



Wither the Weeds:

ArcGIS Geodatabase proof of concept in support of Invasive Species Management Planning in Pennsylvania State Parks

ABSTRACT

This project has developed a proof-of-concept geodatabase to enable site prioritization assessment for Pennsylvania Department of Conservation and Natural Resources, Bureau of State Parks, Invasive Species Management Planning activities within Pennsylvania State Parks. This geodatabase and resulting utilization in an ArcGIS Field Maps application demonstrates the ability of a geodatabase to enable site prioritization and handheld field data synchronization. Further, the synchronization can enable State Park personnel to generate informative visualizations of ongoing remediation activities.

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Prepared for Pennsylvania Department of Conservation and Natural Resources, Bureau of State Parks, Invasive Species Management Planning stakeholders. Submitted for partial satisfaction of the Penn State MGIS degree capstone requirements

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1. Introduction/Overview

1.1. Introduction

Invasive plants are a problem in Pennsylvania State Parks. In general, environmental harm caused by invasive plants can be extensive, including direct impacts on "public health, crops, livestock, agricultural land, and other properties" (USDA, 2020) and significant degradation of native plant habitats. Examples of these impacts in Pennsylvania as a whole and the State Parks include: Giant hogweed sap causes extreme skin sensitivity to UV radiation which can lead to skin blistering, severe burns, and even blindness if eye contact is made (Schneck, 2018); grasses such as Japanese stiltgrass and reed canary grass spread opportunistically, establishing dense patches that exclude other plant species, greatly decreasing biological diversity (Landscape America, 2020); Japanese stiltgrass patches can also hinder forest regeneration (Mulhollem, 2002); kudzu outcompetes other plants by "smothering them under a solid blanket of leaves," girdling or ring-barking trees and other woody stem trunks, and breaking branches or toppling trees due to sheer weight; multiflora rose and other invasive shrubs in forests diminish butterfly habitat and act as population sinks for native birds; (LandScope America, 2020) and poison hemlock causes severe skin irritation on people and is toxic to grazing livestock (Schneck, 2020).

Activities to counter invasive plant infestations in Pennsylvania State Parks are primarily performed by the Pennsylvania Department of Conservation and Natural Resources (DCNR), Bureau of State Parks (Parks Bureau). The principal method used by Parks Bureau to remediate invasive plants in Pennsylvania State Parks is the Invasive Species Management Planning (ISMP) process. This process was developed in conjunction with the Pennsylvania State University (PSU) College of Agricultural Sciences, Plant Science Department Wildland Weed

Management Program (WWMP). ISMP is “site specific ... (and) considers qualities of ... Habitat Management Zones (HMZ) within the park and the invasive species present” within those HMZs (Gover, et al., 2016). Previously the process was driven by subject matter expertise, utilizing workshop training, and an instructional Microsoft Word document with an accompanying Microsoft Excel workbook. That process generated priority indices to determine “a ranked work list” of sites within the respective parks.

Prior to the completion of this project, the site determination process was separate from the in-the-field work and site remediation. Whereas the site prioritization used an Excel workbook, the field work process utilized ArcGIS Field Maps (previously Collector) mobile applications to catalog areas worked within HMZs. Therefore, the site determination process lacked interoperability with the field collection efforts, requiring personnel to capture and input data multiple times into nonintegrated data capture environments. This project has addressed the interoperability shortfall, and this paper will focus on how this proof-of-concept tailored Geographic Information System (GIS) geodatabase (derived from the ISMP workbook) will enable ISMP participants with a multi-user site prioritization capability that integrates field collection activities.

1.2. Importance

The previous ISMP process to identify and develop site work lists was comprised of several steps, took time, and did not allow for multiple users within the Excel workbook. There had been no GIS application for the site prioritization and assessment portion of the ISMP process. As noted previously, on-the-ground site remediation personnel used an ArcGIS Field Maps mobile application. Prior to this proof-of-concept, the site assessment and site remediation

process were not inter-operable, meaning that ISMP participants had to spend additional time transferring information and data between the two systems. The creation of this ArcGIS geodatabase will facilitate efforts of ISMP personnel to determine HMZ prioritization for remediation efforts in the process and should enable visualization of remediation activities to stakeholders.

1.3. End User/Client

The proposed end users/clients for this project are personnel working within the Pennsylvania Parks Bureau, as well as those individuals who support ISMP activities but may not be directly employed by the Bureau. Additional beneficiaries are the WWMP personnel who as ISMP planning partners have been a liaison between this project and Parks personnel.

1.4. Solution

The solution this project provides is an Esri ArcGIS file geodatabase built in ArcGIS Pro desktop, modeled after the existing ISMP workbook tables. The geodatabase was then published to ArcGIS Online as a Feature Layer and Service definition. The Feature layer was then saved as a Web Map within ArcGIS Online, with ArcGIS Arcade “Calculated Expressions” written to select fields within ArcGIS Field Maps.

Esri ArcGIS formats and applications are used in this project because the existing field data capture activity for ISMP uses ArcGIS Field Maps mobile application, and the Bureau maintains and operates existing ArcGIS Online instances. This makes integration and possible expansion of this project much simpler. The other option could have been to create the database using Free and Open-Source Software for Geospatial (FOSS4Geo) formats, such as

PostgreSQL/PostGIS. That option could potentially have lower overall cost in terms of software licenses and PostgreSQL/PostGIS databases are compatible with Esri software (ESRI, 2020). However, there could be greater difficulties and challenges integrating FOSS4Geo options into existing Esri based processes and workflows (Altaweel, 2020; Maurya, et al. 2015).

1.5. Overview

The following is an overview of the remaining sections. Section two covers a background on invasive plants and a literature review. Section three discusses the goals, objectives, and methodology for developing the proof of concept geodatabase and related application in Field Maps. Section four discusses the results. Section five contains references for the paper.

2. Background and Literature Review

2.1. Invasive plants

Issued in 1999, Executive Order 13112 defines invasive plants as plants that are "non-native (or alien) to the ecosystem under consideration and whose introduction does or is likely to cause economic or environmental harm or harm to human health" (Federal Register, 1999; USDA, 2015). Invasive species spread due to tolerating diverse habitats, growing and reproducing very rapidly while out-competing native species for resources, usually because they have no natural predators or pests in the local ecosystem (USDA, 2015). Invasive plants can include noxious weeds but also exotic or non-native plants that have potential to unnaturally dominate native ecosystems without intervention. Noxious weeds are exotic problem species listed by Federal, State, or County entities which, because of being listed, require management actions and restrictions. Frequently, invasive plants are introduced to native ecosystems via anthropogenic (man-made) actions including (but not limited to): transportation of infected plants, soils or water; the seed, garden, nursery or pet store trade; boating traffic; and forest management equipment such as logging trucks and excavators (Oregon Invasive Species Council, 2015; USDA, 2015).

2.2. Invasive plants in Pennsylvania Parks

In Pennsylvania State Parks, invasive plants diminish native wildlife habitat. Invasive plants frequently out-compete native plant species for resources and growing space, primarily through displacement of native plants, which in turn reduces habitat quality. One of the ways invasive plants are so successful at displacement is they emerge earlier in the spring growing season and rapidly exclude native plants through faster growth cycles. This excessive growth

can create monocultures which reduce habitat available for native wildlife and disrupts the food chain. An example is the invasive plant garlic mustard, where “native butterflies lay eggs on garlic mustard, and they either die or the caterpillars don’t properly grow” (DCNR, 2020).

It is important to understand that in State Parks, effectively, “invasive species management... (is)... habitat management” (Gover, et al. 2016). However, “limitations on ... funds or labor resources prevent most land managers from adequately controlling all known invasive plant infestations ... prioritization of effort is critical ... to generate the greatest progress towards satisfying management goals” (Hohmann, et al. 2013).

The principal method used to manage invasive species in Pennsylvania State Parks is the ISMP. The ISMP process consists of three general activities - prioritization, prescription, and implementation. Prioritization consists of identification of the problem, from the perspective of the ecological conditions and of the long-term use expectations for a designated area of the park. Prioritization is necessary to maximize the finite resources and is determined by “creating a series of indices... that assigns values to characteristics of... designated land units and to the invasive species infesting them.” These indices enable the establishment of a work list. In the prescription phase, parks determine their operational details, (i.e., the people, equipment, and materials) needed to accomplish the work list. Finally, implementation is where teams and resources deploy to the field to accomplish the work list, balancing the finite resource requirements of park management (Gover, et al. 2016).

2.3. Geographic Information Systems

As a “computer tool used to store, organize, access, manipulate, analyze, interrelate, and display spatial information” (Dimini, et al., 2010), GIS is “helping stakeholders gain insights to

environmental issues and problems” (Loh & Tapaneeyakul, 2012). Loh and Tapaneeyakul expand on this concept further by identifying GIS as “hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the Earth.” GIS is a very capable tool “for environmental data analysis and planning.” With the ability to symbolize and visualize environmental feature overlays, GIS enable more holistic understanding of relationships between physical features and “influences in a given critical environmental condition ... to determine various environmental parameters and impact analysis” (Shimonti, 2018).

Myriad sources discuss the importance of GIS in the invasive species management and habitat management realm from: a study using multiple regression models to predict the invasion rate of a select species in Joshua Tree National Park (Cullors, 2013); to multi-criteria decision analysis to prioritize landscape management at Ft. Bragg, N.C. (Hohmann et al., 2013); the development of a GIS database to demonstrate the county level distribution of invasive plants in the southeastern United States (Fletcher & Reddy, 2018); and a study that developed a GIS tool to rank invasive species infestations based on their potential risk to native habitats (Tateyama, 2014).

Of additional interest to this project is the contribution GIS can make in a type of habitat analysis known as Floristic Quality Assessments (FQA). FQA is a method of biodiversity evaluation that uses standardized coefficients to calculate indices reflecting the status or “quality of native plant communities for a given area. (FQA) indicates the impacts of invasive species and can also be used to monitor the effectiveness of land-management and restoration practices” (Lotze and Vannais, 2019).

Studies that discuss the benefit of GIS in FQA include: using GIS to provide web-map access to forest biodiversity archives in Trento Province Italy (Geri, et al., 2016); a field survey and GIS mapping of plant types within mountain forest habitat on Mount Tahan, Malaysia (Ismail, 2010); stratified random sampling of floristic diversity and forest cover in South Gujarat, India using remote sensed data and GIS mapping (Bhatt, et al., 2014); and an investigative study by Nelder, Crossley, and Cofinas to examine the sampling rigor in five GIS based vegetation surveys (Nelder, et al. 1994).

2.4. ArcGIS Field Maps

ArcGIS Field Maps is a mobile mapping and data capture product that facilitates users “to capture data, perform inspections, take notes, and share information with” their organizations. Additionally, users can implement the “Field Maps web app to configure maps and deploy them for use in the field” (Esri, ArcGIS Field Maps, 2022). Field Maps replaces ArcGIS Collector, Explorer, and Tracker by performing those applications activities under one program. In fact, those other applications and capabilities are being phased out, with “all future updates will be focused on Field Maps” (Darbyshire, 2020). While Field Maps is a more recent offering, supported on supported on ArcGIS Online and ArcGIS Enterprise 10.9 and later, there are several examples of academic and non-academic utilization across the literature.

Field Maps is used by the Charlottesville Fire department to “establish an easy and efficient method that was simple for firefighters to use” during critical mandated fire hydrant inspection activities (Esri, “Charlottesville FD”, 2022). Flagler County, Florida uses Field Maps (combined with ArcGIS Survey 123) mobile applications to perform “critical aspect(s) of post-hurricane response is conducting a preliminary damage assessment in order to gain access to

Federal Emergency Management Agency funds” (Adams, 2022). Finally, the Ute water district in Grand Junction, Colorado uses Field Maps and Survey 123 to support the districts efforts to comply with the EPA Lead and Copper Rule Revisions published on January 15, 2021.

Specifically, the application enables the water district “to identify and document all service line materials... (and)... improve workflows, reduce time and redundancy over traditional paper record keeping methods” (Martin, 2022).

2.5. ArcGIS Arcade

ArcGIS Arcade is an expression language developed by Esri to “create custom content in ArcGIS applications. (Esri, Arcade Introduction, 2022). Arcade is designed solely for use within ArcGIS. While Arcade does have the ability to “perform mathematical calculations, format text, and evaluate logical statements,” Arcade is also capable of working with geospatial datatypes, known as “feature and geometry data types” (Esri, Arcade Introduction, 2022).

These two datatypes underscore that Arcade is a language that puts geospatial first, that “makes geospatial functions and capabilities” priorities (Esri, Arcade FAQ, 2022). These two geospatial datatypes are built upon and are supported by each other. There are five Geometry types: Point, Multipoint, Polyline, Polygon and Extent. Point being a simple “geometry representing a location with a pair of coordinates”; a Multipoint geometry occurs “where multiple points represent one geometry”; a Polyline is a one-dimensional “list of coordinates representing one or more paths”; a Polygon “is a two-dimensional geometry containing a list of coordinates representing one or more...boundaries”; and an Extent “is a bounding box describing the minimum and maximum coordinates of” a Multipoint, Polyline, or Polygon. All these

geometries may be defined using a Dictionary or a set of key/value pairs. Finally, Features “represent geometries with a dictionary of attributes.” (Esri, Arcade Introduction, 2022)

Arcade was chosen for this project for these reasons and because of its “portability with other apps across the ArcGIS system,” meaning: “expressions written in ArcGIS Pro can be saved to a web map and evaluated with consistent results in a mobile application developed with ArcGIS Runtime, or in a web app, such as ArcGIS Online, or any other app developed with the ArcGIS API for JavaScript” (Esri, Arcade FAQ, 2022).

3. Project Goals and Methodology

3.1. Project Goals

The principal goal of this project is to build a proof-of-concept geodatabase and Field Maps application to demonstrate the capability for a geodatabase to support HMZ site prioritization assessments in the ISMP process. The geodatabase should conform to the existing tables and outputs extant in the ISMP Excel workbook. Examples of the Excel workbook tables are the Habitat Management Zone Identification and Species Impact Index tables below (see Tables 1 and 2). A secondary goal was to enable integration between the site prioritization assessments and the field data collection portions of the ISMP process. As the field collection is performed using ArcGIS Field Maps the site selection process should function within Field Maps.

As a means of “checking” the function of the proof-of-concept, a tertiary goal was to validate that the site prioritization output matched outputs that had previously been completed using the Excel workbook. With the function check, the geodatabase could operate on the backend of the ISMP process, following the understanding that “front-end... work(s) on what the user can see while back-end ... build(s) the infrastructure that supports it” (Concepta, 2017). In this instance, the backend could be the Parks Bureau ArcGIS Online instance. This should facilitate ISMP by providing field staff the ability to record their observations while in the field via an application with a map interface. As identified by Mau-Crimmins & Orr, using digital and mobile applications to map weeds vice via paper maps by hand, “is much faster and more accurate, eliminates the transfer of data from various paper sheets, enhances sharing of information between agencies, allows for easy updates, and can help users to set management priorities” (Mau-Crimmins & Orr, 2005).

Table 1. Habitat Management Zone identification

Table 1. List and characterize the Habitat Management Zones (HMZ) in your park. Type in the name of the HMZ in the column "HMZ Name", then use the drop-down menus in the adjacent columns to select the Habitat Type, Stewardship Value, and Outreach Value. A formula will generate the Site Index for each HMZ. You can use this to sort if you wish to arrange HMZ by "site value"

Begin	HMZ Name	Habitat Type	Stewardship	Outreach	Site Index
Next					
Add Zone					
Help					
Reset					

Table 2. Species Impact Index

Table 3. For each species, its "Impact" and "Restoration Effort" index values are provided. The Impact index is potentially determined by the nature of the invaded site, which is characterized by Habitat Type. Where species are assigned an Impact index of "1", the corresponding Habitat Types are listed. If the species you are considering is not occurring in a listed Habitat Type, assign an Impact index of "0". The Restoration Effort index may be affected by the Extent of the species in question. To find the appropriate Restoration Effort index for the considered species, refer first to the Extent index you assigned in the worksheet "4_HMZ-SPP EXTENT", and use the index value from the corresponding Extent column.

	Present	Common Name	Scientific Name	Growth Form	Impact							Restoration Effort			
					MF	PF	ME	RC	LS	YF	WL	Extent=2	Extent=1	Extent=0	
Begin															
Next		arthroxon	Arthraxon hispidus	AN	0	0	0	0	0	0	0	2	1	1	
Help		Japanese hops		AN	0	0	1	1	1	1	0	2	1	0	
		Japanese stiltgrass	Microstegium vimineum	AN	0	0	0	0	0	0	0	0	0	0	
		jimsonweed	Datura stramonium	AN	0	0	0	0	0	0	0	3	2	2	
		mile-a-minute	Persicaria perfoliata	AN	0	0	1	1	1	1	0	0	0	0	
		<i>exotic biennials</i>	<i>many</i>	BI	0	0	0	1	1	0	1	2	1	1	
		bull thistle	Cirsium vulgare	BI	0	0	0	0	0	0	0	2	1	1	
		common teasel	Dipsacus fullonum	BI	0	0	0	1	1	0	1	1	1	1	
		dames rocket	Hesperis matronalis	BI	0	0	0	0	0	0	0	2	1	1	
		garlic mustard	Alliaria petiolata	BI	0	0	0	0	1	0	1	2	1	1	
		musk thistle	Carduus nutans	BI	0	0	0	0	0	0	0	2	1	1	
		plumeless thistle	Carduus acanthoides	BI	0	0	0	0	0	0	0	2	1	1	

3.2. Methodology

The methodology for this project became straightforward once the project was scoped to be a proof of concept. A file geodatabase was created in ArcGIS Pro (see Figure 1). The geodatabase consists of a polygon feature class for the Nescopeck Park boundary. This boundary is selected from the Pennsylvania State Park Boundaries shapefile, retrieved via the Penn State Pennsylvania Spatial Data Access (PASDA) geospatial data clearinghouse (PASDA, n.d.). The park boundary feature class stores all the HMZs within the park and their attributes.

The significant HMZ attributes, Habitat Type, Stewardship Index, and Outreach Index, are derived from the ISMP workbook.

The Habitat Type field is a means to delineate the areas of a park that are suitable for management, albeit in somewhat approximate definition. As Gover, et al. note, “(w)e are not seeking... descriptive detail... (of) a plant community type in a Natural Heritage survey - we simply want to be clear what the area *should be*” (emphasis in original). As such, there are seven habitat types for the desired conditions:

- Mature Forest (MF): a forest of advanced age, with distinct vertical layers and closed canopy
- Pole Forest (PF): a forest where canopy closure may be occurring, but there are not distinct vertical layers
- Young Forest (YF): a heterogeneous site with a significant population of shrubs or sapling trees
- Wetland (WL): significant wet areas (seasonal or permanent), as well as ‘complexes’ where small wet areas mix with non-wet areas
- Riparian Corridor (RC): any stream channel, river, seasonal tributary, or headwater
- Lakeshore (LS): sites that approximate where submerged aquatic vegetations transitions to native woody canopy along a shoreline
- Herbaceous Opening (HO): an uncommon designation; prairie remnants and designated wildflower areas would be examples

The Stewardship Index is a numeric ranking from 0 – 2 “with a '2' indicating site of high ecological value, and '0' for those less ecologically intact. Any Habitat Type in its ideal form would score a '2', but riparian corridors and wetlands will tend to index as '2' even if they are somewhat disturbed due to their critical value. Values of '1' or '0' indicate increasing levels of disturbance, such heavy-use recreational areas in naturalistic settings.”

Similarly, the Outreach Index ranges from 0 – 2 and “acknowledge(s) that people care more about some places than others, and not necessarily due to strictly ecological criteria. Sites that are more prominent, more visible, or truly ecologically unique will attract interest from people other than the park staff tasked with the operational work.” A score of ‘2’ indicates a site that draw sufficient interest that external organizations would provide funding, help with, or provide other resources to accomplish remediation work; a score of ‘1’ is where sites are “prominent and the highly visible work will help communicate the Park’s mission;” and a score of ‘0’ means it is “unlikely that a particular site will garner any external interest.”

In addition to the polygon feature class, there are also eight tables in the geodatabase, each representing an additional facet of the overall ISMP process. For this project, there are four critical tables: the table that contains the list of Invasive Species (Species_Info); the table for Invasive Species with the HMZs (Species_HMZ); the table for Restoration Index (Restoration); and the table for the Impact Index (Impact).

Species_Info stores the 72 invasive species denoted by the ISMP workbook as having some type of negative effect in Pennsylvania State Parks. Species_HMZ stores the species observed within the HMZs. It is worth noting that there is a many-to-many relationship between HMZs and invasive plant species. More than one species can be in a select HMZ.

The Restoration table contains fields for two additional inter-related indexes, which define the Restoration Effort (RestorationValue) and invasive species Extent (Extent). Like Stewardship and Outreach, these are ranked indexes, with Extent ranging from 0 – 2 and Restoration ranging from 0 – 3.

The Restoration Index reflects the resistance of the invasive species to remediation efforts, as well as how rapidly the native plant community can recover to fill vacant space caused

by the remediation. Restoration's index of 0 – 3 signifies: “native plant community will fill in on its own (3); native plant community fills in, but the invasive... requires at least two growing seasons of suppression (2); The invasive... can be successfully removed... (with)... effort, but native plant(s)... (need) seeding or planting (1); elimination of the invasive is unlikely (0).”

The Extent index describes “*how much is there?* (Emphasis in original) A '2' is assigned to low levels of infestation, where the species is sparse, or not even present but in the vicinity. Assign a '1' to species that are common, but could be present at an even higher density, and '0' to high levels where the species could not get much worse.”

Finally, the table for invasive species Impact index (Impact) ranges from 0 – 1. Because “all invasive species are 'bad' - there is a minimum threshold of disruption that they have already met just to be considered. (Yet) there are some situations where a particular species will really thrive due to its adaptations.” As such, the Impact index value of ‘0’ represents “the invasive species will have a negative impact, but probably no more than other species present.” Whereas, a value of ‘1’ means “(t)his invasive species... will spread quickly, likely reduce or displace the desired species, and substantially interfere with the ecological objectives of the site” (Gover, et al. 2016).

Domain values were encoded into the geodatabase to ensure that no data entry errors occur and to match values as defined in the ISMP Excel workbook (Figure 2). Domains are set for Species, Habitat Types, Extent, Impact, Stewardship, Outreach, and Restoration amongst others. There are more attribute tables in the geodatabase than are requisite for the proof-of-concept, however this should allow for expanding the effort to encapsulate all state parks in later iterations.

Next a relationship class was defined between the HMZ polygon feature class and the Species in the HMZ (Species_HMZ) table. This relationship class can be seen in the geodatabase and is labeled 'HMZ_ISMP_Species_HMZ'. A relationship class may sound like the probably more well-known concept of a “relate” or “Table relate”. There are similarities between both activities, such as they both rely on cardinality, or “the correspondence or equivalency between sets” (ESRI Support GIS Dictionary) and they both “must have a field of the same data type (e.g., text, short integer, long integer, ObjectID)” as the key field or connection between the participating elements (Boden, 2018).

However, sufficient differentiation in utilization exists between the two concepts. As Bowden notes in her discussion of the two, “(a) relate exists in a map or layer file (and)... allow you to select features in a layer, then easily see related features in a different layer or ... table; (Whereas a) relationship class is an object in a geodatabase. Relationship classes enable smart behavior. You can set up rules for how the participating feature classes or tables behave when something happens. For example, with a relationship class in place, if a feature is deleted, then its associated record in the other feature class or table will be automatically deleted” (Bowden, 2018). The difference is significant for this project, as the relationship class enables the Field Maps mobile application user to select an HMZ of interest and then record the relevant species found within the HMZ.

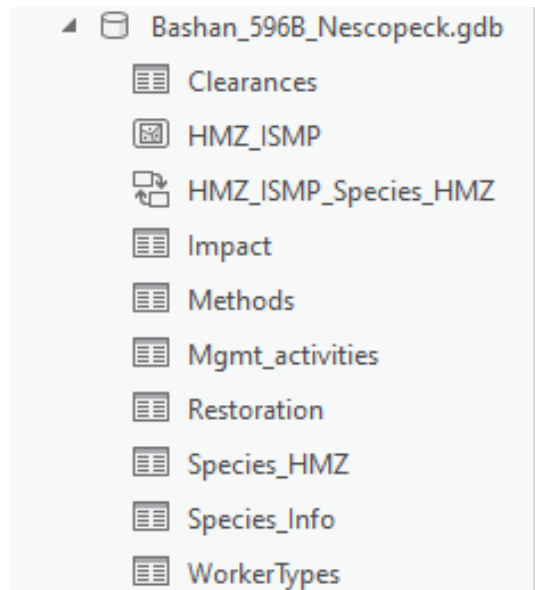


Figure 1. File geodatabase developed for the ISMP process

Domain Name	Description	Field Type
ExtentIndex	Characterization of Invasive Species Extent within HMZ	Short
GrowthForms	The growth form of the invasive plant species	Text
HMZ_Type	Habitat Type identification, what the area "should" be within the HMZ	Text
ImpactIndex	Characterization of Invasive Species Impact	Short
Management_Activities	Organized by the Integrated Pest Management (IPM) categories of Cultural, Mechanical, Biological, and Chemical.	Text
OutreachValue	This index is to acknowledge that people care more about some places than others, and not necessarily due to strictly ecological criteria.	Short
PresenceIndex	Characterization of Presence/Absence Values	Short
RestorationIndex	Restoration Effort considers the resistance of the invasive species population to control measures, and how quickly the native plant community recovers to try to refill the space vacated by your control measures.	Short
SpeciesNames	Names of Invasive plant species	Text
StewardshipValue	Stewardship value of the HMZ	Short
WorkerType	Description of personnel (worker) skill level performing the remediation	Text

Figure 2. Geodatabase domains, derived from the ISMP Excel workbook

The geodatabase was then published to the Penn State University ArcGIS Online organization as a Service definition and hosted Feature layer. The Feature layer was added to a new Web Map, which was then opened for configuration in the Field Maps web app (see Figures 3 and 4). In this iteration of Field Maps, a pop-up form for the Species_HMZ table was instantiated. A pop-up is an ArcGIS Arcade profile, which are “the context in which an Arcade

expression is evaluated and interpreted” (ESRI, Arcade Introduction, 2022) or more simply, the “where” that Arcade can be used in ArcGIS. It is in the form pop-up that the powerful Arcade Calculated Expressions are written.

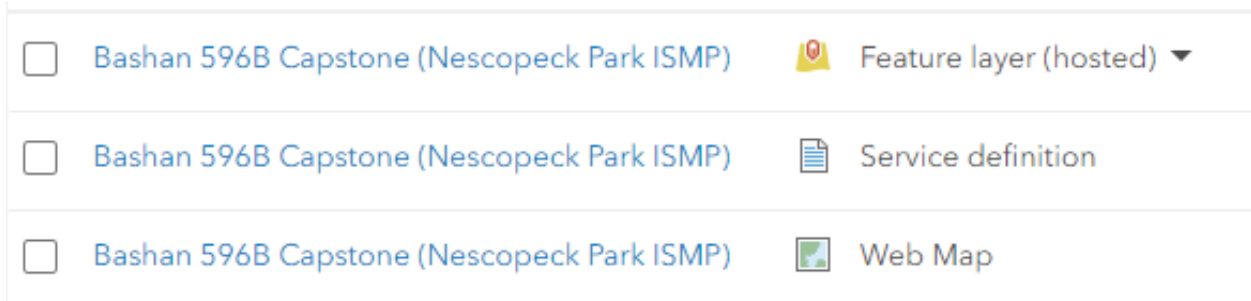


Figure 3. ArcGIS Online Instance

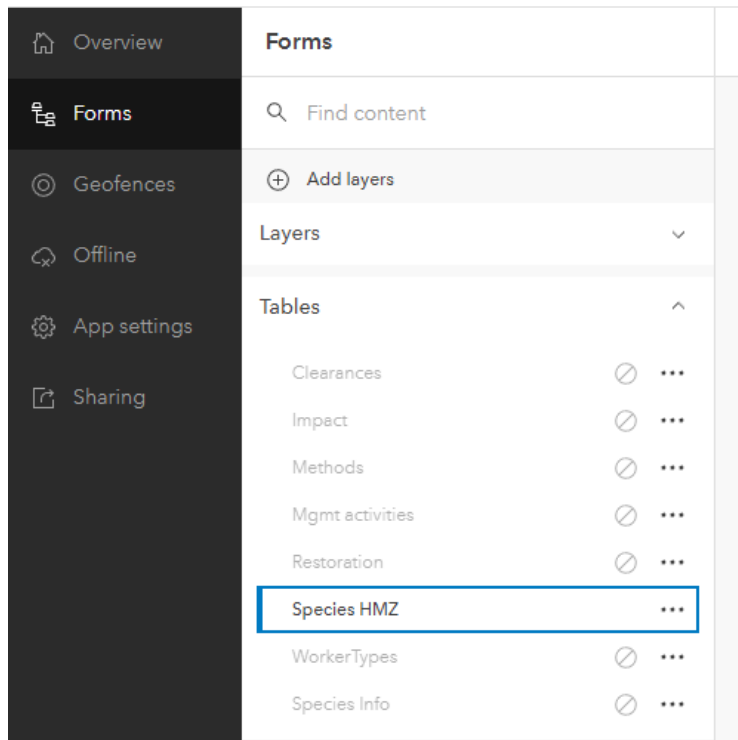


Figure 4. Field Maps Form Example

Three Calculated Expressions were created to automate the determination of invasive species’ Restoration, Impact and Prioritization values (see Figures 5 - 7). As discussed earlier,

Restoration is a measure of the species' resistance to control measures ranging from 0-3, with 0 being highly resistant to 3 being relatively easy to suppress and is considered in conjunction with the species growth extent. Impact is the invasive plant species' "potential to negatively affect the existing plant community more than other... species already present." The third Calculated Expression, "Prioritization Value," is derived from combining Restoration and Impact with: Stewardship (integrity or lack of disturbance); Outreach (stakeholder interest the HMZ generates); and Extent (how much is there?) (Gover, et al. 2016).

Impact Expression:

```
var species_id = $feature["Species_ID"]
var hmz_id = $feature["HMZ_ID"]

var hmz_lyr = FeatureSetByName($map,"HMZ ISMP")
var feat_set = Filter(hmz_lyr,"HMZ_ID = " + hmz_id)
var feat = First(feat_set)
var habitat_type = feat["Type"]

var impact_tbl = FeatureSetByName($datastore, "Impact")
var sql = "HabitatType = " + habitat_type + " and Common_Name = " + species_id + ""
var impact_row = Filter(impact_tbl, sql)

if (Count(impact_row) == 0) {
    return 0
} else {
    var impact_val = First(impact_row)["ImpactValue"]
    return impact_val
}
```

Figure 5. Impact Value Calculated Expression

Restoration Expression:

```
var species_id = $feature["Species_ID"]
var ext = $feature["ExtentChar"]

var rest_tbl = FeatureSetByName($datastore, "Restoration")
var sql = "ExtentValue = " + ext + " and Common_Name = " + species_id + ""
var rest_row = Filter(rest_tbl, sql)

if (Count(rest_row) == 0) {
    return 0
} else {
    var rest_val = First(rest_row)["RestorationValue"]
    return rest_val
}
```

Figure 6. Restoration Value Calculated Expression

Priority Expression:

```
var hmz_id = $feature["HMZ_ID"]
var extent_val = $feature["ExtentChar"]
var impact_val = $feature["ImpactValue"]
var restoration_val = $feature["RestorationValue"]

var hmz_lyr = FeatureSetByName($map,"HMZ ISMP")
var feat_set = Filter(hmz_lyr,"HMZ_ID = " + hmz_id)
var feat = First(feat_set)
var steward_val = feat["Stewardship"]
var outreach_val = feat["Outreach"]

var priority_val = steward_val + outreach_val + extent_val + impact_val + restoration_val
return priority_val
```

Figure 7. Priority Value Calculated Expression

4. Results

The result of this project is the successful development of an ArcGIS geodatabase that meets the three previously stated project goals to:

- 1) support HMZ site prioritization assessment
- 2) enable integration between the site prioritization assessments and field data collection
- 3) validate site prioritization results matched actual ISMP previously completed results

The geodatabase and calculated expression driven Field Maps application successfully determined accurate site prioritization in a mobile hand-held field application. These results can be seen in the Species Prioritization table, which is derived from manual entry of relevant values in a mobile Field Maps instance and then synchronized back to the Web Map and compared against the actual IMSP prioritization results (seen in Figure 8; Tables 3 and 4). Examples of the mobile Field Maps application interface can be seen in Figures 9 – 12.

It is evident that efforts to convert the ISMP site assessment process from a Microsoft Excel workbook flat file format into an inherently more robust GIS geodatabase format will only enhance Parks ISMP invasive plant remediation efforts. This project incorporates a geodatabase into an ArcGIS Field Maps mobile application, providing the ability to compute site rioritization from field observations and potentially serving as an aid to future FQA efforts in PA State Parks.

Bashan 596B Capstone (Nescopeck Park ISMP)

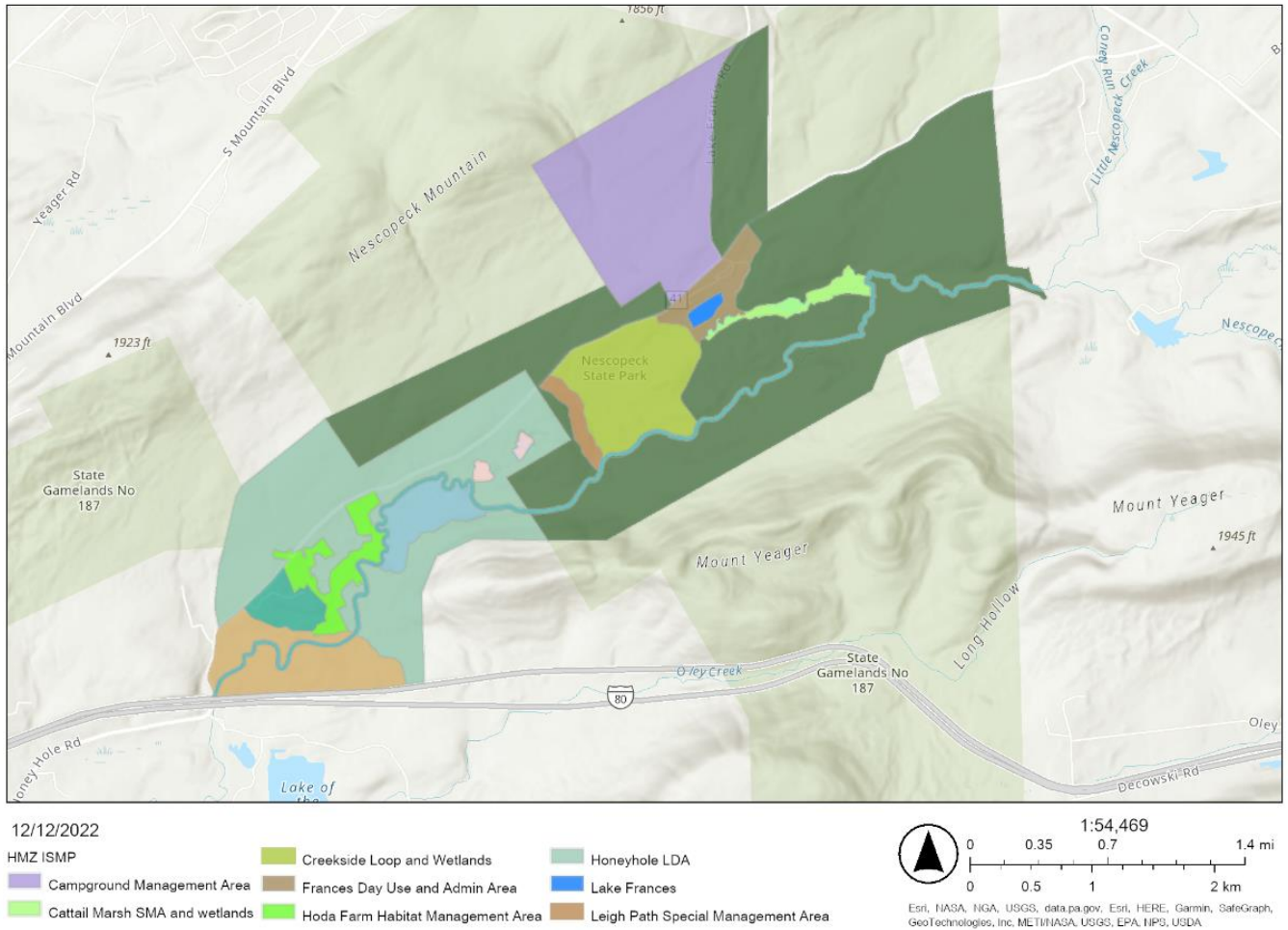


Figure 8. Project Nescopeck Map

Table 3. Species Prioritization (mobile data)

HMZ_ID	Species Identificati...	Extent	Impact	Restoration	Priority
3	exotic biennials	2	1	2	
3	exotic biennials	2	1	2	9
1	Japanese stiltgrass	2	0	0	5
1	exotic biennials	2	1	2	8
1	reed canarygrass	2	1	2	8
9	exotic biennials	2	1	2	9
9	common reed	2	1	1	8
12	exotic biennials	2	0	2	6
14	Japanese knotweed	2	0	2	6

Table 4. Species Prioritization by HMZ (workbook)

HMZ Name	Cattail Marsh SMA	Lower SMA	Nescopeck Creek	Quarry Pond/Wetlands	Woodfrog Loop Wetlands	Lake Frances	Hoda Farm	Lehigh Path	Creekside Loop Wetlands	Frances Day Use Area	Lower Day Use Area	Campground Area	Honey Hole LDA	Nescopeck LDA
Habitat Type	WL	MF	RC	WL	WL	LS	YF	MF	WL	YF	YF	MF	MF	MF
Stewardship Index	2	2	2	2	2	1	1	1	2	0	1	2	2	2
Outreach Index	1	0	2	0	1	1	2	1	2	1	0	0	0	0
Spec. Prior. 0-1														
Japanese stiltgrass	0	0	0	0	0	0	5	4	6	3	3	4	0	0
mile-a-minute	0	0	0	0	0	0	5	0	0	0	0	0	0	0
exotic biennials	8	6	9	7	8	7	7	6	9	5	5	6	6	6
common reed	7	0	8	6	7	6	0	0	8	4	0	0	0	0
Japanese knotweed	0	0	9	0	0	7	0	0	0	0	0	0	0	6
reed canarygrass	8	0	9	7	8	7	0	0	9	5	0	0	0	0
purple loosestrife	7	0	8	6	7	6	0	0	8	4	0	0	0	0
exotic shrubs	7	6	8	6	7	6	7	6	8	5	5	6	6	6
Norway maple	0	0	0	0	0	0	8	0	0	0	0	0	0	0

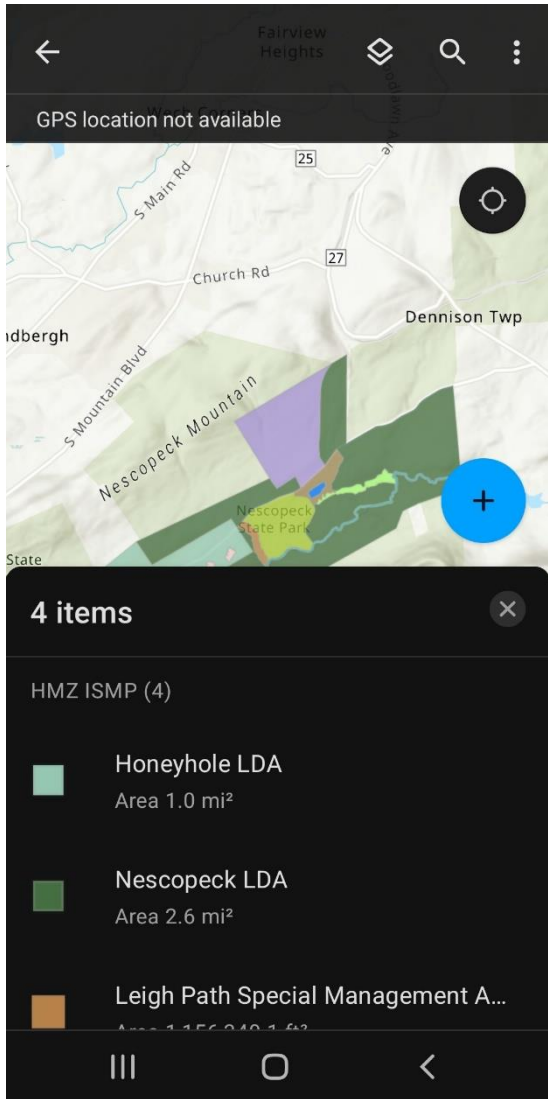


Figure 9. Nescopeck Park and HMZs in Field Maps

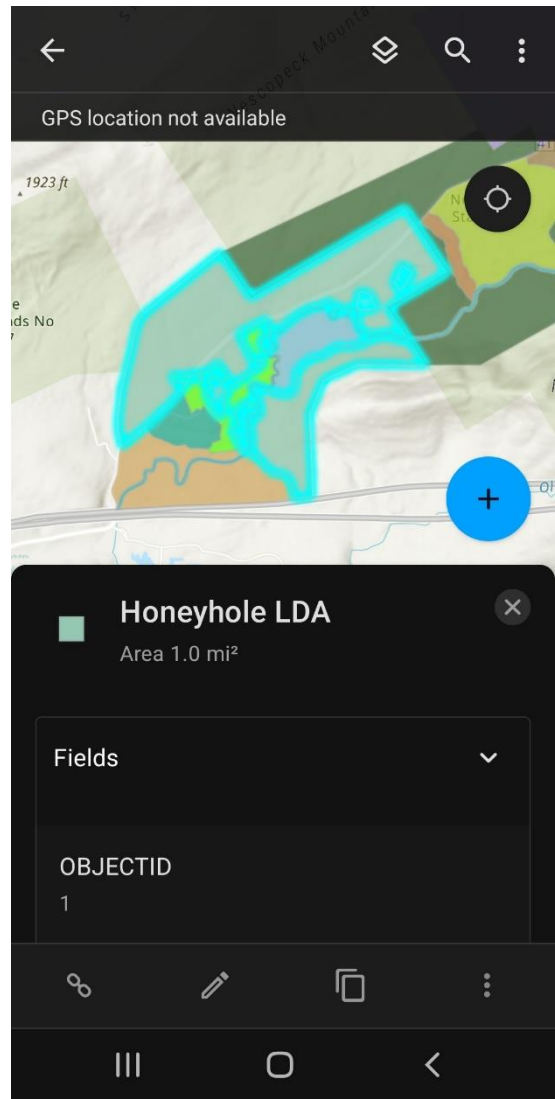


Figure 10. Select HMZ within Nescopeck

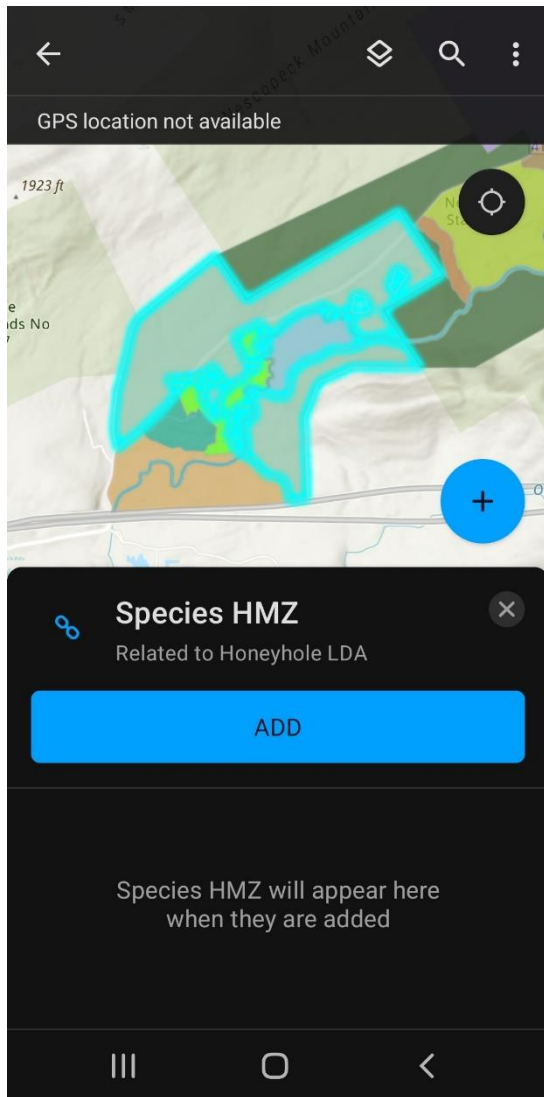


Figure 11. Adding Invasive Species to HMZ via Relationship class linked table

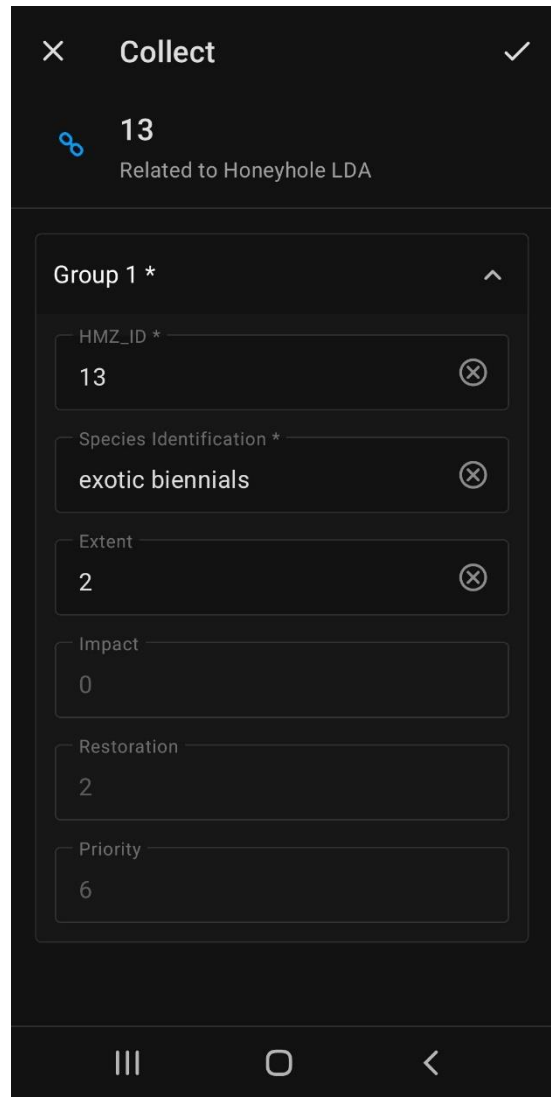


Figure 12. The Species HMZ interface (Calculated Expression fields are muted)

5. References:

- Adams, Matt. (2022) *Designing an ArcGIS Survey123 form to be used with Field Maps to Conduct Post-Storm Damage Assessments* [Master of Science, University of Arizona].
<http://hdl.handle.net/10150/664138>
- Altaweel, M. "Businesses Using Open Source GIS - GIS Lounge." 2020, Accessed December 15, 2022.
<https://www.gislounge.com/businesses-using-open-source-gis/>
- Bhatt, G. D., Kushwaha, S. P. S., & Bargali, K. (2014). Remote Sensing and GIS tools used to analyze the Floristic diversity in South Gujarat. *International Journal of Innovative Research in Science, Engineering and Technology*, 3(12), 13 <https://www.researchgate.net/publication/270578030>
- Boden, Suzanne. "Relates and Relationship Classes Explained." *Esri* (blog), November 28, 2018.
<https://www.Esri.com/about/newsroom/arcuser/relates-and-relationship-classes-explained/>.
- Concepta, "What Is the Difference Between Front-End and Back-End Development? Software Engineering." 2017. Accessed October 11, 2020. <https://www.conceptatech.com/blog/difference-front-end-back-end-development>.
- Cullors, V. (2013). *A Geographic Information System for Invasive Species: Sahara Mustard Weed* [Master of Science, University of Redlands]. <https://doi.org/10.26716/redlands/master/2013.8>
- Darbyshire, Jane. "Migrate to ArcGIS Field Maps." *ArcGIS Blog* (blog). Accessed December 21, 2022.
<https://www.esri.com/arcgis-blog/products/field-maps/field-mobility/migrate-to-arcgis-field-maps/>.
- Dimini, I., et al. "Geographic Information Systems (GIS) and Entomological Research: A Review," *Journal of Food, Agriculture & Environment* Vol.8 (2): 1193-1198. 2010, 6.
- Esri, ArcGIS Arcade. "Introduction | ArcGIS Arcade | ArcGIS Developers." Accessed December 01, 2022.
<https://developers.arcgis.com/arcade/>.
- Esri, ArcGIS Arcade. "Frequently Asked Questions | ArcGIS Arcade | ArcGIS Developers." Accessed December 13, 2022. <https://developers.arcgis.com/arcade/guide/faq/>.
- Esri, "ArcGIS Field Maps." Accessed December 21, 2022. <https://www.arcgis.com/apps/fieldmaps/>.
- Esri, "Cardinality | Definition - Esri Support GIS Dictionary." Accessed December 15, 2022.
<https://support.Esri.com/en/other-resources/gis-dictionary/term/62dad394-3106-4eb7-a5d7-84fc6a1df79f>.
- Esri, "Charlottesville FD Enhances Fire Hydrant Inspections." Accessed December 20, 2022.
<https://www.esri.com/en-us/lg/product/charlottesville-fd-case-study>.
- Esri, "Connect to PostgreSQL from ArcGIS—Help | ArcGIS Desktop," accessed October 3, 2020,
<https://desktop.arcgis.com/en/arcmap/10.3/manage-data/gdbs-in-postgresql/connect-postgresql.htm>
- Esri GeoNet, Using .xls Excel Files | The Esri Community | GIS and Geospatial Professional Community. (2012). Retrieved October 9, 2020, from <https://community.Esri.com/thread/43638>

Federal Register, Vol. 64, No. 25, pg. 6183, February 8, 1999, accessed September 28, 2015
<http://www.gpo.gov/fdsys/pkg/FR-1999-02-08/pdf/99-3184.pdf>

Geri, F., La Porta, N., Zottele, F., & Ciolli, M. (2016). Mapping Historical Data: Recovering a Forgotten Floristic and Vegetation Database for Biodiversity Monitoring. *ISPRS International Journal of Geo-Information*, 5(7), 100. <https://doi.org/10.3390/ijgi5070100>

Gover, A., et al., (2016) "Introduction to the Habitat and Invasive Species Management Planning Process", Pennsylvania State University Wildland Weed Program.

Hohmann, M. G., Just, M. G., Frank, P. J., Wall, W. A., & Gray, J. B. (2013). "Prioritizing Invasive Plant Management with Multi-Criteria Decision Analysis". *Invasive Plant Science and Management*, 6(3), 339–351. <https://doi.org/10.1614/IPSM-D-11-00080.1>

Ismail, M. H. (2010). Determining and Mapping of Vegetation using GIS and Phytosociological Approach in Mount Tahan, Malaysia. *Journal of Agricultural Science*, 2(2), p80.
<https://doi.org/10.5539/jas.v2n2p80>

Johnson, B. A., Mader, A. D., Dasgupta, R., & Kumar, P. (2020). Citizen science and invasive alien species: An analysis of citizen science initiatives using information and communications technology (ICT) to collect invasive alien species observations. *Global Ecology and Conservation*, 21, e00812.
<https://doi.org/10.1016/j.gecco.2019.e00812>

LandScope America, (nd.) "Invasive Species," accessed September 30, 2020,
http://www.landscape.org/pennsylvania/Threats%20and%20Issues/pa_invasives

Le, T. S., Thoa, P. T. K., & Tuan, N. V. (2019). GIS-based habitat model to predict potential areas for the upcoming occurrences of an alien invasive plant, *Mimosa pigra* L. *Forestry Studies*, 70(1), 31–43.
<https://doi.org/10.2478/fsmu-2019-0003>

Lotze, N. and Vannais, J., "Floristic Quality Assessment : ConservationTools," ConservationTools.org and Pennsylvania Land Trust, (2019), accessed October 13, 2020, <https://conservationtools.org/guides/33-floristic-quality-assessment>.

Loh, K., & Tapaneeyakul, S. (2012). GIS for Environmental Problem Solving. In S. Curkovic (Ed.), *Sustainable Development—Authoritative and Leading Edge Content for Environmental Management*. InTech. <https://doi.org/10.5772/50098>

Martin, Robert, (2022) *Lead and Copper Rule Revisions: A Case Study in Identifying and Tracking Lead Water Service Lines with ArcGIS Field Maps* [Master of Science, University of Arizona],
<http://hdl.handle.net/10150/665572>

Mau-Crimmins, T. M., & Orr, B. J. (2005). Monitoring Invasive Plants Using Hand-Held GIS Technology. 4. *USDA Forest Service Proceedings RMRS-P-36*.

Maurya, S.P., Ohri, A., and Mishra, S, (2015). Open Source GIS: A Review, *Proceedings of the National Conference on Open Source GIS: Opportunities and Challenges*,
https://www.researchgate.net/publication/282858368_Open_Source_GIS_A_Review

Mulhollem, J., (2002). Invasive Plants Threaten Pennsylvania Habitat | *Penn State University*. (2002). Retrieved September 30, 2020, from <https://news.psu.edu/story/186050/2002/03/06/invasive-plants-threaten-pennsylvania-habitat>

NAISMA, "Mapping Standards for Program Managers," North American Invasive Species Management Association, (2018), https://www.naisma.org/wp-content/uploads/2019/06/NAISMA_Mapping_Standards.pdf

Neldner, V. J., Crossley, D. C., & Cofinas, M. (1994). USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO DETERMINE THE ADEQUACY OF SAMPLING IN VEGETATION SURVEYS., *Biological Conservation*, 17. [https://doi.org/10.1016/0006-3207\(95\)90049-7](https://doi.org/10.1016/0006-3207(95)90049-7)

Olson, C., & Cholewa, A. F. (2009). A Guide to nonnative invasive plants inventoried in the north by Forest Inventory and Analysis (NRS-GTR-52; p. NRS-GTR-52). U.S. Department of Agriculture, Forest Service, Northern Research Station. <https://doi.org/10.2737/NRS-GTR-52>

Oregon Invasive Species Council, "100 Worst List, 2015 update", accessed October 02, 2015, <http://www.oregoninvasivespeciescouncil.org/100-worst-list>

PASDA, "Pennsylvania Spatial Data Access | Data Summary." Accessed October 15, 2020. <https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=114>.

Paz-Kagan, T., Silver, M., Panov, N., & Karnieli, A. (2019). Multispectral Approach for Identifying Invasive Plant Species Based on Flowering Phenology Characteristics. *Remote Sensing*, 11(8), 953. <https://doi.org/10.3390/rs11080953>

Pennsylvania Department of Conservation & Natural Resources, "Invasive Plants," accessed October 2, 2020, <https://www.dcnr.pa.gov/443/Conservation/WildPlants/InvasivePlants/Pages/default.aspx>

Pennlive, Pennsylvania's official noxious weeds. (2018, July 9). https://www.pennlive.com/wildaboutpa/2018/07/pennsylvanias_official_noxious.html

Pennlive, Poisonous, invasive plant spreading in Pennsylvania. (2020, May 6). <https://www.pennlive.com/life/2020/05/poisonous-invasive-plant-spreading-in-pennsylvania.html>

Schneck, M., (2018, July 9) "Pennsylvania's Official Noxious Weeds," *www.pennlive.com*, Accessed September 30, 2020. https://www.pennlive.com/wildaboutpa/2018/07/pennsylvanias_official_noxious.html

Schneck, M., (2020, May 6) "Poisonous, Invasive Plant Spreading in Pennsylvania," *www.pennlive.com*, <https://www.pennlive.com/life/2020/05/poisonous-invasive-plant-spreading-in-pennsylvania.html>

Shimonti P., "Managing the Environment Using GIS," *Geospatial World* (blog), July 4, 2018, <https://www.geospatialworld.net/blogs/managing-the-environment-using-gis/>

Skurka Darin, G. M., Schoenig, S., Barney, J. N., Panetta, F. D., & DiTomaso, J. M. (2011). WHIPPET: A novel tool for prioritizing invasive plant populations for regional eradication. *Journal of Environmental Management*, 92(1), 131–139. <https://doi.org/10.1016/j.jenvman.2010.08.013>

Stack Overflow, Python—How to insert and push data from xlsx file to sql? (2020), Retrieved October 9, 2020, from <https://stackoverflow.com/questions/56215394/how-to-insert-and-push-data-from-xlsx-file-to-sql>

Tateyama, M. (2014). *Prioritizing Invasive Species Management in the Carlsbad Hydrologic Unit* [Master of Science, University of Redlands]. <https://doi.org/10.26716/redlands/master/2014.13>

Trépanier, M., Gauthier, V., Besner, M.-C., & Prévoist, M. (2006). A GIS-based tool for distribution system data integration and analysis. *Journal of Hydroinformatics*, 8(1), 13–24. <https://doi.org/10.2166/jh.2006.004>

Tsou, M.-H. (2004). Integrated Mobile GIS and Wireless Internet Map Servers for Environmental Monitoring and Management. *Cartography and Geographic Information Science*, 31(3), 153–165. <https://doi.org/10.1559/1523040042246052>

US Department of Agriculture, Natural Resources Conservation Service. "Invasive Species." Accessed September 30, 2020. <http://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/invasive-species-and-pests>.

US Department of Agriculture, National Invasive Species Information Center, "About NISIC", September 2015, accessed September 30, 2015 <http://www.invasivespeciesinfo.gov/whatis.shtml>

US Department of Agriculture, US Forest Service Remote Sensing Lab, Ecosystem Planning, " Data Recording Protocols for Invasive Species Management (Inventory and Mapping)", accessed September 28, 2020 https://www.fs.fed.us/r5/rsi/projects/gis/data/calcovs/NRIS_InvasivePlants_FieldGuide.pdf

US Department of Agriculture, US Forest Service, Pacific Northwest Research Station, "Invasive Species", accessed September 28, 2015 <http://www.fs.fed.us/pnw/invasives/>

Yager, L. Y., & Smith, M. (2009). Use of GIS to Prioritize Cogongrass (*Imperata cylindrica*) Control on Camp Shelby Joint Forces Training Center, Mississippi. *Invasive Plant Science and Management*, 2(1), 74–82. <https://doi.org/10.1614/IPSM-08-074.1>