in the effort to develop an ecological-economic framework for FSDA that specifically aims to quantify and value soil damage or disturbance caused by feral swine trampling, rooting, and wallowing (what is referred to generally as direct *damage* or *disturbance*

throughout this technical report) on emergent wetland landscapes.² This pilot project first developed a prototype for a rapid, low-cost, scalable assessment method easily implemented by field teams regardless of technical skillsets. Next, the pilot project tested this prototype in the field for the intended purpose of helping with FSDA delineation within a wetland area of concern and sampling for wetland damage caused by feral swine. Finally, this pilot project estimated the economic value of the damage observed. In the future, this research aims to develop a framework to assess damage for other natural-resource landscapes (for example, forested landscapes).

1.3 Approach

The US Army Engineer Research and Development Center–Environmental Laboratory (ERDC-EL) led the FSDA framework development and implementation in the field. Economic analysis was led by the US Department of Agriculture–Animal and Plant Health Inspection Service’s (USDA-APHIS) Wildlife Services (WS) program, National Wildlife Research Center (NWRC), Economics Project—hereafter *Economics Project*. Partnership between the US Army Engineer Research and Development Center (ERDC) and the Economics Project provided interdisciplinary knowledge to unify field data and economic variables of interest. Additional partnerships were also established with the USDA-APHIS WS Texas (WS-Texas) and the USDA National Feral Swine Damage Management Program (NFSDMP) in support of field-data collection efforts.

The developed FSDA framework was field tested at Somerville Lake Project (USACE–Fort Worth District) in Texas, 26–30 July 2021. Somerville Lake Project is in the Brazos River drainage basin and includes an 11,456 ac reservoir, constructed for flood control in 1967, which offers outdoor recreation opportunities including fishing, boating, birding, camping, hiking, and hunting. Feral swine damage at Somerville Lake has been occurring since the early 2000s (USACE Park Ranger Amber Owen, pers. comm., phone, May 2021), but feral swine impacts have drawn more

2. The FSDA framework described in this technical report does not collect data to confirm whether feral swine disturbance is, in fact, generating measurable negative impacts on the wetland ecology. However, previous research (for example, Barrios-García et al. 2012) suggests that feral swine rooting, trampling, and wallowing can negatively affect wetland communities; therefore, this technical report uses the term *damage* only under the assumption that feral swine rooting, trampling, and wallowing on wetland communities has damaging, negative impacts on the wetland ecology.

concern over the past five years, with marked impacts to wetlands; the Somerville project's earthen levee systems (that is, USACE infrastructure); and the public-use areas, which creates a safety concern for recreational visitors. To address these concerns, USACE established a feral hog hunting program, allowing permitted hunting by the public in 11 compartments around the lake by means of trapping, shotgun, dogs, or archery (Owen, pers. comm.), and WS-Texas has conducted management efforts within the USACE Somerville Lake area.

2 Methods

2.1 Framework Development

The ERDC-EL team developed a pilot FSDA protocol for implementation by personnel without specific scientific or data-collection experience. This protocol provides guidance and collection metrics for identifying and delineating a damage assessment area (DAA) while providing a sampling schema to quantify direct damage to a wetland DAA. The ERDC-EL pilot protocol was partially informed by the data required for economic valuation of the damage observed, and those methods and the FSDA protocol make up the pilot project's framework.

The pilot framework presented here provides the following content to users:

1. Method for identifying and delineating a wetland DAA
2. Transect sampling (including transect spacing calculator)
3. Interpretive field sampling and data collection
4. Economic valuation introduction and methods

This schema was designed to be applied to DAAs ranging from 0.5 ac to 50 ac and could be applied anywhere feral swine occur. Apart from a GPS for mapping utility, no special technical tools are required to implement the data collection. The FSDA framework includes supplementary direction on transect spacing and layout within a DAA using simple area calculations that can be readily applied to assess damage within (for example, damage occurring on an earthen levee) or adjacent (for example, floodplain forest habitat adjacent to a slough, lacustrine fringe habitat) to an area of interest.

Extensive flooding from Somerville Lake occurred in late spring and early summer of 2020 and pushed most feral swine outside the project boundary. The pilot study was carried out only weeks after the flooding began to recede, and feral swine had recently appeared to have returned to the site (Owen, pers. comm.). This recent return of the invasive species created a unique situation to assess damage in newly exposed areas following receding water levels in many locations, and therefore in this specific case, *recent* damage was a maximum of two weeks old (according

to in-person conversation with local USACE natural resource managers and WS on-site staff).

2.2 Field Protocol

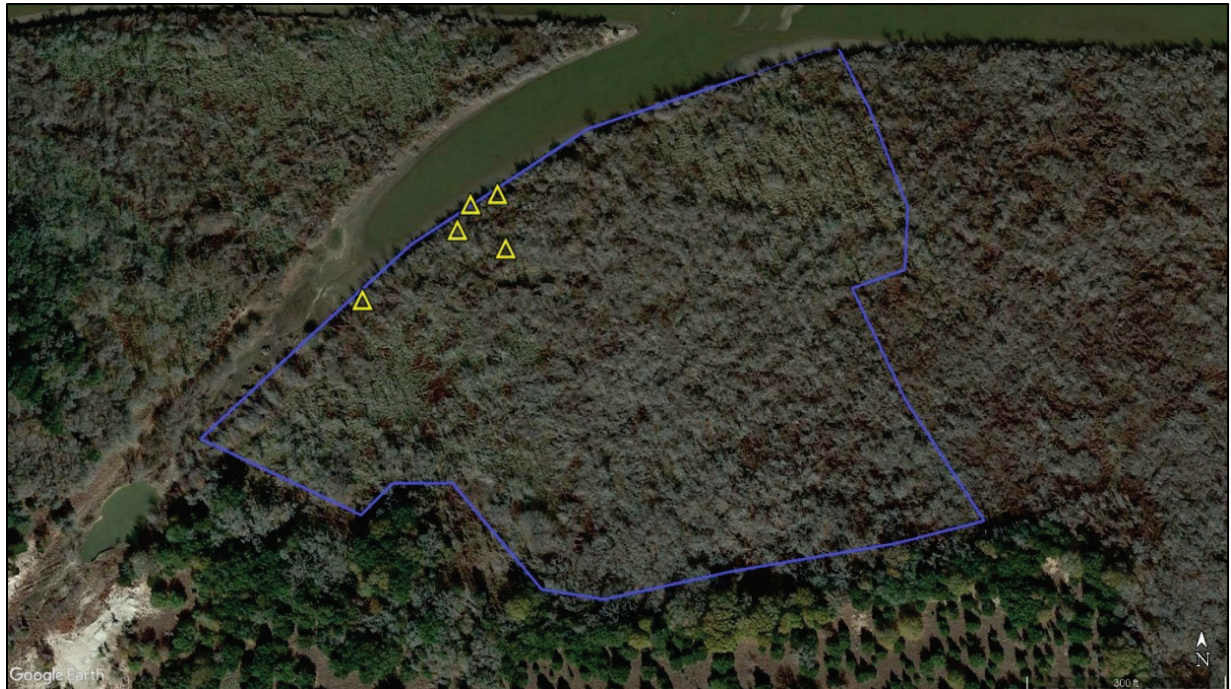
2.2.1 Damage Assessment Area (DAA) Determination

In general, identification of potential DAAs will often be based on preconceived concerns about resource damage for specific areas of interest (for example, wetlands near an earthen levee). The project team used the knowledge of local USACE and WS staff to identify where recent feral swine activity was present to maximize the opportunity for damage observation and testing of the field protocol. Consequently, the damage ratios estimated in this pilot study only apply to damaged areas. For observed damage-ratio estimates to be extrapolated to a larger area, a randomized approach would be necessary.

DAAs should be delineated according to areas of similar ecosystem type or vegetation densities where apparent stand or vegetation strata shift (that is, ecotones or forest-stand change). A boundary extent for each DAA must be created to demarcate the area of interest for evaluation. Specifically, forest boundaries, water bodies, or property boundaries should all be incorporated into creating the DAA's extent. An example of known rooting activity and the resulting DAA boundary for assessment is provided in Figure 1.

Figure 1. Example of known rooting activity (*yellow triangles*) and the resulting 15 ac damage assessment area (DAA) delineated according to similar ecosystem and forest complexity. The southern and eastern boundaries of the DAA were defined by changing forest density and forest-cover types, with the northern and northwestern boundaries determined by the water's edge.

(Modified with permission from Google © 2023. Map data: Google.)



The delineation of a DAA is best defined using Google Earth (Alphabet, Mountain View, California) or a similar geographic information system (GIS) application that provides freely available satellite imagery. Moreover, the aerial viewpoint offers improved stand-level mapping capabilities versus ground efforts for general mapping purposes.

2.2.2 Transect Sampling Layout

Once a DAA is identified, the next step is to determine sampling intensity, which this technical report defines as transect orientation, average distance of a transect, and average spacing between transects. Because of the variability of DAA sizes and shapes with each new assessment area, a standardized method is important for transect orientation and length. This framework used a 1/10 (10%), 1/20 (5%), or 1/50 (2%) sampling intensity based on DAA extent (Table 1). Sampling intensities were considered adequate for quantifying damage within a respective DAA extent and ensured the requirement for a rapid FSDA method.

Table 1. Damage assessment area (DAA) acreage and the respective sampling intensities applied to quantify feral swine damage at each site assessed in the pilot study at Somerville Lake, Texas.

Sampling Intensity	Damage Assessment Area (ac)
1/10 ac	0–1
1/20 ac	>1–5
1/50 ac	>5–50

To determine the transect sampling layout and sampling intensity, the following guidance is as follows for each DAA:

1. Using Google Earth or a similar GIS application, complete the following:
 - a. Calculate the area (ac) of the DAA.³
 - b. Estimate the average length (m) across the DAA (Figure 2; 100 m).
 - c. Estimate the total width (m) of the DAA (Figure 3; 350 m). This distance is used to calculate transect spacing.
2. Determine the desired sampling intensity (for example, 1/50 ac).
3. Using the DAA acreage and desired sampling intensity, determine the area needed to sample (for example, a 15 ac DAA using a 1/50 [0.02] ac sampling intensity would require 0.30 ac total to be evaluated [that is, 15×0.02 ac]).
4. Convert acres to square meters for total square meters to be sampled ($0.75 \text{ ac} \times 4,047 \text{ m}^2 = 1,214.1 \text{ m}^2$).
5. Determine the total length (m) of transect lines required to sample at the required sampling intensity (1/50 ac, which in this DAA is 1,214.1 m²) while also implementing a 1 m width on each side of the transect line (making a 2 m width sampling band). For each 0.5 m distance sampled along each transect, 1 m perpendicular to the transect line will be evaluated, creating a 0.5×1 m sampling grid on each side of the transect line. That is, at each 1 m along the transect line, there is a 1×2 m grid (2 m²) (see Figure 4 for illustration). Therefore, with the 1,214.1 m² sampling requirement, $1,214.1 \text{ m}^2 / 2 \text{ m}^2 = \text{total transect length} = 607.05 \text{ m}$.

3. Note: Because land surveyors frequently use acres while scientific field measurements rely on the International System of Units (<https://www.nist.gov/pml/owm/metric-si/si-units>), this guidance uses both units to make it easier to implement. For a full list of the unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 345–47, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

Figure 2. Example illustrating the average length of 15 ac DAA as positioned perpendicular to the riparian feature (*yellow line*). (Modified with permission from Google ©2023. Map data: Google.)

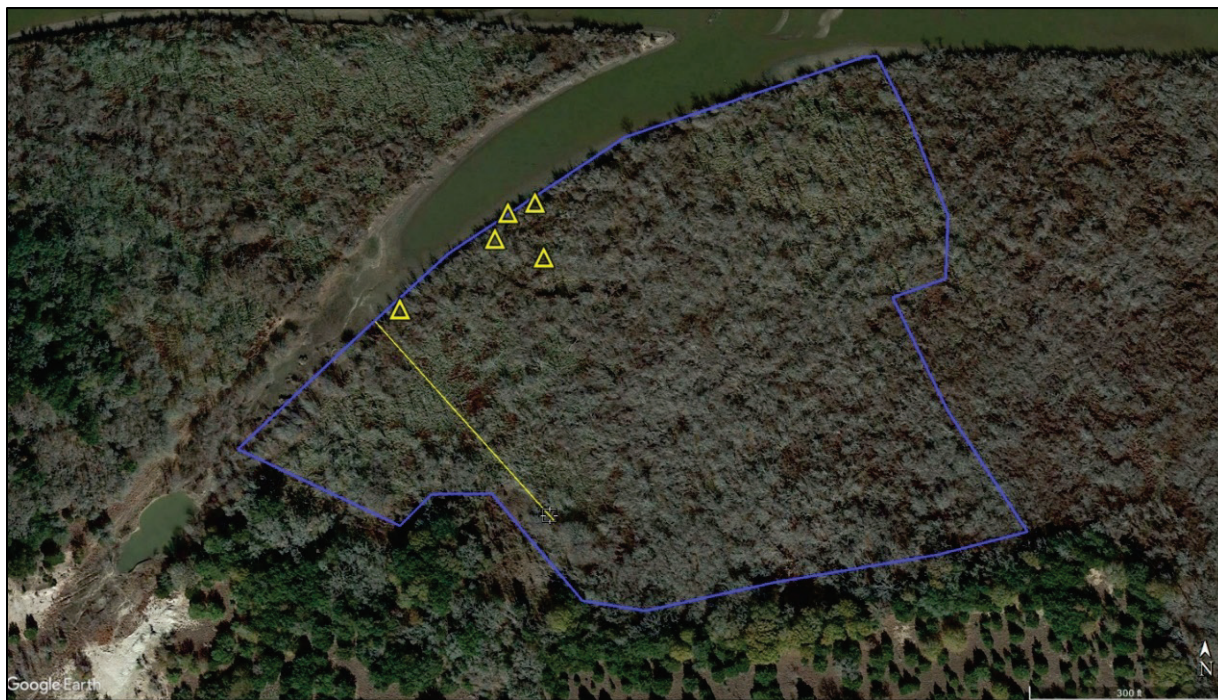


Figure 3. Example illustrating the width of the DAA, positioned parallel to the riparian feature (*yellow line*). (Modified with permission from Google ©2023. Map data: Google.)

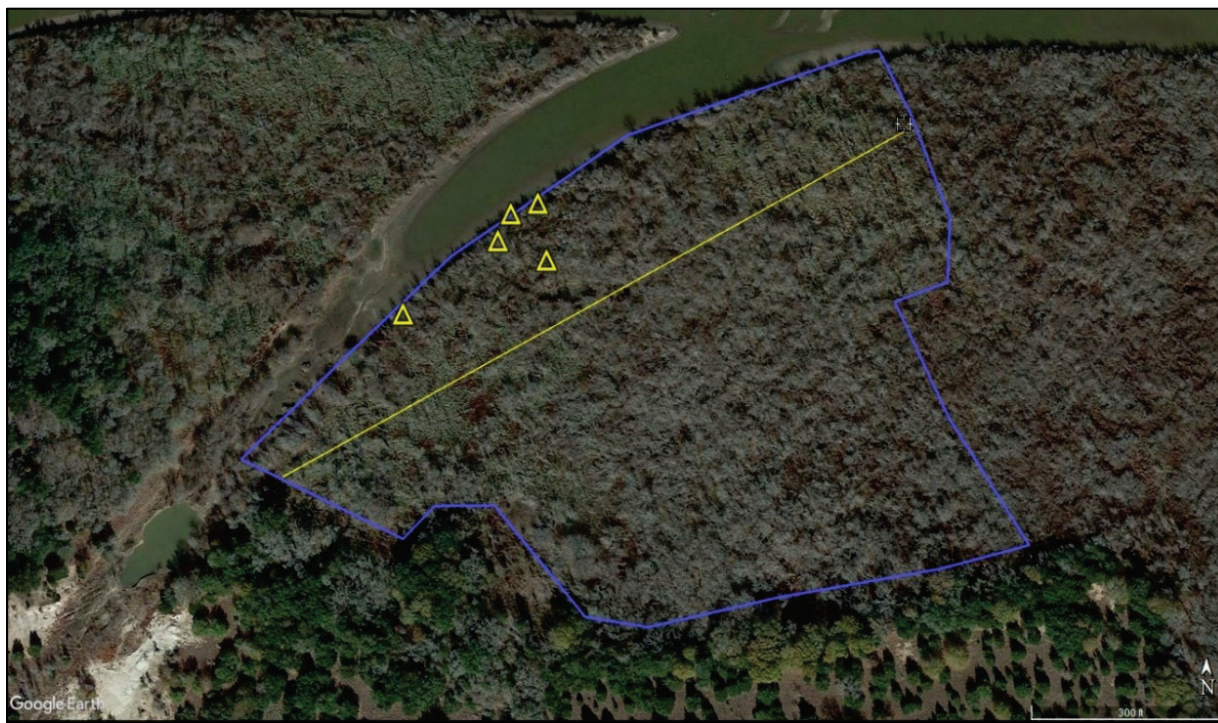
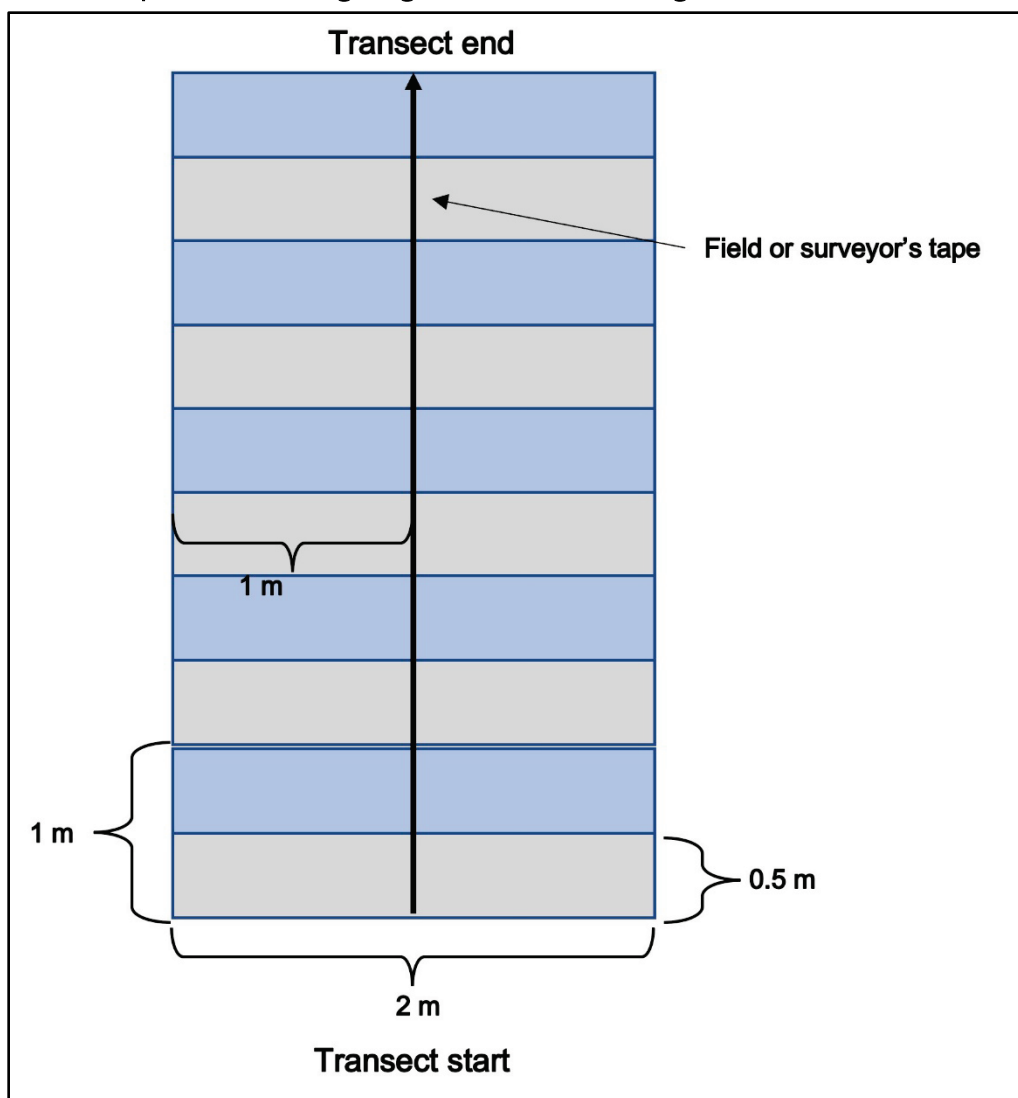


Figure 4. Example illustration of a 5 m transect line with the 0.5×1 m gridded cells illustrated to either side of the established transect line provided by a field or surveyor's tape stretched along the ground for the entire length of the transect line.



6. Estimate the number of transect lines needed within the DAA by dividing the total transect meters to be walked by the average DAA length ($607.05 \text{ m} / 100 \text{ m} = 6.07$ [round down to 6 transect lines]).
7. Calculate the average transect spacing by dividing the average DAA width by the number of transect lines determined in Step 6 ($350 \text{ m} / 6 = 58 \text{ m}$).
8. These calculations determine the number of transects and the average spacing to install transects, as well as the average length of each, to ensure an adequate sampling intensity ($1/50$ in this example) is met during the field-data collection. In this example, that total is 6 transect lines, 100 m long transects spaced 58 m apart. If the field team encounters a situation where a transect cannot be fully evaluated, note the distance not evaluated

and distribute the nonevaluated distance among other observable transects to ensure the total transect length is met (607.05 m in this example).

A sample calculator using Microsoft Excel (Microsoft, Redmond, Washington) was developed by ERDC-EL that provides the required transect spacing and total sample length for the field sampling effort. This calculator only requires the input of the DAA acreage, average length, and average width (Step 1 above). This calculator will be made available once the technique has been vetted thoroughly, reducing the need to calculate Steps 3–8, and making this process easier for the end user.

Transect lines should be measured perpendicular to a feature of interest where hog damage will be evaluated. For example, if the edge of a water body has been disturbed, a lacustrine fringe evaluation could assess the emergent habitat occurring from the water's edge to the transitional boundary (for example, a forest edge). When this evaluation can be done systematically—with transects installed perpendicular and starting at the feature of interest—damage can be quantified as it occurs in relation to, or distance from, the feature of interest (for example, 40% of the observed damage was within 10 m of the water's edge within the DAA). By ensuring transect orientation in this way, an improved understanding of rooting behavior and preference could be determined via repeated measures or extensive sampling within specific habitats where damage is present.

2.2.3 Data Collection

In the field, transect lines are established using field or surveyor's tape (100 m length is ideal) stretched perpendicular to the feature of interest. When assessing wetland habitats (for example, riparian corridor or lacustrine fringe), the water's edge is the starting point for each transect line. When vegetation transitions (for example, property boundaries, slope gradients) create a transitional boundary adjacent to a feature of interest, the edge of this boundary condition is the starting point of the transect line, with all lines established as close to perpendicular as possible. Following these steps creates the opportunity to evaluate damage from multiple sampling sites or a specific feature of interest, like the edge of stream within a forested habitat. As an example, if damage is observed homogenously throughout a forested area, the data will support the forest stand overall as preferred habitat, whereas if 95% of the damage occurs adjacent to the stream's edge, the forest habitat can be considered less preferred than the water feature within this forested area. Using the FSDA

method described herein allows for this discernment to be made when assessing damaged areas. The transect orientation allows for this level of evaluation and is therefore an important consideration when laying out sample transects within a DAA.

For each transect line, GPS coordinates are taken at the beginning and end of each transect and are named using a unique identifier (for example, *So1T1S*—meaning *site one, transect one, start* [S]) for providing map visualizations and document transect location or orientation. At the start and end of each transect line, a survey pin is placed in ground, with the field tape stretched along the ground from the starting to the ending point. Once the transect line has been laid out with the field or surveyor's tape, the field teams (usually 2–3 individuals ideal for one transect effort) assess damage metrics on encountering feral swine damage along each transect using a 1 m stick on either side of the field tape along 0.5 m intervals (Figure 4). This approach creates an evaluation area of 0.5×1 m (0.5 m^2) to minimize damage overestimation. For each observation of damage, an *X* is recorded on the data sheet to indicate which side of the transect line (that is, left quad or right quad) the damage was observed. Damage observations and classifications—age, severity, and behavior—are documented for each transect.

Assessment of age (that is, time since disturbance) and severity of soil damage are collected because these methods are desired for damage assessments in wetland plant communities to determine how recent the damage occurred and how extensive the damage observed was throughout the DAA (Felix et al. 2014). Measurements of damage age and severity connect the ecological and economic elements of the damage assessment. The damage-severity and damage-age classification system used during this pilot study was modified using damage-severity and damage-age measures as recommended by Felix et al. (2014) to account for site-specific conditions. However, the research team was concerned that the damage-age categories (Table 2) originally developed in a Florida study would not directly translate to other wetland areas. As a result, the research team adapted standards for damage-age measures while in the field by visual judgment and team calibration. The severity levels (Table 3) selected for this study are *low*, *medium*, *high*, primarily distinguished by visually estimated differences in the area of soil disturbance within each $0.5 \text{ m} \times 1 \text{ m}$ grid.

Table 2. Example of proposed study methodology guidelines for determining age of damage along transects (adapted from Felix et al. 2014, 10402).

	Damage Age Category		
	1 (Fresh)	2 (Moderate)	3 (Old)
	Estimated Age		
Criteria	1–7 days	8–13 days	≥14 days
Bare or overturned soil	No plants	Plants newly sprouted	New plants distinguishable to genus
Soil texture	Fluffy or moist	Signs of weathering	Weathered, settling, and flattening
Overturned vegetation	Green	Yellowing or wilted	Mostly dead
Disturbed vegetation	Not resprouted	Budding leaves and stems	Extended shoots and stems
Exposed roots	Intact or pliable	Intact or dry	Brittle, breaking off

Table 3. Example of proposed study methodology guidelines for determining severity of damage along transects (adapted from Felix et al. 2014, 10402).

	Damage Severity Level		
	L = Low	M = Medium	H = High
Relative area damaged (%)	≤33	33–66	≥66

Note: Damage-severity classifications were modified to *low*, *medium*, and *high* in lieu of Felix et al. (2014)'s four categories (*surficial*, *moderate*, *extensive*, and *wallow*).

Age and severity are assessed and recorded for each grid where damage was found. Where multiple ages of disturbance are observed within a single grid, the most recent age is recorded. Additionally, feral swine soil disturbance is classified into three behavioral categories—*foraging* (rooting) activity, *trampling*, or *wallows*—and thus respectively are recorded within each 0.5×1 m grid (hereafter *grid*) on either side of the transect line. In tandem with damage evaluation, any feral swine presence as indicated by tracks, vegetation chewing (that is, wads), and scat are also recorded within each transect grid. A simple tally by scat, track, or scat and track was recorded for any areas observed within the grid along each transect line and for both sides of the sample line. Figure 5 provides an example data sheet for recording feral swine damage.

Figure 5. Example data sheet (0–5 m) for recording along a transect line. In this example, damage was observed on the *left* and *right* sides of the transect from 0–3.5 m. Rooting (R), accounting for all damage, and tracks (T) were observed at *left* at 1.5–2 m and 2–2.5 m. (Empty cells indicate no signs observed.)

Severity/Age	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	Severity/Age
			4–5 m			
			3–4 m			
				X		L1
M1		X	2–3 m	X		M1
M1	T	X		X		
	T	X	1–2 m	X		
		X		X		
		X	0–1 m	X	W	
H1		X		X	RW	H1

Note: Only an X is needed to identify rooting damage; however, if a wallow is encountered (also considered damage), an X is marked, and RW would be provided if rooting was also observed. If only a wallow was observed, no R would be recorded (for example, see 0.5–1.0 m, *right-side* grid). Damage severity and age categories are also recorded on the data sheet using the categories provided in this technical report. Last, the *arrows* indicate a continuation of the same severity category to limit the need to rewrite the same category for consecutive grids along the transect line.

Once a transect is completed, the survey pins are pulled, the field tape is picked up and travel to the next transect is initiated. After all transects are completed, the field crew tallies all transects lengths to ensure the minimum sample transect length has been obtained. The final step within the DAA is to make notes on the site-level data sheet to record the type of wetland feature based on National Wetlands Inventory (NWI) and hydrogeomorphic (HGM) landform type. The site-level data sheet is provided in Appendix A, comprising a list of each HGM and NWI classes that occurred within the Somerville Lake project boundary. Additional site-level metrics recorded included description of vegetation and any pertinent field notes relevant for the assessment.

2.2.4 Framework Field Implementation

The general location of the seven selected DAAs are shown in Figure 6. Initially, wetland habitats identified by the US Fish and Wildlife Service (USFWS) NWI Wetlands Mapper database (USFWS 2021) were going to be prioritized for candidate field site selection. However, site-specific information was outdated (early 1980s), and only limited areas were identified within the USACE Somerville Lake project (Figure 7). Moreover, none of the areas identified for the pilot study occurred in locations mapped by the NWI database. Therefore, for this pilot study, DAAs were identified primarily using site scouting and some aerial interpretation provided by WS with an emphasis on establishing DAAs in the west and southwest areas of the lake where wetlands had been historically mapped.

Figure 6. General location of DAAs (*red stars*) evaluated within the US Army Corps of Engineers' (USACE) Somerville Lake project, Texas (*black border*). (Map image is the intellectual property of Esri and is used herein under license. Copyright © 2023 Esri and its licensors. All rights reserved. Map data: Maxar.)

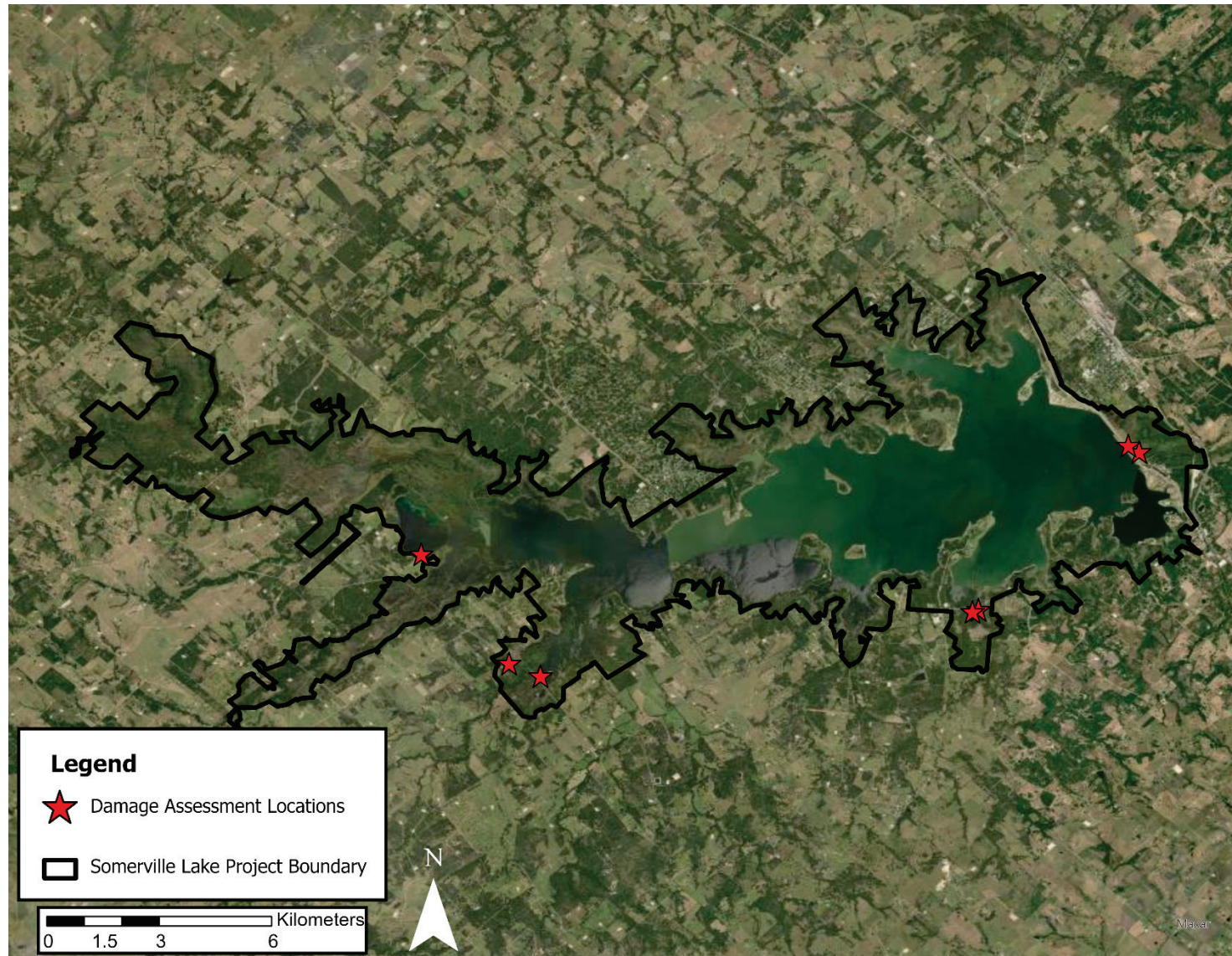
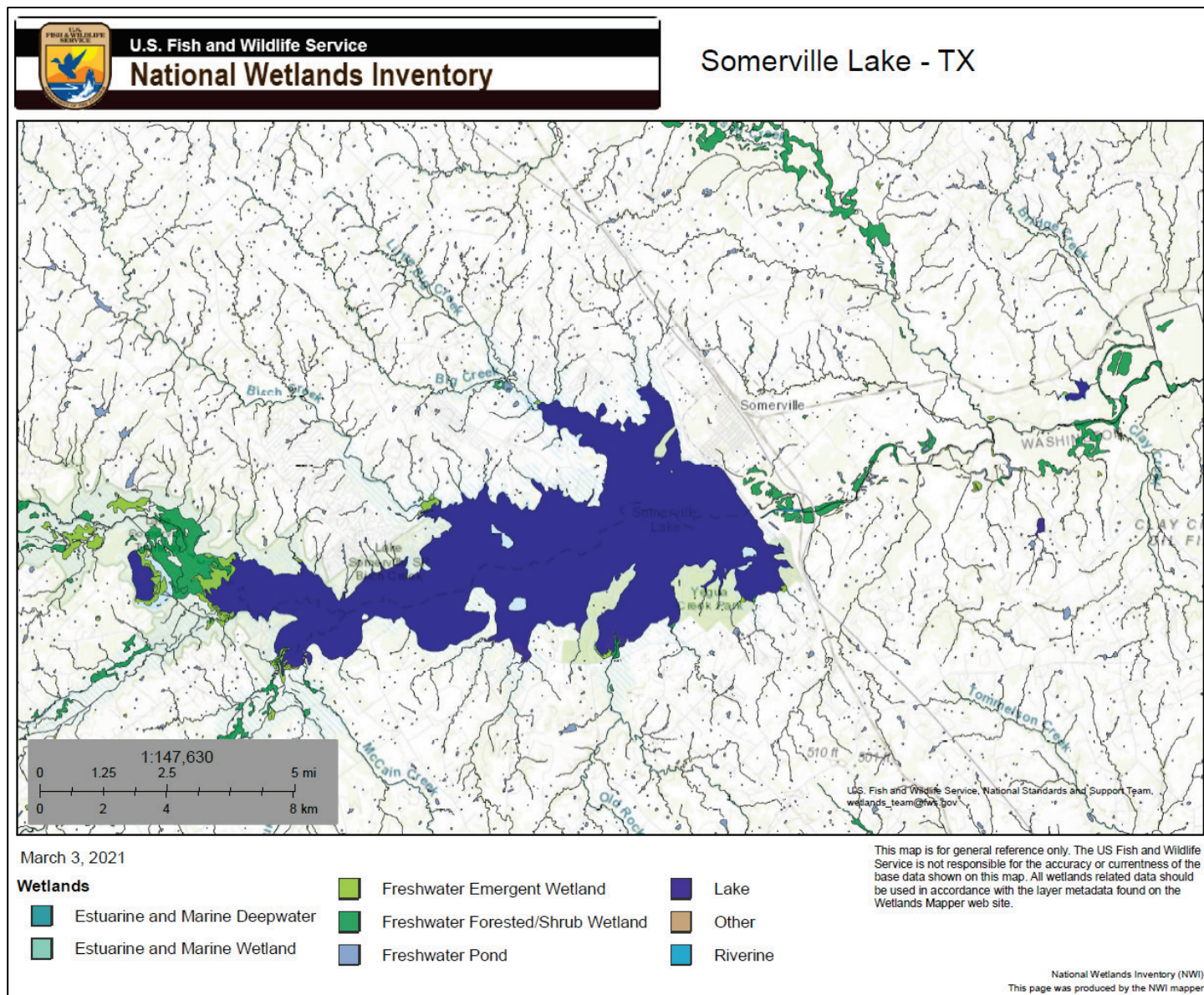


Figure 7. US Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) map for Somerville Lake, Texas (USFWS 2021).



2.2.5 DAA Evaluation

Of the seven DAAs sampled, two areas were USACE infrastructure assessments (the levee slope and toe and the levee flat) and were evaluated separately. The other five DAAs were situated within floodplain or lacustrine fringe habitats. The economic damage analysis from the two infrastructure DAAs were not included in the pilot study but will likely be expanded on in the future.

The first DAA (DAA-1) was a small riparian floodplain site (4.4 ac; Figure 8) identified during the initial site visit and field reconnaissance. While the area of the DAA did not change when collecting the field data, the on-site methodology was adapted when a drainage ditch running through the center of the site was identified and served as primary area of feral swine damage within the predefined DAA. As this feature was oriented in the center of the DAA and in a north–south direction, the team simply divided the three initial 150 m transects into six 75 m transects. As the drainage ditch was absent of standing water except at the far north end of the site, each original transect line shared the same starting point with a 75 m transect established perpendicular to the drainage ditch for 7 m in both east and west directions. While this adaptation would have no bearing on the amount of damage recorded for each transect, the value added is that damage within a specific distance of the drainage ditch could be determined by making this change to the sampling effort. A 1/20 acre sampling intensity was performed for DAA-1 because the DAA was larger than 1 acre and less than 5 ac (Table 1).

The second DAA (DAA-2) was adjacent to DAA-1 and encompassed approximately 2 ac (Figure 8). Esri (Esri, Redlands, California) imagery used in Figure 8 was not current, and therefore the depicted water levels were not present at the time of data-collection efforts. A total of four transects were installed perpendicular to the water's edge, with an average transect length of 50 m. One transect line was 52 m to ensure sampling intensity was maintained. DAA-2, while still within the same floodplain habitat as DAA-1, was directly adjacent to the water's edge created from the impoundment of the leveed highway running across Jerdelle Creek. The extent of damage in DAA-2 was widespread and offered a unique opportunity to test the sampling protocol in an area highly affected by feral swine rooting activity (Figure 9). A 1/20 acre sampling intensity was performed for DAA-2 because the DAA was larger than ≥ 1 ac and < 5 ac.

Figure 8. DAA-1 (*right*) and DAA-2 (*left*) with transect lines layout depicted. In DAA-1, while only three transect lines are visible, there were a total of six transects installed, sharing a common starting point in the middle of each 150 m transect line (that is, six 75 m transects). Water level is shown at flood condition in the aerial image and was not present at time of pilot study and data collection effort. (Map image is the intellectual property of Esri and is used herein under license. Copyright © 2023 Esri and its licensors. All rights reserved. Map data: Maxar, Microsoft.)



Figure 9. Example of damage extent within a portion of DAA-2.



The third and fourth DAA (DAA-3 and DAA-4, respectively) were along the earthen levee and served as the USACE infrastructure assessment (Figure 10). The flat and maintained grassland (34.1 ac) served as DAA-3, and the steep levee slope (8.2 ac) to the southwest was evaluated as DAA-4 (Figure 11). A 1/50 acre sampling intensity was performed for DAA-3 and DAA-4. For the flat levee area in DAA-3, 10 transects were installed with an average transect length of 140 m. For the steep levee area in DAA-4, 10 transects were installed with an average transect length of 38 m.

DAA-5 was a lacustrine fringe wetland habitat and was approximately 2.2 ac (Figure 12). The DAA-5 extent was defined by the water's edge (that is, transect starting point) and forested transitional area at the opposite end of the transect. Esri imagery used for map creation (Figure 12) was outdated and therefore shows a water level not present at the time of the data-collection efforts. An example of the lacustrine fringe habitat within DAA-5 is provided in Figure 12 as well. A total of nine transects were established within DAA-5, with an average transect length of 25 m. Because of the size of DAA-5, a 1/20 acre sampling intensity was used.

Figure 10. DAA-3 (*right of diagonal, large rectangle, levee flat*) and DAA-4 (*left of diagonal, thin rectangle, levee slope*) that were assessed as USACE infrastructure where feral swine damage had been identified by local staff at the Somerville Lake project, Texas. (Map image is the intellectual property of Esri and is used herein under license. Copyright © 2023 Esri and its licensors. All rights reserved. Map data: Maxar.)



Figure 11. DAA-3 (*foreground*, levee flat) and DAA-4 (*background*, levee slope) that were assessed as USACE infrastructure where feral swine damage had been identified by local staff at the Somerville Lake project, Texas.



Figure 12. DAA-5 with transect-lines layout depicted and installed perpendicular to the water's edge at time of field sampling. Water level is shown at flood condition in the aerial image and was not present at time of pilot study and data-collection effort. (Map image is the intellectual property of Esri and is used herein under license. Copyright © 2023 Esri and its licensors. All rights reserved. Map data: Maxar, Microsoft.)



The sixth DAA (DAA-6) was 1 ac and represented a palustrine emergent wetland class (although not mapped in NWI) adjacent to a gravel road impoundment (Figure 13). While the area did not possess standing water, significant and extensive feral swine damage was observed at this location during field reconnaissance (Figure 14). For transect establishment within DAA-6, the gravel road served as the baseline location with all transects oriented perpendicular. A total of six transects were established within DAA-6, with an average transect length of 32 m. Because of the size of DAA-6, a 1/10 acre sampling intensity was used.

The seventh DAA (DAA-7) (Figure 15) was 1.55 ac and was represented as a grassland riparian habitat directly adjacent to a wooded riparian floodplain corridor. For DAA-7, the woodline served as the baseline to orient transect sampling lines. A total of eight transects were established with an average transect length of 32 m. Because of the size of DAA-7, a 1/10 acre sampling intensity was used.

Figure 13. DAA-6 with transect-lines layout depicted and installed perpendicular to the gravel road. (Map image is the intellectual property of Esri and is used herein under license. Copyright © 2023 Esri and its licensors. All rights reserved. Map data: Maxar, Microsoft.).



Figure 14. DAA-6 rooting and trampling activity observed during reconnaissance.



Figure 15. DAA-7 with transect-lines layout depicted and installed perpendicular to the forest edge transitional boundary. (Map image is the intellectual property of Esri and is used herein under license. Copyright © 2023 Esri and its licensors. All rights reserved. Map data: Maxar, Microsoft.).



2.3 Economic Valuation Methods

The third objective of this pilot study was to estimate the economic value of the damage observed. Three ways of estimating the dollar value of a good or service are through (1) revealed willingness to pay (WTP) (for example, analysis of market prices); (2) expressed WTP (for example, human survey responses); or (3) derived WTP (for example, circumstantial evidence like cost of flood mitigation) (King 1998). In general, economic valuation estimates are more simply achieved for goods and services that are market products (for example, groceries, stocks, clothing), which inherently have an associated market price. For goods and services not traded in the market, economists often rely on *nonmarket valuation* methods (Champ 2017). These methods aim to identify an individual's maximum WTP or minimum willingness to accept, or WTA, monetary compensation for changes in a resource personally affecting them (Shaw and Wlodarz 2012).

2.3.1 Asset Value and Annual Benefits from Wetlands

In the United States, wetland values have historically been quantified through nonmarket valuation using a surrogate market that exists for *compensatory mitigation* (restoration, establishment, enhancement, or preservation of aquatic resources for the purpose of offsetting adverse impacts caused by human development) and is federally regulated under the authority of Section 404 of the Clean Water Act (see also EPA 2023 for more information).⁴ In compensatory mitigation, wetland mitigation banks can create wetland credits, which can then be sold to developers who need them to offset adverse impacts to wetlands from development (Spanjer 2018). The wetland values in this credit market are expressed in US dollars (USD) per acre (or an equivalent measure) or USD per credit, or both, which have been used for economic valuation of feral swine wetland damage in studies like Engeman et al. (2003) and Engeman et al., “Management Methods,” (2007).

In these studies, the authors argue that the wetland-mitigation-bank values represent an empirical WTP, and they use values reported by King (1998). One of the peculiar features of the mitigation banking market is

4. Federal Water Pollution Control Act of 1948 § 404, 33 U.S.C. § 1344. <https://www.govinfo.gov/content/pkg/USCODE-2021-title33/pdf/USCODE-2021-title33-chap26-subchapIV-sec1344.pdf>.

that credit price information is incredibly difficult to ascertain for those not involved in or well connected to the existing market (for example, Hallwood 2003; Spanjer 2018). Also, the geographic area “within which mitigation credits can be traded is physically demarcated by a service area defined on the basis of hydrographic criteria” (Vaissière and Levrel 2015, 5). Even where there is a supply and a demand for wetland credits, the markets exhibit a very low trading volume, and “an oligopolistic or monopolistic market enables mitigation banks to control, at least partially, prices that would be knocked down by free competition” (Vaissière and Levrel 2015, 10). It is thus safe to assume that mitigation credit prices do not consistently reflect restoration and conservation costs.

Another approach for wetland valuation is the valuing of the benefits that people derive from ecosystem processes and functions, called *ecosystem services*, (ES) (Costanza et al. 1998; Butchart et al. 2005; Costanza et al. 2017). Various meta-analyses of wetland values exist (for example, Brouwer et al. 1999; Woodward and Wui, 2001; Brander et al. 2006; Ghermandi et al. 2008; De Groot et al. 2012) with various market- and nonmarket-valuation methodologies reported. Figure 16 summarizes various types of ecosystem services that wetlands can provide in the context of economic market (use) and nonmarket (nonuse) categories and the associated economic-valuation methods that could be used.

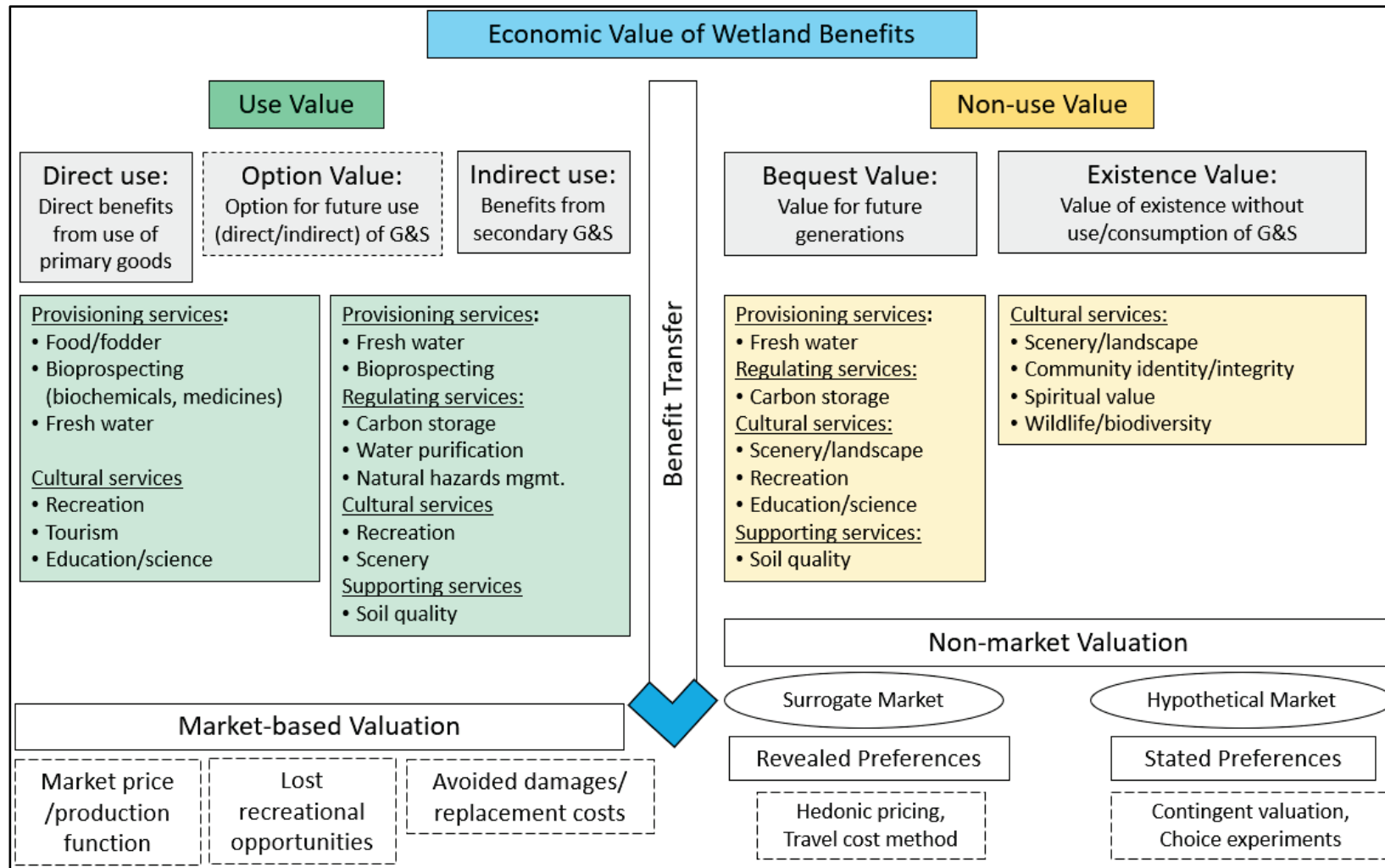
To quantify wetland damage value observed using this framework, this pilot study used an economic technique called *benefit transfer*, whereby economic benefit estimates from preexisting primary studies (often site specific) are applied to another study (Plummer 2009; Costanza et al. 2017). As Rolfe et al. (2015) explain, “the goal is to provide empirical estimates for the particular issue of interest when time, funding, or other constraints prevent the use of primary research to generate these estimates Benefit transfer is often the only option available for providing needed information. As a result, benefit transfer is an indispensable component of virtually all large-scale benefit-cost analyses in the United States, European Union, and elsewhere” (4). Specifically, the pilot study relies on ES values from the Ecosystem Service Valuation Database (ESVD), which was developed with the long-term goal of providing “better information on the economic benefits of ecosystems and biodiversity and on the costs of their loss” (ESP, n.d.). At the time of retrieval in September 2021, the publicly available database contains over 5,400 economic-value records from over 800 studies pertaining to various

biomes, ecosystem services, and geographic regions around the world. Aggregate values over larger spatial and temporal scales have been applied in certain cases (Costanza et al. 2014), which is the benefit-transfer approach used for this pilot study.

The pilot study subset the analysis to studies most relevant to Somerville Lake. The research team selected studies located in the United States related to the *inland wetland* biome, providing 113 valuations from the ESVD database, and further focused the analysis on studies valuing two ecosystem services provided by the Somerville Lake: *opportunities for recreation and tourism* and *moderation of extreme events*. The mean value for these studies is, respectively, international dollar⁵ (I\$, 2020) 4,138 per hectare per year and I\$(2020) 7,319 per hectare per year, which sum up to I\$(2020) 11,457 per hectare per year, translating to USD (2020) 4,637 per acre per year. Valuation of inland wetlands depends on many characteristics, such as type of wetland (for example, freshwater marsh versus wooded marsh) and GDP per capita in the study area of interest (De Groot et al. 2012). In a meta-analysis of inland wetland values reported in a global database, the economic-valuation method (for example, hedonic pricing, travel cost, production function) was also a contributing factor to the ultimate value of a wetland unit (De Groot et al. 2012). For future iterations of the valuation methods applied within this framework, specific ecological and socioeconomic characteristics will be incorporated, and expert opinion from ecologists will help define the comprehensive set of ecosystem services provided by wetlands at Somerville Lake.

5. The *international dollar* (also known as the *Geary-Khamis dollar*) is a hypothetical unit of currency that economists describe to have the same purchasing power parity, or PPP, than that of a US dollar.

Figure 16. Wetland ecosystem services and associated economic valuation methods (G&S—goods and services).
(Accessible version available in Appendix B.)



Note: Adapted from *The Economics of Ecosystems and Biodiversity* (TEEB 2009) and Robinson et al. (2014). Valuation methods listed are primary examples but not an exhaustive list.

Feral swine damage impacts also have a temporal context, and therefore the economic valuation for damage must consider impacts to ecosystem services over time. Once damage has occurred, the effect is often not sustained given the tendency for ecological systems to recuperate. For this aspect, foundations of a methodology called *habitat equivalency analysis* (HEA) are borrowed to conceptualize this aspect of the valuation approach. HEA is a restoration scaling method that was developed in conjunction with the emergence of natural resource damage assessment, or NRDA, in the United States in the 1980s (Ray 2008; Desvousges et al. 2018). To the best of the authors' knowledge, this methodology has never been applied to feral swine damage. HEA is based on the principal that, pursuant to the authority of Section 107(f) of the federal Comprehensive Environmental Response, Compensation, and Liability Act, or CERCLA, as amended.⁶ Section 9607(f),⁷ and other applicable federal and state laws, designated federal and state authorities who may act on behalf of the public as natural-resource trustees, or NRTs, to pursue claims for natural-resource damages for injury to, destruction of, or loss of natural resources resulting from the release of hazardous substances to the environment. The underlying concept of HEA is that the public can be compensated for an injury to natural resources through habitat-replacement projects if the replacement provides adequate resources of the similar type.

2.3.2 Damage Value–Recovery Estimation

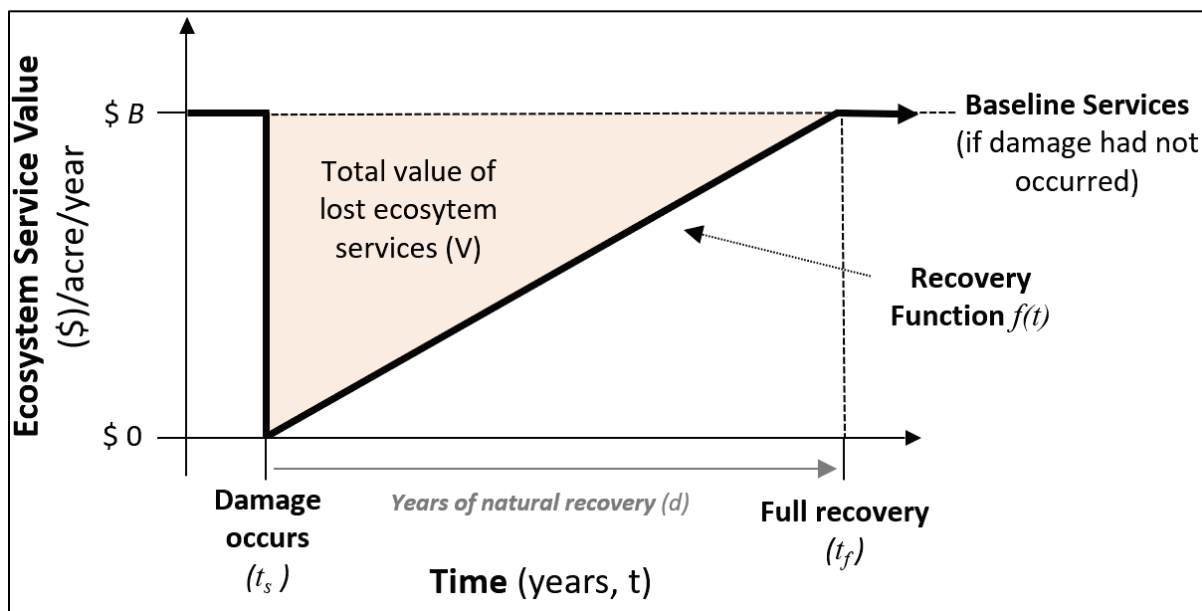
The assumption with HEA is that the public equally values a unit of services at the injury site and a unit of services at the restoration site (Michel et al. 2002). This service-to-service approach dates to at least King and Adler (1992); however, Unsworth and Bishop (1994) are the first to formally lay out the economic principles of the HEA method (Shaw and Wlodarz 2012, 631). Past attempts to value wetland damage by feral swine have not considered the transitory nature of the impacts of damage over time. That is, previous studies have assumed that 1 ha of damage equals only the prescribed economic USD per hectare without consideration of the value of the wetland resource as it recovers from damage over time. This pilot study applies the underlying principles of the HEA approach by

6. Comprehensive Environmental Response, Compensation, and Liability Act of 1980 § 107(f), 42 U.S.C. § 9607(f), as amended by Pub. L. No. 99-499 §107(d)(1). (2021). <https://www.govinfo.gov/content/pkg/USCODE-2021-title42/pdf/USCODE-2021-title42-chap103-subchapl-sec9607.pdf>.

7. 42 U.S.C. § 9607(f).

considering the feral swine damage as the injury,⁸ and instead of evaluating replacement costs the pilot study evaluates the costs of natural ecological recovery (natural restoration of ecosystem services) over time. Hence, the calculations for this pilot project of the per acre economic value of the damage observed involve two components: (1) the previously described value of the annual benefits of the wetland ecosystem service functions and (2) the value of the time it takes for ecosystem services to naturally return to the HEA concept of *baseline function* (original function if damage had not occurred) (for example, Desvousges et al. 2018). Figure 17 shows the conceptualization of this project-specific valuation approach, adapted from Shaw and Wlodarz (2013) in their review of the specific uses and utility of economic valuation methods (including HEA) used for environmental damage caused by humans and natural disasters.

Figure 17. Visual of economic value of lost ecosystem services from feral swine damage.
(Adapted from Shaw and Wlodarz 2012, 632.)



In Figure 17, the y -axis represents the conceptual annual economic value of the ecosystem services provided by one acre of the (inland) wetlands. On the x -axis is time, where damage occurs at t_s (start of injury to ecosystem services caused by feral swine damage). Before damage occurs, the model assumes that the baseline $\$B$ (or standard, in USD) benefits of

8. Given that HEA often refers to damage as *injury*, henceforth in our framework *damage* and *injury* are interchangeable terms.

ecosystem service function before damage (before t_s) are constant and valued at $\$B$ per acre per year.

Referring to Figure 17, at the point where feral swine damage occurs (t_s), it is assumed that the baseline service benefits drop to $\$0$ per acre per year. The time for natural recovery to baseline conditions is indicated by d years, ending at t_f (the effective finish of injury). This pilot study assumes that the process of ecosystem service recovery can be represented as a linear function under two primary assumptions: (1) that natural recovery has begun immediately after damage occurs and (2) that repeat damage⁹ at another time will not occur (the effect being the potential that recovery will be undone). The *orange area* below the dashed line represents baseline services and above the recovery function from time t_s to t_f is the estimated value of the total economic loss of ecosystem service benefits caused by feral swine damage. Because a dollar received today is considered more valuable than one received in the future, all monetary streams must be discounted using a discount rate to convert future economic value into present economic value. A simplified representation of the economic value of the damage severity, s , to one acre of wetland (V_s) ($\$/acre$) is presented below in Equation (1), with a detailed description of variables to follow:

$$V_s = \int_{t_s}^{t_f} \frac{B - f(t)}{(1 + \rho)^t} dt = B \int_{t_s}^{t_f} \frac{\left[1 - \frac{t - t_s}{t_f - t_s}\right]}{(1 + \rho)^t} dt = B \int_0^d \frac{\left[1 - \frac{t}{d}\right]}{(1 + \rho)^t} dt. \quad (1)$$

Equation (1) integrates the difference between the baseline and the recovery function over $d = t_f - t_s$ years, discounted by the discount rate ρ (ρ). In this study, the selected discount rate specifically equates the value of ecosystem services provided by natural recovery over time to the present value of services lost at the time of feral swine damage (Shaw and Wlodarz 2012; Dunford 2018). Though the historically accepted discount rate equation dates to Ramsey (1928), contemporary economists have expanded on Ramsey's analysis, including elements like uncertainty of growth per capita consumption and defining differences in categories of environmental goods and services (produced and environmental). In

9. Research on the cumulated impact of feral swine damage from repeat visitation should be considered for future research and will be addressed in the Section 4.

short, a contentious debate about what is the acceptable real discount rate has existed since the 1980s (Dunford 2018). This pilot study uses the formally accepted 3% real discount rate used by the Department of Interior (DOI) and NOAA (NOAA 1999). It is worth noting that given the short duration of the recovery process (see below), the choice of a discount rate does not have a sizeable impact on damage estimates.

For the application of this equation to the data collected for this pilot project, the Economics Project sought out expert opinion regarding the required time for recovery (variable d , in years) from feral swine disturbance using the severity data collected at Somerville Lake. Dr. Jim Cathey, associate director for the Texas A&M University–Natural Resources Institute, advised that the Somerville Lake project area lies within the Post Oak Savannah ecoregion which tends to be dominated by sandy soils, whereas around the lake, the soils are more clay-like (J. Cathey, pers. comm., phone, 21 September 2021). This expert opinion is also supported by USDA–Natural Resources Conservation Service soil maps for Burleson, Lee, and Washington Counties (USDA-NRCS 2023). According to the relative sensitivity of the soil and plant communities found at Somerville Lake, Dr. Cathey recommended that *high-severity* physical damage (wallows) may take three years for the soil to recover and about one year for vegetative recovery—with recovery herein referenced to the baseline condition prescribed in Figure 17 (J. Cathey, pers. comm., 21 September 2021). Using this information—and specifically for the purposes of this pilot study—this technical report prescribes the following years (variable d) for natural recovery by severity category: *low severity*—one year to recover to baseline function ($d = 1$); *medium severity*—two years ($d = 2$); and *high severity*—three years ($d = 3$). The associated value per acre of ecosystem-service recovery for $d = 1$ is USD 2,296; for $d = 2$ is USD 4,547; and for $d = 3$ is USD 6,754. Further development and recommendations for this aspect of ecological-economic valuation are provided in Section 4.

Once V_s has been calculated for each respective category of damage severity, this value is multiplied by A_s , the number of acres pertaining to that type of damage severity, to estimate the overall value of damage in the time period the damage is believed to have occurred. This final calculation is presented by Equation (2):

$$F = \sum_{s \in \{low, medium, high\}} V_s \times A_s , \quad (2)$$

where F is the final value of wetland damage observed in the time period of interest (for example, the two-week period known for this pilot study), which equals the sum of the values V_s —calculated in Equation (1) (for the specific severity category of damage s)—multiplied by the number of damaged acres (converted from m^2 beforehand) also in the specific damage category s . Once all values of damage have been calculated by severity category, they can be summed to determine the final estimated economic value of damage observed in the sample area in the time period of interest.

3 Results

3.1 Field Data Results

On completion of the pilot study's field-data collection efforts, the spatial extent of sampling (acres), and respective observed feral swine damage was summarized for each DAA (using a 1/10, 1/20, or 1/50 sampling intensity) (Table 4 and Figure 18, respectively). Note that while DAA-3 and DAA-4 are included here, they are not summarized in the economic analysis section given that they were not wetland areas. The spatial sampling extent ranged from 1.0 ac (DAA-6) to 34.1 ac (DAA-3). Sampling intensities, based on acreage, ranged from 1/50 for DAA-3 and DAA-4 to 1/10 for DAA-6 and DAA-7. Figure 18 provides the relative damage estimated for each of the seven DAAs evaluated in this pilot study. The average percent damage for all seven DAAs was 25%, with the highest measured damage occurring in DAA-1 and DAA-2 (45% and 42%, respectively) and the lowest observed within DAA-5 at 2%. The average damage percentage translates to the proportion of the total transect length within a given DAA with observed damage on left and right sides of the transect.

To assess the severity across DAAs with varying transect length and sampling intensity, the proportion of severity categories was calculated to show the relative distribution of damage-severity categories that could be compared across each DAA (Figure 19). The highest proportion of high-severity damage was observed within DAA-1 and DAA-2, where the highest proportion of damage was also observed. Damage in the DAAs with the highest proportion of damage (DAA-1 and DAA-2) was primarily (more than 90%) high-severity damage. Additionally, 85% of damage observed within DAA-6 was categorized as high severity, but only 12% of the DAA was observed with feral swine damage. The lowest levels of damage severity were observed in DAA-3, DAA-4, and DAA-5. DAA-3 and DAA-4 were the levee slope and levee flat grasslands evaluated for impact to USACE earthen infrastructure; these had low-severity damage (48% and 76%, respectively). DAA-5 was the least damaged area sampled (2% damage overall), with 55% of total damage considered as low-severity rooting activity.

Table 4. Summary of DAAs by total acreage, sampling intensity, and damaged acres detected.

DAA	Description	Total Acres (DAA size)	Sampling Intensity	Transect Length (m)	Area Sampled (m ²)	Area Sampled (ac)	Acres Damaged (% of sample)
1	Riparian forest floodplain	4.4	1/20	450	900	0.2	45
2	Riparian forest floodplain	2.0	1/20	202	404	0.1	42
3 ^a	Earthen levee, flat maintained grassland	34.1	1/50	1430	2,860	0.7	21
4 ^a	Earthen levee, steep levee slope	8.2	1/50	379	758	0.2	21
5	Lacustrine fringe wetland habitat	2.2	1/20	222	444	0.1	2
6	Grassland riparian habitat	1.0	1/10	192	384	0.1	12
7	Grassland riparian habitat directly adjacent to wooded riparian floodplain corridor	1.6	1/10	320	640	0.2	29

^a Not included in the economic analysis results because they were not wetland areas.

Figure 18. Relative damage observed at each DAA (1–7) with different sampling intensities based on DAA area.

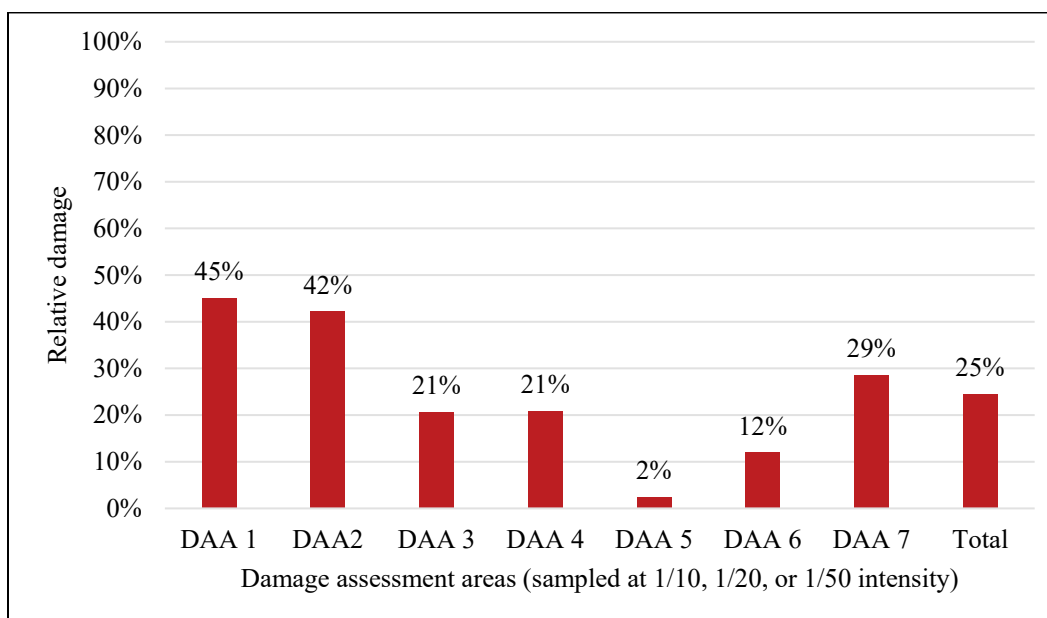
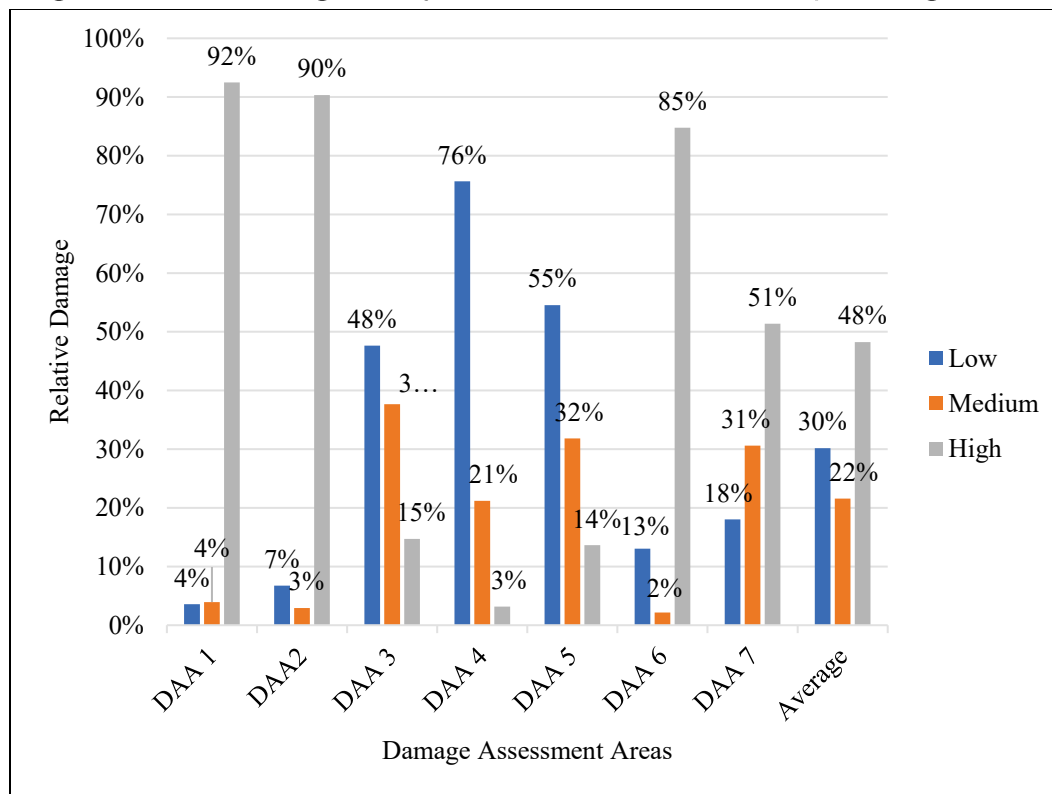


Figure 19. Relative damage severity observed across all transect samples for a given DAA.



To summarize disturbance age across DAAs, the proportion of age categories was calculated to demonstrate the relative distribution across each DAA (Figure 20). Greater than 95% of the damage recorded within DAA-1 and DAA-2 was considered Category 1 (fresh), with the average Category 1 damage for all DAAs at 37% across all age categories. The largest proportion of Category 3 damage (old) was observed at DAA-3 and DAA-4. These two locations were not exposed to the flooding impacts in spring–summer of 2021—the most likely reason for observing older damage at these assessment areas.

Scat was rarely observed and was only recorded along a transect sample within DAA-2, where fresh sign was primarily observed (96%) (Figure 22). Tracks were not observed along transects within DAA-3 or DAA-4 and were infrequently encountered (less than 5%) in all DAAs except DAA-2 and DAA-5, with 10% and 16% of transect samples observed with tracks, respectively (Figure 21).

Figure 20. Relative disturbance age observed across all transect samples for a given DAA.

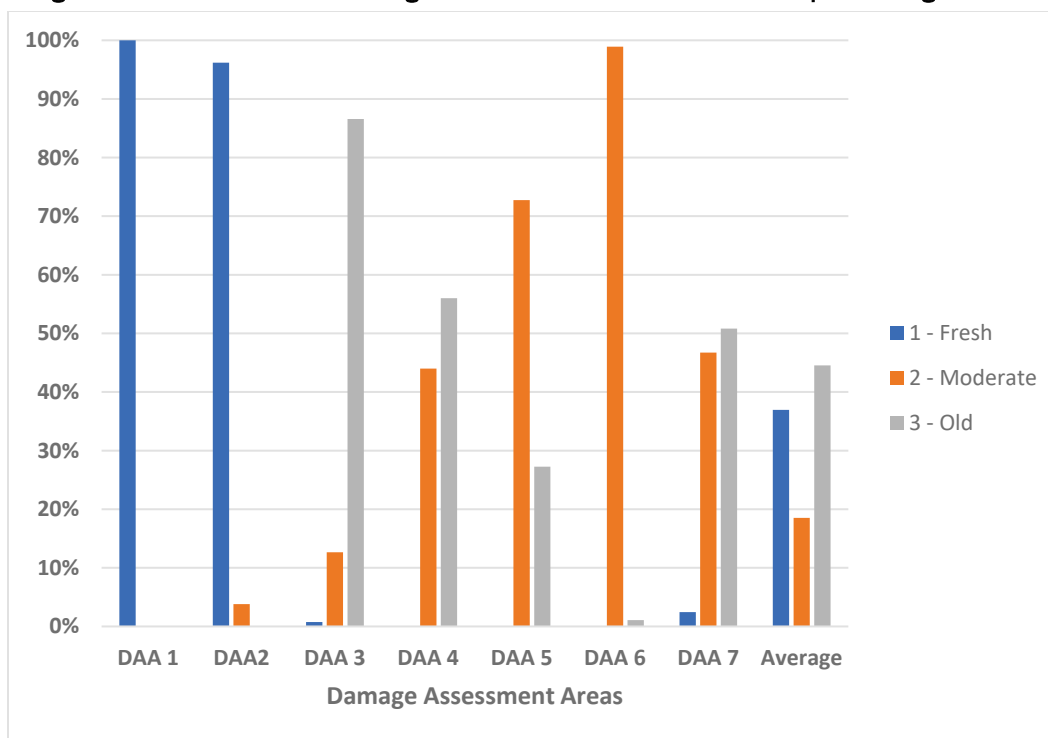
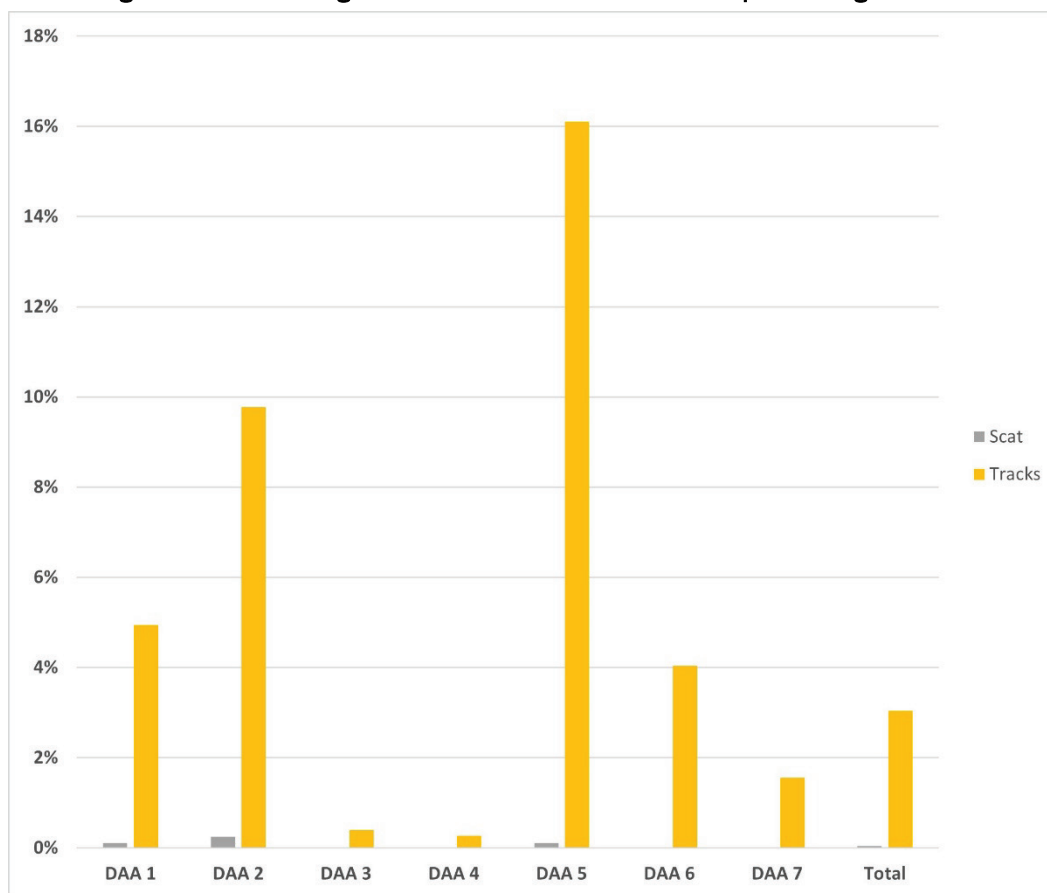


Figure 21. Example of tracks where sign would have been recorded along the transect on both sides of the sample area (that is, *left* and *right* sides perpendicular to the measuring tape).



Figure 22. Relative sign observed across all transect samples for a given DAA.



3.2 Economic Results

Table 5 summarizes total acres damaged (also by severity level of damage—low, medium, high) based on total acres sampled, the estimated economic value of damage by DAA, the estimated value of damage per acre by DAA, and all associated overall values. Based on the data collected in the given observation period (26–30 July 2021), we estimate that in approximately two weeks on the 0.68 acres sampled, feral swine damaged 0.20 acres of wetland for an estimated \$1,240 in wetland ecosystem services damage. Dividing this total by the total acres sampled, this is roughly \$1,809/acre of damage caused in two weeks. These values only represent the estimated economic value of the damage captured during the sampling event and should not be considered as representing all wetland/riparian habitat damage at Somerville Lake. High severity damage was proportionally highest except for DAA-5 where differences in categories of severity observed were minimal.

The primary intended use of these economic estimates is to inform management decision-making and benefit-cost analysis for USACE projects like Somerville Lake. Given that the sample was not a randomized representative sample, it is not possible to estimate differences in the total economic values by DAA, however it is possible to compare the economic damage value per acre across all samples (Figure 23). Based on these relative damage values per acre (Table 5), it is apparent that the samples for DAA-1 and DAA-2 would be of highest concern with high severity damage being most costly on a per-acre basis, followed by the samples for DAA-7, DAA-6, and finally DAA-5.

Figure 23. Breakout of economic damage per acre sampled by DAA and severity level. (Figure estimates displayed are rounded to the nearest dollar).

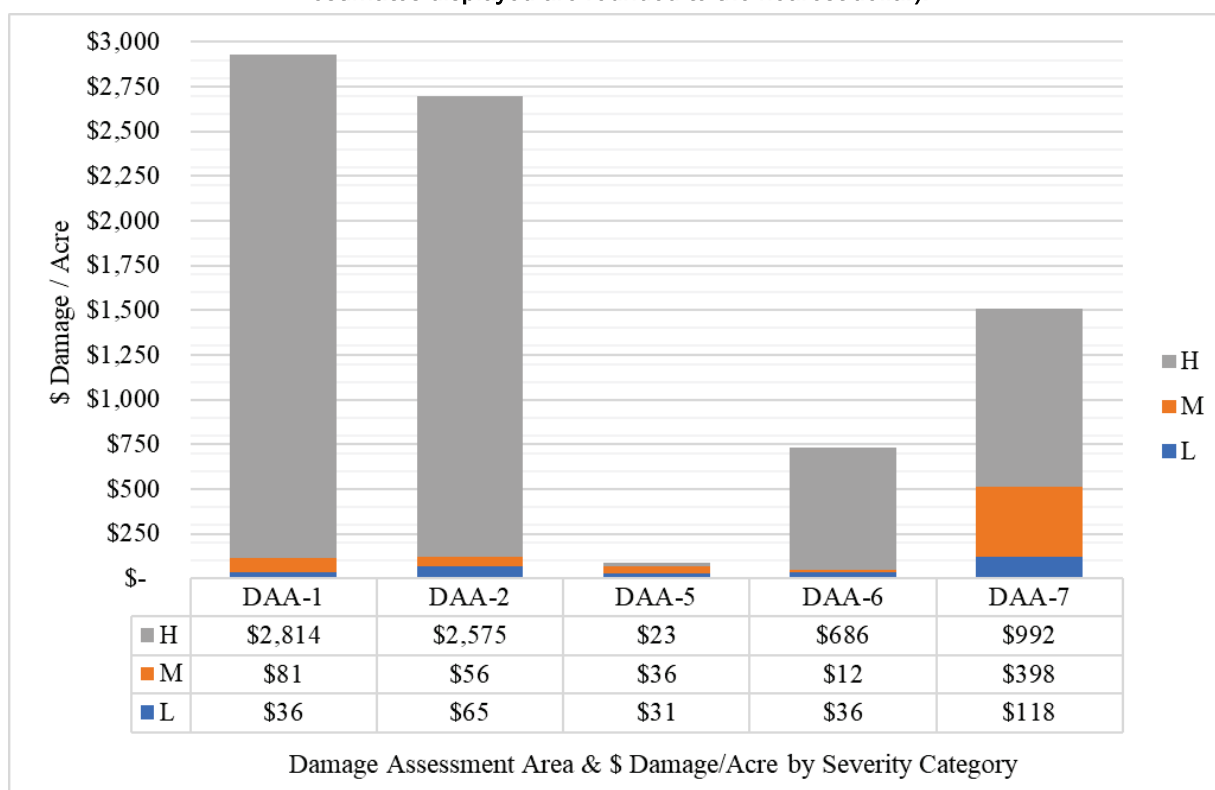


Table 5. Summary of estimated economic value (\$) of sampled acres damaged by severity in an approximately two-week period at Somerville Lake, July 2021 (rounded to the nearest dollar).

DAA	Acres Damaged	Acres Sampled	Low	Medium	High	Total	Damage / Acre Sampled (\$/acre)
DAA-1	0.10	0.22	0.003	0.004	0.093	\$652	\$2,931
DAA-2	0.04	0.10	0.003	0.001	0.038	\$269	\$2,696
DAA-5	0.00 ^a	0.11	0.001	0.001	0.000 ^c	\$10	\$90
DAA-6	0.01	0.09	0.001	0.000 ^b	0.010	\$70	\$734
DAA-7	0.05	0.16	0.008	0.014	0.023	\$239	\$1,508
Total	0.20	0.68	0.017	0.020	0.164	\$1,240	\$1,809

^a 0.003

^b 0.0003

^c 0.0004

4 Discussion

4.1 Overview

An FSDA framework was successfully field validated at the USACE Somerville Lake project to quantify and value soil damage caused by feral swine trampling, rooting, and wallowing within wetland habitats. From the authors' understanding, this effort is the first to develop and test a rapid FSDA framework that can quantify, assess, and value damage, which is critical for land manager decision-making. Overall, the FSDA successfully assessed a range of locations (sites ranging from 1 to 34.1 ac) and documented feral swine damage estimates ranging from 2% to 45% of damage on acres observed. Damage age and severity were also assessed to gain more detail on feral swine activity and associated impacts.

The total value of economic damage caused by feral swine in roughly two weeks within the entire 0.68 wetland acres observed was estimated to be \$1,240. This translates to an estimated \$1,809 of economic damage value per acre occurring in the study time frame on all assessed acres. When using these estimates, it is important to recognize that they are a lower bound estimation of the total economic loss likely occurring on the wetland landscape primarily because (1) the valuation of the benefits provided by well-functioning wetlands at Somerville Lake only considered two of the ecosystem services provided and (2) the damage assessment considered only soil disturbance rather than other wetland damage such as wildlife impacts (for example, depredation, habitat suitability) or changes to vegetation composition.

4.2 Next Steps

Considering the holistic objectives of this study, future research will refine the ecological-economic approaches and assumptions. For example, future field methods will be based on the pilot study presented here but will be adapted to capture a randomized and representative sample of the wetland area of concern and incorporate land-cover classification types prior to establishing the DAAs of interest. This refinement would ensure that the DAAs are represented by corresponding land classifications for the natural resource of interest (in this case, wetlands).

Also, during field validation, it was quickly apparent that the NWI data source used to help delineate land classifications did not match current field conditions, possibly because of the lack of updated NWI data for Somerville Lake and the inability to predict severe flooding in the summer of 2021. Future research will need to go beyond the USFWS NWI database for a more timely or updated source to identify wetlands and their boundaries prior to fieldwork. Other options to explore regarding land-cover data are tools like the Major Land Resource Area Geographic database (UDSA-NRCS 2022) or national data on watersheds like the Environmental Protection Agency's (EPA) StreamCat data set from the National Aquatic Resource Surveys database (EPA 2021). Improving the framework in this way will ensure that damage is indeed being observed on technically defined wetland areas and will better inform natural recovery time lines on a more site-specific basis, therefore improving the reliability and accuracy of economic estimates. These improvements will also support better identification of DAAs prior to fieldwork, which lends to the efficient allocation of time in the field.

Data regarding the relative density of feral swine for damage assessment efforts, and a methodology like rapid population assessments (RPAs) (Schlichting et al. 2020) as developed by WS, will be important for future research if feral swine control efforts are to be implemented. The RPA method uses camera grids and bait sites to establish a relative density estimate and index for evaluating relative changes in populations from pre- to postcontrol operations.

In terms of the rapid assessment capabilities of the existing framework, the pilot study validated a simplified methodology for assessing feral swine acres damaged, severity of damage, and age of damage. The goal of this simplification is for the framework to be applied by a broad range of staff with different skill sets (for example, a specialist like a botanist is not required for data collection). In addition to the already-mentioned need for a randomized sampling approach for this framework, the parameters should be reevaluated and improved on. For example, the age parameter will need improvement because it will not always be the case that the window of time over which damage has occurred (for example, two weeks) will be known because of events like recent flooding. Simplification and ease of use was also the objective in the development of the transect sampling calculator by ERDC-EL, with a goal to produce a rapid method that can be used repeatedly to assess a range of feral swine damages and

implemented readily by a user without in-depth field-sampling knowledge or experience.

Economic estimates of damage caused by invasive feral swine on USACE projects are important for assisting land managers in identifying areas of primary concern for feral swine control efforts and then quantifying the return on investment (ROI) from control efforts. Areas of improvement for the current economic estimation methods would primarily include (1) quantifying damage in such a way that damage estimates can be extrapolated to the entire wetland area of concern (previously addressed above) (2) refining the assumptions and data that constitute economic damage per acre estimates, and (3) adding a layer of information regarding investment on feral swine control efforts (for example, trapping, aerial gunning, fencing) for cost-benefit analyses for ROI. The Economics Project recognizes the importance of developing a framework that can be carried out in a timely manner by a range of skill sets.

Improvements regarding assumption and data supporting damage-valuation estimates (see item two listed above) are multifaceted. One, the current assumption in the damage-per-acre value is that repeat damage will not occur on the damage observed. This assumption may not be realistic, though it may also be true in some cases, and being able to determine the accuracy of this assumption will improve the estimation of time required for ecosystem services to return to baseline conditions. Additionally, research on the cumulative impact of feral swine damage from repeat visitation should be considered for future research, and previous research around feral swine feeder systems (for example, for baiting) may be a good starting point for figuring out methods for detecting repeat visits (for example, Long et al. 2010; Pound et al. 2012). Another way to refine the damage-per-acre value estimate would be improving the age and severity parameters in the field protocol so estimations of time required for ecosystem-service recovery to baseline conditions are more detailed and specific. Also, at the time the economic analysis was conducted, the ESVD was being updated, and use of the updated information will be an improvement for future studies. Updated wetland values will be incorporated to improve the asset value estimated used for the damage-per-acre value equation (Equation 1), and as mentioned in Section 2.3, specific ecological and socioeconomic characteristics of the area of interest should be considered as well. Last, applying a more accurate recovery function (Figure 17) for the ecological

damage observed would be ideal, which will once again require more refining of the ecological field methods and data collection.

As outlined above, additional research is critical for defining and then refining which characteristics (for example, damaged or not damaged, severity, age) are collected about feral swine damage observed in the field. Primary goals for future research include capturing a randomized sample of the damage for the ability to extrapolate estimates to an entire wetland area of interest, incorporating relative abundance estimates of feral swine density, and algebraic fine-tuning for the economic estimation equations.

5 Conclusion

This FY21 pilot study was the first step in the broader research effort to develop an ecological-economic framework for an FSDA that quantifies and values soil disturbance caused by feral swine trampling, rooting, and wallowing on wetland landscapes. This research is needed because of the increased spread and therefore presence of feral swine on sensitive natural-resource landscapes like wetlands habitats. This study achieved the primary objective of developing and testing the FSDA prototype, which was an important and successful first step in this multiyear endeavor to produce a ready-to-go and accessible damage-assessment framework that also allows for economic estimation of the value of the damage observed.

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Appendix A: Field Data Collection Sheet

The field-data collection sheet comprises the following six pages.

Figure A-1. Site-level data sheet (HGM—hydrogeomorphic).

Evaluators:	Date:	Site:	Acres:	Est. Transects:
		Avg. Width:	Length:	Total Transect Length:
				No. Transects Used:

NWI	
<u>Type</u>	
☐	PFO-1 Forest
☐	PSS-1 Scrub Shrub
☐	PFO-1/PSS-3 Mix
☐	PEM-1 Emergent
<u>Feature</u>	
☐	ditched
☐	excavated
☐	impounded

HGM	
<u>Type</u>	
☐	Connected depression
☐	Unconnected depression
☐	Flat
☐	Connected lacustrine fringe
☐	Unconnected lacustrine
☐	Fringe riverine overbank
☐	Riverine backwater
☐	Slope or seep

Figure A-1 (cont.). Site-level data sheet.

Site Description/Notes

A.1 Hydrogeomorphic Method and Key

The Hydrogeomorphic Approach to Assessing Wetland Functions, or *HGM Approach*, is a method to assess the functional condition (Smith et al. 1995) of a specific wetland referenced to data collected from wetlands across a range of physical conditions. It uses a wetland-classification system based on geomorphic position and hydrologic characteristics to group wetlands into seven different wetland classes as defined by Brinson (1993).

- **Connected depression**—Slight slope or gradient, within five-year flood frequency, typically has stream input and output
- **Unconnected depression**—Slight slope or gradient, not in five-year flood frequency, maintained by precipitation, runoff, or groundwater
- **Flat**—Little to no slope or gradient, maintained by precipitation and runoff, overland flow of surface water minimal
- **Connected lacustrine fringe**—Fringe associated with lakes and rivers or streams, within the five-year flood frequency
- **Unconnected lacustrine fringe**—Fringe associated with lakes and ponds, not within the five-year flood frequency
- **Riverine overbank**—Floodplain, frequently flooded by high-flow or high-velocity water directly from a stream or river
- **Riverine backwater**—Floodplain, frequently flooded by low-velocity backwater
- **Slope or seep**—Sloping land surface with groundwater discharge creating wetland areas along the slope gradient

A.2 National Wetland Inventory (NWI) Classification Code Descriptions and Key

The US Fish and Wildlife Service (USFWS) developed the National Wetland Inventory (NWI) wetland classification codes as a series of number and letter codes used to classify wetlands throughout the United States. There are over 5,200 alphanumeric combinations. The codes and descriptions below were observed throughout the Somerville Lake, Texas, sampling area. All codes and descriptions can be found on the USFWS website (<https://www.fws.gov/program/national-wetlands-inventory/classification-codes>) (USFWS 2021).

- **P (Palustrine)**—The palustrine system includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or

lichens and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt. It also includes wetlands lacking such vegetation but with all the following four characteristics: (1) area less than 8 ha (20 acres), (2) active wave-formed or bedrock shoreline features lacking, (3) water depth in the deepest part of basin less than 2.5 m (8.2 ft) at low water, and (4) salinity due to ocean-derived salts less than 0.5 ppt

- **PFO** (Palustrine, Forested)—Characterized by palustrine system with woody vegetation 6 m tall or taller
- **PSS** (Palustrine, Scrub, and Shrub)—Characterized by palustrine systems that include areas dominated by woody vegetation less than 6 m (20 feet) tall. The species include true shrubs, young trees (saplings), and trees or shrubs small or stunted because of environmental conditions.
- **1** (Broadleaf Deciduous)—Woody angiosperms (trees or shrubs) with relatively wide, flat leaves shed during the cold or dry season; for example, black ash (*Fraxinus nigra*).
- **3** (Evergreen)—Plant community where evergreen trees or shrubs represent more than 50% of the areal coverage of trees and shrubs. The canopy is never without foliage; however, individual trees or shrubs may shed their leaves.
- **A** (Temporarily Flooded)—Surface water is present for brief periods (from a few days to a few weeks) during the growing season, but the water table usually lies well below the ground surface for most of the season.
- **C** (Seasonally Flooded)—Surface water is present for extended periods, especially early in the growing season, but is absent by the end of the growing season in most years. The water table after flooding ceases is variable, extending from saturated to the surface to a water table well below the ground surface.
- **F** (Semipermanently Flooded)—Fresh surface water persists throughout the growing season in most years. When surface water is absent, the water table is usually at or very near the land surface. This modifier is used for riverine, lacustrine, and palustrine habitats.
- **d** (ditched)—A partly drained wetland has been altered hydrologically, but soil moisture is still sufficient to support hydrophytes. Drained areas that can no longer support hydrophytes are not considered wetland. This modifier is also used to identify wetlands containing, or connected to, ditches. The *partly drained* or *ditched* modifier can be applied even if the ditches are too small to delineate. The *excavated*

modifier should be used to identify ditches large enough to delineate as separate features; however, the *partly drained* or *ditched* modifier should also be applied to the wetland area affected by the ditching.

- **h** (impounded or diked)—These wetlands have been created or modified by an artificial barrier or dam that obstructs the inflow or outflow of water.
- **x** (excavated)—This modifier is used to identify wetland basins or channels excavated by humans.

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(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign
		19-20m					39-40m					59-60m					79-80m					99-100m		
		18-19m					38-39m					58-59m					78-79m					98-99m		
		17-18m					37-38m					57-58m					77-78m					97-98m		
		16-17m					36-37m					56-57m					76-77m					96-97m		
		15-16m					35-36					55-56m					75-76m					95-96m		
		14-15m					34-35m					54-55m					74-75m					94-95m		
		13-14m					33-34m					53-54m					73-74m					93-94m		
		12-13m					32-33m					52-53m					72-73m					92-93m		
		11-12m					31-32m					51-52m					71-72m					91-92m		
		10-11m					30-31m					50-51m					70-71m					90-91m		
(L) Sign	(L) Quad	Transect	Right Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign	(L) Sign	(L) Quad	Transect	(R) Quad	(R) Sign
		9-10m					29-30m					49-50m					69-70m					89-90m		
		8-9m					28-29m					48-49m					68-69m					88-89m		
		7-8m					27-28m					47-48m					67-68m					87-88m		
		6-7m					26-27m					46-47m					66-67m					86-87m		
		5-6m					25-26m					45-46m					65-66m					85-86m		
		4-5m					24-25m					44-45m					64-65m					84-85m		
		3-4m					23-24m					43-44m					63-64m					83-84m		
		2-3m					22-23m					42-43m					62-63m					82-83m		
		1-2m					21-22m					41-42m					61-62m					81-82m		
		0-1m					20-21m					40-41m					60-61m					80-81m		

Appendix B: Plaintext Version of Figure 16

Provided below is a plaintext version of Figure 16.

1. Economic Value of Wetland Benefits
 - a. Use Value
 - i. Direct use: Direct benefits from use of primary goods
 1. Provisioning services:
 - a. Food/fodder
 - b. Bioprospecting (biochemicals, medicines)
 - c. Fresh water
 2. Cultural services
 - a. Recreation
 - b. Tourism
 - c. Education/science
 - ii. Option Value: Option for future use (direct/indirect) of G&S
 - iii. Indirect use: Benefits from secondary G&S
 1. Provisioning services:
 - a. Fresh water
 - b. Bioprospecting
 2. Regulating services:
 - a. Carbon storage

- b. Water purification
 - c. Natural hazards mgmt.
- 3. Cultural services
 - a. Recreation
 - b. Scenery
- 4. Supporting services
 - a. Soil quality
- b. Nonuse Value
 - i. Bequest Value: Value for future generations
 - 1. Provisioning services:
 - a. Fresh water
 - 2. Regulating services:
 - a. Carbon storage
 - 3. Cultural services:
 - a. Scenery/landscape
 - b. Recreation
 - c. Education/science
 - 4. Supporting services:
 - a. Soil quality
 - ii. Existence Value: Value of existence without use/consumption of G&S

1. Cultural services:
 - a. Scenery/landscape
 - b. Community identity/integrity
 - c. Spiritual value
 - d. Wildlife/biodiversity
2. Associated Economic Valuation method
- iii. Market-based Valuation (for Use Values)
 1. Market price / production function
 2. Lost recreational opportunities
 3. Avoided damages/replacement costs
- iv. Non-market-based Valuation (for Non-use Values)
 1. Surrogate Market
 - a. Revealed Preferences
 - b. Hedonic pricing, Travel cost method
 2. Hypothetical Market
 - a. Stated Preferences
 - b. Contingent valuation, Choice experiments
- v. Benefit Transfer (for all values)

Abbreviations

DAA	Damage assessment area
DOI	Department of the Interior
EPA	Environmental Protection Agency
ERDC	US Army Engineer Research and Development Center
ERDC-EL	US Army Engineer Research and Development Center–Environmental Laboratory
ES	Ecosystem services
ESVD	Ecosystem Service Valuation Database
FSDA	Feral swine damage assessment
G&S	Goods and services
GIS	Geographic information system
HEA	Habitat equivalency analysis
HGM	Hydrogeomorphic
NFSDMP	National Feral Swine Damage Management Program
NWI	National Wetlands Inventory
NWRC	National Wildlife Research Center
RPA	Rapid population assessment
ROI	Return on investment
USACE	US Army Corps of Engineers
USD	US dollars
USDA-APHIS	US Department of Agriculture–Animal and Plant Health Inspection Service
USFWS	US Fish and Wildlife Service

WS	Wildlife Services
WS-Texas	US Department of Agriculture–Animal and Plant Health Inspection Service, Wildlife Services Texas
WTP	Willingness to pay

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

US Army Engineer Research and Development Center (ERDC)
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

US Department of Agriculture (USDA)–Animal and Plant Health Inspection Service (APHIS)
Wildlife Services (WS)
National Wildlife Research Center (NWRC)
4101 LaPorte Avenue
Fort Collins, CO 80521

Colorado State University (CSU)
College of Liberal Arts
Department of Economics
C306 Clark Building
1771 Campus Delivery
Fort Collins, CO 80523-1771

US Department of Agriculture (USDA)–Animal and Plant Health Inspection Service (APHIS)
Wildlife Services (WS)
National Feral Swine Damage Management Program (NFSDMP)
4101 LaPorte Avenue
Fort Collins, CO 80521