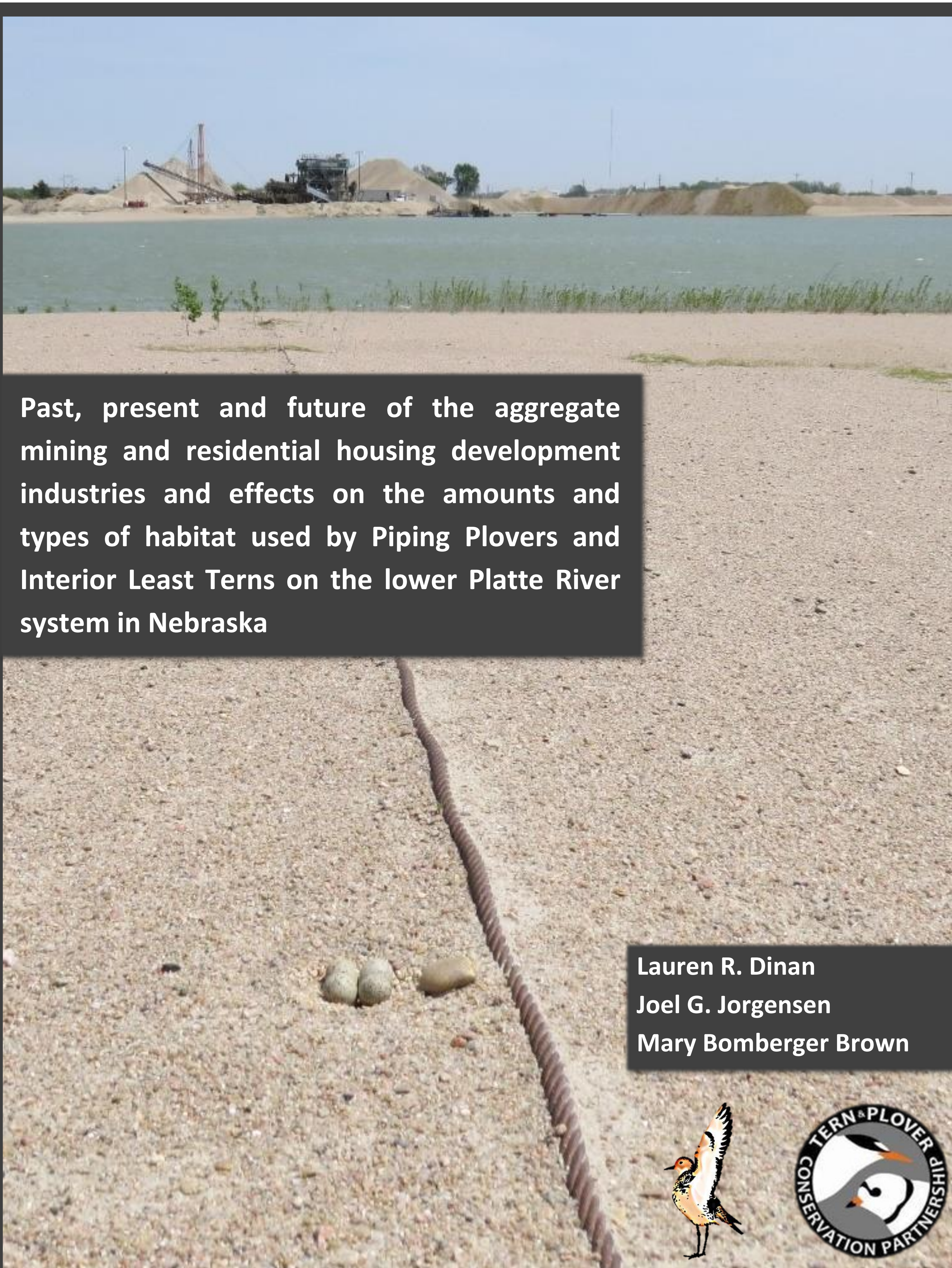

Past, present and future of the aggregate mining and residential housing development industries and effects on the amounts and types of habitat used by Piping Plovers and Interior Least Terns on the lower Platte River system in Nebraska

Lauren R. Dinan
Joel G. Jorgensen
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Unless otherwise noted, all photographs by Lauren R. Dinan.

INTRODUCTION

Humans have influenced the type, amount, and spatial distribution of nesting habitat used by Piping Plovers (*Charadrius melodus*; hereafter, plovers) and Interior Least Terns (*Sternula antillarum athalassos*; hereafter, terns) in Nebraska for more than a century. Historically, terns and plovers breeding in the interior of the United States placed their nests on midstream river sandbars and shorelines of natural water bodies (Thompson et al. 1997, Elliott-Smith and Haig 2004). Since settlement by European Americans, the environment has been modified in ways that have reduced habitats used by terns and plovers in some areas and created, intentionally and incidentally, habitats used by terns and plovers in other areas. Alterations of large river systems, such as the Missouri and Platte, have greatly reduced availability of river sandbar nesting habitat in those systems and contributed to the federal listing of both species under the Endangered Species Act (ESA; 7 U.S.C. § 136, 16 U.S.C. § 1531 et seq.). Nesting habitat has been created as a result of the mining of sand and gravel (aggregate) and associated creation of sandpit lakes along these river systems. The amount and types of tern and plover nesting habitat continues to evolve and is influenced by numerous variables.

The first known instances of terns and plovers nesting at off-river sandpit lakes in Nebraska occurred in 1920 (terns) and 1922 (plovers) at Capitol Beach Lake near Lincoln, Lancaster County, Nebraska (Pickwell 1925, Ducey 1985). Both of these nesting records occurred on a strip of sandy beach on the south side of natural wetland (Chester Basin) that that was dredged. The dredging operation created a large sloping beach of sand and gravel which provided habitat for nesting terns and plovers (Pickwell 1925, Ducey 1985). Over the years these sorts of off-river sandpit lakes have become the primary nesting habitat for terns and plovers nesting along the lower Platte River, with river sandbars providing nesting habitat only during years when suitable sandbar habitat is present. From 2008 – 2017, 87% of plover nests and 74% of tern nests along the lower Platte River occurred on off-river sandpit lakes (Nebraska Game and Parks Commission and Tern and Plover Conservation Partnership, unpublished data). During this 10-year period, 54% of the plover nests and 33% of the tern nests that were recorded on river sandbars were found in 2009 (note: survey intensity was variable during the 10-year period), a year when a number of high quality river sandbars were created due to a high flow event that occurred in May and June of the previous year (2008).

Local and regional economic conditions influences the number, spatial distribution, and status of off-river sandpit lakes. The landscape of the Platte River Valley is punctuated by manmade lakes that were created by sand and gravel mining and dredging operations. Aggregate mining (sand and gravel) is considered an essential, strategic national defense industry and is an important part of the Nebraska and U.S. economies. In 2015 alone, there were 153 active sand and gravel mining operations and processing plants and 49 active dredging operations in Nebraska (U.S. Geological Survey, unpublished data). Over 12.6 million metric tons of construction quality sand and gravel, with a value of over $90 million, were sold or used by producers in Nebraska in 2015 (U.S. Geological Survey, unpublished data). The major uses for construction quality sand and gravel are concrete, asphalt, road base and coverings, fill sand and gravel, snow and ice control, and flood control (U.S. Geological Survey 2016). The lifespan of a sand and gravel mine is finite and once mining ceases the mines are generally repurposed. A number of mines and the associated sandpit lakes have been reclaimed into lakeshore housing developments, parks, and state wildlife and recreation areas (Moak 1999); others have been reclaimed and are used as agricultural fields. The conversion of post-production mines into lakeshore housing developments is expected to continue. Recently, the U.S. Department of Housing and Urban Development reported that the housing market is tight and that demand for 10,050 new homes to be constructed in the next three years is expected (U.S. Department of Housing and Urban Development 2017). The Omaha World-Herald reported that the number of permits issued to build new housing in greater Omaha-Council Bluffs metropolitan area rose 8% in 2017, which is the highest level in a decade (Gonzalez 2018); lakeshore housing developments contributed to this tally.

While sand and gravel mines are an important part of the Nebraska and U.S. economies by producing millions of metrics tons of aggregate, they are also an important driver of landscape level change that creates and maintains nesting habitat for terns and plovers. Sand and gravel mines are, with increasing frequency, being converted to lakeshore housing developments after aggregate extraction has been completed. The majority of the off-river nesting sites along the lower Platte River began as sand and gravel mines. However, a few nesting sites were never functioning mines, but rather were dredged for the sole purpose of creating a sandpit lake for a residential housing development. While these off-river sandpit lakes are relatively stable when compared to the dynamic river sandbars, the amount of available tern and plover nesting habitat does change over time. The conversion of a sand and gravel mine into a lakeshore housing development usually extends the span of time in which a site provides nesting habitat appropriate for use by nesting terns and plovers. The increasing demand for new home construction suggests that sand and gravel mines will continue to transition to lakeshore housing developments well into the future. When a sand and gravel mine is abandoned the site may provide suitable tern and plover nesting habitat for additional years but these sites eventually become colonized by vegetation and no longer possess suitable habitat. Sand and gravel mines that are filled in with soil after mining is complete and reclaimed for agriculture no longer possess suitable tern and plover nesting habitat.

The amount, spatial distribution, and duration of nesting habitat provided at off-river sites is determined mostly by industry economics. Mining practices, though, are evolving with the development of new technologies and innovations. As of this writing, little or no attention has been directed to questions regarding how evolving mining practices will affect the number, type, and size of sites that provide suitable tern and plover nesting habitat and how those changes will affect species' numbers. To address these questions, there needs to be a better understanding of how sand and gravel mines function today and how mining practices could change as technology continues to advance and the industry finds ways to increase efficiency and productivity. The purpose of this study is to evaluate how the distribution of sand and gravel mines and lakeshore housing developments will change as mine sites are taken out of production and new mine sites are built further away from population centers and their associated markets. The results will improve our understanding of how changes in sand and gravel mining and dredging practices at off-river sandpit lakes will affect terns and plovers nesting habitat. These results have important implications for planning and implementation of actions intended to assist in the recovery of populations of terns and plovers at local and regional scales. Our specific objectives are as follows:

1) Evaluate past, current, and future sand and gravel mining practices at off-river sandpit lakes along the lower Platte river system in eastern Nebraska.
2) Investigate how different past, current, and future mining practices have affected or may affect tern and plover nesting habitat availability and use at off-river sandpit lakes.
3) Create science-based models to illustrate how trends in mining practices could affect terns and plovers.

The results of this study have broader implications pertaining to the recovery of the Northern Great Plains Piping Plover population and the Interior Least Tern population. Plovers originally captured and color banded along the lower Platte River are known to move between nesting sites along the lower Platte River and Missouri River between and within years (Hunt et al. 2014) forming a metapopulation. Thus, there is an interconnectedness between tern and plover populations on the lower Platte and other river systems that must be considered.

METHODS

Study Area

The study area includes tern and plover off-river nesting sites adjacent to the lower Platte River and a small portion of the Loup River in eastern Nebraska (Figure 1). Our study area extended from the Loup Power District Diversion (near Genoa, Nance County, Nebraska) 218km downstream to where the lower Platte River joins the Missouri River (near Plattsmouth, Cass County, Nebraska).

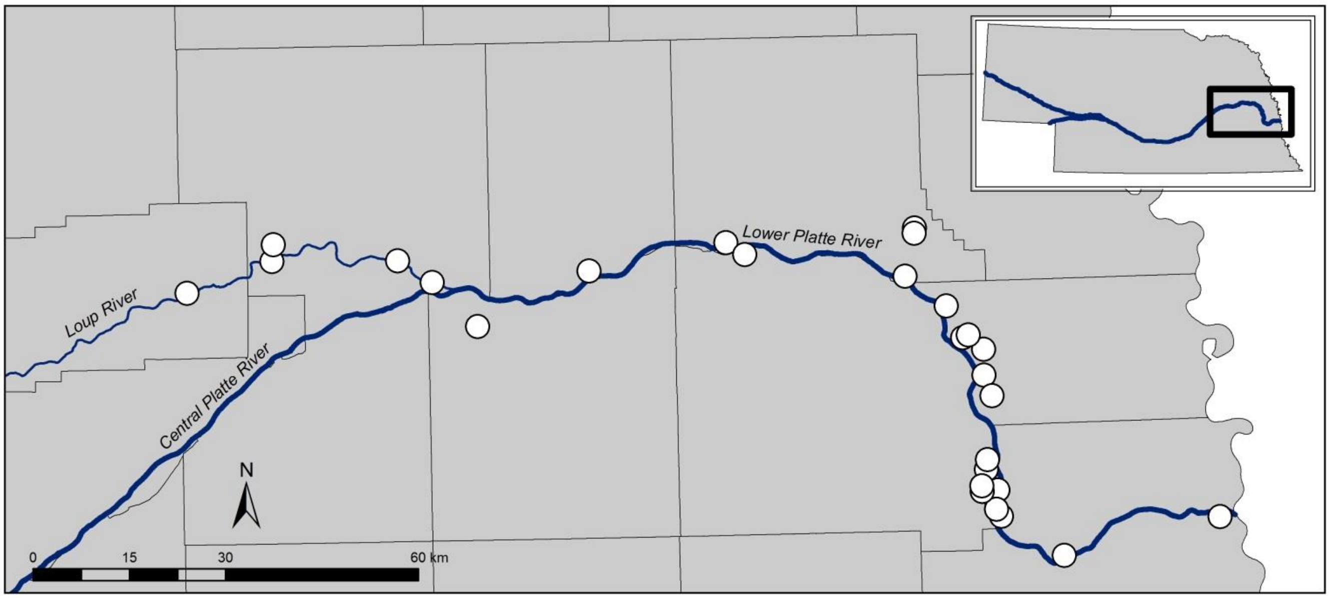

Figure 1. Map of our study area along the lower Platte River and a small portion of the Loup River. Off-river nesting sites are represented with white dots.

Study Species

Piping Plovers are migratory shorebirds that place their nest and eggs directly on the ground. The species was first described in 1824 from a type specimen collected in New Jersey (American Ornithologists' Union 1998). Meriwether Lewis and William Clark saw Piping Plovers, and recorded their observations in what was to become the state of Nebraska, during their 1803–1805 "Voyage of Discovery" across North America. The species was placed on the Endangered Species List on 10 January 1986 (50 Federal Register 50726–50734).

Interior Least Terns are swallow-shaped birds that are often seen in flight. They are colonial nesters that place their nest and eggs directly on the ground. The Least Tern was first described in 1847 from a type specimen collected in Guadeloupe, West Indies (American Ornithologists' Union 1998). Meriwether Lewis and William Clark recorded their first observation of an Interior Least Tern on 5 August 1804 along the Missouri River, near present day Omaha, Nebraska while on their 1803—1805 "Voyage of Discovery". The species was placed on the Endangered Species List on 27 June 1985 (50 Federal Register 21784–21792).

Adult Piping Plover. Photo by Joel Jorgensen

Adult Least Tern. Photo by Joel Jorgensen

Evaluation of Mining Practices and Off-River Sandpit Types

We conducted a literature review of sand and gravel mining practices across the Midwest of the United States and in Nebraska and evaluated the types of off-river sandpits within our study area. We categorized all off-river sandpits into six distinct site types: 1) active traditional open pit mines, 2) active modern open pit mines, 3) abandoned open pit mines, 4) active stream dredging mines, 5) lakeshore housing developments, and 6) transition sites (Figure 2). Active traditional open pit mines (traditional mines) and active modern open pit mines (modern mines) are both sandpit types actively mined by a sand and gravel mining company and regulated by the Mine Safety and Health Administration (MSHA). The difference between these two types of sand and gravel mines is primarily how waste sand is stored (Figure 3). Traditional mines store waste sand along the water's edge, forming large expanses of sandy shorelines. Modern mines only store waste sand for short periods of time before it is disposed. Abandoned open pit mines (abandoned mines) are no longer actively mined or regulated by MSHA. These mines have been taken out of production but have not been reclaimed. Active stream dredging mines (stream mines) pump sand and gravel out of a stream or river bed and deposit it nearby on land. This is a unique type of sand and gravel mine in which there is no open pit lake. Lakeshore housing developments (housing developments) are off-river sites usually managed by a homeowners association (HOA), with at least one house having homeowners in residence on the property. Transition sites are off-river sites no longer managed by a sand and gravel mining company and that does not have homeowners in residence on the property; transition sites are primarily managed by the real estate developer and are transitioning from a mine to a housing development. During the transition period, aggregate is redistributed, large areas are disturbed and other areas are shaped to be suitable for housing.

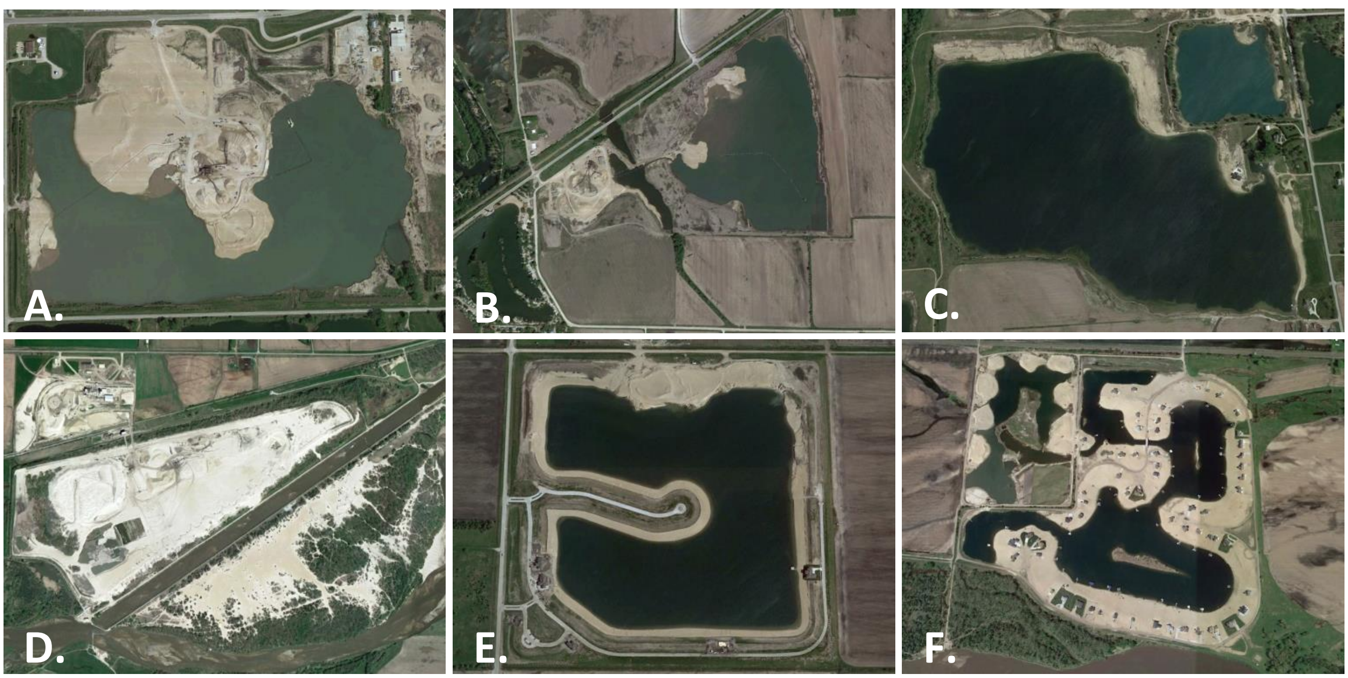

Figure 2. Aerial photos of the six distinct off-river nesting site types A) traditional mine, B) modern mine, C) abandoned mine, D) active stream dredging mines, E) transition sites, and F) lakeshore housing developments.

A) Traditional Mine (2012 - 2016)

B) Modern Mine (2012 – 2016)

Figure 3. A: shows the amount of exposed waste sand at a traditional mine near Valley, Dodge County, Nebraska from 2012 – 2016. B: shows the amount of exposed waste sand at a modern mine near Ashland, Saunders County, Nebraska from 2012 – 2016.

We used Google Earth (https://www.google.com/earth/) historical and current aerial imagery along with our sandpit database to determine the average number of years sand and gravel mines within our study area remained active and in production. We evaluated the average number of years suitable nesting habitat remained at a site after the mine is taken out of production, reclaimed or abandoned. We used Google Earth historical and current aerial imagery to summarize the total number of off-river sites with suitable nesting habitat within our study area each year from 1993 – 2016 for all sites combined and for each distinct site type. This summary included both monitored and unmonitored off-river sites with suitable tern and plover nesting habitat. We used linear regression and locally weighted scatter plot smoothing (lm) in R Studio (2015) to show the general trends in the number of potential off-river nesting sites within our study area each year from 1993 – 2016 for all sites combined and for each distinct site type. We defined potential off-river nesting sites as all off-river sites that appear to have expanses of suitable tern and plover nesting habitat when looking at Google Earth's aerial imagery. We did not include 2017 in this analysis since Google Earth does not have 2017 aerial imagery for our study area at the time of this writing. We used our tern and plover nest monitoring database to summarize the total number of monitored off-river sites within our study area each year from 2008 – 2016 for all sites and for each distinct site type.

Evaluation of Bird Use by Site Type

We used our tern and plover monitoring database, which includes all nest monitoring data from 2008–2017, to investigate how the different activities and practices at each distinct site type affect tern and plover use at off-river sites. We determined the total number of tern and plover nests at each distinct site type each year from 2008 – 2017. We then calculated the total average number of tern and plover nests per site and at each distinct site type each year from 2008 – 2017. Since there was only one active stream dredging mine in our study area, we excluded this site and site type from our summaries and analyses.

Projected Trends in Site Numbers and Bird Use over Time

We used the linear regression model created in R Studio (2015) showing general trends in the total number of potential off-river nesting sites within our study area from 1993 – 2016 to predict the total number of potential off-river nesting sites each year in the future out to 2050. The number of potential off-river nesting sites were predicted for each year using the linear equation ($y = mx + b$). We multiplied the predicted number of off-river sites each year by the average number of tern and plover nests per site per year to predict the total number of tern and plover nests along the lower Platte River study area each year from 2017 – 2050. We used the same methods described above to predict the total number of sites, tern nests, and plover nests at traditional and modern mines from 2017 – 2050. Linear regression models were not a good fit for abandoned mines, transition sites, and housing developments, so we used polynomial regression models. We were unable to predict the number of sites in the future using the polynomial regression models.

RESULTS

Evaluation of Mining Practices and Off-River Sandpit Types

<u>Literature Review of Sand and Gravel Mining Practices</u>

Sand and gravel deposits are the result of the erosion of bedrock and the subsequent transport, abrasion, and deposition of the material (Langer 1988). The principal geologic agents that affect the distribution of sand and gravel deposits are ice and water, but gravity and wind may also influence the formation of these deposits (Langer 1988). Large portions of the midwestern United States, including Nebraska, are covered with soft, semi-consolidated, sedimentary rocks (Langer 1988). Sand and gravel deposits found in Nebraska date back to the Paleogene Period of the Cenozoic Era (~66 million years ago; Condon 2005). In Nebraska, large sand deposits occur in the north-central part of the state (Sandhills ecoregion) with small deposits of gravel occurring haphazardly throughout the area (Woods and Lovell 1960). Sand and gravel deposits also are found along most of Nebraska's rivers. Along the Platte River Valley sand and gravel deposits are formed as rocks erode from the Rocky Mountains to the west and are transported across the landscape by streams and rivers (Condon 2005). As rocks are transported downstream, the tumbling motion causes them to break apart making sand and gravel which settles out of the moving water and forms the river bed. As river channels have moved across the landscape over time, sand and gravel deposits have been left behind throughout the Platte River Valley.

The two most important determinants of selecting a mine site are 1) the presence of accessible and useable sand and gravel deposits underlying the property and 2) the mine site's proximity to markets (Pit and Quarry 2016). The transportation of sand and gravel over great distances is costly and may be economically prohibitive, so it is important to place a site in close proximity to markets (e.g., near towns or cities, major roads, railroads, and future construction sites; Pit and Quarry 2016). Competitors' locations, permitting restrictions, and zoning laws or restrictions are also important variables in determining location of a mine site. Additional factors considered during the mine site selection process are the amount of overburden to be removed (material that lies above the sand and gravel deposit), thickness and amount of the sand and gravel within the deposit, the quality of the sand and gravel, and the presence of conflicting land uses (Fish 2001).

Sand and gravel are typically mined in moist or wet conditions by open pit excavation and dredging (U.S. Environmental Protection Agency 1995). Sand and gravel mining involves four main activities: 1) preparation, 2) extraction, 3) processing, and 4) shipping (Figure 4). Preparation is the removal and storage or disposal of the overburden; this includes the clearing of existing vegetation and stripping of the topsoil and other material that overlies the sand and gravel deposit (Buttleman 1992). Extraction is the removal of the sand and gravel from the site where it occurs (Fish 2001). Extraction includes excavating the sandpit lake using power shovels, draglines, front-end loaders, bucket wheel excavators, light blasting, and dredging (U.S. Environmental Protection Agency 1995). Processing is the preparation of the sand and gravel for its intended use (Fish 2001). Processing involves transportation, classification, product storage, and waste sand storage or disposal. After the sand and gravel is extracted the materials are transported to the processing plant by suction pump, belt conveyors, earth movers, trucks, or other means (U.S. Environmental Protection Agency 1995). The raw sand and gravel is put through a combination of sorters, screens, crushers, washers, and classifiers; after classification, the sand and gravel is dewatered. The classified sand and gravel is transported by elevators and conveyors to storage bins or is placed in individual size class stockpiles. Typically, more fine sand is produced than can be sold; this material is considered waste sand and is either disposed of or stored. Waste sand is stored along the water's edge, forming large expanses of sandy shorelines and creating tern and plover nesting habitat. The processed sand and gravel is most often shipped by trucks but may also be shipped by rail (USGS 2003).

After mining at a site is completely finished the final reclamation process begins. The goal of reclamation is to return the site to a beneficial use. The end points of reclamation can be variable and range from 1) filling in the lake and transitioning the site into a beneficial use such as cropland or 2) basic shoreline stabilization and transitioning the site and lake into a public recreation area, lakeshore housing development, etc. (Buttleman 1992). The proposed reclamation is generally included in the project mining plan prepared when the site is initially opened and describes a concept for the final end use of the site (Buttleman 1992). The proposed reclamation affects mining activities throughout the entire mining process from site preparation to shipping. With the reclamation concept in mind, mining activities such as clearing, stripping, stockpiling, waste sand storage and disposal, and landform construction are directed towards final reclamation (Buttleman 1992); some mine sites are not reclaimed and are abandoned as inactive sites.

Progressive reclamation promotes cost-effective disposal of waste materials including topsoil and waste sand (Buttleman 1992). The objective of progressive reclamation is to reclaim small sections of a site as soon as the sand and gravel is removed from those areas (Buttleman 1992). Progressive reclamation occurs over the life of the mining operation, being implemented as each mining stage is completed, rather than being carried out at the end of operations after the entire deposit has been extracted (Buttleman 1992). Modern mines implement progressive reclamation whereas traditional mines typically wait until mining is complete before implementing any reclamation activities. Progressive reclamation is thought to benefit wildlife more generally since many species require access to plant communities in varying stages of succession (Buttleman 1992). However, terns and plovers require a specific, early succession type of nesting habitat and progressive reclamation tends to decrease the amount and duration of availability of that specific nesting habitat (e.g., waste sand). If the expanses of waste sand along the shoreline of sandpit lakes are not present, then the site no longer offers suitable tern and plover nesting habitat.

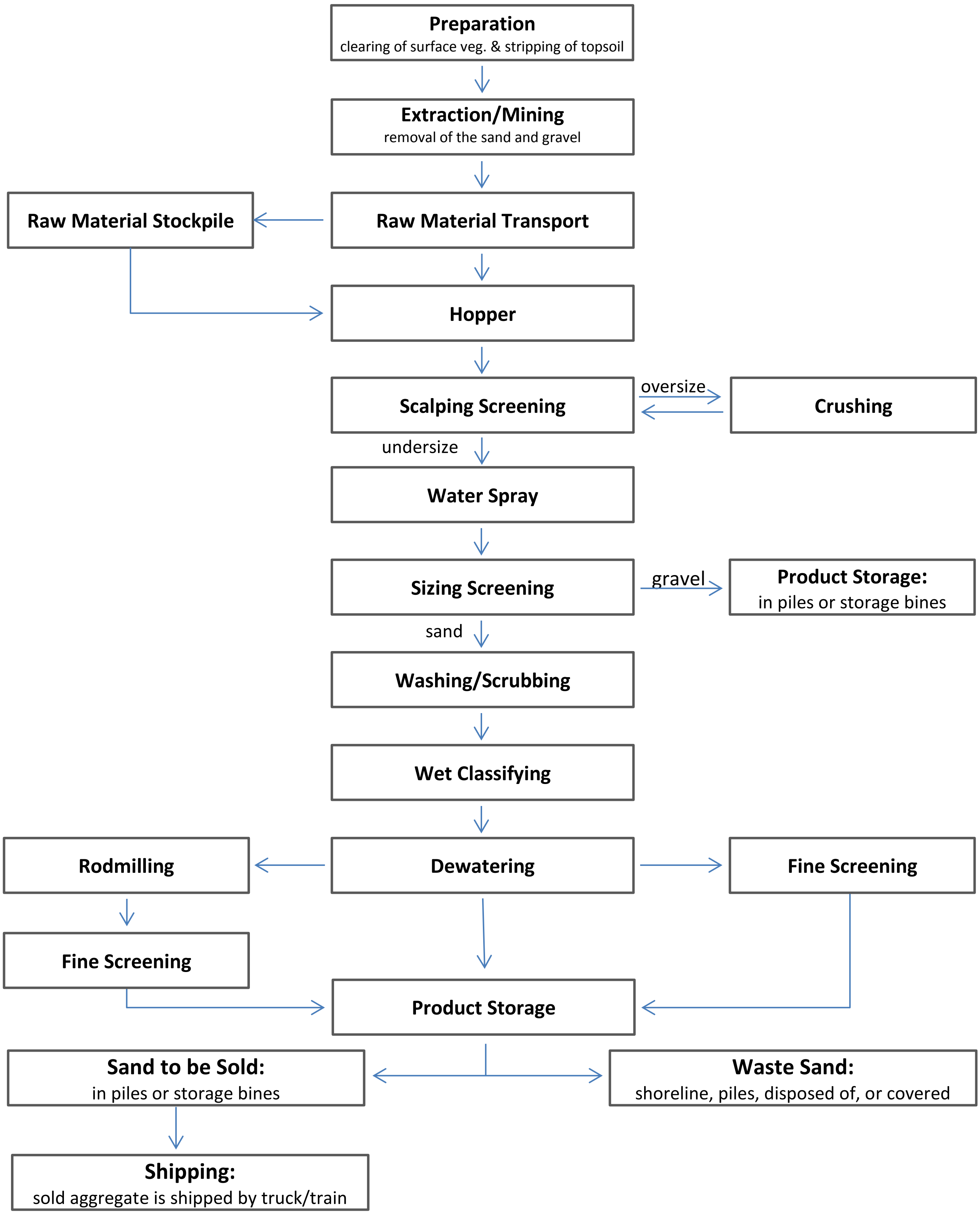

Figure 4. Basic flowchart showing the main stages of sand and gravel preparation, extraction, and processing (adapted from U.S. Environmental Protection Agency 1995).

Evaluation of the Types of Sandpits in our Study Area

Within our study area, all off-river nesting sites began as either traditional mines or modern mines with the exception of one active stream dredging mine. The difference between traditional mines and modern mines is the result of different mining practices and appears to also be linked to the reclamation plan and the application of progressive reclamation.

From year to year, a traditional or modern mine may: a) remain categorized in the same distinct site type, b) be taken out of production and left as an abandoned open pit mine, c) go out of production, be filled back in with top soil, and reclaimed for other purposes (e.g., agricultural uses, urban development, residential or recreational uses, etc.), or d) go out of production, be developed for housing, and change from a mine site to a transition site. An abandoned open pit mine typically remains categorized in the same distinct site type from one year to the next, but more vegetation colonizes and grows across the site reducing its suitability for nesting terns and plovers. Transition sites either 1) remain categorized in the same distinct site type or 2) change from a transition site to a lakeshore housing development. Each year lakeshore housing developments remain categorized in the same distinct site type, but more houses are built and more people take up residence reducing the amount of habitat and its suitability for nesting terns and plovers.

We found that the average life of an open pit sand and gravel mine in our study area is 21.8 years (95% CI: 17.58, 26.02; SE: ±1.97). When a mine is filled back in with top soil and reclaimed for other uses, the site goes from providing nesting habitat to no longer providing nesting habitat in a very short amount of time, generally less than a year. When a mine site is abandoned or is reclaimed as a lakeshore housing development the amount of time suitable nesting habitat remains at a site is extended for as little as two to as many as ten years, depending on the size of the site and the establishment of vegetation across the site. A site is categorized as a transition site for a short amount of time, usually from one to three years. All transition sites eventually become lakeshore housing developments and usually offer nesting habitat throughout the entire time the site is in transition. The amount of time suitable nesting habitat remains at a lakeshore housing development is variable and can range from five to sixteen or more years depending on the rate of home construction and how the site is maintained by property owners. Since there was only one active stream dredging mine in our study area, which has been present and operating for decades, we excluded this site and site type from our summaries and analyses.

From 1993 – 2016, there was an average of 47.1 (± 0.8) potential off-river nesting sites in our study area each year (Table 1, Figure 5). There was a 1% average annual decrease in the number of potential off-river nesting sites over this 24-year period. Active traditional mines had the highest number of sites per year with a mean of 23.7 (± 1.3). However, the number of active traditional mines decreased an average of 3% over the 24-year period. Lakeshore housing developments had the second highest number of sites per year with a mean of 8.9 (± 0.4). The number of lakeshore housing developments ranged from 5 to 12 and had a 1% average annual increase over this 24-year period. Abandoned mines had the third highest number of sites per year with a mean of 8.0 (± 0.7). The number of abandoned mines ranged from 3 to 14 and had a 2% average annual increase over this 24-year period. Active modern mines had the fourth highest number of sites per year with a mean of 5.0 (± 0.7). The number of active modern mines ranged from 1 to 11 and had a 13% average annual increase over this 24-year period. Transition sites had the lowest number of sites per year with a mean of 1.5 (± 0.3). The number of transition sites ranged from 0 to 4 and had a 10% average annual increase over this 24-year period (Table 1, Figure 6).

From 2008 – 2016, we monitored an average of 23.2 (± 1.2) off-river sites in our study area each year (Table 2). Active traditional mines had the highest number of sites monitored per year with a mean of 10.9 (± 0.6). Active modern mines and abandoned mines had the second highest number of sites monitored per year with a mean of 3.9 (± 0.4 and ± 0.6, respectively). Lakeshore housing developments had the third highest number of sites monitored per year with a mean of 3.6 (± 0.2). Transition sites had the lowest number of sites monitored per year with a mean of 1.2 (± 0.6).

Table 1. Number of potential off-river sites each year from 1993 – 2016 within each distinct site type.

Year	Traditional	Modern	Abandoned	Transition	Housing	Grand Total
1993	29	1	13	3	6	**52**
1994	31	1	12	2	8	**54**
1995	30	1	8	2	9	**50**
1996	29	1	9	2	8	**49**
1997	33	1	8	0	10	**52**
1998	33	1	6	1	10	**51**
1999	32	2	4	3	11	**52**
2000	30	3	3	3	7	**46**
2001	26	3	5	4	8	**46**
2002	26	3	6	1	11	**47**
2003	24	3	8	1	11	**47**
2004	23	4	4	0	10	**41**
2005	24	5	4	1	10	**44**
2006	23	5	5	1	11	**45**
2007	23	6	5	0	12	**46**
2008	21	8	6	1	11	**47**
2009	19	7	11	0	12	**49**
2010	18	8	12	0	11	**49**
2011	17	8	14	0	7	**46**
2012	18	8	14	0	7	**47**
2013	17	10	12	0	7	**46**
2014	16	10	8	2	6	**42**
2015	13	10	8	4	6	**41**
2016	13	11	8	4	5	**41**
Mean	**23.7**	**5.0**	**8.0**	**1.5**	**8.9**	**47.1**
SE	**1.3**	**0.7**	**0.7**	**0.3**	**0.4**	**0.8**
L 95% CI	**21.1**	**3.6**	**6.7**	**0.9**	**8.1**	**45.6**
U 95% CI	**26.2**	**6.4**	**9.4**	**2.0**	**9.8**	**48.6**

Table 2. Number of off-river sites monitored each year from 2008 – 2016 within each distinct site type.

Year	Traditional	Modern	Abandoned	Transition	Housing	Grand Total
2008	10	2	2	1	3	**18**
2009	9	2	3	0	4	**18**
2010	8	3	5	0	4	**20**
2011	10	4	6	0	4	**24**
2012	12	4	6	0	4	**26**
2013	14	5	5	0	4	**28**
2014	13	5	3	2	3	**26**
2015	11	4	2	4	3	**24**
2016	11	5	2	4	3	**25**
Mean	**10.9**	**3.8**	**3.8**	**1.2**	**3.6**	**23.2**
SE	**0.6**	**0.4**	**0.6**	**0.6**	**0.2**	**1.2**
L 95% CI	**9.6**	**3.0**	**2.7**	**0.1**	**3.2**	**20.8**
U 95% CI	**12.1**	**4.6**	**4.9**	**2.3**	**3.9**	**25.6**

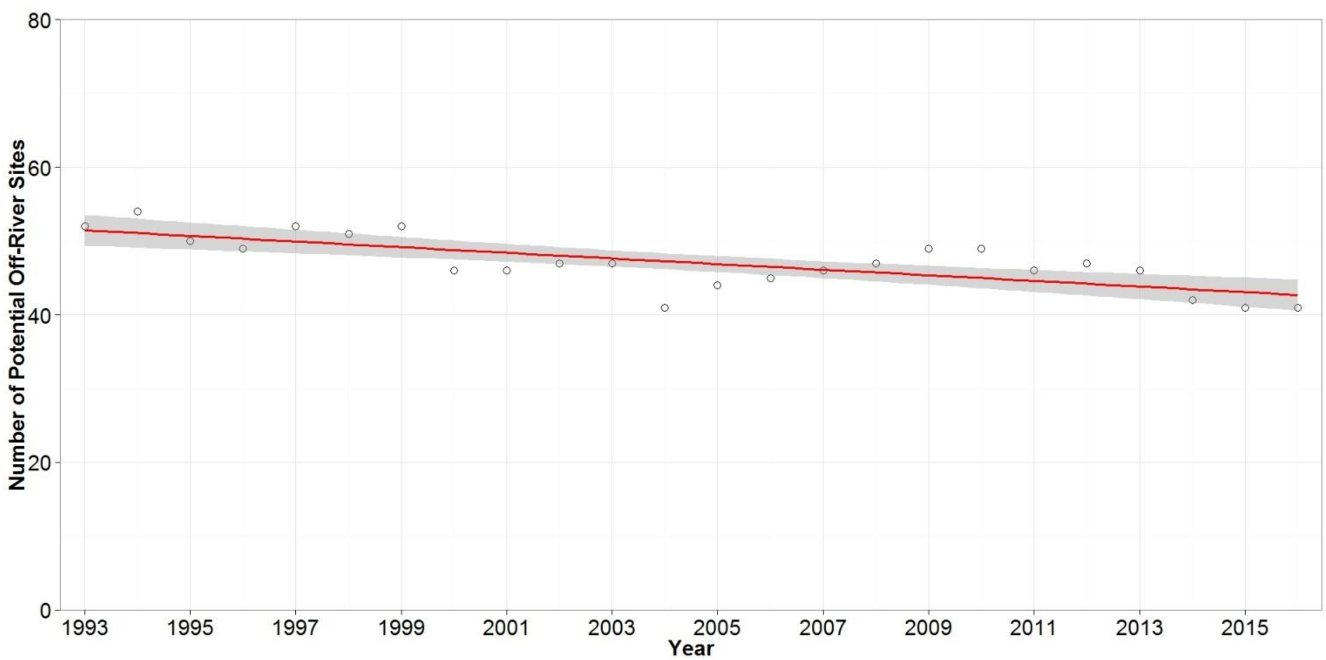

Figure 5. Total number of potential off-river nesting sites from 1993 – 2016. Trend line was created using linear regression (lm) in R Studio (2015). Gray band shows standard error.

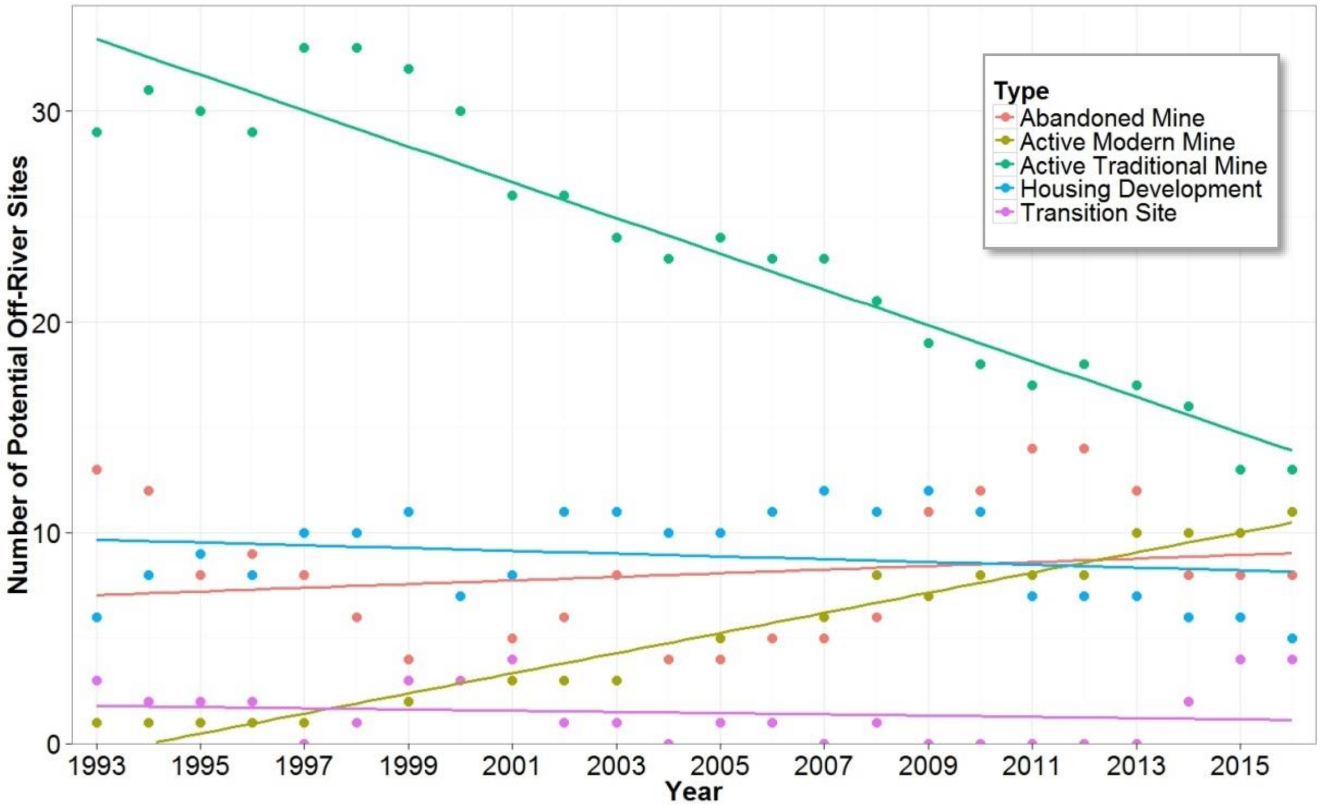

Figure 6. Number of potential off-river nesting sites by site types from 1993 – 2016. Trend lines were created using linear regression (lm) in R Studio (2015).

Evaluation of Bird Use by Site Type

Piping Plovers

From 2008 – 2017, there was an average of 54.0 (95% CI [44.2, 63.8], range: 28-79) plover nests per year and 2.3 (95% CI [1.9, 2.7], range: 1.6-3.4) plover nests per site per year (Table 3 and 4). Transition sites had the highest number of plover nests per site per year with a mean of 7.6 (95% CI [3.9, 11.3], range: 3.5-14.0); however, we did not monitor any transition sites from 2009-2013, so this mean was calculated using only five years of data. Housing developments had the second highest number of plover nests per site per year with a mean of 4.5 (95% CI [3.7, 5.2], range: 1.7-6.5). Traditional mines had the third highest number of plover nests per site per year with a mean of 1.9 (95% CI [1.5, 2.3], range: 0.9-3.0). Abandoned mines had the fourth highest number of plover nests per site per year with a mean of 1.3 (95% CI [0.7, 1.8], range: 0.5-3.0). Modern mines had the fifth highest number of plover nests per site per year with a mean of 0.6 (95% CI [0.1, 1.1], range: 0.0-1.8).

Interior Least Terns

From 2008 – 2017, there was an average of 205.4 (95% CI [162.7, 248.1]) tern nests per year and 8.9 (95% CI [7.1, 10.7], range: 3.8-13.5) tern nests per site per year (Table 5 and 6). Transition sites had the highest number of tern nests per site per year with a mean of 24.5 (95% CI [12.0, 36.9], range: 9.0-42.5); however, we did not monitor any transition sites from 2009-2013, so this mean was calculated using only five years of data. Traditional mines had the second highest number of tern nests per site per year with a mean of 10.7 (95% CI [8.5, 12.8], range: 3.0-

14.4). Housing developments had the third highest number of tern nests per site per year with a mean of 9.4 (95% CI [6.5, 12.3], range: 3.3-19.8). Abandoned mines had the fourth highest number of tern nests per site per year with a mean of 4.4 (95% CI [3.1, 5.7], range: 0.3-7.0). Modern mines had the fifth highest number of tern nests per site per year with a mean of 1.5 (95% CI [0.7, 2.3], range: 0.0-3.5).

Table 3. Number of plover nests each year from 2008 – 2016 within each distinct site type.

Year	Traditional	Modern	Abandoned	Transition	Housing	Grand Total
2008	24	1	5	4	16	**50**
2009	8	0	2		18	**28**
2010	11	0	3		20	**34**
2011	12	0	8		26	**46**
2012	29	8	6		18	**61**
2013	27	2	7		18	**54**
2014	26	4	3	7	11	**51**
2015	18	2	1	36	11	**68**
2016	33	0	1	30	5	**69**
2017	24	9	6	14	26	**79**
Mean	**21.2**	**2.6**	**4.2**	**18.2**	**16.9**	**54.0**
SE	**2.7**	**1.1**	**0.8**	**6.3**	**2.1**	**5.0**
L 95% CI	**16.0**	**0.5**	**2.6**	**5.8**	**12.8**	**44.2**
U 95% CI	**26.4**	**4.7**	**5.8**	**30.6**	**21.0**	**63.8**

Table 4. Number of plover nests per site each year from 2008 – 2016 within each distinct site type.

Year	Traditional	Modern	Abandoned	Transition	Housing	Grand Total
2008	2.4	0.5	2.5	4.0	5.3	**2.8**
2009	0.9	0.0	0.7		4.5	**1.6**
2010	1.4	0.0	0.6		5.0	**1.7**
2011	1.2	0.0	1.3		6.5	**1.9**
2012	2.4	2.0	1.0		4.5	**2.3**
2013	1.9	0.4	1.4		4.5	**1.9**
2014	2.0	0.8	1.0	3.5	3.7	**2.0**
2015	1.6	0.5	0.5	9.0	3.7	**2.8**
2016	3.0	0.0	0.5	7.5	1.7	**2.8**
2017	2.4	1.8	3.0	14.0	5.2	**3.4**
Mean	**1.9**	**0.6**	**1.3**	**7.6**	**4.5**	**2.3**
SE	**0.2**	**0.2**	**0.3**	**1.9**	**0.4**	**0.2**
L 95% CI	**1.5**	**0.1**	**0.7**	**3.9**	**3.7**	**1.9**
U 95% CI	**2.3**	**1.1**	**1.8**	**11.3**	**5.2**	**2.7**

Table 5. Number of tern nests each year from 2008 – 2016 within each distinct site type.

Year	Traditional	Modern	Abandoned	Transition	Housing	Grand Total
2008	138	7	12	9	40	**206**
2009	27	0	17		25	**69**
2010	115	0	31		79	**225**
2011	103	11	18		49	**181**
2012	163	5	2		28	**198**
2013	123	8	14		30	**175**
2014	142	9	21	71	22	**265**
2015	108	3	11	170	32	**324**
2016	150	1	7	85	10	**253**
2017	87	15	8	14	34	**158**
Mean	**115.6**	**5.9**	**14.1**	**69.8**	**34.9**	**205.4**
SE	**12.3**	**1.6**	**2.6**	**29.2**	**5.9**	**21.8**
L 95% CI	**91.5**	**2.8**	**9.0**	**12.5**	**23.3**	**162.7**
U 95% CI	**139.7**	**9.0**	**19.2**	**127.1**	**46.5**	**248.1**

Table 6. Number of tern nests per site each year from 2008 – 2016 within each distinct site type.

Year	Traditional	Modern	Abandoned	Transition	Housing	Grand Total
2008	13.8	3.5	6.0	9.0	13.3	**11.4**
2009	3.0	0.0	5.7		6.3	**3.8**
2010	14.4	0.0	6.2		19.8	**11.3**
2011	10.3	2.8	3.0		12.3	**7.5**
2012	13.6	1.3	0.3		7.0	**7.6**
2013	8.8	1.6	2.8		7.5	**6.3**
2014	10.9	1.8	7.0	35.5	7.3	**10.2**
2015	9.8	0.8	5.5	42.5	10.7	**13.5**
2016	13.6	0.2	3.5	21.3	3.3	**10.1**
2017	8.7	3.0	4.0	14.0	6.8	**6.9**
Mean	**10.7**	**1.5**	**4.4**	**24.5**	**9.4**	**8.9**
SE	**1.1**	**0.4**	**0.6**	**6.3**	**1.5**	**0.9**
L 95% CI	**8.5**	**0.7**	**3.1**	**12.0**	**6.5**	**7.1**
U 95% CI	**12.8**	**2.3**	**5.7**	**36.9**	**12.3**	**10.7**

Projected Trends in Site Numbers and Bird Use over Time

The linear regression models were a good fit for predicting the number of traditional (R^2 = 0.9026, *P*-value < 0.0001) and modern mines (R^2 = 0.9545, *P*-value < 0.0001) in the future. However, the linear regression models for abandoned mines (R^2 = -0.0117, *P*-value = 0.4011), transition sites (R^2 = -0.02326, *P*-value = 0.4969), and housing developments (R^2 = 0.0032, *P*-value = 0.3111) did not show significant trends between the number of sites and year. We found that polynomial models better fit our data for abandoned mines, transition sites, and housing developments; however, we were unable to use the polynomial models to predict the number of each of these three site types into the future.

The linear regression analysis for the predicted number of off-river sites each year showed a significant relationship between the number of sites and year (R^2 = 0.5138, *P*-value < 0.0001). The predicted number of off-river sites was found using the following equation: Sites = -0.3809*year + 811 (Figure 7). The year coefficient (-0.3809) indicated that for every additional year, we expect the number of off-river nesting sites to decrease by 0.3809. We predicted that there will be approximately 30 potential off-river nesting sites within our study area in 2050 (Table 7). Using the equation produced from our linear regression model and the average number of nests per site per year (plover = 2.33, tern = 8.85), we estimated that there will be 69 plover nests and 263 tern nests in our lower Platter River study area in 2050 (Table 7).

Table 7. Predicted number of off-river sites, plover nests, and tern nests from 2017 – 2050.

Year	Sites	Plover Nests	Tern Nests
2017	42	98	374
2018	42	98	371
2019	41	97	367
2020	41	96	364
2021	41	95	361
2022	40	94	357
2023	40	93	354
2024	40	92	350
2025	39	91	347
2026	39	90	344
2027	38	90	340
2028	38	89	337
2029	38	88	334
2030	37	87	330
2031	37	86	327
2032	37	85	323
2033	36	84	320
2034	36	83	317
2035	35	82	313
2036	35	82	310
2037	35	81	307
2038	34	80	303
2039	34	79	300
2040	34	78	296
2041	33	77	293
2042	33	76	290
2043	32	75	286
2044	32	75	283
2045	32	74	280
2046	31	73	276
2047	31	72	273
2048	30	71	270
2049	30	70	266
2050	30	69	263

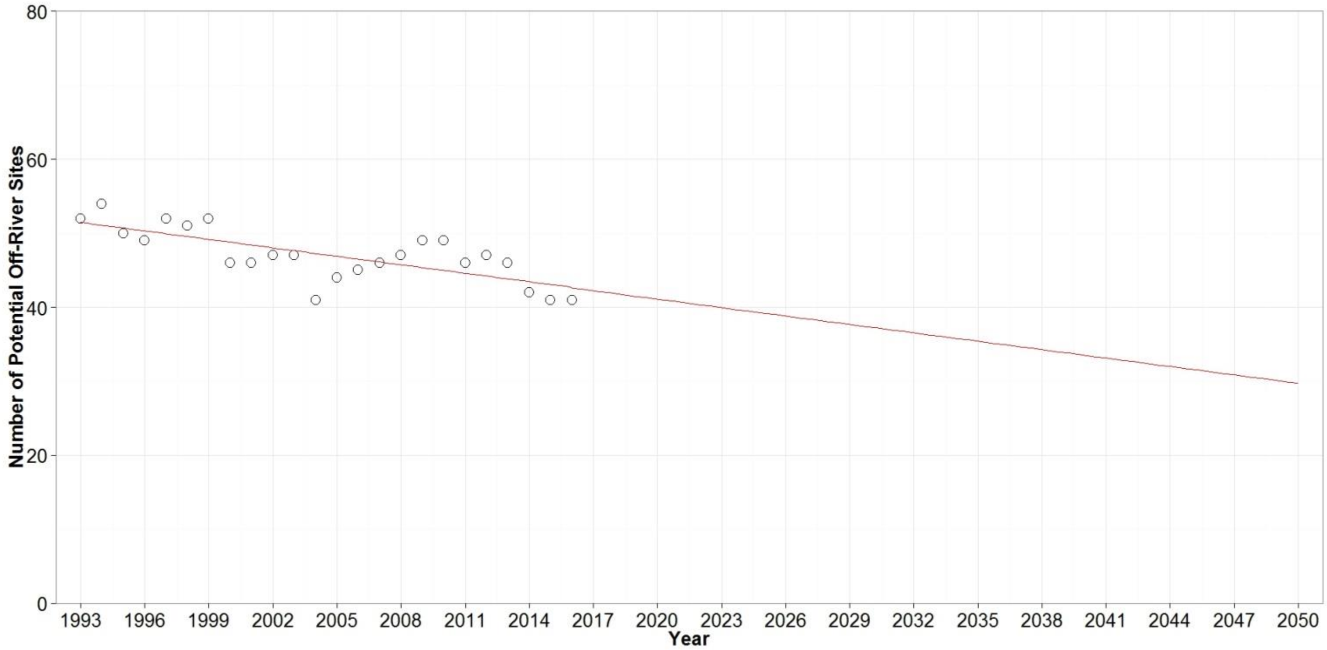

Figure 7. Linear regression model showing the predicted number of off-river nesting sites along the lower Platte River study area ($R^2 = 0.5138$, *P*-value < 0.0001). The actual number of potential off-river nesting sites from 1993 – 2016 are represented with open circles. The trend line was created using linear regression and locally weighted scatterplot smoothing (lm) in R Studio (2015).

The linear regression model for traditional mines had a *P*-value of < 0.0001, indicating that there is a significant relationship between the number of traditional mines and year, and an R^2 value of 0.9026, indicating that this model explains 90.26% of the variability in the data. The predicted number of traditional mines was found using the following equation: Sites = -0.8496*year + 1,727. The year coefficient equaled -0.8496 and indicated that for every additional year we expect the number of traditional mines to decrease by 0.8496. We predicted there will be no traditional mines within our study area by 2035 and therefore there will be no tern or plover nests at traditional mines within our study area by that date (Table 8, Figure 8).

The linear regression model of modern mines had a *P*-value of < 0.0001, indicating that there is a significant relationship between the number of modern mines and year, and an R^2 value of 0.9545, indicating that this model explains 95.45% of the variability in the data. The predicted number of modern mines was found using the following equation: Sites = 0.4774*year + -952. The year coefficient equaled 0.4774 and indicated that for every additional year we expect the number of modern mines to increase by 0.4774. We predicted that there will be approximately 27 modern mines within our study area in 2050 and 40 tern nests and 18 plover nests and at these modern mines in 2050 (Table 8, Figure 9).

Table 8. Predicted number of off-river sites, plover nests, and tern nests at traditional and modern mines from 2017 – 2050.

Year	Traditional			Modern		
	Sites	Plover Nests	Tern Nests	Sites	Plover Nests	Tern Nests
2017	13	25	139	11	7	17
2018	12	24	130	11	8	17
2019	11	22	121	12	8	18
2020	10	20	112	12	8	19
2021	10	19	102	13	9	19
2022	9	17	93	13	9	20
2023	8	15	84	14	9	21
2024	7	14	75	14	10	22
2025	6	12	66	15	10	22
2026	5	10	57	15	10	23
2027	4	9	48	16	11	24
2028	4	7	39	16	11	25
2029	3	5	30	17	11	25
2030	2	4	21	17	12	26
2031	1	2	12	18	12	27
2032	0	0	2	18	12	27
2033	0	0	0	19	12	28
2034	0	0	0	19	13	29
2035	0	0	0	20	13	30
2036	0	0	0	20	13	30
2037	0	0	0	21	14	31
2038	0	0	0	21	14	32
2039	0	0	0	21	14	32
2040	0	0	0	22	15	33
2041	0	0	0	22	15	34
2042	0	0	0	23	15	35
2043	0	0	0	23	16	35
2044	0	0	0	24	16	36
2045	0	0	0	24	16	37
2046	0	0	0	25	17	37
2047	0	0	0	25	17	38
2048	0	0	0	26	17	39
2049	0	0	0	26	18	40
2050	0	0	0	27	18	40

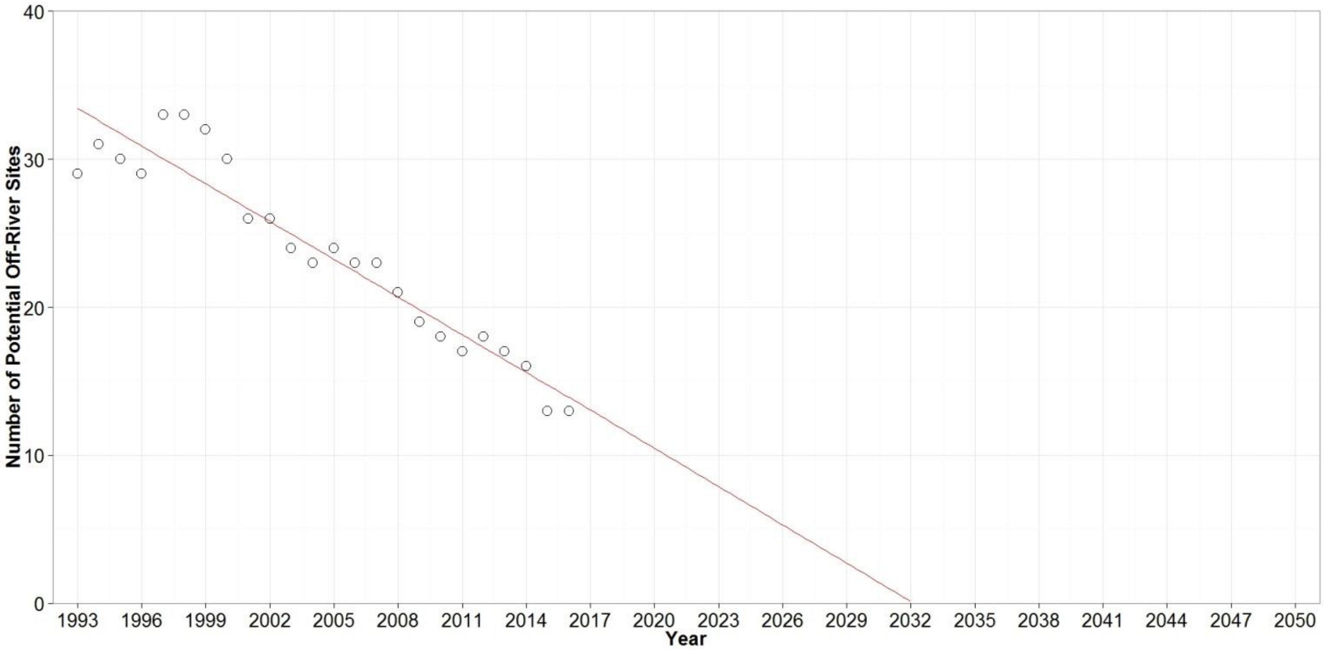

Figure 8. Linear regression model showing the predicted number of traditional mines along the lower Platte River study area (R^2 = 0.9026, P-value < 0.0001). The actual number of traditional mines from 1993 – 2016 are represented with open circles. The trend line was created using linear regression and locally weighted scatterplot smoothing (lm) in R Studio (2015).

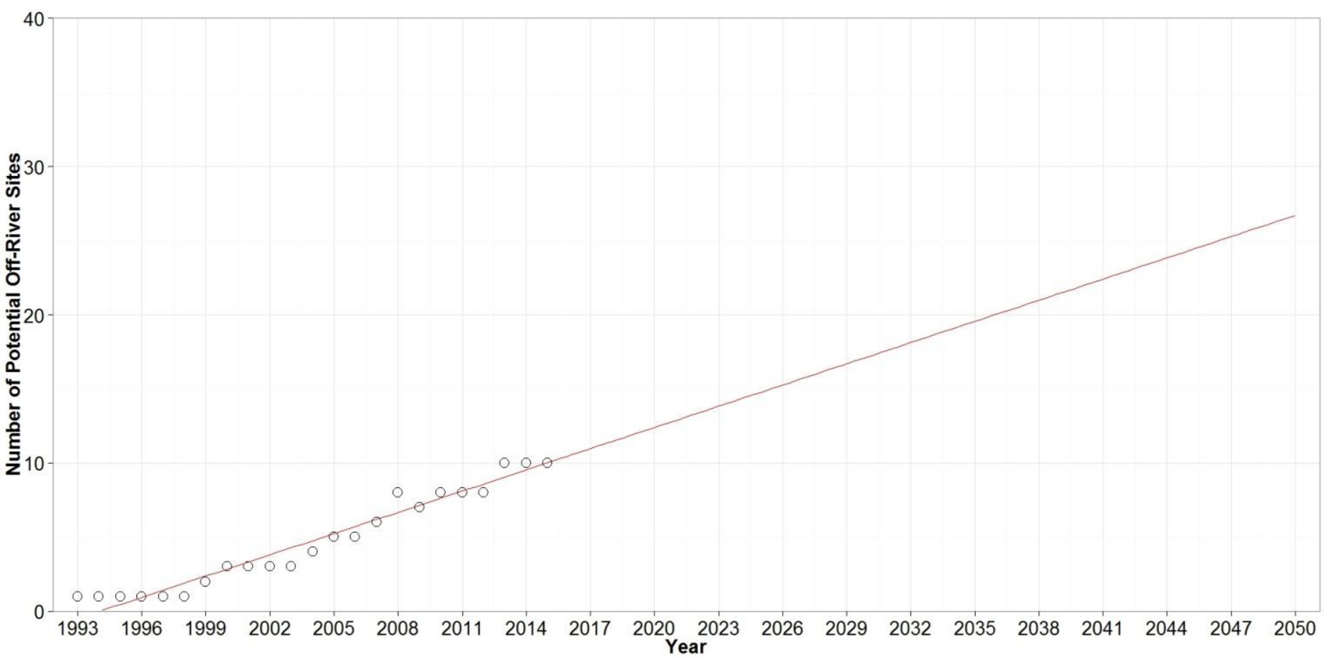

Figure 9. Linear regression model showing the predicted number of modern mines along the lower Platte River study area (R^2 = 0.9545, P-value < 0.0001). The actual number of modern mines from 1993 – 2016 are represented with open circles. The trend line was created using linear regression and locally weighted scatterplot smoothing (lm) in R Studio (2015).

For abandoned mines, we found that the 3rd order polynomial model best fit the data (R^2 = 0.5962, P-value < 0.0001; Figure 10). The P-value (P-value < 0.0001) indicated that there is a significant relationship between the number of abandoned mines and year. The R^2 value ($R^2 = 0.5962$) indicated that this model explains 59.62% of the variability in the data. This results indicates that the number of abandoned mines within our study area is cyclical.

For transition sites we found that the 3rd order polynomial model best fit the data ($R^2 = 0.4289$, *P*-value = 0.0025; Figure 11). The *P*-value (*P*-value = 0.0025) indicated that there is a significant relationship between the number of abandoned mines and year. The R^2 value ($R^2 = 0.4289$) indicated that this model only explains 42.89% of the variability in the data. While the 3rd order polynomial model was the best fitting model we can see that the data appears more variable than cyclical.

For housing developments we found that the 3rd order polynomial model best fit the data ($R^2 = 0.6018$, *P*-value < 0.0001; Figure 12). The *P*-value (*P*-value < 0.0001) indicated that there is a significant relationship between the number of housing developments and year. The R^2 value ($R^2 = 0.6018$) indicated that this model explains 60.18% of the variability in the data.

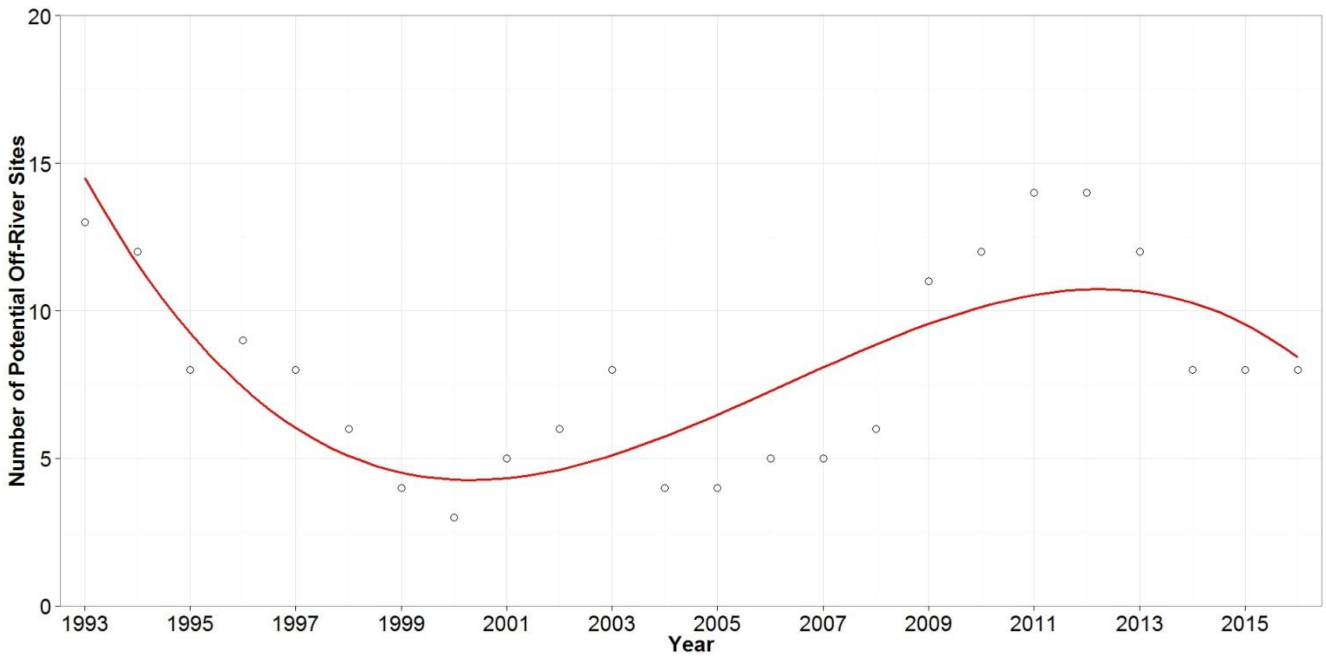

Figure 10. Polynomial regression model (3rd order) showing the number of abandoned mines along the lower Platte River study area from 1993 – 2016 ($R^2 = 0.5962$, *P*-value < 0.0001). The trend line was created using 3rd order polynomial regression and locally weighted scatterplot smoothing (lm) in R Studio (2015).

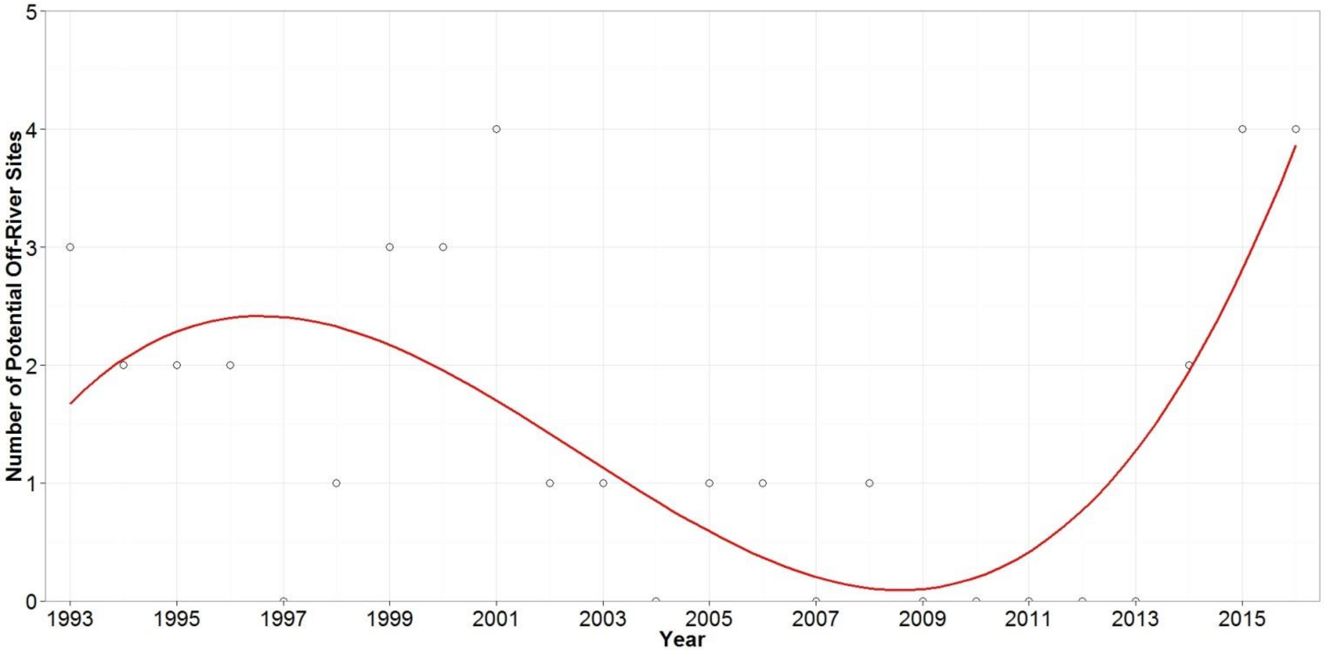

Figure 11. Polynomial regression model (3rd order) showing the number of transition sites along the lower Platte River study area from 1993 – 2016 (R^2 = 0.4289, *P*-value = 0.0025). The trend line was created using 3rd order polynomial regression and locally weighted scatterplot smoothing (lm) in R Studio (2015).

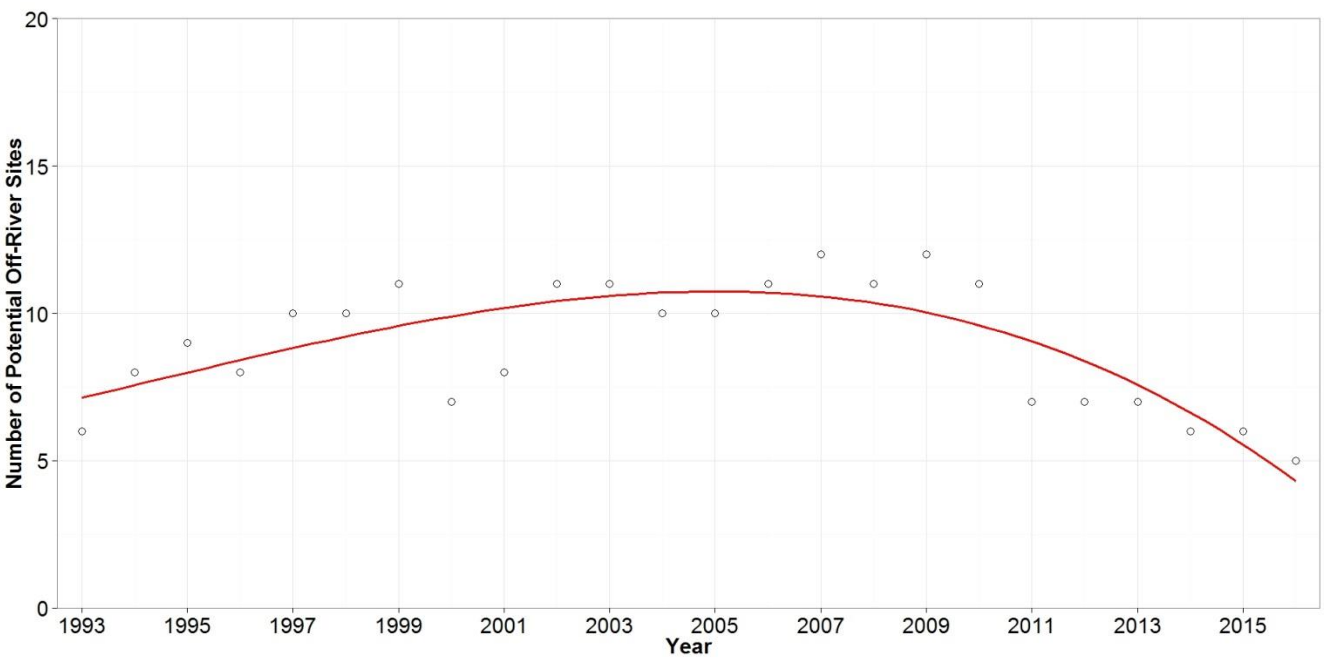

Figure 12. Polynomial regression model (3rd order) showing the number of housing developments along the lower Platte River study area from 1993 – 2016 (R^2 = 0.6018, *P*-value < 0.0001). The trend line was created using 3rd order polynomial regression and locally weighted scatterplot smoothing (lm) in R Studio (2015).

DISCUSSION

Piping Plovers and Interior Least Terns have nested on areas of bare or sparsely-vegetated sand adjacent to water incidentally created by open pit mining in the Platte River valley for nearly a century. As the sand and gravel mining industry has matured, the presence of these sites has been a reliable source of nesting habitat as other habitats (e.g., river sandbars) declined in abundance or disappeared. The practice of converting abandoned mines to lakeshore housing developments has matured and generated additional areas of nesting habitat. Even though off-river habitats along the Platte River have been a reliable source of nesting habitat for many decades, mining industry practices continually evolve which is altering the amount, spatial distribution, and type of off-river nesting habitats available to these birds.

Predictions based on our modeling analyses suggest that the number of off-river sandpit lakes with suitable tern and plover nesting habitat will exhibit a continual decrease of, on average, 1% per year through 2050. Our analyses also suggest that the number of traditional mines will decrease, the number of modern mines will increase, and the number of abandoned mines, transition sites, and housing development will be variable, changing with the local and regional economy. Even though modern mines are expected to increase in number, our results suggest that this increase will likely not be sufficient to sustain current populations of terns and plovers along the lower Platte River. This is due to evolving mining technologies and practices, in particular the implementation of progressive reclamation at traditional and modern mines.

Mining is of state and national economic and strategic importance, so the industry will persist in Nebraska as long as adequate deposits of aggregate are available and accessible and will be largely immune to economic cycles. However, as aggregate deposits directly adjacent to the lower Platte River are depleted, mining operations will likely move further away from rivers, with unknown effect on the availability of tern and plover nesting habitat. As areas of the lower Platte River are mined and aggregate deposits exhausted or otherwise become developed, it is inevitable that mining companies will have to relocate mine sites further upstream and away the Platte River confluence with the Missouri River.

As the Omaha/Council Bluffs metropolitan area continues to grow to the west and south there will be demand for fairly affluent, lifestyle housing in those areas. Lakeshore housing developments provide much of that affluent, lifestyle housing with access to water-based recreation activities (e.g., swimming, boating, fishing) and potentially larger lot and home sizes. Consequently, we expect the demand to convert post-production sand and gravel mines into lakeshore housing developments will continue. The beaches at these developments extend the amount of time tern and plover nesting habitat is available. However, if the demand for this segment of the housing market continues, these developments will likely quickly fill with houses and only offer suitable tern and plover nesting habitat for a few of years.

Even though trends in the number of modern and traditional mine sites has been steady over the years, this has not been the case for abandoned mines, transition sites, housing developments, which show greater variation in number. The amount of time these sites are in any of these states or stages is likely influenced by variables we were unable to consider in the analysis such as economic cycles and local zoning regulations. For example, we are aware of at least one abandoned mine that is not suitable for conversion to a housing development because of its location in the flood plain. Our predictions of the future numbers of off-river habitat types is based on past trends and we cannot anticipate unforeseen changes in industry practices or economics. Unanticipated changes may dramatically alter the amount of nesting habitat available, and correspondingly the number of terns and plovers, present along the lower Platte River in the future.

If our prediction of an overall gradual decline in the number of Piping Plovers and Interior Least Terns is accurate, this will have broader implications for recovery efforts across the Great Plains. Piping Plovers nesting at off-river sites along the lower Platte River are part of a larger metapopulation that includes nesting habitats along the Gavin's Point Dam reach of the Missouri River (Hunt et al. 2015, Catlin et al. 2016, Ziegler et al. 2017). Catlin et al. (2016) showed that off-river sites along the lower Platte River were actually critical to the survival of this broader metapopulation. Other than short-term bird and site management conducted by the Tern and Plover Conservation Partnership (Brown et al. 2010), off-river sites are largely unmanaged and it has been tacitly assumed that they will continue to provide nesting habitat for tern and plover in perpetuity. However, our results show this may not be the case and trends apparent in our analyses for the lower Platte River may be of special interest to agencies tasked with managing the birds the region.

The impacts of the changing aggregate mining and real estate development industries is certain to impact the nesting of Interior Least Terns and Piping Plovers in the lower Platte River system as well as over much of the Great Plains. It has generally been assumed that off-river sites along the lower Platte River and its tributaries will be reliable source of habitat, but this assumption may not be valid. Agencies, such as the U.S. Fish and Wildlife Service and Nebraska Game and Parks Commission, must be cognizant of trends in off-river sites and adapt management actions to these changes so to not hinder the recovery of the species.

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Appendix A. Basic flowchart showing how decisions made by aggregate producers affect tern and plover reproductive success.