

SEDIMENT TRANSPORT BY MUD-NESTING BARN SWALLOWS IN
WHITE SANDS NATIONAL MONUMENT, NEW MEXICO

by

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DEDICATION

This work is dedicated to Jared K. McLendon, Mindy and Larry Meeker, and to my parents, Jade Meeker and W. Scott McCollough. This work is dedicated in the memory of Shayn Cooley.

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ABSTRACT

The effects of avian nest building on the landscape are not well-known. Birds can create and modify their landscape, and this is seen in nesting behaviors. Some birds will transport mud to build nests and depending on the sensitivity of the landscape, the effects can be widespread. This research quantified the mass of sediment transported by the Barn Swallow in the desert environment of White Sands National Monument, New Mexico and identified resources provided by humans that may aide in their residence in this unlikely area. This knowledge will supply a better insight to the human mitigated geomorphic impact of avian nest building and can help in future management for desert-dwelling species.

I. INTRODUCTION

Bird nesting behavior has been vigorously studied by biologists, but its effect on the landscape is not well known (Collias 1964). The study of animal effects on the landscape (zoogeomorphology; see Butler 1995) was largely fixated on large mammals, such as grizzly bears (Butler 1992). This has led to myopic focus on easily discernible landscape impressions. Smaller animals like birds can modify their environment but even so, impressions have been understudied. Birds create burrows (Hornung 1982), tunnels in riverbanks (Ali et al. 2010), and mounds while nesting (Collias 1964). This can and does affect the environment in discernable ways under certain conditions.

About 5% of bird species, most of which are from the *Hirundinidae* family (Rowley 1970), use mud to create nests. Mud nests can be simple individual open-cup nests or can be incorporated into complex gourd-shaped enclosed colonies (Goodfellow 2011). Mud-nesting birds' geomorphic competency has recently received modest treatment (Tsikalas and Butler 2015). One study conducted in Central Texas found one colony of mud-nesting birds moved up to 953.6 kg of sediment. Multiple colonies moved up to 2,125 kg combined (Tsikalas and Butler 2015). Bird sediment movement can significantly affect sensitive landscapes.

The Barn Swallow (*Hirundo rustica*; Figure 1) is one of the most extensively studied birds. It has been treated by many researchers (Scordato and Safran 2014). Most

studies occurred where there are plentiful mud and sediment resources, resulting in a minor geomorphic impression. In contrast, a population of Barn Swallows reside in White Sands National Monument, New Mexico (WSNM) (pers.obs.). This area is in the Tularosa Basin in the northern end of the Chihuahuan desert (Metzler and Forbes 2011) and is far different than other more recognized Barn Swallow habitats (Ambrosini et al. 2002b, Ringhofer and Hasegawa 2014).

This research quantified the amount of sediment moved by a population of Barn Swallows inhabiting the eaves of the Visitor Center at White Sands National Monument, New Mexico (WSNM), and established the resources provided by the park's built infrastructure in this particular desert environment. In addition, nest characteristics (orientation, distance to ceiling, etc.) and surrounding landscape analysis were measured to supply insight into this newly discovered habitat for Barn Swallows. This study adds to an emerging area of zoogeomorphology and can guide future management practices as climate change brings about unprecedented alterations to desert environments.

Study Species

Background. Barn Swallows are insectivorous passerines that have expanded from rural habitats to urban cities in Asia, North Africa, Europe, and North America (Teglhøj 2017). This is one of the most widespread swallow species in the world (Scordato and Safran 2014). They can be up to 17 cm tall and easily distinguished from other swallows by their long and deeply forked tail (Møller et al. 1998). They sport

glossy blue-black outer back feathers, cinnamon or buffed-colored underparts, and reddish to orange coloring from throat to forehead. Barn Swallows are found in pairs, or aggregate into small colonies. Their song (expressed by both sexes) is a constant liquid chattering, twittering, and warbling, often followed by a “whir”. When threatened they issue a “cheep” sound and express a “churee” whistle if they dive toward the threat.



Figure 1. A pair of Barn Swallows perched outside the Visitor Center of White Sands National Monument, New Mexico. Photo by Aidan K. McLendon.

Barn Swallows experience low breeding dispersal and typically migrate to the same breeding areas each year (Ambrosini et al. 2002b). They are a double brooded species, meaning they can have up to two nesting cycles (e.g. broods) per breeding season (Grüebler and Naef-Daenzer 2008). Each brood comprises of 4-5 eggs, with incubation beginning after the penultimate or last egg is laid (Mainwaring et al. 2009). Incubation lasts for about 13-17 days. Nestlings begin to fledge around day 18-23 and reach adult size by day 33 (Mainwaring et al. 2009). Barn Swallows are relatively short-lived species; an individual may only experience one lifetime breeding season (Ambrosini et al. 2002b). Indeed, fewer than half will reach the next breeding season (Møller 2002).

Distribution. Barn Swallow distribution in Europe has been linked to livestock and farmland (Ambrosini et al. 2002b). Barn Swallows tend to nest around farm buildings, open fields, near water, under bridges, or with other suitable structures for mud nests construction (Figure 2; Ringhofer and Hasegawa 2014). They originally nested primarily in caves, but Barn Swallow nesting sites now principally rely on human-made structures for nest support (Ringhofer and Hasegawa 2014).

The dependency of Barn Swallows on human presence gives ample opportunity for ecological study. They are thus a model species (Scordato and Safran 2014). Common Barn Swallow research themes are the effects of

coloniality in birds (Hasegawa and Arai 2015), climate change and/or agriculture development (Ambrosini et al. 2002b, Møller 2002, Gruebler and Naef-Daenzer 2008, Ambrosini et al. 2011b, García-Pérez et al. 2014) and sexual selection (Neuman et al. 2007).

This attention has not afforded immunity from worldwide bird declines. Many bird species, including Barn Swallows, are experiencing localized population declines across Europe (Evans et al. 2007). This is also seen in North America despite federal protection (NPS 2016a). A 20-year study in Britain revealed almost 85% of farmland birds experienced numeric and habitat declines (Benton et al. 2002). Many attribute the worldwide bird abundance and distribution declines to intensified agriculture and increased pesticide use (Ambrosini et al. 2002b, Benton et al. 2002, Evans et al. 2007, Gruebler and Naef-Daenzer 2008, García-Pérez et al. 2014).

Increased agriculture means larger land tracts devoted to specific crops or land cover, some of which does not support the arthropods preferred by insectivorous birds. For example, Ambrosini et al. (2002b) found that Barn Swallows foraged over hayfields 13 times more than over cornfields. Evans et al. (2007) found that insect communities differ depending on land-cover; pastureland had up to 7 times more insects than cereal crops. More intense land has reduced non-cropped area (hedges, etc.) that otherwise acts as shelter for many organisms

(Benton et al. 2002). This shift of land cover decreased insect abundance, and this contributes to bird population declines.

Pesticide use has also expanded over the years. Researchers have established a direct negative relationship between pesticide use and breeding success of certain bird species (Evans et al. 2007). Pesticides are effective. They kill prey insect species, and this forces parent birds to expend more time and energy searching for food, with an attendant increase in off-nest time. This leaves the nest unattended and vulnerable to predation, lessening the chance of breeding success. Food supply decreases may be an influential factor on the health of the nestlings (feeding rates, growth rates, and weights; Benton et al. 2002) or the main cause of nest failure in some bird populations (Grüebler and Naef-Daenzer 2008, García-Pérez et al. 2014).



Figure 2. Barn Swallow nest. Barn Swallows use mud, grass and twigs in their nests for structure and employ feathers and hair for insulation. Mud nest building can be cumbersome because birds can only transport pellets of mud from source site to nest site using their beaks. Photo provided by D.R. Butler.

Study Site

Geography. White Sands National Monument is a branch of the Chihuahuan Desert that is in the southern region of New Mexico, west of Alamogordo (32.7872° N, 106.3257° W; Figure 3) (USDA 2017). Its most striking feature is 284.9 km² (110 square miles) of white gypsum sand (Metzler and Landry 2016) that piles up into dunes up to 80 meters high (Bugbee 1942). This is one of the largest white sand fields in the United States (Houk and Collier 1994). WSNM is in the Tularosa Basin and is between two mountain ranges: the Sacramento Mountains to the east and the San Andres Mountains to the west (USDA 2017; Figure 4). Elevation ranges from the lowest point of 792.5 meters (2,600 feet) in the basin and more than 2,590 meters (8,500 feet) in the mountains (USDA 2017).

The Visitor Center is at the entrance to the park. Administration buildings are located around the Visitor Center (NPS 2016b). WSNM was founded in 1933 and construction of the Visitor Center and surrounding buildings were complete in 1938 (NPS 2016b). These buildings are still in use today (NPS 2016b).

Deeper into the dune fields, the park supplies covered picnic areas connected by a road (pers. obs.). Bathrooms are provided near these covered picnic areas and are free for the public to use (pers. obs.).

New Mexico and White Sands National Monument

Aidan K. McLendon, Texas State University

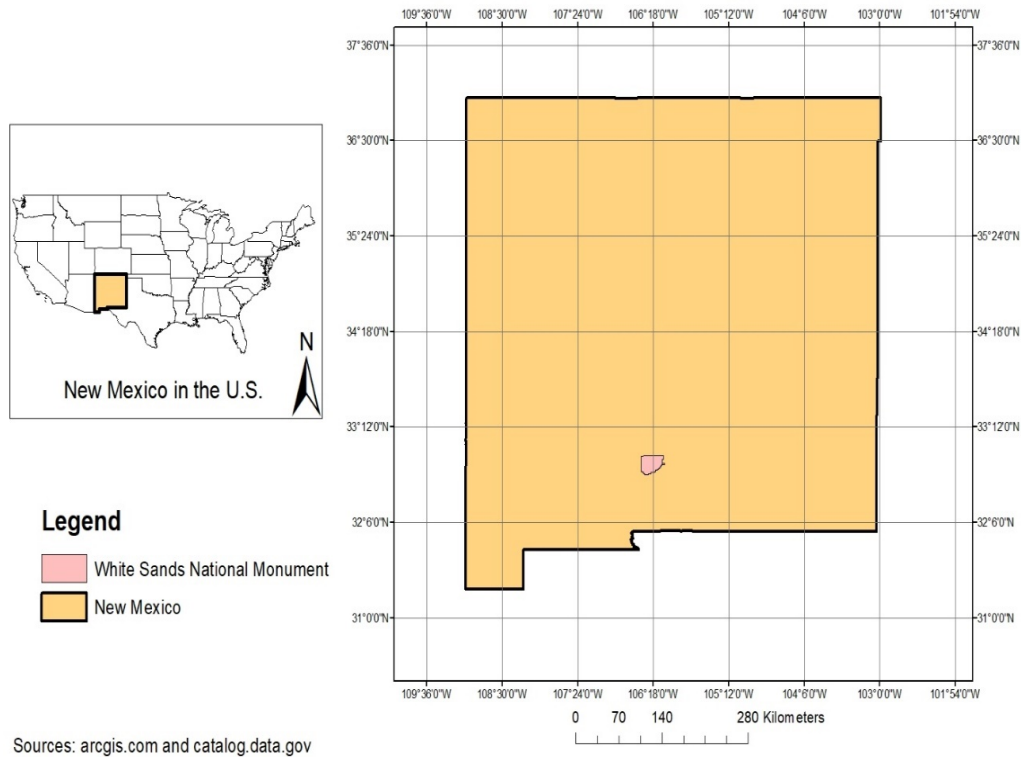


Figure 3. New Mexico in relation to the U.S. (inset) and the location of White Sands National Monument inside New Mexico. Map created by author.



Figure 4. Tularosa Basin satellite imagery. The striking white gypsum dunes lie in the Tularosa Basin, enclosed by the Sacramento Mountains to the east and the San Andres Mountains to the west (USDA 2017). Image taken from Google Earth.

Climatic Conditions. WSNM experiences harsh climatic conditions.

Temperatures rapidly vary; one observer experienced a 15.5°C one-day fluctuation (Bugbee 1942). Summers average in the 30s (°C) but temperatures higher than 37.7°C are not uncommon (NPS 2016a). Precipitation is low, averaging about 203 mm a year (NPS 2016a). More than half of the annual precipitation falls during intense summer thunderstorms (NPS 2017).

Wind is the most important climatic factor in WSNM (NPS 2016a). Generally, a light breeze will flow from the South, East, or West (Houk and Collier 1994). Southerly winds can blow across the desert at around 16-32 kph and reach up to 88.5 kph during early spring (NPS 2016a). This area experiences monsoon-like storms through the spring and summer, and the wind is so strong and highly variable, that large sand dunes are constantly created, moved, and destroyed (Bugbee 1942, NPS 2016a). This wind can prohibit insectivorous birds from efficiently catching insect prey on the wing, as intense winds tend to decrease insect densities (Møller 2013).

II. RESEARCH QUESTIONS

Research Question

This research, guided by a conceptual framework (Figure 5), will answer the following question:

In the desert environment of WSNM, to what extent do Barn Swallows transport sediment for nest-building and is their settlement bolstered by resources provided by the Visitor Center?

Hypotheses

This research is based on two null and alternative hypotheses:

- 1) **H₀**: The Barn Swallows do not contribute to sediment transportation in WSNM.
H_A: The Barn Swallows contribute to sediment transportation in WSNM.
- 2) **H₀**: The Barn Swallows are not utilizing resources provided by the Visitor Center in WSNM.
H_A: The Barn Swallows are utilizing resources provided by the Visitor Center in WSNM.

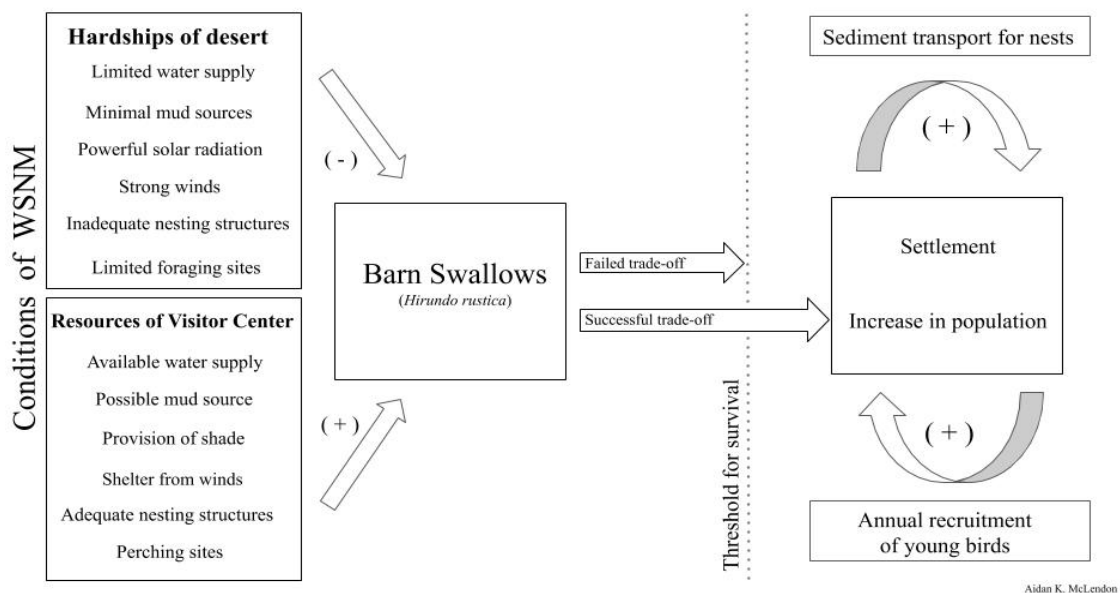


Figure 5. A conceptual basis framework for this research. The desert often presents hardships for some species. The Barn Swallows in WSNM, however, may be opportunistically using human-supplied resources provided at the Visitor Center. These resources offset desert burdens and by supporting some of the Barn Swallow's basic needs, thereby allowing occupation and subsequent population growth. This would cause a positive feedback loop in both the increase in geomorphic impact of their mud-nests and in the recruitment of more birds to this location.

III. LITERATURE REVIEW

Zoogeomorphology

Charles Darwin introduced the earthworm as an earth-moving agent in his work published in 1892 (Darwin 1892). Since then, different fields of study have undertaken this idea and molded their own definitions of animals as participants on the process of environmental alteration. In ecology, the term “ecosystem engineer” reflects the idea that organisms rework their habitats (Wright et al. 2002). In geography, the term “biogeomorphology” encompasses the actions of plants and animals that reshape their landscapes (Naylor et al. 2002). This can be further broken down into phytogeomorphology (emphasis on plants) and zoogeomorphology (emphasis on animals).

Zoogeomorphology (the interaction of animals and the movement, deposition, and mixing of earth materials) was featured in *Zoogeomorphology* (Butler 1995). Butler (1995) was the first to spotlight the effects of animals instead of having them share the stage with plants like earlier works in the biogeomorphology field. Since then, zoogeomorphology has gained traction and diverse studies have been published with appreciable results (Smallwood and Morrison 1999, Avenant and Smith 2003, Hinze et al. 2006, Hall et al. 2009, Eriksson 2011, Le Roux et al. 2011).

Zoogeomorphology can be grouped into even smaller sub-disciplines. There have been several studies on the effects of burrowing rodents, such as pocket gophers (Reichman and Seabloom 2002), roof rats (Flannelly et al. 1986), and ground squirrels

(Laundre 1993), with most of the concentration on higher alpine regions. Other organisms, although heavily underrepresented in the literature (especially in Geography-oriented journals), have been shown to have environmental impacts. For example, riverine habitat hosts several organisms that modify the riverbed and channel, such as the burrowing actions of the Rock Bass (Noltie and Keenleyside 1987) and benthic insects (Charbonneau and Hare 1998). To date, birds have not been adequately treated, however.

Avian zoogeomorphology studies birds as contributors to the moving, mixing, and deposition of soil and/or earth materials. Since birds are often thought to spend most of their time in-flight or perching (Butler 1995), not many studies have been done on their impacts to the landscape under a specific Geography lens. Ecology and zoology consume most of the research and literature on birds and these tend to fixate on reproductive lifecycles, physiology, and habitat requirements. These topics mention how bird interact with the landscape, but few studies have attempted to study and/or quantify it.

When birds are not flying, they are indeed impacting their environment. They alter vegetation (Gillham 1978), influence nutrient inputs (Anderson and Polis 1999, Mosbech et al. 2018), transport rocks by the ingestion of gastroliths (Wings 2003), and through nest-building behaviors such as scraping of ground (Reid et al. 2002), movement and transportation of mud (Tsikalas and Butler 2015), and burrowing (Hendricks et al. 2013). Although this behavior has been observed in many studies, quantification of the actual geomorphic impact of such behaviors is not common.

A few studies have focused on the characteristics of bird burrows (Ramos et al. 1997) and certain nesting preferences for burrowing birds (Sullivan et al. 2006, Smalley et al. 2013). However, as of this date, only one published geographical paper quantifies the amount of sediment displaced by bird nesting action. Tsikalas and Butler (2015) studied mud-nesting species in Central Texas and found that the colony moved over 2,000 kg of sediment for their nests. During the duration of one summer, the colony moved 560 kg as nesting material (Tsikalas and Butler 2015). The effects of this sediment transfer are not well-known. In sensitive environments, this movement could be detrimental or important for the ecosystem; further research is warranted.

Bird migrations and climate change

Some organisms use the natural fluctuation in season, daylight, and temperatures as cues for migration and breeding cycles. Avian species use these cues to find concurrent favorable weather, ideal insect abundance, and egg-hatching opportunities (Ambrosini et al. 2011a). Perceived changes to hours of daylight, or photoperiod, is a common cue and is genetically regulated (Caprioli et al. 2012), however responses are flexible. In fact, many birds can alter their reproductive timing to match the perceived variation (Ambrosini et al. 2011a, Caprioli et al. 2012) and is one of the most important reproductive determinations a bird can make (Grüebler and Naef-Daenzer 2008).

Breeding timing decisions based on environmental cues can correctly synchronize peak food abundance, optimal weather conditions, and bird egg hatching times. For

example, Martin and Wiebe (2004) found that the Arctic willow ptarmigan in Manitoba, Canada, breed based on snowmelt timing in the area. The ptarmigan's main food source, the willow tree (Weedon 1969), grow catkins and leaves that can sustain the birds and their young through the summer.

Variances in bird breeding timing is not the only response to environmental cues. Diversity in egg numbers (Daan et al. 1988) and sizes (Järvinen 1994) have been observed and were dependent on environmental circumstances, such as food availability and warmer temperatures, respectively.

Flexibility in reproductive components does not come as easily for migratory birds. One difficulty to properly synchronized breeding grounds is that they do not know the conditions until they arrive from their wintering grounds. Some birds will migrate more than hundreds of kilometers and the conditions at their wintering grounds may be completely different than those at their breeding grounds. In addition, the timing of the development of reproductive anatomical parts or even individual arrival at breeding grounds (Møller 1994) may differ between males and females. These variables illustrate the delicate web of factors that could have huge impacts on a migratory bird's overall fecundity (i.e. fertility and/or reproductive success). Climate change is beginning to entangle this web.

Warming global temperatures are causing birds to migrate and/or breed earlier (Møller 2002, Martin and Wiebe 2004). Although birds that arrive early have traditionally obtained more benefits (e.g. preferred nesting sites, ample mate choices,

higher chances for second nests, etc.; Møller 2002), climate change leads to unpredictable and prolonged storm seasons that can potentially cause complete nest failure (Järvinen 1994, García-Pérez et al. 2014). Some birds may be able to re-nest, but other birds are limited to one nesting attempt a year. Migratory birds are often not as well adapted to inclement weather (in contrast to the year-round birds) and may not be able to survive the widening range of weather being brought on by climate change.

Nest Characteristics

Nest Features. The nest serves multiple functions and purposes. The primary functions are protection of the eggs from inclement weather and stealthy, pervasive predators (Collias 1964). Eggs need to be kept in a stable environment in order to grow, and exposure to harsh weather conditions will lead to nest failure (Dawson et al. 2005, Hosseini-Moosavi et al. 2017). Nests can provide insulation and protection from chilly winds, and shade from over-exposure to solar radiation. Predation and nest features are complexly intertwined (Barrientos 2009). Birds will build nests that combat the burden of the ever-present predator and this manifests through different nest features that attempt to defy the dominant predator type (e.g. olfactory, visual, auditory, or thermal; Barrientos et al. 2009).

Secondary functions of nests could be signals of procreation quality or potential parental investment (Soler et al. 1998b), or other social cues (Ringhofer and Hasegawa 2014). Some birds will use the nest or other structures as an indicator of their worth as a

mating partner (Soler et al. 1998b). By building a nest in a certain way, male birds can flaunt their willingness to parent (Soler et al. 1998a) or their genetic quality (Møller 1994). Female wrens will decide which male to mate with depending on how many nests he has built on his territory (Evans and Burn 1996). Male Satin Bowerbirds will create ‘bowers’, or grassy tunnels, that are decorated with materials such as flowers and feathers to attract potential mates (Borgia 1985). These behaviors are reliant on the bird’s unique life-history and adaptations to their environment.

Although nest-building may be guided by genetics, different techniques to combat varying selective pressures have arisen and a wide variety of nest architecture exists in the avian world (Collias 1964). A diversity of building materials, shapes, sizes, and orientations exist throughout nests, although commonalities have been found in birds that occupy similar habitats (Collias 1964; Biddle et al. 2018). This makes species identification through nest observation more difficult, but it highlights the environment’s effect on bird life-history and evolution.

In the nesting cycle, the nest building phase can be a very large energy expenditure and is an investment for the future of their young (Mainwaring and Hartley 2013). Characteristics of the nest are dependent on many factors and serve as a trade-off between parental investment and the selection pressures of their environment. In other words, a bird can build a simple nest in a short time but will have to spend more time and effort in other areas of the nesting cycle. For example, the Piping Plover will build a simple scrape nest on sandy ground (Farrell et al. 2018). Plovers will not have to invest

much energy into nest construction, but this decision comes with a tradeoff: there is little protection from predators and inclement weather. Farrell et al. (2018) found that high temperature ranges (because of a lack of insulation and/or protection) were the cause of most Plover nest failures in Nebraska over a 15-year period.

Conversely, a bird can spend days to weeks building an elaborate nest to combat pressures of predators and the environment. For example, female Yellow-rumped cacique weave together nests that look like hanging baskets (Robinson 1985). In addition to the remarkable skill that is needed to build these nests, they are often built near wasp nests and other conspecifics (Robinson 1985). All this effort is for protection from avian, reptile, and mammal predators that live in the Amazonian region of Peru. One study found fewer than 40% of nests were lost to predation (Robinson 1985). Yellow-rumped cacique trade an enormous amount of energy in nest building for the efficient protection it serves against predators. It should be noted that another trade-off of elaborate nest building is skill: a nest not built perfectly can completely fail.

Those are just two examples of how each nest is a trade-off between energy expended in the nesting cycle and the two strongest potential pressures of the environment, climate and weather (Warning and Benedict 2015). There are other pressures in the environment that can shape how and where a bird will build its nest.

Mud Nests. A few birds have learned how to utilize mud as a nesting material (Winkler and Sheldon 1993). Mud can be a great material because of its versatility and strength. Birds can use mud as a binding agent for other materials, such as grass or twigs

(Tsikalas and Butler 2015), or it can be used as the dominant nest material, as with the Barn Swallows. Only about 5% of bird species, most found within the *Hirundinidae* family, use mud as the major element of their nests (Rowley 1970). This could be because of the relative difficulty of building mud nests. It has been observed that over 1,000 mud-carrying trips from mud source to nest are needed to complete the nest (Emlen 1954). This effort is burdensome, given birds can only use their beak for transport (Winkler and Sheldon 1993). The benefit to all this hard work is that previously inaccessible areas, such as cliff walls or rock faces in high elevations, are now within reach (Winkler and Sheldon 1993).

Barn Swallow nests are easy to identify in the field. Using man-made structures (such as eaves of barns, houses, bridges, etc.) the birds will bring mud pellets to a site and adhere the pellets to the vertical sides of the structure thus creating a nest (Tsikalas and Butler 2015). Both sexes participate in nest building (Soler et al. 1998b) and will build from the bottom up, adding pellet by pellet. There will be momentary breaks between nest building trips to allow the mud to fully dry before adding more wet mud to the nest, and this gives their nest a banded appearance (Emlen 1954). Barn Swallows will also use other materials, such as twigs, grass, and hair, for structure and insulation (Soler et al. 1998b).

Desert species

Barn Swallows are globally widespread (Huin and Sparks 1998), but many of the studies focused on this species have been in non-desert environments, such as Italy (Ambrosini et al. 2002a), Denmark (Møller 1994), Israel (Vortman et al. 2011), and Japan (Ringhofer and Hasegawa 2014; See Appendix for summary table of Barn Swallow studies). European Barn Swallows do migrate across desert areas to reach their breeding grounds (Rubolini et al. 2002); however, there have been no mentions of Barn Swallows in studies that listed desert birds observed in an area (Fischer et al. 1972, Gutzwiller and Barrow 2008).

The nest characteristics of Barn Swallows differ from birds adapted to the harsh desert environment. Verdins and Black-tailed Gnatcatchers living in the Sonoran Desert will build nests out of twigs (McCreedy and van Riper III 2014), often in cacti or available shrubbery. Others exhibit ground-nesting behaviors, and often use vegetation or rocks for sun and wind protection (Hartman and Oring 2003). A trend has been seen in bird communities that live in arid climates: densities follow vegetation structure (Austin 1970). Desert birds use the sparse vegetation as shelter and a food source. The Barn Swallows, however, are not directly dependent on vegetation for either, since they nest in human structures and are insectivores. This isolation from other birds and the typical adaptations of the desert environment could either enable or hinder the success of this bird population; however, there is little information available for such analysis.

Although this population's existence is peculiar in the desert environment because of a scarcity of mud sources, the unique ability of Barn Swallows to construct mud nests on man-made structures may be a considerable factor that allows them to survive. Mainwaring (2015) briefly describes some advantages and disadvantages of birds using man-made structures. Other studies have observations of the effect of urbanization on bird community structure (Mills et al. 1989, Green and Baker 2003). To date, there is no fitness or community structure data on the WSNM population to compare to other studies, and this author highly recommends further investigations into this topic.

Further inquiry or considerations of adaptations for this population of Barn Swallows are food availability (Brown et al. 1979, Hutto 1985), clutch size and/or breeding attempts (Ambrosini et al. 2011a), overall nestling fitness (Dawson et al. 2005), arrival time, alteration of wintering grounds (Ambrosini et al. 2011b) and heat stress adjustments (Fisher et al. 1972, Schleucher et al. 1991).

IV. METHODS

Primary Data

Field work in WSNM was conducted over three days (April 5-7, 2019). Barn Swallow nests around the Visitor Center were counted, identified, and nest dimensions were obtained to the nearest tenth of a centimeter. The height (H), largest radius (a), and smallest radius (b) were entered in the following formula to calculate the volume of sediment composing the nests:

$$V_{\text{Ellipsoid}} = \{ (4\pi/3) * H * (a/2) * (b/2) \}$$

The equation is for the volume of an ellipsoid, modified from Soler et. al (1998b). Once the dimensions of a typical Barn Swallow nest were obtained, the measured radius was divided by two to give the proper volume measurement for a quarter of an ellipsoid. When nest material volume was calculated, the mass was derived by multiplying the volume of the nest (in m^3) by the density of the average density of a combination of gypsum and sand ($1842 \text{ kg}/m^3$). The final mass is equal to the mass of sediments moved per nest in kilograms.

The diameter of individual pellets (Emlen 1954) were measured on intact nests and nest imprints and were selected at random. The radius of the pellets was entered the equation for the volume of a sphere:

$$V_{\text{Sphere}} = \{ (4\pi/3) * r^3 \}$$

The mass of the average pellet was derived by multiplying the calculated volume by the average density of a combination of gypsum and sand (1,842 kg/m³). The mass of the average nest was divided by the average pellet mass to equal the number of pellets comprising an average nest.

The nest orientation (direction of b-axis; Hartman and Oring 2003) of each nest and imprint was measured using a compass in addition to the GPS coordinates using a handheld Garmin eTrex 20x (Garmin 2019). The total height from floor to ceiling and the distance from the top of intact nests and imprints to the ceiling were measured to the closest tenth of a centimeter (Møller 1983).

Because of the high probability of the presence of ectoparasites and/or other transmittable diseases (Møller 1992), between each nest measurement all instruments were sanitized, and gloves were changed and discarded.

Eight central point observations (Lynch and Whigam 1984) were taken around the Visitor Center, each lasting ten minutes. The same two observers conducted the observations to lessen observer bias. During the observations, activities, such as flight duration and distance, foraging, singing, and other Barn Swallow behaviors were noted. Barn Swallows are known to forage for nesting materials within 400-meters of the nest site (Ambrosini et al. 2002a).

The Visitor Center was explored on foot to identify any potential resources that can be used by the Barn Swallows, such as water and mud sources and perching sites, within 400 meters of nests. Exploration of the supplied picnic structures was conducted

further into the dune fields for any evidence of Barn Swallow presence apart from the Visitor Center.

Secondary Data

Wind speeds, directions, and rainfall during the previous three Barn Swallow breeding season (March-September, 2016-2018) were taken from one weather station located at the nearby Holloman Air Force Base, accessed via MesoWest website hosted by the University of Utah (MesoWest 2019). Land cover data was taken from the Southwest Regional Gap Analysis Project website (Lowry et al. 2005).

Analysis

All nest dimensions were analyzed for descriptive analysis: mean, median, mode, and range. This provides insight into the dispersion level of nest dimensions and allowed further comparisons to other mud-nesting bird species (and other zoogeomorphological) studies. The presence of Barn Swallow nests and mass measurements was used to accept the first alternative hypothesis.

Results of the central point observations allow for a discussion of potential resources found around the Visitor Center of WSNM that the Barn Swallows utilize. This information grants more insight into the further repercussions of climate change and the alterations of bird behavior in other areas.

Landcover data and field observations were used to identify any trends in foraging. Landcover data was used to analyze the vegetation and identification of vegetation *in situ* during field work was used to ground-truth the landcover data. Central point observations were used to identify areas of high use by the Barn Swallows, and any potential preference for certain vegetative structures. Comparison of the Visitor Center and the picnic structures farther in the dunes allow for identification of resources other than human-made structures that Barn Swallows can use, such as water and mud sources. The second alternative hypothesis was accepted given that the picnic structures had no other resources that were found around the Visitor Center, and that Barn Swallows did not inhabit the picnic structures but did inhabit the Visitor Center.

V. RESULTS

Nest mass

A total of 13 intact nests and 5 imprints (remains of a previously existing nest) were located around the WSNM Visitor Center (Figure 6). Surrounding administration buildings are excluded because of the limitations of the WSNM field work permit. The average height (H), large radius (a), and small radius (b) of the 13 intact nests were 8.46 cm, 8.98 cm, and 8.92 cm, respectively (Table 1). The average mass of the 13 intact nests was 1.31 kg (2.90 lbs.) and resembles the median mass of 1.35 kg (2.97 lbs.; Table 2). The total mass of sediment present for the 13 intact nests was 17.08 kg (37.67 lbs.). Calculations excluded imprints because of the lack of measurements for the large and small radius.

A pilot study was conducted in WSNM in August of 2018. Six intact nests were measured using the same calculations. The average mass of the six nests was 0.95 kg (2.09 lbs.) and the total mass of all nests combined was 5.73 kg (12.63 lbs.). The average mass of the 2018 nests is statistically different than the average mass of the 2019 nests ($P=0.05$), indicating an increase in nest mass over time. However, this calculation was based on a small sample size ($n=6$). Barn Swallows are known to re-use nests and the WSNM population of birds may have fortified previously existing nests in addition to building new ones.

Nest orientation

From the 5 imprints measured, 40% (2/5) are oriented to the NW, and the remaining are oriented to the NNE (1/5), SE (1/5), and the SW (1/5). Of the 13 intact nests, 23% (3/13) are oriented to the NE, 15% (2/13) are oriented to the N, 15% (2/13) are oriented to the E, and the remaining nests (6/13) are oriented to the NNE, ENE, SE, SW, W, or NW (Figure 7). Findings of wind speed and direction are in a later section.

Pellet size and amount

131 pellets were measured randomly from the intact nests and imprints. The average diameter and mass of an individual pellet was 0.93 cm and 7.75×10^{-4} kg, respectively. Given that the average mass of one intact nest is 1.31 kg, one nest could contain up to 1,689.46 pellets of sediment (Table 3).



Figure 6. Distribution of intact nests and imprints found around the Visitor Center. Most intact nests (red circle) and nest imprints (yellow square) were in the front walkway and the courtyard. Background image taken from Google Earth. Map created by author.

Table 1. Dimensions of intact nests found around the Visitor Center; n=13. Note: H is the height of the nest, a is the large radius, and b is the small radius. The total mass of sediment present for the 13 intact nests was 17.08 kg (37.67 lbs.).

| Nest ID | H (cm) | a (cm) | b (cm) | Volume (m ³) | Mass (kg) |
|---------|--------|--------|--------|--------------------------|-----------|
| C1 | 10 | 8 | 8 | 0.0007 | 1.2339 |
| C2 | 9.5 | 10.5 | 8.5 | 0.0009 | 1.6347 |
| C3 | 11 | 8.5 | 9 | 0.0009 | 1.6224 |
| C5 | 9 | 9.5 | 10 | 0.0009 | 1.6484 |
| C6 | 8 | 8 | 12 | 0.0008 | 1.4807 |
| C7 | 8 | 9 | 12 | 0.0009 | 1.6658 |
| C8 | 5.5 | 7 | 8 | 0.0003 | 0.5938 |
| F1 | 7 | 10.25 | 9 | 0.0007 | 1.2450 |
| F2 | 11 | 9.25 | 8.5 | 0.0009 | 1.6674 |
| F3 | 8 | 8.5 | 9.5 | 0.0007 | 1.2455 |
| F4 | 7 | 11.75 | 8.5 | 0.0007 | 1.3479 |
| F6 | 7 | 7.5 | 6 | 0.0003 | 0.6073 |
| B1 | 9 | 9 | 7 | 0.0006 | 1.0932 |

Table 2. Descriptive statistics for the mass of the 13 intact Barn Swallow nests.

| Sample size | Minimum | Maximum | Mean | Median | Mode | Std. Dev. | Variance |
|-------------|---------|---------|---------|---------|---------|-----------|----------|
| 13 | 0.59 kg | 1.67 kg | 1.31 kg | 1.35 kg | 1.67 kg | 0.37 | 0.139 |

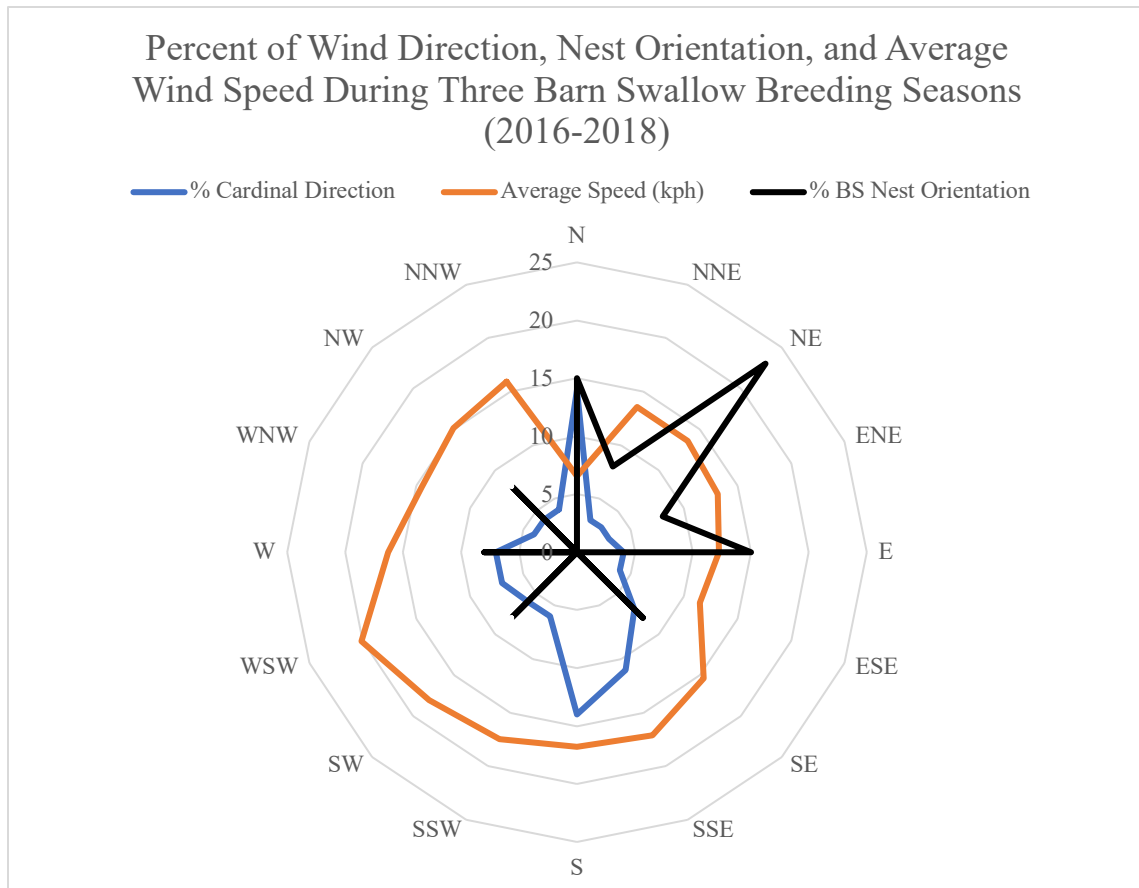


Figure 7. Rose diagram for nest orientation, wind speed, and wind direction. Shown is the percent of nest orientations of the 13 observed intact Barn Swallow nests around the Visitor Center, the percent of wind from a cardinal direction and the average wind speed per cardinal direction during three previous Barn Swallow breeding seasons (March-September, 2016-2018). The vertical axis is adequate for all three categories as the range for the nest orientation percent, wind direction percent, and average wind speed is 0-23%, 3-14%, and 6.54-20.13 kph, respectively. The center of the diagram represents the Visitor Center. The intact nests are oriented more towards the North to East (0-90 degrees). The

wind came from the North (0 degrees) and South (180 degrees) most often, although the highest wind speeds were from the SE to W (135-270 degrees). Figure by author.

Table 3. The method used to calculate the number of pellets per nest. The average diameter of an individual pellet (n=131) was 0.93 cm. The volume of an average pellet is derived by multiplying $(4/3 \pi)$ by the cubed radius. Mass is calculated by multiplying the volume and the average density of sand and gypsum (1,842 kg/m³). The mass of an average intact nest is divided by the mass of an average pellet to derive the number of pellets needed to equal the mass of the nest.

| Average Diameter (m) | Radius (m) | $(4)/(3)$ | π | r^3 | Volume (m ³) | Mass (kg) | Average nest mass (kg) | # of pellets / nest |
|----------------------|------------|-----------|-------|---------|--------------------------|-----------|------------------------|---------------------|
| 0.0093 | 0.00465 | 1.33333 | 3.14 | 1.01E-7 | 4.20947E-7 | 0.000775 | 1.31 | 1689.48 |

Landscape Survey

Potential resources from Visitor Center.

Water and mud sources. Weather data was taken from the MesoWest database. Precipitation during the last three barn swallow breeding seasons (2016-2018) occurred late in the summer, after the first estimated clutch initiation period (Mid-May; Saino et al. 2004) (Figure 8). The estimated time between first and second clutch initiations is 74 days. If a breeding pair in this region were to start their first clutch on May 17 (Saino et al. 2004), incubate for 14 days (Saino et al. 2004), successfully fledge their young in 21 days (Møller 1990), and have an interclutch interval of 39 days (Møller 2007), their second clutch attempt would occur around July 30th. Precipitation in this region is scarce until August and may precede both nest-building time frames for the Barn Swallows.

Other sources of water and mud were found around the Visitor Center. In the courtyard located to the southwest of the building, a water filling station (Figure 9) and water pump (Figure 10) were located. Over the duration of the field work, the water filling station was used continuously by visitors and surrounding soils were dampened with each use.

Foraging Sites. Central point observations revealed that the Barn Swallows regularly utilize three areas for foraging within 400 meters of the Visitor Center. The first area (Plot A) is directly to the ENE of the Visitor Center. Lowry et al. (2005) classified this area as Chihuahuan Mixed Salt Desert Shrub. Vegetation identified in the field by author and field assistant were Skunkbush Sumac (*Rhus trilobata*), Soap tree Yucca

(*Yucca elata*), Rubber Rabbitbush (*Ericameria nauseosus*), Fourwing Saltbush (*Atriplex canescens*), Purple Sand Verbena (*Abronia angustifolia*), and Sand Sagebrush (*Artemisia filifolia*). The second area, Plot C, is southwest of the Visitor Center and is of the same classification.

The third area, Plot B, is located directly NNW of the Visitor Center. Lowry et al. (2005) classified this area as Chihuahuan Gypsophilous Grassland and Steppe. The author and field assistant identified the following plants in this region: Fourwing Saltbush (*Atriplex canescens*), Purple Sand Verbena (*Abronia angustifolia*), Soap tree Yucca (*Yucca elata*), and Honey Mesquite (*Prosopis glandulosa*).

Barn Swallows would fly to and from these sites from the Visitor Center courtyard. Flight through the foraging areas varied in altitude from an estimated 1-8 meters high. Perching sites were found in all three areas, and Barn Swallows were observed to use branches and gate posts to preen and sing.

Wind speed and direction. Wind data were collected from the nearby Holloman Air Force Base via the MesoWest database (MesoWest 2019). The data was isolated to only include wind directions during the duration of the three previous Barn Swallow breeding season (March-September 2016-2018; Figure 7). Winds from the North and South were documented most often; 14% and 14%, respectively. Winds from the SSE were observed 11% of the time, and from the SE 7% of the time.

Wind speed per direction was obtained from the Holloman Air Force Base via MesoWest database. The average wind speed (kph) for a given cardinal direction was

isolated during the three previous Barn Swallow breeding season (Figure 7). The WSW and SW produced the highest average speed of wind; 20.13 kph and 18.08 kph, respectively. The SSW produced an average of 17.4 kph winds and the SSE produced winds averaging to 17.07 kph.

Distance of nest to the ceiling. Of the 13 intact nests and 5 nest imprints observed around the Visitor Center, the average height from the top of the nest to the ceiling of the building structure was 4.94 cm and ranged from 3-8 cm (Table 4). This distance in addition to the average height of intact nests and imprints (10 cm) accounts for 5% of the total height of the building structure (279 cm).

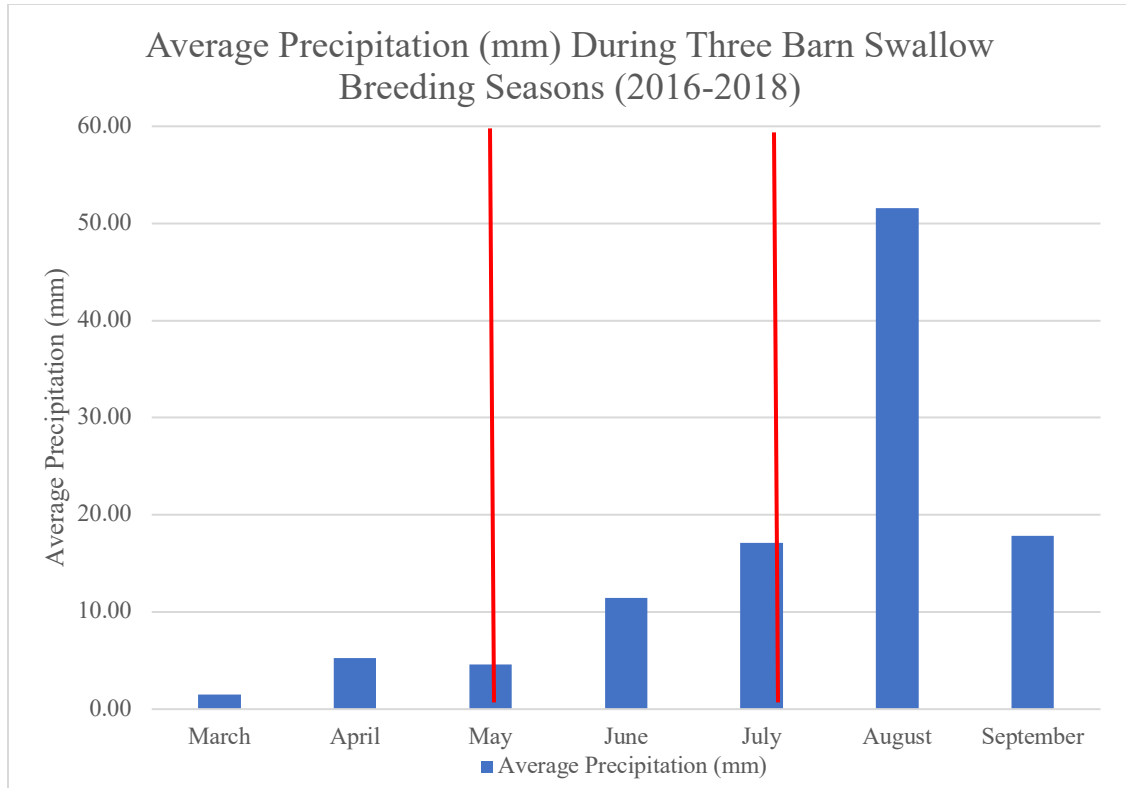


Figure 8. Precipitation measured from the nearby Holloman Air Force Base during the 2016-2018 Barn Swallow breeding seasons. Most of the rainfall occurs after the first estimated clutch initiation period of the breeding season (mid-May [first line]; Saino et al. 2004) and shortly before the estimated date of initiation for the second clutch (late July [second line]; Møller 2007). Data gathered from the MesoWest database (MesoWest 2019). Figure created by author.



Figure 9. Water filling station located in the south courtyard of the Visitor Center. Note the abundance of water on the ground and surrounding landscape capable of becoming mud. Photo by author.



Figure 10. Water pump located in the southern courtyard, across from the water filling station. Note the puddle of water and mud created after use. Photo by author.

Table 4. The distance from the top of the Barn Swallow nests to the ceiling. The average distance was 4.94 cm. The height of the ceiling was 279 cm. Nests were deemed either ‘intact’ if whole or ‘imprint’ if evidence of a previously existing nest.

| NEST ID | Distance to roof (cm) | Status |
|---------|-----------------------|---------|
| C1 | 4.5 | Intact |
| C2 | 4.5 | Intact |
| C3 | 5 | Intact |
| C4 | 8 | Imprint |
| C5 | 5 | Intact |
| C6 | 4 | Intact |
| C7 | 3.5 | Intact |
| C8 | 5.5 | Intact |
| C9 | 7 | Imprint |
| WB1 | 3 | Imprint |
| F1 | 4 | Intact |
| F2 | 5 | Intact |
| F3 | 5 | Intact |
| F4 | 3 | Intact |
| F7 | 5 | Imprint |
| F6 | 6 | Intact |
| B1 | 5 | Intact |
| B2 | 6 | Imprint |

Exploration of dune fields

Further into the dune fields, the park supplies covered picnic areas and bathrooms. The presence of Barn Swallows (such as intact nests, imprints, or guano deposits) was not found in any of these structures. The lack of evidence of Barn Swallow colonization of these structures could be because of the scarcity of available water and/or mud sources. Large insects, such as beetles, are known to live in the dunes of WSNM and therefore a lack of arthropods cannot be considered a potential cause. The orientation of the picnic structures was not measured; however, the architecture could supply protection from heat and winds (pers. obs.).

VI. CONCLUSIONS

The relationship between birds and their landscape can be observed in the diversity of their nesting behaviors. Some birds burrow tunnels into riverbanks (Ali et al. 2010), create elaborate tunnels on isolated arctic islands (Hornung 1982), or build large mounds of soil and decomposing vegetation to incubate their eggs (Collias 1964). Methods of nesting are not simply a reflection of certain species innate behaviors but as a convergent evolution between bird species that occupy similar landscapes (Collias 1964).

The action of moving and mixing soil can have implications on the fertility, grain size distribution, and erosion of the landscape (Wilkinson et al. 2009). The action of transporting sediment from one area to another creates impressions in which seeds and organic material can accumulate (Eldridge et al. 2012). In arid and semi-arid areas, this transfer of sediment and nutrients can have large scale implications (Eldridge et al. 2012).

In this study, both alternate hypotheses are accepted. The first alternate hypothesis is that the Barn Swallows are active in sediment transport in WSNM; this hypothesis is accepted because the presence of Barn Swallow nests were observed and measured. The second alternate hypothesis is that Barn Swallows utilize resources provided by the Visitor Center. Picnic structures farther in the dune fields provide similar resources as the Visitor Center, sans water and mud sources. Barn Swallows were only found to colonize the Visitor Center and were not evident in the picnic structures. The lack of water and mud sources could be the driving factor in the absence of Barn Swallows in the dunes,

and the abundance of water and mud sources could be a major factor in the presence of Barn Swallows around the Visitor Center.

Nest mass

Barn Swallows in White Sands National Monument, NM, were found to have moved a minimum of 17.08 kg (37.67 lbs.) of sediment for nest construction of the current colony. The age of the nest and imprints was not determined, and WSNM personnel claim to not destroy nests at any time, thus making the aging of nests outside the scope of this study. The mass only accounts for the nests found around the immediate vicinity of the Visitor Center (n=13) and does not include any nests that could be located on the administration buildings nearby. In addition, evidence of previous nests (imprints; n=5) exists that have since been destroyed that were not included in the total colony mass calculation.

Evidence of introduced sediments, such as quartz sand, into the native garden was apparent. For this reason, it is assumed that the Barn Swallows are not using a sediment that contains only gypsum, but a 1:1 ratio of gypsum and other moved earth sources. Therefore, the total mass of gypsum sand moved by this colony of barn swallows is 8.54 kg (18.84 lbs).

As the population of Barn Swallows grows, so will the geomorphic impact of their nesting behaviors. For example, if the population grows to 15, 25, 50, or 100 breeding pairs, the total mass of sediment transported for nest construction is estimated to

be 19.71 kg (43.46 lbs.), 32.86 kg (72.44 lbs.), 65.71 kg (144.88 lbs.), or 131.43 (289.75 lbs.) respectively. In addition, Barn Swallows were found to fortify previously existing nests and could further increase their sediment transport. The status of the population of Barn Swallows occupying the Visitor Center has yet to be determined; further study into population declines or increases is advised.

Energy expenditure

Each of the Barn Swallow nests of WSNM were estimated to contain close to 1,700 individual pellets of mud. Barn Swallows can only carry one pellet in their beak at one time and will make many trips from the mud source site to the nesting site (Tsikalas and Butler 2015). The effort of nest building could be counteracted by the ease of access to mud sources. A water filling station and water pump are found in the southern courtyard of the Visitor Center and are open for the public to use. Both the filling station and water pump have soil nearby that can easily become saturated and suitable for Barn Swallow nests. Although the area experiences monsoon-like summer thunderstorms, the barn swallow breeding season precedes the rain by three months. The artificial sources of water for nest building may allow for better and more efficient nest building strategies for this population of Barn Swallows.

Resources provided by Visitor Center

Barn Swallows have adapted to living close to humans, and therefore have experienced human mitigated range expansion and are widespread (Gurley and Kopachena 2015). In addition, Barn Swallows are a generalist species and can utilize a wide variety of landscapes (Henderson et al. 2007). Barn Swallows inhabiting the Visitor Center of WSNM are aided by the following resources located by this study: water and mud sources, foraging sites, shelter from harsh climatic conditions, and protection from predators.

Water and mud sources. Two artificial sources of water and mud were in the southern courtyard of the WSNM Visitor Center: a water filling station and a water pump. Both were used continuously by visitors at all times of the day. With each use, water would spill onto the ground and into the adjacent native garden. The input of water into the native garden allowed for mixing between the water and soil with intermediate organic material and other allogenic earth materials (quartz sand), thus creating suitable mud for nesting Barn Swallows. The presence of supplied earth materials and water may be a vital source of adequate mud for the Barn Swallows to use. Given the lack of Barn Swallows further into the dunes even though structures exist that may be suitable for nest building, the presence of water and differing mud mixtures may be the essential resource that leads to Barn Swallow colonization in this arid environment.

Foraging sites. Barn Swallows were observed to utilize three areas within 400 meters of the Visitor Center. These areas contained evenly spaced vegetation with plant species adapted to arid environments, such as Four-wing Saltbush (*Atriplex canescens*). Barn Swallows were observed to use these areas in addition to fences as perching sites for preening, singing, and courtship displays.

The presence of small bushes and some woody vegetation can increase the abundance of insect prey (Cody 1981). The relatively flat fields, loose gypsum soils, and evenly distributed vegetation of the three foraging areas adjacent to the Visitor Center may provide adequate opportunities for insects in this arid environment (Hingrat et al. 2007). Barn Swallows were observed to fly over the three areas between 1-8 meters high. Barn Swallows in low flight were assumed to be aerially feeding, as the optimum feeding height for Barn Swallows has been determined as 0.3-2 meters above the ground (Turner 1982). High flights of the Barn Swallows were observed during a period of hefty wind speeds and were assumed as escape flights from the drafts. Although studies have shown that Barn Swallows favor agricultural and farmland (Ambrosini et al. 2002a), arthropod abundance may be enough to sustain this population. Alternatively, given the ease of access to adequate nesting material, energy that would otherwise be expended on nest building could be transferred to foraging instead.

Shelter from climatic conditions. Barn Swallows use the Visitor Center building structure to their advantage. By orienting their nests N to NE, the walls and eaves of the

roof provide protection from the strong S to SW winds. The adaptive behavior of orienting a nest for a more favorable microclimate is seen in desert birds, such as the Desert Lark (Hartman and Oring 2003). The aggregation of nests in the courtyard provides evidence for the use of the building architecture and orientation by Barn Swallows as protection from the strong winds. In addition, the roof of the Visitor Center reduces the amount of solar radiation that reaches the nest and can help to regulate the temperature of the nest to a suitable range rather than experience high diurnal air temperatures of harsh environments (Hartman and Oring 2003).

Protection from predators. Nest predation is among the leading cause of nest failures and varies in both large and micro-scale of nesting sites (Ringhofer and Hasegawa 2014). The elevation of nests has been found to be efficient for protection from non-avian predators, such as snakes (Collias 1964). The WSNM Barn Swallows were found to build their nests <5 cm from the roof of the Visitor Center and this accounted for only 5% of the total height of the Visitor Center walls. This aligns with a previous study in which Barn Swallows nested just below the ceilings, accounting for 5-8% of the total height of farming buildings in Denmark (Møller 1983).

Ringhofer and Hasegawa (2014) found that crows would predate less on Barn Swallow nests that were near the presence of people. WSNM reported a total of 528,425 visitors in 2016 (NPS 2017) and averaged 43,710 visitors per month between the years 1988-2016 (NPS 2017). WSNM receives around 72% of its annual visitors during the

Barn Swallow breeding season (March-September). The proximity of WSNM Barn Swallows to humans and the high placement of nests may lessen the predation pressure of both avian and non-avian predators.

Competition. Given that the Barn Swallows are utilizing resources provided anthropogenically, competition between Barn Swallows and native desert birds of the region may be unfair. The Cactus Wren is an insectivorous scrub-specialist species (Crooks et al. 2001) and the human mitigated range expansion of generalist species, such as the Barn Swallows, could have harmful effects on this resident bird in WSNM. Anthropogenic resources given to the generalist species (nesting habitat, protection from predators, etc.) may increase their population and could lead to higher aggression between the species (Cody 1981).

Climate change

The worldwide warming trend caused by climate change has provoked alterations in environmental selection pressures and subsequent adaptive behaviors of birds (Visser et al. 2009, Karell et al. 2011). Shortening of migration routes (Ambrosini et al. 2011b), discrepancies in the fitness of first and second broods (Møller 2002), and overall declines of bird populations because of a discrepancy between the peak food abundance and breeding regimes (Both et al. 2006) have all been tied to changes in the climate.

Many birds in arid regions use rainfall as a cue for breeding initiation (Lloyd 1999). Variance in weather patterns brought on by climate change, such as longer drought periods and pulsed inputs of rainfall events (IPCC 2007), may cause unreliable cues for birds in arid environments. Migratory birds may be particularly impacted by shifting environmental cues by relying on the temperament of their wintering grounds to accurately convey the conditions of their breeding grounds that can be up to 20,000 km apart (Egevang et al. 2010).

The increasing unreliability of environmental cues for breeding times can cause disparity in the overall fitness of birds from one year to the next (Bildstein et al. 1992). Droughts can cause a reduction of food supply and can cause major declines in bird populations from one year to the next (Bildstein et al. 1992). Large bird populations may be able to withstand the boom and bust fluctuations over time, however threatened and/or endangered birds may not. In this study, only 13 intact Barn Swallow nests were located around the Visitor Center. Given the growing intensity of arid-land drying and heat intensity (Iknayan and Beissinger 2018), the status of this population of Barn Swallows cannot be fully determined without continued study.

Climate change is causing an expansion of desert and arid lands (Iknayan and Beissinger 2018). Generalist species, such as the Barn Swallow, may easily adapt to this as long as their minimum needs are met, such as free-standing water (Fischer et al. 1972). In the case of the WSNM Barn Swallows, many resources are found within 400 meters of their nesting site and provide a distinct advantage to overcoming the harsh conditions of

the desert. Desert birds are closely linked to their environment (Iknayan and Beissinger 2018), and although expansion of arid lands may extend their range, introduction of generalist species could cause severe competition for resources.

Final remarks

This study provides substantial opportunities for future investigations on Barn Swallows in WSNM as well as other locations. The introduced formula for deriving the mass of Barn Swallow nests from the nest dimensions allows for passive examination of their geomorphic impact on the landscape. The formula for calculating an estimated number of pellets per nest can be used as a variable for effort put into nest building by Barn Swallow breeding pairs. The geomorphic impact of Barn Swallow nests and the effort put towards nest building may vary from this desert population and other regions and is deserving of comparative studies. Understanding differences between nest architecture and placement of Barn Swallow nests worldwide can provide information into how Barn Swallows are active geomorphic agents and how they modify and utilize their environment in both micro- and macro-scales (Warning and Benedict 2015).

This research was limited by the lack of knowledge of this population of Barn Swallows. A full investigation into the overall fitness of the WSNM Barn Swallows is needed to determine the status of the WSNM Visitor Center as a beneficiary source site of resources or as an “ecological trap” (Battin 2004) for Barn Swallows. Topics such as number of eggs per clutch, differences between first and second broods, migration routes

and timing, the effect of insect abundance and precipitation patterns on Barn Swallow fitness, and potential competition between the Barn Swallows and other bird species in the area are promising topics for further investigations. This population of Barn Swallows is deserving of study over a period longer than three days in order to understand the population dynamics and overall fitness of desert-dwelling Barn Swallows.

The Barn Swallows of WSNM are unique and may provide insight into the shifting patterns of birds worldwide in the context of climate change. The introduction and advancement of a generalist species into an arid environment could have serious repercussions on the established assemblage of desert birds in this region. Shareholders in arid regions may use this study to make informed decisions on how to preserve bird communities and support the complexities and diversity of the sensitive arid environment, such as the conservation of riparian ecosystems within arid environments (Trammell et al. 2011).

APPENDIX SECTION


Overview of previous studies featuring the Barn Swallow. Barn Swallows are well-known in many areas and are continually used as a focal species on diverse topics. Note the lack of studies using Barn Swallows in a desert environment.

| Study title | Study topic and/or provided keywords | Study area | Citation |
|--|---|--|--------------------------|
| The distribution and colony size of barn swallows in relation to agricultural land use | Abundance, breeding ecology, conservation, management | N. Italy | Ambrosini et al. 2002a |
| Latency in response of barn swallow <i>Hirundo rustica</i> populations to changes in breeding habitat conditions | Abundance, breeding ecology, conservation, distribution, historical data, latency, livestock farming, population trends | N. Italy | Ambrosini et al. 2002b |
| Environmental effects at two nested spatial scales on habitat choice and breeding performance of barn swallow | Breeding habitat choice, cross-fostering, hierarchical linear models, parental effects | N. Italy | Ambrosini and Saino 2010 |
| Higher degree-days at the time of breeding predict size of second clutches in the barn swallow | Degree-days, ecological mismatch, fecundity, phenology, thermal delay | Kraghede, Denmark | Ambrosini et al. 2011a |
| Climate change and the long-term northward shift in the African wintering range of the barn swallow <i>Hirundo rustica</i> | Bird migration, connectivity, EURING swallow project, phenology, wintering range | Data from European Union for Bird Ringing Data Bank (2008) | Ambrosini et al. 2011b |
| Seasonal, meteorological, and microhabitat effects on breeding success and offspring phenotype in the barn swallow, <i>Hirundo rustica</i> | Immunocompetence, livestock farming, nesting quality, seasonal trends, temperature | N. Italy | Ambrosini et al. 2006 |
| Linking agricultural practice to insect and bird populations: a historical study over three decades | Farming, farmland, generalized additive models, population trends, suction trap | Scotland | Benton et al. 2002 |
| Clock gene variation is associated with breeding phenology and maybe under directional selection in the migratory barn swallow | Photoperiod response, gene, Clock orthologues, breeding phenology | N. Italy | Caprioli et al. 2012 |
| Fitness loss and germline mutations in barn swallows breeding in Chernobyl | Mutations, partial albinism, loss of fitness | Chernobyl, Kanev, and Italy | Ellegreen et al. 1997 |

| | | | |
|---|--|---|--------------------------------|
| Effects of crop type and aerial invertebrate abundance on foraging barn swallows <i>Hirundo rustica</i> | Agricultural intensification, cereal, farmland, grassland management, invertebrates, silage | Oxfordshire, England | Evans et al. 2007 |
| Influence of climate on annual survival of Barn Swallows (<i>Hirundo rustica</i>) breeding in North America | Aerial insectivore, El Nino Southern Oscillation, long-distance migration, mark-recapture data, North Atlantic Oscillation, survivorship | Ontario, Canada and Seattle, Washington | Garcia-Perez et al. 2014 |
| Fitness consequences of pre- and post-fledging timing decisions in a double-brooded passerine | Family breakup, mark-recapture models, parental care, post-fledging survival, radio telemetry, selection, timing of reproduction | Switzerland | Grüebler and Naef-Daenzer 2008 |
| The reproductive benefits of livestock farming in barn swallows <i>Hirundo rustica</i> : quality of nest site or foraging habitat? | Aerial insectivores, annual reproductive output, cattle-farming, high elevation, indoor breeding, micro- and macro-habitat, multi-broodedness, nestling survival, timing of breeding | Switzerland | Grüebler et al. 2010 |
| Reproductive success of synoptic nesting barn swallows and cave swallows in Northeastern Texas | Reproduction success, distribution | NE Texas, USA | Gurley and Kopachena 2015 |
| Infanticide on a grown nestling in a sparse population of Japanese barn swallows (<i>Hirundo rustica gutturalis</i>) | Infanticide, nest site, resource competition | Kanagawa Prefecture, Japan | Hasegawa and Arai 2015 |
| Arrival and progression of the swallow <i>Hirundo rustica</i> through Britain | Arrival date, migration | The Royal Meteorological Society phenological reports of Britain, 1875-1947 | Huin and Sparks 1998 |
| Glucocorticoid response to food availability in breeding barn swallows (<i>Hirundo rustica</i>) | Body condition, corticosterone, reproductive investment, weather | Switzerland | Jenni-Eiermann et al. 2008 |
| Hatching asynchrony and growth trade-offs within barn swallow broods | Compensatory growth, growth trade-offs, hatching asynchrony | Cumbria, UK | Mainwaring et al. 2009 |
| North Atlantic Oscillation (NAO) effects of climate on the relative importance of first and second clutches in a migratory passerine bird | Body condition, breeding success, demography, immune response, phytohemagglutinin, population dynamics | Kraghede, Denmark | Møller 2002 |
| Long-term trends in wind speed, insect abundance and ecology of an insectivorous bird | Body mass, breeding success, food availability, insects, survival rate | Kraghede, Denmark | Møller 2013 |

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|---|--|---|-----------------------------|
| Male tail streamer length does not predict apparent or genetic reproductive success in North American barn swallows <i>Hirundo rustica erythogaster</i> | Social monogamy, sexual selection, reproductive success, sexual dimorphism | Tompkins County, New York | Neuman et al. 2007 |
| Social cues are preferred over resource cues for breeding-site selection in Barn Swallows | Habitat selection, nest predation, old nest | Niijima, Shikinejima, and Kouzushima islands near Japan | Ringhofer and Hasegawa 2014 |
| Replacement of body feathers is associated with low pre-migratory energy stores in a long-distance migratory bird, the barn swallow | Moult, migration, energy stores, fueling | Italy | Rubolini et al. 2002 |
| Nest building is sexually selected behavior in the barn swallow | Nest building, parental investment, sexual selection | Badajoz, Spain | Soler et al. 1998a |
| Nest building, sexual selection and parental investment | Nest building, parental investment, sexual selection, signal | Secondary sources | Soler et al. 1998b |
| State-dependent behavior in breeding barn swallows (<i>Hirundo rustica</i>): Consequences for reproductive effort | Body state, energy, trade-offs, reproduction, life-history theory | Stirling, Scotland | Spencer and Bryant 2002 |
| Geomorphic impacts of mud-nesting swallows in Central Texas | Avian, biogeomorphology, birds, mud nest, zoogeomorphology | San Marcos, Texas, USA | Tsikalas and Butler 2015 |
| Barn swallows <i>Hirundo rustica</i> form eggs mainly from current food intake | Food intake, egg production, aerial insectivore | Central Scotland | Ward and Bryant 2006 |

Field work permit provided by White Sands National Monument.

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|  <p align="center">SCIENTIFIC RESEARCH AND COLLECTING PERMIT</p> <p align="center">Grants permission in accordance with the attached general and special conditions</p> <p align="center">United States Department of the Interior National Park Service White Sands</p> | <p>Study#: WHSA-00078 Permit#: WHSA-2019-SCL-0004 Start Date: Apr 02, 2019 Expiration Date: Dec 31, 2019 Coop Agreement#: Optional Park Code: WHSA</p> |
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| <p>Name of principal investigator: Name: Mrs Aidan McLendon Phone: 5126531493 Email: amccollough14@gmail.com</p> |
| <p>Name of institution represented: Texas State University - San Marcos</p> |
| <p>Additional investigators or key field assistants:</p> |
| <p>Study Title: Geomorphic Impacts of Barn Swallow Nests in the Desert Environment of White Sands National Monument, New Mexico.</p> |
| <p>Purpose of study: The focus of this present research is to quantify the volume of sediment moved by barn swallows for their nest construction and to determine if their settlement in White Sands National Monument is promoted by resources provided by the Visitor Center.</p> |
| <p>Subject/Discipline: Birds / Ornithology</p> |
| <p>Locations authorized: Visitor center.</p> |
| <p>Transportation method to research site(s): Vehicle to visitor center parking area, and foot during field work.</p> |
| <p>Collection of the following specimens or materials, quantities, and any limitations on collecting:</p> |
| <p>Name of repository for specimens or sample materials if applicable:</p> |
| <p>NPS General Conditions for Scientific Research and Collecting Permit (available at the RPRS HELP page) apply to this permit. The following specific conditions or restrictions, and any attached conditions, also apply to this permit: Copies of final reports, thesis, dissertation, and/or publications must be submitted to: White Sands National Monument, Attn Resource Management, POB 1086, Holloman AFB, NM 88330.</p> <p>A copy of the approved research/collection permit must be in possession at all times in the field.</p> <ol style="list-style-type: none"> 1. You are responsible for the research-related activities of your staff. Please ensure that all field staff adhere to all conditions of your permit. Field staff must possess a copy of your permit at all times while in the field. 2. You are required to notify the monument's research coordinator TWO WEEKS in advance of your trip, and advise them of your planned activities. Each week you will be required to completed the attached Back Country Travel Plan and submit the plan to the research coordinator and others assigned prior to conducting research activities. Once working in the park, report all emergencies by calling 911. 3. Unless otherwise authorized on your permit, you must carry out all of your activities out of public view. If you have obtained special permission to collect in front-country areas, you may be required to arrange for a uniformed escort. 4. If you collect specimens that are to be permanently retained, regardless of where they are kept, they must be accessioned and cataloged into the National Park Service's Automated National Catalog System, and must bear National Park Service accession and catalog numbers. 5. All equipment left in the field including plot markers must be specifically authorized in advance. Label all equipment with your name, date of installation, phone number, and the words "Research Study #XXXX." If you are authorized to place equipment or plot markers at White Sands, you will be required to GPS their locations. |

6. Specific authorization must be obtained in advance before using chemicals or hazardous materials at White Sands. For specific information regarding the transport, use, and disposal of chemicals or hazardous materials, please contact the monument's research coordinator.

7. Cultural resources must not be adversely impacted by your research activities. Any ground disturbances must be specifically authorized in advance. Report any findings of artifacts such as lithic scatters or historical trash to the Research Permit Officer.

8. The Permittee agrees to notify the Superintendent of White Sands National Monument of every subject discovery or invention that relates in any respect to research results derived from use of any research specimens or other materials collected from White Sands National Monument, or that may be patentable or otherwise protected under the intellectual property (IP) laws of the United States or other jurisdiction. Notification must occur within sixty (60) days of the time that an inventor or other agent of the Permittee reports such a subject discovery or invention to the person(s) responsible for patent or other proprietary rights matters in the Permittee's organization, and in no case not less than sixty (60) days before a patent application is filed. Additionally, the Permittee agrees to notify the Superintendent of White Sands National Monument within thirty (30) days of filing any patent application or other IP claim in the United States or other country that relates in any respect to research results or other discoveries or inventions derived from use of any research specimens or other materials collected from White Sands National Monument. For purposes of this paragraph, the term "subject discovery or invention" means any discovery or invention related to or derived from research specimens or other materials collected from White Sands National Monument. All invention disclosures shall be marked as confidential under 35 U.S.C. Section 205.

09. Your permit does not authorize the bearer or those that accompany them to conduct commercial filming activities. Commercial film permits must be obtained from the monument's film coordinator.

10. EACH YEAR, INVESTIGATORS ARE REQUIRED TO SUBMIT COPIES OF JOURNAL ARTICLES, THESES, AND DISSERTATIONS THAT ARE DERIVED FROM THE RESULTS OF WHITE SANDS RESEARCH. THE PARK REQUESTS THAT YOU SUBMIT ARTICLES IN PDF FORMAT AND THAT ONE BOUND COPY OF EACH DISSERTATION/THESIS IS SUBMITTED.

Recommended by park staff(name and title):

Approved by park official:

Title:

Superintendent

Reviewed by Collections Manager:

Yes _____ No _____

Date Approved:

I Agree To All Conditions And Restrictions Of this Permit As Specified
(Not valid unless signed and dated by the principal investigator)

(Principal investigator's signature)

(Date)

THIS PERMIT AND ATTACHED CONDITIONS AND RESTRICTIONS MUST BE CARRIED AT ALL TIMES WHILE CONDUCTING RESEARCH ACTIVITIES IN THE DESIGNATED PARK(S)

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