Send proof to:
Patrick Farrell
Headwaters Corporation
4111 4th Avenue, Suite 6
Kearney, NE, USA 69945
Phone: 734-545-0405
E-mail: farrellp@headwaterscorp.com

Reducing Effort When Monitoring Shorebird Productivity

PATRICK D. FARRELL[1,*] AND DAVID M. BAASCH[1]

[1] Executive Director's Office for the Platte River Recovery Implementation Program, 4111 4th Avenue, Suite 6, Kearney, Nebraska, USA, 68845

*Corresponding Author; E-mail: farrellp@headwaterscorp.com

Abstract.—While several methods have been employed to estimate shorebird abundance and productivity, little attention has been given to differences in methods used to collect these data. Within central North America, Interior Least Tern (*Sternula antillarum athalassos*; here after, Least Tern) and Piping Plover (*Charadrius melodus*) monitoring is often accomplished through surveys from a distance or within the nesting colony. Four years of season-long monitoring were implemented from within (inside) and outside the nesting colonies at off-channel nesting sites along the central Platte River to compare differences of productivity components and estimates. Inside monitoring efforts resulted in more nests and early-development chicks being detected resulting in lower nest and brood survival estimates than outside monitoring efforts estimated. Less older Least Tern chicks were observed by outside monitoring crews, but more older Piping Plover chicks and fledglings were observed by inside monitoring efforts. More Least Tern fledglings and higher fledglings per brood were observed from outside the nesting colony which, when combined with lower breeding pair counts, would result in higher fledge ratios. Given the ability to estimate differences between survey technique observations, lower effort monitoring from outside the colony can result in reasonable estimates of abundance and productivity measures.

Key words.—*Charadrius melodus*, Interior Least Tern, monitoring techniques, Piping Plover, productivity, shorebird, *Sternula antillarum athalassos*

Running Head: Reducing Shorebird Monitoring Effort

Extensive monitoring of avian species has occurred throughout the world for a multitude of reasons. Shorebirds have been the subjects of successful population monitoring due their locations of breeding activities, colonial nature, and role as indicators of ecosystem health (Kushlan 1993, Diamond and Devlin 2003). Within central North America, Interior Least Tern (*Sternula antillarum athalassos*; here after, Least Tern) and Piping Plover (*Charadrius melodus*) breeding productivity has been monitored and utilized to compare regional differences and population trends (Larson et al. 2000, Haig et al. 2005, Lott et al. 2013, Catlin et al. 2016). Several methods have been employed to estimate Least Tern and Piping Plover abundance and productivity including single mid-June surveys on the Mississippi River (Lott 2006), periodic inside the nesting area (hereafter, inside) and/or outside the nesting area from a distance (hereafter, outside) monitoring on the lower Platte River (Brown et al. 2017), season-long periodic inside monitoring on the Missouri River (Shaffer et al. 2013), and season-long inside and/or outside monitoring on the central Platte River and more recently on the Missouri River (PRRIP 2015, Andes et al. 2018). Even though many different monitoring protocols have been practiced, little attention has been given to differences in methods used to collect productivity and abundance data (Shaffer et al. 2013).

Proximity of observers to nests and nesting colonies is an important consideration between monitoring techniques for shorebirds. Survey proximity has been investigated for only the most extreme differences. Aerial surveys tend to underestimate abundance numbers compared to nesting site (i.e., inside) searches (Savereno 1992). Inside surveys can also result in extensive productivity information unattainable by outside surveys such as egg floating for nest initiation dates and chick banding for individual survival estimations (Roche et al. 2016, Baasch and Keldsen 2018). However, inside surveys require short-term colony disturbances which have been linked to higher nest failure rates and decreased reproductive success of colonial nesting species (Carney and Sydeman 1999, Blackmer et al. 2004, Carey 2009, Seefelt and Farrell 2018). Consideration of additional stressors and suppressing productivity through investigators entering nesting sites are especially important for threatened and endangered species. Outside monitoring can greatly decrease investigator disturbance, but the comparable accuracy to inside methods is less well understood (Hillman et al. 2013).

Least tern and Piping Plover monitoring has been accomplished through both inside and outside methods (Hillman et al. 2013, Roche et al. 2016). On the central Platte River, monitoring from outside the nesting colony (generally 20 m – 200 m away from nests) has been used to evaluate Least Tern and Piping Plover productivity since the early 1990s (Jenniges and Plettner 2008). Nesting has primarily been documented on off-channel sandpits created by sand and gravel mining operations and through efforts to construct similar, peninsula-type nesting habitat through excavation activities (Jenniges and Plettner 2008, Baasch et al. 2017, Baasch and Keldsen 2018, Farrell et al. 2018). These habitats are highly accessible to investigators, but only outside surveys were conducted for several decades to minimize potential effects of investigator presence on Least Tern and Piping Plover productivity (Jenniges and Plettner 2008).

From 2009-2016 the U.S. Geological Survey - Northern Prairie Wildlife Research Center (USGS) assisted the Platte River Recovery Implementation Program (PRRIP) with implementing a study protocol that included grid-search surveys from within the nesting colony (inside monitoring) and to band and re-sight Least Tern and Piping Plover adults and chicks at nesting sites within the PRRIP Associated Habitat Area (PRRIP 2015). During 2013 – 2016, double-blind survey techniques were implemented from both inside and outside nesting colonies at all sites with nesting Least Terns or Piping Plovers. Duplicating monitoring efforts allowed us to obtain and compare independent estimates of reproductive measures between techniques. The objective of this study was to quantify differences in Least Tern and Piping Plover productivity metrics including: 1) observed nest period duration; 2) nest and chick counts; 3) breeding pair and fledgling counts; and 4) nest and brood survival. Our findings allowed us to better understand the influence of survey effort on estimates of productivity and abundance.

METHODS

Study Area

The Associated Habitat Reach for the PRRIP is a 145-km reach extending from Lexington, Nebraska, downstream to Chapman, Nebraska, USA, and encompasses central Platte River channels and off-channel habitats (sandpits and constructed off-channel sand and water sites) within 5.6 km of the river (Fig. 1). PRRIP and Nebraska Public Power District maintained eight managed, off-channel nesting sites through 2016 that incorporated both inside and outside monitoring techniques and were utilized for this study. Management activities at each site included predator fencing and trapping, pre-emergent herbicide application, and tree removal.

During the 2013 – 2016 nesting seasons, eight managed, off-channel sites where nesting was documented were monitored from inside as well as outside the nesting area intensively (i.e., at least twice per week) through early September or until the cessation of nesting or brood-rearing activities of both species. We implemented double-blind survey techniques so that both inside and outside survey crews were unaware of observations made by the other crew. Given the intensity of survey effort for both techniques, inside and outside surveys generally occurred on the same day or within one day of each other. Piping plovers initiate nests earlier in the year (late April) than Least Terns (mid- to late May) in our study area and monitoring season duration was set to capture all breeding activities of the two species (PRRIP 2015, Baasch and Keldsen 2018). Monitoring objectives included locating and documenting Least Tern and Piping Plover adults, nests, chicks, fledglings, and breeding pairs. Inside surveys involved systematic, 10-m grid searches with 4-6 evenly spaced investigators entering colony sites and walking through nesting areas to identify nest locations and chicks at least twice per week (2013–2016; PRRIP 2015, Keldsen and Baasch 2017). Given inside surveys were conducted with numerous combinations of 8 individuals where 4-6 people were generally used during each inside survey of each site, comparisons between observers was not possible. In addition, fledglings were documented by inside survey crews based on band combinations observed during river and other survey efforts.

Outside surveys were performed at least twice per week for at least 30 minutes with binoculars and spotting scopes at a distance of greater than 50 m from outside the nesting sites. On days inside surveys preceded outside surveys at a site, a rest period of at least 1 hour was enforced between the end of inside and beginning of outside surveys to allow displaced adults and chicks to settle into pre-survey behavior patterns. Only 1 outside surveyor was used at each site annually so comparisons between observers was not possible. During each outside survey, sites were visually scanned at least 5 times from multiple locations. Outside nests were identified by the presence of an incubating adult as outside monitoring personnel only entered the nesting colony to confirm nest fates when necessary. When an active nest was located by either survey method, the date was recorded as “first observed” and a GPS point was recorded for the location. Active nests were defined as any scrape containing 1 or more viable eggs. Active nests were monitored at least twice per week until successful (≥1 chick observed hatched), failed (evidence of nest destruction or abandonment), or unknown fates (no evidence present) were determined. If a brood was observed, but the associated nest was not, the brood was included in our analysis. Broods were considered fledged when chicks were observed in sustained flight or were observed at 21 (Least Tern) or 28 (Piping Plovers) days of age (PRRIP 2015). Nests or broods with unknown fates were considered to have hatched or fledged if observed as active for at least 21 (Least Tern) or 28 (Piping Plovers) days during either reproductive stage. Breeding pair estimates were obtained using methods outlined in Baasch et al. (2015).

We compared inside and outside monitoring survey components including number of days a nest was observed (nest exposure days), number of days a brood was observed (brood exposure days), number of chicks <15 days old per brood, average number of chicks ≥15 days old per brood, and number of fledglings per brood using two-tailed, two-sample t-tests incorporating an alpha level of 0.05. Nest and brood direct measures of productivity (i.e., overall and annual breeding pair and fledgling counts) were visually inspected and interpreted annually. To evaluate indirect measures of productivity (i.e., nest and brood survival), we used several pieces of survey information including: 1) the day the nest or brood was found; 2) the last day the nest or brood was active; 3) the day the nest or brood was fated as successful or failed; and 4) nest or brood fate (successful or fledged=0, respectively, or failed=1). Days were standardized to only include the entire breeding season for both Least Terns and Piping Plovers, which we designated as 15 April to 15 September.

We calculated nest and brood daily survival rate (DSR) to obtain incubation and brooding period survival rates (DSR^n) separately for each species where n was 21 days for Least Tern nests and broods and 28 days for Piping Plover nests and broods. Nest or brood fate logistic regression models were developed, with a logit link function, using the nest survival models in package RMARK in Program R for both nest and brood survival analyses using monitoring technique as an explanatory variable (Rotella et al. 2000, Dinsmore et al. 2002, Laake 2013, R Development Core Team 2017). To test for statistical differences between monitoring techniques, chi-square tests were performed to compare the null model and model including survey technique within the nest survival modeling framework in Program MARK (White and Burnham 1999). Additionally, we performed our nesting and brood-rearing period survival modeling effort to obtain annual estimates of nest and brood survival using each survey technique.

RESULTS

Nest and chick counts for Least Terns and Piping Plovers were generally greater based on inside versus outside monitoring in any given year from 2013 to 2016 (Table 1). Least tern nests and chicks were observed, on average, for a similar number of exposures days regardless of technique (Table 2). Overall, inside survey crews observed more young Least Tern chicks than outside survey crews but no difference was found between average number of Least Tern chicks that were <15 days old within a brood (Table 2). However, outside survey crews observed more Least Tern chicks ≥15 days old, chicks ≥15 days old per brood ($t_{674.10}$= -4.13, P = <0.001), fledglings, and fledglings per brood ($t_{662.80}$ = -4.12, P = <0.001) than inside survey crews.

Inside survey crews observed more Piping Plover nests and broods than outside survey crews (Table 1). Piping plover nests were observed longer by inside survey crews than outside survey crews ($t_{282.58}$ = 4.51, P = < 0.001), whereas Piping Plover brood exposure days were similar between survey methods (Table 2). Contrary to Least Terns, inside survey crews counted more overall Piping Plover chicks and fledglings. Inside survey crews observed more <15 days old chicks per brood than outside survey crews ($t_{296.36}$ = 2.34, P = 0.02) but both techniques observed a similar number of ≥15 days old chicks and fledglings per brood (Table 2).

Annual breeding pair estimates obtained from inside surveys data, calculated following methods outlined in Baasch et al. (2015), and were higher than those obtained from outside the colony for Least Terns and Piping Plovers (Table 1; Fig. 2). Outside monitoring of Piping Plover fledgling counts were lower for three of four years, which is largely attributable to observations of fledglings off their natal site during river and other survey efforts (Fig. 2D). Inside survey crews documented 3, 8, 4, and 5 fledglings via band combinations during river surveys in 2013–2016, respectively and other observations likely occurred off site as well. The opposite was observed for Least Terns, where outside monitoring crew fledgling counts were higher for all years (Fig. 2B). Combining breeding pair and fledgling estimates, annual Least Tern fledglings per breeding pair obtained from within the nesting area were lower than estimates obtained by outside survey crews while comparison of annual Piping Plover fledglings per breeding pair was variable (Fig. 3). Given the stable differences in annual breeding pair estimates obtained from surveys conducted inside and outside the nesting colonies (Fig. 2A, 2C), we applied an adjustment factor to breeding pair counts to display a more realistic estimate for fledglings per breeding pair for outside survey crews. We calculated the difference between breeding pair estimates obtained during inside and outside surveys and divided this by the number of breeding pairs observed by inside survey crews to estimate the proportion of breeding pairs not documented by outside survey crews. We estimated outside survey crews failed to observe 7.9% of Least Tern and 12.6% of Piping Plover breeding pairs. This resulted in applying breeding pair adjustment factors of 1.079 for Least Tern and 1.126 for Piping Plover breeding pairs which resulted in a reduction of outside survey fledge ratios by 7.3% and 11.2%, respectively (Fig. 3).

We observed variable results in our nest and brood survival estimates between inside and outside monitoring of Least Terns and Piping Plovers. Average nest survival estimates were higher for inside survey crews than outside survey crews, especially for Piping Plovers ($\chi_1^2 = 4.416$, $P = 0.036$; Fig. 4). Inside survey crews obtained higher estimates of Piping Plover nest survival during three out of four years (Fig. 5). Least tern average brooding period survival rate was higher for outside monitoring (χ_1^2 = 13.997, P = <0.001), but somewhat lower for Piping Plovers (Fig. 4). Least tern brood survival estimates were higher for outside monitoring crews during all years (Fig. 5).

DISCUSSION

Several methods have been employed to estimate shorebird abundance and productivity throughout their range. While we found many similarities between inside and outside monitoring techniques at nesting sites along the central Platte River, inside monitoring efforts resulted in more nests and early-development chicks being detected so excluding these nests and chicks from survival analyses resulted in higher estimates of survival from outside the nesting area. Reduced detection of nests from outside the nesting colony was likely related to an inability to observe nests due to visual obstruction of the terrain and not observing nests during the early initiation phase when adults were not tending nests regularly which can lead to biases for several productivity measures (Shaeffer et al. 2013). While Piping Plovers fledgling counts were higher for inside surveys overall, more Least Tern fledglings and fledglings per brood were observed from outside the nesting colony, which would result in higher direct productivity measures such as fledge ratios (i.e., fewer nests or breeding pairs + higher fledgling counts = higher fledge ratios). Although differences between monitoring techniques were observed, both techniques described direct productivity on the central Platte River as near or above the proposed productivity estimates for species recovery in the region (Lutey 2002).

Off-channel sites have accounted for >95% of Least Tern and Piping Plover nests and broods along the central Platte River since 2001 and productivity at these sites is highly important to the local populations (Baasch et al. 2017). Four years of intensive monitoring at off-channel nesting sites provided sufficient data to compare monitoring techniques from inside and outside the nesting colony and their influence on central Platte River Least Tern and Piping Plover productivity estimates. Though colony disturbance has been linked to higher nest failure rates and decreased reproductive success of colonial nesting species (Carney and Sydeman 1999, Blackmer et al. 2004, Carey 2009), we did not observe a noticeable decrease in productivity associated with inside monitoring efforts which is similar to findings of Roche et al. (2014) on the Missouri River.

Least tern and Piping Plover nest and young chick counts were lower along the Missouri River when survey duration was protracted (Shaffer et al. 2013). Shaffer et al. (2013) reported detectability of Least Tern chicks increased with age, but detectability of Piping Plover chicks was more constant as chicks aged due to precocial development and behavior. Differences in detectability of older Least Tern chicks due to behaviors of older chicks (e.g., hiding under objects and in depressions) and adults (e.g., flying, dive-bombing, etc.) as investigators entered the nesting area likely explain the lower estimates of brood survival for inside crews in our study as well. Our results indicate monitoring of Least Tern breeding development through early chick rearing stage is similar between methods whereas inside survey chick detectability was lower relative to outside survey detectability for older chicks close to fledging. Lower detectability may have led to inside surveys fating broods with chicks capable of sustained flight prior to 21 or 28 days of age as unknown or failed when outside survey crews fated these chicks as fledged.

More Least Tern fledglings were counted by outside surveys in our study for several possible reasons. When investigators enter nesting sites, adults take flight and mobile chicks flee observers or move to safety to avoid perceived threats (Conover and Miller 1979, Burger 1982). Adult Least Terns may even mob investigators, adding additional sensory complications for inside survey investigators (Burger 1989). Chicks at fledging age may take flight when investigators enter the nesting site, further complicating inside survey counts when many fledglings are observed together. Fledglings will also leave their natal areas possibly in search of nesting habitat for subsequent years; a behavior that has been termed “prospecting” (Friedrich et al. 2015, Davis et al. 2017). This prospecting behavior by fledglings could potentially result in fledglings being counted at multiple sites from outside the survey area when band combinations cannot be read and correctly associated with a nest. These Least Tern behaviors can result in decreased estimates of fledglings perceived by inside surveys and results in lower direct productivity measures as compared to outside surveys.

Regardless of monitoring technique, Least Tern productivity was similar to past productivity measures on the central Platte River when only outside monitoring occurred (Jenniges and Plettner 2008, Roche et al. 2016). From 1979 to 2003, 1.13 Least Tern fledglings per nest were observed at managed, off-channel nesting sites on the central Platte River (Jenniges and Plettner 2008). We observed similar Least Tern fledglings per breeding pair, but studies from other areas were dissimilar. On the lower Platte River during 1987–1990, overall Least Tern fledglings per breeding pair was only 0.47 and no annual fledge ratio on sandpits exceeded 0.64 for Least Terns (Kirsch 1996). However, more recent fledge ratios on off-channel sites on the lower Platte River were similar to what we observed (Brown and Jorgenson 2008, 2009, 2010, Brown et al. 2011). Extensive management of off-channel nesting sites in the central Platte River could account for increased productivity observed in the region (Jenniges and Plettner 2008). Limited on-site disturbance, predator trapping, moating of the nesting area, and fences to limit land-access to nesting areas for mammalian predators are all utilized in the central Platte River to increase breeding productivity of Least Terns and Piping Plovers and may account for the increased productivity compared to other areas (Baasch et al. 2017, Farrell et al.

2018). Management activities at lower Platte River off-channel nesting sites include nesting site perimeter flagging and individual nest enclosures for Piping Plover nests, where the latter appears to result in productivity levels that are similar to what has been observed along the central Platte River (Kirsch 1996, Brown and Jorgenson 2008, 2009, 2010, Brown et al. 2011).

While it appears all monitoring efforts that employ multiple surveys, especially during the peak of the breeding season, would provide reasonable estimates for tracking long-term trends in shorebird population abundance, some methods appear to provide better estimates of nest and chick survival parameters. Andes et al. (2018) found inside monitoring on a 3-day return interval resulted in reliable estimates of fate and causes of nest loss. While we found similar results, it is important to note that monitoring from outside the nesting area can result in reliable estimates of productivity as well, so long as the nesting areas can be adequately observed. The best method of survey to employ is highly dependent on the objectives of the study, availability of resources, and access to the nesting sites. Inside monitoring efforts seem to provide the most precise estimates of abundance and daily nest and chick survival; however, the techniques used in our study required 4-6 times the labor force and associated costs as outside monitoring efforts which also resulted in reasonable estimates of abundance and productivity measures when sites were viewable from multiple angles from outside the nesting colony. Understanding breeding productivity based on varying monitoring techniques is important for species with wide breeding distributions and several distinct, but interconnected populations (Roche et al. 2010, Lott et al. 2013). Given the relative stability between differences in breeding pair estimates between survey techniques, we were able to adjust our productivity estimates to obtain more informed estimates of the number of breeding pairs, and thus fledge ratios, documented from outside the nesting colony. By accounting for differences among techniques, more appropriate comparisons of productivity would allow conservation programs to make better decisions to reach recovery goals for species with large spatial distributions.

ACKNOWLEDGEMENTS

We thank all members of the Platte River Recovery Implementation Program's Technical Advisory Committee as well as M. Sherfy, M. Ring, and J. Hoeting for their helpful and insightful comments. The Platte River Recovery Implementation Program provided funding for this research. All applicable ethical guidelines for the use of birds in research have been followed, including those presented in the Ornithological Council's "Guidelines to the Use of Wild Birds in Research" (Fair *et al*. 2010).

LITERATURE CITED

Andes, A. K., T. L. Shaffer, M. H. Sherfy, C. M. Hofer, C. M. Dovichin, and S. N. Ellis-Felege. 2018. Accuracy of Nest Fate Classification and Predator Identification from Evidence at Nests of Least Terns and Piping Plovers. IBIS International Journal of Avian Science.

Baasch, D. M., P. D. Farrell, J. M. Farnsworth, and C. B. Smith. 2017. Nest-site selection by Interior Least Terns and Piping Plovers at managed, off-channel sites along the Central Platte River in Nebraska, USA. Journal of Field Ornithology 88:236–249.

Baasch, D. M., T. J. Hefley, and S. D. Cahis. 2015. A comparison of breeding population estimators using nest and brood monitoring data. Ecology and Evolution 4197:4209.

Baasch, D. M., and K. J. Keldsen. 2018. Platte River Recovery Implementation Program: 2017 Interior Least Tern and Piping Plover monitoring and research report, central Platte River, Nebraska. https://www.platteriverprogram.org/PubsAndData/ProgramLibrary/PRRIP%202017%20Tern%20and%20Plover%20Monitoring%20and%20Research%20Report.pdf.

Blackmer, A. L., J. T. Ackerman, and G. A. Nevitt. 2004. Effects of investigator disturbance on hatching success and nest-site fidelity in a long-lived seabird, Leach's storm-petrel. Biological Conservation 116:141–148.

Brown, M. B. and J. G. Jorgensen. 2008. 2008 Interior Least Tern and Piping Plover monitoring, research, management, and outreach report for the lower Platte River, Nebraska. Joint report of the Tern and Plover Conservation Partnership and the Nebraska Game and Parks Commission. http://nlc1.nlc.state.ne.us/epubs/G1800/B025-2008.pdf.

Brown, M. B., and J. G. Jorgensen. 2009. 2009 Interior Least Tern and Piping Plover monitoring, research, management, and outreach report for the lower Platte River, Nebraska. Joint report of the Tern and Plover Conservation Partnership and the Nebraska Game and Parks Commission 2009. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1547&context=natrespapers.

Brown, M. B., and J. G. Jorgensen. 2010. Interior Least Tern and Piping Plover monitoring, research, management, and outreach report for the lower Platte River, Nebraska. Joint Report of the Tern and Plover Conservation Partnership and the Nebraska Game and Parks Commission (2010). http://nlc1.nlc.state.ne.us/epubs/G1800/B025-2010.pdf.

Brown, M. B., J. G. Jorgensen and L. R. Dinan. 2011. Interior Least Tern and Piping Plover monitoring, research, management, and outreach report for the lower Platte River, Nebraska. Joint Report of the Tern and Plover Conservation Partnership and the Nebraska Game and Parks Commission (2011). http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1549&context=natrespapers.

Brown, M. B., L. R. Dinan and J. G. Jorgensen. 2017. 2017 Interior Least Tern and Piping Plover Annual Report for the Lower Platte River, Nebraska. Joint report of the Tern and Plover Conservation Partnership and the Nongame Bird Program of the Nebraska Game and Parks Commission. Lincoln, NE. http://ternandplover.unl.edu/download/annualreport/2017_TPCP_annual_report.pdf.

Burger, J. 1982. An Overview of Proximate Factors Affecting Reproductive Success in Colonial Birds: Concluding Remarks and Summary of Panel Discussion. Colonial Waterbirds 5:58–65.

Burger, J. 1989. Least Tern Populations in Coastal New Jersey: Monitoring and Management of a Regionally-Endangered Species. Journal of Coastal Research 5:801–811.

Carey, M. J. 2009. The effects of investigator disturbance on procellariiform seabirds: A review. New Zealand Journal of Zoology 36:367–377.

Carney, K. M., and W. J. Sydeman. 1999. A Review of Human Disturbance Effects on Nesting Colonial Waterbirds. Waterbirds: The International Journal of Waterbird Biology 22:68–79.

Catlin, D. H., S. L. Zeigler, M. B. Brown, L. R. Dinan, J. D. Fraser, K. L. Hunt, and J. G. Jorgensen. 2016. Metapopulation viability of an endangered shorebird depends on dispersal and human-created habitats: Piping Plovers (*Charadrius melodus*) and prairie rivers. Movement Ecology 4:6.

Conover, M. R., and D. E. Miller. 1979. Reaction of Ring-Billed Gulls to Predators and Human Disturbances at at Their Breeding Colonies. Proceedings of the Colonial Waterbird Group 2:41–47.

Davis, K. L., K. L. Schoenemann, D. H. Catlin, K. L. Hunt, M. J. Friedrich, S. J. Ritter, J. D. Fraser, and S. M. Karpanty. 2017. Hatch-year Piping Plover (*Charadrius melodus*) prospecting and habitat quality influence second-year nest site selection. The Auk: Ornithological Advances. 134:92–103.

Diamond, A. W., and C. M. Devlin. 2003. Seabirds as Indicators of Changes in Marine Ecosystems: Ecological Monitoring on Machias Seal Island. Environmental Monitoring and Assessment 88:153–181.

Dinsmore, S. J., G. C. White, and F. L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476–3488.

Fair, J., E. Paul and J. Jones (Eds.). 2010. Guidelines to the use of wild birds in research. Ornithological Council, Washington, D.C.

Farrell, P. D., D. M. Baasch, J. M. Farnsworth, and C. B. Smith. 2018. Interior Least Tern and Piping Plover nest and brood survival at managed, off-channel sites along the central Platte River, Nebraska, USA 2001-2015. Avian Conservation and Ecology 13:1.

Friedrich, M. J., K. L. Hunt, D. H. Catlin, and J. D. Fraser. 2015. The importance of site to mate choice: Mate and site fidelity in Piping Plovers. The Auk: Ornithological Advances 132:265–276.

Haig, S. M., C. L. Ferland, F. J. Cuthbert, J. Dingledine, J. P. Goossen, A. Hecht, and N. McPhillps. 2005. A complete species census and evidence for regional declines in Piping Plovers. Journal of Wildlife Management 69:160–173.

Hillman, M. D., S. M. Karpanty, and J. D. Fraser. 2013. Nest and breeding population abundance of Least Terns: assessing bias and variation in survey timing and methods. Journal of Field Ornithology 84:287–298.

Jenniges, J. J., and R. G. Plettner. 2008. Least Tern Nesting at Human Created Habitats in Central Nebraska. Waterbirds 31:274–282.

Keldsen, K. J., and D. M. Baasch. 2017. Platte River Recovery Implementation Program: 2016 Interior Least Tern and Piping Plover monitoring and research report, central Platte River, Nebraska. https://www.platteriverprogram.org/PubsAndData/ProgramLibrary/PRRIP%202016%20Tern%20and%20Plover%20Monitoring%20and%20Research%20Report.pdf.

Kirsch, E. M. 1996. Habitat selection and productivity of Least Terns on the lower Platte River, Nebraska. Wildlife Monographs 3–48.

Kushlan, J. A. 1993. Colonial Waterbirds as Bioindicators of Environmental Change. Colonial Waterbirds 16:223–251.

Laake, J. L. 2013. RMark: an R interface for analysis of capture-recapture data with MARK. United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center.

Larson, M. A., M. R. Ryan, and B.G. Root. 2000. Piping plover survival in the great plains: an updated analysis. Journal of Field Ornithology 71:721–729.

Lott, C. A. 2006. Distribution and Abundance of the Interior Population of the Least Tern (*Sternula antillarum*), 2005: A review of the first complete range-wide survey in the context of historic and ongoing monitoring efforts. U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS.

Lott, C. A., R. L. Wiley, R. A. Fischer, P. D. Hartfield, and J. M. Scott. 2013. Interior Least Tern (*Sternula antillarum*) breeding distribution and ecology: implications for population-level studies and the evaluation of alternative management strategies on large, regulated rivers. Ecology and Evolution 3:3613–3627.

Lutey, J. M. 2002. Species recovery objectives for four target species in the Central and Lower Platte River (Whooping Crane, Interior Least Tern, Piping Plover, Pallid Sturgeon). United States Fish and Wildlife Service. http://cwcbweblink.state.co.us/WebLink/0/doc/169287/Page4. aspx.

Platte River Recovery Implementation Program (PRRIP). 2015. Platte River Recovery Implementation Program 2015 central Platte River tern and plover monitoring and research protocol. https://www.platteriverprogram.org/PubsAndData/ProgramLibrary/PRRIP%202015%20Tern%20and%20Plover%20Monitoring%20and%20Research%20Protocol.pdf.

R Development Core Team. 2017. R: A language and environment for statistical computing v. 3.4.0 R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/, accessed 1 February 2019.

Roche, E. A., J. B. Cohen, D. H. Catlin, D. L. Amirault-Langlais, F. J. Cuthbert, C. L. Gratto-Trevor, J. Felio, and J. D. Fraser. 2010. Range-Wide Piping Plover Survival: Correlated Patterns and Temporal Declines. Journal of Wildlife Management 74:1784–1791.

Roche, E. A., T. L. Shaffer, M. J. Anteau, M. H. Sherfy, J. H. Stucker, M. T. Wiltermuth, and C. M. Dovichin. 2014. Detection probability of Least Tern and Piping Plover chicks in a large river system. USGS Northern Prairie Wildlife Research Center. 298.

Roche, E. A., M. H. Sherfy, M. M. Ring, T. L. Shaffer, M. J. Anteau, and J. H. Stucker. 2016. Demographics and movements of Least Terns and Piping Plovers in the Central Platte River Valley, Nebraska. USGS Open-file Report 2016-1061.

Rotella, J. J., M. L. Taper, and A. J. Hansen. 2000. Correcting nesting-success estimates for observer effects: Maximum-likelihood estimates of daily survival rates with reduced bias. The Auk 117:92.

Savereno, L. A. 1992. Accuracy and precision of techniques used to census Least Tern nests. M.S. Thesis, Clemson University, Clemson, 83 pages.

Seefelt, N.E., and P.D. Farrell. 2018. Indirect Negative Impacts of Double-crested Cormorant (*Phalacrocorax auritus*) Management on Co-nesting Caspian Terns (*Hydroprogne caspia*) in Northern Lake Michigan, USA. Waterbirds 41:417–424.

Shaffer, T. L., M. H. Sherfy, M. J. Anteau, J. H. Stucker, M. A. Sovada, E. A. Roche, M. T. Wiltermuth, T. K. Buhl, and C. M. Dovichin. 2013. Accuracy of the Missouri River Least Tern and Piping Plover Monitoring Program: considerations for the future. Open-File Report, USGS Numbered Series, U.S. Geological Survey, Reston, VA. http://pubs.er.usgs.gov/publication/ofr20131176.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:S120–S139.

Table 1. Comparison of total counts from inside and outside monitoring of nesting colonies for Interior Least Tern (top) and Piping Plover (bottom) breeding pairs, nests, chicks <15 days old (Chicks <15 D), chicks ≥15 days old (Chicks ≥15 D), and fledglings (Interior Least Tern = 21 days old; Piping Plover = 28 days old).

Interior Least Tern

Technique	Breeding Pairs	Nests	Broods	Chicks <15 D	Chicks ≥15 D	Fledglings
Inside	261	424	251	554	230	192
Outside	242	357	201	409	294	256

Piping Plover

Technique	Breeding Pairs	Nests	Broods	Chicks <15 D	Chicks ≥15 D	Fledglings
Inside	116	156	113	380	206	142
Outside	103	143	95	285	166	117

Table 2. Nest or brood specific average ($\bar{x}$) and standard deviation (SD; ±) comparison of monitoring techniques from inside and outside the nesting colony for Interior Least Tern (top) and Piping Plover (bottom) nest exposure days, brood exposure days, average number of chicks <15 days old from each brood (LessThan15d), average number of chicks ≥15 days old from each brood (MoreThan15d), and average number of fledglings (Interior Least Tern = 21 days old; Piping Plover = 28 days old) observed from each brood (Fledglings).

Interior Least Tern

Technique	Nest Exposure Days	Brood Exposure Days	LessThan15d	MoreThan15d	Fledglings
Inside	16.75 (± 6.41)	15.10 (± 6.24)	1.31 (± 1.23)	0.54 (± 0.84)*	0.45 (± 0.76)*
Outside	16.27 (± 7.27)	16.14 (± 5.97)	1.15 (± 1.13)	0.82 (± 1.04)*	0.72 (± 0.99)*

Piping Plover

Technique	Nest Exposure Days	Brood Exposure Days	LessThan15d	MoreThan15d	Fledglings
Inside	23.96 (± 7.66)*	19.65 (± 9.00)	2.44 (± 1.67)*	1.32 (± 1.52)	0.91 (± 1.25)
Outside	19.64 (± 8.81)*	18.66 (± 7.98)	1.99 (± 1.60)*	1.16 (± 1.37)	0.82 (± 1.22)

*Indicates a statistically significant difference between inside and outside monitoring techniques.

FIGURE CAPTIONS

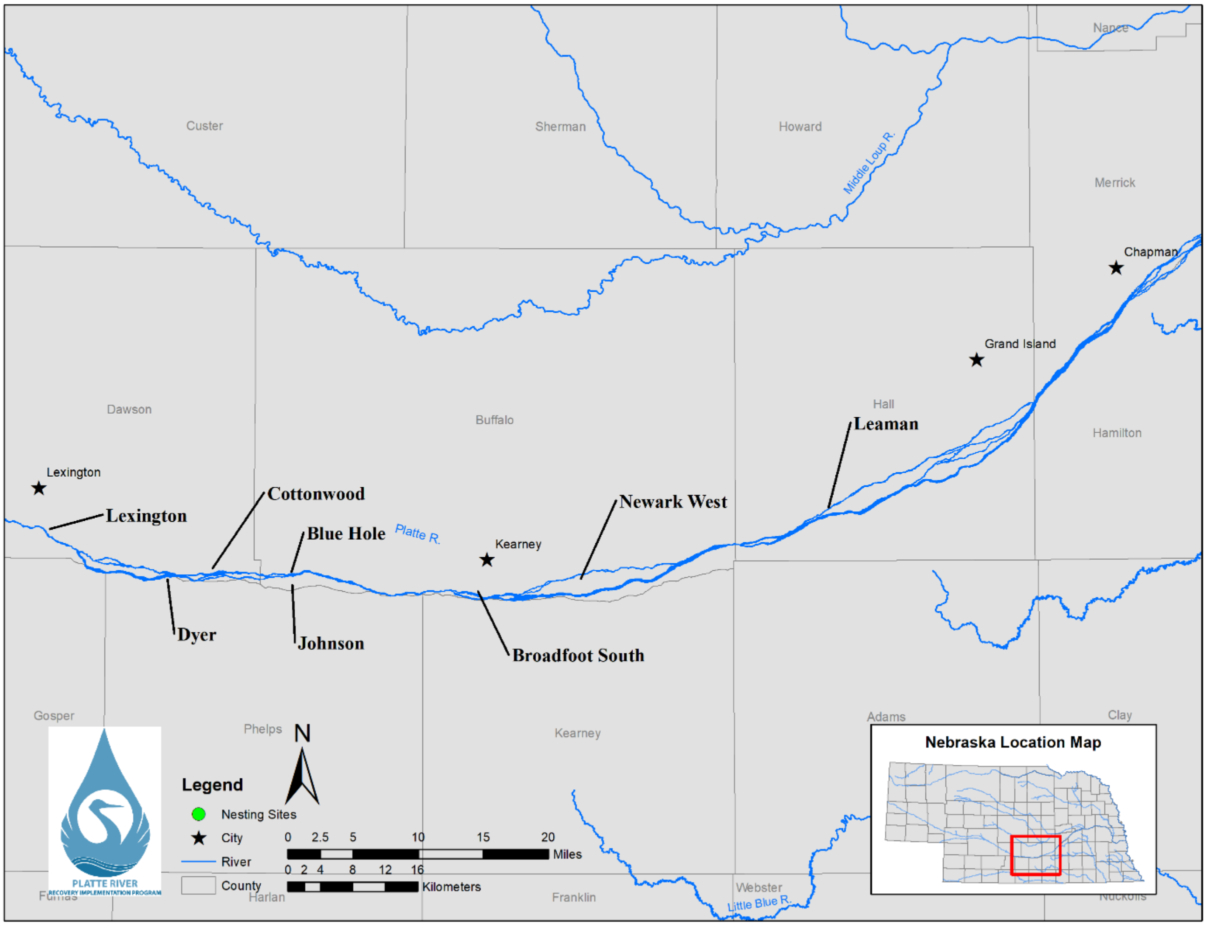
Figure 1. Associated Habitat Reach of the central Platte River extending from Lexington, NE downstream to Chapman, NE including eight managed, off-channel nesting sites that were included in the productivity monitoring analyses.

Figure 2. Annual estimates of Interior Least Tern (top) and Piping Plover (bottom) breeding pairs (A, C) and fledglings (B, D) observed using inside (black) and outside (gray) monitoring techniques on eight, central Platte River off-channel nesting sites, 2013–2016.

Figure 3. Annual Interior Least Tern (A) and Piping Plover (B) fledglings per breeding pair estimates using inside (black) and outside (grey) monitoring techniques on eight, central Platte River off-channel nesting sites, 2013–2016. Dashed lines represent adjusted fledgling per breeding pair estimates for outside survey crews to account for known nests, and thus breeding pairs, not detected by outside monitoring crews (see Fig. 2).

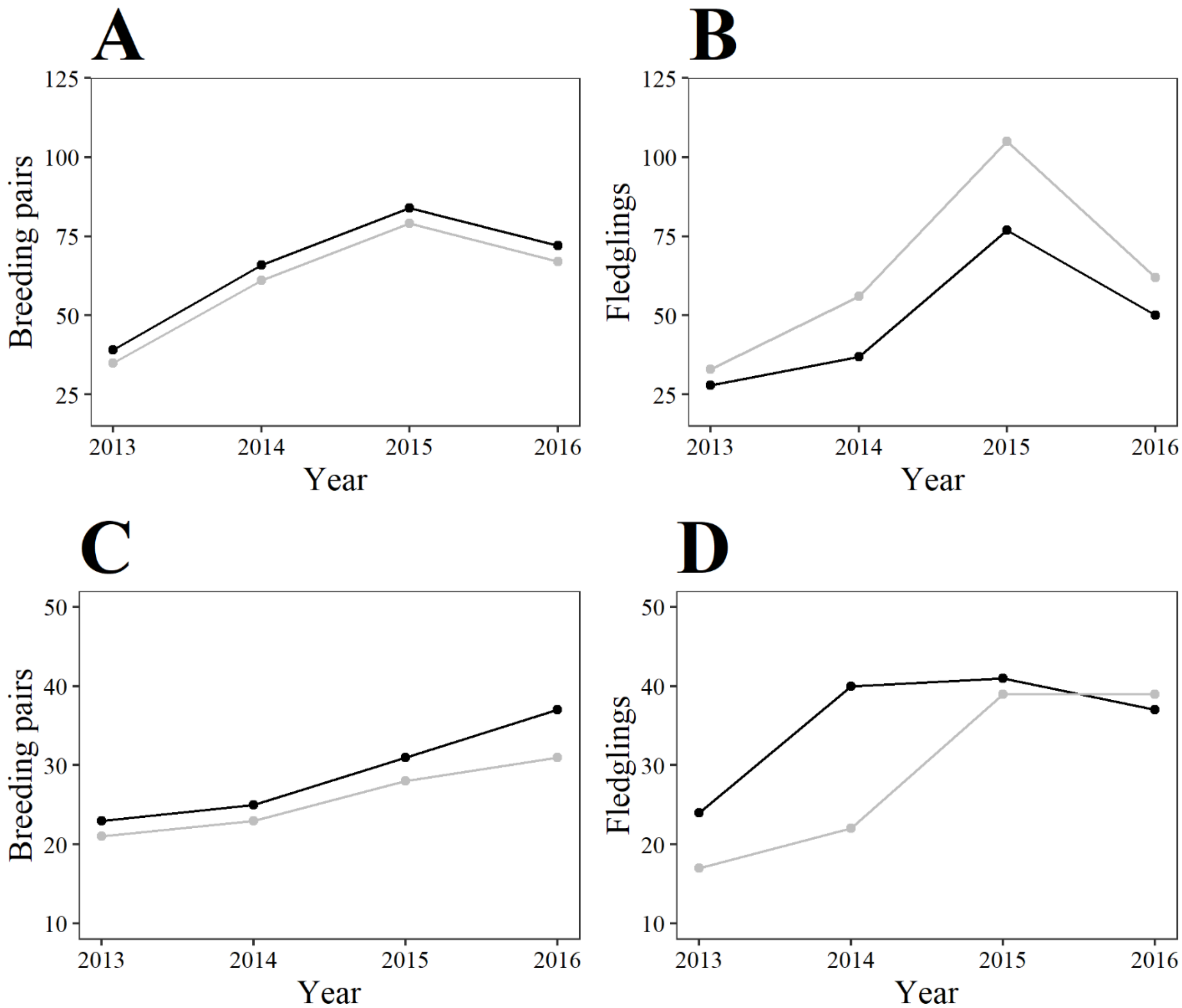
Figure 4. Estimated nesting- (nest) and brood-rearing (brood) period survival rates, with 95% confidence intervals, obtained by monitoring from inside (black line) and outside (dashed line) the nesting colony for Interior Least Tern (LETE) and Piping Plover (PIPL).

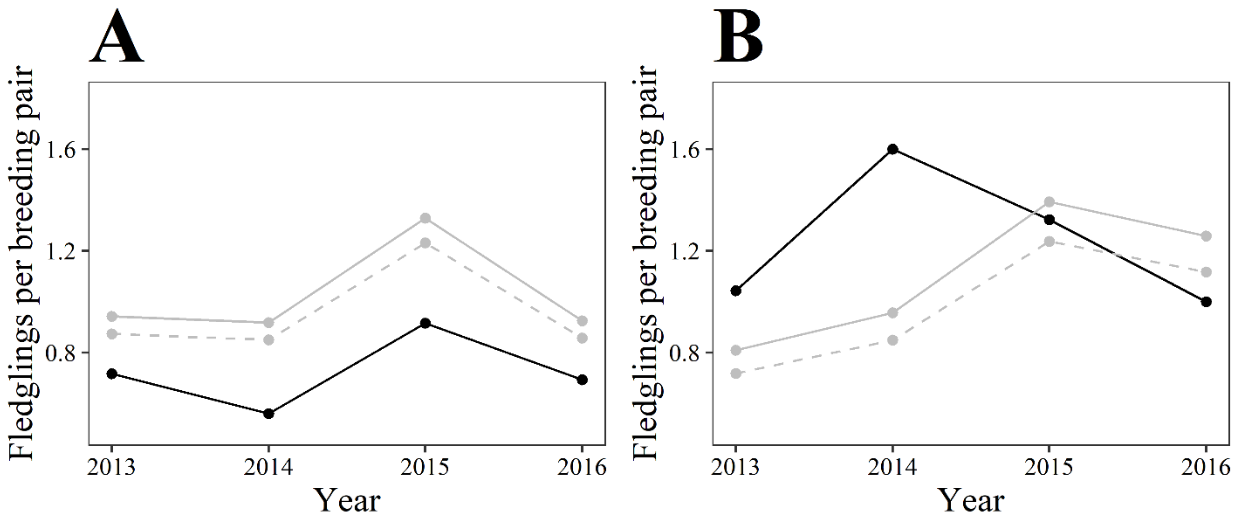
Figure 5. Estimated annual nesting- (nest) and brood-rearing (brood) period survival rates, with 95% confidence intervals, obtained by monitoring from inside (black line) and outside (dashed line) the nesting colony for Interior Least Tern (LETE; A, B) and Piping Plover (PIPL; C, D).

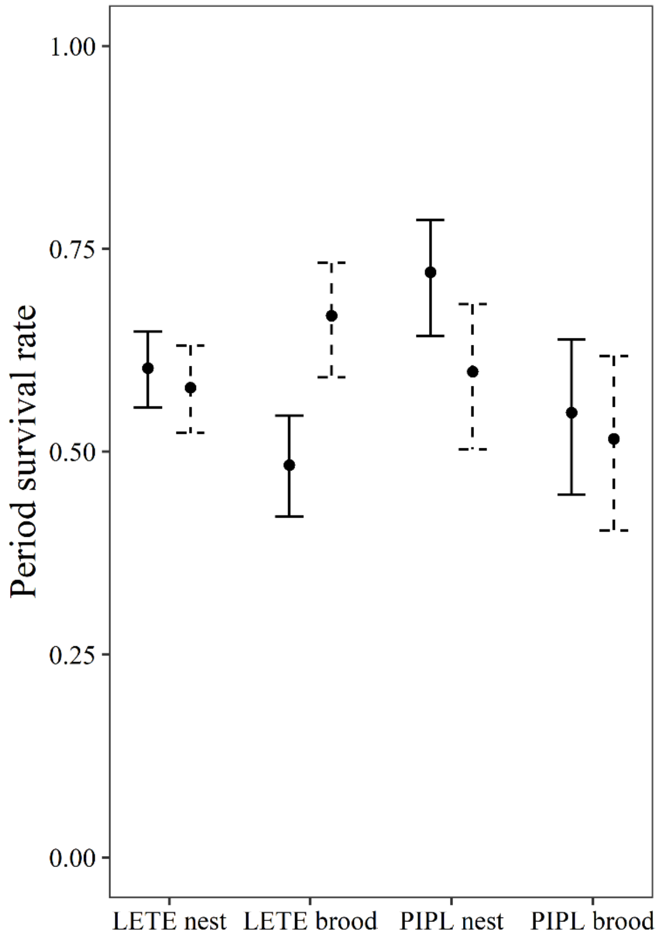


Nance
Custer
Sherman
Howard
Middle Loup R.
Merrick
Chapman
Grand Island
Hall
Leaman
Dawson
Buffalo
Hamilton
Lexington
Lexington
Cottonwood
Blue Hole
Platte R.
Kearney
Newark West
Dyer
Johnson
Broadfoot South
Gosper
Phelps
Kearney
Adams
Clay
Nebraska Location Map
Legend
Nesting Sites
City
River
County
0 2.5 5 10 15 20
Miles
0 2 4 8 12 16
Kilometers
Furnas
Harlan
Franklin
Webster
Little Blue R.
Nuckolls
PLATTE RIVER
RECOVERY IMPLEMENTATION PROGRAM

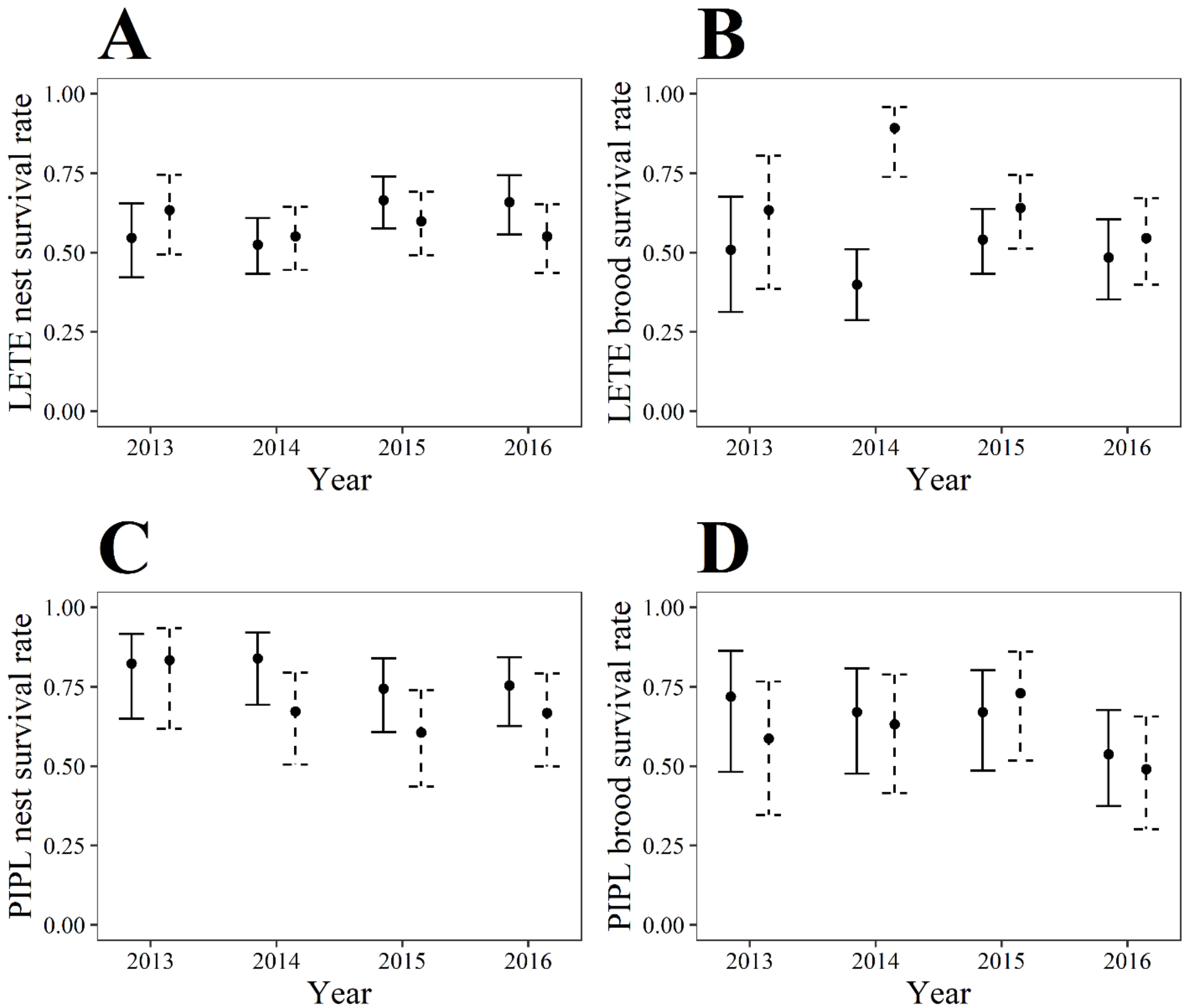
515


A
B
C
D
Breeding pairs
Fledglings
125
100
75
50
25
10
20
30
40
2013
2014
2015
2016
Year


A
B
Fledglings per breeding pair
Year
0.8
1.2
1.6
2013
2014
2015
2016



Period survival rate
1.00
0.75
0.50
0.25
0.00
LETE nest
LETE brood
PIPL nest
PIPL brood


A
LETE nest survival rate
1.00
0.75
0.50
0.25
0.00
2013
2014
2015
2016
Year
B
LETE brood survival rate
1.00
0.75
0.50
0.25
0.00
2013
2014
2015
2016
Year
C
PIPL nest survival rate
1.00
0.75
0.50
0.25
0.00
2013
2014
2015
2016
Year
D
PIPL brood survival rate
1.00
0.75
0.50
0.25
0.00
2013
2014
2015
2016
Year