Prepared in cooperation with the U.S. Army Corps of Engineers

Accuracy of the Missouri River Least Tern and Piping Plover Monitoring Program—Considerations for the Future

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U.S. Department of the Interior
U.S. Geological Survey

Cover photograph: Two piping plover chicks and an egg near Lake Sakakawea, North Dakota (July 7, 2007). Photograph taken by U.S. Geological Survey personnel.

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By Terry L. Shaffer, Mark H. Sherfy, Michael J. Anteau, Jennifer H. Stucker, Marsha A. Sovada, Erin A. Roche, Mark T. Wiltermuth, Thomas K. Buhl, and Colin M. Dovichin

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square hectometer (hm^2)	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

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1.0 Introduction

The upper Missouri River system provides nesting and foraging habitat for federally endangered least terns (*Sternula antillarum*; hereafter "terns") and threatened piping plovers (*Charadrius melodus*; hereafter "plovers"). These species are the subject of substantial management interest on the Missouri River for several reasons. First, ecosystem recovery is a goal for management agencies that seek to maintain or restore natural functions and native biological communities for the Missouri River system. Terns and plovers are recognized as important ecosystem components that are linked with the river's ecological functions. Second, although both species breed beyond the Missouri River system, the Missouri River is one of the principal breeding areas in the Northern Great Plains; thus, the river system is a focal area for recovery actions targeted at regional population goals. Third, a Biological Opinion for Missouri River operations established annual productivity goals for terns and plovers, and the recovery plan for each species established annual population goals. Meeting these goals is a key motivation in management decision making and implementation with regard to both species.

A myriad of conservation and management interests necessitate understanding numbers, distribution, and productivity of terns and plovers on the Missouri River system. To this end, a Tern and Plover Monitoring Program (TPMP) was implemented by the U.S. Army Corps of Engineers (hereafter "Corps") in 1986, and has since provided annual estimates of tern and plover numbers and productivity for five Missouri River reservoirs and four river reaches (U.S. Army Corps of Engineers, 1993). The TPMP has served as the primary source of information about the status of terns and plovers on the Missouri River, and TPMP data have been used for a wide variety of purposes. In 2005, the U.S. Geological Survey (USGS) Northern Prairie Wildlife Research Center (NPWRC) was tasked by the Corps to evaluate the accuracy of the TPMP and provide guidance on revising the program to assess tern and plover numbers and reproductive success. Accordingly, NPWRC studied terns and plovers on two river reaches and one reservoir (hereafter "the evaluation"), and used the results of those studies to help understand properties and potential limitations of TPMP data and to provide guidance for TPMP revisions. The purpose of this report is to present an overview and evaluation of the TPMP data, the results of our intensive monitoring, and propose an alternative idea that provides a framework for making decisions about how to monitor terns and plovers.

2.0 Current Tern and Plover Monitoring Program

A part of our evaluation was focused on understanding the history of the TPMP. This was accomplished through reviews of procedural manuals (U.S. Army Corps of Engineers, 1993, 2005, and 2009), exploration of data summaries and databases, observation of Corps monitoring crews during field work, and discussions with Corps staff.

2.1 History and Objectives

The TPMP was initiated in 1986. In early years, the program was primarily a survey of adult and fledgling numbers on each of the reaches and reservoirs. Survey guidelines from the Atlantic Coast piping plover recovery plan (U.S. Fish and Wildlife Service, 1988) served as the initial program guidance, and the Corps developed its own guidance for the Missouri River in 1993 (U.S. Army Corps of Engineers, 1993). Before 1993, tern and plover surveys were done by South Dakota State University and the U.S. Fish and Wildlife Service (hereafter "Service"). In these early years, adult surveys were done throughout the Missouri River system, but productivity data were collected only on the lower river reaches. The 1993 guidance incorporated a productivity survey throughout the Missouri River system, which included methods for determining causes of nest and chick losses. In 1993, the Corps began the adult census and productivity monitoring utilizing field projects located on the Missouri River with limited assistance by the Service, most notably on Fort Peck Lake. In 2002, the Service withdrew from surveying Fort Peck Lake and since

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then all survey work on the Missouri River has been done by Corps crews, supplemented by South Dakota Game, Fish, and Parks personnel operating from the field offices (Coral J. Huber, oral commun., 2006). The 1993 guidance was the first attempt to standardize data collection techniques throughout the river system and it went through two subsequent revisions (U.S. Army Corps of Engineers, 2005, 2009).

The three iterations of TPMP guidance reflect a progression in development of data collection tasks. The documents were targeted at field crews responsible for data collection, and included substantial background material on natural history of terns and plovers, the Endangered Species Act (ESA), the Missouri River, the Biological Opinion, and field safety. U.S. Army Corps of Engineers (2009) also provided guidelines for aging chicks and eggs, determining nest fates, implementing various management actions, and coordinating with researchers. All three documents provided information on field methods for collecting a variety of tern and plover data and for recording these data in the Corps' Tern and Plover Data Management System (TPDMS).

Despite the attention devoted to background and methodology in the TPMP guidance documents, there was no mention of the underlying objectives that motivated the collection, summarizing, and interpretation of TPMP data. The program grew in scope and complexity from its beginnings as a survey of adult numbers to the present program. The program now includes widespread productivity data collection, implementation of management practices, and evaluation of threats to terns and plovers. Although each successive iteration of the program added new complexity, program development was not accompanied by a statement or prioritization of objectives. Clearly articulated, prioritized objectives are fundamentally important for collecting management-relevant data, particularly when resources are limited and there are multiple competing priorities for data (Lyons and others, 2008, Sherfy and others, 2011).

Although direct statements of the TPMP's objectives are lacking, the guidance documents do provide insight into the motivation for data collection. U.S. Army Corps of Engineers (1993) was derived from the Atlantic Coast piping plover recovery plan (U.S. Fish and Wildlife Service, 1988), suggesting that meeting recovery needs was of high importance to the early TPMP program; however, recovery goals typically are evaluated at a large spatial scale and U.S. Army Corps of Engineers (1993) also suggests that finer-scale data were important to evaluate species status for the river or its subunits. For example, year-end survey reports are expected to include number of adult birds and fledglings per site, locations of nesting colonies, and causes of nest, egg, or chick losses. The reporting interval is also indicative of the temporal scale at which data were deemed important. U.S. Army Corps of Engineers (1993) provides guidance on weekly written reports and year-end survey reports, but does not indicate how either reporting interval is linked to a monitoring objective.

U.S. Army Corps of Engineers (2005) goes into greater detail in summarizing elements of the ESA that are relevant to terns and plovers on the Missouri River. It also recognizes the 2000 Biological Opinion as a new motivating factor behind data collection. Although a direct statement of objectives is absent, U.S. Army Corps of Engineers (2005) makes several statements that are similar to guiding objectives, such as:

- "The ultimate goal of our work is to recover least terns and piping plovers on the Missouri River."
- "We do productivity surveys to measure the 'fledge ratio' for the two species and help direct future river management decisions."
- "This data (nest initiation date) is important in determining long-term trends by the birds as to when they are arriving on the nesting grounds."
- "A census of adult least terns and piping plovers is conducted during the breeding season as a compliance measure with the Biological Opinion."
- "The adult census is important for several reasons. First, it is a part of the recovery plans for the two species….Second, it is a component of the fledge ratio, which is used to calculate productivity. Third, the adult census is used to chart long-term population trends of the two species on the Missouri River."
- "In addition to surveying the birds, we take several actions to increase the productivity and our knowledge of the species."
- "We can take several measures to reduce disturbance of the birds."
- "When conducting surveys your primary activity is research."
- "An important, though often overlooked part of human deterrence measures, is educating the public."
- "In order for the WMD (Water Management Division) to make sound water management decisions, data needs to be collected accurately and reported quickly."
- "The Threatened and Endangered Species Data Management System (TESDMS) was created to provide near real-time data for water management decisions."

Thus, there was a substantial broadening in the types of questions that appeared to motivate data collection between U.S. Army Corps of Engineers (1993) and U.S. Army Corps of Engineers (2005) and an associated evolution in scope of TPMP data collection and reporting. These statements reflect interest in many diverse uses of data, including assessment of compliance with the Biological Opinion, evaluating species recovery, evaluating long-term population trends, doing research, and providing near real-time data for making management decisions.

The very first sentence in the introduction of U.S. Army Corps of Engineers (2009) states "The U.S. Army Corps of Engineers is working to restore the ecological functions of the Missouri River through its Missouri River Recovery Program," reflecting the importance of river ecosystem recovery as a motivation for monitoring terns and plovers. Subsequent sections, however, provide little indication of linkages between the TPMP and the Missouri River Recovery Program, and do not mention the Missouri River Ecosystem Restoration Program (MRERP). Rather, the introduction is followed by an extensive description of the ESA, species recovery plans for terns and plovers, and the 2003 Amendment to the Biological Opinion. Although an overriding statement of prioritized monitoring objectives remains absent from U.S. Army Corps of Engineers (2009), the ESA section does close with a statement focused on monitoring requirements:

> “Much of the monitoring the Corps conducts for least terns and piping plovers are requirements set forth in the Biological Opinion. These include conducting an adult census, determining productivity, determining mortality, determining incidental take, determining the effectiveness of habitat creation and restoration efforts, predation management, human disturbance management, water management, law enforcement coordination and management actions to increase productivity. These will all be discussed throughout the handbook.”

In addition to these needs on the Missouri River, U.S. Army Corps of Engineers (2009) also acknowledges that TPMP data are components of regional-scale population assessments (“International Piping Plover Adult Census” and “Range Wide Interior Least Tern Adult Census”). Thus, the trend evident through the three guidance documents is for increasing complexity and breadth of information needs that are presumed to be addressed by the TPMP.

2.2 Data Collection

A general theme throughout the guidance documents is that surveys for adults are the primary means of locating nesting colonies, with further monitoring effort (for example, nest searching) done only in locations where adults are observed. U.S. Army Corps of Engineers (1993) suggests that surveys should correspond with arrival times of the birds “…in order to determine nest initiation times.” Actual counts of adult birds were then initiated about 3 weeks after nest initiation. During the initial survey, technicians were advised to observe birds from boats with binoculars and provide counts of adult birds and nests. An observation distance of 30 feet was recommended. Nests were not marked during this initial survey, which was also termed a general census (U.S. Army Corps of Engineers, 1993). Later in the season, a complete adult count was done, using methods “similar to those in the initial count,” with total number of adults per area being the “only information needed” (U.S. Army Corps of Engineers, 1993). The term breeding pair was not defined in U.S. Army Corps of Engineers (1993), and the only information on adults requested in annual reports was adult birds per site. Annual reports also contained information on “… locations of nesting colonies, condition of nesting habitat, causes of nest/egg/chick losses, fledglings per site, and recommendations for habitat maintenance/creation” (U.S. Army Corps of Engineers, 1993). Examples of weekly reports in U.S. Army Corps of Engineers (1993) indicate nest, chick, and fledgling counts by site, but neither the total number of nests found nor any measure of nest success is included in the annual summary report.

Production surveys were a component of the early program, although the section of U.S. Army Corps of Engineers (1993) describing these surveys was missing from all available copies; however, the permit conditions from 1993 provide insight into techniques that were used to find nests. Nests were apparently checked for success or failure at 5- to 7-day intervals, and numbering of eggs was authorized. An egg flotation cup was included in the supplies list, but there was no other mention of egg flotation, candling, or any other method of estimating nest age or initiation date. The supplies list also included a stadia rod and transit for nest elevations, but there was no specific guidance on how to collect the data or how the data were used. The permit conditions also allowed construction of nest exclosures at piping plover and least tern nest sites.

Substantially more types of data were discussed in U.S. Army Corps of Engineers (2005). One of the most notable elements appearing in 2005 was fledge ratio as a response variable measured by the TPMP. Although the document provides extensive guidance on methods to count fledglings and adults, there was no explicit statement of how fledge ratio was calculated or the scale at which it was being measured (sandbar, reach, or river system). The only indication of scale is a description for a TPDMS data table that presents fledge ratio information by river reach.

Under the 2005 guidance, the TPMP was divided into two primary components—a Productivity Survey and an Adult Census. The Productivity Survey was described first, and it represented a substantial amount of the document (38 pages) because of the many types of data collection that were described. The lead paragraph in this section stated the Biological Opinion fledge ratio goals for species recovery (1.13 plover fledglings per pair and 0.70 tern fledglings per pair on a 3-year running average), suggesting that they were the primary performance metrics being targeted through this survey.

The Productivity Survey was subdivided into four primary types of data collection—Nest Site Survey, Nest Survey, Chick Survey, and Banded Plover Survey (U.S. Army Corps of Engineers, 2005). The goal of the Nest Site Survey was to find locations of nesting birds, which was accomplished by weekly checks of “all possible habitat sites” (U.S. Army Corps of Engineers, 2005). These checks were visual scans from boats, with sites being entered for Nest Surveys only if adults were seen or heard. Crews were advised to rely on information from the surveys of previous years to focus their efforts, but were also advised to search “all beaches and exposed islands” on reservoirs and “all sandbars” on rivers (U.S. Army Corps of Engineers, 2005). There was a provision for doing on-the-ground Nest Site Surveys for large sandbars or known historical use sites where adults were not seen or heard from the boat, but these surveys were described as “a good idea,” giving crews discretion in making these decisions (U.S. Army Corps of Engineers, 2005). The guidance also suggested surveying marginal habitat, but said these surveys may be suspended if no birds were seen.

Nest Site Surveys were done on sites where adult birds were seen. The "best" approach identified was to observe a site from a distance to locate adults sitting on nests, and then navigate to that area to find the nest (U.S. Army Corps of Engineers, 2005). The guidance also suggests watching adult behavior (broken-wing displays of plovers and bombing runs of terns) to determine when a crew member was in the vicinity of a nest. There was brief mention of grid-searching as a viable technique for "large areas" when "enough personnel" were available, but there was very limited guidance on how to conduct such a search or select a method based on site conditions (U.S. Army Corps of Engineers, 2005). Although neither spatial extent nor return interval were explicitly stated, the guidance did state that Nest Surveys were done on "…all possible habitat sites within the survey area on a weekly basis" (U.S. Army Corps of Engineers, 2005).

Chick Surveys were done later in the season, with the objectives of finding and assigning an age to the chicks. Again, the primary guidance was to observe habitats from a boat or an isolated area outside the nesting area, watching for chicks and adult behavioral cues. Crews were advised to look near hatched nest bowls (young chicks) and on shorelines (near-fledging chicks). The "beater method" was also described, in which an observer was stationed at one end of a sandbar and beaters move through the sandbar (U.S. Army Corps of Engineers, 2005). Advice was also given on avoiding double counts of fledglings and the potential for fledglings to be confused with adults.

Banded Plover Surveys were treated very briefly. The guidance advised watching adults for presence of bands and to associate banded birds with nests if possible. No provisions for recording data were provided, other than a report to the supervisor. There was no guidance for band resighting on least terns.

The four components of the Productivity Survey were presented separately as though they were four unique types of surveys that were done independently, when in fact they were likely done concurrently. Each survey type description acknowledged multiple approaches to searching habitat, but there was no mechanism mentioned for recording which types of surveys were done and which ones were successful or unsuccessful.

The second primary component of U.S. Army Corps of Engineers (2005) was the Adult Census, representing the first appearance of "census" as a type of data collected under the TPMP. As with the Productivity Survey, the introductory paragraph again referenced compliance with the Biological Opinion and the species recovery plan goals. Additionally, the Adult Census was described as a component of the fledge ratio and an indicator of long-term population trends on the Missouri River. The Adult Census was done across a 2-week window in mid to late June. During the Adult Census, a crew was given a choice of methods for determining the count of adult birds on each site:

Total adult count—All adult birds seen on a site were tallied.

Visual estimate—Several counts of birds seen overhead and on the ground were averaged.

Best guess estimate—Criteria for this method were not well-defined, and the method was available only in some years.

Nests & broods—This method was based on the assumption that each nest or brood represented two adults. The adult count was recorded as the sum of nests and broods multiplied by 2. This approach was recommended for large sites where adult counts were difficult, or sites where fewer than expected adults were counted.

The Adult Census guidance also allowed for adjusting counts on a site based on the number of adults, nests, and broods seen on adjacent sites. Accordingly, substantial latitude was given to crews in determining what should be counted on a site and what approach to use in recording the adult count; however, there was no requirement for crews to record which of the methods they used. Further, the guidance did not clearly distinguish whether breeding population (that is, pairs) or total adult count was the desired measure of adult abundance. For example, choices available to crew members on a site would allow either a total adult count or the sum of nests and broods multiplied by 2 to be recorded.

Following the detailed sections on Productivity Survey and Adult Census, U.S. Army Corps of Engineers (2005) described methods for various management actions, including placement of piping plover nest cages, nest relocation, specimen collection, restricting public access, law enforcement, and education. The document also contained a summary of the TPDMS, which emphasized the timely availability of TPMP data to the Water Management Division via the internet for decision support.

Whereas the lead paragraph in the Productivity Survey section of U.S. Army Corps of Engineers (2005) emphasized fledge ratio goals in the Biological Opinion for "species recovery" and "directing future river management decisions," this same section in U.S. Army Corps of Engineers (2009) stated "One of the goals of the Missouri River Recovery Program is to recover least terns and piping plovers on the Missouri River," without identifying any associated performance metrics.

U.S. Army Corps of Engineers (2009) described an approach to monitoring that is generally similar to the approach in U.S. Army Corps of Engineers (2005). It included a Productivity Survey with three components (Adult Survey, Nest Survey, and Chick Survey), and an Adult Census. The Banded Plover Survey that was included in U.S. Army Corps of Engineers (2005) was eliminated from the Productivity Survey in U.S. Army Corps of Engineers (2009), but guidance was included in the Research section on resighting banded piping plovers. Despite the substantial number of banded least terns on the Missouri River in 2009, there was no parallel guidance on resighting these birds. U.S. Army Corps of Engineers (2009) also provided a great deal of procedural details, including methods for aging chicks, floating eggs, documenting nest fates, and recording various data elements in the electronic database.

New to the program in U.S. Army Corps of Engineers (2009) was guidance on recording supporting evidence for determining the fate of terminated nests. This guidance was accompanied by a Decision Flow Chart that crews were instructed to use in assigning nest fates based on the observed evidence. Prior to 2009, crews were instructed to assign a cause to nest fates, which allowed them some discretion to interpret the evidence they observed and assign a cause of failure. The suite of nest fates was modified in 2009 to include Successful, Probable Successful, Undetermined, Failure, and Probable Failure, whereas U.S. Army Corps of Engineers (2005) specified possible fates of Hatched, Destroyed, Abandoned, Nonviable Eggs, Unknown, and Collected.

The 2009 guidance allowed crews to create “brood records” in situations where broods were observed and there was “irrefutable evidence that a nest was not found” (U.S. Army Corps of Engineers, 2009). These observations were apparently recorded as nests, despite a nest never having been found, although the TPDMS has since been modified so that they are only recorded as broods. The practice of recording nests where no nest was found introduces a bias into the data because detection of the nest was dependent on its fate (that is, if the nest had failed, it never would have entered the TPDMS because no brood would have been seen).

Guidance for the extent of data collection in U.S. Army Corps of Engineers (2009) was similar to U.S. Army Corps of Engineers (2005), with statements such as “all sandbars on the river should be surveyed” being common. U.S. Army Corps of Engineers (2009) included a greatly expanded discussion of how various management actions should be implemented, which presumably reflects an increasing importance of their role in the monitoring program. U.S. Army Corps of Engineers (2009) also provided the first mention of incidental take in any of the guidance documents, likely because it was a primary component of the 2003 Amendment to the Missouri River Biological Opinion. Interestingly, incidental take was not covered in U.S. Army Corps of Engineers (2005). U.S. Army Corps of Engineers (2009) included incidental take as a response variable that is directly measured using TPMP data, and also referenced the incidental take statements in the 2003 Biological Opinion as an important motivation for measuring fledge ratio. Crews were given guidance on determining whether a nest was at risk of failure because of inundation or erosion and on recording fate evidence consistent with incidental take (for example, flooded nests); however, there was no discussion of how decisions were made about which nests were lost and considered incidental take.

The Adult Census field methods were changed in U.S. Army Corps of Engineers (2009). Field crews no longer had the flexibility to choose how the census number should be determined on a given site. Rather, they were instructed to record the total count of adults, the number of nests found, and the number of broods seen. Corps staff later determined the adult census number for each site and reach based on data obtained throughout the census period; however, U.S. Army Corps of Engineers (2009) did not provide details on how field data were manipulated to determine adult census numbers.

The TPDMS section in U.S. Army Corps of Engineers (2009) was more explicit about the timeline for data reporting than previous versions. Crews were reminded that prompt data entry into the TPDMS was important because the TPDMS was used daily by the Corps for water management decisions that may affect terns and plovers.

2.3 Data Uses and Inferences

TPMP data have been used to answer a wide variety of management questions and make inferences at many spatial and temporal scales. This review of data uses was based largely on data summaries and presentations that have been generated since 2006, which were readily available and reflect current uses of TPMP data. This was also the period when the TPMP’s focus had been broadest.

A theme throughout reports using TPMP data was that the data were implicitly treated as a complete census of bird responses, with no acknowledgment of possible bias or measurement uncertainty. In many places, the guidance documents (for example, U. S. Army Corps of Engineers, 2005) used the terms “survey” and “census” interchangeably. The term Adult Census has become part of the vernacular for reporting on Missouri River terns and plovers. This term suggests that counts of tern and plover adults, nests, and fledglings are a complete and true census, which is now a widely accepted assumption. None of the guidance documents acknowledged that the many sources of measurement uncertainty for terns and plovers (for example, movements, double-counting, nondetection) make obtaining a true census extremely difficult.

A common use of TPMP data is to graphically describe long-term trends in adult abundance and compare the pattern to the population goal from the species recovery plan. For example, piping plover adult census data for 1986–2009 indicate dramatic changes in piping plover abundance over time, with numbers fluctuating above and below the recovery goal of 850 adults; however, the lack of measures of precision (that is, confidence intervals) complicates conclusions about the true underlying pattern in the data, particularly during periods when changes were slight (for example, 1992–95). This use of data also simultaneously presented measures of breeding population and adult abundance without acknowledging the important difference between them. For example, the piping plover recovery plan has a recovery goal of 425 breeding pairs for the Missouri River system, which was presented in the figure as 850 adults. Although it is true that 425 pairs would equate to 850 adults, a count of 850 adults would only equal 425 pairs if every adult was a breeder that was paired with another adult that was also counted. Hence, presence of nonbreeders and incomplete detection of adults would cause an adult count to inaccurately represent number of breeding pairs. Methods for deriving the Adult Census measure under the TPMP have also varied among years and among sites within years. At least four methods for counting adults [Total Adult Count, Visual Estimate, Best Guess Estimate, and 2*(Nests+Broods)] have been used in the past, with the choice among methods sometimes made by the field crew who collected the data and sometimes made by a program manager in the office.

Similarly, TPMP data are used to describe long-term trends in fledge ratio and compare annual measures to Biological Opinion fledge ratio goals. This analysis is linked to the Adult Census because the denominator of the predicted fledge ratio is Adults/2, therefore making the assumption that the Adult Census is a complete enumeration of breeding population. These types of data summaries have been presented annually, suggesting that tracking annual changes in breeding population and status relative to recovery goals is a high priority. These summaries also suggest that inference at the scale of the Missouri River is important.

Inferences at other spatial scales also are frequently supported with TPMP data. For example, the Emergent Sandbar Habitat (ESH) Program began constructing sandbars in 2005 as nesting habitat for terns and plovers. Various other management actions (for example, mowing, burning, herbicide) have been applied to natural sandbars to enhance value for nesting birds. The efficacy of these management actions has been evaluated using nest numbers, nest success, adult numbers, fledgling numbers, and fledge ratio data from the TPMP. Information about single sandbars has also been sought from the TPMP, with the data being used to portray trends in bird use and productivity on single sites over time. Similarly, TPMP data have been used to justify implementation of management actions (vegetation removal, predation management) at the sandbar scale; however, there have been no sampling design considerations built into the TPMP to accommodate evaluation of management questions or supporting implementation of sandbar-scale actions.

Use of the TPMP to obtain information about individual nests has become increasingly common. Most notably, assessing nest inundation risk and targeting nest-based management actions (deploying exclosures, raising or moving nests) are data uses that emphasize the need to understand biological processes and take action at the scale of individual nests. Several management actions meant to alleviate threats of nest mortality (for example, including deployment of predator cages on plover nests and adjustment of water levels to avoid inundation of low-elevation nests) are implemented based on assumptions that the nest database provides accurate information about at-risk nests. These data uses illustrate an assumption that the TPMP provides complete information on nests.

Annual incidental take reports have become a very visible application of TPMP data. These reports also imply complete counts of nests lost to Corps operations. Measuring incidental take is a new element of the TPMP, being completely absent from the 2005 guidance and first appearing in the 2009 guidance. Counts of lost nests considered incidental take are currently compared to limits established in the 2003 Biological Opinion Amendment, which were apparently derived in part using TPMP data. The incidental take limit is treated as an absolute standard and the annual count of flooded nests is treated as a true census. Thus, neither measure acknowledges that an unknown amount of information on nests lost to flooding is missing from the analysis and could affect the take limit and the annual incidental take value.

The Corps' program manager plays a pivotal role in translating field data into summaries presented in the TPDMS. Many decisions and manipulations of data are made between collection in the field and reporting in the TPDMS. Examples include determination of which flooded nests are reported as incidental take and how many adult birds are reported for the adult census. In most cases, the steps taken in these data manipulations are not documented, making it difficult to separate raw field observations from assumptions made based on interpretation of field data. Frequently, the original observations of the field crews become lost in the process, and the TPDMS reports present an unknown mixture of field-observed data and manipulated data.

2.4 Summary

The TPMP has changed substantially since its inception. It began as a series of surveys focused on measuring numbers of birds and locations of nesting colonies. Field crews submitted weekly written reports to a project manager, who summarized the data and prepared an annual report. There is no indication that weekly reports were used in decision-making, and the annual summary reports contained more descriptive information (locations of nesting colonies; condition of nesting habitat; causes of nest, egg, or chick losses; recommendations for habitat maintenance and creation) than quantitative information (adult birds per site, fledglings per site). The current program collects a wide array of field data and derives numerous daily quantitative reports on the status of the nesting season.

The changes documented in the three versions of the guidance manual did not always coincide with written revisions. For example, incidental take was not mentioned as a program element until the 2009 guidance, yet incidental take reports are available in the TPDMS dating back to 1993. It is likely that small program changes were implemented annually, but that guidance manuals were updated infrequently. It also appears that many of the changes documented in the 2005 and 2009 guidance had already been implemented when the manuals were written. Thus, the manuals are more accurately a retrospective description of how the program had changed, rather than a prospective analysis of its needs for the future.

Advancement in technology appears to have been a significant factor in the expectations and uses of TPMP data. The early program relied on written data sheets and faxed weekly reports, but the modern program makes field data available for decision-making on nearly a daily basis; however, it is not clear from the field manuals whether use of field computers and the TPDMS were prompted by an explicit, prospective need for daily updates on the status of the birds, or whether daily-scale questions were incorporated into the TPMP after technological advancement made daily data readily available. This is an important distinction, because an objective that is stated prospectively enables stronger inference and more reliable knowledge than one that is stated retrospectively (Sherfy and others, 2011). Although it is likely that the need for daily updates motivated these changes, no corresponding statement of objectives has been made or prioritized.

The program relies heavily on institutional knowledge and the discretion of the program manager, rather than written guidance that clearly documents program objectives and decision-making processes. The guidance documents are intended for field crews who implement the TPMP; they are not programmatic guidance, which may be the reason that some fundamental elements (statements of objectives, background on calculation of fledge ratios, breeding pairs, and incidental take) are lacking. Not only are the program's objectives not clearly stated, they are not well understood or agreed upon by the primary entities using the data for making management decisions. Having objectives, assumptions, and approaches clearly stated in writing would help ensure that the program produces reliable, scientifically defensible conclusions.

Additionally, the TPMP lacks a formal underlying sampling design and accordingly cannot readily deal with biases and cannot generate measures of precision about its estimates. Although it is designed as a complete census, there are practical limitations on completely enumerating any life stage of tern or plover populations on the Missouri River. These limitations are well-known and acknowledged throughout the guidance documents (for example, instructions on documenting broods in areas where no nest has previously been found). Accordingly, the TPMP is a sampling program with unknown statistical properties, and the values reported in the TPDMS are prone to unknown but potentially large biases. Many of these limitations are a direct consequence of the lack of clearly stated and measurable objectives.

3.0 Evaluation of the Monitoring Program

3.1 Background

Despite uncertainty about the highest priority objectives or data uses for monitoring of least terns and piping plovers on the Missouri River, one certainty is that the value of the monitoring program is dependent upon the quality of its data. In light of the ESA, status for both species and the many potential uses of monitoring data, particular attention to the validity of monitoring procedures is warranted. The program outlined in this section facilitates effective use of adaptive management by providing a critical assessment of ongoing monitoring programs. Coupled with an understanding about the highest priority prospectively stated objectives for tern and plover monitoring, this assessment will enable informed decision-making on appropriate metrics and procedures (including timing and frequency of surveys) for future monitoring efforts.

Productivity of upper Missouri River least terns and piping plovers currently is monitored by the Corps for a wide variety of conservation purposes. The utility of productivity parameters measured under the TPMP hinges on several key methodological questions that are related to species biology and are fundamental to the design of a monitoring program. Specifically, it is critical to understand the accuracy of counts that may be used for population modeling applications, as well as if counts are strongly correlated with the parameters they are assumed to index (that is, population size and trends). Data from the TPMP indicate spatial and annual variation in abundance (measured by adult counts) and productivity (measured by fledge ratios) of terns and plovers. Analyses of these parameters are used to make conclusions regarding effectiveness of the ESH management program, progress toward benchmarks in the Biological Opinion, and status and trends of tern and plover populations in the upper Missouri River system; however, there are several challenges and difficulties associated with monitoring tern and plover productivity that could affect confidence in conclusions drawn from these analyses. Each of the three principal biological elements addressed during monitoring (nests, fledglings, and adults) has its own unique set of challenges, including but not limited to the following:

Nests—Successful nesting attempts, defined as hatching at least one live young, are a fundamental requirement for population growth, and are one of the most readily monitored elements of productivity. A substantial amount of management effort on the Missouri River goes toward providing suitable nesting habitat and protecting known tern and plover nests from the principal sources of nest loss (flooding, predation, and human disturbance). Accordingly, the monitoring program focuses heavily on searching for and monitoring fate of nests. Length of the interval between investigator visits to a given nesting area can bias detection toward successful nests, potentially leading to underestimates of initiated nests and nest loss rate, and an inability to quantify causes of nest loss. Although true to some degree for all species, these considerations are of greatest significance to rare species for which limitations on productivity are a management concern.

Fledglings—Because recruitment into a breeding population first requires survival of young from hatch to fledging, indices of fledging rate may be useful indicators of population growth. For example, fledge ratio (fledglings/estimated breeding pairs) is used by the Corps and the Service to assess productivity of terns and plovers by Missouri River reach and for the entire upper Missouri River system. One of the principal challenges in counting fledglings is age- and habitat-specific variation in detectability of chicks. Least tern and piping plover chicks exhibit changes in their size and plumage during development that likely lead to differences in age-specific detectability (that is, they become less cryptic as they develop). Additionally, compared to piping plover chicks, least tern chicks are relatively inactive prior to fledging and hide among vegetation or other physical structure at older ages; however, just prior to fledging age, they become more active and are more easily detected because they spend more time on sandbar shorelines. It is difficult to reliably associate fledging-age tern chicks with nesting colonies because behavioral changes correspond with flight capability. Behavioral changes are less pronounced in piping plover chicks because they are precocial; however, physical features (for example, vegetation, rocky substrate) can make chick detection problematic.

Adults—A count of adults is presumed to be an index to number of breeding pairs, and therefore a correlate of *potential* productivity of the monitored area. This count, or a modified version of it, is incorporated into the fledge ratio (fledglings/estimated breeding pairs) reported by the Corps. The Corps uses a metric derived from a single count of adults or counts of nests and broods during a standard survey window in June as the input to this fledge ratio; however, a single count during a breeding season may not accurately portray breeding effort in an area, particularly where nest loss rate is high and adults move between nesting attempts. These uncertainties are further complicated by movements of adults between nesting and feeding areas and by the presence of an unknown number of nonbreeding adults. The fact that adult counts comprise breeders and nonbreeders makes the estimation of fledge ratio (number of young fledged/number of breeding pairs) particularly challenging. Despite potential inaccuracies in assessment, this parameter is key to determining whether recovery objectives and other conservation benchmarks are being met.

Our evaluation was designed to provide an assessment of accuracy for the TPMP, and provide a scientifically valid protocol that can guide future monitoring efforts. Revision of the existing protocol entailed reviews of existing data and procedures, as well as directed studies aimed at quantifying their accuracy. The evaluation had the following goals:

1. Assess the accuracy of existing procedures for monitoring the numbers of adults, nests, and fledged young and the survival rates and fates of nests.

2. Provide guidance on metrics needed to assess adult numbers and reproductive success of piping plovers and least terns and develop a standardized protocol for collecting compatible data.

3.2 Study Design

The field aspects of this evaluation were intended to address challenges specific to monitoring productivity of terns and plovers in reservoir and riverine environments. Although the Biological Opinion reporting requirements are specific to riverine environments, the Corps also monitors, manages, and reports aspects of tern and plover abundance and productivity on reservoirs.

Data collection followed a protocol structured to produce two estimates for each productivity parameter being evaluated (for example, nests, chicks, adults). Investigators in this design were the two agencies collecting tern and plover data (USGS and Corps). The goal of the USGS effort was to obtain complete information or at least highly accurate estimates on biological quantities of monitoring interest (for example, nests or chicks). The goal of the Corps' effort was to monitor as usual and obtain data having accuracy typical of the TPMP. The USGS and Corps crews worked mostly independently and USGS did not share any information about sites being searched, numbers of nests or birds under observation, or other biological information. Thus, the USGS data would represent appropriate benchmarks for assessing accuracy of data collected under the TPMP.

3.2.1 Study Areas

We selected three study areas for field work—two river reaches and one reservoir (fig. 1). According to Adult Census data in the TPMP, these three study areas accounted for 73 percent of the adult least terns and 74 percent of the adult piping plovers on the Missouri River system during June 2005 (the year prior to initiation of field work).

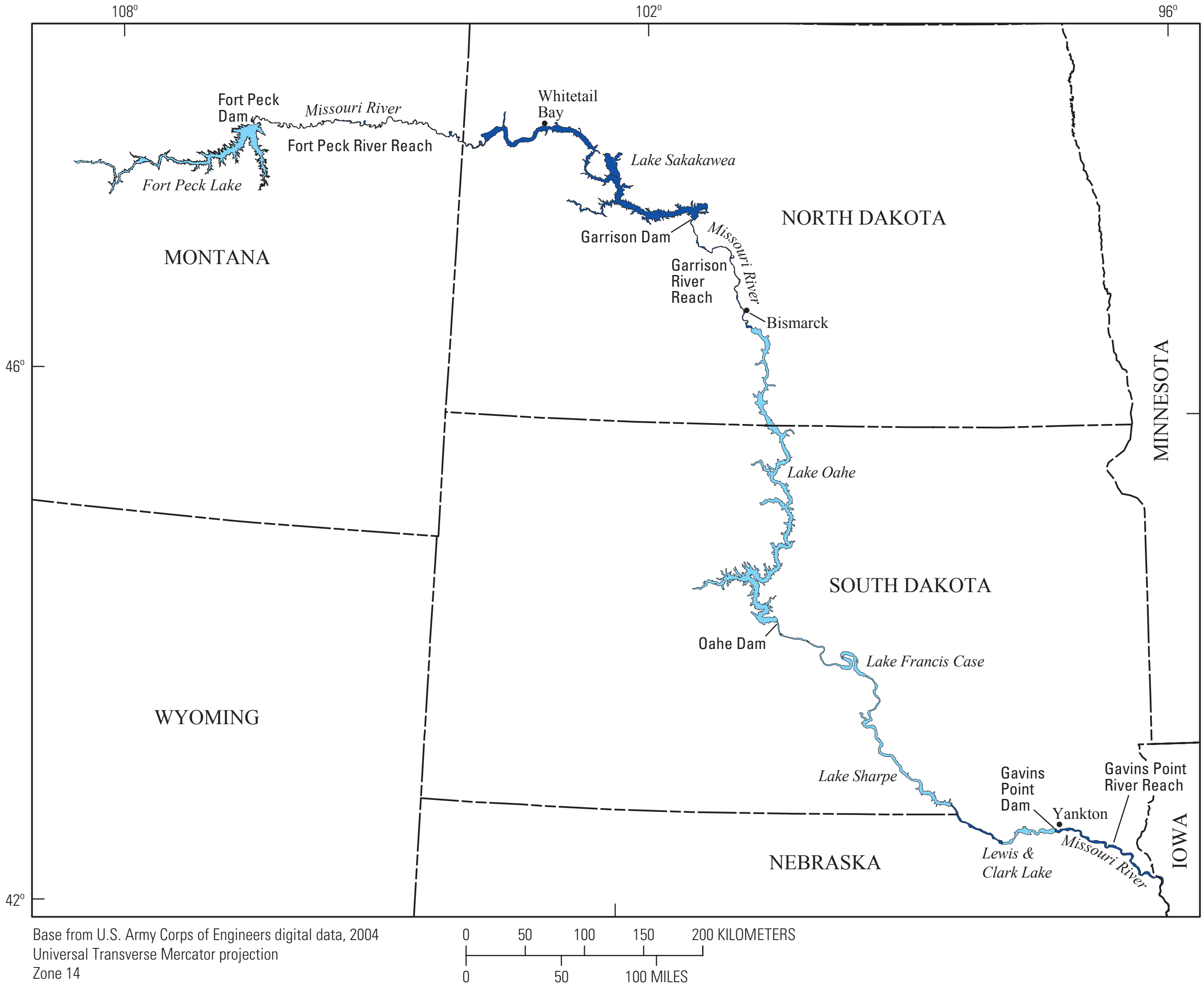
Gavins Point River Reach (GVP)—This study area began at the Gavins Point Dam [River Mile (RM) 811.0] near Yankton, S. Dak., and continued for 59 miles to Ponca State Park (RM 753.0), Nebr. (fig. 1). This study area contained the highest abundance of nesting least terns in the upper Missouri River system, as well as a substantial nesting population of piping plovers.

Garrison River Reach (GRR)—This study area began at the Garrison Dam (RM 1390) and continued for 86 miles to the headwaters of Lake Oahe (RM 1304) south of Bismarck, N. Dak. (fig. 1). This study area contained a moderate to high density of nesting terns and plovers.

Lake Sakakawea (SAK)—This study area was a mainstem impoundment of the Missouri River, ranging from the Garrison Dam to 178 river miles northwest (fig. 1). In the years leading up to this study, water levels of the lake had been declining as a consequence of below-average snowfall in the northern Rocky Mountains. The lake shoreline was used increasingly by nesting piping plovers between 1998 and 2005. SAK experienced record low water levels and very high use by piping plovers in 2005.

3.2.2 Sampling Units and Segmentation

We sought unbiased estimates of population parameters for each study area. We chose to obtain these estimates under probability-based sampling designs because the monitoring effort required to achieve complete (or nearly so) information on quantities of interest made complete censuses of



Base from U.S. Army Corps of Engineers digital data, 2004
Universal Transverse Mercator projection
Zone 14

Figure 1. Upper Missouri River system and study area locations.

study areas infeasible, particularly for SAK. For this reason, we anticipated that a modified TPMP would have to rely on probability-based sampling to make a reliable inference to an entire reach. Conducting our research under these principles helped us understand the need for supporting information, challenges, and data outputs of such a design throughout the Missouri River system.

Probability-based sampling involves collecting data on a subset of sampling units representative of some larger area of interest (for example, a complete study area). If sampling units (hereafter *"units"*) are spatially defined (as they are in this report), the complete set of units covers the entire area of interest, and units do not overlap (Cochran, 1977). Each sampling unit must have a nonzero probability of being selected for sampling (that is, of being included in the sample). Data collected on a probability-based sample of units can be used to generate unbiased estimates of the desired parameter for the larger area of interest. For example, enumerating nest numbers on a probability-based sample of units within a study area allows unbiased estimation of nest numbers for the entire study area, provided the total number of units in the study area is known.

Missouri River sandbars and shoreline beaches are ephemeral, and can vary considerably in abundance and distribution among years. These changes happen in response to varying water level, flow rate, and redistribution of sand. In many cases, these changes are substantial enough that units of habitat may be present in one year and absent the next, or may be one large unit in one year and several smaller units the next. Consequently, neither sandbars nor beaches represent a discrete, definable sampling unit, and the extensive changes in their acreage and distribution among years make it problematic to consider them as discrete sampling units (Sherfy and others, 2008). Thus, data collected on units of sandbars or beaches are not readily incorporated into a probability-based sampling scheme, and present challenges in deriving study-area-scale estimates of parameters.

A viable alternative is to divide each study area into sampling units that are spatially defined and do not change in abundance, form, or distribution. For the two river study areas, we created shape-files dividing each study area into adjacent units, with each unit being a fixed number of river miles (RM) in length and having the river bank as its outer limit. Units were 3 RM for the GVP (*N*=19) and 4 RM for the GRR (*N*=22). We used different unit lengths on each study area because of differences in habitat structure and bird numbers, our goal being that one crew should be able to completely search all suitable nesting habitat in two units in one day and be reasonably certain of finding nearly all active nests. Once established, unit boundaries were fixed for the duration of the study, but amount of habitat in a given unit could vary from year.

SAK is composed of shoreline and island habitats, and the extent ranges from Garrison Dam, N. Dak., to White Tail Bay, N. Dak. (fig. 1). The lower boundary of SAK was defined based on an elevation of 539 meters (m) mean sea level (m.s.l.) from digitized topographic maps from prior to the construction of the Garrison Dam. The upper boundary of SAK was defined as the maximum flood level of the reservoir (565 m m.s.l.).

We divided the shoreline into sampling units of approximately 2 kilometers (km) in length along the shoreline at an intermediate elevation of 554 m (fig. 2). Each unit division-line was drawn perpendicular to the shoreline, creating a polygon for each unit that would encompass all potential shoreline habitats for lake elevations greater than (>) 539 m. We identified islands within SAK that remain detached from the shoreline under most observed water levels. Islands were segmented or grouped (with other nearby islands) so that each island unit had a shoreline of approximately 2 km at an elevation of 554 m. As a result of water-level fluctuations, the length of the shoreline and the area of habitat within a unit varied annually.

3.2.3 Stratification and Sampling Fractions

The probability-based sampling approach can be further refined by assigning each unit to one of several strata, which are groups of units sharing similar properties. Stratified sampling takes advantage of known sources of variation in the quantity of interest. By dividing units into similar groups and sampling from each group, gains in overall precision of estimates can be realized if differences among groups are large relative to within-group variation (Cochran, 1977). We assigned each river or reservoir unit to a stratum based on historical use of the unit by nesting terns and plovers as documented in the TPDMS. We used spatial queries of the TPDMS data for the 5 years (8 years at SAK) prior to beginning field work on each study area to extract all TPDMS nest records for each unit. We examined the distribution of nest counts among units to identify natural break points in the data, and accordingly assigned each unit to a high-, medium- or low-use stratum. We also considered our research effort in determining stratum definitions. For river study areas, we aimed to include all of the high-use units, most of the medium-use units, and about one-half of the low-use units in our sample.

We partitioned GRR into 22 4-RM units and excluded 1 of these units from the sampling frame because it had no history of emergent sandbar habitat or nesting terns or plovers (unit starting at RM 1388; table 1). The remaining 21 units were assigned high, medium, or low use based on the number of tern and plover nests reported during 2001–05. Similarly, we partitioned GVP into 19 3-RM segments and assigned each segment to high, medium, or low use based on nest numbers reported by the TPMP during 2003–07 and information on locations of newly created engineered sandbars (table 2). On SAK, the low-use stratum was readily evident as those 2-km shoreline units with 0 or 1 nests during the prior 8 years, and we assigned the remaining segments to medium (2–9 nests) or high (>9 nests) use. The goal of stratification was to focus effort on areas that received greatest recent use or had potential to receive greatest future use by terns and plovers while also including a sample of lower-use units. This approach allowed for unbiased estimation of parameters of interest for the entire study area.

Our sample included 81 percent of 4-RM units at GRR, 84 percent of 3-RM units at GVP, and 6 percent of 2-km shoreline units at SAK (table 3). Sampling fractions were highest for the high-use stratum, intermediate for the medium-use stratum and lowest for the low-use stratum. One-hundred percent sampling of the high-use stratum and 80 to 100 percent sampling of the medium-use stratum of river study areas gave us confidence that we could estimate nest and chick numbers with a high degree of precision. We anticipated that the 6 percent overall sampling fraction for SAK would lead to considerable uncertainty in our estimates of the same parameters. We further believed it would be educational to quantify that uncertainty so that future monitoring programs could have reasonable expectations of precision.

3.3 Field Methods

We intensively surveyed nests, fledglings, and adults in an effort to obtain reliable information and accurate study-area-wide estimates. Nests and fledglings present different logistical challenges than adults, both being time intensive to survey, but with nests and fledglings generally receiving more attention during monitoring. We employed one sampling scheme involving intensive surveys of nests and marked chicks on the stratified sample of units described above, and another scheme involving extensive double-sampling (Eberhardt and Simmons, 1987) of entire river study areas to obtain estimates of adult numbers. Because of the massive effort required to obtain accurate estimates of population parameters, it was impractical to simultaneously sample all three disjunct

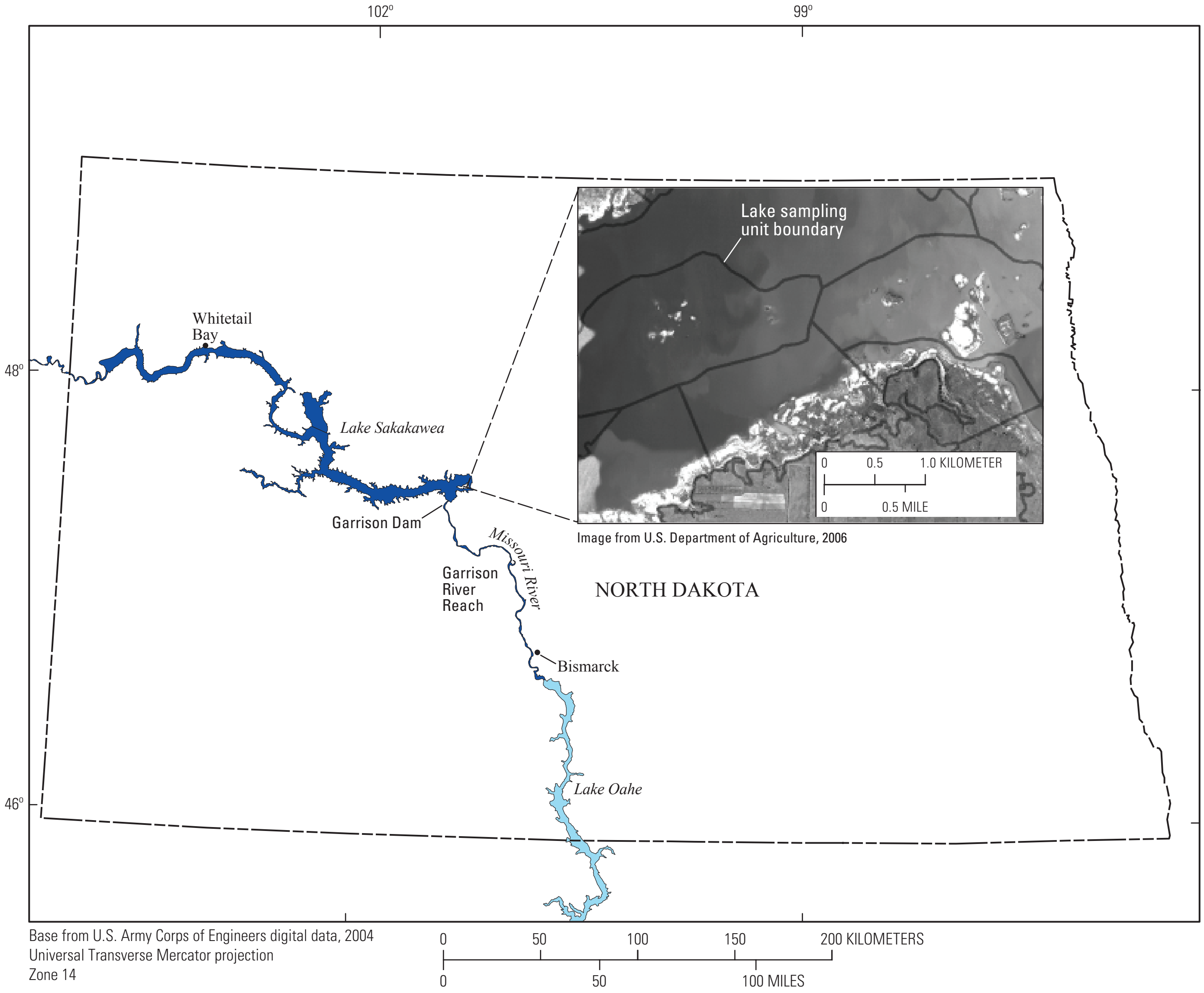


Image from U.S. Department of Agriculture, 2006

Base from U.S. Army Corps of Engineers digital data, 2004
Universal Transverse Mercator projection
Zone 14

Figure 2. North Dakota depicting Lake Sakakawea (shaded in dark blue) and an example of how the lake was segmented into sampling units.

study areas. Thus, we surveyed each study area for a 2-year period (GRR 2006–07, SAK 2007–08, GVP 2008–09) and staggered the timing of entry among study areas.

Lake Sakakawea is primarily used by piping plovers, although a small number of least terns also nest there. When the lake is in drawdown state, its exposed shoreline supports a substantial number of nesting plovers, but use by terns has never been known to be high. Accordingly, we anticipated that least tern data on SAK would be too sparse for analysis, and we focused our efforts there on piping plovers.

3.3.1 Nests

We completely searched all suitable habitats in each unit for tern and plover nests at approximately 2- to 3-day intervals, from the arrival of plovers on the study area in mid-April through the end of nest initiation in early August. On river-study-area sandbars that were bisected by a unit boundary, we only surveyed the sandbar if its centroid (geographic center) fell within the unit. Crews of 2–4 observers systematically walked grid patterns through nesting habitat, primarily looking for nests, but occasionally also searching based on the behavior of adult birds (more commonly used on reservoirs). We defined a nest as a scrape or depression in the substrate containing at least one egg. Nests destroyed or abandoned prior to discovery were excluded from nest survival calculations. On each subsequent nest-searching visit to the site, we thoroughly searched all suitable habitats, including previously searched habitats and any new habitat that was not present during previous searches. We also visited all known nests to confirm their status, fate, or both. During each visit, we

Table 1. Segmentation and stratification used on the Garrison River Reach of the Missouri River to obtain a probability sample of 4-river-mile units for estimating productivity parameters for least terns and piping plovers in 2006 and 2007.

[RM, river mile; Total nests, total number of tern and plover nests documented in the Tern and Plover Data Management System for the 5 years (2001–05) prior to the evaluation. Stratification was based on total nests in prior years. River miles in bold were randomly selected for study.]

Lower RM	Upper RM	Total nests	Stratum
1304	**1307**	56	High
1308	**1311**	77	High
1312	**1315**	4	Low
1316	**1319**	91	High
1320	1323	0	Low
1324	**1327**	35	High
1328	1331	16	Medium
1332	**1335**	53	High
1336	**1339**	22	Medium
1340	**1343**	3	Low
1344	**1347**	92	High
1348	**1351**	93	High
1352	**1355**	28	Medium
1356	**1359**	35	High
1360	**1363**	83	High
1364	**1367**	155	High
1368	**1371**	27	Medium
1372	**1375**	24	Medium
1376	1379	6	Low
1380	**1383**	6	Low
1384	1387	0	Low

recorded the presence of markers used by the Corps to identify nests, but we did not deploy any additional markers. We did not survey nests during rain, severe weather, or temperatures >90 degrees Fahrenheit.

On the day of nest discovery, we estimated incubation stage by flotation of one or more eggs (Mabee and others, 2006). We estimated nest initiation date by backdating from the discovery date, assuming one egg was laid per day (one egg every other day for plovers) excluding the first egg; if we discovered a nest with a single unincubated egg, we assigned the discovery date as the initiation date. We estimated hatch date by assuming a 20-day incubation period for least terns and a 25-day period for piping plovers. Near the estimated hatch date, we attempted to visit nests daily for two reasons. First, we wanted to minimize uncertainty in assigning nest fates (Grant and others, 2005). Second, a goal of our chick-banding approach was to band hatched chicks in the nest bowl so that chicks could be reliably associated with known nests and we would have accurate information on hatchling numbers.

Table 2. Segmentation and stratification used on the Gavins Point River Reach of the Missouri River to obtain a probability sample of 3-river-mile units for estimating productivity parameters for least terns and piping plovers in 2008 and 2009.

[RM, river mile; Total nests, total number of tern and plover nests documented in the Tern and Plover Data Management System for the 5 years (2001–05) prior to the evaluation. Stratification was based on total nests in prior years. River miles in bold were randomly selected for study.]

Lower RM	Upper RM	Total nests	Stratum	Engineered sandbars
754	**756**	362	High	No
757	**759**	73	High	Yes
760	**762**	233	High	Yes
763	**765**	0	Low	No
766	**768**	26	Low	No
769	**771**	445	High	Yes
772	**774**	3	High	Yes
775	**777**	85	High	Yes
778	**780**	98	Medium	No
781	**783**	129	Low	No
784	786	10	Low	No
787	**789**	248	High	No
790	**792**	56	Medium	Yes
793	**795**	224	Medium	No
796	**798**	32	Medium	No
799	**801**	122	Medium	No
802	**804**	225	Medium	No
805	807	35	Low	No
808	810	30	Low	No

We assigned one of five fates (successful, probable successful, failure, probable failure, unknown) to each nest based on observed evidence (Mabee, 1997), defining a successful nest as having hatched at least one egg. We classified a nest as successful only if we observed at least one live chick in the nest bowl, and as probable successful if other evidence (for example, eggshells, pipping fragments, chick droppings, chick tracks, or presence of chicks near the nest bowl) suggested that the nest had hatched (Page and others, 1985; Dirks, 1990). Nests were classified as probable failures when the eggs were missing but no other evidence was present to inform fate determination. Nests were classified as failed when the eggs were destroyed or were missing but could not have hatched based on the previously established incubation stage. When nest abandonment was suspected, we floated at least one egg during three successive nest visits before making a fate determination. When eggs were missing but the nest could have hatched based on the previously established incubation stage, we classified the nest as unknown fate. We recorded the nest fating date as the date on which evidence supporting our fate determination was first observed, although in some cases we

Table 3. Number of sampling units and sample sizes by stratum. Sampling fractions are also shown.

[N, number; n, number sampled; n/N, fraction; sampling units were 4-river-mile units at Garrison River Reach (GRR), 3-river-mile units at Gavins Point River Reach (GVP), and 2-kilometer shoreline or island units at Lake Sakakawea (SAK)]

Study area	Stratum											
	Low			Medium			High			Total		
	N	n	n/N	N	n	n/N	N	n	n/N	N	n	n/N
GRR	6	3	0.50	5	4	0.80	10	10	1.00	21	17	0.81
GVP	6	3	0.50	6	6	1.00	7	7	1.00	19	16	0.84
SAK	403	5	0.01	88	7	0.08	53	18	0.34	544	30	0.06

visited nests after the fating date to confirm fate determination (for example, abandoned nests) or estimate total number of hatched young.

We defined full clutch size as the number of eggs present when incubation was evident through egg floatation. Because we used this metric to represent reproductive investment by a breeding pair, we recorded a value only when evidence suggested that laying was complete and no eggs had been lost. We recorded a null value for nests destroyed before incubation began and for nests exhibiting evidence of broken eggs, parasitism, or a history of missing eggs prior to incubation.

3.3.2 Chicks and Fledglings

Nests were visited daily near the expected day of hatch. Minimum hatchling count (MINCHICKS) was the observed number of newly hatched chicks in or within 0.3 m of the nest. Maximum hatchling count (MAXCHICKS) was computed as MINCHICKS plus the total count of unknown-fate eggs from successful and unknown-fate nests.

Chicks were captured by hand at the nest site, typically within a day of hatch. We marked chicks of both species using a metal band and a unique combination of color bands. Least tern chicks received three celluloid color bands (two bands placed below the tibiotarsal joint and one above) and a size 1A stainless steel USGS metal band placed below the tibiotarsal joint. Piping plover chicks received as many as two Darvic color bands placed below the tibiotarsal joint on each leg, and a size 1A USGS aluminum band or colored Darvic flag on opposite legs above the tibiotarsal joint.

Following banding, each site was revisited every 2–3 days and chicks were resighted using spotting-scopes and by reading bands of physically recaptured chicks. Teams of surveyors systematically grid-searched against river flow, recording information on nest initiation and survival as well as chick recapture information. Piping plovers typically were recaptured visually based on color-band resighting, with physical recapture rare unless required for other concurrent studies (SAK, GVP). On SAK, concurrent studies on habitat use required tracking of plover broods, and so detailed information on prior locations was available to aid in resighting or recapture efforts. Least tern chicks often hid under objects or laid flat over their leg bands limiting ability to observe bands remotely. Most recaptures of least terns involved handling the bird which facilitated identification and maintenance of individual color-bands; upon release, terns were directed away from surveyors and toward the center of the site. As cohorts of least terns were approaching 15 days of age, additional effort was employed to promote physical capture of all near-fledging-age terns in a colony. After a sandbar had been systematically searched, surveyors walked the edge of the sandbar or shoreline to return to the entry point with minimal disruption to chicks or adults.

We monitored fledging-age chicks rather than fledglings. Counts of fledglings are problematic because the ability of surveyors to perceive fledging is limited, assumptions of closure for fledged birds (for example, movement of fledglings in and out of our survey units) are no longer valid, and in-flight fledglings can be mistaken for adults and vice-versa. We defined a fledging-age tern chick as a chick 14–18 days of age and a fledging-age plover chick as one 18–25 days of age. Analyses of chick survival in relation to chick age revealed that mortality dropped off substantially when chicks reached these ages (fig. 3). Our use of fledging-age chicks as a proxy for fledglings may have led to slightly liberal estimates, but this is uncertain because age at fledging varies among individuals.

3.3.3 Adults

We used double-sampling methodology (Eberhardt and Simmons, 1987) to survey adult terns and plovers on river study areas. Approximately once every 7 days we attempted to count adult terns and adult plovers within the full study area. We partitioned the GVP study area into four stretches and the GRR study area into three stretches of approximately equal size: for example, for GVP lower (RM 754–769), lower-middle (RM 769–781), uppermiddle (RM 781–796), and upper (RM 796–811). We considered location of boat ramps and the amount of habitat when choosing boundaries for the stretches. Four crews (three at GRR) of three technicians (hereafter “primary crews”) used jon boats to survey one stretch each by floating and motoring downstream, stopping occasionally as time permitted to survey on foot. Primary crews were rotated each week so that the same crew surveyed a given stretch once in every 4-week period (3-week period at

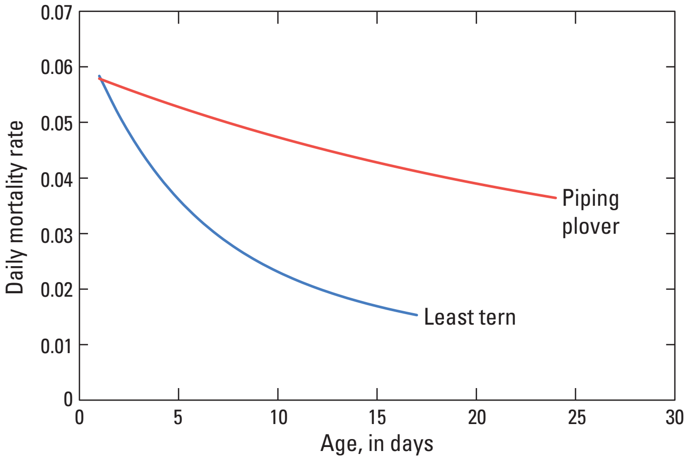


Figure 3. Observed daily mortality rate of least tern and piping plover chicks (2006–09) in relation to age.

GRR). Surveys commenced shortly after sunrise and generally were completed between 1000 and 1500. Surveys were done from mid-April to late July or early August. All observed adults were counted, including known breeding adults (for example, adults on nests) and adults of unknown breeding status.

In addition to the primary survey, 2 crews (1 at GRR) of 4 technicians did a second survey on 2 of 4 (1 of 3 at GRR) stretches, beginning approximately 30 minutes after the primary survey began. Stretches that were double-surveyed changed weekly so that each stretch was double-counted on average once every 4-week (3-week at GRR) period and so that each primary crew was observed approximately the same number of times. Each stretch was sub-divided into 3-RM units (2-RM units at GRR); 3 or 4 3-RM units (7 to 13 2-RM units at GRR) in each stretch were randomly chosen to be surveyed by a secondary crew. A new sample of survey units was randomly chosen for the secondary crew(s) each week. The secondary crews used boats and personal watercraft to navigate to and around sandbars that they surveyed. Secondary crews also accessed each sandbar on foot and made a concerted effort to obtain a count of adult least terns and plovers within each unit that was as complete as possible.

We also used double-sampling methodology to survey adult plovers and terns on SAK. During regularly scheduled productivity visits (3 times per week) on our 30 units we counted all adults we observed. We then calculated the mean number of adults for each unit by week and summed the unit means to produce a weekly estimate (hereafter primary survey). In the middle of each week a secondary survey of adults was done on 10 randomly selected units (hereafter "secondary survey"); each week a new sample of units was selected. The secondary crew was not responsible for collecting any other data and took enough time to thoroughly survey the entire unit on foot.

3.4 Data Analysis and Estimation

We used a mean-per-unit (MPU) estimator for stratified random sampling to extrapolate observed numbers of nests, hatched nests, chicks, fledging-age chicks, and breeding adults to the full study area and to estimate the standard error (SE) of the estimate (Levy and Lemeshow, 1991). Ninety-five percent confidence intervals for the study area total were obtained by taking the estimate plus or minus 1.96*SE. If the lower confidence limit was less than the observed total for nests and minimum number of chicks, we set the lower confidence limit equal to the observed total.

In situations where detection bias was known or suspected to be an issue (for example, counts of fledging-age chicks) and we were able to estimate detection probability, we computed the ratio of the expanded total divided by the estimated detection probability to account for the imperfect detection. Confidence intervals for the ratio were computed by taking ratios of the upper-to-lower and lower-to-upper confidence limits for numerator and denominator. We compared counts reported by the Corps to our estimates by computing *percent relative bias (hereafter "%Bias")*, the difference between the reported count and our estimate as a percentage of our estimate.

3.4.1 Nests

Finding and monitoring nests is fundamental for measuring avian productivity and assessing threats. Accordingly, evaluating bias in nest numbers under the TPMP was a central element of the evaluation. We used MPU-estimators to generate study-area-scale estimates of the total number of tern and plover nests and hatched tern and plover nests for each study area and year in the evaluation. We compared these estimates to reported nest numbers and hatched nest numbers in the TPDMS, and calculated *%Bias* for each comparison. We included successful and probable successful nests when tallying hatched nests.

We recognized that our counts of nests were subject to imperfect detection and we quantified that by estimating nest detection probability. Under the assumption that daily nest detection probability (DNDP) was homogeneous among and within nests, we estimated DNDP, conditional on a nest being active, as the number of nests found divided by the cumulative number of opportunities to find those nests. Number of opportunities to find a particular nest was determined from the number of times the habitat unit (for example, sandbar) was nest-searched subsequent to the nest being initiated and before being found. For example, a nest initiated on day 120 and discovered on day 130 on a sandbar that had been searched on day 123 and 127 would be credited with three opportunities for discovering that nest. We further estimated the probability of detecting a nest that progressed at least into early incubation as $1-(1-\text{DNDP})^3$, reasoning that we would have at least three opportunities to detect the nest before it failed. Similarly, we estimated the probability of detecting a successful nest as $1-(1-\mathrm{DNDP})^7$, reasoning that we would have at least seven opportunities (more for plovers) to detect the nest before the eggs would hatch.

We used the logistic-exposure method (Shaffer, 2004) to examine variation in nest survival relative to nest initiation date and cumulative monitoring impact (CMI), which we defined as the number of times a nest was approached by research or monitoring crews (that is, USGS plus Corps approaches), relative to the length of time the nest was under observation. For example, a nest under observation for 4 days received a CMI value of 1.0 if approached four times during the interval and a value of 0.5 if approached two times during the interval. We defined an approach as a USGS monitoring or research event (nest visit, chick search, or secondary adult survey) within 50 m of a nest or a recorded visit to the sandbar by a Corps monitoring crew. CMI was computed for GRR and SAK only, because we did not have a complete record of research events by other researchers at GVP. Even if we had, most GVP sandbars were visited frequently enough that the range in CMI values would likely have been small. We estimated study-area-wide nest success by raising daily survival rates to the 24th (terns) or 35th (plovers) power. These values correspond to the average length of laying plus incubation for the two species.

We used two approaches to determine which nests found by USGS crews had also been found by Corps crews. The Corps marked most nests with a numbered tongue depressor that allowed us to link USGS and TPMP data; however, the tongue-depressor marker was absent on some nests under Corps surveillance, so we used Universal Transverse Mercator (UTM) coordinates to map the location of all USGS and Corps nests that could not be linked based on Corps markers. We looked for pairs of Corps and USGS nests that were within the likely GPS error distance (approximately 1 meter) and that also had similar features (for example, nest initiation date, egg number). The Corps nest from each matching pair was classified as found by the TPMP, and all remaining USGS nests that could not be paired with a Corps nest were classified as missed by the TPMP.

We evaluated the accuracy of the TPMP at assigning fates by cross-tabulating fates assigned by USGS and Corps crews for found nests. The probable failure code was rarely used by USGS crews (n=12 nests, only 2 of which were found). Thus, all nests coded as probable failures were included with failed nests for this analysis. Because an important element of the evaluation was to illustrate information loss resulting from nests being overlooked, we also report a summary of fates for nests missed by the TPMP monitoring crews as recorded in the evaluation dataset.

Overlooked nests also provide an opportunity to learn about ways the monitoring program might be adjusted to minimize the number of missed nests. We identified four primary factors that might lead to a nest being missed, but we assigned only one factor to each missed nest. We used a sequential classification in which we determined which missed nests met the first factor criterion, removed those nests from further consideration, then determined which nests met the second factor criterion, and so on:

1. Late Start Date—TPMP field crews often began regular nest surveys several weeks after the nesting season started, allowing time for nests to be initiated and fail before monitoring began. The Corps provided a start date for TPMP monitoring for each study area and year, and we assigned this factor to all nests with termination dates prior to the monitoring start date.

2. Habitat Not Searched—Nests may be missed if the sandbar or shoreline where they are located is never visited by TPMP monitoring crews. We used River Miles from TPDMS data to determine which sites had been searched by TPMP crews. We assigned this factor to any remaining missed nests at locations not visited by TPMP crews.

3. Search Interval Too Long—Nests that are initiated and fail between TPMP-monitoring visits would not be detected. We used TPMP visit records from active nests to determine when each sandbar or shoreline was visited by TPMP crews. Nests passing the first two queries were assumed to be on sandbars or shorelines that were searched by TPMP crews and were active after the start date of monitoring. Any such nest that did not have a TPMP visit to its sandbar or shoreline while it was active (that is, between its initiation and termination dates) was assigned this factor.

4. Vigilance/Search Pattern—Nests that did not meet any of the above criteria should have been detected if the habitat was thoroughly searched. Thus, we assumed that all remaining nests escaped detection at least once by a crew that was otherwise in the right place at the right time.

3.4.2 Chicks and Fledglings

Quantifying production of chicks and fledglings is a fundamental need for determining avian productivity and assessing threats. Accordingly, evaluating bias in chick and fledgling numbers under the TPMP was another central element of the evaluation. We used MPU estimators to generate study-area-scale estimates of the total number of tern and plover chicks (that is, hatchlings) and tern and plover fledging-age chicks for each study area. Because of uncertainty in the fate of some eggs, we computed maximum and minimum estimates of chicks and fledging-age chicks. Counts of fledging-age chicks were corrected for nondetection based on estimates of detection probability described below. We compared study-area-wide estimates of chicks and fledging-age chicks to chick and fledgling numbers reported in the TPDMS, and calculated relative bias for each metric.

We built Cormack-Jolly-Seber (CJS) recaptures-only models in program RMark 2.0.1 and MARK (Laake, 2011; White and Burnham, 1999) to estimate the detection probability (p) of least tern (n=1,635) and piping plover (n=1,318) chicks from hatch through 18 and 25 days of age, respectively. We estimated detection probabilities for the six possible combinations of species by study area: Piping plovers at GRR (*n*=354), piping plovers at GVP (*n*=713), piping plovers at SAK (*n*=251), least terns at GRR (*n*=335), least terns at GVP (*n*=986), and least terns at Lewis and Clark Lake (*n*=1314). Although Lewis and Clark Lake was not a focus of the evaluation, we included chick detection data from there (2007–08), from GVP (2006–07) and from SAK (2006, 2009) to bolster sample size for estimating *p*.

CJS models concurrently estimate detection probability and apparent survival (φ), which is the probability an individual survives between sampling occasions and remains on the monitored study area (Sandercock, 2006). Because our primary interest in this analysis was estimating detection probability, we chose a parameterization for apparent survival that we believed to be biologically reasonable. This apparent survival parameterization was then used in all subsequent models as we determined the best parameterization for detection probability. Our parameterization of apparent survival posited that for each group (that is each study area by species combination) survival varied according to a constant log-linear trend of age in least tern and piping plover chicks [φ (species*study area*age)], where ‘*’ indicates a multiplicative relation among model parameters. Although this is not the most highly parameterized model, it has been previously shown to be a well-supported model for daily apparent survival in plover chicks (Colwell and others, 2007; Dinsmore, 2008; Roche and others, 2010).

Once we had developed a model that accounted for variation in detection probabilities, we added a monitoring impact covariate to determine if frequent monitoring activities affected apparent survival. Using individual capture histories, we created an individual occasion-specific covariate that posited a tapering effect of monitoring impact on daily survival rates. On a day during which a site was the subject of a targeted search (that is a chick had an encounter history value of either “1” or “0”) the monitoring covariate value was equal to “3”, a “2” on the day following a search if the site was not visited (that is a chick had an encounter history value of ‘.’), and a “1” on the second day following a search (Rotella and others, 2004; Roche and others, 2010). This tapering pattern was reset at each new site visit (that is for a capture history of “11”, then the occasion specific covariate would be “3321”) and remained at zero after three days had passed. We built models in which the impact of monitoring was (1) the same for both species and (2) variable depending on species. We considered a drop in Akaike’s Information Criterion corrected for sample size and overdispersion (QAICc; Burnham and Anderson, 2002), relative to our best model without this covariate, as evidence in support of the monitoring impact covariate.

One pertinent information need from the monitoring program is the number of fledged chicks. We estimated the probability of detecting a fledging-age least tern or piping plover chick at least once during a user-specified number of site visits (2, 3, 4 or 5) based on age-dependent detection probability estimates generated by program MARK. We used age-dependent daily detection probabilities for each species-by-study area combination from a simplified model of detection, including the covariates of age, number of hours searched, and crew size. These detection probabilities represented the probability that a chick was detected on a single visit under conditions specified by the covariates. As site visits may result in recaptures of mixed aged chicks, we built a simulation model where in each iteration a number of ages corresponding to the number of site visits were randomly chosen from a uniform distribution defined by the fledging-age range for the species of interest (that is 4 site visits for piping plovers yielded 4 ages selected between 18–25 days). The corresponding estimate of age-dependent daily detection probability and its standard error were then selected from the species-by-study area specific MARK estimates. We used these values to generate a beta-distributed, age-dependent detection probability for each age (that is the number of which corresponded to the number of site visits) randomly chosen for that iteration. To determine the age-dependent daily probability of not detecting a chick, we subtracted these values from 1.0 (for example for four site visits we generated four daily probabilities of not detecting a chick). Thus, the simulation allowed us to estimate probability of detecting a fledgling under various monitoring conditions.

To determine the probability of detecting a fledging-age chick at least once in as many site visits, we multiplied each daily probability of not detecting a chick and then subtracted this product from 1.0. We iterated this process of randomly selecting ages and generating age-dependent daily detection probability 1,000 times for each combination of group (that is species-by-study area combination), number of visits (3–5 for plovers, 2–5 for terns), number of hours searched (1–3 hours), and crew size (2–4 workers). We generated mean detection probabilities and 95-percent confidence intervals from the values of these 1,000 iterations.

3.4.3 Adults

We viewed our primary crew counts as subject to detection error in the form of over- or undercounting; however, we assumed that secondary crew counts reflected actual number of adults present at the time of primary and secondary surveys. Our primary and secondary crew counts were close in time to minimize potential for movements that would violate this assumption. We modeled the relation between secondary and primary crew counts as follows:

$$Y_{ij} = \beta_{ij} + \theta_{ij} X_{ij} + \varepsilon_{ij}, \tag{1}$$

where

Y_{ij} is the secondary crew count on unit i during survey j,

X_{ij} is the primary crew count on unit i during survey j,

β_{ij} is an unknown intercept parameter for unit *i* and survey *j*,

θ_{ij} is an unknown slope parameter for unit *i* and survey *j*,

ε_{ij} denotes random variation assumed to follow a normal distribution.

The parameters β_{ij} and θ_{ij} allow for the possibility of over- or undercounting by primary crews. We considered models in which θ_{ij} was assumed constant among units, weeks, or both; and we considered models in which θ_{ij} was allowed to increase or decrease monotonically with survey number, vary in proportion to the amount of bare or sparsely vegetated sandbar habitat (dry sand plus wet sand) within a survey unit, increase or decrease with primary crew size, vary with date-specific flow (flow metrics were unit-specific for GVP but not unit-specific for GRR), or vary with three weather metrics. Weather metrics were precipitation versus no precipitation, wind less than (<) 7 kilometers per hour (kmph) vs. wind greater than or equal to (≥) 7 kmph, and temperature (log-transformed) recorded at the actual time of the survey.

Detection models were fit with PROC GENMOD (SAS Institute, 2004) and evaluated via Akaike's Information Criterion adjusted for sample size (AICc; Burnham and Anderson, 2002). We used the top-supported model to estimate *Y* for units surveyed only by primary crews. Total number of adults for the study area was estimated by summing secondary crew counts for units that were double-surveyed and estimated counts for units surveyed only by primary crews. The standard error in the estimated total reflects variation in detection rate.

3.4.4 Breeding Population

We defined the breeding population (BPOP) for a study area as the number of adults that attempted ≥1 nest within the study area. Our ultimate goal was to arrive at an unbiased estimator of BPOP. We defined a metric to represent the absolute minimum BPOP that could be inferred by evidence from periodic nest monitoring. The metric (MINBPOP) was based on the sum of active nests, recently failed nests that had advanced to incubation, and previously hatched nests for each day of the nesting season. Unit-specific values were expanded to reflect the study area total for each day of the nesting season. MINBPOP was computed as the maximum value of the study area total across all days of the nesting season. A nest was considered active on a given day if it was visited and determined to be active on that day, or it was not visited that day but was determined to be active on the most recent prior visit. A nest was considered recently failed if it had advanced to incubation and was known or believed to have failed within a prescribed interval of time [hereafter minimum renesting interval (MRI)] preceding the day in question. MRI was set to 5 days for piping plover (Roudybush and others, 1979; Amat and others, 1999) and to 9 days for least tern (Wendeln and others, 2000). Nests that failed prior to reaching incubation were not included when calculating MINBPOP because they could have indicated the same breeding pair as a continuation nest located on the day in question. Previously hatched nests included any nest fated as successful (known or probable) on an earlier visit or on the day in question.

MINBPOP will be less than or equal to (≤) BPOP if the following conditions are met:

- The male and female of a breeding pair have only one nest active on any single day of the breeding season.
- The interval between failure of a nest that has reached incubation and the initiation of a new nest (that is when laying commences) by either adult is >MRI.
- Individual males or females contribute ≤1 successful nest (that is double-brooding does not happen or happens at inconsequential levels).

Note that the above conditions do not preclude mate-swapping.

Considering the aforementioned assumptions, daily MINBPOP estimates will almost always underrepresent the true BPOP, and the study-area-wide maximum will also underestimate BPOP unless nesting synchrony is high. For example, breeding pairs that made multiple attempts may not be accounted for by MINBPOP if none of their nests were active on the day that MINBPOP attained maximum value or none of their nests had recently failed. A special but uninteresting case in which MINBPOP will not underrepresent BPOP is when all nests are successful (that is, nest success is 100 percent).

The above considerations led us to undertake a simulation study to investigate the properties of MINBPOP under various situations and to assess its utility in estimating BPOP. We developed SAS code to simulate nesting populations of known size and properties that included timing of nest initiations, nest success rate, renesting probability, and MRI (table 4). Timing of first-nest initiations was based on observed temporal distributions of nests; scenarios corresponding to observed patterns for each year and study area were considered (six scenarios for plovers and four for terns). Five levels of nest success were considered: high constant, intermediate constant, low constant, low to high within season, and high to low within season (table 4). Two levels of renesting probability and MRI, both tailored to the species, were considered (table 4).

Each simulated breeding population was subjected to four simulated monitoring scenarios (table 4). Monitoring scenarios were characterized by either semi-weekly (that is, every 3 days) or weekly surveys for nests and either intermediate or high nest detection. Nest detection was defined as the probability of detecting a nest conditional on the nest being active on the day of the simulated search. A low-detection scenario was not considered because plovers and terns nest in open areas and adults and nests are usually highly visible.

The focus of our simulations was the relation between MINBPOP and BPOP, which we quantified by the ratio MINBPOP to BPOP. A value equal to 1.0 indicates perfect detection and no bias in MINBPOP as an estimator of BPOP. Values

Table 4. Input parameters to simulation study of the performance of minimum breeding population size as an estimator of breeding population size for Garrison River Reach (2006–07), Gavins Point River Reach (2008–09), and Lake Sakakawea (2007–08).

[GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; Timing of first-nest initiations was based on observed temporal distributions of nests. Five levels of nest success, two levels of renesting probability, two levels of minimum renesting interval (MRI), two levels of monitoring frequency, and two levels of nest detection were considered.]

	Piping plover	Least tern
	Properties of the breeding population	
Timing of first nests	GRR 2006 (fig. 4) GRR 2007 (fig. 4) GVP 2008 (fig. 4) GVP 2009 (fig. 4) SAK 2007 (fig. 4) SAK 2008 (fig. 4)	GRR 2006 (fig. 7) GRR 2007 (fig. 7) GVP 2008 (fig. 7) GVP 2009 (fig. 7)
Nest success probability	High constant (0.6) Intermediate constant (0.3) Low constant (0.05) Low to high within season (0.05–0.6) High to low within season (0.6–0.05)	High constant (0.8) Intermediate constant (0.5) Low constant (0.2) Low to high within season (0.2–0.8) High to low within season (0.8–0.2)
Renesting probability	High (0.9–0.4) Low (0.5–0.1)	High (0.9–0.3) Low (0.5–0.1)
MRI	Short [~uniform (2,4)] Long [~uniform (6,8)]	Short [~uniform (7, 9)] Long [~uniform (10,14)]
	Properties of the monitoring program	
Monitoring frequency	Semi-weekly (every 3 days) Weekly	Semi-weekly (every 3 days) Weekly
Daily nest detection probability	High (0.9) Intermediate (0.5)	High (0.9) Intermediate (0.5)

< 1.0 indicate negative bias in MINBPOP as an estimator of BPOP, with the percent bias increasing as the ratio of MINBPOP to BPOP decreases. Because our interest was in estimating the detection ratio (MINBPOP divided by BPOP), we simulated large breeding populations (that is, 10,000 breeding pairs). We determined that simulated populations of this size were sufficient to reduce stochastic variability in the detection ratio to a negligible amount.

We used simulation results to develop a regression model that allowed us to estimate the detection ratio under actual conditions encountered in the field. Specifically, we based our estimate of the detection ratio for a given year and study area on the observed temporal distribution of nests, the observed nest success rate, semi-weekly nest monitoring, and conditional nest detection probability equal to 0.5. Semi-weekly nest monitoring matched our monitoring protocol and conditional nest detection probability of 0.5 was consistent with estimates from our study (see Results section). By observing MINBPOP under a specific set of field conditions and by estimating the detection ratio for the same set of conditions, we were able to estimate BPOP as MINBPOP divided by the estimated detection ratio. We had no way of assessing renesting probability from field data, so we report a range of BPOP estimates based on simulations of low and high renesting probability.

3.5 Results

3.5.1 Nests

Daily detection probabilities of plover nests by USGS crews varied from 0.41 (GVP 2008) to 0.65 (GRR 2006) (table 5). Assuming at least three opportunities to discover a nest that reached incubation, we estimated that we discovered ≥ 80–96 percent of plover nests that advanced to the incubation stage. Discovery of a successful nest was virtually certain with probabilities ranging from 0.98 to 1.00 (table 5).

Daily detection probabilities of tern nests varied from 0.44 (GVP 2008) to 0.49 (GRR 2006) (table 5). Assuming at least three opportunities to discover a nest that reached incubation, we estimated that we discovered ≥ 83–86 percent of tern nests that advanced to the incubation stage. Discovery of a successful nest was virtually certain with probabilities ranging from 0.98 to 0.99 (table 5).

Relative bias in Corps estimates of total nest numbers ranged from -75 percent to -13 percent (table 6). Bias was greatest on SAK, where the USGS expanded estimate was 3–4 times greater than the number of nests reported in the TPDMS. Bias was lowest on the GVP, where birds were concentrated on a few constructed sandbars. For the 4 years of GVP and GRR data, bias in the Corps counts was consistently lower for least terns than for piping plovers.

Hatched nest data indicated the same general pattern in relative bias as did total nests, being greatest on SAK and least on GVP (table 7). For plovers on GVP, the Corps reported a greater number of hatched nests than the USGS expanded estimate, leading to positive bias in both years. Corps reports of hatched nests were moderately lower than the USGS estimates for least terns on GVP, and underestimation of hatched nests was substantial on GRR.

The Corps' reported apparent nest success was higher than the USGS nest success estimate in all cases, and there was a clear trend for plover nest success to be more strongly biased than tern nest success (table 8). Using the Mayfield method did not completely remove bias in the Corps' nest success estimates; there was a modest improvement in bias for most data sets, and an extreme overcorrection that produced a negative bias for piping plovers on SAK. The most severe bias

Table 5. Daily detection probabilities for least tern and piping plover nests on three Missouri River study areas, 2006–09, along with probability that a nest would be detected in three and seven visits.

[LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea]

Species	Study area	Year	Number of opportunities	Number of detections	Daily detection probability	95-percent confidence interval	Three visits	Seven visits
LETE	GRR	2006	241	117	0.49	0.42–0.55	0.86	0.99
LETE	GRR	2007	227	107	0.47	0.41–0.54	0.85	0.99
LETE	GVP	2008	436	194	0.44	0.40–0.49	0.83	0.98
LETE	GVP	2009	290	136	0.47	0.41–0.53	0.85	0.99
PIPL	GRR	2006	366	237	0.65	0.60–0.70	0.96	1.00
PIPL	GRR	2007	411	205	0.50	0.45–0.55	0.87	0.99
PIPL	GVP	2008	572	237	0.41	0.37–0.45	0.80	0.98
PIPL	GVP	2009	314	194	0.62	0.56–0.67	0.94	1.00
PIPL	SAK	2007	202	107	0.53	0.46–0.60	0.90	0.99
PIPL	SAK	2008	167	86	0.51	0.44–0.59	0.89	0.99

Table 6. Estimated total least tern and piping plover nests on the Missouri River in 2006–09, as determined by U.S. Geological Survey research crews (count, expanded estimate, and 95-percent confidence interval) and U.S. Army Corps of Engineers monitoring crews.

[LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Species	Study area	Year	Total nests				
			USGS count	USGS expanded estimate	USGS 95-percent confidence interval	Reported by Corps	Relative bias (percent)
LETE	GRR	2006	120	125	120–136	79	-37
LETE	GRR	2007	103	112	103–127	75	-33
LETE	GVP	2008	196	201	196–215	156	-22
LETE	GVP	2009	136	141	136–155	123	-13
PIPL	GRR	2006	242	262	242–291	109	-58
PIPL	GRR	2007	199	222	199–258	126	-43
PIPL	GVP	2008	237	249	237–278	181	-27
PIPL	GVP	2009	194	196	194–202	170	-13
PIPL	SAK	2007	107	537	299–774	136	-75
PIPL	SAK	2008	86	436	241–631	138	-68

Table 7. Estimated hatched least tern and piping plover nests on the Missouri River in 2006–09, as determined by U.S. Geological Survey research crews (count, expanded estimate, and 95-percent confidence interval) and U.S. Army Corps of Engineers monitoring crews.

[LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Species	Study area	Year	Hatched nests				
			USGS count	USGS expanded estimate	USGS 95-percent confidence interval	Reported by Corps	Relative bias (percent)
LETE	GRR	2006	73	76	73–86	47	-38
LETE	GRR	2007	69	77	69–92	57	-26
LETE	GVP	2008	125	127	125–133	107	-16
LETE	GVP	2009	97	100	97–108	93	-7
PIPL	GRR	2006	66	72	66–83	52	-28
PIPL	GRR	2007	104	120	104–144	80	-33
PIPL	GVP	2008	107	111	107–118	118	6
PIPL	GVP	2009	88	88	88–88	89	1
PIPL	SAK	2007	27	128	56–199	51	-60
PIPL	SAK	2008	18	92	38–145	58	-37

Table 8. Estimates of nest success for least terns and piping plovers on the Missouri River in 2006–09, as determined from data collected by U.S. Geological Survey research crews and by U.S. Army Corps of Engineers (apparent and Mayfield nest success) monitoring crews.

[LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers; U.S. Geological Survey nest success estimates are from a logistic-exposure analysis (Shaffer, 2004) and are comparable to Mayfield estimates.]

Species	Study area	Year	Percent nest success				Relative bias (percent)	
			USGS estimate	USGS 95-percent confidence interval	Corps reported apparent	Corps reported Mayfield	Corps reported apparent	Corps reported Mayfield
LETE	GRR	2006	65	54–73	77	76	18	17
LETE	GRR	2007	78	68–85	89	87	14	12
LETE	GVP	2008	66	59–73	75	69	14	5
LETE	GVP	2009	73	64–80	79	76	8	4
PIPL	GRR	2006	21	16–27	54	46	157	119
PIPL	GRR	2007	47	39–54	73	65	55	38
PIPL	GVP	2008	42	35–48	67	53	60	26
PIPL	GVP	2009	41	34–49	54	46	32	12
PIPL	SAK	2007	25	17–33	41	12	64	-52
PIPL	SAK	2008	28	19–37	44	16	57	-43

was for piping plovers on the GRR in 2006, when the Corps' apparent nest success estimate (54 percent) was 2.5 times higher than the USGS estimate (21 percent).

We documented 635 nests that were missed by the TPMP during monitoring (table 9). Raw numbers of missed nests generally were greater for plovers than for terns, and were particularly high for GRR in 2006 (*n*=145 missed nests). Failed nests (*n*=448) accounted for 70 percent of the missed nests, but hatched (successful plus probable successful) nests (*n*=139) were also common in the dataset. Although fewer least tern nests tended to be missed than piping plover nests, the proportion of missed nests that hatched was substantially higher for terns (32–47 percent) than for plovers (3–24 percent).

Table 9. Numbers and fates of nests missed by the Tern and Plover Monitoring Program of least terns and piping plovers on the Missouri River in 2006–09. Fates were determined by U.S. Geological Survey research crews.

[LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea]

Species	Study area	Year	Fate					Total
			Successful	Probable success	Probable failure	Failed	Unknown	
LETE	GRR	2006	13	2	2	22	8	47
LETE	GRR	2007	12	6	0	13	7	38
LETE	GVP	2008	15	2	0	28	2	47
LETE	GVP	2009	6	1	0	10	0	17
PIPL	GRR	2006	6	10	4	118	7	145
PIPL	GRR	2007	6	15	0	61	4	86
PIPL	GVP	2008	13	4	0	59	2	78
PIPL	GVP	2009	1	0	0	38	0	39
PIPL	SAK	2007	9	6	4	55	4	78
PIPL	SAK	2008	5	7	2	44	2	60
Total			**86**	**53**	**12**	**448**	**36**	**635**

We generated cross-tabulation tables for fates of nests found by both USGS and Corps crews for each species, study area, and year (tables 10–19), as well as summary tables by species (tables 20–21). Diagonal elements in these tables reflect nests for which the two independent fate determinations agreed (that is, both crews assigned the same fate). Although we report successful and probable successful fates separately, we initially combined these fates to assess fate agreement. When the two fates were combined, agreement in fates between the datasets was good [82 percent for terns (table 20), 84 percent for plovers (table 21)]; however, when the two fates were treated separately, fate agreement was 37 percent for terns and 55 percent for plovers. This was largely because a high number of nests fated as successful by the USGS crew and probable successful by the Corps crew (*n*=172 for terns and *n*=167 for plovers). These nests represented a much greater percentage of the dataset for terns (42 percent) than for plovers (28 percent). The USGS nest fate “successful” was only assigned if chicks were observed in the nest bowl, which was indisputable evidence of success. Of these nests, a small percentage was fated as “failed” or “unknown” by the Corps [*n*=25 (10 percent) for terns, *n*=16 (7 percent) for plovers].

Most of the missed nests (*n*=399; 63 percent; table 22) were attributed to the Vigilance / Search Pattern factor. However, this factor was far more frequently assigned to tern nests (*n*=126; 85 percent of missed tern nests) than to plover nests (*n*=273; 56 percent of missed plover nests). There was also a substantial species difference in the Late Start Date factor, which was assigned exclusively to plover nests (*n*=82; 17 percent of missed plover nests). The Habitat Not Searched factor was assigned to an approximately equal percentage of tern (9 percent) and plover (7 percent) nests, but the Search Interval Too Long factor was more frequently assigned to plover (*n*=96; 20 percent of missed plover nests) than to tern (*n*=9;

Table 10. Fates of least tern nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Garrison River Reach in 2006.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	9	1	0	0	10
Probable success	29	8	0	1	38
Failed	0	0	9	0	9
Unknown	10	2	5	1	18
Total	**48**	**11**	**14**	**2**	**75**

Table 11. Fates of least tern nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Garrison River Reach in 2007.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	9	3	0	0	12
Probable success	22	16	1	4	43
Failed	0	1	3	1	5
Unknown	2	2	3	4	11
Total	**33**	**22**	**7**	**9**	**71**

Table 12. Fates of least tern nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Gavins Point River Reach in 2008.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	17	10	0	1	28
Probable success	52	14	2	7	75
Failed	3	0	25	3	31
Unknown	7	4	1	2	14
Total	**79**	**28**	**28**	**13**	**148**

Table 13. Fates of least tern nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Gavins Point River Reach in 2009.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	13	3	0	0	16
Probable success	69	1	2	3	75
Failed	0	0	21	2	23
Unknown	3	1	1	0	5
Total	**85**	**5**	**24**	**5**	**119**

Table 14. Fates of piping plover nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Garrison River Reach in 2006.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	3	1	0	0	4
Probable success	16	20	1	7	44
Failed	2	1	31	3	37
Unknown	2	6	4	1	13
Total	**23**	**28**	**36**	**11**	**98**

Table 15. Fates of piping plover nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Garrison River Reach in 2007.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	7	3	0	1	11
Probable success	24	36	0	5	65
Failed	1	1	23	1	26
Unknown	6	9	1	1	17
Total	**38**	**49**	**24**	**8**	**119**

Table 16. Fates of piping plover nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Gavins Point River Reach in 2008.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	24	3	0	1	28
Probable success	52	9	0	16	77
Failed	0	0	49	0	49
Unknown	2	0	0	3	5
Total	**78**	**12**	**49**	**20**	**159**

Table 17. Fates of piping plover nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Gavins Point River Reach in 2009.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	9	1	0	1	11
Probable success	59	15	3	2	79
Failed	1	0	57	1	59
Unknown	2	0	0	4	6
Total	**71**	**16**	**60**	**8**	**155**

6 percent of missed tern nests) nests. Mean nest visit intervals ranged from 2.4–3.4 days for USGS crews, and 7.0–9.4 days for Corps crews (table 23).

3.5.2 Nest Initiations and Success

Piping plovers—Plovers began initiating nests in late April to early May except at SAK in 2008 where first initiations appeared approximately 2 weeks later and then peaked quickly (fig. 4). Noticeable peaks in nest initiations were apparent at GRR (2006), GVP (2009), and SAK (2007 and 2008). Plover nest success was strongly related to nest initiation date at all study areas in all years ($P \leq 0.05$). Nest success increased with initiation date at GRR and GVP, but was negatively related to initiation date on SAK (fig. 5). The number of times a sandbar was visited by monitoring crews

Table 18. Fates of piping plover nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on Lake Sakakawea in 2007.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	1	0	0	0	1
Probable success	10	0	0	0	10
Failed	0	0	15	0	15
Unknown	0	1	3	0	4
Total	**11**	**1**	**18**	**0**	**30**

Table 19. Fates of piping plover nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on Lake Sakakawea in 2008.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	1	1	0	1	3
Probable success	6	2	3	0	11
Failed	0	0	14	4	18
Unknown	0	0	0	0	0
Total	**7**	**3**	**17**	**5**	**32**

between successive nest visits (CMI) had no impact on daily survival rate of nests ($P > 0.90$) at SAK in either year or at GRR in 2007; however, daily survival rate of plover nests at GRR in 2006 increased with number of visits to a sandbar ($P = 0.04$; fig. 6).

Least terns—Least terns began initiating nests in late May, except at GRR in 2007 where first-nest initiations did not happen until early June (fig. 7). A noticeable peak in number of nests initiated was apparent at both study areas in both years but the peak was about a week later at GRR in 2007. The length of the nest initiation period was considerably shorter for terns (56 days) than plovers (83 days). Least tern nest success indicated a consistent decline with nest initiation date (fig. 8); however, the decline was supported statistically ($P < 0.05$) only at GVP in 2009 ($P < 0.001$ at GVP in 2009, $P > 0.30$ elsewhere or in other years). The number of times a sandbar was visited by monitoring crews (CMI) between successive nest visits had no impact on daily survival rate of tern nests at GRR in either year ($P > 0.70$).

Table 20. Fates of least tern nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on the Garrison River Reach (2006–07) and Gavins Point River Reach (2008–09) of the Missouri River.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	48	17	0	1	66
Probable success	172	39	5	15	231
Failed	3	1	58	6	68
Unknown	22	9	10	7	48
Total	**245**	**66**	**73**	**29**	**413**

Table 21. Fates of piping plover nests as determined by U.S. Geological Survey research and U.S. Army Corps of Engineers monitoring crews on Lake Sakakawea (2007–08), the Garrison River Reach (2006–07), and Gavins Point River Reach (2008–09) of the Missouri River.

[USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Corps fate	USGS fate				Total
	Successful	Probable success	Failed	Unknown	
Successful	45	9	0	4	58
Probable success	167	82	7	30	286
Failed	4	2	189	9	204
Unknown	12	16	8	9	45
Total	**228**	**109**	**204**	**52**	**593**

3.5.3 Chicks and Fledglings

Piping plover chicks—We estimated ≥ 300–500 plover chicks were produced each year on GVP, GRR, and SAK study areas, with considerably higher numbers possible on SAK (table 24). Numbers of chicks reported by the Corps indicated a slight negative bias for GRR and SAK, but were within confidence bounds of USGS estimates of minimum total chicks (minimum based on number of chicks banded) for SAK.

Least tern chicks—Production of tern chicks ranged from 174 (155–206, GRR 2007) to 297 (283–311; GVP 2008) (table 24). Number of tern chicks reported by the Corps indicated a negative bias for GRR in both years and for GVP in 2008, with numbers falling outside USGS confidence bounds for minimum chick production.

Detection of chicks—Of the 2,953 total chicks banded, 94 percent of all piping plovers (*n*=1,238 of 1,318) and 93 percent of all least terns (*n*=1,523 of 1,635) were banded

Table 22. Classification of primary factors leading to nests being missed during least tern and piping plover nest monitoring on the Missouri River, 2006–09.

[LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea]

Species	Study area	Year	Late start date	Habitat not searched	Search interval too long	Vigilance/ search pattern	Total
LETE	GRR	2006	0	0	1	46	47
LETE	GRR	2007	0	4	2	32	38
LETE	GVP	2008	0	10	4	33	47
LETE	GVP	2009	0	0	2	15	17
PIPL	GRR	2006	27	0	39	79	145
PIPL	GRR	2007	4	13	27	42	86
PIPL	GVP	2008	13	20	9	36	78
PIPL	GVP	2009	1	2	7	29	39
PIPL	SAK	2007	19	0	10	49	78
PIPL	SAK	2008	18	0	4	38	60
Total			**82**	**49**	**105**	**399**	**635**

Table 23. Number, mean, and standard deviation for length of intervals between nest visit days for least tern and piping plover nests under the U.S. Army Corps of Engineers monitoring program and the U.S. Geological Survey research program.

[GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; n, number; Corps, U.S. Army Corps of Engineers; SD, standard deviation; USGS, U.S. Geological Survey]

Study area	Year	Corps			USGS		
		n	Mean	SD	n	Mean	SD
GRR	2006	501	8.0	2.4	1,977	2.9	2.9
GRR	2007	549	7.9	2.7	1,770	3.4	3.4
GVP	2008	1,031	7.0	7.0	2,668	2.9	1.4
GVP	2009	945	7.0	7.0	2,649	2.4	0.9
SAK	2007	282	8.5	8.4	850	2.6	1.0
SAK	2008	308	9.4	9.4	871	2.4	0.8

within 5 days of hatch; 87 percent (*n*=1,073) of all piping plovers and 92 percent (*n* = 1396) of all least terns were banded within 1 day of hatch. The best CJS model indicated that daily detection probabilities of color-banded chicks were variable depending on species and study area, and that detection varied with several covariates, such as chick age, monitoring effort, and habitat (Erin A. Roche, unpub. data, 2013).

In general, daily detection probabilities declined with age; however, these declines were only strongly supported among least terns at GRR [estimate=-0.0322, 95 percent confidence interval (CI): -0.0609 to -0.0036]. In general, daily detection probabilities decreased by 0.00–0.05 between 2 days of age and the age at which monitoring stopped (that is least terns: 18 days, piping plovers: 25 days); however, daily detection probabilities for piping plovers at SAK indicated a slight, but well supported, increase with age (estimate = =0.0294, 95 percent CI: 0.0047 to 0.0541).

Monitoring effort, in terms of hours spent searching and crew size, had a positive effect on daily detection probabilities. Search time was strongly supported for all species at all study areas, resulting in a 0.01–0.06 increase in daily detection probabilities for each hourly increase in time spent searching per sandbar or shoreline unit. Crew size had a strongly supported positive effect on daily detection probabilities for all species-by-study area combinations with the exception of piping plovers at GRR and SAK. For species and study areas where this effect was strongly supported, daily detection probabilities increased by 0.02–0.06 when crew size was increased by a single individual.

After accounting for effects of year, age, and monitoring effort, the amount of suitable and unsuitable habitat had a negative effect on daily detection probabilities in least terns and piping plovers. The negative effect of suitable nonvegetated habitat on daily detection probability was strongly supported at all study areas, while the negative effect of unsuitable vegetated habitat was strongly supported at all study areas except for GVP; however, the magnitude of this negative effect was much more pronounced for changes in available suitable

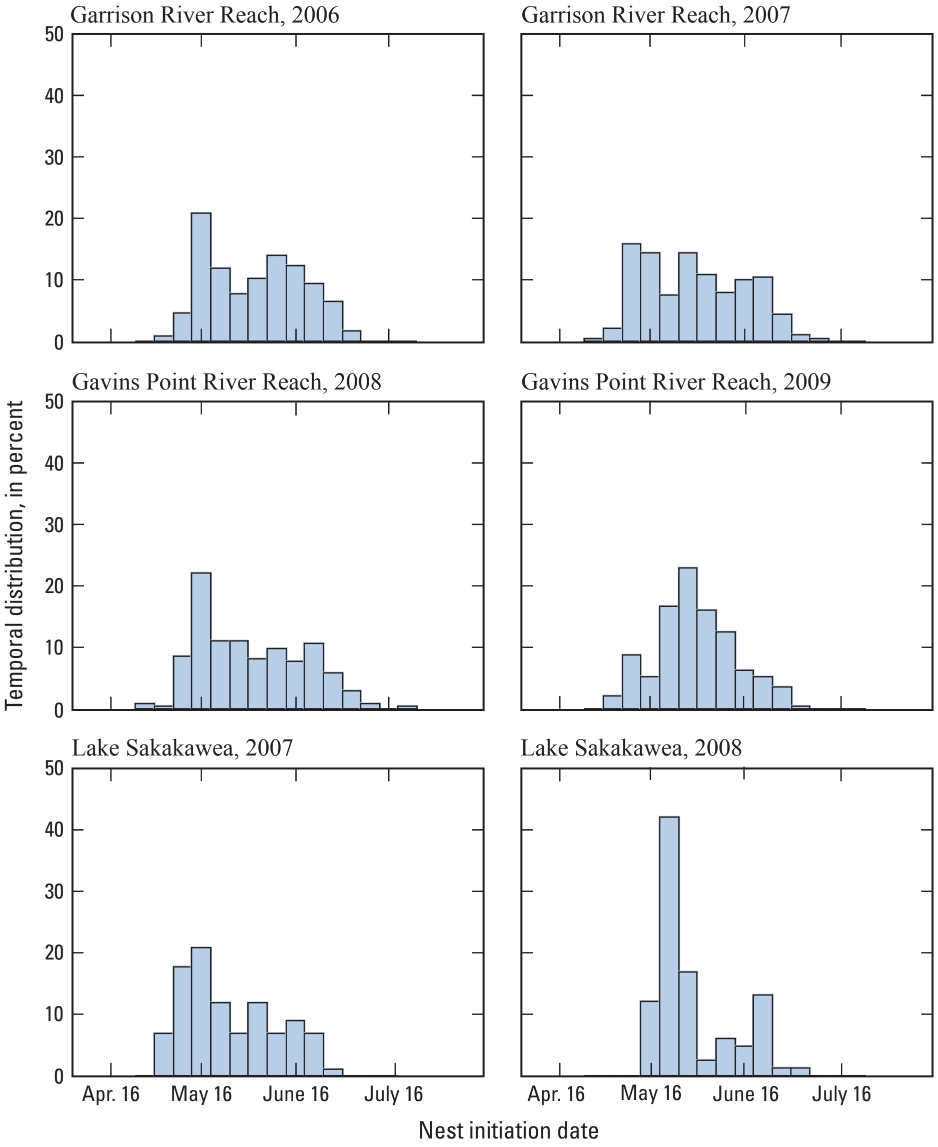


Figure 4. Temporal distribution of observed piping plover nest initiations for the Garrison River Reach, Gavins Point River Reach, and Lake Sakakawea in 2006–09.

habitat than that of hiding cover. Daily detection probabilities decreased by 0.03–0.06 with a 50-hectare (ha) increase in available suitable habitat, whereas daily detection probabilities decreased by 0.00–0.03 with a 50-ha increase in hiding cover.

Detection probabilities responded differently for each species with respect to number of chicks and nests at a given site. Detection probabilities of piping plovers declined with increasing number of chicks and nests at all study areas; however, daily detection probabilities of least terns increased with number of chicks and nests at all study areas except GRR. An increase of five chicks plus nests was associated with a 0.01–0.08 decrease in daily detection probabilities in piping plovers and a 0.00–0.03 increase in daily detection probabilities in least terns.

There were strongly supported but small magnitude declines in daily detection probability associated with doing surveys closer to midday for piping plovers at GRR and SAK and for least terns at GVP; however, daily detection probability of piping plovers at GVP increased with the time from sunrise and sunset. In all cases, delaying survey timing by 30 minutes in the morning was associated with a < 0.01 change in daily detection probability.

We used the values generated by our top-supported model for detection probability and the simulation model described in section 3.4.2 to estimate the probability of detecting a piping plover or least tern chick at least once in 3–5 (2–5 for terns) site visits (table 25). Although the probability of detecting a piping plover at least once in five site visits exceeded 95 percent at two of the study areas, the highest probability of detecting a least tern at least once after five visits was 82 percent for least terns at GRR (table 25).

The probability of detecting a fledging-age chick at least once was highly dependent on species, number of chicks and nests, and number of days a site was visited (table 25). Generally, probabilities of detecting fledging-age least terns once in three site visits ranged between 0.56–0.65 and increased by 10–11 percent with an additional site visit. Detection probabilities of fledging-age piping plovers in three site visits were

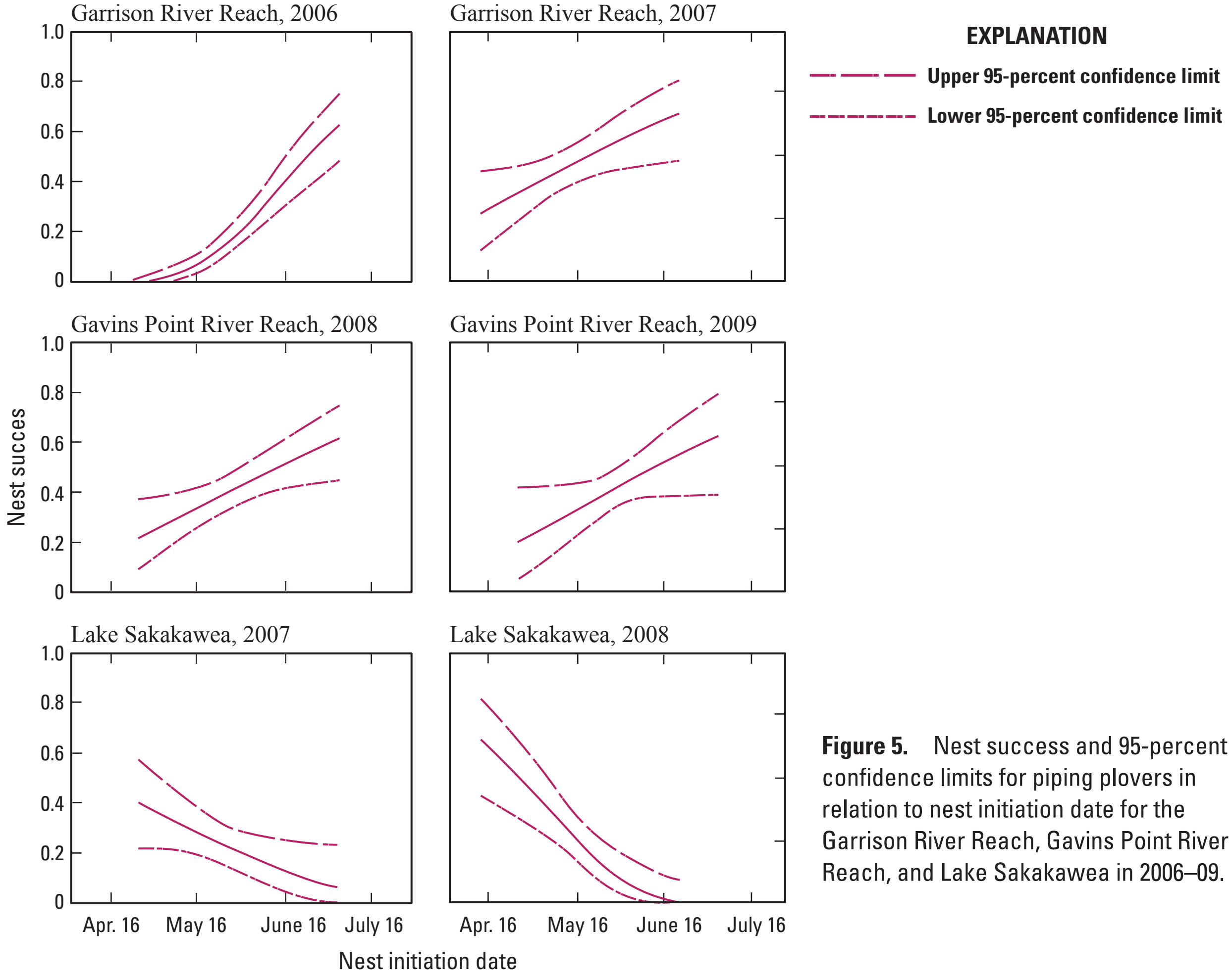


Figure 5. Nest success and 95-percent confidence limits for piping plovers in relation to nest initiation date for the Garrison River Reach, Gavins Point River Reach, and Lake Sakakawea in 2006–09.

much higher, ranging between 0.70–0.99. Three-visit detection probability of fledging-age piping plovers at SAK was 0.99 and thus did not increase with additional visits; however, detection increased 10 and 7 percent with an additional visit at GVP and GRR, respectively (table 25).

The addition of a species-specific monitoring impact covariate on survival improved model fit (six point decrease in QAICc relative to our previous top model for detection probability). Monitoring was positively associated with survival of least tern chicks (estimate= 0.56, 95-percent CI: 0.32–0.79) on visit days, but was not related to survival of piping plover chicks (estimate= 0.05, 95-percent CI: −0.13–0.23). Specifically, daily apparent survival rates of least tern chicks were 0.07–0.08 higher on days during which monitoring was done compared to 2 days after monitoring.

Piping plover fledglings—USGS crews averaged 2.45 (GVP 2008) to 4.54 (GVP 2009) attempts to observe banded plover chicks between the age of 18 and 25 days, leading to estimated detection rates ranging from 0.70 (GVP) to 0.99 (SAK) (tables 25, 26). USGS study-area-wide estimates of minimum number of fledging-age plover chicks corrected for imperfect detection ranged from 109 (GVP 2009) to 222 (SAK 2007; table 27). Numbers of fledglings reported by the Corps for GRR in 2007 indicated a negative bias (45 percent relative bias) that was outside confidence bounds for detection-corrected minimum estimates by USGS (table 27, fig. 9). Fledgling numbers reported by the Corps for GVP (2008) and SAK were within confidence bounds of USGS minimum estimates (table 27; figs. 10, 11).

Least tern fledglings—USGS crews averaged 1.97 (GRR 2007) to 2.46 (GVP 2008) attempts to observe banded least tern chicks between the age of 14 and 18 days, leading to detection probabilities ranging from 0.42 at GVP in 2009 to 0.54 at GRR in 2006 (table 26). USGS estimates of minimum number of fledging-age tern chicks corrected for imperfect detection ranged from 92 (GRR 2007) to 257 (GVP 2008; table 27). Numbers of fledglings reported by the Corps indicated a strong negative bias (29–53 percent) that was outside confidence bounds of USGS detection-corrected minimum estimates except for GRR in 2007 (table 27; figs. 12, 13).

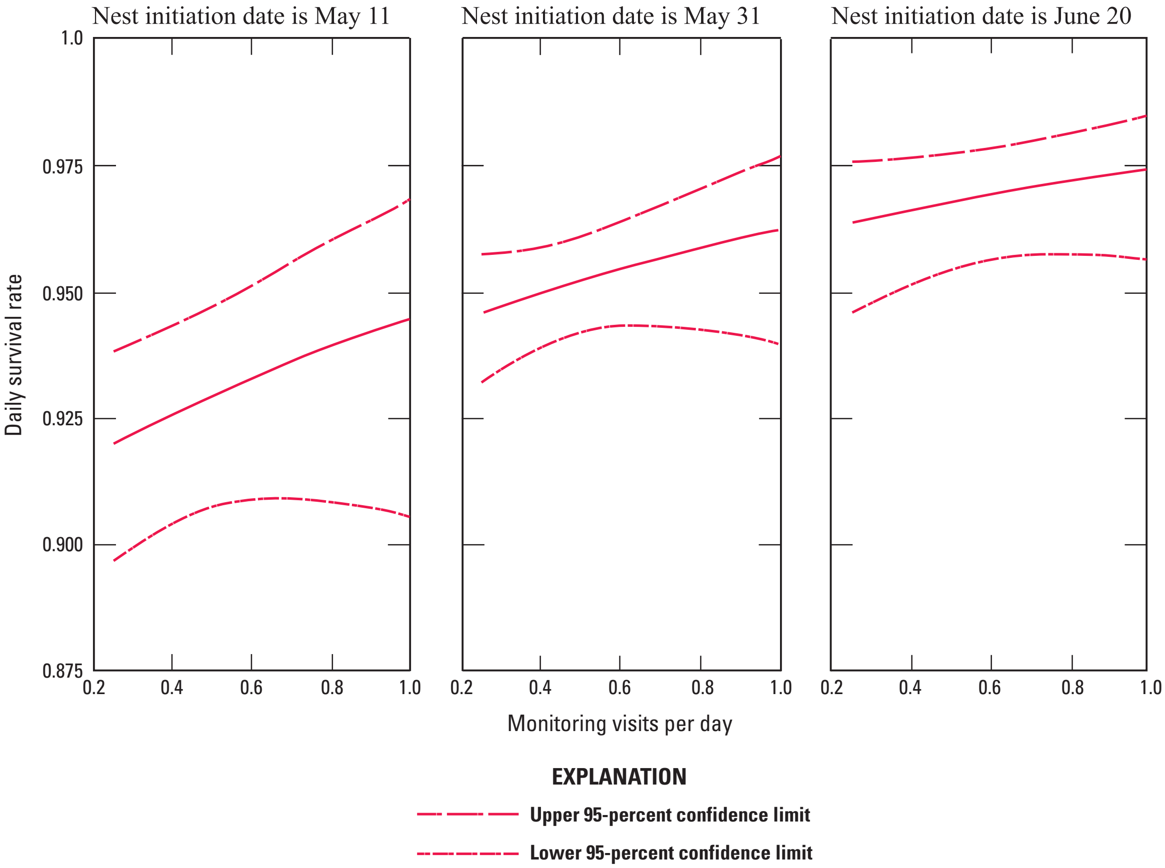


Figure 6. Daily survival rate and 95-percent confidence limits of piping plover nests for the Garrison River Reach in 2006 in relation to frequency of monitoring visits and nest initiation date.

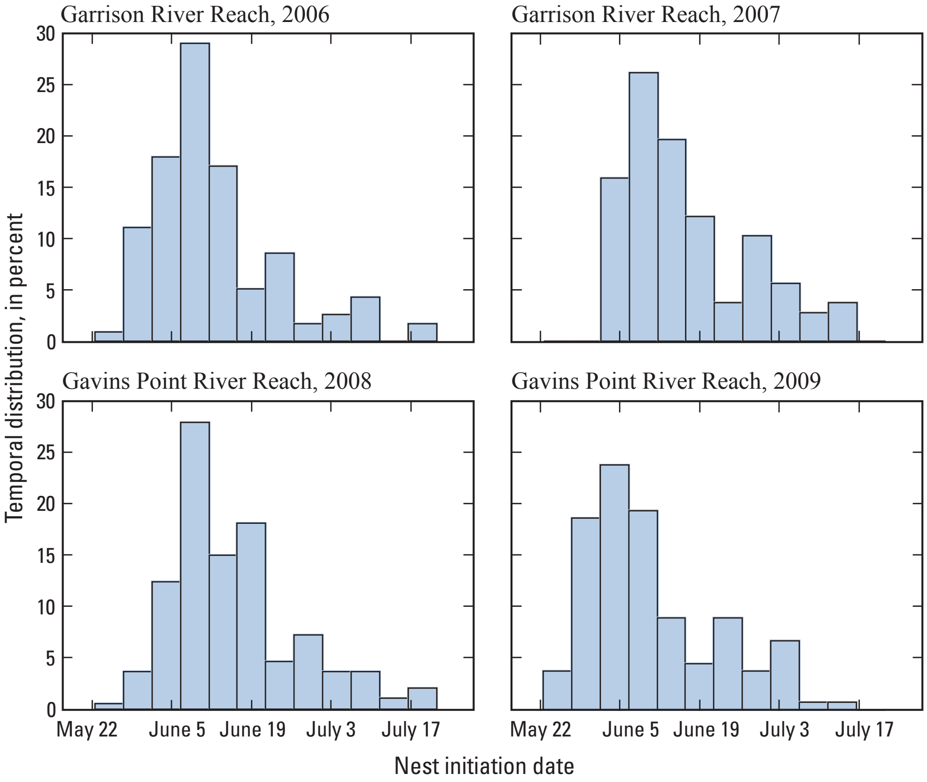


Figure 7. Temporal distribution of observed least tern nest initiations for Garrison River Reach and Gavins Point River Reach in 2006–09.

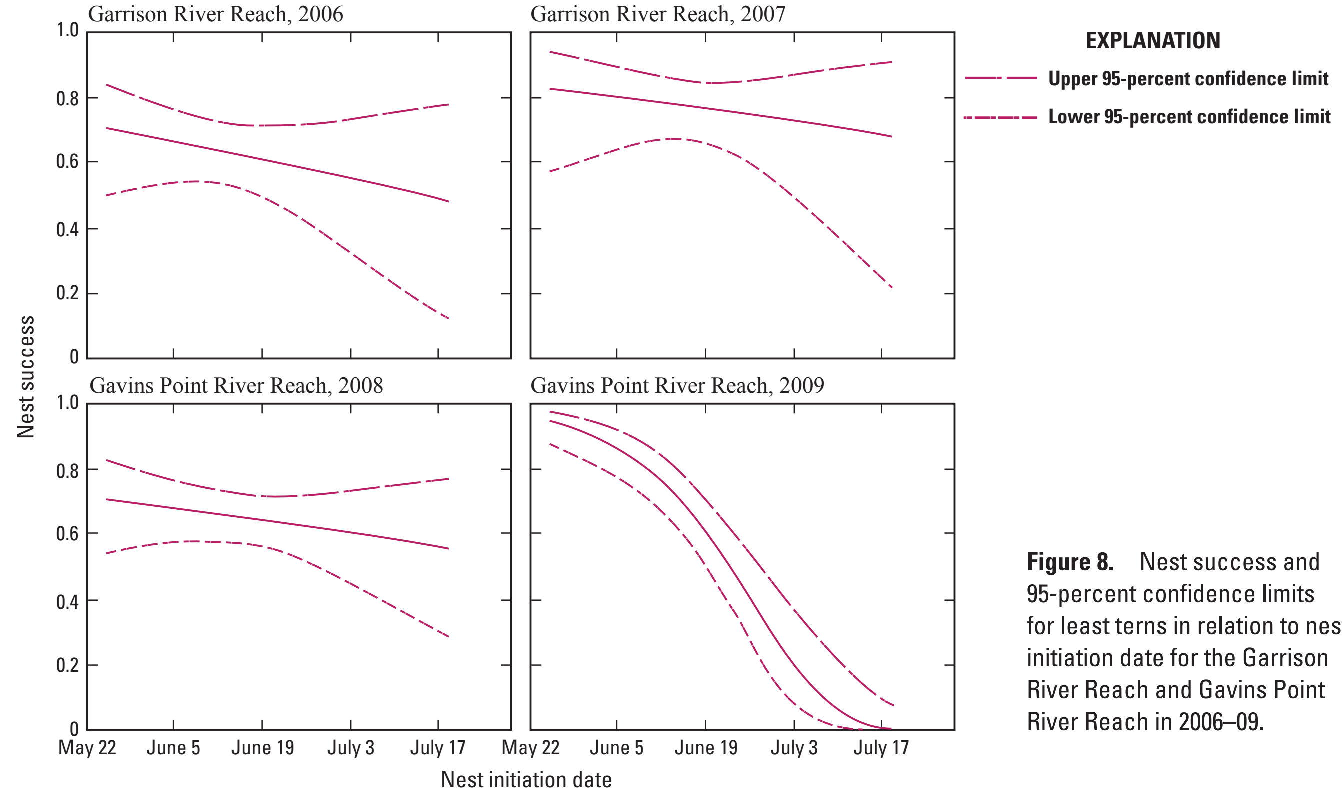


Figure 8. Nest success and 95-percent confidence limits for least terns in relation to nest initiation date for the Garrison River Reach and Gavins Point River Reach in 2006–09.

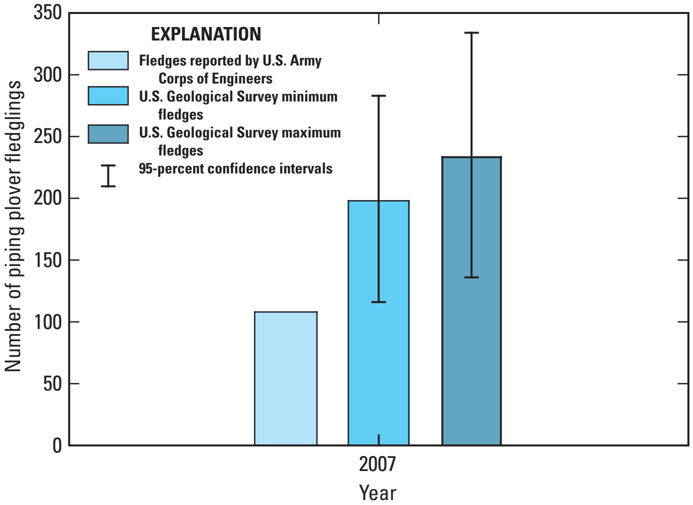


Figure 9. Number of fledged piping plovers reported by the U.S. Army Corps of Engineers for the Garrison River Reach in 2007, along with U.S. Geological Survey minimum and maximum detection-corrected estimates and 95-percent confidence intervals.

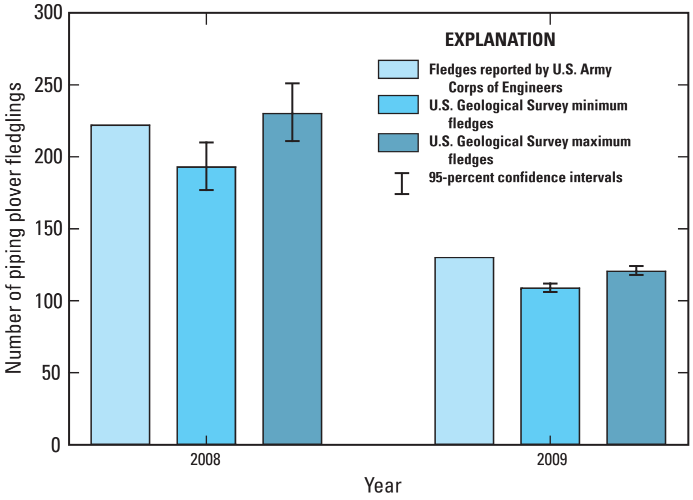


Figure 10. Number of fledged piping plovers reported by the U.S. Army Corps of Engineers for the Gavins Point River Reach in 2008 and 2009, along with U.S. Geological Survey minimum and maximum detection-corrected estimates and 95-percent confidence intervals.

3.5.4 Adults

Piping Plovers

GRR 2006—Detection of plovers by primary crews in 2006 declined as area of suitable habitat increased within the unit (table 28). Detection-corrected estimates of plover adults peaked at 256 on May 25, dipped to 195 on June 7, and then rebounded to about 230 on June 20 before beginning a gradual decline for the remainder of the season (fig. 14). The coefficient of variation (CV) for estimates [(SE/ Estimate)*100] ranged from 6 percent (June 14, 2006) to 15 percent (August 2, 2006; appendix 1, *http://pubs.usgs.gov/of/2013/1176/Appendix_1.xls*). Number of adults reported by the TPMP was lower than the USGS estimate and was outside 95-percent confidence intervals for the same time period (fig. 14).

Table 24. Estimates of minimum and maximum chick production in relation to numbers reported by the U.S. Army Corps of Engineers 2006–09.

[USGS minimum estimates are based on numbers of chicks banded and maximum estimates include counts of whole eggs with unknown fates in successful nests and counts of whole eggs from nests with unknown fates. LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; NA, not applicable; Corps, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey]

Species	Study area	Year	Reported by Corps	Total chicks (minimum)				Total chicks (maximum)			
				USGS count	USGS expanded estimate	USGS 95-percent confidence interval	Relative bias (percent)	USGS count	USGS expanded estimate	USGS 95-percent confidence interval	Relative bias (percent)
LETE	GRR	2006	127	170	179	170–202	-29	194	203	194–227	-37
LETE	GRR	2007	151	155	174	155–206	-13	200	220	200–255	-31
LETE	GVP	2008	275	292	297	283–311	-7	356	361	356–375	-24
LETE	GVP	2009	240	230	236	230–253	2	266	274	266–296	-12
PIPL	GRR	2006	NA	NA	NA	NA	NA	271	298	271–349	NA
PIPL	GRR	2007	318	343	393	343–476	-19	410	463	410–558	-31
PIPL	GVP	2008	451	397	409	397–428	10	473	488	473–518	-8
PIPL	GVP	2009	330	319	325	319–342	2	356	360	356–371	-8
PIPL	SAK	2007	295	99	484	184–784	-39	110	1,561	715–2,406	-81
PIPL	SAK	2008	300	77	342	152–533	-12	92	1,532	720–2,344	-80

Table 25. Mean probability of detecting a chick at least once in two, three, four, or five visits to a site and associated lower and upper 95-percent confidence intervals as estimated by a simulation model, described in the methods section, based on our top-supported model.

[These values were based on age-dependent daily detection probabilities for each species by study area. LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; Est., estimation; LCL, lower confidence limit; UCL, upper confidence limit; NA, not applicable]

Species	Study area	Number of visits											
		Two			Three			Four			Five		
		Est.	LCL	UCL	Est.	LCL	UCL	Est.	LCL	UCL	Est.	LCL	UCL
LETE	GRR	0.50	0.43	0.57	0.65	0.58	0.71	0.75	0.71	0.80	0.82	0.79	0.86
LETE	GVP	0.42	0.39	0.46	0.56	0.53	0.59	0.67	0.64	0.69	0.75	0.72	0.77
PIPL	GRR	NA	NA	NA	0.86	0.84	0.89	0.93	0.92	0.95	0.96	0.95	0.97
PIPL	GVP	NA	NA	NA	0.70	0.67	0.73	0.80	0.78	0.82	0.86	0.85	0.88
PIPL	SAK	NA	NA	NA	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

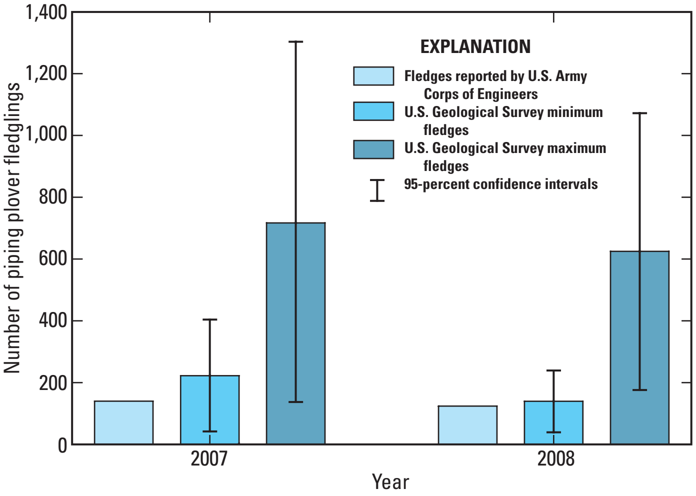


Figure 11. Number of fledged piping plovers reported by the U.S. Army Corps of Engineers for Lake Sakakawea in 2007 and 2008, along with U.S. Geological Survey minimum and maximum detection-corrected estimates and 95-percent confidence intervals.

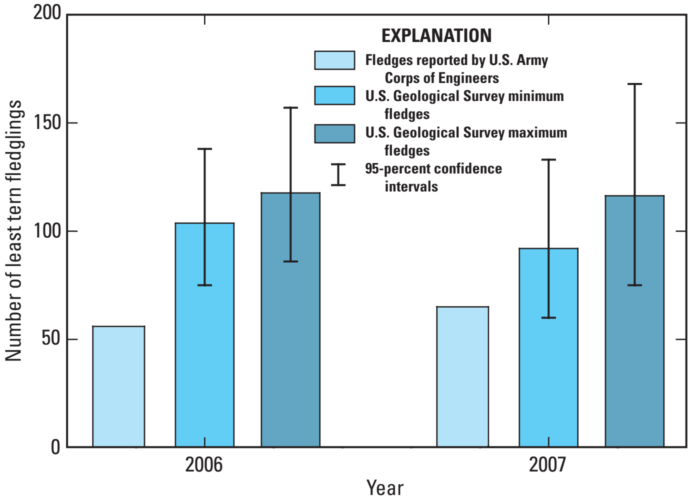


Figure 12. Number of fledged least terns reported by the U.S. Army Corps of Engineers for the Garrison River Reach in 2006 and 2007, along with U.S. Geological Survey minimum and maximum detection-corrected estimates and 95-percent confidence intervals.

Table 26. Average number of attempts to relocate a fledging-age chick (14–18 days for terns, 18–25 days for plovers), and the estimated detection probability from simulation by species and study area.

[Detection probability values and confidence intervals interpolated from table 25. LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; NA, not applicable]

Species	Study area	Year	Attempts	Detection probability	95-percent confidence interval
LETE	GRR	2006	2.33	0.54	0.47–0.61
LETE	GRR	2007	1.97	0.50	0.43–0.57
LETE	GVP	2008	2.46	0.49	0.46–0.53
LETE	GVP	2009	1.98	0.42	0.39–0.46
PIPL	GRR	2006	NA	NA	NA
PIPL	GRR	2007	2.54	0.86	0.84–0.89
PIPL	GVP	2008	2.45	0.70	0.67–0.73
PIPL	GVP	2009	4.54	0.80	0.78–0.82
PIPL	SAK	2007	3.38	0.99	0.99–0.99
PIPL	SAK	2008	3.41	0.99	0.99–0.99

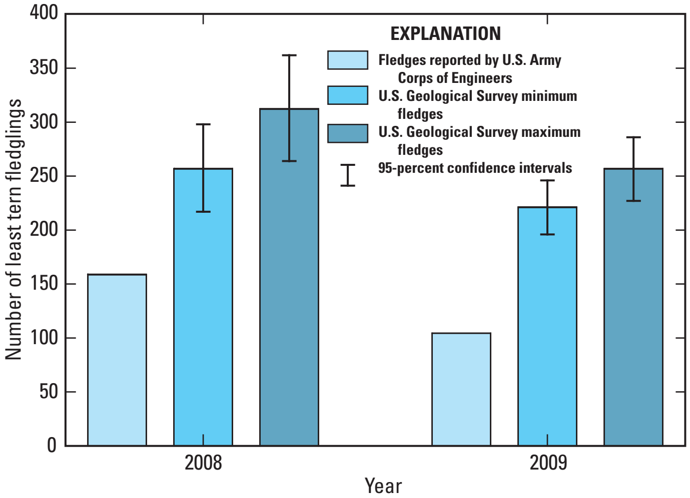


Figure 13. Number of fledged least terns reported by the U.S. Army Corps of Engineers for the Gavins Point River Reach in 2008 and 2009, along with U.S. Geological Survey minimum and maximum detection-corrected estimates and 95-percent confidence intervals.

GRR 2007—Detection of plovers by primary crews in 2007 varied with the discharge from Garrison Dam (table 28). Crews tended to undercount at higher discharges and overcount at lower discharges. Detection-corrected estimates of plover adults steadily climbed as the season progressed, reaching a peak of about 335 on July 3 (fig. 15). More than 300 plovers were estimated during 3 surveys between late June and mid-July. The CV for estimates ranged from 4 percent (July 3) to 12 percent (April 25) (appendix 1, *http://pubs.usgs.gov/of/2013/1176/Appendix_1.xls*). Number of adults reported by the TPMP was lower than the USGS estimate and was outside 95 percent confidence intervals for the same time period (fig. 15).

GVP 2008—Detection of plovers by primary crews in 2008 increased with amount of habitat on a unit; primary crews undercounted plovers on units with little habitat and overcounted on units where habitat was more available (table 28). Overcounting occurred early in the season and undercounting increased as the season progressed. Adult plover estimates climbed steadily from mid-April to a peak of approximately 290 birds in mid-June (fig. 16). Numbers

Table 27. Estimates of minimum and maximum fledging-age chick production in relation to numbers reported by the U.S. Army Corps of Engineers 2006–09.

[U.S. Geological Survey minimum estimates are based on numbers of chicks banded and maximum estimates include counts of whole eggs with unknown fates in successful nests and counts of whole eggs from nests with unknown fates. LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; NA, not applicable; Corps, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey; %, percent]

Species	Study area	Year	Reported by Corps	Total fledging-age chicks (minimum)				Total fledging-age chicks (maximum)		
				USGS count	USGS expand-ed estimate	USGS 95-percent confidence interval	Relative bias (Percent)	USGS expanded estimate	USGS 95-percent confidence interval	Relative bias (percent)
LETE	GRR	2006	56	53	104	75–138	-46	118	86–157	-52
LETE	GRR	2007	65	40	92	60–133	-29	116	75–168	-44
LETE	GVP	2008	159	122	257	217–298	-38	313	264–362	-49
LETE	GVP	2009	105	92	221	196–246	-53	257	227–286	-59
PIPL	GRR	2006	NA	NA	NA	NA	NA	NA	NA	NA
PIPL	GRR	2007	108	136	198	116–283	-45	233	136–334	-54
PIPL	GVP	2008	222	131	193	177–210	15	230	211–251	-4
PIPL	GVP	2009	130	87	109	106–112	20	120	118–124	8
PIPL	SAK	2007	140	42	222	42–404	-37	717	137–1,303	-80
PIPL	SAK	2008	124	24	139	39–239	-11	624	176–1,072	-80

Table 28. Models for estimating number of adult piping plovers and least terns from weekly adult surveys at Garrison River Reach (2006–07) and Gavins Point River Reach (2008–09).

[Extensive counts (X) were made on each 2-river mile (Garrison River Reach) or 3-river mile (Gavins Point River Reach) unit each week and intensive counts (Y) were done on a sample of those units. HABITAT is the area (hectare) of sparse or lightly vegetated dry or wet sand habitat derived from aerial imagery at a single time during the year, DISCHARGE is the average discharge (cubic feet per second) from Garrison Dam on the day of the survey, SURVEYNO ranges from 1 to the total number of daily surveys for a species, FLOW is the unit-specific average flow for Gavins Point River Reach on the day of the survey, and WIND is a unit- and day-specific indicator of wind speed at the time of the survey. WIND=1 if wind speed >4 miles per hour (7 kilometers per hour) and 0 otherwise]

Study area	Year	Piping plover	Least tern
Garrison River Reach	2006	Y = 1.04 + (0.81 + 0.0085*HABITAT)*X	Y = 1.07 + (2.00 – 0.10*SURVEYNO)*X
	2007	Y = 1.39 + (0.27 + 0.50*DISCHARGE)*X	Y = 1.45 + (0.55 + 0.01*HAB – 0.52*WIND)*X
Gavins Point River Reach	2008	Y = 1.51 + (0.86 + 0.04*SURVEYNO – 0.01*HAB)*X	Y = 2.52 + (1.39 – 0.31*FLOW)*X
	2009	Y = 1.40 + (1.35 – 0.18*FLOW)*X	Y = 2.09 + 0.80*X

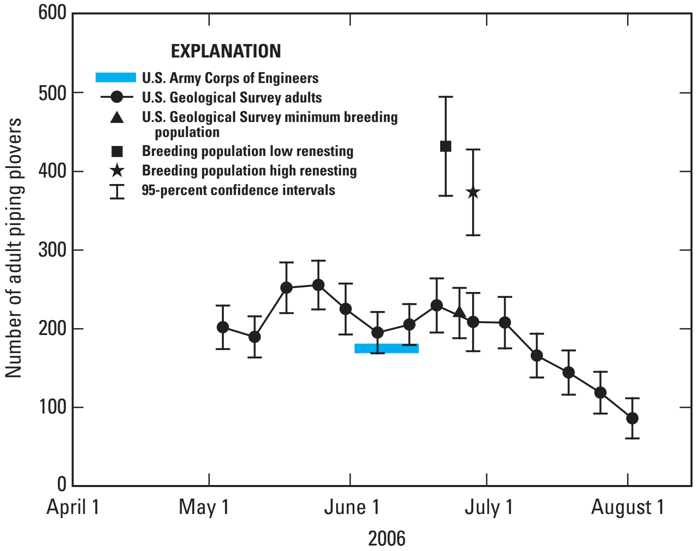


Figure 14. Weekly detection-corrected counts of adult piping plovers from the U.S. Geological Survey adult survey on the Garrison River Reach in 2006, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

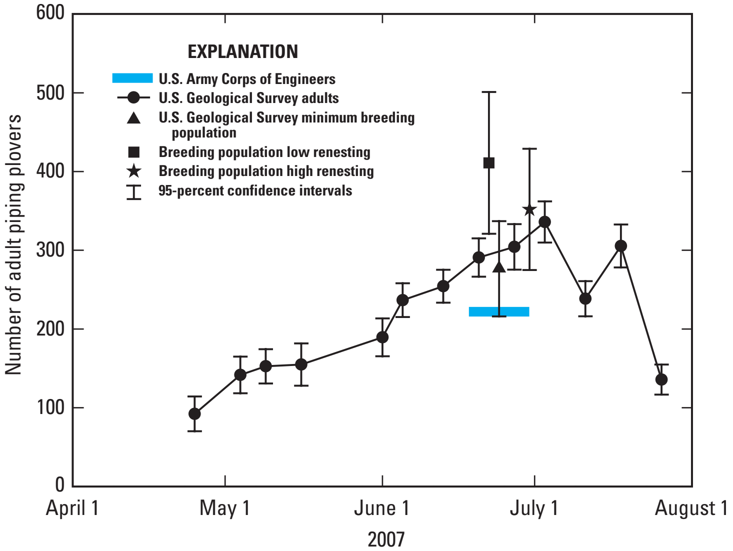


Figure 15. Weekly detection-corrected counts of adult piping plovers from the U.S. Geological Survey adult survey on the Garrison River Reach in 2007, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

remained near that level for nearly a month before beginning a steep decline for the remainder of the season. The CV for estimates ranged from 3 percent (June 10) to 15 percent (April 16; appendix 1, *http://pubs.usgs.gov/of/2013/1176/Appendix_1.xls*). Number of adults reported by the TPMP was greater than the USGS estimate and was outside 95 percent confidence intervals for the same time period (fig. 16).

GVP 2009—Detection of plovers by primary crews in 2009 increased with sampling unit-specific flow; undercounting was more frequent during low flows and overcounting was more frequent during high flows (table 28). Adult plover estimates reached an early peak of 232 birds on April 28 (fig. 17). Estimates declined slightly during May before increasing to approximately 260 on June 3. The peak number of 276 plovers was estimated on June 17. The CV approached 20 percent on the first and last surveys when plover numbers were <40 birds, but otherwise CVs ranged from 3 percent (May 14) to 13 percent (July 29; appendix 1, *http://pubs.usgs.gov/of/2013/1176/Appendix_1.xls*). Number of adults reported by the TPMP was lower than the USGS estimate and was outside 95 percent confidence intervals for the same time period (fig. 17).

SAK 2007—Primary and secondary counts did not differ [mean difference=0.22, SE=0.24, Student's t-statistic (t) = 0.35, degrees of freedom (*df*) = 88, *P*=0.35]. Adult estimates

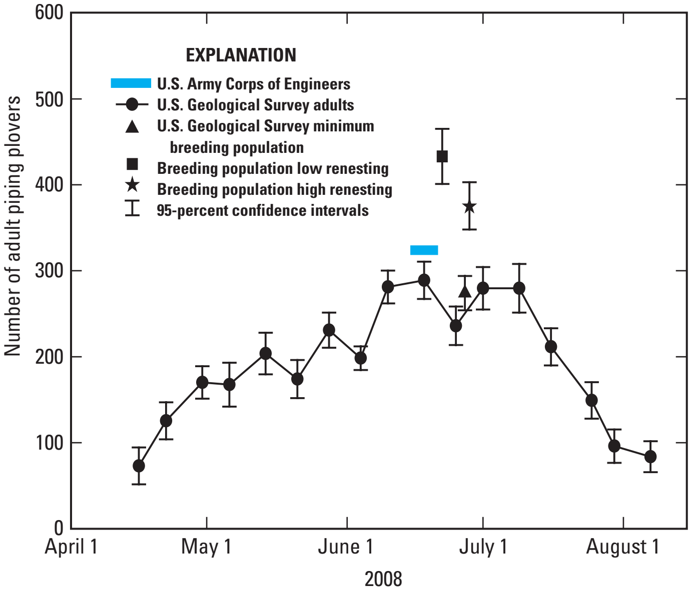


Figure 16. Weekly detection-corrected counts of adult piping plovers from the U.S. Geological Survey adult survey on the Gavins Point River Reach in 2008, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

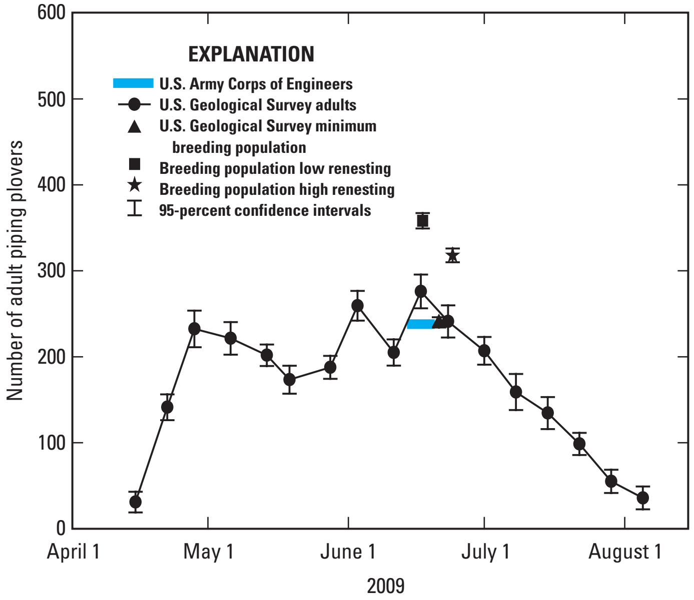


Figure 17. Weekly detection-corrected counts of adult piping plovers from the U.S. Geological Survey adult survey on the Gavins Point River Reach in 2009, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

increased steadily to a peak of 945 (SE=351) birds the week of May 18. Estimates remained between 600–900 until about June 7 before declining steadily (fig. 18). Estimates were widely variable with CVs ranging from 22 percent to 48 percent. Despite considerable variability in estimates of adults for SAK, results suggested the presence of substantially more plovers than reported by the TPMP.

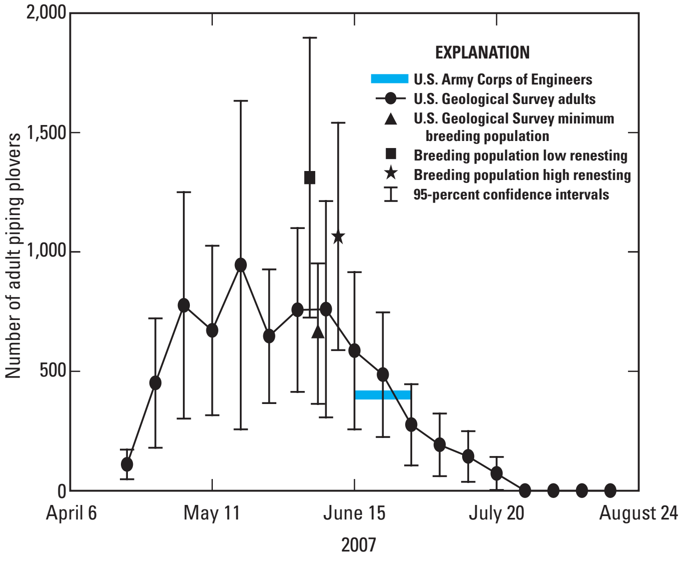


Figure 18. Weekly detection-corrected counts of adult piping plovers from the U.S. Geological Survey adult survey for Lake Sakakawea in 2007, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

SAK 2008—Primary and secondary counts did not differ (mean difference=0.15, SE=0.24, t=0.60, *df* = 73, *P*=0.55). Adult estimates increased steadily to a peak of 640 (SE=147) birds the week of May 25 and then declined steadily for the remainder of the season (fig. 19). Estimates were widely variable with CVs ranging from 18 percent to 47 percent. Despite considerable variability in estimates of adults for SAK, results suggested the presence of substantially more plovers than reported by the TPMP.

Least Terns

GRR 2006—Detection of terns by primary crews in 2006 increased as the season progressed with undercounting occurring early in the season and overcounting occurring later in the season (table 28). Tern estimates peaked at approximately 185 on June 7 and again on July 5, after which estimates declined steadily until fewer than 100 terns remained on August 2 (fig. 20). The CV in the estimated total ranged from 7 percent (June 7) to 16 percent (August 2; appendix 1, *http://pubs.usgs.gov/of/2013/1176/Appendix_1.xls*). Number of adults reported

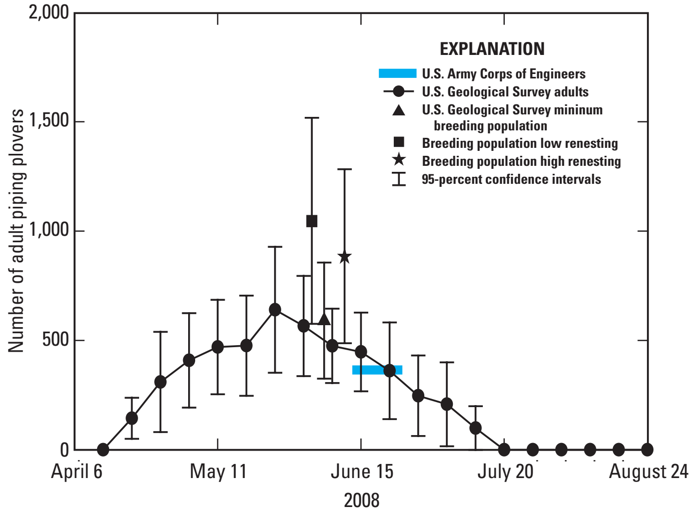


Figure 19. Weekly detection-corrected counts of adult piping plovers from the U.S. Geological Survey adult survey for Lake Sakakawea in 2008, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

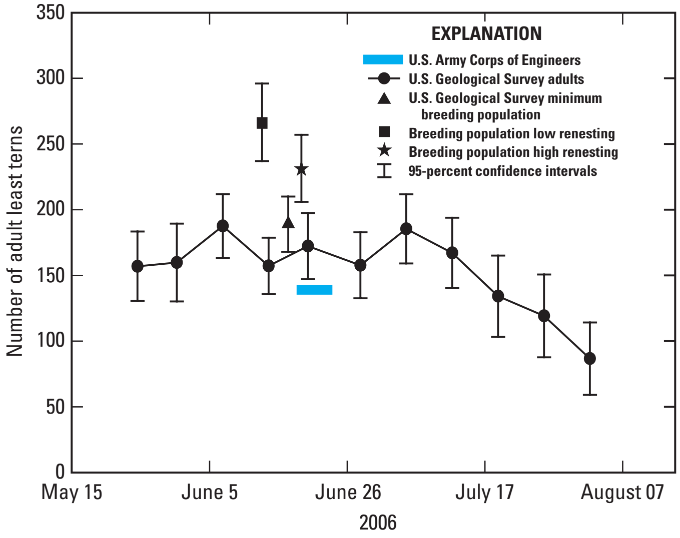


Figure 20. Weekly detection-corrected counts of adult least terns from the U.S. Geological Survey adult survey on the Garrison River Reach in 2006, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

by the TPMP was lower than the USGS estimate and was outside 95 percent confidence intervals for the same time period (fig. 20).

GRR 2007—Detection of least terns by primary crews in 2007 varied with amount of suitable habitat and with winds in excess of 7 kmph (table 28). Detection declined as habitat increased. Overcounting happened, on average, when wind speeds were greater than 7 kmph. Tern estimates approached 200 by mid-June and remained there until reaching 215 adults on July 18 (fig. 21). The CV for estimates ranged from 6 percent (June 13) to 12 percent (June 1; appendix 1). Number of adults reported by the TPMP was substantially lower than the USGS estimate and was outside 95 percent confidence intervals for the same time period (fig. 21).

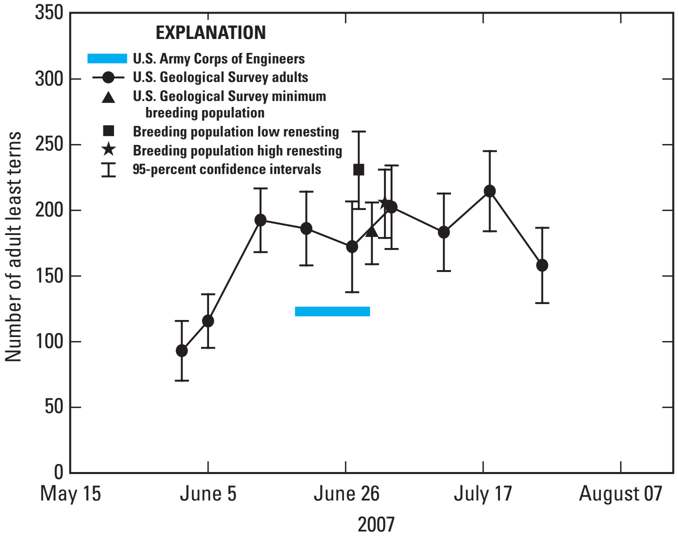


Figure 21. Weekly detection-corrected counts of adult least terns from the U.S. Geological Survey adult survey on the Garrison River Reach in 2007, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

GVP 2008—Detection of terns in 2008 depended on sampling unit-specific flows, with overcounting happening at high flows (table 28). Tern estimates increased fairly steadily to a peak of approximately 240 adults in mid-June, and persisted at that level until early July when estimates began to decline (fig. 22). The CV for estimates ranged from 4 percent (June 4) to 21 percent (May 14) and was less than 8 percent for all surveys except the first (appendix 1). Number of adults reported by the TPMP was greater than the USGS estimate and was outside 95 percent confidence intervals for the same time period (fig. 22).

GVP 2009—Detection of terns in 2009 did not vary with respect to date, flows, wind speed, temperature, or abundance of habitat (table 28). Tern estimates exceeded 150 birds by May 28 and except for 2 surveys (June 11 and July 8) stayed above 150 until July 29 when numbers began to decline (fig. 23). The CV for estimates ranged from 4 percent (July 1) to 20 percent (May 14) and was less than 8 percent for all surveys except the first (appendix 1, *http://pubs.usgs.gov/*

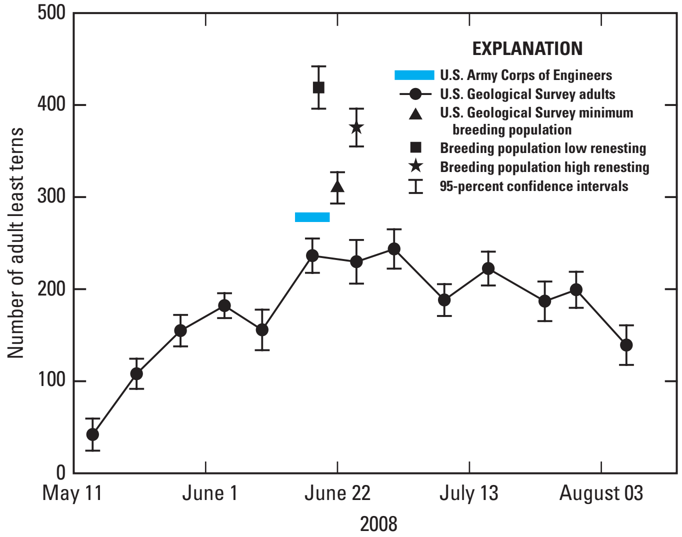


Figure 22. Weekly detection-corrected counts of adult least terns from the U.S. Geological Survey adult survey on the Gavins Point River Reach in 2008, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

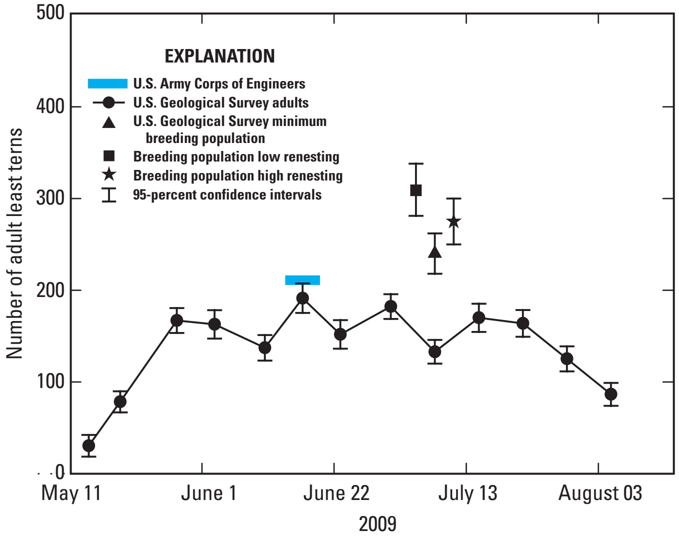


Figure 23. Weekly detection-corrected counts of adult least terns from the U.S. Geological Survey adult survey on the Gavins Point River Reach in 2009, along with minimum breeding population (MINBPOP), and breeding population (MINBPOP adjusted for bias) at low and high renesting rates. The blue horizontal bar is the Tern and Plover Monitoring Program reported adult count, and its width corresponds to the dates of the U.S. Army Corps of Engineers' adult census.

of/2013/1176/Appendix_1.xls). Number of adults reported by the TPMP was greater than the USGS estimate and was barely within 95 percent confidence intervals for the same time period (fig. 23).

3.5.5 Breeding Population

Our simulation study of the detection ratio MINBPOP divided by BPOP revealed patterns that were dependent on attributes of the breeding population and properties of the monitoring program (figs. 24–29 and 30–31). The four panels of each graph correspond to properties of the monitoring program (that is, combinations of return interval and nest detection probability). As expected, nest success had a major effect on the proportion of the breeding population represented by MINBPOP. Renesting also was important, especially when nest success was low; however, proportion of the breeding population represented by MINBPOP was not overly sensitive to variation in renesting interval. The detection ratio increased with daily nest detection probability, and the difference in the detection ratio between high and intermediate nest detection often approached 0.2. Shortening the monitoring interval led to increases in the detection ratio, but increases were slight when daily nest detection was high. Results were similar among breeding areas and years (figs. 24–31). The pattern of response was similar for simulated piping plover and least tern populations, but MINBPOP captured a larger proportion of BPOP for terns than for plovers (figs. 30–35). This result follows from the fact that least terns had a more compressed nest initiation period than did piping plovers (figs. 4, 7).

Study-area-wide estimates of plover MINBPOP ranged from 220 (95 percent CI 188–252; GRR 2006) to 658 (95 percent CI 364–952; SAK 2007; table 29). Minimum breeding population size of terns ranged from 183 (95 percent CI 159–206; GRR 2007) to 310 (95 percent CI 293–327; GVP 2008). The strong dependence of MINBPOP divided by BPOP on nest success and renesting rate provided a means to estimate the detection ratio for each study area and year (figs. 24–29). We used observed nest success (table 8) as input to the regression model. Results indicate that MINBPOP captured 50–67 percent of plover breeding adults under low renesting and 59–79 percent of plover breeding adults under high renesting. For terns, MINBPOP captured 71–79 percent of breeding adults under the low renesting scenario and 82–89 percent of breeding adults under the high renesting scenario (table 29).

Bias-corrected BPOP for plovers varied from 365 (95 percent CI 356–374; GVP 2009) to 1,311 (95 percent CI 725–1,897; SAK 2007) under low renesting and from 318 (95 percent CI 310–326; GVP 2009) to 1,065 (95 percent CI 589–1,541; SAK 2007) under high renesting (table 29). Plover breeding adults exceeded maximum adult survey numbers in all cases (figs. 14–19). Tern breeding population size varied from 231 (95 percent CI 201–260; GRR 2007) to 419 (95 percent CI 396-442; GVP 2008) under low renesting and from 206 (95 percent CI 179–231; GRR 2007) to 376 (95 percent CI 355–396; GVP 2008) under high renesting.

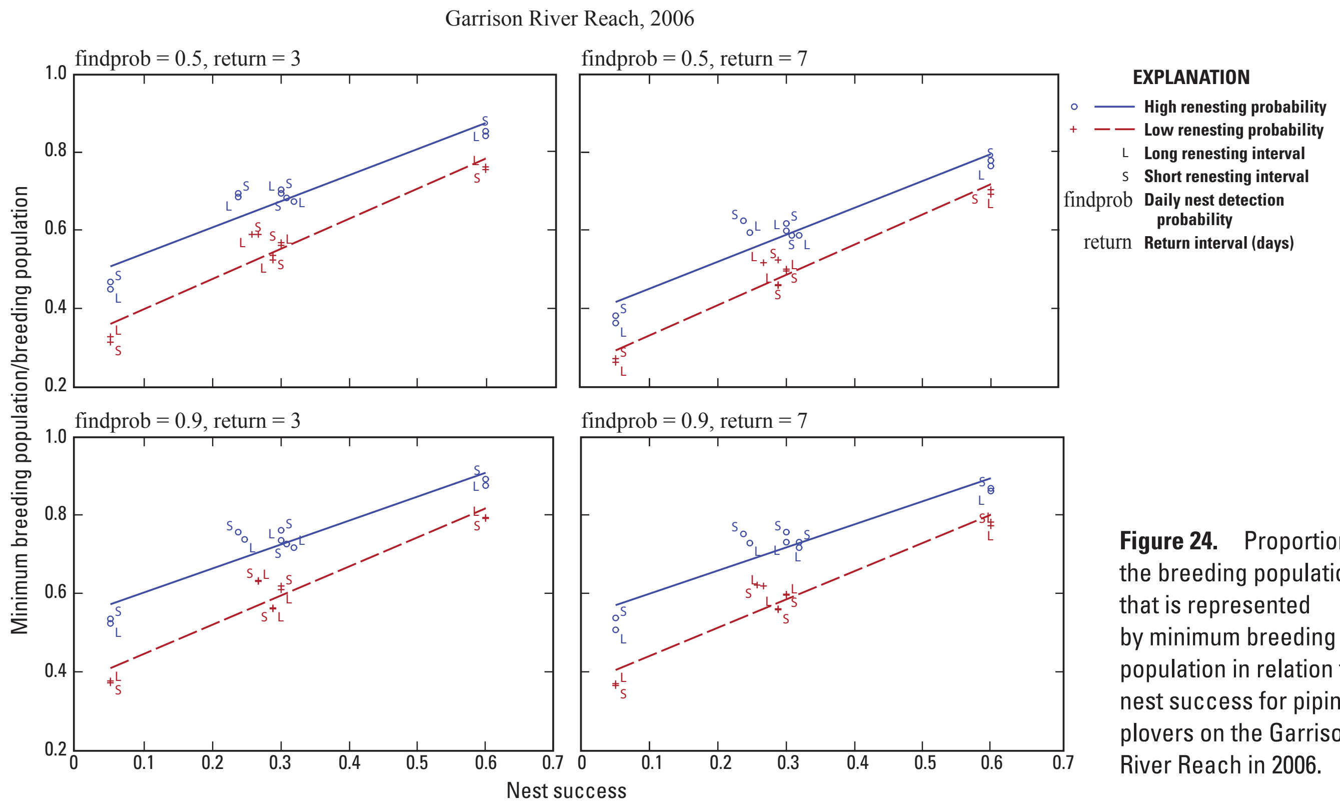


Figure 24. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for piping plovers on the Garrison River Reach in 2006.

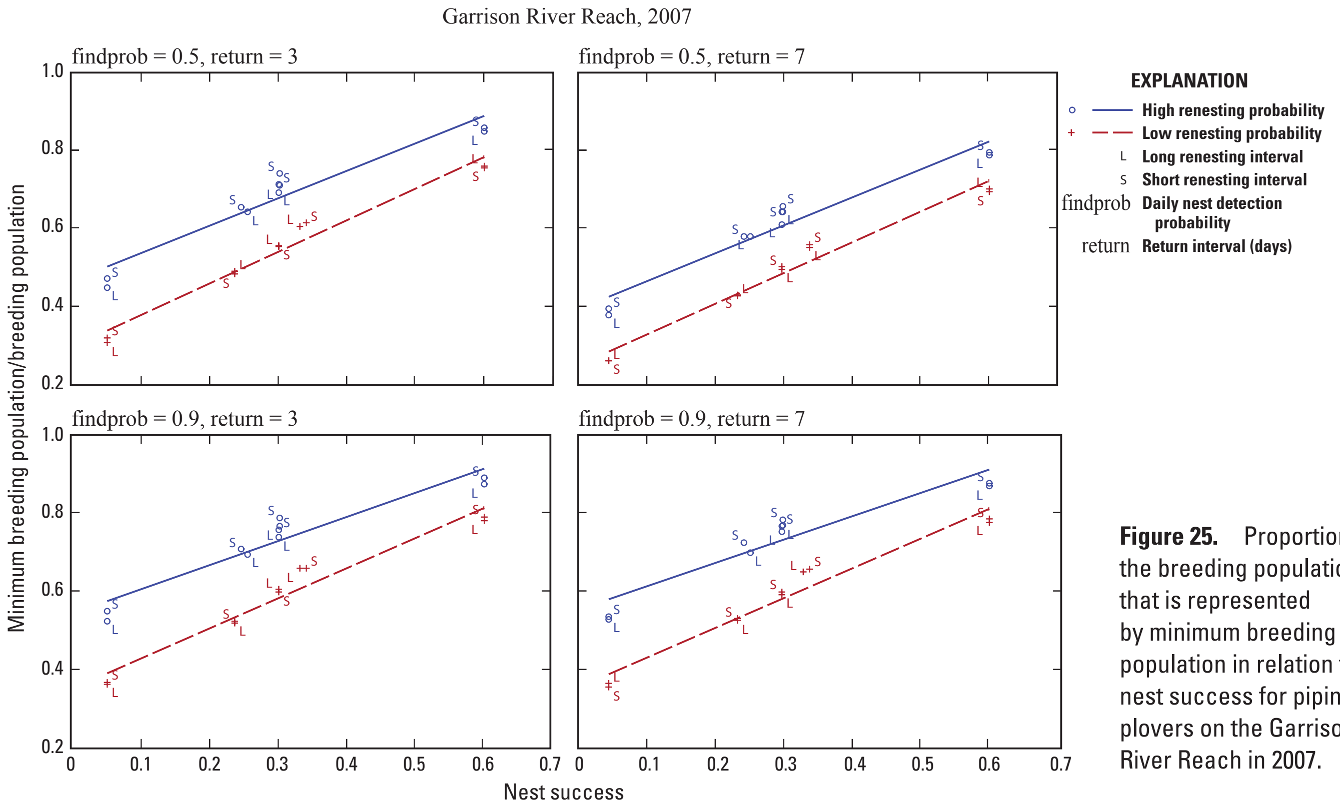


Figure 25. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for piping plovers on the Garrison River Reach in 2007.

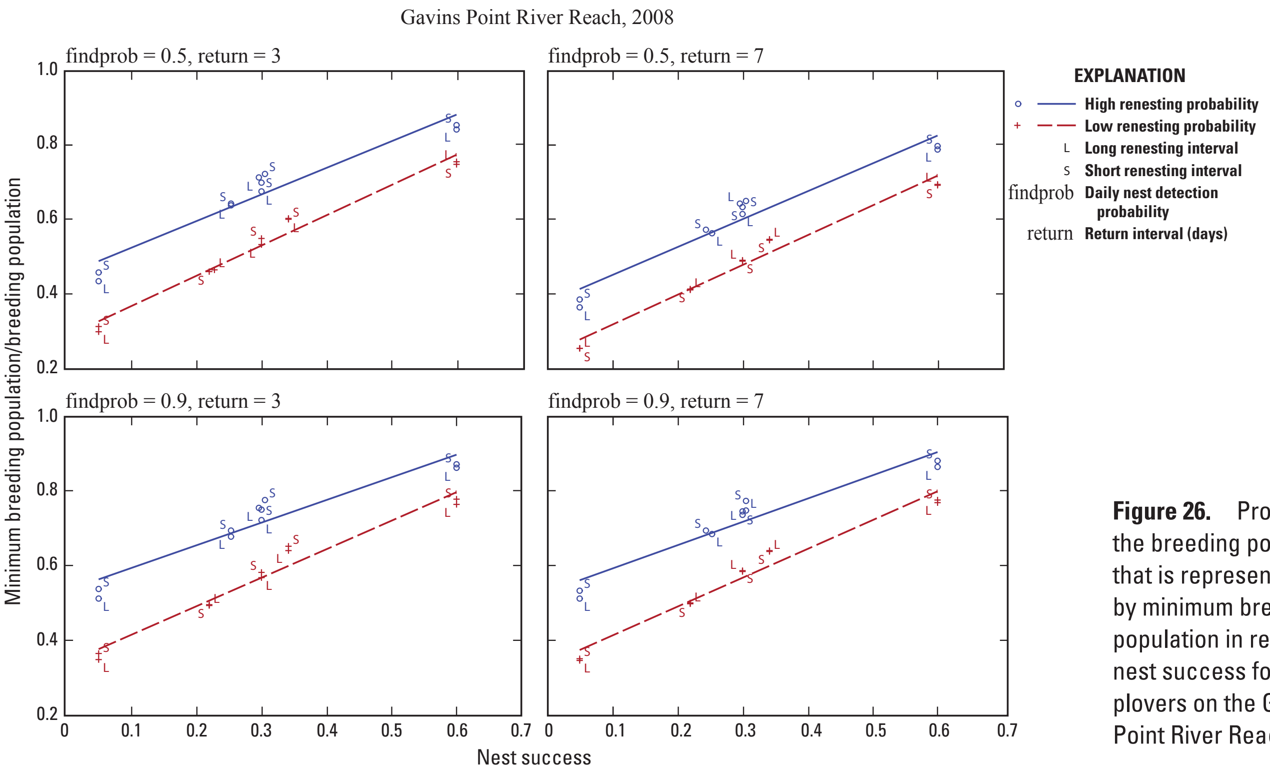


Figure 26. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for piping plovers on the Gavins Point River Reach in 2008.

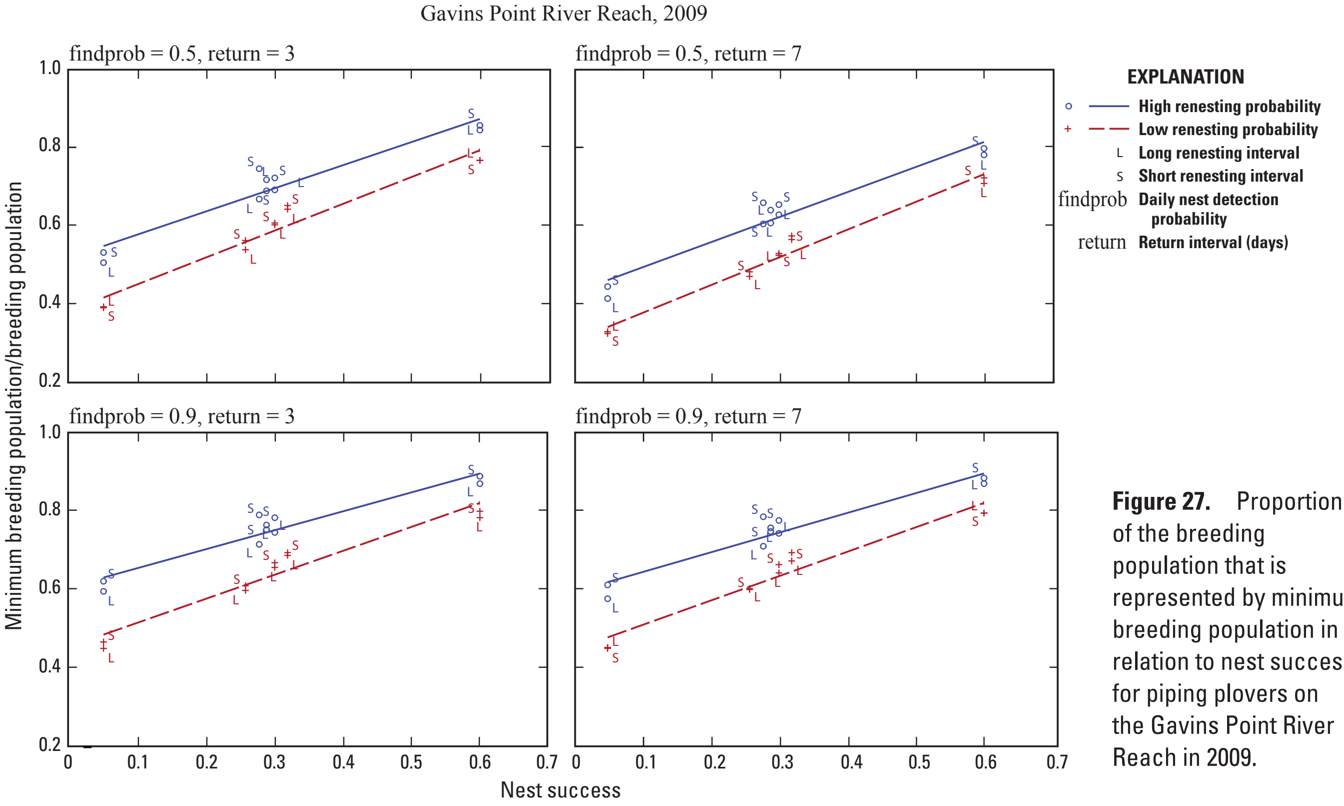


Figure 27. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for piping plovers on the Gavins Point River Reach in 2009.

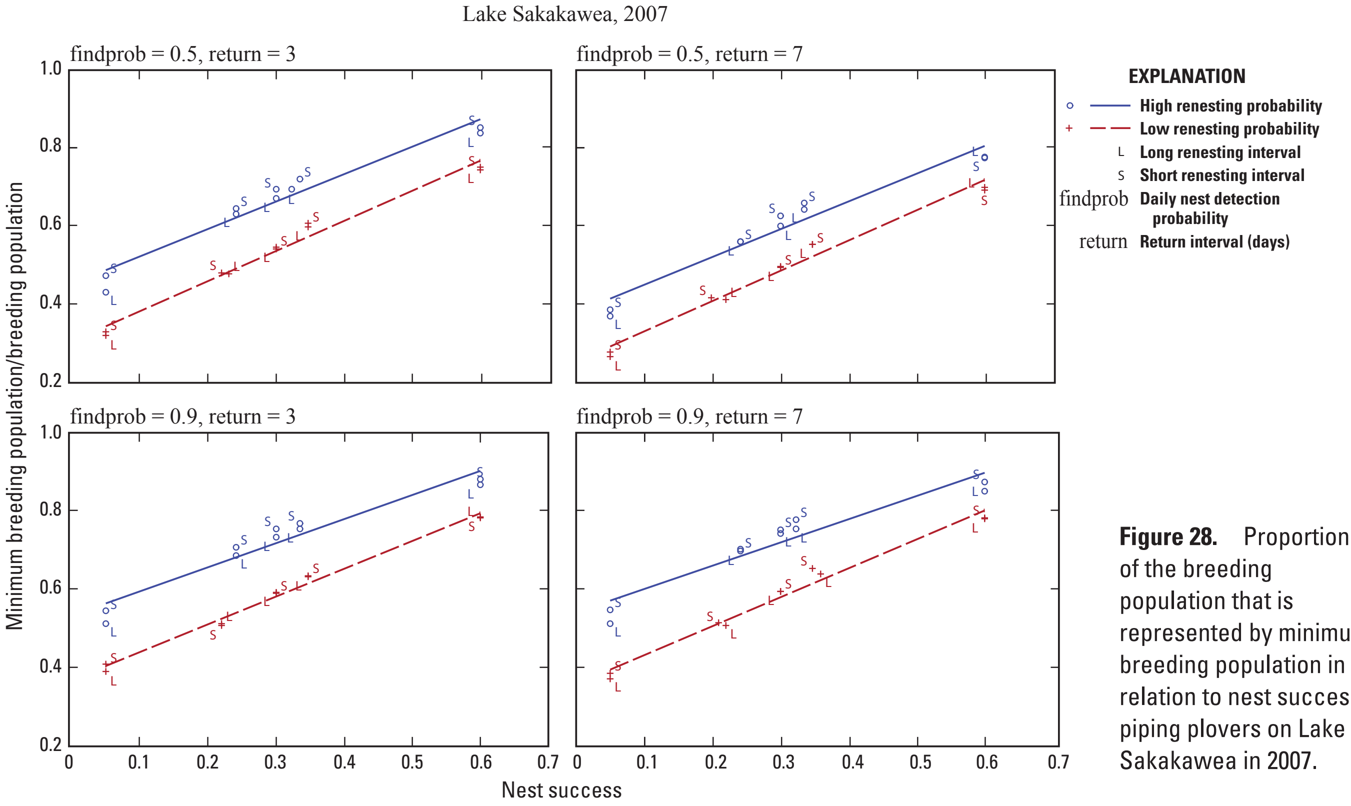


Figure 28. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success piping plovers on Lake Sakakawea in 2007.

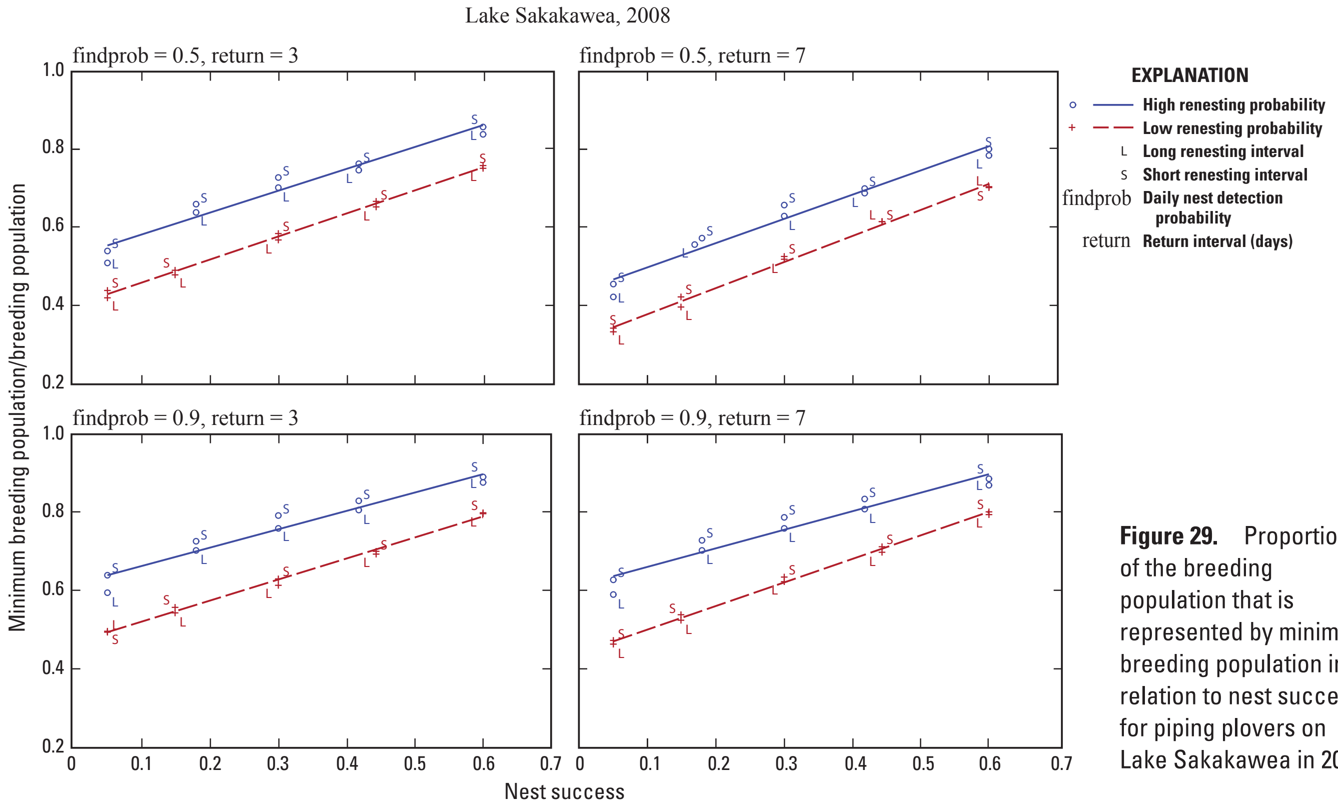


Figure 29. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for piping plovers on Lake Sakakawea in 2008.

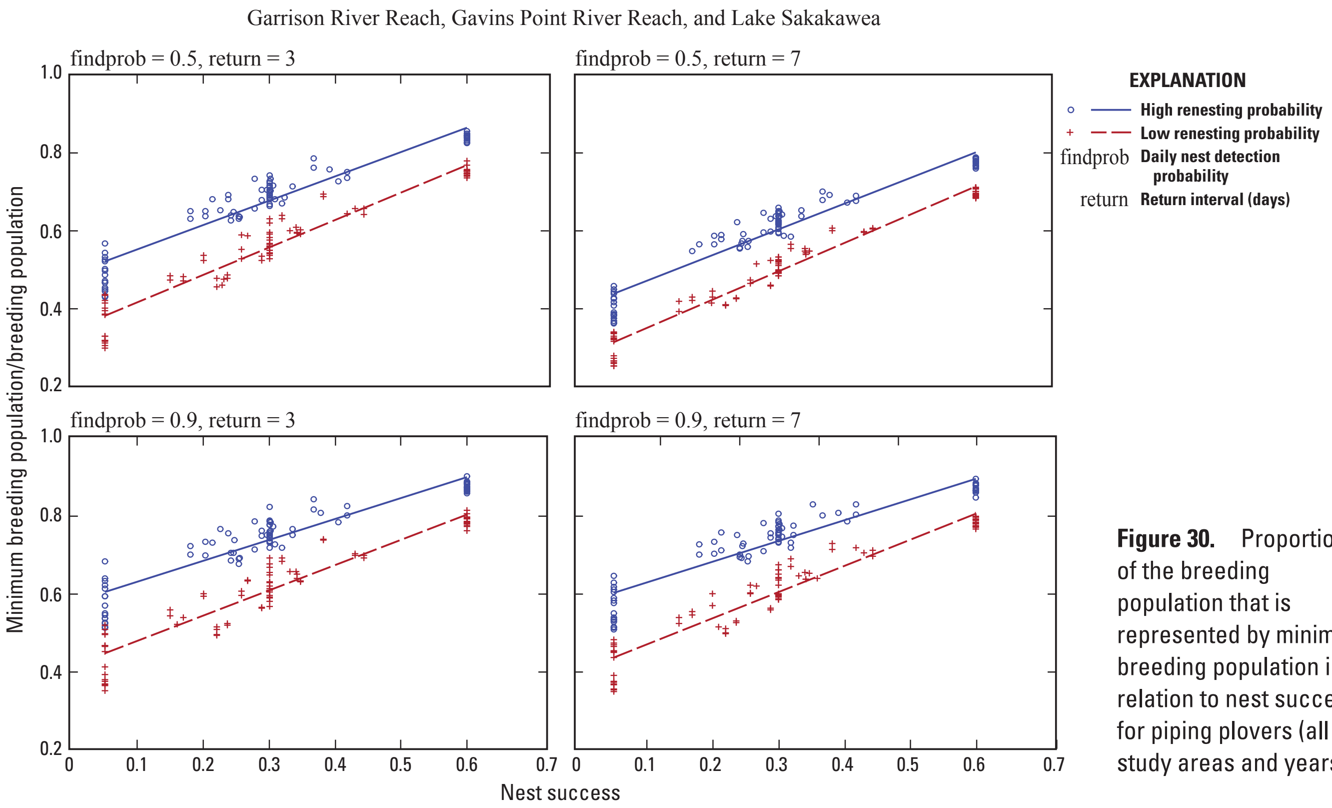


Figure 30. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for piping plovers (all study areas and years).

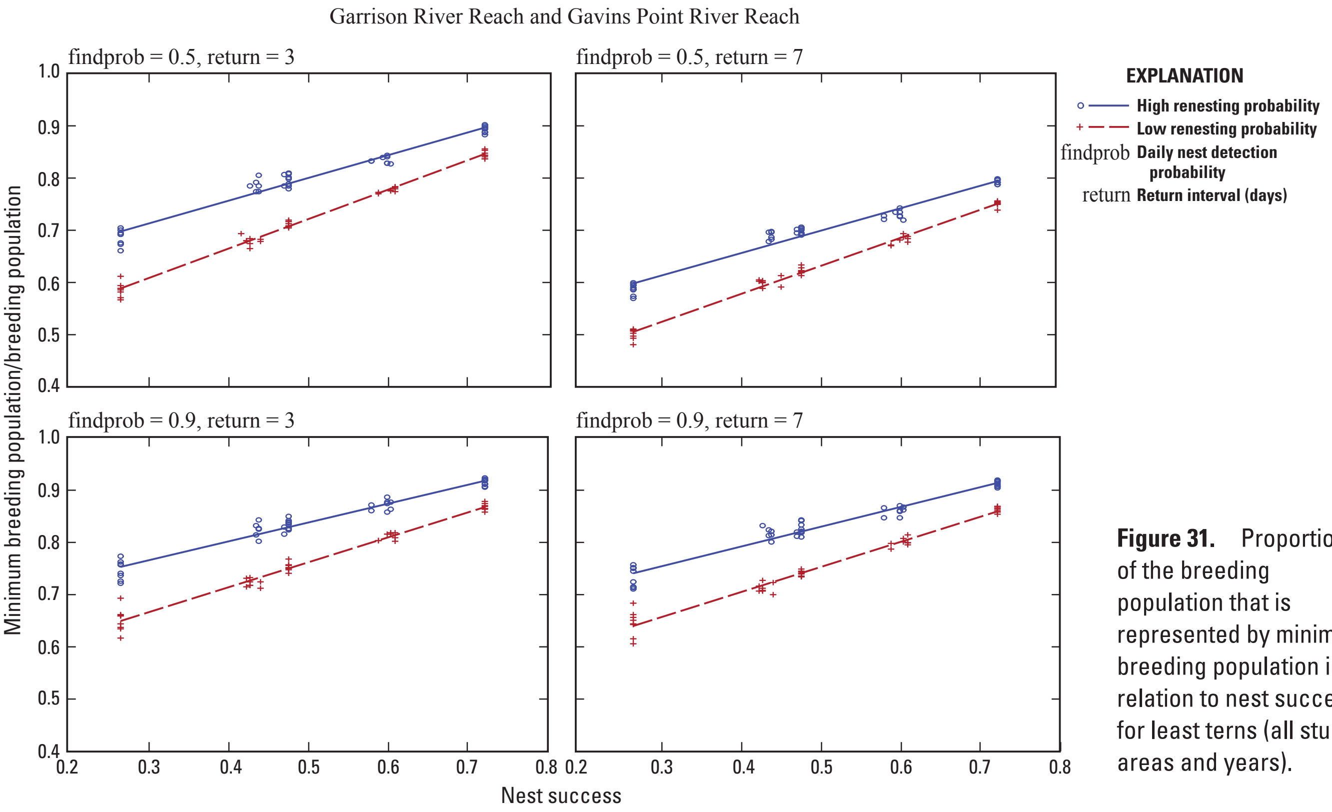


Figure 31. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for least terns (all study areas and years).

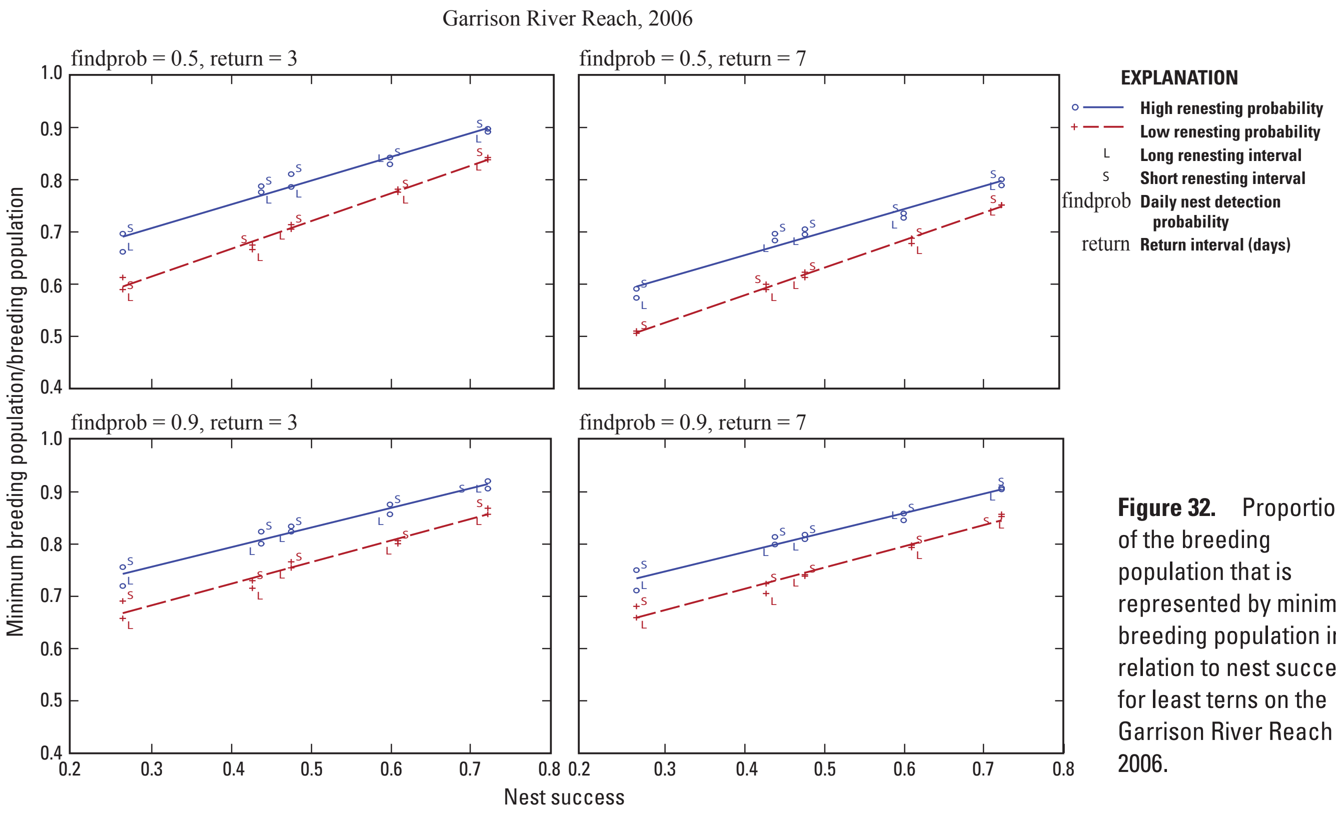


Figure 32. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for least terns on the Garrison River Reach in 2006.

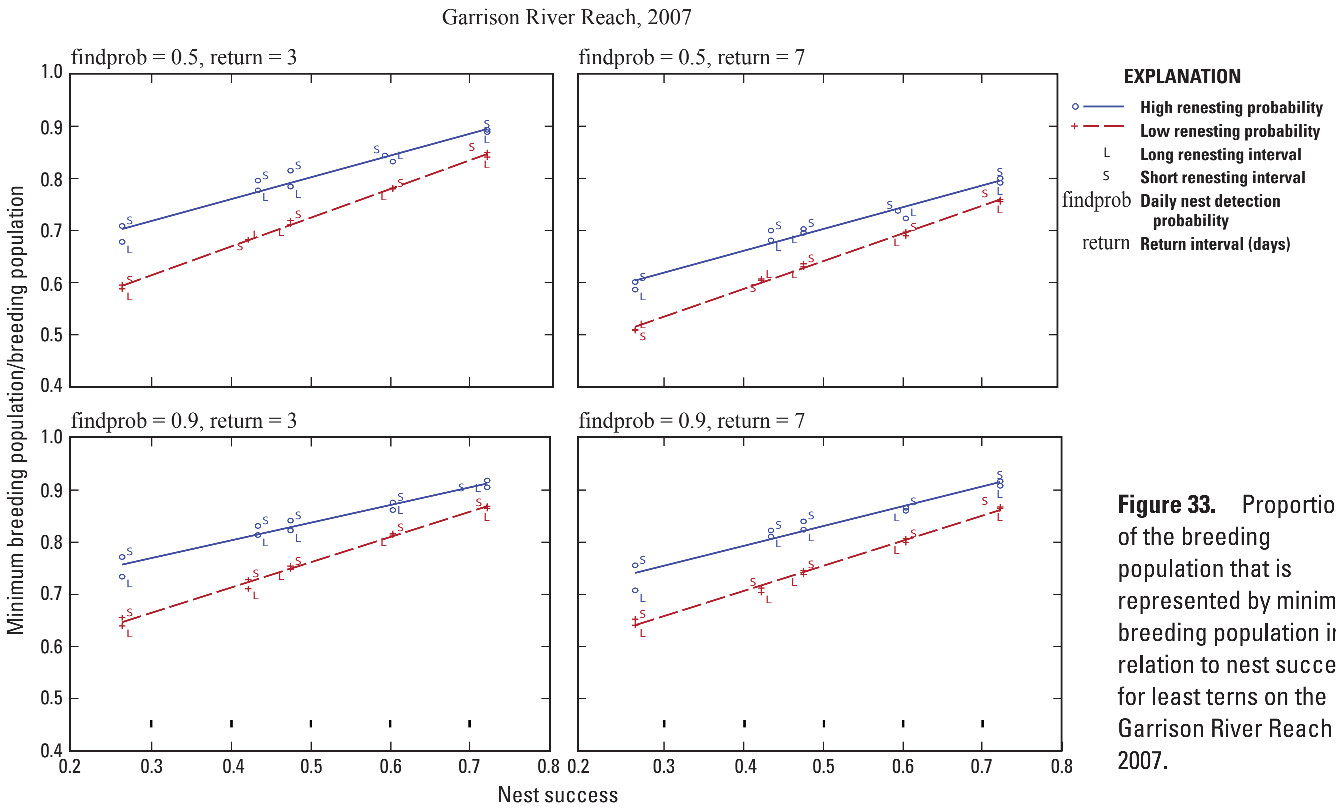


Figure 33. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for least terns on the Garrison River Reach in 2007.

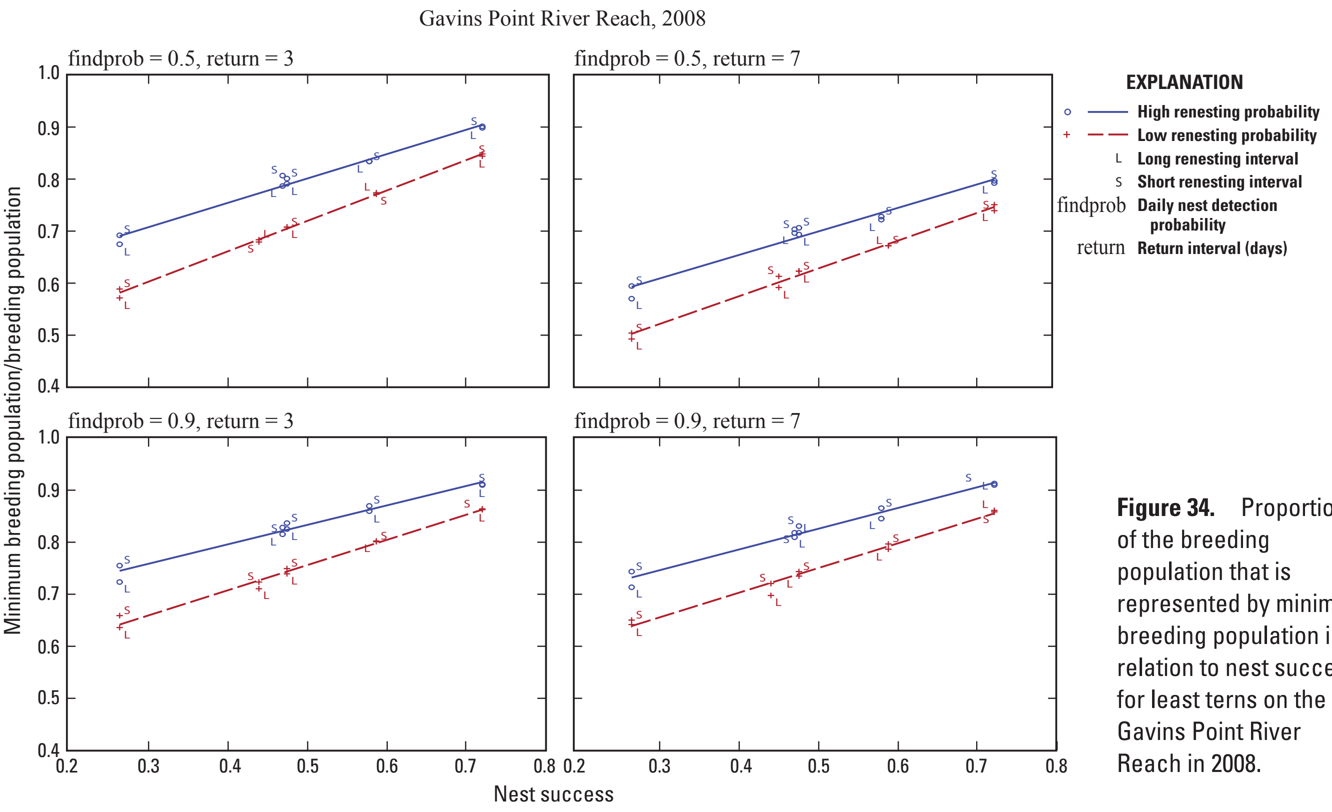


Figure 34. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for least terns on the Gavins Point River Reach in 2008.

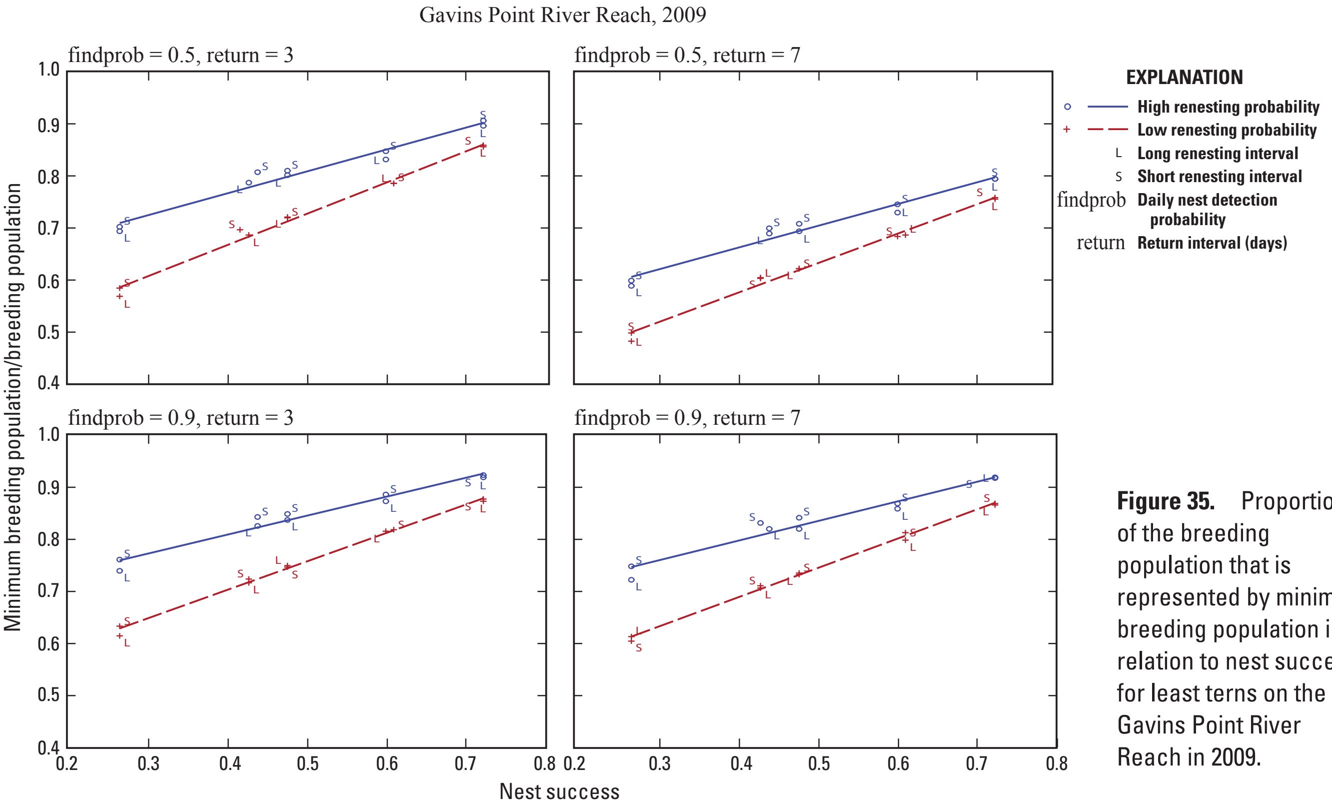


Figure 35. Proportion of the breeding population that is represented by minimum breeding population in relation to nest success for least terns on the Gavins Point River Reach in 2009.

Table 29. Minimum breeding population size (MINBPOP) and breeding population size (BPOP) adjusted for underestimation of BPOP by MINBPOP.

[MINBPOP was inferred from daily counts of active, recently failed, and previously hatched nests and provides a lower bound on BPOP. BPOP was computed as MINBPOP divided by a detection ratio (MINBPOP ÷ BPOP), which was estimated via simulation analysis. Simulations revealed that the detection ratio varied with nest success and renesting rate. Because renesting rate was not measured, BPOP estimates are shown for low and high renesting scenarios. Relative Bias (percent) is the difference between the number reported by the Corps and the USGS estimate as a percentage of the USGS estimate. LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; MINBPOP, absolute minimum breeding population; BPOP, breeding population; USGS, U.S. Geological Survey; Corps, U.S. Army Corps of Engineers]

Species	Study area	Year	MINBPOP		BPOP				BPOP reported by Corps	BPOP relative bias (percent)		Detection ratio (MINBPOP/BPOP)	
					Low renesting		High renesting						
			USGS expanded estimate	USGS 95-percent confidence interval	Estimate	95-percent confidence interval	Estimate	95-percent confidence interval		Low renest	High renest	Low renest	High renest
LETE	GRR	2006	189	168–210	266	237–296	231	206–257	139	-48	-40	0.71	0.82
LETE	GRR	2007	183	159–206	231	201–260	206	179–231	123	-47	-40	0.79	0.89
LETE	GVP	2008	310	293–327	419	396–442	376	355–396	278	-34	-26	0.74	0.82
LETE	GVP	2009	240	218–262	309	281–338	275	250–300	211	-32	-23	0.78	0.87
PIPL	GRR	2006	220	188–252	432	369–495	374	319–428	175	-59	-53	0.51	0.59
PIPL	GRR	2007	277	216–337	411	321–501	352	275–429	222	-46	-37	0.67	0.79
PIPL	GVP	2008	274	254–294	433	401–465	375	348–403	324	-25	-14	0.63	0.73
PIPL	GVP	2009	240	234–246	365	356–374	318	310–326	238	-35	-25	0.66	0.75
PIPL	SAK	2007	658	364–952	1,311	725–1,897	1,065	589–1,541	401	-69	-62	0.50	0.62
PIPL	SAK	2008	590	325–856	1,046	576–1,518	884	487–1,283	365	-65	-59	0.56	0.67

Tern breeding adults exceeded maximum adult survey numbers in all cases, although numbers were similar for GRR in 2007 (figs. 20–23).

Lower confidence intervals for BPOP exceeded adult numbers reported by the Corps for plovers and terns for all study areas and years (table 29). Adult tern numbers reported by the Corps for each of our study areas underrepresented number of breeding terns by 32–48 percent, assuming low renesting, and from 23–40 percent, assuming high renesting. Adult plover numbers reported by the Corps for each of our study areas underrepresented the number of breeding plovers by 25–69 percent, assuming low renesting, and from 14–62 percent, assuming high renesting.

3.5.6 Fledge Ratio

Minimum fledge ratio estimates [minimum fledging-age chicks/(BPOP/2)] of plovers varied from 0.27 (SAK 2008) to 0.96 (GRR 2007) under the low-renesting scenario and from 0.32 (SAK 2008) to 1.12 (GRR 2007) under the high-renesting scenario (table 30). Maximum fledge ratio estimates of plovers ranged from 0.66 (GVP 2009) to 1.19 (SAK 2008) under low renesting and from 0.76 (GVP 2009) to 1.41 (SAK 2008) under high renesting (table 31). Fledge ratio estimates were highly variable for SAK, less so but still highly variable for GRR, and less variable for GVP. Plover fledge ratios reported by the Corps for GVP exceeded upper confidence limits of USGS estimates in all cases except for maximum fledge ratio under high renesting in 2008 (table 31) Relative bias in plover fledge ratios reported by the Corps for GVP ranged from 33 to 83 percent for minimum fledge ratio (table 30) and from 12 to 65 percent for maximum fledge ratio (table 31).

Minimum fledge ratio estimates [minimum fledging-age chicks/(BPOP/2)] of terns varied from 0.78 (GRR 2006) to 1.43 (GVP 2009) under the low renesting scenario and from 0.89 (GRR 2007) to 1.61 (GVP 2009) under the high renesting scenario (table 30). Maximum fledge ratio estimates of terns ranged from 0.88 (GRR 2006) to 1.66 (GVP 2009) under low renesting and from 1.02 (GRR 2006) to 1.87 (GVP 2009) under high renesting (table 31). Fledge ratio estimates were highly variable, but less so for GVP than GRR. Least tern fledge ratio reported by the Corps for GVP in 2009 was below the USGS lower confidence limit for minimum and maximum fledge ratio (table 30, 31). Tern fledge ratio reported by the Corps for GVP in 2008 was below the USGS lower confidence limit for maximum fledge ratio but within confidence bounds for minimum fledge ratio (table 30, 31). Relative bias in tern fledge ratio reported by the Corps for GVP ranged from -7 to -38 percent for minimum fledge ratio (table 30) and from -24 to -47 percent for maximum fledge ratio (table 31).

3.6 Discussion

A critical assumption underpinning our approach to evaluating accuracy of the TPMP is that USGS estimators were themselves unbiased and sufficiently precise to provide meaningful benchmarks against which TPMP results could be compared. Bias in an estimator can result from several sources

Table 30. Estimates of U.S. Geological Survey minimum fledge ratios in relation to numbers reported by the U.S. Army Corps of Engineers 2006–09.

[BPOP, breeding population; Fledge ratio is defined as number of fledging-age chicks divided by number of breeding pairs (BPOP/2). U.S. Geological Survey minimum fledge ratios are based on resightings of banded fledging-age chicks corrected for imperfect detection. U.S. Geological Survey breeding population estimates depended on renesting probability. Because of uncertainty over renesting probability, results are shown for two scenarios, high and low renesting. Relative bias (percent) is the difference between the number reported by the U.S. Army Corps of Engineers and the U.S. Geological Survey estimate as a percentage of the U.S. Geological Survey estimate. LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; Corps, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey]

Species	Study area	Year	Reported by Corps	Low renesting			High renesting		
				USGS expanded estimate	USGS 95-percent confidence interval	Relative bias (percent)	USGS expanded estimate	USGS 95-percent confidence interval	Relative bias (percent)
LETE	GRR	2006	0.81	0.78	0.51–1.17	4	0.90	0.59–1.35	-10
LETE	GRR	2007	1.06	0.80	0.46–1.32	33	0.89	0.52–1.48	18
LETE	GVP	2008	1.14	1.23	0.98–1.50	-7	1.37	1.09–1.68	-17
LETE	GVP	2009	1.00	1.43	1.16–1.75	-30	1.61	1.30–1.97	-38
PIPL	GRR	2006	NA	NA	NA	NA	NA	NA	NA
PIPL	GRR	2007	0.97	0.96	0.46–1.77	1	1.12	0.54–2.06	-14
PIPL	GVP	2008	1.37	0.89	0.76–1.05	54	1.03	0.88–1.21	33
PIPL	GVP	2009	1.09	0.60	0.57–0.63	83	0.68	0.65–0.72	60
PIPL	SAK	2007	0.70	0.34	0.04–1.11	107	0.42	0.06–1.37	68
PIPL	SAK	2008	0.68	0.27	0.05–0.83	155	0.32	0.06–0.98	116

Table 31. Estimates of U.S. Geological Survey maximum fledge ratios in relation to numbers reported by the U.S. Army Corps of Engineers 2006–09.

[BPOP, breeding population; Fledge ratio is defined as number of fledging-age chicks divided by number of breeding pairs (BPOP/2). U.S. Geological Survey maximum fledge ratios are based on resightings of banded fledging-age chicks corrected for the probability of detection. Maximum fledge ratio allows for potential additional chicks that could have been produced from eggs with unknown fates. U.S. Geological Survey estimates of BPOP depended on renesting probability. Because of uncertainty over renesting probability, results are shown for two scenarios, high and low renesting. Relative Bias (percent) is the difference between the number reported by the U.S. Army Corps of Engineers and the U.S. Geological Survey estimate as a percentage of the U.S. Geological Survey estimate. LETE, least tern; PIPL, piping plover; GRR, Garrison River Reach; GVP, Gavins Point River Reach; SAK, Lake Sakakawea; Corps, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey]

				Low renesting			High renesting		
Species	Study area	Year	Reported by Corps	USGS expanded estimate	USGS 95-percent confidence interval	Relative bias (percent)	USGS expanded estimate	USGS 95-percent confidence interval	Relative bias (percent)
LETE	GRR	2006	0.81	0.88	0.58–1.32	-8	1.02	0.67–1.53	-20
LETE	GRR	2007	1.06	1.01	0.58–1.67	5	1.13	0.65–1.88	-6
LETE	GVP	2008	1.14	1.49	1.19–1.83	-24	1.66	1.33–2.04	-31
LETE	GVP	2009	1.00	1.66	1.35–2.03	-40	1.87	1.51–2.29	-47
PIPL	GRR	2006	NA	NA	NA	NA	NA	NA	NA
PIPL	GRR	2007	0.97	1.13	0.54–2.08	-14	1.32	0.64–2.43	-27
PIPL	GVP	2008	1.37	1.06	0.91–1.25	29	1.23	1.05–1.44	12
PIPL	GVP	2009	1.09	0.66	0.63–0.69	65	0.76	0.72–0.80	44
PIPL	SAK	2007	0.70	1.09	0.14–3.59	-36	1.35	0.18–4.42	-48
PIPL	SAK	2008	0.68	1.19	0.23–3.72	-43	1.41	0.28–4.40	-52

including the manner in which study units are chosen, imperfect or inadequate field protocols, and improper data analysis. Our approach to overcoming sampling bias was to employ probability sampling in a rigorous manner that allowed sampling variation (precision) to be quantified. We used standardized field protocols and an ambitious monitoring schedule to minimize measurement error associated with collection of field data. We sought ways to minimize and quantify potential effects of our monitoring on metrics of interest. We performed rigorous data analyses to understand and account for or partially mitigate for detection and observer bias. Despite these efforts, we acknowledge that some of our estimators are biased; however, we contend that the bias should be slight and not compromise our evaluation of the TPMP.

We expected that the number of nests detected under the USGS research program would exceed the number detected under the TPMP, because it was known that TPMP search intervals were long and start dates late in relation to first arrival dates of piping plovers. Thus, the outcome of biased nest numbers under the TPMP was not surprising. What was uncertain was the magnitude of bias and if it would be consistent across species, study areas, and years. The only discernible commonality among years and study areas we observed was for bias to be more pronounced for plover than tern nests, which likely is because of the earlier arrival and nest initiation of plovers compared to terns. Analyses of USGS data indicated we did not find all nests, suggesting that actual biases in TPMP nest numbers are more severe than reported.

Nests fated probable success by the Corps and successful by the USGS are a symptom of the Corps' longer visit interval. It was much more likely that a hatched tern nest would be fated probable success by the Corps and successful by the USGS. This suggests the Corps crews do a good job of interpreting nest fate evidence at successful nests where chicks are no longer present in the nest scrape, although error rates in these determinations were decidedly nontrivial (10 percent for terns, 7 percent for plovers).

Our results illustrate that multiple procedural issues can lead to nests being missed during monitoring. Although we identified Vigilance/Search Pattern as the dominant factor for missed nests, we suspect that the other three factors (Late Start Date, Habitat not Searched, Search Interval too Long) were underestimated for several reasons. First, the dates used in this analysis reflected the start of early-season nest surveys by Corps permanent staff before regular (weekly) surveys are started by seasonal staff. Distinguishing other causes of missed nests was challenging because information about where the TPMP crews searched for nests was incompletely documented, particularly when no nests were found. The best available information on TPMP nest searching effort was available when visits documented observations of active nests, but those data are inherently problematic because they do not indicate when a site was visited and no nests were found (whether or not they existed). Given more complete information on location of monitoring and dates of nest searches, it is likely that the relative importance of the four factors responsible for missed nests would have changed.

Our analyses of TPMP data on missed nests and total nests revealed that bias in nest abundance under the TPMP was greater for plovers than for terns. The Late Start Date factor was assigned only to plover nests, suggesting that the TPMP protocol was temporally suited for detection of the first tern nests, but not the first plover nests, in a season. This contributed to discrepancies between the USGS determination of nest failure and the underrepresentation of TPMP-observed failed nests, while accounting for a greater percentage of all missed nests in plovers than in terns.

Our data indicated an opposite temporal trend in nest success between terns and plovers on riverine study areas, with nest survival increasing in relation to initiation date for plovers and declining for terns. Coupled with the TPMP's late starting date and the observed early-season nest initiations by plovers, this pattern points to greater uncertainty about interpreting TPMP-reported nest success values for plovers. Discrepancies between probable successful and successful fates for the USGS and Corps were markedly different between species. The Corps frequently assigned the probable success fate to nests fated as successful by USGS, which means that the USGS crew observed chicks in nest bowls more frequently than Corps crews because of differences in nest-visit interval. The inconsistency also means that Corps crews often correctly interpreted nest fate evidence even when chicks were not observed in the nest bowl. This discrepancy in correct fate assessment was much more pronounced for terns than plovers, suggesting that tern chicks are found in the nest bowl for fewer days after the first egg hatches than plovers. This may be a consequence of more synchronous hatch or smaller clutch size (and thus fewer eggs to hatch) in terns than in plovers. Alternatively, the Corps' search interval could have grown longer as the season progressed, reducing likelihood of terns being observed in nest bowls. If banding chicks is a priority in the future, particularly for terns, it will be important to maintain a search interval suitable for observing chicks in the nest bowl at hatch.

Analyses of USGS data suggested we found nearly all hatched nests. A substantial number of nests missed by TPMP crews hatched (22 percent, 139 hatched nests of the 635 missed), particularly on GRR and SAK. Bias in estimates of hatched nests was low at GVP (1–6 percent), likely due to nests being concentrated in a few well-known sites, but ranged from -60 to -26 percent on GRR and SAK (table 7). In the missed nest analysis, we found three hatched nests assigned to Late Start Date (meaning that nest monitoring started extremely late relative to nesting phenology), and three hatched nests assigned to Search Interval Too Long (meaning the interval between searches was extremely long).

Despite biases in numbers of hatched nests, TPMP-derived counts of plover chicks generally agreed with minimum chick counts reported by USGS. This finding suggests that the Corps was able to compensate for the difference in hatched nests by accurately enumerating plover chicks from known and unknown nests. TPMP-reported values for plover chicks per nest and plover chicks per successful nest indicated positive bias, owing to the fact that counts of nests and hatched nests generally indicated negative bias. Negative bias in counts of tern chicks was evident or suggested, depending on the study area and year. This is not surprising given the more limited mobility and visibility of young tern chicks compared with plover chicks.

We went to considerable effort to quantify and understand variability in detection probabilities of color-banded plover and tern chicks. It is important to recognize that these detection probabilities pertain to color-banded chicks and do not apply to counts of chicks made regardless of color-marks. Our analyses revealed some interesting but predictable patterns in detection probability (table 25). Our ability to detect fledging-age tern chicks was lower than for fledging-age plover chicks. This was due partly to behavioral differences between species and also because we had fewer opportunities to locate fledging-age tern chicks than fledging-age plover chicks. Our estimates of detection probability were reasonably precise, meaning we could reliably adjust observed counts of fledging-age chicks for detection bias. Our analyses revealed substantial negative bias in TPMP-derived counts of fledging-age plover chicks at GRR and of terns at GRR and GVP. Results also suggested a negative bias for plovers at SAK, although wide confidence intervals precluded definitive conclusions. The only scenario in which bias was not apparent was for plovers at GVP. We speculate a few possible explanations why this may have been the case. First, sandbars at GVP where plover chicks were found typically had more open sand and less vegetation than sandbars at GRR. Second, nests were more concentrated and at higher densities on fewer sandbars at GVP than at GRR. These two differences may have contributed to improved visibility and more accurate enumeration of plover chicks by TPMP crews at GVP. Lastly, plover chicks had been marked prior to our study at GVP but not at GRR. TPMP crews at GVP may have begun to cue on color-marked individuals when counting fledging-age chicks.

Accurate estimates of adults, breeding adults, or both, are highly desirable for most bird monitoring programs, including the TPMP. We attempted to quantify adults and breeding adults. Our approach to quantifying adults on river study areas was based on weekly surveys of all breeding habitat within the study area. We faced a tradeoff between doing a rapid but possibly inaccurate survey (*extensive* survey) and taking time to be thorough and complete in our counts (*intensive* survey). The double-sampling design allowed us to do both. The accuracy of double-sampling estimators depends on two critical characteristics: quality of the data provided by the intensive survey (that is closeness of the count of individuals to the true unknown number) and strength of the relation between extensive and intensive counts as described by some statistical model estimable from the data. Our analyses indicated the above relation was not constant among study areas, years, or even from survey to survey within a year. Although we were able to account for the nonconstancy in our analyses, the finding suggests that raw counts of adults are prone to bias. Patterns in estimated adult numbers of plovers and terns by USGS throughout the breeding season indicated marked variability between years on a given study area. Although peak counts generally were similar between years, numbers built more rapidly in one year than the other. Variability among surveys was substantial and precluded reliable inference concerning abundance from any single survey. Furthermore, no uniformly best survey window for either species was apparent for all years and study areas. This finding has important implications for interpreting results of one-time surveys of plovers and terns and for designing an effective monitoring program for either species.

In addition to quantifying the number of adults present on each study area at weekly intervals, we estimated the number of *breeding* adults (denoted as BPOP), defined as the number of individuals that contributed ≥1 nest at any time during the season. By definition, our MINBPOP metric provided a minimum estimate of BPOP. MINBPOP was based on periodic nest monitoring data, including information on nest initiation and termination dates and on nest fates. Importantly, MINBPOP could be determined directly from field data whereas BPOP could not; however, we did simulations that allowed us to examine and quantify the bias in MINBPOP as an estimator of BPOP. Our simulations predict that the bias increases as nest success decreases or as renesting probability increases and that neither renesting interval nor timing of first nests had much effect for either species. Because we could estimate nest success but not renesting probability from field data, we provided two BPOP estimates, one assuming low renesting and the other assuming high renesting. Regardless if renesting was assumed high or low, our BPOP estimates revealed substantially more breeding adults than were indicated by our adult surveys, which was opposite of what we expected. In hindsight, we believe our findings illustrate the difficulty of obtaining complete counts of unmarked adult plovers or terns over large areas. Even though we went to substantial effort to obtain complete counts with our intensive adult surveys, the vastness of the area, the mobility of tern and plover adults, and the fact that birds are cryptic even under ideal conditions, suggest that we undercounted adult plovers and especially adult terns (figs. 14–23). Although we anticipated bias in MINBPOP as an estimator of BPOP, we were surprised by how much of the bias could be explained by variability in nest survival rate. Findings from our simulations and the fact that we presented estimates under high and low renesting gave us confidence in our BPOP estimates and the finding that TPMP counts of adults, like USGS adult survey counts, had substantial downward bias.

We did not expect to find much consistency in comparisons of TPMP-derived fledge ratios and fledge ratios derived from our data. We were surprised by how tight the confidence intervals were on USGS fledge ratio estimates for GVP and attribute that to the fact that even though we sampled only 84 percent of the study area, the 16 percent we did not sample was largely devoid of sandbars and birds; thus, our survey was essentially a census. Because fledge ratio depends on estimates of breeding adults and fledging-age chicks, and we found substantial bias in TPMP-reported values of both quantities, we were not surprised that fledge ratio comparisons indicated no clear patterns.

3.7 Monitoring Implications

The value of a monitoring program clearly depends on how well the program achieves its intended purpose of informing management. The history and records of the TPMP indicate that the activities of the TPMP have had many purported uses, ranging from implementing management practices to assessing regional population trends to informing near real-time water management decisions and reducing incidental take. In this section, we consider implications of our research findings for several of those uses. It should be recognized that our accuracy assessment was limited to a 4-year period (2006–09), a short window of time compared to the 26 years that the TPMP has been in operation. We assumed our findings were representative of the performance of the TPMP over the larger timeframe, but that assumption could be questioned as explained in the next paragraph.

It is obvious from the history of the TPMP that the program has evolved over the course of its 26-year history. The degree to which current performance of the TPMP characterizes past performance is unknown but reasons exist to expect some differences. Based on results of the TPMP, plover numbers on the Missouri River were in decline from a 26-year peak when our study began and tern numbers reached their 26-year peak during the second year of our study (Greg Pavelka, unpub. data, 2010). Water-surface elevation at SAK was near an all-time low, exposing extensive amounts of shoreline nesting habitat for plovers. The ESH program was creating expansive units of engineered sandbar habitat on GVP and nearby Lewis and Clark Lake whereas naturally created habitat on GVP had become vegetated or had deteriorated as a result of erosion. These changes resulted in birds nesting at higher densities on fewer sandbars than had been reported previously (Catlin and others, 2011). Having birds concentrated may have led to more accurate counts by TPMP surveyors because there were fewer places where surveyors had to look. Alternatively, if counting became more difficult at individual locations as bird numbers increased, accuracy of the overall count may have deteriorated relative to a situation in which numbers were similar but birds were more widely distributed. Our results contrasting GRR and GVP are consistent with the former argument; however, regardless of which argument holds, the assumption that current performance of the TPMP matches past performance is circumspect because of physical changes to the environment during the past 26 years.

An overarching finding of our evaluation is confirmation that the TPMP is neither a complete census of terns and plovers nor a complete census of tern and plover nests. Therefore, any application of the TPMP data or resulting summaries that presupposes this as a necessary condition will be flawed and subject to substantial risk of erroneous conclusions. A prime example is the use of TPMP data to assess if population or productivity goals involving exact numbers of adults or fledglings are being met. Our findings indicate that reported numbers of adults were substantially lower than actual numbers, often by 50 percent or more, and that reported numbers of fledglings were also frequently biased, especially for least terns. Yet another example of misuse is reliance on the TPMP for determining incidental take of nests. Our results revealed severe bias in TPMP-derived estimates of nests, especially nests that failed.

If the goal of monitoring is to track population trend, bias is not necessarily a critical flaw; however, the variation in bias from year to year must be small relative to variation in population size, and the bias must be independent of population size (Johnson, 2008). In that regard, the fact that TPMP-reported numbers of adults were consistently low may bode well for the use of the TPMP as a tool for assessing population trends within individual reaches of the Missouri River. Although the direction of bias was consistent among USGS study areas, the magnitude varied among study areas, with bias in plover numbers being least severe for GVP and most severe for SAK (table 29). An implication of the unequal bias is that as the distribution of plovers shifts among reaches, the magnitude of bias in plover numbers for the river as a whole changes. This makes inference about trends in population size on the Missouri River problematic. We illustrate the problem with an example that considers three hypothetical study areas: A, B, and C (table 32). Each study area has a different monitoring bias, ranging from -65 percent at study area A to -20 percent at study area C. Two scenarios are considered. The total population (1,000) is identical in both scenarios, but the distribution of the population differs. In scenario 1, 60 percent of the population is in study area A whereas in scenario 2 only 5 percent of the population is in study area A. *Estimated* total population under scenario 1 is 470 compared to 718 under scenario 2 (table 32). The true population size has not changed but the monitoring program indicates 248 (52 percent) more individuals under scenario 2, all because of a change in population distribution. Although the example is hypothetical, the values for %Bias and True N in table 32 are plausible for the various segments of the Missouri River (table 29). USGS estimated many more than 50 plovers on SAK, but 2007 and 2008 were characterized by low surface-water elevations and substantial area of exposed shoreline habitat at the onset of the breeding season. This was in stark contrast to 1997 when the lake level was approximately 11 m higher and the TPMP reported only 63 adult plovers (Greg Pavelka, unpub. data, 2010).

A common use of the TPMP is to track recovery of tern and plover populations. If recovery means achieving some prescribed population size or level of productivity, then this use does not appear compatible with the current TPMP because of the problems cited above. Another problematic use of TPMP data is the count of nest losses attributed to certain causes (for example, flooding) as a metric of incidental take.

Table 32. Hypothetical example illustrating the problem of estimating a population total by summing across sub-populations when estimator bias varies among sub-populations.

[Two scenarios are illustrated. The population total is 1,000 in each scenario, but the distribution of the population differs between scenarios leading to vastly different estimated totals. N, number]

Site	Percent bias	Scenario 1		Scenario 2	
		True N	Estimated N	True N	Estimated N
A	-65	600	210	50	18
B	-50	200	100	200	100
C	-20	200	160	750	600
Total		**1,000**	**470**	**1,000**	**718**

Our observations at GRR in 2006 revealed substantial flooding-related loss of early initiated plover nests that coincided with increased releases from Garrison Dam in mid-May. Very few of those nests were under observation by the TPMP, and accordingly were not included in the incidental take accounting for that year. Because these data are absent from the TPMP, an opportunity was lost to learn about relations between early-season flow patterns and plover productivity along with an opportunity to adjust management actions to minimize early-season nest mortality.

The utility of the current TPMP to direct management decisions involving nests of terns or plovers is clearly limited. The 7- to 10-day return interval characteristic of the TPMP does not lend itself to accurate counts of newly initiated nests even though such nests may be numerous and their success critical to overall reproductive output. This is especially problematic for piping plovers because many early nests are initiated before regular TPMP monitoring begins. The TPMP provides the foundation for predation management in the form of installing predator exclosures around plover nests or removing predators from certain sandbars. The effectiveness of the TPMP for this use is difficult to evaluate, but the fact that many plover nests were initiated and destroyed before they could be located and protected points to a potential deficiency in the monitoring program. The hundreds of nests falling into this category represented critical but lost opportunities to enhance productivity by deploying cages. Even successful nests that must persist for 24–35 days, depending on species, were overlooked at a surprisingly high rate. It seems clear that the current TPMP is not nearly as effective for predation management purposes as it could be.

A related implication is that any management that depends on the TPMP to direct where management is done (as is the case currently) has potential to render TPMP-monitored sites or nests as unrepresentative of remaining sites or nests, thereby biasing monitoring results. This would not be an issue if the TPMP was functioning as a complete census; however, we reiterate our earlier statement that any application of the TPMP that assumes a complete census is problematic.

Our BPOP estimates for SAK were highly variable and far from definitive, but they suggested the very real possibility that numbers of plovers breeding at SAK far exceed numbers reported by the TPMP. Although not part of the evaluation, we also estimated BPOP at SAK in 2006 and 2009 and observed plover numbers that exceeded values reported by the TPMP by ≥500 birds each year. Although confidence intervals for our estimates were wide, it seems unlikely that the same pattern would emerge 4 years in a row unless values reported by the TPMP were underrepresenting actual numbers. We believe plover numbers are being substantially undercounted at SAK and possibly other large reservoirs on the Missouri River (for example, Lake Oahe).

Another purported use of the TPMP is evaluating management activities, although the type and scale of management activities are often unspecified. One activity that is sometimes singled out is habitat creation and restoration, such as that done by the ESH program. In all cases, evaluation of management appears to have been a retrospective use of TPMP data without consideration for the scale of data collection or underlying objectives. Although it is desirable for a good monitoring program to track progress toward achieving management objectives, monitoring often lacks adequate experimental design features to distinguish changes resulting from habitat manipulation from changes brought about by other causes. Directed research that utilizes a well-defined, objective-driven experimental design is generally necessary to address questions about cause and effect. To the extent that tracking population changes coincident with management actions constitutes evaluation of those actions, the TPMP may be adequate if performance of the TPMP is not enhanced or diminished by the same management actions. In the case of the creation of large engineered sandbars that lead to concentrated nesting by plovers and terns, that assumption may be invalid.

Although the Corps routinely reports fledge ratios (for example, Greg Pavelka, unpub. data, 2010), there is scant evidence in the scientific literature of the use of fledge ratio as a useful monitoring metric. We believe the primary reason for this is that fledge ratios are notoriously difficult to estimate with much precision. Fledge ratio is, after all, a ratio and numerator and denominator are subject to sampling error and bias, usually of considerable magnitude (see tables 27 and 29 for evidence of considerable bias in TPMP estimates of both numerator and denominator). Fledge ratio inherits both sources of error, resulting in a potentially biased estimator with wide confidence intervals that is slow to reveal evidence of an imperiled population. Although fledge ratio has initial intuitive appeal, over-reliance on it as a monitoring metric seems unwise. Effective management of endangered species populations would seem better served by monitoring metrics that indicate more sensitivity and accuracy than fledge ratio and that can provide advance warning of population decline.

The TPMP can be thought of as an estimator; a process used to estimate some attribute of a population. Although bias in an estimator may not be fatal, lack of precision usually is. Worse yet is the situation where precision is unknown and the lack of a variance estimator gives the misleading appearance of no variance at all. Such is the case for the TPMP. In addition to issues mentioned above, the inability to attach a measure of precision to outcomes produced by the TPMP is among its primary weaknesses, making defense of the program as scientifically valid exceedingly difficult.

A potentially useful analog for monitoring leading indicators of population performance comes from waterfowl science. Waterfowl biologists speak of recruitment rate when referring to the reproductive rate of a waterfowl population (recruitment rate is fledge ratio divided by 2; Cowardin and others, 1995); however, when it comes to monitoring, waterfowl biologists use metrics like breeding population size, nest success, brood survival, and waterfowl habitat (for example ponds in the spring or amount of perennial nesting cover; Cowardin and others, 1995). Declining breeding populations and low nest success serve as alarm calls for waterfowl managers. It is possible that adopting a similar approach would lead to significant advances in least tern and piping plover monitoring and management.

4.0 Evaluation of the TPDMS and Monitoring Metrics

There is substantial guidance in the TPMP manuals regarding procedures for data entry into the TPDMS, but very little written documentation on the calculations that are done to generate the data tables and reports. Likewise, there is no metadata or other description of variable names and how they should be interpreted. Thus, the TPDMS creates the appearance that data have been consistently collected and summarized for many years. This is somewhat at odds with the trends observed in the field manuals, where the evident pattern was of increasing complexity and diversity of data collection. For example, the TPMP manuals suggest that quantifying incidental take was initiated in 2009, yet incidental take reports are available in the TPDMS going back to 1993. Thus, either the manuals do not accurately reflect when this significant program change happened, or incidental take has been calculated retrospectively from existing data that may not have been collected with this purpose in mind.

Several of the metrics in the TPDMS are clearly composite measures that are derived from multiple raw data sources. An example is the reporting of adult count data, which takes at least three forms. In some cases, total adult counts are reported, in others (nests plus broods)*2 from the day of the census is reported, and in yet others, a data manager makes a decision about which value should be reported. This leaves a great deal of uncertainty about how any data point labeled adults should be interpreted. Summary and manipulation of data is not inherently a problem, but raw field data (that is, what was observed in the field) should be preserved, manipulations of data should be clearly documented, and each data field should be labeled so that its meaning is clear.

Much of the data in the TPDMS has been manipulated to fit the reporting requirements of the Biological Opinion;

however, data labels frequently imply other meanings, leading to a high likelihood that the data could be misinterpreted in the future. Many common biological terms are used (for example, “nest”), but the absence of metadata generates uncertainty about how these terms should be interpreted. Data presentation in the TPDMS can lead to biologically improbable conclusions, illustrating the uncertainty over how terms are defined and how data are summarized. For example, on SAK in 2008, the TPDMS reports 138 piping plover nests and 585 eggs. These data could potentially be used to estimate average clutch size of plovers nesting on SAK in 2008, which would yield 4.2, a biologically implausible value that suggests five-egg plover nests were common on SAK; however, five-egg plover nests are uncommon. In 4 years of plover studies on the Missouri River, USGS crews have documented four five-egg nests among 1,317 plover nests, of which none were at SAK. For 138 nests to produce 585 eggs, there would need to be 105 four-egg nests, 33 five-egg nests, and no nests with <4 eggs. Verbal discussion with the Corps revealed the source of this discrepancy (Coral J. Huber, oral commun., 2011). Broods that were observed in areas where no nests were found were added to the egg count for Biological Opinion reporting purposes, but were not recorded as nests. This practice invalidates the data label “egg” because not all units reported as eggs were observed in the field as eggs. As illustrated here, these data manipulations generate modified data values, they obscure raw data records, and they can lead to future problems in data interpretation. This particular circumstance also illustrates a more fundamental problem, because it reveals a substantial number of nests that persisted long enough to hatch, yet were undetected during nest searches.

On Fort Peck River in 2008, the TPDMS reports 17 successful least tern nests, which should equate to a bare minimum of 17 pairs (34 adults) in the breeding population; however, an Adult Census of 22 (that is, 11 pairs) is reported in the TPDMS. Similarly, for Lake Oahe in 2009, the TPDMS reports 39 successful least tern nests, which should mean the breeding population was at least 78 adults, but an Adult Census of only 71 was reported. This implausible circumstance [breeding population <(2*successful nests)] was noted several other times (for example, least terns in 2010 on Fort Peck River, GRR, and GVP). We did not attempt to list all occurrences exhaustively, but we did find this discrepancy only in tern data, suggesting some sort of procedural flaw in how Adult Census figures for terns were derived. This likely happened because terns are actively nesting during the census window, leaving open the possibility that a pair has >1 active nest during the census window because of nest failure and renesting.

Fledge ratio is a metric that is commonly used to track trends in tern and plover productivity on the Missouri River system. Fledge ratios were used by Ryan and others (1993) as a predictor of population growth in a demographic simulation model for Northern Great Plains piping plovers, but this metric is not widely used elsewhere in monitoring programs as an indicator of productivity. It is composed of two component measurements that themselves can be leading indicators of system problems. For example, a declining trend in chick survival or in breeding population would indicate a problem that may warrant management attention, and it would also more clearly point to potential causes and solutions than would a change in their ratio. Because they inherently measure magnitude of one value relative to the other, ratios provide no insight into the absolute magnitude of the component measures. For example, a 3.0 fledge ratio for least terns indicates a highly productive population, but it would be interpreted very differently if it were reported for 2 adult birds (for example, on Fort Peck Reservoir in 2006), or for 200 adult birds on GRR. Similarly, the 0.77 fledge ratio reported for GRR plovers in 2006 and the 0.78 fledge ratio for GVP plovers would suggest similarly productive populations, yet these populations differed substantially in density, timing of nest mortality, and principal factors contributing to nest loss.

To further aid in refining data presentation and summary in the TPDMS, we provide the following notes reflecting on our observations since 2006:

- June 19, 2006—The Census and Fledge Ratio Page does not indicate whether the adult numbers are pairs or total adults.

- May 20, 2006—Early-season nests took several days to appear in the TPDMS after discovery.

- June 19, 2006—It was not readily apparent if moved nests, or nests protected with an exclosure, or both, were attributed as having had these management actions taken.

- June 19, 2006—The Nest Fate Summary Table has a No Evidence column between the column headers for Human Disturbance and Abandoned, and it isn’t clear where the No Evidence nests belong.

- June 19, 2006—The tables are difficult to read. Locking the headings in place would help. The printable format could also be improved.

- June 19, 2006—Attempting to download data produced a blank .dbf file.

- June 6, 2007—The TPDMS indicated 51 plover nests on GRR in the Nest Summary Tables, but a shapefile downloaded the same day indicated 49 plover nests on GRR. Part of the discrepancy was at RM 1304, where the shapefile indicated three nests but the Nest Fate Summary Table indicated four nests.

- June 2007—Field crews reported that at some nests, the tongue depressor was marked with multiple nest numbers. This observation suggested a marker had been used at one nest, then recycled for use at a second nest. Tongue depressors should be used once and discarded to avoid confusion over nest numbers.

- October 30, 2007—The Nest Summary Table indicated one active plover nest on the Niobrara River, as well as chicks as young as 0–5 days.
- October 30, 2007—On the Nest Summary Table, Total Nests should equal Active plus Successful plus Unsuccessful plus Undetermined. This was not the case for Niobrara least terns (33 total; 15 successful, 5 unsuccessful) or piping plovers (19 total; 1 active, 6 successful, 6 unsuccessful, 2 undetermined).
- October 30, 2007—The Nesting Season Summary for 2006 indicates six out of seven plover nests on Fort Peck Reservoir being successful, with apparent and Mayfield nest success of one.
- June 2, 2008—The most current field journal entry was May 6 for GVP, May 8 for Lewis and Clark Lake, May 7 for GRR, April 29 for Riverdale, and May 7 for Williston.
- June 2, 2008—Fort Peck Reservoir and Lake Francis Case are missing from the least tern table in the 2007 Productivity Data Summary; there was one nest shown for each of these breeding areas on the Nest Summary Table but zero chicks fledged. Breeding areas where no nests were found (that is, plovers on Lake Francis Case) also are not listed. Zero fledglings is not the same as zero nests.
- June 10, 2008—The At Risk Table in Data Summary Table only shows how many nests are currently at risk. Once fated or no longer at risk, they are removed. Going back to previous years (2005–07), there is no way to determine how many at risk nests were found because the table is all zeros.
- June 10, 2008—The Nest Fate Summary Table shows Total Nests by species and segment, with fates of Successful, Probable Success, Unsuccessful, and Undetermined. This table showed 304 total plover nests, with 53 unsuccessful. Clicking on the Unsuccessful column heading brought up a summary of the possible fate determinants, but they were all zeros. Likewise, clicking on a segment name and then a fate produced a table of all zeros.
- July 31, 2008—The Productivity Table for 2007 shows zeros for chicks of all ages, except for two 16- to 20-day plover chicks on SAK and 17 plover chicks of various ages on the Niobrara.
- July 31, 2008—There is no way to determine how many chicks were previously observed at various ages. Looking back at 2007 data, it is clear how many plover fledglings were estimated (that is, 108 for GRR), but it is impossible to tell how many more than that were initially seen at younger ages. There is no obvious way to determine total number of chicks hatched.
- July 31, 2008—There are no zeros for numbers of nests in the nest summary tables; it is easy to tell where nests have been found, but impossible to tell what habitat has been searched and had no nests discovered.
- July 31, 2008—If information is needed about bird use of a particular site, the user has to pull up data separately for both species and add them together.
- July 14, 2009—Total Nests should be Active plus Successful plus Unsuccessful plus Undetermined nests, but the numbers do not add up in the Nest Summary Table (fig. 36). This table also shows 1 piping plover brood on GVP, but the Productivity Table on that same day showed 152 piping plover chicks.

5.0 Objectives for Future Monitoring

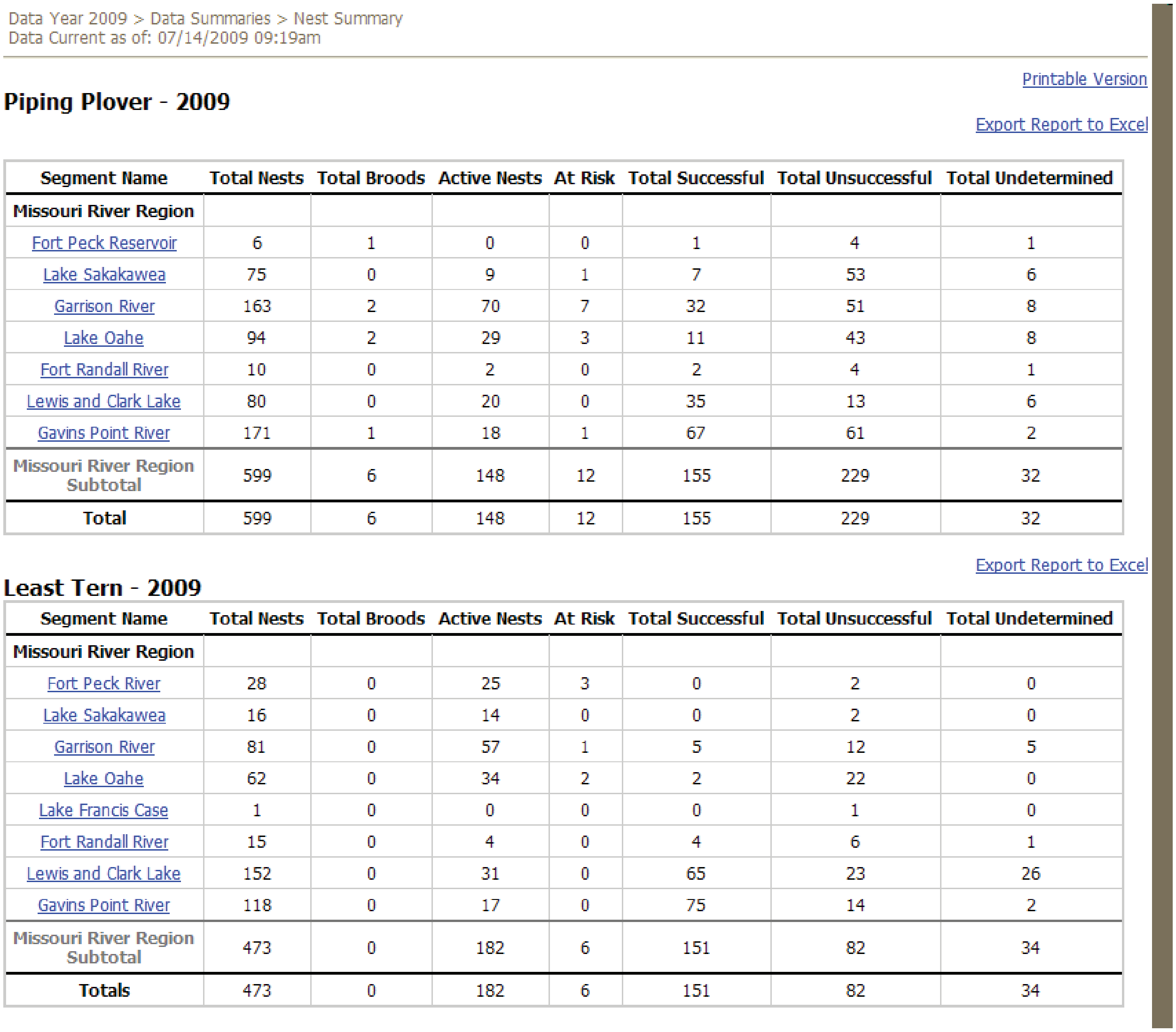
Knowing the primary objectives of monitoring is essential for designing a program that will meet those objectives (Sherfy and others, 2011), with the objectives of management directly driving objectives of the monitoring program. The importance of this basic and arguably self-evident concept cannot be overemphasized, but is often underappreciated. Considerable effort has gone into identifying and articulating the objectives of the TPMP. Through these discussions, the program’s principal purpose has been identified as assessing population trends and productivity of terns and plovers consistently from year to year on the Missouri River. It has become clear, however, that the monitoring program is being used to accomplish much more than that, including assessing and applying many types of management actions that target trends and productivity. These additional elements purportedly were not the original intent of the TPMP. The USGS evaluation was undertaken to assess the Corps’ current monitoring efforts, evaluate their accuracy, and provide guidance on what should be measured and how to achieve the monitoring program’s original intent. It is important to recognize that such a program may not answer all possible questions about the birds, management actions, or response of plovers or terns to those actions. With these ideas in mind, we offer a proposed revision of the monitoring program that is premised on the following primary objective that was articulated and agreed upon by the Corps and Fish and Wildlife Service:

- Quantify annual size and interannual trends in BPOP and productivity [that is, fledging-aged young (FY)] of least terns and piping plovers for the Missouri River system.

We anticipate that additional information needs will be identified that can be met, either wholly or in part, through the monitoring program; however, pursuit of multiple objectives within a single monitoring framework typically requires tradeoffs among competing information needs that are largely driven by whether to monitor versus whether to manage. For example, locating nests for active management (for example, installing nest exclosures) is a need accommodated by the framework proposed here, but applying exclosures detracts from nest searching and monitoring effort. This has the effect of reducing the precision of estimates or driving up the effort required to maintain accuracy at a prescribed level. Further negotiation will be necessary to decide on the role and priority of secondary objectives, and may lead to additional revisions of the program proposed here. Some of these additional needs may be better suited for directed research rather than monitoring. For example, the monitoring program may not be sufficient to fully document bird response to unique events, such as the flood of 2011. Focused research may be necessary to supplement the monitoring program for these types of questions, depending on desired information needs. Accordingly, it would be beneficial to maintain capacity for a robust research program, including the means to identify and prioritize research and monitoring needs.

6.0 Proposed Approach to Monitoring

At the 2011 Missouri River Natural Resources Conference in Nebraska City, Nebr., representatives from the Corps and the Service agreed that accurate estimators of BPOP and FY for piping plovers and least terns are desired for the various Missouri River reaches and the entire River. Accuracy within the context of this monitoring objective implies minimal bias and sufficiently high precision to afford meaningful assessments of population size and population trajectory. Accurate estimators provide managers with information on how many plovers or terns use the upper Missouri River for breeding, the distribution of breeding plovers and terns among



Data Year 2009 > Data Summaries > Nest Summary
Data Current as of: 07/14/2009 09:19am

Piping Plover - 2009

Segment Name	Total Nests	Total Broods	Active Nests	At Risk	Total Successful	Total Unsuccessful	Total Undetermined
Missouri River Region							
Fort Peck Reservoir	6	1	0	0	1	4	1
Lake Sakakawea	75	0	9	1	7	53	6
Garrison River	163	2	70	7	32	51	8
Lake Oahe	94	2	29	3	11	43	8
Fort Randall River	10	0	2	0	2	4	1
Lewis and Clark Lake	80	0	20	0	35	13	6
Gavins Point River	171	1	18	1	67	61	2
Missouri River Region Subtotal	599	6	148	12	155	229	32
Total	599	6	148	12	155	229	32

Least Tern - 2009

Segment Name	Total Nests	Total Broods	Active Nests	At Risk	Total Successful	Total Unsuccessful	Total Undetermined
Missouri River Region							
Fort Peck River	28	0	25	3	0	2	0
Lake Sakakawea	16	0	14	0	0	2	0
Garrison River	81	0	57	1	5	12	5
Lake Oahe	62	0	34	2	2	22	0
Lake Francis Case	1	0	0	0	0	1	0
Fort Randall River	15	0	4	0	4	6	1
Lewis and Clark Lake	152	0	31	0	65	23	26
Gavins Point River	118	0	17	0	75	14	2
Missouri River Region Subtotal	473	0	182	6	151	82	34
Totals	473	0	182	6	151	82	34

Figure 36. Screen capture of the Nest Summary Table from the Tern and Plover Data Management System on July 14, 2009.

reaches, and their productivity by reach and, therefore, for the entire upper Missouri River. It should be recognized that these monitoring goals are highly ambitious and not achievable in most bird monitoring programs involving areas as expansive and diverse as the Missouri River. The considerable resources available for monitoring, specific features of plover and tern breeding biology, the ability to remotely assess plover and tern breeding habitat at coarse scales over large areas, and technological advancements in remote monitoring systems for marked individuals may make these goals practical for Missouri River piping plovers and least terns. If not, objectives (particularly those related to quantifying actual population size) may have to be scaled back (for example, to tracking trend only).

A census approach in which all suitable habitat is surveyed for BPOP and FY has been demonstrated to be infeasible. The Missouri River system is too massive to allow all potential habitat to be effectively surveyed within a compressed time window that is necessary to overcome over- or undercounting that can result from redistribution of these highly mobile birds. Thus, a primary design consideration is that monitoring be built around probability-based sampling that will provide inferences about the full study system. A major challenge in designing a sampling scheme is that breeding plovers and terns are, at least partly, opportunistic and disperse within and across years in response to changes in habitat. Depending on the amount of water in the system and decisions regarding management of that water, habitat changes can be major and abrupt. The net result is that a sample of monitoring units that yields numerous birds one year may yield few or no birds another year, not because populations have declined but because habitat has changed. The sampling approach must therefore recognize and embrace the dynamic nature of habitat along the Missouri River. Guiding principles behind the monitoring program proposed here are as follows: Habitat is more easily and affordably monitored than birds, and by monitoring habitat over large areas and collecting companion data on response of breeding terns and plovers to habitat features at sample study sites, reliable inferences regarding population size and trend should be possible. These principles have been used effectively in surveys of breeding waterfowl over large areas (Cowardin and others, 1995).

6.1 Monitoring Metrics

1. Counts of *nests* provide a direct measure of use by breeding plovers and terns. Nests provide a critical basis for obtaining data necessary to monitor key vital rates. Complete counts can be difficult and expensive to obtain but issues of incomplete detection can usually be overcome.
2. *Hatched nests* are a requisite and partial indicator of successful breeding. Near-complete counts are usually attainable.
3. *Nest survival* is a key vital rate. Low nest survival generally is an indicator of low reproductive rate. Nest survival estimates provide a means to identify and diagnose causes of reproductive failure. They can also provide information to trigger proactive or reactive management.
4. *Nest fates*, along with evidence collected at unsuccessful nests, provide insights into the causes of reproductive failure and can help identify remedial management actions.
5. *Chicks* (hatchlings) are another indicator and requirement of successful breeding. Hatchling counts provide an upper limit on reproductive output in terms of fledged young. A declining trend in hatchling numbers per successful nest could be an indicator that clutch sizes have diminished or that clutches are being partially lost, possibly from predation.
6. *Chick survival* is another key vital rate. Low chick survival generally is an indicator of low reproductive rate and may be symptomatic of a declining population. Chick survival estimates provide a means to identify and indirectly diagnose reasons for reproductive failure. They can also provide information that can be used to trigger proactive or reactive management.
7. Count of *fledging-age chicks* is a strong correlate of number of fledged young and is a metric of net reproductive output of a breeding population. Fledging-age chicks are susceptible to undercounting. Mark-recapture monitoring of chicks provides a means to measure detectability and possibly correct for imperfect detection.
8. MINBPOP is a correlate of breeding population size derived from nest monitoring data. MINBPOP is sensitive to variability in nest survival so measurement of nest survival should go hand-in-hand with measurement of MINBPOP.

We view the count of fledging-age chicks and BPOP (which can be estimated from MINBPOP and nest success) as the primary performance metrics for the TPMP. Quantifying them requires information be collected on metrics 1–8, which individually have limited value. Collectively, however, they provide information that can help managers understand limits to reproduction and causes of reproductive failure.

6.2 Sampling Unit and Sampling Frame

The sampling universe is the totality of breeding habitat potentially used by nesting plovers or terns within the Missouri River system. Knowing the sampling universe is critical when developing a sampling frame but can be difficult to specify completely. The dynamic nature of habitat on the Missouri River, particularly high interannual variability, compounds this difficulty. For example, underwater islands in a reservoir could potentially become suitable habitat at some future time of reduced water levels. Under our proposal, sampling units for river reaches would be units of fixed length; we propose 3-RM units. All habitat on a unit selected as part of the sample would be intensively surveyed for nests and chicks. The amount of habitat within a unit will vary from year to year, but units themselves would be fixed and, unlike sandbars, static and enumerable. The stratum to which a unit is assigned may change from one year to the next in recognition of changes to habitat within and among units. A new sample of units would be drawn prior to the monitoring season each year. The 3-RM unit length, although arbitrary, should accommodate issues of habitat scale and logistics that will come into play. Unit length would not change year to year. Units would be large enough to fully encompass many large sandbars but small enough they can be effectively and efficiently surveyed by field crews. Regardless, unit boundaries would in some cases bisect larger sandbars or those near unit boundaries. Standard protocols would need to be developed to handle these circumstances.

Sampling units for reservoirs would be lengths of shoreline with accommodations for inclusion of appropriate offshore habitats. Various details and decision rules for delineating sample units remain to be worked out and will be refined during a pilot season. Sampling units have been identified and delineated for SAK but considerable effort and additional data will be required to delineate sampling units on Lake Oahe and other reservoir habitats. Our experiences doing research on GRR, GVP, and SAK provide a useful starting point for tackling the problem and anticipating likely complications. An important issue that has been discussed but is beyond the purview of USGS is the spatial extent of the sampling universe. Decisions about whether to include Missouri River reaches with historically low bird use (for example, Fort Peck) will ultimately play into decisions about the sampling frame and what new data are required to develop the sampling frame and reach-specific habitat models and inventories.

6.3 Stratification Based on Habitat

Although a census approach for birds is not feasible, an annual census of suitable habitat is feasible, if done remotely, and already is underway for several reaches. By combining previously acquired habitat data with physiographic features (for example, bluff height and amount of habitat on reservoirs or channel characteristics on river reaches) we believe potential sampling units can be ranked according to their anticipated level of use by plovers and terns in the upcoming breeding season. At the very least, units that are likely to have limited or no habitat and a remote chance of experiencing more than occasional use by nesting terns or plovers can be identified. The next section provides proof of concept for this approach. We propose using these habitat assessments to stratify units annually prior to the nesting season and to direct monitoring toward areas where birds are likely to be present, but in a way that preserves the probabilistic nature and integrity of the sample for extrapolating to the full reach. The result will be a stratified random sample of units on which BPOP and FY will be intensively monitored. If special interest exists in a particular sandbar(s) within a unit not selected for sampling, the situation can be accommodated by assigning such units to a separate stratum and sampling 100 percent of units in that stratum. Under this scenario, all habitat within the unit, not just habitat on the sandbars of interest, would be surveyed for BPOP and FY.

6.4 Reach-Wide Estimation of BPOP and FY

Estimates of BPOP and FY from sample units provide the principal data for extrapolating values to the full reach. The method of extrapolation (that is the estimator) can be either design-based, model-based, or a hybrid of the two. A common design-based estimator for a population total (for example BPOP for the reach) is the mean-per-unit estimator.

$$BPOP_{MPU} = \Sigma N_h \bar{x}_h \qquad (2)$$

where

$BPOP_{MPU}$ is the mean-per-unit estimate for $BPOP$,
N_h is the number of units in stratum h,
$\bar{x}_h$ is the sample mean per unit in stratum h, and
Σ is the summation across all strata.

Design-based estimators have an advantage over model-based estimators; the only information required is the sample counts themselves. Design-based estimators are best suited for situations in which a large proportion of the variability in counts can be captured by the stratification. We expect that the approach to stratification outlined above, although effective for deciding in advance of the breeding season where to survey, will be unable to fully account for some important sources of variability in counts. Some of those sources will be identifiable and quantifiable from remote sensing data collected during the breeding season. For example, the amount of suitable habitat will vary from unit to unit and result in a somewhat predictable response by nesting plovers and terns. By exploiting the relation between observed counts and suitable habitat measured remotely during the breeding season, model-based estimation of BPOP that provides better accuracy than mean-per-unit estimation may be possible. Our experiences to date developing habitat-based estimators for tern and plover numbers have been promising but not fully satisfactory. Habitat-based estimation of population size remains an active research area that will be facilitated by collection of the additional data described here.

The following is for illustration purposes only, but provides an example of how habitat data and bird monitoring data might be used together to facilitate estimation of population parameters at the reach level. The ideas are borrowed from duck survey methodology that has been in use for >20 years throughout the U.S. Prairie Pothole Region (Cowardin and others 1995). There is only 1 stratum in this example but the ideas are general and extension to multiple strata is straightforward. Suppose there are 6 units, 2 of which are intensively surveyed giving rise to BPOP and FY values in the 2 rightmost columns (table 33). The mean-per-unit design-based estimate of FY for the entire stratum is (5+3)/2 * *N* = 4 * 6 = 24 fledging-age chicks. Although not shown, the mean-per-unit estimate of BPOP is (10+2)/2 * *N* = 36 breeding adults. What is shown for BPOP is a ratio estimate that utilizes predictions from a model relating some habitat feature to number of breeding adults. That estimate, 20.4, is substantially different than the mean-per-unit estimate. Which estimator to use depends largely on the strength of the relation that underlies BPOP predictions derived from the habitat model. In practice, many estimators from simple to complex are possible. Our experiences to date using these methods with tern and plover data have been thwarted by the issue of extreme skewness in the data. Alternative modeling strategies are available that may prove useful in overcoming this issue, but we have yet to fully explore them. Although final choice of an estimator remains an open issue, the importance of acquiring good data to support estimation cannot be overstated. Furthermore, remotely acquired habitat information on all units during the breeding season should be viewed as an integral component and priority needs of the tern and plover monitoring program.

6.5 Determining MINBOP on Sample Units

In the absence of having a large proportion of the adult population marked, coming up with an unbiased estimator of adult numbers from adult counts seems beyond reach. Our research experience doing weekly adult surveys revealed that counts were often highly variable from one week to the next, even though we employed double-survey methodology in an attempt to adjust counts for birds that were either overlooked or double-counted during primary surveys. No clear period of time emerged as a universally appropriate window for surveying across years, even within the same study area. These reasons and the fact that breeding adults are not easily distinguished from nonbreeders led us to favor intensive nest monitoring as an alternative means for assessing breeding adults. By ”intensive,” we mean frequent (2–3 times weekly) nest searches and frequent re-visits that lead to consistently high (≥ 0.5) daily nest detection probabilities. Standardized nest-monitoring protocols must be followed to limit variation in detection probabilities among years and reaches, and directed studies to quantify detection probability for a subset of reaches and years may be advisable.

Table 33. Hypothetical example illustrating use of habitat and bird data for estimation of least tern or piping plover breeding population and fledged young using a habitat-based estimator in a probability-based sampling scheme.

[BPOP, breeding population; HAB, habitat; FY, fledged young]

Segment	BPOP prediction from HAB model	BPOP measured by intensive surveys	FY measured by intensive surveys
1	4		
2	6	10	5
3	3		
4	0		
5	0		
6	4	2	3
Total	**17**	**12**	**8**

Stratum-wide BPOP = (10 + 2) / (6 + 4) * 17 = 1.2 * 17 = 20.4 (ratio estimator using remotely sensed habitat data to predict BPOP which is then calibrated to observed counts on units that were intensively surveyed).

Stratum-wide FY = (5 + 3) /2 * N = 4 * 6 = 24 (mean-per-unit estimator).

The relation between number of breeding adults on a reach and number of nests those adults initiate that are detected by searchers is not straightforward. However, our research suggests BPOP can be reasonably inferred from analyses of data from repeated nest surveys. The method is built around the MINBPOP metric (see Breeding Population section). MINBPOP is based on the sum of active, recently failed, and previously hatched nests for each day of the nesting season, and is assigned the maximum value across all days within a reach. As its name suggests, MINBPOP by itself underrepresents the true breeding population size. Our simulation study revealed that the proportion of overlooked nests can be reasonably approximated from the survival rate of nests. Underestimation of BPOP by MINBPOP can therefore be handled through analytic adjustment involving the estimated nest survival rate, albeit at a cost of reduced precision.

6.6 Determining FY on Sample Units

Counts of fledglings are problematic in that age at fledging varies. In addition, the ability of surveyors to perceive fledging is limited. For these reasons, we propose emphasis be placed on obtaining reliable counts of chicks reaching some minimum or average age at which fledging is believed imminent (e. g., 14–18 d for terns). Comparisons of counts of fledging-age chicks unassisted by bird marking with counts of individually marked chicks corrected for nondetection indicated that counts of unmarked birds were inaccurate (table 27) We propose that chicks be individually marked shortly after hatch and resighted periodically throughout the fledging period. Collection of data in a mark-recapture framework will provide information on detection probability and survival rate of chicks, both of which can be used to estimate FY. Because nest monitoring will be intensive, few hatched nests will escape detection, making determination of number of hatchlings reasonably feasible. Multiplication of total resightings of fledging-age chicks and the reciprocal of resighting probability of fledging-age chicks provides an estimate of FY. That estimator is subject to error in estimated detection probability as well as sampling variation in number of fledging-age chicks, but our results indicate that detection probabilities can be reasonably estimated from focused chick monitoring, particularly when information can be borrowed across years as would be possible with the TPMP. The effective sample size in a mark-recapture study depends not only on the number of animals marked but especially on the number of encounter occasions in which an animal is sighted. Thus, resighting of marked chicks should be a primary focus of the monitoring effort. An important added benefit of a mark-recapture chick study is the information it provides not only on detection rate but also on chick survival. By monitoring interannual trends in nest survival and chick survival, it should be possible to identify issues of low recruitment in a timely enough manner to implement management actions to reverse a negative trend before the population suffers irreversible loss. We did simulations to provide insight into sample sizes (banded chicks) and monitoring effort (attempts to resight fledging-age chicks) required to detect a decline in chick survival from approximately 0.6 to 0.2 over a 5-year period (appendix 2, *http://pubs.usgs.gov/of/2013/1176/Appendix_2.pdf*). Simulations postulating other rates of decline over shorter or longer timeframes also are possible.

6.7 Management Actions and Constraints on Monitoring

Placement of exclosures around individual plover nests has been used to reduce nest predation and, ostensibly, to increase fledgling production in some Missouri River reaches. The latter topic, if nest exclosures promote higher productivity, remains a question of debate. Resolving this uncertainty is a high priority for plover managers because it has important management implications. We anticipate the use of exclosures will continue under the new monitoring program, posing design challenges for a sample-based monitoring program. If nest exclosures are deployed on sample units but not elsewhere, then sample units become atypical of the larger population of units they are supposed to represent. We propose an approach to deploy nest exclosures in which no nests would be protected with exclosures on some sample units and most of the nests, possibly all nests, would be protected on remaining units. Under such a scenario, the sample units without exclosures provide the basis for extrapolation to unsampled units and for reach-wide estimation of population parameters. An important side-benefit of this approach is the comparative data it yields on effects of nest exclosures on plover nest survival and chick survival. Assuming that use of exclosures elevates nest survival, one would expect higher chick densities on treatment units, possibly leading to density-dependent effects on chick survival and fledging rate. By monitoring nest survival and chick survival, it should be possible to assess the relative effect of these two vital rates on overall plover productivity. This information will be useful for identifying bottlenecks to plover productivity and for managing accordingly. The proposed approach to exclosing nests would also provide comparative data on possible crossover effects of plover management (that is nest exclosures) on productivity of co-occurring least terns, a potentially critical question that is not effectively addressed with existing monitoring data. An important question not considered in the proposed monitoring framework is the effect of plover nest exclosures on adult mortality of either plovers or terns. Key elements of a design to investigate those questions would be in place, but the addition of focused research on adult survival would be needed. The number of sample units on which to deploy nest exclosures is a management decision that has implications for minimum sample size requirements to meet monitoring objectives.

7.0 Spatial Data Needs and Analysis

7.1 Habitat-Based Stratification

A sampling regime to estimate population parameters for terns and plovers will create a need for habitat-based stratification to help direct sampling toward areas with suitable habitat. Building a habitat-based stratification for a sampling regime requires an annual census of habitat for each breeding area and an understanding of relations among habitat features and relative distributions of terns and plovers within each area. Riverine and reservoir habitats are dynamic, thus habitat-based stratification will be most effective if the sampling frame is restratified periodically, perhaps annually, in response to predicted changes in habitat availability. We propose treating each river reach and reservoir as a separate sampling frame or population for the purposes of stratification because river management, local weather, and tributary inflows often cause partially independent dynamics of habitat among reaches and reservoirs; however, an initial stratification for the new TPMP would have to be based on one model, applied to all river reaches, and another model applied to all reservoirs because we did not collect data on all reaches and reservoirs.

7.2 Reservoir Habitat Census and Stratification

In the following section we provide an example approach for a census of habitat and a model for stratification at SAK. The stratification of reservoirs throughout the Missouri River system can be accomplished using the procedures we outline in our example, but additional data will be required to accomplish and evaluate these procedures on other reservoirs.

Two main data sources needed to estimate the amount of habitat on reservoirs are a Digital Terrain Model (DTM) with vertical accuracy <1 m and annual satellite imagery with pixel sizes ≤30 m. We developed habitat estimates using two sources of satellite imagery. We collected Probationary System of Earth Observation satellite 5 (SPOT) imagery (Satellite Imaging Corporation; Magnolia, Tex.) during mid- to late-summer in 2007 and 2008. Imagery was collected during mid- to late-summer to correspond with field habitat observations. Given the marked mid-summer rises in water level at SAK, mid- to late-summer imagery acquisitions missed habitat that was potentially available when birds were settling into breeding territories. Accordingly, we also collected Landsat 5 TM (hereafter TM) imagery for early summers of 2006–09 from the USGS Earth Explorer website (U.S. Geological Survey, 2013). Landsat 5 TM (30-m pixels) has a more coarse spatial resolution than pan-sharpened SPOT (2.5-m pixel), but TM has more acquisition flexibility because the entire study area could be collected with only 2 passes and the satellite return interval was 16 days.

We collected field observations of habitat during the post-breeding season during 2006–09. These observations were done on our sample of units at transects that were perpendicular to the shoreline and spaced 100 m apart. On each transect we collected habitat data every 5 m within a 1-m^2-square quadrat. We used approximately one-half of our field observations to develop models to predict habitat using satellite imagery, and the other one-half to evaluate the accuracy of those predictive models.

SPOT—We did an atmospheric correction and orthorectification on all SPOT scenes. We used the DTM to create a mask to exclude the lake surface. The mask was set at the elevation of the water surface for the scene with highest water level; this eliminated spatial differences in potential habitat based on acquisition date of the scene. We also excluded data from above our study area with a mask at 565 m m.s.l. We pan-sharpened the SPOT multispectral bands to the resolution of the panchromatic band (2.5-m pixels), and we mosaicked all scenes within a year, which resulted in a single contiguous map of the study area for each year.

We calculated the first principal component (PC1) of the red [0.63–0.68 micron (µm)] and green (0.50–0.59 µm) bands. We used a multiple regression to predict our yearly field observations of percent vegetation cover (n_{2007}=10,852; n_{2008}=10,627) with PC1 and the near infrared band (0.78–0.89 µm). Plovers select 6-m nesting areas that have vegetation cover less than 15 percent (Anteau and others, 2012) and 95 percent of nests were in areas with slopes <10 percent (based on our DTM). We classified each pixel as <15 percent or ≥15 percent vegetation cover. Then each pixel was classified as plover habitat if it had <15 percent vegetation cover, <10 percent slope, and ≥75 percent of adjoining pixels also had <15 percent vegetation cover (fig. 37). For 2007 and 2008, 76 and 75 percent of our vegetation cover classifications were correct, respectively, and our omission (12 percent) and commission (12 percent) errors were equal. We made adjustments to the water-surface elevation mask so that data from 2007 could be used to index habitat in 2006 and data from 2008 could be used to index habitat in 2009.

LANDSAT 5 TM—We chose previously collected TM images for their lack of clouds, acquisition date relative to the early-nesting period and lower-water elevations (mid-May to late-June), and those with the best available orthorectification (Level 1T processed precision and terrain correction). For each year, we excluded the lake water by creating a mask from the DTM at the elevation of the water-surface elevation for the scene with highest water level; this again eliminated spatial differences in potential habitat based on acquisition date of the scene. We also excluded data from above our study area with a mask at 565 m m.s.l. Once images were masked, we did an atmospheric correction and computed the standardized reflectance factor index. Any clouds present in the study area were manually masked out of the image and that area replaced with data from another image from that year or the previous year. We mosaicked both scenes and any area that was supplemented because of cloud coverage (Anteau and others, in press).

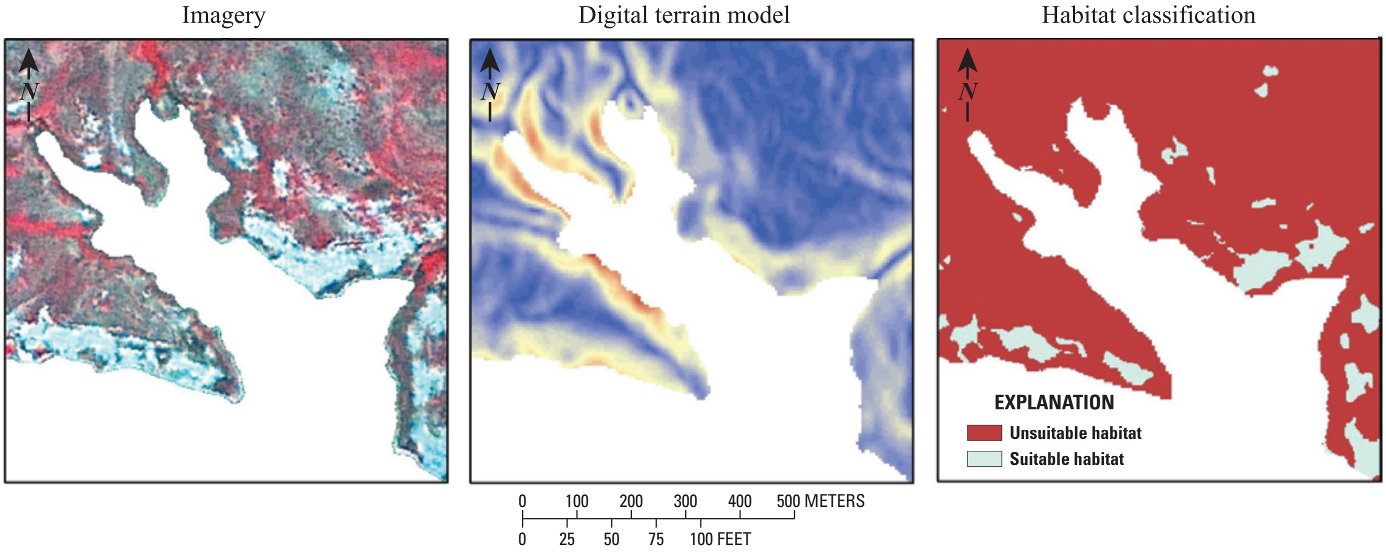


Figure 37. Examples of high-resolution satellite data, Digital Terrain Model (DTM), and our composite habitat classification we used at Lake Sakakawea.

We calculated the Normalized Difference Vegetation Index (NDVI) as

$$NDVI = (NIR\text{-}RED)/(NIR+RED) \quad (3)$$

where

NIR is the near infrared (0.76–0.90 µm) band, and

RED is the red band (0.63–0.69 µm).

We averaged field observations taken within each pixel and only used pixels that had ≥3 observations for our subsequent model and evaluation (n_{2006}=813, n_{2007}=1.534, n_{2008}=1,516, n_{2009}=581). *NDVI* predicted our yearly field observations of percent vegetation cover, despite the fact that imagery was acquired much earlier in the season than our field observations of habitat. At a scale relevant to 30-m pixels, plovers selected nesting habitat with vegetation cover less than 30 percent (Anteau and others, 2012). We classified each pixel as <30 percent or ≥30 percent vegetation cover. For 2006–09, 76 percent of our classifications were correct and our omission (12 percent) and commission (12 percent) errors were equal. We resampled each year of TM data from its original 30-m pixels to 5-m pixels to match the resolution of the DTM. Each pixel was only classified as plover habitat if it had <30 percent vegetation cover, and <10 percent slope (Anteau and others, in press).

7.2.1 Breeding Piping Plover Pairs

We estimated the number of breeding plover pairs that used each of our units as the unit-specific daily maximum from the sum of active nests plus all previously hatched nests plus nests failed during incubation within the previous 5 days. This estimate represented the minimum number of breeding pairs that used each unit and provided us with a relative distribution of breeding pairs on each unit within each reach.

7.2.2 Habitat-Based Model to Predict Breeding Plover Pairs

We expected that a number of habitat features would affect the distribution of plovers on SAK (table 34). We used a repeated measures analysis of covariance to examine habitat features that affect the natural log of plover pairs [ln(plover pairs+1)]. To ensure proper error terms and degrees of freedom for each test we specified that measurements repeated yearly and that the 2-km unit was the experimental unit; we used a first order autoregressive covariance structure and included year as a fixed blocking variable in all models. We evaluated 12 competing models, each comprised of various combinations of our variables of interest; numbers of model parameters ranged from 3 to 15. We repeated our modeling procedure using habitat data derived from SPOT and TM. We used an information-theoretic approach (AICc) to select the most parsimonious candidate model (Burnham and Anderson, 2002).

Model selection for TM and SPOT data sets indicated that the same model was the best fit for both data sources. That model included the effects of year, landform, bluff, habitat, proportion of habitat, landform by habitat, and landform by

Table 34. Variable names and descriptions and predicted relations with relative distribution of piping plover pairs at Lake Sakakawea.

[NW, northwest; ≥, greater than or equal; m, meter; ha, hectare; LANDSAT, land sensing satellite; SPOT, probationary system of earth observation satellite]

Variable name	Variable description	Prediction
Tributary	Number of tributaries within each segment	Piping plovers are attracted to tributaries because tributaries increase density of invertebrate forage of the segment.
Wind fetch	Mean wind fetch of the segment from the direction of prevailing winds (NW)	Piping plovers are attracted to segments with higher fetch because those segments receive more wave action that erodes away fine sediments (producing nesting habitat) and more aquatic invertebrates are washed up on the beach.
Landform	Shoreline or island segment	Piping plovers prefer nesting on islands because they are more secure from nest predators.
Bluff	Segments with bluffs have ≥25 m rise in elevation within 250 m of the shore	Piping plovers avoid nesting near high bluffs.
Habitat	Amount (ha) of potential piping plover habitat on each segment based on LANDSAT or SPOT data	Shoreline segments with more habitat will have more piping plover pairs (LANDFORM-by-HABITAT interaction).
Proportion of habitat	Proportion of the segment that is piping plover Habitat based on LANDSAT or SPOT data	Island segments with higher proportion of habitat will have more piping plover pairs (LANDFORM-by-PROPORTION OF HABITAT interaction).

proportion of habitat; however, the model using SPOT-derived habitat estimates had a much better fit than the model using the TM [difference in Akaike's Information Criterion (ΔAICc; Burnham and Anderson, 2002)=7.9]. Our models using SPOT and TM indicated that units without bluffs had 793 percent and 678 percent, respectively, more plover pairs than those with bluffs. Indeed, there was nearly complete avoidance of units with bluffs by plover pairs (fig. 38). On shoreline units, breeding pairs increased with the amount of habitat, but appeared not related to proportion of habitat (fig. 39). On island units, breeding pairs increased with the proportion of habitat, but our data suggested a weak decrease in response to increasing habitat (fig. 39). Coupling these results suggests that plovers nest in higher density on smaller islands that have a high proportion of habitat.

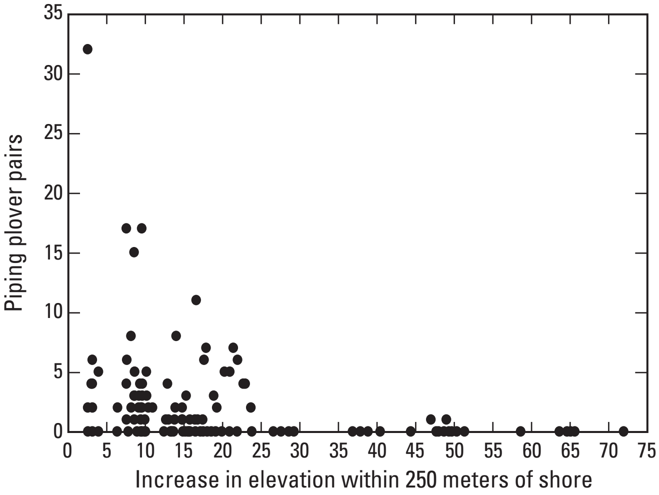


Figure 38. Number of piping plover pairs for each segment and year in relation to the increase in elevation within 250 meters of the shore at Lake Sakakawea. We defined a segment as having "bluff" if it had ≥25 meter increase in elevation within 250 meters of the shore.

7.2.3 Comparing Spatial Resolution of Habitat Data

Recent habitat monitoring for the Missouri River has involved the acquisition and interpretation of high-resolution (<1-m pixel) satellite imagery; however, reservoir habitats have not been included in such monitoring efforts. SPOT and TM data sources provided similar results in predicting the number of breeding plover pairs; however, parameter estimates differed. This suggests that whatever sensor is used to collect habitat data needs to be used for at least an entire reach each year.

Our model for predicting breeding plover pairs that used TM-derived habitat estimates had shallower slopes associated with habitat than did our model that used SPOT-derived estimates, likely because of larger habitat estimates from the TM dataset (fig. 39). Habitat models for each sensor yielded the same classification accuracy and omission or commission errors. Accordingly, there are three potential reasons why TM provided higher habitat estimates. First, the TM sensor used earlier acquisition dates that more closely estimated the amount of habitat when plovers were selecting breeding territories. Second, pixels with vegetation cover estimates of 15 to 30 percent were classified as 100 percent habitat with our TM classification, but only part of that area would be classified as habitat using a higher resolution sensor. Third, we used a greater threshold value for TM because plovers tend to nest in unvegetated patches that are interspersed with vegetated areas and at the 30-m scale of a TM pixel this averaged to a relevant threshold of 30 percent vegetation cover (Anteau and others, 2012). Large (>30 m) areas with 15 to 30 percent vegetation cover would have been classified as habitat, but would not likely be nesting habitat based on our understanding of plover habitat selection. Throughout SAK, most areas were either unvegetated (0–15 percent vegetation) or vegetated (>50 percent), but approximately 10 percent of our field observations (measured at a 1-m scale) had percent vegetation values between 15 and 30 percent fig. 40). We terminated our field habitat measurements on units when they were consistently vegetated, so vegetated habitats are underrepresented in our field observations; thus, the proportion of SAK that has vegetation between 15 and 30 percent must be lower than 10 percent. Further, only 1 percent of our field observations had pixel-summarized values of vegetation cover between 15 and 30 percent and also had >66 percent of individual observations within a pixel fall within that same category; however, if other reservoir habitats have more large areas with consistent 15 to 30 percent vegetation cover, the spatial resolution of TM may be too coarse to estimate plover habitat.

Our procedures for estimating the amount of habitat on reservoirs appear to be able to accommodate satellite imagery of various resolutions; however, each sensor requires a dataset of ground data to build a predictive model and evaluate the resulting classification. Moreover, it is unclear if our model will have the same accuracy on other reservoirs, particularly if substrate reflectance varies appreciably from that at SAK. Accordingly, field habitat measurements will have to be incorporated into the new monitoring program for reservoirs. If a stratification is needed for the pilot year of the new plan, TM will be the only available option because we have a predictive model for that sensor and there is little likelihood that the other reservoirs were acquired by the SPOT sensor in their entirety. Unfortunately, the TM sensor on the LANDSAT 5 satellite failed in 2011 but a new LANDSAT satellite equipped with a TM sensor was launched on February 11, 2013.

A clear tradeoff exists between image resolution and the likelihood of data availability for large reservoir systems. Based on our experience at SAK, collection of satellite imagery with higher resolution than SPOT is not feasible because of the study area size and timing constraints associated with collection of habitat data. Preliminary evaluation of RapidEye

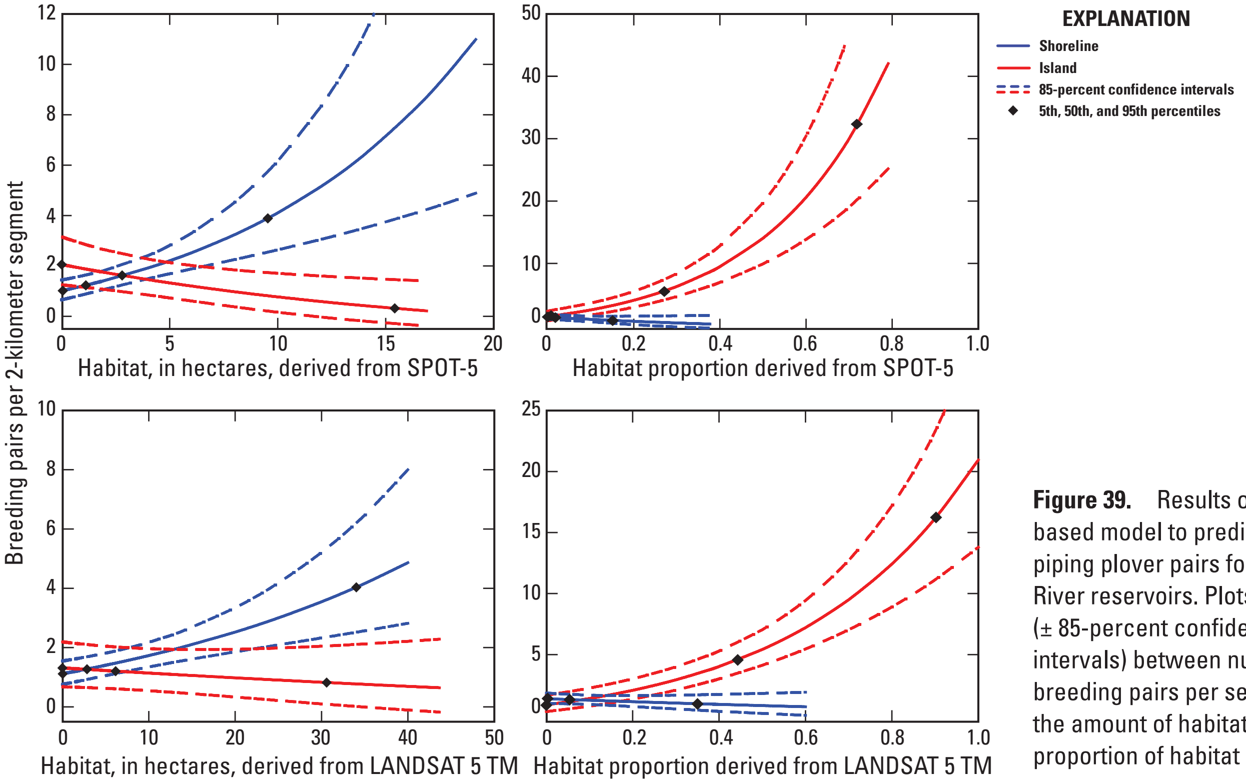


Figure 39. Results of habitat-based model to predict breeding piping plover pairs for Missouri River reservoirs. Plots of relations (± 85-percent confidence intervals) between numbers of breeding pairs per segment and the amount of habitat and the proportion of habitat by landform.

satellite imagery (6.5-m pixels) suggests a high likelihood of success in collecting imagery, and the resolution of this sensor is similar to the scale at which plovers evaluate habitat characteristics.

7.2.4 Application of Habitat-Based Stratification to Reservoirs

Reservoir habitats on the Missouri River are very large and preclude sampling intensities that are possible on river reaches. Lower sampling intensities increase sampling error and variances of estimates. Moreover, there are vast stretches of shoreline on reservoirs that have no documented use by plovers. Our results indicate that presence of bluffs could be an objective way to identify units that have little or no probability of use by breeding plovers. The bluff variable was calculated so that it would vary annually with the level of the lake because it is based on an elevation change within 250 m from the shore. We created a variable we call static bluff to help identify units that are not likely to get used by plovers at any lake level. Units with a static bluff were those that had bluffs in all 4 years of our study and never had recorded use by plovers since the beginning of the TPMP. Accordingly, 54 percent of SAK units have a static bluff. Because the static bluff variable considers a range of years and, therefore, a range of water conditions, water levels it is more conservative at identifying units that have little or no probability of use by breeding plovers than the bluff variable. We observed only one breeding pair of plovers, during 2 of 4 years, on a unit in our sample that had a bluff (fig. 38). This 2-km unit had a bluff on one end and suitable habitat on the other end, so this incongruence with the trend of bluff avoidance seems due to a chance transition between topographically complex and flat areas. Regardless, that unit did not have a static bluff.

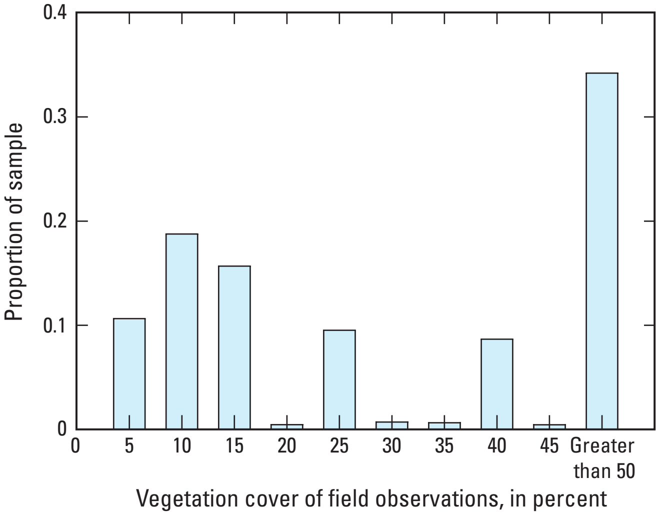


Figure 40. Percent vegetation cover for 31,766 field observations at Lake Sakakawea during summers 2006–09.

One approach to dealing with areas that have little or no probability of use by plovers is to assign units with a static bluff to a separate and large stratum of units (*n*=291); however, this requires that the static-bluff stratum be sampled and provides little hope of attaining a meaningful stratum estimate, in the event that any units in that stratum were indeed used, unless sampling intensities are high. Furthermore, sampling areas with low probability of use takes resources away from sampling efforts in strata that have higher probabilities of use by breeding plovers. Perhaps a better alternative is to remove units with a static bluff from the sampling frame with the explicit assumption that the number of plover pairs that may breed within units with a static bluff is negligible and not worth estimating. The result of excluding static-bluff sites would be increased sampling intensities for the same overall sampling effort and lower variances for estimates.

The amount of potential habitat at SAK and other reservoirs can vary widely in response to annual changes in water level. Further, because of variation in the distribution of substrate or slope at various elevations, the relative abundance of habitat and potential suitability of that habitat could shift from unit to unit annually. Because of this variation, current satellite data are needed to estimate available habitat and build a stratification for 1 year into the future. Because water levels can change from one year to the next, estimates of available habitat might be improved by incorporating a projection of spring water level through an adjustment of an elevation-derived mask. The application of an elevation-derived mask to a habitat map is straightforward in the event that water levels are projected to be higher than they were in the previous year—it simply masks out habitat that is projected to be covered by water; however, the procedure is more complex when water levels are projected to be lower than in the previous year. One approach would be to assume that any newly exposed area is plover habitat, as long as it has a slope less than 10 percent; however, it is not clear what duration of inundation is required to completely remove terrestrial and wetland vegetation on shorelines of reservoirs. Furthermore, some areas of reservoir shorelines may revegetate more quickly than others and may not become available that breeding season. We suspect that finer, less eroded soils would be those that quickly revegetate. Further, plovers selected coarse substrates and selected against silt (Anteau and others, 2012), suggesting that those areas that quickly revegetate may not be used by plovers even if they are available in the first post-inundation season. Further research is needed to examine vegetation succession on reservoirs to develop at strategy for estimating the abundance of newly exposed habitat.

Predictions of the relative distribution of breeding plover pairs among units can be made by applying our habitat model for SAK separately to data for other Missouri River reservoirs. In years following the initiation of this monitoring plan, adequate data should become available to build reservoir-specific models for stratification. Reservoir-specific models would provide better predictions for numbers of pairs expected and would also inform decisions about annually distributing sampling effort among reservoirs and river reaches.

Our stratification model ignores the use of reservoirs by terns because this topic was outside the scope of our study. We suspect that the plover stratification may be useful for terns on reservoirs because they select similar breeding habitats on riverine sandbars (Sherfy and others, 2012) and one model fits terns and plovers on river reaches (see Habitat-based stratification for river reaches section). Tern data collection also could be supplemented by including units with known tern colonies in a separate stratum for which all units are surveyed; data from this stratum could be added to tern estimates without adding any sampling variance.

7.3 Habitat-Based Stratification for River Reaches

In the following section we provide an approach and models for the stratification of river reaches of the upper Missouri River system. Our models are based on data from GRR (2006–07) and GVP (2008–09) combined. These stratification models could be applied separately to river reaches throughout the upper Missouri River, but ultimately it would be preferable to develop reach-specific models for stratification from data collected from a new monitoring program.

Although we propose that tern and plover monitoring be done on 3-RM units on river reaches, these units are too large to build meaningful associations between numbers of breeding pairs and habitat features. Accordingly, we further segmented GRR and GVP into 1-RM units. Our habitat-based predictive models used 1-RM units, and we propose that the predicted number of breeding terns and plovers for each 1-RM unit be summed within 3-RM units to assign membership of each 3-RM unit to a stratum.

7.3.1 Census of Dynamic Riverine Habitats

Since 2006, the Corps and the USGS have collected high-resolution satellite imagery (0.6-m pixels) for all of the river reaches in the upper Missouri River system. The USGS has developed an object-based approach to classify habitats important for terns and plovers from this imagery and delivered resulting habitat classifications (L. L. Strong, unpub. data, 2011) to the Corps. We summarized the amount of dry- and wet-sand habitats from these data sets to 1-RM river units for GRR and GVP (table 35).

7.3.2 Quantifying Static Riverine Habitat Features

In years when the amount of dry- and wet-sand habitat changes dramatically from that of the previous year due to fluvial processes during extremely high flow events, estimates of those habitats from the previous year may not be useful to predict the abundance of tern and plover breeding pairs. Accordingly, we developed several habitat metrics that are more static with respect to fluvial processes and we suspected these would be useful in predicting abundance of tern and plover breeding pairs (table 35).

Table 35. Variable names and descriptions and predicted relations with relative distribution of least tern and piping plover pairs on river reaches of the upper Missouri River.

[NW, northwest; ≥, greater than or equal; m, meter; ha, hectare; LANDSAT, land sensing satellite; SPOT, probationary system of earth observation satellite]

Variable name	Variable description	Prediction
	Dynamic habitat features	
Unvegetated dry sand	Amount (ha) of dry sand with vegetation cover approximately <5%, based land-cover classifications derived from high-resolution (0.6 m pixels) satellite imagery	Riverine segments with more dry sand will have more least tern and piping plover pairs because they have more nesting habitat.
Wet sand	Amount (ha) of wet sand with vegetation cover approximately <30%, based land-cover classifications derived from high-resolution (0.6 m pixels) satellite imagery	Riverine segments with more wet sand will have more least tern and piping plover pairs because piping plovers will have more foraging habitat and amount of wet sand indexes shallow-water foraging habitat for least terns (J.H. Stucker, U.S. Geological Survey, unpub. data, 2005–08).
	Static habitat features	
River-breaks width	Width of the river valley (m); break to break distance estimated with a distance-raster procedure	River-Breaks width is positively correlated with development of emergent sandbar habitat and the number of least tern and piping plover pairs.
Channel width	Width of the river channel (m); estimated during flood stage (early July 2011 flows); bank to bank distance estimated with a distance-raster procedure	Channel width is positively correlated with development of emergent sandbar habitat (Elliott and Jacobson, 2006) and the number of least tern and piping plover pairs.
Bluff	Segments with bluffs have ≥15 m rise in elevation within 250 m of either channel edge.	Least tern and piping plover pairs avoid nesting near high bluffs.

7.3.3 Breeding Least Tern and Piping Plover Pairs

We estimated the number of breeding plover pairs that used each of our units as the unit-specific daily maximum from the sum of active nests plus all previously hatched nests plus nests failed during incubation within the previous 5 days. We estimated the number of breeding terns using the same rules except we counted nests that failed during incubation within the previous 9 days. We summed plover and tern pairs within each unit. This estimate represents the minimum number of breeding tern and plover pairs that used each unit and provides us with a relative distribution of breeding pairs on each unit within each reach.

7.3.4 Habitat-Based Model to Predict Breeding Tern and Plover Pairs

We used a repeated measures analysis of covariance to examine habitat features that affect the natural log of tern and plover pairs [ln(tern pairs + plover pairs +1)]. To ensure proper error terms and degrees of freedom for each test, we specified that measurements repeated yearly within each reach and that the 1-RM unit was the experimental unit; we used a compound symmetry covariance structure and included year within reach as a fixed blocking variable in all models. We considered 15 candidate models; each model was composed of various combinations of our dynamic and static variables. However, three of our models contained only static variables. Numbers of model parameters ranged from 6 to 12 for all candidate models. We used AICc to select the most parsimonious candidate model (Burnham and Anderson, 2002).

Our overall best model included effects of year within reach, bluff, dry sand, wet sand, and median distance to trees. The number of breeding tern and plover pairs increased with the amount of dry- and wet-sand habitats and the median distance to trees (fig. 41). Our best model that only included static habitat features did not fit the data as well as our best overall model (ΔAICc=70.9). The static model included effects of year within reach, bluff, channel width, and median distance to trees. This model indicated that units without bluffs had 317 percent more breeding tern and plover pairs than those with bluffs. The number of breeding tern and plover pairs increased with channel width and the median distance to trees (fig. 42). Our model indicated that units without bluffs had 177 percent more breeding tern and plover pairs than those with bluffs. Indeed, there was complete avoidance of units with bluffs by breeding tern and plover pairs on GVP, but avoidance was incomplete at GRR (fig. 43).

7.3.5 Application of Habitat-Based Stratification to River Reaches

River reaches are not as large as reservoir habitats on the Missouri River. Therefore, the number of units required to achieve sampling intensities that yield estimates with low CVs is not as great on river reaches as it is on reservoirs. Our data suggest that the presence of a bluff on a riverine unit did not have as strong, complete, or consistent of an effect upon

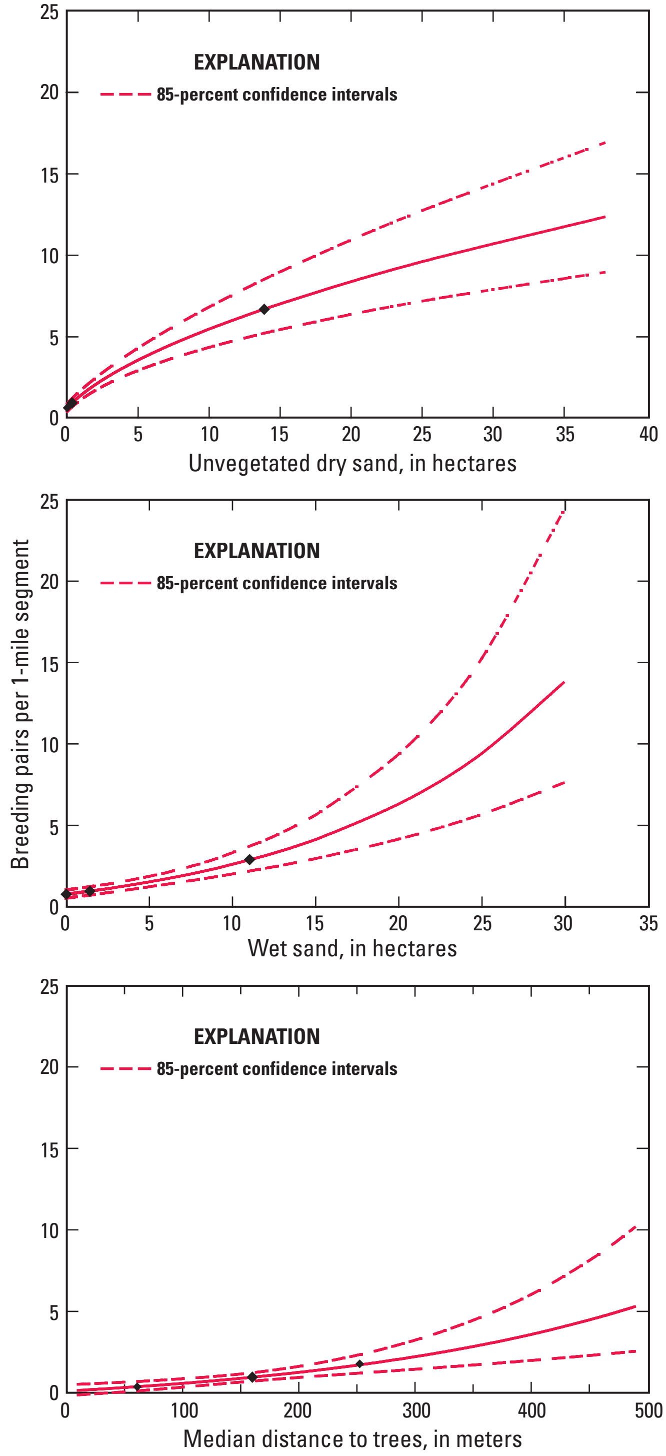


Figure 41. Results of habitat-based model to predict breeding least tern and piping plover pairs for river reaches. Plots of relations (± 85-percent confidence intervals) between numbers of breeding pairs per 1-RM river segment and amounts of dry- and wet-sand habitats and the distance to trees.

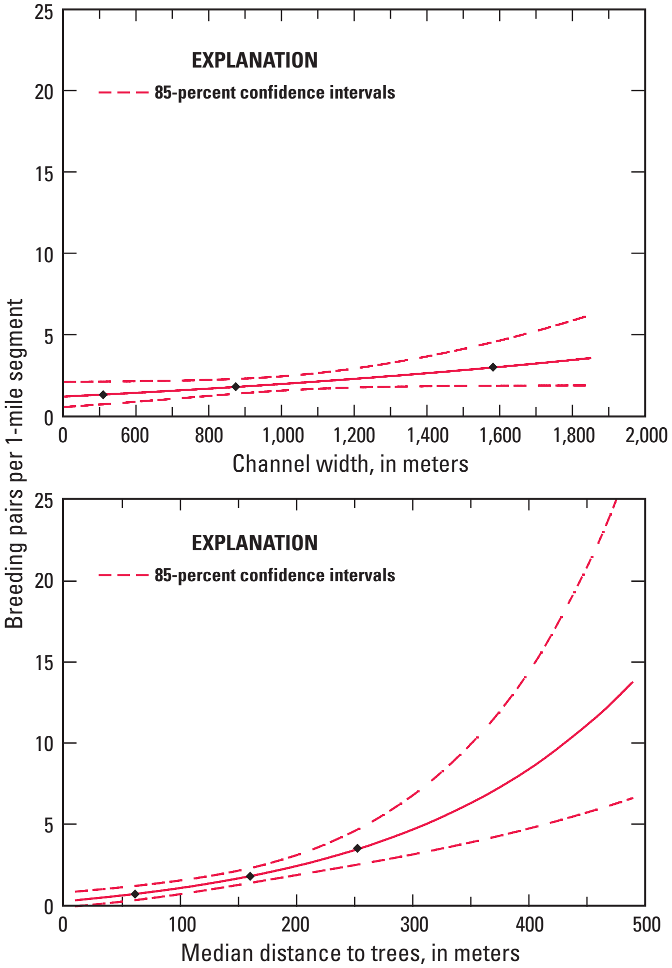


Figure 42. Results of habitat-based model to predict least tern and piping plover pairs for river reaches using only static habitat features. Plots of relations (± 85-percent confidence intervals) between numbers of breeding pairs per 1-RM river segment and channel width and the distance to trees.

bird distribution as it did on SAK. Accordingly, we propose that bluffs be incorporated into the stratification on river reaches through inclusion in the model, rather than to exclude units with bluffs from the sampling frame (as proposed for reservoirs).

The amount of potential habitat on river reaches of the upper Missouri River can vary annually in response to changes in flow and fluvial processes during extremely high flow events. Current-year satellite data are needed to estimate habitat and build a stratification for 1 year into the future. Further, satellite imagery should be acquired during the period of the breeding season that is coincident with the selection of territories by terns and plovers. Despite the poorer fit of our static model, in years following extremely high flow events it may better predict bird distributions than our more complex model; however, if the fundamental river geomorphology that contributed to the formation and maintenance of dry- and wet-sand habitats remains consistent, then we would expect to see those habitats form again in similar locations after extremely high flow events. Accordingly, our model including amounts of dry- and wet-sand habitats could perform well in years following extremely high flow events, except for locations

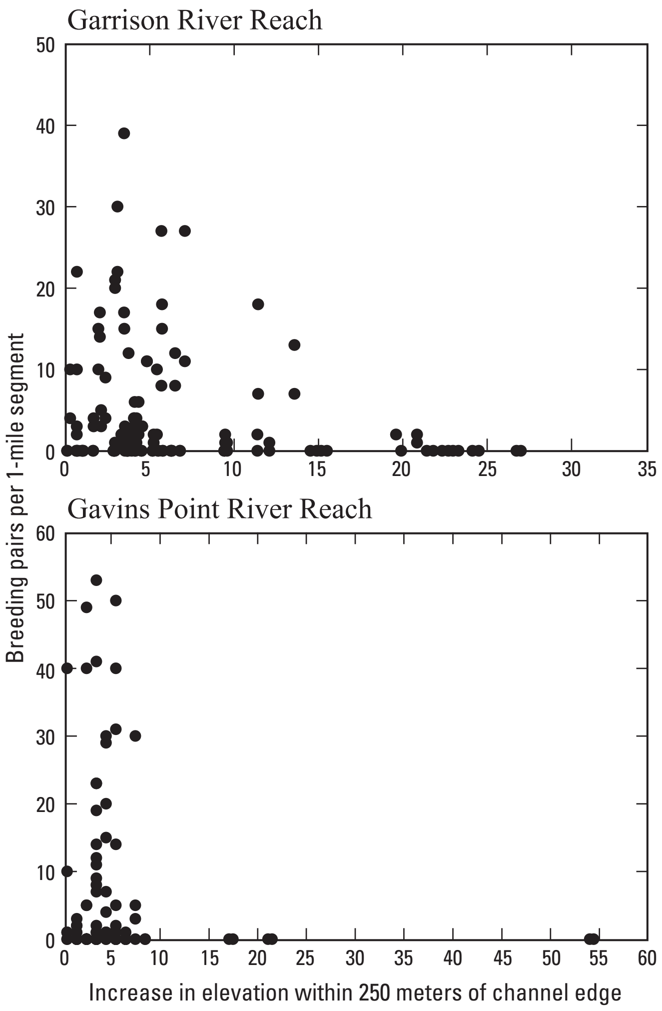


Figure 43. Number of least tern and piping plover pairs for each 1-RM river segment and year in relation to the increase in elevation within 250 meters of the shore at Garrison and Gavins Point River Reaches. We defined a segment as having "bluff" if it had ≥15 meters increase in elevation within 250 meters of either channel edge.

in which constructed sandbars are placed where geomorphic processes would not have supported their natural formation (for example, Ponca Complex at GVP). Further research is required to better understand how sandbar habitats are created and if, or how, they may shift among units after extremely high flow events.

Relative distribution of breeding tern and plover pairs among 1-RM river units within a reach can be predicted by applying our habitat model individually to each reach. We propose that those estimates be summed within 3-RM units and then classified into three strata. Threshold levels of predicted pairs for strata could be established by reviewing the distribution of predicted pairs from all river reaches. If monitoring plans proposed here were implemented, adequate data to build reach-specific models for stratification would become available. Based on our results, we believe that reach-specific models would provide better predictions of numbers of pairs expected and would also be useful in informing decisions about annually distributing sampling effort among river reaches and reservoirs.

8.0 Data Summary and Reporting

8.1 Database Management

Decisions will need to be made about recording, archiving, and distributing least tern and piping plover data from the new monitoring program. The TPDMS provides a framework that could be modified to account for new elements of the monitoring program. For example, the current program aims for a complete census of nests, chicks, and adults for the entire river system. The revised program would adopt a sampling approach in which biological data are collected on a sample of spatial units within each river reach. Raw counts of nests and chicks are updated regularly throughout the nesting season TPDMS as an indicator of nesting season phenology and activity. Because censuses would no longer be sought in the new program, any future presentation of raw data should explicitly state that the data are drawn from a sample of habitats and do not represent complete counts. One use of these data has been to assess number of nests at risk of flooding as a result of changing water level. This capacity can be built into the new monitoring program, but presentation of at-risk nest data would be based on data from the sample of units extrapolated to the full reach for the period of time in question. The revised program would also eliminate some aspects of the existing program that are central to the TPDMS, such as chick counts, fledgling counts, and the adult census. Because none of these data would be collected under the new program, the associated sections of the TPDMS would be unnecessary. The calculation and reporting of fledge ratio would also become obsolete and would no longer be a component of the TPDMS. Rather, the system would focus on reporting BPOP, FY, and their 95 percent confidence intervals for each reach of the river system.

8.2 Deriving and Reporting MINBPOP and FY

The ability to accurately monitor plover and tern populations would hinge on successful collection of bird monitoring data on sample units and on acquiring reach-wide imagery at the appropriate time of year and spatial resolution. Multiple possibilities exist for making reach-wide estimates of breeding adults and fledging-age chicks from bird and habitat monitoring data (see Reach-wide estimation of BPOP and FY section). The method of choice would ultimately depend on available imagery and the strength of relations between imagery-derived habitat metrics and bird monitoring data. The monitoring program proposed here emphasizes the collection of good data that can support various approaches to reach-wide estimation of bird metrics. Some possible approaches can be identified now and others would come later. To meet an anticipated need for immediate results from annual monitoring, USGS would develop software to produce mean per unit or ratio estimates of BPOP and FY. These routines could be executed at the end of the monitoring season to produce initial estimates (totals and SEs) of breeding population and fledging-age young.

9.0 Implementation

9.1 Pilot Effort

If the proposed monitoring plan was to be implemented, USGS suggests a joint monitoring effort in which USGS personnel would work closely with the Corps to implement the plan on a pilot basis in the first year of the new monitoring plan. The USGS and researchers at Virginia Polytechnic Institute and State University are evaluating changes in habitat and responses of terns and plovers to the flood event of 2011. The 2011 flood created monitoring conditions in 2012 that neither USGS nor the Corps had encountered before. The proposed collaborative approach to a pilot effort would allow USGS to work out unforeseen complications under actual field conditions, and provide the Corps with the knowledge and experience they would need to monitor in subsequent years. USGS would provide guidance and assistance with many aspects of planning and execution, including but not limited to stratification and selection of sample units prior to the field season, developing permit requests and crew schedules, training Corps crew leaders and crew members, processing imagery, and trouble-shooting problems as they arise.

9.2 Monitoring Workforce

We believe monitoring of nests and chicks would be best accomplished by 3- to 4-person field crews, each consisting of a GS-6 level equivalent crew leader and GS-5 level equivalent crew members with specialized experience and knowledge of avian ecology and behavior. Crew leaders typically require experience equivalent to or in excess of that required for a Master's degree in wildlife or ecology. Crew members will have experience comparable to a Bachelor's degree in wildlife or a related field. We estimate that one 4-person crew working 50 hours per week can survey 5 to 6 river sampling units, and a 3-person crew working on a reservoir can survey 8 to 10 units, provided all units are centrally located and travel times are kept reasonable. Our estimates assume units will be surveyed twice per week for nests and chicks, and that nests near hatching will be monitored daily. At least one crew person, preferably two, should be highly skilled in deploying individual markers on 1-day-old plover and tern chicks. In addition to field crews, it is highly desirable, if not critically important, to have field-experienced biologists (GS-7 level equivalent or above) oversee and coordinate the work of multiple field crews. A single biologist may be able to oversee monitoring on multiple reaches, but larger reaches with more birds may require a coordinator dedicated to each reach. Continuity of monitoring personnel from year to year is highly desirable. A cadre of experienced individuals with a thorough understanding of monitoring protocols will be invaluable for training new hires and maintaining consistency in data collection. Staffing strategies that minimize turnover in personnel responsible for marking chicks should be emphasized.

9.3 Workforce Training

Consistent application of data collection protocols by field personnel is critical to success of the monitoring program. Technicians will need training in interpretation and application of field protocols and permits. It will be important for the Corps to develop and maintain capability for providing that training each year. USGS will work collaboratively with the Corps to develop training materials for Corps biologists. Explanation of terms and conditions of endangered species permits and the need for full compliance with permits will be emphasized during training and throughout the field season. Procedures for handling, marking, and recapturing chicks will require special considerations to avoid placing birds at risk as a result of monitoring activities.

9.4 Annual Timeline and Agency Roles

An annual timeline and work schedule is shown in fig. 44. Calendar periods for tasks related to imagery and logistics are approximate. Under this proposal, USGS would have a major role in most activities during the pilot year but the role of the USGS in monitoring beyond the pilot year is less certain. We anticipate that roles and responsibilities of individual agencies would become clearer as the pilot year unfolds.

9.5 Field Activities

Crews hired to implement the monitoring program should be trained and equipped to do a number of tasks, each of which would generate data needed to estimate BPOP or FY. It is important that the priority of the crews is completing these tasks on each of the selected sampling units at the chosen return interval.

1. Grid-search for nests—Nest numbers, status, and distribution are the foundation for generating estimates of BPOP and FY. Thus, all suitable nesting habitat in each selected unit should be thoroughly searched for active nests at the chosen return interval. This task must be completed consistently with full adherence to nest searching protocols throughout the entire nesting period of both bird species and throughout all nesting habitat on the unit during each visit.

	Task	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Imagery/Logistics	Order imagery	USACE	USACE	USACE	USACE	USACE							
Imagery/Logistics	Obtain ES and associated permits (banding)		USACE	USACE									
Imagery/Logistics	Order banding supplies			USACE	USACE								
Imagery/Logistics	Choose spatial sample units for annual monitoring[2]				NPWRC	NPWRC	NPWRC						
Imagery/Logistics	Acquire imagery								USACE	USACE	USACE		
Imagery/Logistics	Process imagery[3]	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC	NPWRC
Imagery/Logistics	field season (start - end)							USACE[1]	USACE[1]	USACE[1]	USACE[1]	USACE[1]	
Field Crew	Prepare crew leader and tech position advertisements		USACE[1]										
Field Crew	Advertise crew leader and tech positions			USACE	USACE								
Field Crew	Hire crew leader and tech positions				USACE	USACE	USACE						
Field Crew	Crew leaders - enter on duty						USACE						
Field Crew	Crew members enter on duty							USACE					
Field Crew	Train crews							USACE[1]					
Field Crew	Train banders								USACE[1]	USACE[1]			
GOAL	Estimate BPOP and FY[4]	NPWRC	NPWRC									NPWRC	NPWRC

[1] Effort completed with assistance of NPWRC as delineated in annual work plan

[2] Contingent on satellite imagery acquisition.

[3] Assumes NPWRC continued involvement in processing river reach imagery; reservoir segments in question. Timing is uncertain.

[4] Timing will depend on how refined the estimates need to be and when remote sensing analyses are completed

Figure 44. Annual timeline and work schedule for implementing a proposed new monitoring program for least terns and piping plovers on the upper Missouri River system by the U.S. Army Corps of Engineers (Corps) in cooperation with the U.S. Geological Survey, Northern Prairie Wildlife Research Center (NPWRC).

2. Monitor nests—Measures that enhance accuracy of nest fate determination will improve accuracy of nest survival estimates, improving reliability of BPOP and FY estimates. Thus, crews should visit each active nest during every nest-searching visit to a unit. Further, nests near their hatch date should be visited daily to facilitate accurate fate determination, counting and banding chicks, and applying bands to chicks in the nest bowl.
3. Band chicks—Crews should be equipped to band any newly hatched chicks encountered during nest searching and monitoring. Daily nest visits near the projected hatch date will increase likelihood that brood identity and nest association of hatched chicks is known and that hatchling counts are accurate.
4. Resight chicks—Estimating chick survival and fledging rates is dependent on resightings of previously banded chicks. Accordingly, crews should be prepared to resight marked chicks on each monitoring visit. Depending on the chosen approach to chick marking (see appendix 4), this could involve traditional visual resightings (for example, using binoculars and spotting scopes), or it could involve monitoring via electronic detection of of radio frequency identification (RFID) tags (see appendix 4). If the latter approach is developed, crews will need to deploy and maintain batteries, data-loggers, antennas, and other monitoring equipment. In lower-density breeding areas, detection rate may be improved by recording the whereabouts of each brood during visits and targeting subsequent searches to its last known or projected location.
5. Deploy exclosures—The proposed monitoring approach allows for deployment of nest exclosures at piping plover nests on some of the units selected for monitoring. Crews should be prepared to deploy these exclosures on the day of nest discovery. This will entail considerable preparation, including transporting exclosures to the field during monitoring visits and ensuring that adequate numbers of exclosures are available.

This list of crew tasks excludes some management activities that traditionally have been done by tern and plover monitoring crews. These are excluded from the task list because they fall outside the realm of the revised program's principal objective (see Proposed approach to monitoring section), and decisions about their future implementation have not been made. Time available for monitoring will likely be at a premium; thus, adding these management activities to the task list could compromise quality of monitoring data. Additionally, implementing any management measures only on the units visited by the monitoring crews would make those units atypical of the river-wide population of units for which BPOP and FY estimates are desired. Because preserving the probabilistic nature and integrity of the sample for extrapolating to the full reach is important, caution should be exercised in using the monitoring program to deliver management actions. Management actions deployed on monitored units and not on other units could bias estimates and inferences from the monitoring program. In addition, management activities executed by other means should be closely coordinated with the monitoring program to ensure satisfactory outcomes of management and monitoring. Examples of management activities include, but are not limited to the following:

- Deploying and maintaining visual barriers, fencing, and signage
- Predation management (other than nest exclosures)
- Moving or elevating nests or broods
- Habitat management (for example, vegetation control)

9.6 Monitoring Effort and Sample Size

Monitoring effort can be prescribed in terms of the following: number of monitored units (that is sampling intensity), frequency and thoroughness of nest monitoring, proportion of hatchlings banded, and frequency and thoroughness of chick resighting attempts. Each component has implications for monitoring accuracy and together they determine the number of crew hours required for monitoring. A desirable level of effort achieves an acceptable level of reliability, minimizes the potential for negative impacts of monitoring on bird populations, and minimizes monitoring cost. A complete discussion of effort considers the amount needed and its allocation among study areas and strata (for example, high or low expected use), with the goal of identifying an optimal allocation of effort whereby accuracy is maximized for given overall cost. In practice, reliability (the reciprocal of variance) is used as a surrogate for accuracy when determining the optimal allocation of sample units. Optimal sample sizes under stratified random sampling are proportional to strata sizes (that is number of sampling units) and intra-stratum variances. Not knowing intra-stratum variances beforehand will require they be approximated to arrive at sample size targets. Sample sizes can later be defined when better data on intra-stratum variances become available. An inherent difficulty in evaluating sample sizes is that optimal sample size and optimal allocation become moving targets due to annual variation. Furthermore, sample sizes that provide adequately precise estimates of breeding population may not provide adequate estimates of fledging-age chicks, or vice-versa.

Sampling intensity—Although specifying exact prescriptions for monitoring effort will be challenging, research data provide insights to guide initial choices. Appendix 3 (*http://pubs.usgs.gov/of/2013/1176/Appendix_3.xls*) shows hypothetical sample sizes needed to estimate MINBPOP and FY at three levels of precision. Precision is specified in terms of the CV of the estimate. A CV of 5 percent means the SE of the estimate will be 5 percent of the estimate. Thus, if the estimate of MINBPOP is 100 we would expect its SE to be about 5. An approximate 95 percent confidence interval, derived by taking the estimate plus or minus 2 times the SE, would be the interval between 90 and 110. With a CV of 20 percent, the expected SE would be 20 and a 95 percent confidence interval would be between 60 and140. Sample sizes in appendix 3 (*http://pubs.usgs.gov/of/2013/1176/Appendix_3.xls*) are in terms of number of units (4-RM units on GRR, 3-RM units on GVP, and 2-km units on SAK) necessary to achieve the specified level of precision. Sample sizes were derived from stratum totals and intra-stratum variances observed by USGS and vary by year. Sample sizes also depend on species and choice of metric (MINBPOP or FY).

An implicit but enormously important assumption behind appendix 3 (*http://pubs.usgs.gov/of/2013/1176/Appendix_3.xls*) is that the relative variances observed by USGS (among and within strata) from 2006 to 2009 are representative of future conditions. This assumption should be questioned for at least two reasons. First, USGS defined strata on the basis of past Corps monitoring data (number of nests); the stratification proposed here would be based on inferred relations between habitat and bird use. Second, the flood of 2011 had profound effects on distribution of habitat and birds. Sample size calculations need not be based on past data but relative variances must be specified.

Sample sizes in appendix 3 were derived from a mean-per-unit estimator assuming optimal allocation of sample units among strata (the optimal allocation is not shown but is straightforward to compute). Ratio estimation or some other form of model-assisted procedure that exploited bird-habitat relations should reduce sample size requirements. The amount of reduction is unknown and would depend on the strength of bird-habitat relations. Uncertainty arising from adjusting MINBPOP for variation in nest survival is not reflected in appendix 3. Such adjustment, which may be desirable to remove bias in the MINBPOP estimator (see Determining MINBPOP on sample units section), would result in larger standard errors and wider confidence intervals or require that sample sizes be increased. Sample sizes in appendix 3 do not consider that nest exclosures may be deployed at plover nests on some sampling units. Taking that possibility into account would inflate sample size requirements for plovers. Least tern sample sizes would be unaffected unless it was believed that nest exclosures impact tern abundance or productivity. Another assumption behind appendix 3 is that monitoring cost per unit is the same for all strata. In practice, high-use units will cost more to monitor than low-use units because of differences in effort related to nest monitoring, chick banding, and chick relocation. Incorporating monitoring costs into appendix 3 would be straightforward but would require cost differentials be specified.

The above considerations, especially uncertainty related to the 2011 flood, suggest a future monitoring strategy that errs on the side of oversampling, at least initially. In addition to addressing monitoring objectives, an aim of monitoring in the first few years should be to obtain data needed to refine sample sizes and sample allocation. High sampling intensities for the first several years would enhance precision in future years and provide data to determine if monitoring effort can be scaled back and by how much, and ensure that effort is allocated among strata and study areas in an appropriate way. Given that reach-specific stratification models will not be available for all reaches, stratification may not reach full effectiveness in the first few years, providing more reason to sample more intensively at first.

Nest monitoring—Shorter intervals between nest searches mean less opportunity for nests to fail without being discovered and increased opportunity to locate nests that ultimately produce hatchlings. Methods proposed for estimating number of fledglings hinge on the critical assumption that hatchling numbers can be accurately determined. Shorter intervals also lead to fewer errors in nest fate determinations and in assigning causes of nest failure. We propose that each unit of habitat be systematically searched for nests twice per week, resulting in a 3- to 4-day return interval. We further propose that clutches near hatching be monitored daily to facilitate fate determination and enumeration and marking of hatchlings.

Chick banding—Sample size requirements for estimating FY (appendix 3) are based on the assumption that all hatchlings will be marked and followed to determine if fledging age is reached. Although it is possible to estimate FY by marking a fraction of the chicks, doing so will mean a reduction in the nominal precision levels listed in appendix 3 or will require that number of sample units be increased to offset loss of precision resulting from sampling variation induced by not monitoring all chicks. In addition, reducing the sample size of marked chicks impacts the precision of mark-recapture estimators of chick detection and survival rates. Analyses are underway to quantify the implications of marking various proportions of hatchlings. Our preliminary advice is to plan on marking 50–100 percent of hatchlings and recognize there are implications for monitoring accuracy.

Chick resighting—Analyses of existing data suggest that multiple resighting attempts of fledging-age chicks are necessary to achieve moderately high to high detection probabilities of fledglings (tables 25 and 26). We propose resighting be attempted on each habitat unit three times per week. Resighting attempts should begin no later than 19 days after the first plover chick or 15 days after the first tern chick is banded, whichever comes first; however, we recommend that resighting efforts begin immediately, thereby maximizing information on timing of chick mortality relative to age and date. Near-immediate and frequent monitoring of chicks on reservoir shorelines is extremely helpful in keeping track of chicks that move off sample units but still must be monitored.

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Appendixes 1–4

Appendix 1. Detection-Corrected Adult Numbers by Survey Date for the Gavins Point and Garrison Reaches

http://pubs.usgs.gov/of/2013/1176/Appendix_1.xls

Appendix 2. Results of Simulation Study Relating Sample Size, Monitoring Search Frequency, and Survival of Least Tern and Piping Plover Chicks

http://pubs.usgs.gov/of/2013/1176/Appendix_2.pdf

Appendix 3. Estimated Sample Sizes Under Optimal Allocation for Achieving Three Levels of Precision for MINBPOP and Fledged-Age Young

http://pubs.usgs.gov/of/2013/1176/Appendix_3.xls

Appendix 4. Individual Marking of Chicks

Individually marking animals is a standard procedure for monitoring efforts that require estimates of survival and dispersal. Marks can be temporary or permanent, but the method employed needs to be adequate to meet short- and long-term objectives of the effort. Marking methods must ensure that marks are not lost and that bird behavior or survival are not impacted, all of which are undesirable and jeopardize the validity of estimates. For birds, uniquely numbered U.S. Geological Survey (USGS) Bird Banding Lab (BBL) metal bands are a safe and standard marking technique, designed for a lifetime of wear. To facilitate repeated observation without the need for physical recapture, multiple plastic color bands, flags, or both are deployed to increase visibility. Unfortunately, plastic leg band materials (celluloid or Darvic) fade, become brittle, and are lost, frequently within 1 or 2 years of application. Loss of plastic color bands, uncertainty over one or more colors, or misidentification of a color can render a sighting inconclusive or inaccurate, making repeated physical recapture necessary to reapply leg bands and fully confirm identities. Despite their limitations, plastic color bands have been widely used to mark large numbers of birds, including piping plovers (*Charadrius melodus)* and least terns (*Sternula antillarum)* on the Platte River, Missouri River, and Canadian Prairies. This work has brought to light an additional shortcoming. First, the recognizable number of color options [less than (<) 10] for bands is limited, unless unique combinations are reused within 10–15 years. And although current technology (color bands) is functional within a research context, its efficacy in large-scale population monitoring effort is unclear and untested.

Most studies of long-lived [greater than (>) 8 years] bird species (for example terns, puffins, albatrosses, gulls, geese) employ metal USGS bands in combination with more sturdy field-readable bands. Field-readable bands typically have a limited combination of letters and numbers (two to three) in a contrasting color that are more easily observed from a distance than the 9-digit BBL bands, yet provide a unique identity, without the need for multiple color bands. Thick engraved PVC plastic or anodized aluminum bands are used with most waterbirds and seabirds, and engraved plastic is used for seabirds, shorebirds (fig. 4-1), and recently even passerines. All field-readable bands are subject to human error in field observation or recording, although bands with alpha-numeric codes tend to have fewer errors than multiple color bands because of partial band loss and difficult color interpretations. Application of a single field-readable band also is less time-consuming compared to use of multiple color bands, reducing overall handling.

For situations in which the individuals are sensitive, cryptic, or visually difficult to identify without physical recapture (for example least tern chicks), marking methods which permit automated detection and reduce opportunity for human error are desirable. Use of radio frequency identification (RFID) via application of passive integrated transponder (PIT) tags attached externally on a leg band is a recent technological advance. PIT tags have been used safely for years with fish, but recent applications with bats and birds illustrate their potential in mark-recapture studies. A potential benefit of deploying handheld or remote sensors at a site is that birds can be marked and relocated with limited handling, requiring minimal visual confirmation and allowing data to be collected around the clock. Because sensors identify the individuals, human-associated error in observing or recording resightings is substantially reduced. Development of RFID radar methods in particular may hold promise for remote detection.

Figure 4-1. Least tern marked with a field-readable band on its left leg and a U.S. Geological Survey-Bird Banding Laboratory stainless steel band on its right leg.

Development and implementation of a new marking technique needs to focus on assessment of three important objectives:

- Can the marking method be implemented without affecting bird survival?
- Is field implementation possible?
    - Marks can be rapidly deployed, and accurately resighted/detected
- Are the marks retained?
    - Short-term (days): chick to fledging
    - Long-term (years): post-fledging through adult

Although no existing marking method is fool-proof, it is important to choose techniques that are safe for the animals involved while maximizing successful resightings. The immediate needs of the proposed monitoring plan can probably be met through the use of multiple color bands; however, directed studies which develop and evaluate alternative marking and data collection options should be given high priority to ensure that long-term monitoring needs can be met safely and efficiently. A study which directly compares current marking methods and one or more alternative field marking techniques is required to determine safety and tradeoffs in the application of these marking methods for large-scale monitoring of piping plovers and least terns on sandbars of the Missouri River. A study would ideally be done within one or more confined areas (for example a sandbar) where direct and repeated observations of individuals over time could be made by researchers and naïve observers, and to ensure safety of marked individuals. Ideally, simultaneous mark-recapture estimates would be developed using one or both methods, for plovers and terns. A single season will likely be adequate to determine the efficacy for marking chicks, but assessment of retention on adults will take several additional years of observation. USGS has identified four methods that may hold potential and currently are available, or in development for field trials:

1. Acetal leg bands—These bands are made from a new material; chemically, it is similar to nylon, but the material is now being sold as leg bands in sizes appropriate for piping plovers and least terns. The greatest benefit of acetal leg bands is that 15 colors are available now, and the price per band comparable to celluloid or Darvic. Celluloid, the standard band material for use with least terns is going out of production, so an alternative must be found, and Darvic bands are sometimes difficult to obtain. Northern Prairie Wildlife Research Center (NPWRC) deployed acetal bands on least terns and piping plovers in 2012.

2. Field-readable legs bands—Field-readable bands have been used successfully with other tern and plover species. The band material, a multi-layered impact acrylic (PMMA) material, is formed into a durable field-readable band, which is designed to last the life of the bird, but be easily observable from 50–100 meters (m). With a single durable band, and a minimal number of letters and numbers, reports from resighting will be simplified and band retention maximized. Once a bird is marked with field-readable bands, they are expected to last a lifetime. NPWRC acquired a series of these bands in sizes appropriate for piping plovers and least terns and deployed bands on a small sample of least terns in 2012.

3. RFID: low and high frequency tags—Current PIT tag or RFID technology has been modified for internal and external use with a variety of bird species, most notably with long-term research on common terns (*Sterna hirundo*) (Becker and Wendeln, 1997; Bonter and others, 2011); however, this technology is hampered by limited detection ranges (<1 m) requiring either the observer be in close proximity to birds, or manipulating bird behaviors (movement, hiding, or both) to increase passive detection rates. RFID tags for this application would cover the low frequency [LF; 125–150 kilohertz (kHz)] or high frequency [HF; 156 megahertz (MHz)] ranges depending on how they were applied (internal or external). We believe it possible to attach PIT tags externally, on a leg band. Internal injection might be more permanent, but may require additional safety and detection considerations. Internal injection is currently used with terns, penguins, and hummingbirds (Becker and Wendeln, 1997; Dugger and others, 2006; Bonter and Bridge, 2011; Brewer and others, 2011; Bridge and Bonter, 2011).

4. RFID: Ultra-high frequency (UHF) tags—These RFID tags (also referred to as Gen2 RFID) function in the UHF range (868–928 MHz; North America is restricted to 902–928 MHz range) with greater distance detection than LF or HF RFID, but can permit multidimensional relocation from a distance through the use of radar. Current detection range of these tags is approximately 10 m from sensor, but may be much further soon, although tag size may be more of a limiting factor than tag weight. Application of these tags to wildlife is in the early stages of development but has potential to advance remote detection options.

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