Development of a GIS Database of Incomplete Forensic Anthropology Cases in Southeastern Michigan

Casey Butler

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Abstract
With many forensic anthropology cases of human skeletal remains, the skeletons may be incomplete for a variety of reasons, such as: animal scavenging, acid bone diagenesis, fluvial transport, among other factors. There are many studies that address these taphonomic factors; however, prior research fails to examine different methods in tracking incomplete forensic anthropology cases. This study investigates different geographic information system (GIS) methods applied to the forensic sciences to determine the best software to track forensic anthropology cases using a spatial mapping system to record and track 15 incomplete cases from Southeastern Michigan. The final ArcGIS tool developed here notes the case number, bones missing, location (including latitude and longitude coordinates), photographs, measurements from the contralateral bone from the recovered side, along with other pertinent details in order to facilitate fast information retrieval for the Forensic Anthropologist concerning incomplete skeletal cases.

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DEVELOPMENT OF A GIS DATABASE OF INCOMPLETE FORENSIC
ANTHROPOLOGY CASES IN SOUTHEASTERN MICHIGAN

By
Casey Butler

A Senior Thesis Submitted to the
Eastern Michigan University
Honors College
in Partial Fulfillment of the Requirements for Graduation
with Honors in the Department of Sociology, Anthropology, and Criminology

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ABSTRACT

With many forensic anthropology cases of human skeletal remains, the skeletons may be incomplete for a variety of reasons, such as: animal scavenging, acid bone diagenesis, fluvial transport, among other factors. There are many studies that address these taphonomic factors; however, prior research fails to examine different methods in tracking incomplete forensic anthropology cases. This study investigates different geographic information system (GIS) methods applied to the forensic sciences to determine the best software to track forensic anthropology cases using a spatial mapping system to record and track 15 incomplete cases from Southeastern Michigan. The final ArcGIS tool developed here notes the case number, bones missing, location (including latitude and longitude coordinates), photographs, measurements from the contralateral bone from the recovered side, along with other pertinent details in order to facilitate fast information retrieval for the Forensic Anthropologist concerning incomplete skeletal cases.
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I extend my gratitude to the Honors college of Eastern Michigan University, which granted me the permission to conduct this research for my Senior Honors Thesis and released this work to aid future students of Forensic Anthropology in their studies.
**INTRODUCTION**

Once skeletal remains are discovered, it is common that not all bones are able to be located due to taphonomic agents. Taphonomy is the study of postmortem processes that affect the preservation or recovery of a dead organism (Haglund *et al.* 1997). Forensic Anthropologists use forensic taphonomy in the reconstruction of events during or after death by analyzing the collected data and in distinguishing perimortem (at the time of death) and postmortem modifications (after death) from antemortem healed trauma (before death) (Haglund *et al.* 1997). Over time, a forensic anthropologist can become overburdened with the task of having to go through their many records of forensic cases to query information on which cases have incomplete skeletons and the coordinates from where those skeletal remains were originally recovered. To keep skeletal remains from becoming commingled when random bones may be discovered over time, a spatial analysis system can easily retrieve information using simple icons for each incomplete skeleton at their recovered location over a specified period of time. By clicking on the icon on the map associated with the incomplete skeletal case, ideally there will be a display detailing the case number, what bones are missing from the remains, and the specific longitudinal and latitudinal coordinates of each case. The goal of this thesis is to explore previous applications of spatial analysis systems used in the forensic sciences today. Each of the identified spatial analysis systems currently applied in forensic sciences will be evaluated for the pros and cons in order to determine the most appropriate program to meet the needs of the Forensic Anthropologist. The ultimate goal of this honors senior thesis project is to compile a list of incomplete forensic anthropology cases from the last four years provided by Dr. Megan Moore, the Forensic
Anthropology consultant for Wayne, Washtenaw, and Monroe counties in Southeastern Michigan. The incomplete cases will then be added to a new digital tool created here to maintain a searchable map of these cases using either ArcGIS, Google Earth, or CrimeSTAT IV. For this analysis it is hypothesized that ArcGIS or Google Earth will have more potential as a spatial database for incomplete Forensic Anthropology cases. Also, the hope is that this searchable GIS database of incomplete skeletal remains will allow easier access in the future for tracking these incomplete cases.

BACKGROUND

Anthropology is a broad field that is defined as the study of humankind (Christensen et al. 2014). Within Anthropology there are four main subfields: Linguistic Anthropology, Biological Anthropology, Archaeology, and Cultural Anthropology. Biological Anthropology (also referred to as Physical Anthropology), applies a biocultural perspective to the study of evolution and the diversity among humans and other primates. Many Biological Anthropologists focus largely on skeletal biology to look at variations among and between populations in order to create a biological profile. This biological profile is formulated from an examination of unknown skeletal remains in order to estimate the age, sex, ancestry, stature, and life history of an individual in order to individuate a skeleton for medicolegal purposes or to reconstruct a population history for bioarchaeological applications. This knowledge can be applied to specialized areas within this subfield, such as: Bioarchaeology, Paleontology, or Forensic Anthropology.

Forensic Anthropology is a rather new field within Anthropology, being practiced for approximately the last 40 years (DiGangi & Moore, 2013). Forensic Anthropology is
the application of Biological Anthropology within the legal system. A Forensic
Anthropologist primarily focuses on one individual at a time, estimating if the skeletal
remains are of medicolegal significance, are contemporary, and by building a biological
profile of the human skeletal remains. A biological profile includes the estimation of sex,
stature, ancestry, and age. Human osteology is the study of human bones. Within an
osteological analysis, a Forensic Anthropologist will also distinguish and document
antemortem, perimortem, and postmortem trauma to the remains. Antemortem trauma is
a type of trauma that occurred before death, leaving evidence that the bone has healed or
was in the process of healing at the time of death. Perimortem trauma is trauma to the
skeleton at or around the time of death with no signs of healing. Postmortem damage is
any damage that occurs after the time of death, which can include animal scavenging,
weathering, or even damage caused from the excavation (Christensen et al. 2014).

Keeping note of which Forensic Anthropology cases are complete or incomplete,
from where they were recovered, and what bones are missing from the skeletal remains
can be very tedious, especially when there are multiple Forensic Anthropologists working
within a certain region. When a new Forensic Anthropologist is hired into an area, there
could be difficulty in accessing the previous records on past cases causing the proper
filing of these to become time consuming or impossible. It is ideal to have a single
system containing at least twenty years-worth of incomplete skeletal forensic cases that is
user friendly and accessible to relevant and essential personnel. Furthermore, proper
documentation with the case number, recovery location (including exact global
coordinates), date of recovery, possible picture of the already recovered remains,
measurements and photos of the contralateral (i.e. opposite side) bones and listing which
bones or teeth are missing. For information on incomplete skeletal remains to be documented, it would require a great deal of time that a Forensic Anthropologist does not have to spare. Dedicating time of "community service" to compiling this database to create a new digital tool to inventory these incomplete cases would reduce stress and save time for the Forensic Anthropologist. This would eliminate the task of having to go through years of completed forensic cases to find the global coordinates of a bone (if available), especially if additional bones were to appear at a later date at the same location.

Proper documentation of the location of skeletal remains avoids or limits the possibility of commingling among cases. Commingling can be defined as the intermixing of body parts, in this case the skeletal remains, between two or more individuals (Christensen et al. 2014). A literature review of current methods of digital data storage or mapping systems used by Forensic Anthropologists revealed that there is a very limited amount of information on systems available and being used. Published forensic research is abundant on how geographic coordinates were initially obtained for the location of human remains. Police systems on crime data tracking is often utilized. Unfortunately, the data used in crime data tracking are summarized onto a fixed graph, which lacks the ability to insert additional information into each pin.

PROBLEM OF INCOMPLETE REMAINS AND THE ROLE OF TAPHONOMY

The problem with incomplete human skeletal remains in a forensic context can lead to a deceased individual not being placed as a whole within their final resting place. When skeletal remains are not located and recovered at the decomposition site, this can lead to many issues later in time. If someone were to stumble upon the unrecovered bones
at a later date, this could potentially raise questions about whether the bones belong to a different decedent. If proper documentation of previous recoveries of remains at a certain location are not maintained or become lost, this could potentially lead to the commingling of remains with an individual to whom they do not belong.

Taphonomy is the study of postmortem processes that affect the preservation or recovery of a dead organism (Haglund et al. 1997). Bone diagenesis (i.e. bone deterioration or dissolution) can be caused by a range of taphonomic agents including: chemical, thermal, animal, plant, human origin, or a combination of multiple agents (Moore et al. n.d.). The following section will review the variety of taphonomic factors that can lead to incomplete recovery of human skeletal remains. Many of these taphonomic factors may cause the complete destruction of bones to prevent future recovery altogether. Other taphonomic factors may simply lead to the misplacement and the dissociation of bones with the rest of the skeleton.

CARNIVORE SCAVENGING

During the decomposition of human remains, carnivorous scavengers can disarticulate and scatter remains across a potentially vast recovery area, causing destruction to the skeletal elements, and affecting the survival of the elements. Scavengers play a significant role as taphonomic agents, often causing the loss of bones and leading to an incomplete set of skeletal remains. Carnivores can also destroy or alter the appearance of important indicators on the bone for determining the cause and manner of death. Bones and teeth can be lost due to the movement of the remains by scavengers during all phases of decomposition (Haglund et al. 1997). Remains exposed to the surface are often highly subjected to disarticulation by carnivores, especially canids such
as wolves, foxes, coyotes, domestic dogs, along with vultures and felids (cats). Bears and pigs are two omnivorous scavengers that also have been known to feast on and disarticulate human skeletal remains. Common scavengers within aquatic environments are fish and sharks. Knowledge of animal scavenging among human remains particular to different environments and ecosystems can be useful in the recovery effort of locating missing bones from incomplete skeletons.

There are four generally recognized tooth marks left by scavenging carnivores: punctures, furrows, pits, and scores. Punctures are oval-shaped penetration marks through the cortex, this is produced when the bone collapses under the pressure made from a tooth cusp (Moraitis et al. 2010). Furrows are “channels,” produced by the cusps of what are considered cheek teeth, these channels can extend longitudinally from the ends of bones into its marrow cavity (Christensen et al. 2014). Extreme furrowing can occur when there is a “scooping out” of bone; this is caused by the removal of the cancellous tissue being licked out from the intentionally opened shaft end of the long bones. Pitting consists of non-perforating indentations often caused by the tips of a scavengers’ teeth. Lastly, scoring is the creation of linear, parallel scratches that are produced by teeth being dragged and slipped over cortical bone (Haglund et al. 1997).

Among carnivorous canids, there is a recognized pattern of gnawing on the ends of bones (Miller, 1969). Due to the morphology of the mammalian mouth and dentition, mammals such as canids have gnawing incisors that are located anteriorly, making it difficult to use their incisors on an object that is larger or longer than the distance their mouths can open (Miller, 1969). Members of the dog family will typically gnaw at the shaft ends of the long bones using their incisors. This act of gnawing will leave behind
very shallow grooves transverse to the longitudinal axis on the bones. Cancellous bone in the ends of bone is softer than compact bone in the shaft and is located on an area of the bone where animals can easily maneuver them into a position to be gnawed. Within areas where canids tend to live in, it is common for their tooth marks to be found on the remaining bones of incomplete cases. When examining canid tooth marks on the remains, proper documentation should be done to help disguise the taphonomic factors that aid in the postmortem trauma to the skeletal remains.

During the scavenging process, scavengers can consume, modify, disarticulate, and disperse soft and bony tissues (Christensen et al. 2014). After all soft tissues of human remains are consumed, the first parts of the human skeleton to be worked on are the olecranon processes of the humeri (at the elbow), calcanei (i.e. heel bone), the ribs, and the spinous processes of the vertebrae; all of which contain relatively soft cancellous tissue (Miller, 1969). Bones can be gnawed on or consumed at any stage of decomposition. The gnawing of bones can change the morphology of the bone making it difficult to identify scavenging from postmortem trauma, while consumption of the entire bone itself will cause the skeletal remains to become incomplete. Furthermore, perimortem trauma to the skeleton can cause fragmentation and allow faster access or to those areas.

Canid scavengers have also been known to drag entire limbs from the decomposition area, which then creates the problem of scattering that can lead to the incomplete recovery of remains. Spradley and colleagues had noted that among the scavenging done by vultures, a bone was recorded to be 15.8 meters (51.7 feet) away from the area of decomposition (2012). It should also be noted that carnivore scavenging
can potentially cause even greater taphonomic damage to infant remains. Due to infant skeletal remains being rather small, infant bones can be completely consumed, which can lead to incomplete skeletal remains or complete destruction of the remains (Guy et al. 1997; Miller 1969).

When remains become incomplete due to the scavenging by carnivores, there are multiple actions to be taken in the attempt to find the missing bones. Some of the smaller bones can be recovered from the scat (feces) of the canids (Haglund et al. 1997). Following scat trails or searching for local animal dens in the area could also lead to the location and recovery of missing remains. Canid scavenging can also be helpful if a domestic dog was to discover the remains, because the family could alert authorities to its location. Overall, it is very important to utilize all types of faunal evidence (if available), including scat, in the recovery of missing human remains.

**RODENT SCAVENGING**

Like carnivorous canid scavengers, rodents can cause the transportation, dispersion, and destruction of skeletal remains. The activity of rodents can affect the complete recovery of the remains, human identification, and antemortem interpretation (Haglund et al. 1997). The term rodent is used to categorize mice, rats, squirrels, rabbits, gerbils, and porcupines, among others. Raccoons and opossum scavenging have been commonly mentioned and associated within rodent scavenging research, although they are not part of the taxonomic order *rodentia*. All rodent species have been documented to play a part in the postmortem modification of human skeletal remains.

Both rodents and lagomorphs (rabbits) have protruding incisors that make it easier for gnawing on bones. Rodents often make modifications to bones that are characterized
by paired, broad, shallow, flat-bottomed grooves on dense portions of skeletal remains caused by the anterior incisor teeth (Klippel et al. 2007). The incisive movement consists of the maxillary flat-bottomed incisors being pressed against a bone, and then dragged across it. Haglund and colleagues (1997) define gnawing as a type of incisive movement capable of reducing hard fibrous substances, which may not always be digested by the rodent.

Rodents typically will gnaw bone for calcium and other mineral content. Common areas where rodent gnawing occurs is where cortical bone is less dense along the epiphyseal lines of the proximal end of the humerus, and the proximal and distal ends of the tibia and femur (Klippel et al. 2007), as well as on projections on the skull. In some cases, coyotes and wolves can cause shallow grooves within a bone that can often be mistaken for rodent gnaw marks (Christen et al. 2014). Knowledge of rodent and rabbit gnawing is important to help distinguish perimortem trauma from postmortem damage to the bones.

**BONE DIAGENESIS BY ACID**

In taphonomy, the term diagenesis is any physical, chemical, or biological change to the bones after being deposited (Christenson et al. 2014). There are many factors in the depositional environment that can contribute to bone diagenesis, such as soil pH, groundwater, weathering, plant growth through bones, and transport of bones by physical and natural forces. These factors can all cause alterations and deterioration of human skeletal remains. The outcome of these changes on bones can often lead to human skeletal remains being incomplete.
Skeletal remains must go through an extensive decomposition process before the structural breakdown of bone can occur. Ross and colleagues (2011) stated that the taphonomic micro-environment (chemistry and temperature of the immediate surroundings) may have a larger impact than the macro-environment (atmosphere and climate) in the distortion of skeletal remains. The micro-environment plays a significant role in the rate at which decomposition occurs. Both of these two factors are always important to document when recovering remains.

Growing plants will sprout and extend their roots below the surface of the ground in order to find a source of water and nutrients to absorb. Roots of plants can secrete acid that will potentially etch and damage the surface of buried remains. The acidic secretion is due to the roots of plants releasing hydrogen ions that react with the salts within the soil (Haglund et al. 1997). The typical pattern of root damage resembles a meandering network of shallow grooves. The damage created from the root-etched network can become so dense that the outer surface of bones can become etched away completely causing delamination of the surface (White et al. 2005).

Though bones are complex in structure, they are very sensitive to environmental factors such as acidic soils. When considering a pH scale, a pH level of 1 is considered the highest acidity, the pH level of 7 is neutral (e.g. water), and a pH level of 14 is the most alkaline (Urry et al. 2016). Postmortem changes in the pH of soil can allow for structural damage to the bones. The area of the bone in direct contact with the soil can disintegrate, which gives the appearance of having dissolved (Haglund et al. 1997). Acidic soils can contribute to skeletal remains not being completely recovered by altering the bone shapes and hence causing the bones to go unrecognized or misinterpreted as
other objects. Before exhuming buried human remains, the Forensic Anthropologist should consider testing the pH of the soil at the recovery site to determine the best plan of action for the excavation to prevent further damage to the remains.

**FLUVIAL TRANSPORT, GRAVITY, AND OTHER FACTORS**

The transportation and scattering of human skeletal remains can be caused by gravity, water and fluvial movements, or other factors. Water and gravity can disperse skeletal remains downstream or downhill, along with the assistance of different natural transportability (i.e. the shape of the bone) will affect how far the bones are able to be transported and dispersed. There are many other human factors that can lead to the incomplete recovery of human skeletal remains; these can range from thermal damage to particular bones being kept as a "trophies."

Gravitational forces can be responsible for the dispersion of skeletal remains. If the decomposition site of remains is on a steep grade, gravity will cause the skeletal remains to move downhill. It should be noted that the different morphology and weight of each bone can affect how far each element is transported and dispersed. The morphology of the cranium, for example, is roughly spherical allowing it to be more susceptible to the gravitational movement of rolling downhill (Christensen *et al.* 2014). Upon the search and recovery of human remains, police authorities, along with the consulting Forensic Anthropologist, may have difficulty recovering all of the bones due to fact that the paths along which the skeletal elements traveled may not have been a straight line.

Fluvial Transport is the movement of remains within an aquatic environment. Water is an important factor in the scattering and loss of human skeletal remains, along with a number of factors that can affect the movement and dispersion within water, such
as the presence of rocks, aquatic plants, aquatic animals, etc. Fluvial transportation can cause the destruction of skeletal elements, as well as transport and disperse the skeletal remains across large distances. Possible factors that could affect the rate of dispersion are: if the body is floating, the presence of clothing, aggressiveness of the water current, and aquatic scavengers (Badgley, 1986).

Typically, when a body is first placed within a body of water, it is prone to sink. This is caused by multiple factors, such as: weight, salinity, temperature, velocity of water, etc. (Christensen et al. 2014). Once the body has sunken to the bottom, it is dragged along the seafloor or riverbed by the movement of the water. Throughout decomposition, gases fill the body, which will cause it to float unless being weighted down. As decomposition advances and the remains skeletonize, disarticulation in the water will begin at the more flexible joints. The first to become disarticulated in the water normally are the hands, mandible, cranium, and extremities (Christensen et al. 2014). Water chemistry factors such as: pH and salinity; also contributes an important role in the rate of decomposition. Stagnant water is normally associated with higher amounts of bacteria that leads to an accelerated decomposition rate, this can contribute to the remains becoming skeletal and disarticulated before a recovery can be done (Christenson et al. 2014).

There are a variety of other factors that could influence incomplete recovery of human skeletal remains in Forensic Anthropology cases. For example, when the remains are first discovered, bones may be taken to serve as a “trophy” and placed in a private display cases, or even sold online (Yucha et al. 2017).
During the seasons of fall and winter in temperate regions like Michigan, the leaves and snow fall to the ground and the remains can become covered. The skeletal remains can therefore be difficult to find under the foliage and snow, which can lead to incomplete recovery of a skeleton. Additionally, natural weathering can occur to skeletal remains that are exposed on the surface, which can break the bones down due to heating and cooling cycles that cause surface cracks in the bone. Over time, weathering can make bones less recognizable or cause complete destruction.

If remains undergo thermal damage, this can cause difficulty in the recovery of human skeletal remains. As Haglund and colleagues (1997) described, incomplete burned remains can be one of the greatest taphonomic problems for a Forensic Anthropologist, because the bones will fragment, become discolored, and shrink, almost becoming unrecognizable. This can also complicate the analysis of the bones because it becomes difficult to estimate the number of individuals represented within the skeletal remains. If burned fragments of skeletal remains are scattered across various locations, the task of the Forensic Anthropologist can be extremely difficult.

The last major factor that can contribute to incomplete skeletal remains is when the bones are not recognized as human and are therefore not recovered. This can occur when the Forensic Anthropologist is not present at the recovery site. One of the goals of the Forensic Anthropologist (or Forensic Archaeologist) is to conduct a controlled excavation or surface search in order to recover the complete set of remains, record their inventory and note the context (Haglund et al. 2001). Having knowledge and training in skeletal anatomy is a crucial skill to accomplish this task. To an untrained individual, a bone can just look like a rock or any animal bone. This is why before attempting a
recovery of skeletal remains, the consulting Forensic Anthropologist for that county should always be present at the scene. Taphonomic factors should always be documented when attempting to map the location of human skeletal remains at a recovery site, in order to take steps to ensure that the most complete recovery possible is undertaken. When it is clear that remains are incomplete, documentation of the incomplete remains can potentially help to reassociate elements at a later date. The use of different mapping methods can provide easily searchable maps that could help in these situations.

DIFFERENT MAPPING METHODS

Geographic information system (GIS) is a computer system that allows the storing and displaying of three-dimensional coordinate data on digital representations of the earth’s surface. GIS is a technological tool that assists in the comprehending of geography, and provides a visual, spatial, and temporal means of displaying data (ESRI, 2006). Data can be digitally layered on a map by type, date, time, and location. GIS is a valuable tool for many professions, especially for first responders, such as: law enforcement officers, paramedics, and emergency medical technicians. Within the medicolegal system, GIS has previously been used as a mapping tool to assist in identifying missing or deceased adolescent victims of serial child abductors and murder victims (ESRI, 2006).

While exploring previous applications of spatial analysis systems used in the forensic sciences, most research has focused on the spatial patterning of scavenged human remains, and how to map those scattered remains. A Global Positioning System (GPS) has been a beneficial tool to track and map disarticulated remains (Spradley, 2012;
Listi et al. 2007). GPS uses latitude and longitude coordinates to determine the exact location of the recovery (Dirkmaat et al. 2008). Spatial analytical methods can help find scavenger patterns in movement, transportation, and the spread of scavenged human remains. Noting the precise location is crucial when creating a digital inventory of incomplete cases. Devices that can be used for GPS are commonly used and include cell phones, GPS handheld receivers, GPS navigation devices (commonly uses in vehicles), Tablets, etc.

When creating a geospatial record of evidence, a Differential Global Positioning (DGPS) unit provides a decrease in potential plotting error. Walter & Schultz (2013) stated that, “GPS units do not usually offer appropriate degree of accuracy for mapping scattered remains, DGPS units offer decimeter to centimeter error margins allowing for a more appropriate mapping of remains (p. 33).” This is very important to consider when recording location, if the wrong coordinates are recorded this could affect whether bones are associated with the correct forensic case, especially if there are multiple cases within a particular area. DGPS is a type of handheld device that can be moved to each bones location when mapping scattered remains to ensure that the most accurate coordinates are recorded.

ArcGIS

One possible mapping system to create an inventory of incomplete forensic cases is ArcGIS. This is a geospatial data analysis system in which flags can be placed digitally at the coordinates where remains have been recovered (Bunch et al. 2017). ArcGIS is a secure mapping system that is easily manageable and relatively user friendly. When exploring this digital tool, you are granted a free trial that provides tutorials for how to
create your own personal map. There are online classes offered in learning how to use the program. Some of the online classes are free, but other courses have instructors working with students for more advanced training, which can be more expensive.

Upon creating a new account on ArcGIS, you have the ability to create your own URL.¹ There are many different selections of map styles, such as: imagery, imagery with labels, topographic, street maps, national geographic, ocean, and terrain maps. Once the map style is selected, coordinates can be pinned onto the personalized map with the title, description, link for a photograph of the remains, and a customized pin placed onto the map. For this study, an outline of a human figure was placed at a random location as a test and visualization of this methodology.

ArcGIS has an option to analyze pinned data, along with the ability to actually print out directions to the recovery site. Measurements of distance can be included between pinned points on the map in various units, which could be a useful tool when remains have been scattered. In this program, there is a customizable tool called the ArcGIS toolbox (Charleux 2015). The ArcGIS toolbox has approximately 30 categories, such as: spatial statistics toolbox, location referencing toolbox, and geoanalytics toolbox. Each toolbox selection contains powerful tools that allow the fundamentals of GIS operations, such as: data managing, geocode addresses, import S-100 cell, trace, and many other tools within each category of toolboxes. On the website for the Environmental Systems Research Institute (ESRI) (supplier of the ArcGIS software), there is a help section that provides directions for what each tool is within the toolbox, and how to use each tool. However, this particular option is through ArcGIS Pro. ArcGIS

¹ Please note, that to ensure confidentiality of the actual forensic cases used for this pilot study, the URL cannot be included in this thesis.
Pro is a newer GIS application that is part of the ArcGIS Desktop; however, it is faster, more powerful, and has a better user interface, and subsequently costs more (ESRI, n.d.).

ArcGIS is a widely used geographic information system within law enforcement and is often used to recognize spatial relationships between a criminal act and the crime scene or body location. There have been famous cases in which ArcGIS 10.1 was used, for example, the mapping of Casey Anthony's 3-year-old daughter's skeletal remains (Bunch et al. 2017). Although ArcGIS has a great amount of potential, exact latitudinal and longitudinal coordinates are not easily displayed on the screen or on the pinned locations unless physically typed into the description box. Also, when attempting to save pinned data coordinates, the system was not extremely user friendly.

**Google Earth**

When exploring Google Earth, there are two options of program types: Google Earth and Google Earth Pro. Google Earth is a free, user friendly software program that provides a three-dimensional, high-resolution, aerial imagery model of the entire earth (Visser et al. 2014). This program has the ability to import, overlay, and visualize geographic data. Google Earth is used among a wide variety of occupations, such as: the social sciences, paleontology, geology, and ecology. Satellite photos are updated in the system regularly to fill in gaps caused by clouds and harsh weather, etc. Google Earth Pro is now also free and has a 4.8% higher pixel resolution, uses high-definition imaging, contains better measuring tools, and imports data from ESRI, the same creators of ArcGIS (Harrington & Cross, 2015). Google Earth Pro has an option that allows you to examine and plot points on the globe in varying timeframes, starting from the year 1930 until 2018.
An account can be made to secure and save data applied to the Google Earth maps. When placing a pin on the location of the recovery, the exact latitudinal and longitudinal coordinates can be searched or displayed. The thumb pin marker allows for a title, description, and an image to be displayed when a pin is selected. For this particular application, the title for the pin could be the case number, while the description text box could be used to contain information on the date in which the remains were discovered, what is missing from the skeletal remains, and any miscellaneous information that could be of use if additional remains were to be discovered at a future time.

Though Google Earth is an ideal system to use in the inventory of incomplete forensic anthropology cases, the mapping system has been noted to have issues. Visser and colleagues (2014) have found that the geographical coordinates displayed on the Google Earth programs have been as far away as 171.6 meters away from their actual location. Before committing to use this as a digital tool, further research on the accuracy of location markers should be confirmed. Other problems that have been noted when using Google Earth are: low resolution imagery, incorrect geo-referencing of images, and low spectral resolution of imagery (Visser et al. 2014).

**CrimeSTAT IV**

The last mapping system reviewed here is CrimeSTAT IV, which is a free, spatial statistics program used for the analysis of criminal incident locations (Police Foundation, 2015). CrimeSTAT IV is a Windows-based program and interfaces with most desktop GIS programs. This digital program has a time-series forecasting module that allows for easy spatial plotting over a considerable time range for forensic cases. Manhein and colleagues (2006) used CrimeSTAT III to assess dispersal patterns among dumped and
scattered human remains; however, there was a dearth of critical reviews provided within the literature.

Many police departments and criminal researchers use CrimeSTAT IV to analyze spatial distributions and to graph crime “hotspots.” A hotspot is an area where crime has a tendency to occur (Levine, 2006). Hotspot mapping is a popular technique used by police departments as a resource to reduce crime (Chainey et al. 2008). There are different mapping techniques used to identify these hotspots, such as: point mapping, thematic mapping of geographic areas, grid thematic mapping, etc.

Unfortunately, CrimeSTAT IV geographical maps are just basic layout maps that do not display a large variety of map types with features such as imagery. This mapping system also does not have the ability to display case information for every individual pin displayed on the map. However, CrimeSTAT IV would make a useful tool if a Forensic Anthropologist wanted to examine patterns of more frequent areas from which skeletal remains are recovered. The data collected from the frequent disposal locations of remains could indicate criminal “hotspots,” or this case, “skeletal remains hotspots.” Overall, this type of mapping system is not capable of mapping each individual incomplete case.

The three technical mapping programs reviewed here can be useful in creating an inventory of incomplete skeletons, each in their own way. ArcGIS has the ability to plot among different types of maps, apply information and pictures to the pinned locations, and has the capability to map over a large time frame. The one unfortunate factor of ArcGIS is the higher cost, which could limit its applicability. Google Earth Pro is a free and user-friendly program that is simple to navigate. Google Earth allows the ability to include notes and photographs attached to pinned location. When searching a location in
the Google Earth Pro program, one has the ability to type the pin’s precise longitudinal and latitudinal coordinates into the search bar. One issue with this program, is that coordinate data can be erroneous, and can be up to 171.6 meters away from their actual location (Visser et al. 2014). This could potentially lead to a significant problem when trying to plot the site of a forensic recovery. CrimeSTAT IV is not an ideal program for creating an inventory with individual descriptions for each plotted case. Law enforcement use this to study hotspots where crime is concentrated. However, CrimeSTAT IV could be a great tool if a Forensic Anthropologist were to examine and map areas where skeletal remains were likely to be found.

Finally, NamUs is a database that is a publicly accessible via a website that is a regularly updated, developing tool for investigating and solving the many national cases of missing and unidentified decedents. The general capabilities of NamUs are the ability to post key details online that will allow other medicolegal personnel the ability to assist in the identification process of difficult or unidentifiable incomplete Forensic Anthropology cases. The NamUs database is a very useful tool in the identification process for a Forensic Anthropologist. Merging NamUs with an incomplete skeletal remains database could also facilitate communication between Forensic Anthropologists concerning where incomplete skeletal remain cases have been previously recovered.

MATERIALS AND METHODS

Selection of the software program used to conduct this feasibility test were made by referencing prior research within the forensic sciences using different mapping systems. Within this literature CrimeSTAT IV, Google Earth, and ArcGIS showed the
most promise. The selection of these systems was decided by prior applications to mapping scattered human remains or crime. However, little to no research literature has mentioned the use of these GIS systems in creating a database for tracking incomplete skeletal remains over time.

Following research, the selection of a final database to be used for documenting and tracking incomplete forensic anthropology cases was made through conducting trials. When attempting to use this GIS systems there was no previous knowledge on how to use them to test how user friendly each one was. During the trial of each system, key variables were noted to assist in the decision of which system would be the overall most compatible. Table 1 lists the variables assessed. Key variables that were considered were accuracy of pinned locations, whether individual pinned points could be made for each case, user friendliness, the ability to attach a textbox of information and photographs to the pin, price, map and tool variety, and the ability to carry out various analyses among the pinned data. As seen in Table 1, there is an X symbol placed in each box to indicate what that specific system has the capability to perform.

<table>
<thead>
<tr>
<th>Programs</th>
<th>Accuracy</th>
<th>Individual Points</th>
<th>Text Box</th>
<th>User Friendly</th>
<th>Photos</th>
<th>Map Variety</th>
<th>Low Cost</th>
<th>Tool Variety</th>
<th>Carry Out Various Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcGIS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>CrimeSTAT IV</td>
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<td>Google Earth</td>
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A total of 15 cases were used in this pilot study for the analysis of geographic spatial database systems. Each of the 15 incomplete cases were selected by the consulting Forensic Anthropologist of Southeastern, Michigan (Dr. Megan Moore), based on the number of bones missing from each case and the taphonomic factors that were noted to cause the remains to be incomplete. The data gathered from these cases included: site location, bone inventory, taphonomic factors, and antimere size. These data were collected from the Wayne County Medical Examiner’s Office Case Report Summaries completed by the Medical Examiner Investigators or from the Forensic Anthropologist’s Report and/or bench notes for each case.

RESULTS

There are a variety of different taphonomic factors that contribute to skeletal remains becoming incomplete. From the 15 cases used within this study, each case had multiple contributing factors. Table 2 provides a visual representation of the cases labeled 1-15. There has been a category labeled “F.A. absent” to express that a contributing factor of the skeletal remains not being completely recovered could be due to the consulting Forensic Anthropologist not being present at the site to recover the remains. There is another category labeled “other,” this title is used to express the range of miscellaneous variables that could have been a taphonomic factor in the incomplete remains. Within the “other” category, this could include factors such as: heavy debris, demolition occurring at the recovery site, construction interferences with graves, or that the factors are just unknown through reading the case reports.
Taphonomic factors can affect the persistence of skeletal remain assemblages. This means it is very important to document every detail that could have been a contributor to the skeletal remains not being completely recovered for future reference, if a second recovery is required at a later date. Case #’s 10 and 15 both are two different cases merged into a single case each (see Table 1). Both of these cases are examples of bones being recovered months to years later. Examining the documented coordinates and notes on taphonomic factors such as animal scavenging, allowed for the successful match among one case with another enabling them to become a more complete set of remains.

<table>
<thead>
<tr>
<th>Case #</th>
<th>Animal Scavenging</th>
<th>Vegetation overgrowth</th>
<th>Gravity</th>
<th>Fluvial Transport</th>
<th>Burning</th>
<th>Weathering</th>
<th>F.A. Absent</th>
<th>Other</th>
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Table 2. Taphonomic Factors of the 15 Incomplete Forensic Anthropology Cases.
Upon completion of research and a trial run on all three of the different spatial analysis systems that are used in forensic sciences (ArcGIS, Google Earth, and CrimeSTAT IV), each individual database has its own pros and cons. The overall most reliable spatial analysis system for this particular application was ArcGIS. This system is promising due to its many different tools and features. For example, there are many different selections of maps, such as: imagery, imagery with labels, topographic, street maps, national geographic, ocean, and terrain maps. Once the proper map is selected, coordinates can be pinned onto the personalized map with the title, description, link for a photograph of the remains, and a customized pin placed onto the map.

There were multiple reasons why ArcGIS was chosen over CrimeSTAT IV and Google Earth. CrimeSTAT IV has limitations in what can be included on a map. The general use of CrimeSTAT IV is for a spatial statistics program to map crime (Figure 1). There is the ability to plot and highlight certain hotspot areas where crime is isolated in order to be compared to other hotspots or areas, but there is not the ability to insert information onto each pin in order to maintain a record of incomplete skeletal remains. This system would be useful for collecting data on where more concentrated areas of skeletal remains are likely to be found. However, for this pilot study this system could not be used.
Google Earth was a promising candidate for this pilot study. There are many highlighted features such as this system being free and user friendly with the continuous satellite updates on photographs of the globe, or the ability to pinpoint locations and add details into the text box for each case as seen in Figure 2. Google Earth also has the benefit of being able to insert latitude and longitude coordinates into the search bar and bring up the pinned cases for that location. However, Visser and colleagues (2014) found that coordinates obtained from imagery were grossly inaccurate, to be as far as 171.6 meters away from their actual pinned location. This could lead to many problems for the Forensic Anthropologist when tracking incomplete cases.
The ArcGIS system has many useful features. ArcGIS has an option to analyze pinned data and to print directions to the recovery site, which is useful if the Forensic Anthropologist needed to return to the recover site in attempt to locate more bones, especially in areas that lack a cellular signal. Also, the ability to analyze and note measurements of the distances between pinned points on the map in various units make a useful tool when remains have been scattered. Upon creating a mock incomplete case, imagery map with labels was used for the background map and a human figure for the icon (Figure 3). When creating a textbox to attach to the pinned location, the ArcGIS system was user friendly when adding key information, such as: case number, missing bones, photos, measurements of the existing side, longitude and latitude coordinates, along with other valuable information. The mock incomplete case displayed in Figure 3 is extremely brief with sample information to provide a visual representation of ArcGIS.
Additionally, in the ArcGIS Pro program there is a tool entitled “Spatial Analyst Toolbox.” This particular feature is available with a Spatial Analyst license. This toolbox provides a wide range of spatial analysis and modeling tools for both feature and raster data. As the ArcGIS help section explains, a raster consists of a matrix of pixels organized into a grid, where each pixel holds a value representing information, an example of this is aerial photographs or imagery from satellites. There are 23 tools within the Spatial Analyst Toolbox. Each of the tools are broken down into different categories of related functionality. Examples of the tools offered are: map algebra, overlay, surface, hydrology, groundwater, distance, and density. On the ESRI website there is a help page that breaks down what the Spatial Analyst Toolbox can offer, a description of each tool, and how it can be used.

**CREATION OF THE ARCGIS FORENSIC ANTHROPOLOGY TOOL**

At the first attempt of compiling all 15 incomplete forensic anthropology cases, there was a steep learning curve using ArcGIS system. Informative reviews in the literature search provide details about why ArcGIS is useful, but only briefly explain how
to begin using the system. Further training was obtained on the ArcGIS system software website created by ESRI. Under the support tab there is a selection for training, once that tab is selected there are a wide range of free and informative videos. There are also options for further training through classes that are taught by an online instructor, but for a cost. Once having established a basic understanding of the GIS system, it became fairly easy to navigate through the selections, the maps, and the pin point options.

Within this study, the image of an outlined human figure was placed at the location of incomplete skeletal cases (see Figure 4). This symbol was chosen as a universal symbol indicating a “crime scene” for each pinned location. The example provided in Figure 4 is an overview of what the 15 incomplete Forensic Anthropology cases in Southeastern Michigan look like once the ArcGIS programed is opened. For the provided examples of the incomplete skeletal remains database in both Figures 4 and 5, a street map with a labels template was used as the “basemap.” For each case, numerous sizes of the icon pins were created to better represent each pin without creating too much overlap in clustered areas or hotspots.

![Figure 4. ArcGIS spatial analysis of 15 incomplete skeletal cases from Southeastern, MI.](image-url)
Upon inserting a specific location into the search bar, each incomplete case can have a pin dropped to mark its location, ArcGIS then allows a text box to be attached to the pinned coordinates. Within each textbox for a pinned location there is documentation of each of the 15 cases, including: address, longitudinal and latitudinal coordinates (if given), case number, a list of each missing bone, photos of the existing remains, measurements of the contralateral bone from the existing side, and notes of anything that could aid in the determination of whether a bone found at a later date belongs to a previously recovered case (Figure 5). Additionally, there are notes added within the description box on the connection of cases that correlate with one another. Within this study, there was one specific case in which only a single femur was initially recovered, and years later the rest of the remains were recovered just down the road. Figure 5 presents a sample case created to demonstrate the appearance and format of what each pin contains.

**Figure 5.** Example of pin’s textbox information for mock incomplete case.
DISCUSSION

Overall, among the three researched GIS systems for this study, ArcGIS is the most useful for this particular Forensic Anthropology application. While this analysis only reviews the basic functions of ArcGIS, Google Earth, and CrimeSTAT IV, future research on Forensic Science applications of these systems will still need to be conducted. One key improvement that requires further exploration of the ArcGIS database system is whether there is a “shortcut” to simply type the case number within the search bar and automatically retrieve the pin location and information. Also, the example of the information in Figure 2 is only a brief summary in order to provide a visual of what each pinned case contains. The database provided to the consulting Forensic Anthropologist for Southeastern Michigan contains greater details with in depth descriptions. If this database for incomplete skeletal remains is successful, ArcGIS could be a promising tool for Forensic Anthropologist across that nation or even globally to use for tracking their incomplete cases. Unfortunately, there is the lack of comparable programs for tracking incomplete skeletal cases.

When conducting research on applications of spatial analysis systems in the forensic sciences, it was difficult to find information. One common subject that appeared in search databases was the Forensic Data Bank (FDB) at the University of Tennessee and the programs and methods used to get location coordinates for this program. The FDB contains extensive demographic information on variation within contemporary human skeletons to help Forensic Anthropologists estimate the biological profile to individuate skeletal remains of forensic cases (Dirkmaat et al. 2008).
Throughout completion of this pilot study there were multiple limitations. For this research there was only the use of 4 years of data on 15 incomplete cases, limiting the ability to test how each system (ArcGIS, CrimeSTAT IV, Google Earth) stores larger amounts of data. The mock cases created as visuals for each database within this pilot study represents only the basic functions of each system. There was no authorized access to the data on the NamUs website to see if it would be compatible with the data gathered from incomplete Forensic Anthropology cases. Most importantly, there was little to no previous research on the methods used to keep track of incomplete cases. The lack of research creates the limitation of gathering data from other researchers on comparable programs for creating an incomplete Forensic Anthropology case database.

Future research on this topic could be on the creation of an exclusive database for Forensic Anthropologists to acquire information on incomplete skeletal remains nationwide that could store all the data on one server. This digital tool could potentially enable future Forensic Anthropologists easy access to this information accumulated over time. After the completion of the analysis and chosen database of incomplete remains, it could be possible to further this study by merging this potential system with the government website NamUs used to track unidentified individuals and missing persons nationwide.

CONCLUSION

A variety of taphonomic factors can lead to incomplete Forensic Anthropology cases. If missing bones are not found upon initial recoveries, it is possible the missing bones can be found at a later date in the future. As time passes, it can be difficult for the
Forensic Anthropologist to sift through the increasing number of cases to locate to which case the isolated bone (or bones) could belong. Among the busy life of a Forensic Anthropologist, one might not have enough resources to compile all of their incomplete cases into one organized system, not to mention going through records of the predecessors of the Forensic Anthropologist.

This thesis introduced what Forensic Anthropology entails, the concept of medicolegal significance, and the key values of what makes up a biological profile. The many taphonomic factors that can lead to incomplete recovery of human skeletal remains was also explored. The research here compares the feasibility of previous and potential applications of spatial analysis systems used in forensic sciences, along with examples of what occupations currently use these systems. The final product is the creation of a database for incomplete skeletal remains.

The purpose of this research was to investigate different methods used in forensic sciences to determine the best geographic information system program in creating a spatial mapping system to record and track 15 incomplete Forensic Anthropology cases in Southeastern Michigan. Skeletal remains can become incomplete from multiple factors whether that be animal scavenging, acid bone diagenesis, fluvial transport, gravity, or the many other contributing factors. However, prior research has failed to examine different methods for keeping track of incomplete skeletal remains. This database of incomplete skeletal cases created here will be a very useful tool in eliminating the commingling of skeletal remains recovered near or at the same recovery site when bones are found at a later time.
After researching and conducting trial runs on three highly referenced GIS systems; ArcGIS, Google Earth, and CrimeSTAT IV, each system has both pros and cons. Overall, ArcGIS was the most promising system for this particular application due to its various tools and options. Each of the 15 incomplete skeletal cases for this study were pinpointed on an overlay of various maps in the proper coordinates with the icon of a human crime scene outline. Once a selected pin is clicked on, the information attached includes case numbers, list of missing bones, three-dimensional coordinates, photos of remains, measurements of contralateral bones from the existing sides, along with other important details relevant to each case.

Though this research only used the basics of the ArcGIS system, the database for incomplete skeletal remains has great potential. Further research should be conducted on the implications and security of this GIS system. In order to fill the existing gap of a more modern record keeping of incomplete cases. Forensic Anthropologists should take an opportunity to expand their skillset and learn how to navigate the ArcGIS instead of going through paper documents to locate recovered bones to previous recoveries. ArcGIS has the potential to go further than just the 15 incomplete cases used for this pilot research.

The outcome of this research is an act of community service, as well as a senior Honors thesis project. This community service compiles a list of incomplete forensic anthropology cases in southeastern Michigan over the past four years, but it could extend further. The information obtained from this research provides the Forensic Anthropologist with a new, user-friendly digital tool to inventory incomplete cases using either ArcGIS or Google Earth. These two systems seem to have promising applications,
whereas CrimeSTAT IV has limitations for this particular Forensic Anthropology function.

In conclusion, if a bone were to appear at random, this research provides an ideal tool for the Forensic Anthropologist to type the location or the exact longitude and latitudinal coordinates within the search bar on the ArcGIS system website, and then to have the forensic cases recorded in that area to appear. Once a pin is clicked on, it displays the case number, date of recovery, what bones are missing from the remains, a picture of the already recovered remains, and any relevant information. This type of database is applicable to Forensic Anthropology cases beyond Southeastern Michigan, nationally, and even globally. Furthermore, there is a promising possibility that unidentified Forensic Anthropology cases could be merged with the government website NamUs, where a larger diverse community of Forensic Anthropologist, Medical Examiners, criminal justice professionals, victim advocates, families of missing persons, and the general public can help identify remains. Overall, this service is important because it can provide the final step of closure to grieving family members of the deceased.
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