J. Field Ornithol. 77(2):184–194, 2006 DOI: 10.1111/j.1557-9263.2006.00040.x

Effect of floating nest platforms on the breeding performance of Black Terns

David A. Shealer,[1] Joshua M. Buzzell, and Jonathan P. Heiar

Department of Biology, Loras College, 1450 Alta Vista, Dubuque, Iowa 52004, USA

Received 22 March 2005; accepted 27 July 2005

ABSTRACT. In 2003 and 2004, we placed 41 floating nest platforms on Grassy Lake in southeastern Wisconsin (USA) to test the hypothesis that reproductive success of Black Terns (*Chlidonias niger*) is limited by the quality of suitable nesting habitat. Extreme differences in water levels between these 2 yr provided a natural experiment to evaluate the effectiveness of the nest platforms during a drought year (2003) when natural nesting substrate was abundant, and a flood year (2004) when natural substrate was limited during the peak nesting period. Terns nested on 27 of 41 (66%) of the platforms in 2003 and 26 of 41 (63%) in 2004. No difference in the occupancy rate of platforms and natural nests was evident in 2003, but the pattern of clutch initiations early in the season in 2004 indicated that platforms were preferred over natural substrates. In 2003, nest survival rates did not differ between nests placed on platforms and those placed on natural substrates, but platform nests had significantly higher hatching success and nest survival rates in 2004. Both the Kaplan-Meier and Apparent Nest Success methods of calculating nest survival provided similar estimates. In both years, eggs laid on platforms were significantly larger than those laid on natural substrates, suggesting that platforms were occupied by high-quality birds. Our study indicates that floating nest platforms can be an effective management tool to enhance nesting habitat for Black Terns and other aquatic birds that construct floating nests, primarily because platforms provide nest sites when natural sites are not available due to flooding. Nest platforms also may be useful for addressing questions concerning habitat selection and parental quality.

SINOPSIS. **Efecto de plataformas artificiales para anidar en el desempeño reproductivo de *Chlidonias níger***

De 2003-2004 colocamos 41 plataformas flotantes para poner aprueba la hipótesis que el éxito reproductivo de la gaviota *Chlidonias níger*, esta limitado por la calidad y lo apropiado del hábitat de anidamiento. El estudio se llevó a cabo en el Grassy Lake, Wisconsin. Extremos (bajos y altos) en los niveles de agua, causados por sequía (2203) y fuertes lluvias (2004) proveyeron el escenario adecuado para evaluar la efectividad de las plataformas. Las gaviotas anidaron en 27 (66%) de las 41 plataformas en el 2003 y en 26 (63%) de las 41 en el 2004. No se encontraron diferencias en la tasa de uso de las plataformas y áreas naturales en el 2003, pero el inicio de las camadas temprano en la temporada durante el 2004, dieron a indicar que las plataformas fueron preferidas a los lugares naturales. Durante el 2003, no hubo diferencia en la tasa de supervivencia de nidos en plataformas y o en áreas naturales. Sin embargo, durante el 2004 el éxito de eclosionamiento, de los nidos y la supervivencia fue mas alto en las plataformas. Tanto el método Kaplan-Meier como el "Aparente Éxito de Anidamiento", utilizados para calcular la supervivencia de los nidos, ofrecieron resultados similares. En ambos años el tamaño de los huevos fue mayor en las plataformas que en áreas naturales, lo que implica que las primeras fueron utilizadas por aves sumamente vigorosas o de alta calidad. El estudio indica que las plataformas flotantes pueden ser una herramienta de manejo adecuada para mejorar el hábitat de anidamiento de la gaviota estudiada, al igual que otras aves que construyen nidos flotantes. Las plataformas proveen de lugares de anidamientos cuando no hay disponible lugares naturales debido a inundaciones. Las plataformas de anidamiento muy bien pudieran proveer de información útil con respecto a la selección de hábitat y la calidad del cuidado parental.

Key words: artificial nest, Black Tern, *Chlidonias niger*, habitat selection, nest platform, nest survival, reproductive success, supplemental habitat

The Black Tern (*Chlidonias niger*) is a fairly common summer resident in wetlands of the Upper Midwest region of the United States and in the prairie provinces of Canada. However, breeding populations in these regions have declined approximately 70% over the past century (Dunn and Agro 1995), most likely due to extensive loss of wetland habitat (Dahl 1990). In Wisconsin, the Black Tern is classified as a species of special concern (Shuford 1999), and trend analysis based on data from the North American Breeding Bird Survey indicates a 4.3% annual decline between 1966 and 2003 (Sauer et al. 2004). Although not significantly different

---

[1] Corresponding author. Email: david.shealer@loras.edu

from zero ($P = 0.08$), this trend is supported by roadside surveys conducted by the Wisconsin Department of Natural Resources (WDNR) from 1979 to 1982 and from 1995 to 1997 that revealed statewide declines of up to 60% in the breeding population between survey periods (Matteson and Mossman 2000).

Although WDNR survey data indicated an apparent overall increase of about 20% in the breeding population between survey periods, the average number of breeding sites in Columbia County declined from 10 to 5 and about 70% of the total number of breeders were restricted to one colony at Grassy Lake (Matteson and Mossman 2000). Despite its apparent regional importance as a breeding site for Black Terns, Grassy Lake appears to be either an "attractive sink" (Delibes et al. 2001) or an ecological trap (Kristan 2003, Battin 2004). Three factors suggest that the colony is not self-sustaining: Nest success is chronically poor (Shealer 2002), apparent adult survival is low, and no fledglings from Grassy Lake have ever been recaptured there as breeding adults (Shealer 2003, unpubl. data). Poor reproductive performance at Grassy Lake is due mainly to a lack of suitable nesting substrate. Terns nest in the exposed middle portion of the lake, and nest loss due to storms and rapid water-level fluctuations (Cuthbert 1954, Bergman et al. 1970, Gilbert and Servello 2005) can be catastrophic in some years.

Floating nest platforms have been used as a management tool for a variety of aquatic birds (Techlow and Linde 1983, Lampman et al. 1996, Hancock 2000, Piper et al. 2002), and about half the breeding population of Black Terns in the Netherlands and Germany relies annually on nesting platforms (van der Winden et al. 1996, Beintema 1997). We installed floating nest platforms on Grassy Lake in 2003 and 2004, and then monitored the nesting phenology of the birds and compared measures of breeding performance each year between pairs that nested on the platforms and those that used natural substrates. Differences in water levels between 2003 and 2004 provided a natural experiment that also enabled us to compare the effectiveness of the nest platforms between a drought year when natural nesting substrate was abundant to a flood year in which it was scarce.

METHODS

Fieldwork was conducted from 10 May to 24 July 2003 and from 10 May to 11 August 2004 at Grassy Lake (43°20′N, 89°09–10′W) in Columbia County, Wisconsin. Grassy Lake (65 ha) is a shallow (0.5–1.5 m), unmanaged permanent wetland surrounded by agricultural land in the southeastern part of the state. The dominant rooted aquatic vegetation provides nesting substrate for Black Terns on the lake and consists of pond lily (*Nymphaea odorata*), spatterdock (*Nuphar polysepala*), water-shield (*Brasenia schreberi*), and bulrushes (*Scirpus* spp.). A cattail (*Typha* spp.) marsh borders the southwestern edge of the lake, but, except for floating rootstock that drifted into the lake, terns did not nest among the cattails during our study.

Nest platform construction and placement. Floating nest platforms (46 cm^2) were constructed by sandwiching blocks of polystyrene (4 cm thick) between two pieces of treated plywood (each 1.3 cm thick). A jigsaw was used to cut a 30-cm^2 opening, centered through the top piece of plywood and the polystyrene, and plastic hardware cloth (1.3 cm mesh) was stretched between the top and middle layers. The platforms were then fastened together with toggle bolts (10 cm). A 30-cm^2 piece of green outdoor carpet was fitted over the exposed hardware cloth to provide a natural looking substrate. Holes were drilled through the carpet and gaps were created in each corner of the platform to provide drainage during heavy rains or overwash by waves. Platforms were anchored in place on the lake surface by embedding PVC pipes (3 m long, 1.3 cm diam.) into the lake bottom after passing them through a metal pipe bracket fastened to each platform. The pole served as a guide rail that enabled the platform to rise and fall with changes in water depth. A PVC T-joint was placed on top of each pole to provide a perch site (blueprints for the platform design are available from the senior author).

In 2003 and 2004, platforms were placed in the lake on 10 May before terns began nesting, and each platform was field tested for buoyancy and structural integrity at that time. Platforms were spaced 10–15 m apart in clusters of 5–10, as recommended by Rabenold (1988), to accommodate the tendency of Black Terns to nest semicolonially (Dunn and Agro 1995). At the time of platform placement, the lake was devoid of emergent vegetation, so our decisions about where to install them were based largely on the spatial distribution of nests the previous year. Platforms were numbered and Universal Transverse Mercator (UTM) coordinates (to the nearest 0.01″) were recorded for each platform using a PLGR+96 receiver (Rockwell-Collins Cedar Rapids, IA, USA.). Each platform was positioned in the same location during both years of the study.

Field protocols. Nest searches were begun on 14 May 2003 and 20 May 2004. Searches were conducted 2–3 times per week throughout the season (23 total visits in 2003 and 17 in 2004). During each visit, water depth was recorded at a single location in the center of the lake, all platforms were checked for nesting activity, and the entire lake was surveyed by canoe to locate new nests on natural substrates. Information recorded at each nest included nest number, UTM coordinates, type of substrate, clutch size, egg dimensions (length and maximum breadth), egg mass (to nearest 0.1 g), and relative stage of incubation by flotation of eggs (Westerkov 1950, Dunn 1979). Egg flotation enabled us to schedule our visits to each nest to determine hatching success and to band all chicks that hatched.

Eggs were numbered with a nontoxic permanent marker to determine hatching order. The laying date of each egg that hatched was estimated by subtracting 23 d from the known or estimated hatching date. This duration represented the average interval for eggs of known incubation duration over the study period. For eggs that failed to hatch, laying date was estimated by one of the two methods. If the nest was found with an incomplete clutch (1–2 eggs) during the laying interval, 1 d was subtracted for each egg in the clutch. If the nest was first found with a complete clutch, the difference between the mass of the egg on the day it was found and its estimated fresh mass, calculated from linear dimensions (LB^2k_m, where L and B are length and breadth in cm, and k_m is a species-specific mass constant [Hoyt 1979]) was divided by the average daily mass loss (0.07 g; Shealer, unpubl. data). The quotient was the estimated age (in d) of the egg when first found. A sample of 51 freshly laid eggs measured in 1999 and 2000 gave a k_m of 0.52, with no significant difference between first-, second-, and third-laid eggs (Kruskal-Wallis $\chi^2_2 = 2.18$, $P = 0.34$). Analysis of covariance (ANCOVA) was used to examine sources of variation in the estimated fresh mass of eggs. Explanatory variables included the main effects of year (2003, 2004), nest type (platform, natural), a year × nest type interaction term, and the covariate laying date.

All nests were checked periodically throughout the incubation period, but each was visited between 20 and 24 d of incubation to determine nest survival during the incubation period and to record hatching success. All chicks, when first found, were banded with incoloy USGS leg bands. Enclosures were placed around most nests to monitor chick growth and survival. Enclosures were constructed of wire-mesh poultry fencing (25 cm high, 70–80 cm diameter) for natural nests, and wooden barriers (8 cm high, 30 cm^2) for nests on artificial platforms. In 2003, the wooden barriers failed to retain chicks for more than 3–5 d, so wire fences were fastened to the PVC poles to confine the chicks for a longer time in 2004. Chicks were weighed and their condition was assessed during each visit to the nest. Enclosures were removed from each nest when the youngest surviving chick in the brood had reached 30 g (ca. 6 d of age). Chicks were weighed when encountered opportunistically after this time. Growth performance of chicks was assessed by examining linear growth rate (LGR), defined as the mostly linear portion of the growth curve when chicks are growing most rapidly (2–11 d after hatching; Dunn and Agro 1995; Shealer, unpubl. data). LGR was calculated only for chicks with at least three measurements during this interval.

Nest survival analysis. We used Kaplan-Meier product-limit survival analysis (Kaplan and Meier 1958) to estimate survival probability of nests. This procedure is described clearly by Pollock et al. (1989) and more recently by Nur et al. (2004). The Kaplan–Meier estimator is unbiased and does not require many of the restrictive assumptions (summarized by Jehle et al. 2004) of the traditional Mayfield method (Mayfield 1961 1975) for estimating nest survival probability. The time variable used was days after the first egg was laid, and we used both known and estimated dates of clutch initiation to compute nest survival. We tested for overall differences in the survival function between years and substrate types (natural, platform) using log-rank tests. We used the Cox proportional hazards model (Marubini and Valsecchi 1995) to estimate the hazard rate ratio, *h*, between nests on platforms and those on natural substrates for the 2 yr combined. We also used the Cox model to test for differences in nest survival as a function of three independent variables: year, nest substrate (natural, platform), and date of nest initiation (early, late). We used 15 June as the cutoff point between early and late nests, except in cases where the original pair failed early and produced a second clutch at the same nest site before 15 June.

We examined two point estimates generated by the Kaplan–Meier survival function that corresponded to two benchmarks in the nesting period: nest survival to day 24 (an index of hatching success), which represented the average interval from the laying of the first egg to the hatching of the last chick, and nest survival to day 36 (nest success), which represented chick survival to about 12 d post-hatch, the approximate age when chicks first attain adult mass (Dunn 1979). We compared these estimates to our subjective assessments of nest fates using the apparent nest success (ANS) estimator, defined as the number of successful nests (see below) divided by the total number of nests found. Although the ANS estimator has long been recognized as biased (Mayfield 1961, Hensler and Nichols 1981), Johnson and Shaffer (1990) enumerated several circumstances where this method was preferred over the Mayfield estimator. Because several of these conditions seemed to apply to our study system, and because the Kaplan–Meier method produces nest survival estimates only for a particular time interval (and not for an event such as hatching that can occur over varying time intervals), we were interested in determining the degree of concordance between the two estimates. For the ANS method, a nest was considered to have hatched if at least one chick, either alive or dead, was found at the nest site. When no chicks were found at or near the nest site around the expected day of hatching, we used certain criteria (e.g., fresh guano around the nest, presence of replacement nests nearby, or aggressive adults overhead) to make a subjective determination regarding the fate of the nest. A successful nest was defined as one in which at least one chick had reached day 12 on the last day it was encountered, it was growing normally (i.e., had not lost mass on the last day it was found), and it was not found dead later. Nests with undetermined fates were excluded from the analysis (in the Kaplan–Meier method they are treated as censoring variables) where appropriate.

RESULTS

Water depth and breeding population size. Water depth of Grassy Lake throughout the 2003–2004 breeding seasons is shown in Figure 1. In previous years, depth averaged 70–80 cm throughout the season (Shealer, unpubl. data), so water levels during the 2003 breeding season were consistently below this average. Consequently, these drought conditions exposed mudflats and enabled rooted aquatic vegetation to penetrate the lake surface, providing abundant natural nesting substrate for Black Terns in May and June.

In 2004, water depth was only slightly above the average level on 10 May, but the area was inundated by heavy rains, which caused flooding in May and early June. During one 24-h period in mid-May, the area received over 20 cm of rain, which resulted in a 30-cm increase in water depth over a 1-week period (Fig. 1). High water levels were maintained throughout the season, which, compared to 2003, greatly reduced the amount and quality of natural substrate available to prospecting terns at Grassy Lake.

Despite differences in water depth between the 2 yr, the total number of clutches initiated was similar (Table 1). The main difference was in the timing of clutch initiations. In 2003, over 80% of the clutches were begun before 15 June, a pattern consistent with the drought conditions and abundant availability of nesting substrate early in the season. In the flood year of 2004, however, more than twice as many late nests were recorded than in 2003. Late nests comprised unknown fractions of replacement nests by pairs that failed during the early period and pairs that delayed their initial nesting attempt because of high water.

Terns laid 29 clutches of eggs on 27 of 41 (66%) platforms in 2003 and 27 clutches on 26 of 41 (63%) platforms in 2004, which represented about a third of all nest starts in each year. Egg laying commenced on 23 May 2003 and 24 May 2004, respectively, and although the first clutches were laid on natural substrates, nest platforms were used extensively in both years by early nesting terns (Table 1). This tendency was

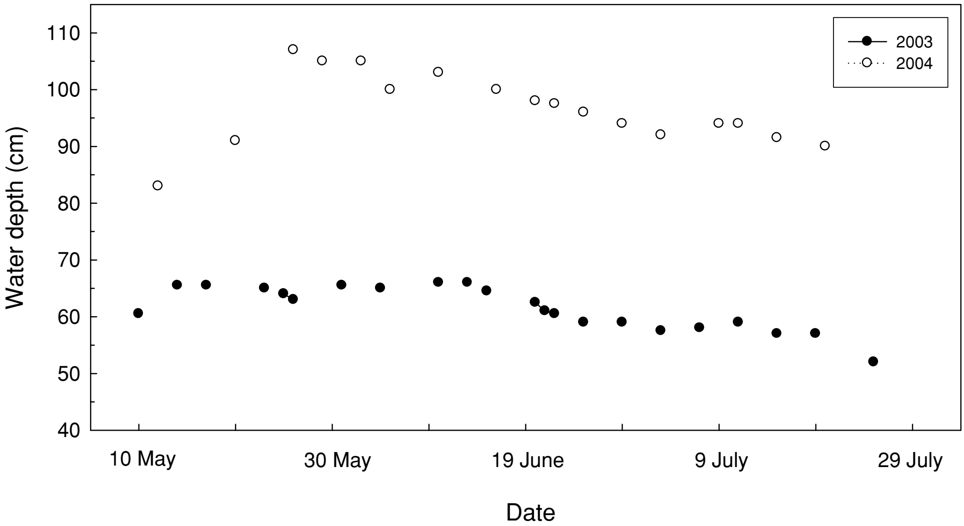

Fig. 1. Water depth throughout the breeding season of Black Terns at Grassy Lake during the drought year of 2003 and the flood year of 2004.

more pronounced in the flood year of 2004 than in 2003 (Fig. 2). Logistic regression indicated that the tendency of terns to initiate clutches on platforms instead of natural substrates was constant throughout the 2003 breeding season (log likelihood = 0.09, $\chi^2_1 = 0.19$, $P = 0.66$), but in 2004 declined significantly (log likelihood = 2.02, $\chi^2_1 = 4.04$, $P = 0.045$) by 3.8% per day, consistent with the gradual increase in availability of natural substrates later in the season. Despite this apparent limitation of breeding habitat, however, the overall proportion of nesting pairs that used platforms was similar between 2003 (0.345) and 2004 (0.342).

Clutch sizes ranged from 1 to 5 eggs in both years of the study. Modal clutch size in each year was 3. Clutch size distributions (1–2 eggs versus 3 or more) did not differ significantly between years ($\chi^2_1 = 0.69$, $P = 0.40$) or between type of nest substrate (natural or platform, $\chi^2_1 = 1.41$, $P = 0.24$). However, late clutches were smaller on average than early clutches in both years, with the difference more pronounced in 2003 (Table 1).

The ANCOVA model explaining variation in fresh egg mass ($F_{4,392} = 3.26$, $P = 0.012$) revealed a significant difference between platform nests and natural nests ($P = 0.001$), with eggs on platforms significantly larger (10.71 ± 0.81 [SD]) than those laid on natural substrates (10.45 ± 0.74 g). Neither the year effect, the year × nest type interaction term, nor the

Table 1. Number of clutch initiations on platforms and natural substrates, clutch sizes, and Kaplan–Meier estimates of nest survival to day 24 for Black Terns nesting at Grassy Lake, southeastern Wisconsin, 2003–2004.

	No. clutches initiated		Clutch size (x ± SD)		Nest survival Kaplan–Meier estimate ± SE (N)	
Year	Early	Late	Early nests	Late nests	Early nests	Late nests
2003						
Total	71	13	2.77 ± 0.62	2.08 ± 0.90	0.677 ± 0.057 (70)	0.375 ± 0.171 (8)
Platform	24	5				
Natural	47	8				
2004						
Total	47	32	2.77 ± 0.68	2.55 ± 0.57	0.543 ± 0.074 (46)	0.398 ± 0.104 (32)
Platform	19	8				
Natural	28	24				

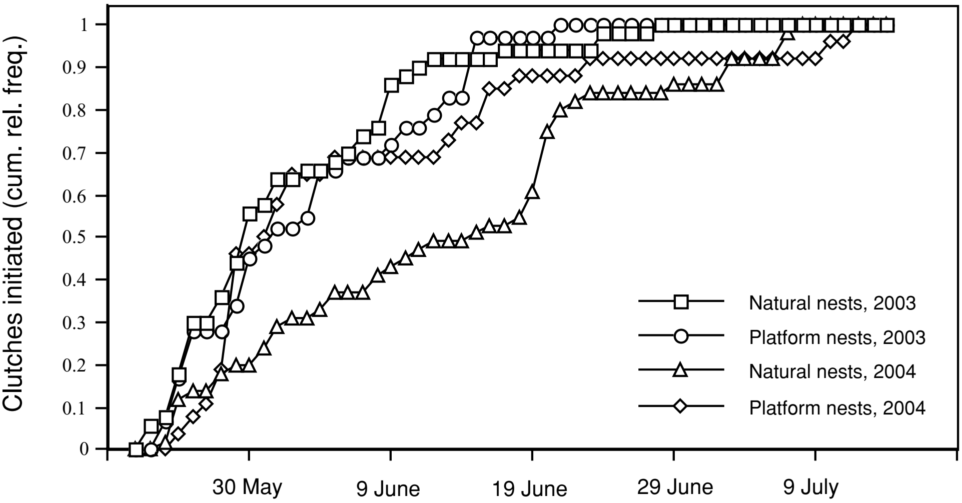

Fig. 2. Cumulative relative frequency of clutch initiations by Black Terns nesting on artificial nest platforms and on natural substrates, 2003–2004. Note the delay in use of natural substrates during the flood year of 2004.

covariate (laying date) was significant (all $P >$ 0.10). The laying order was known for only a fraction of the eggs, which precluded adding this term to the ANCOVA model. However, for eggs of known laying order ($N = 118$), there was no significant difference in mass for eggs laid first, second, or third and higher in a clutch ($F_{2,115} =$ 0.75, $P = 0.48$).

Nest success estimates. Kaplan–Meier nest survival functions for 2003 and 2004 are shown in Figure 3. In 2003, there was no significant difference in survival probability between nests on platforms and those on natural substrates (log-rank test, likelihood ratio $\chi^2_1 =$ 1.34, $P = 0.25$), despite a tendency for survival probability to be slightly higher among nests on natural substrates throughout the nesting period. The survival function differed significantly (likelihood ratio $\chi^2_1 = 5.10$, $P = 0.024$) between the two nest types in 2004, with nests on platforms having a higher survival probability than nests on natural substrates after about day 10 of incubation and continuing through the nesting period.

The results of the Cox proportional hazards regression for the effects of nest type (natural substrate or platform) on nest survival gave an estimated risk (failure rate) ratio of 0.91 (95% CI: 0.72–1.13), meaning that nests on platforms were about 90% as likely to fail per day than those on natural substrates. This estimate did not, however, differ significantly from equality (likelihood ratio $\chi^2_1 = 0.74$, $P = 0.39$). The Cox model that included year, nest type (platform nest or natural substrate), clutch initiation date (early or late), and a year × nest type interaction was significantly different from the null model ($\chi^2_3 = 11.99$, $P = 0.018$), but only the interaction term was significant ($P =$ 0.027). Thus, nesting platforms were associated with enhanced nest survival in 2004, but not in 2003.

Hatching success estimates ranged from 60% to 70%, except for natural nests in 2004 for which the estimate was 50% lower. Comparisons between the ANS estimator and the Kaplan–Meier method were nearly identical (Table 2), with no clear under- or overestimate bias. Both methods indicated that hatching success (or nest survival to day 24) differed significantly ($P <$ 0.05) between nests on platforms and those on natural substrates only in 2004. Hatching success, as indexed by the Kaplan–Meier survival function, was numerically higher for early nests than late nests but did not differ significantly among the two periods in either 2003 ($t_{76} =$ 1.70) or 2004 ($t_{76} = 1.17$, $P > 0.05$ for both years).

Chick growth and survival. The ANCOVA model for variation in LGRs of

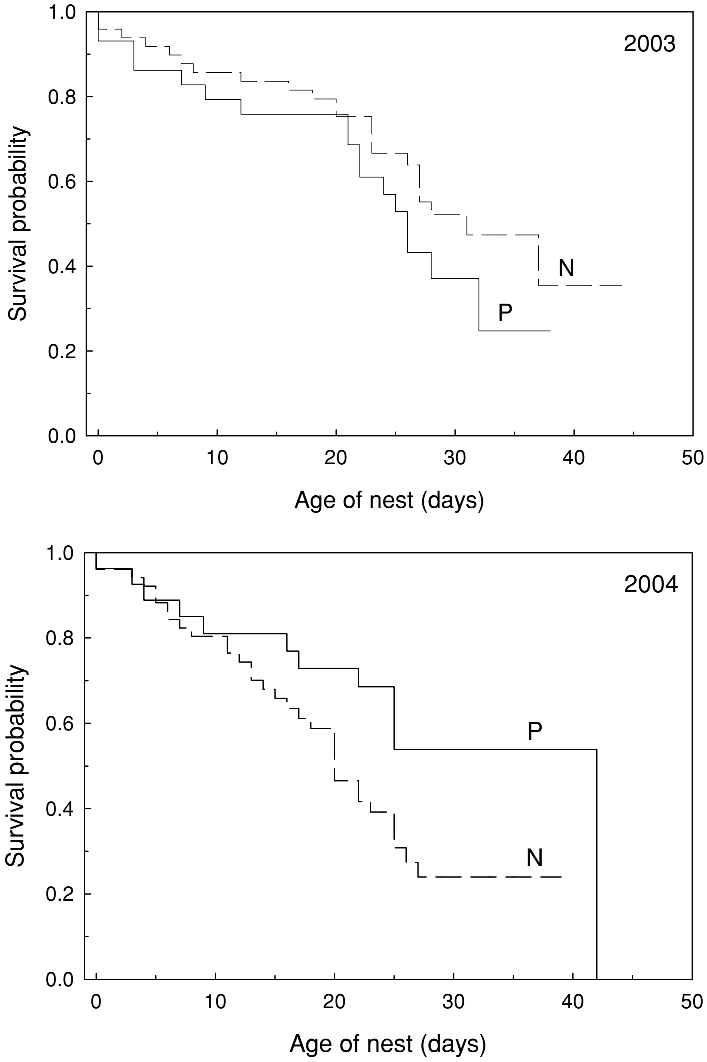

Fig. 3. Kaplan–Meier survival curves for Black Tern nests on artificial nest platforms (P) and natural substrates (N) at Grassy Lake, 2003–2004. Overall nest survival was significantly higher among platform nests in 2004, but not in 2003. Vertical line at day 42 in 2004 indicates true fledging age and not nest failure.

chicks ($F_{5,42} = 2.89$, $P = 0.025$) indicated that growth differed significantly between years ($F_{1,42} = 6.63$, $P = 0.014$), with growth performance in 2004 better than in 2003 (Table 3). However, neither of the other main effects in the model (substrate type, hatch order), the covariate (hatch date), nor any of the interactions was significant (all $P > 0.1$).

Estimates of chick survival to day 12 were low for both years, and differed significantly between natural nests and platform nests only in 2004 (Table 2). Comparisons between the ANS and Kaplan–Meier methods again were similar, but the ANS method produced consistent underestimates ranging from 3% to 9%. Although both estimators indicated higher survival of chicks reared on platforms in 2004, the proportion of banded chicks reencountered at >12 d (Table 2) did not differ between those reared on platforms and those on natural substrates in either year (2003: $\chi^2_1 = 1.47$, $P = 0.23$; 2004: $\chi^2_1 = 0.02$, $P = 0.88$).

Table 2. Comparison of measures of nesting success for Black Terns at Grassy Lake in southeastern Wisconsin, 2003–2004. Given are estimates of apparent success and Kaplan–Meier estimates (with 95% CI), the total number of chicks banded, and the number of chicks reencountered at ≥12 d of age. Asterisks (*) indicate significant ($P < 0.05$) within-year differences between nests on platforms and natural substrates.

Year	Nest type	No. nests	Hatching success: Apparent nest success	Hatching success: Kaplan–Meier estimate	Chick survival (day 12): Apparent nest success	Chick survival (day 12): Kaplan–Meier estimate	No. chicks encountered (≥12 d)
2003							
	Platform	26	0.615 (0.429–0.801)	0.610 (0.429–0.791)	0.192 (0.041–0.343)	0.247 (0.008–0.486)	26 (5)
	Natural	53	0.698 (0.529–0.867)	0.667 (0.533–0.801)	0.283 (0.161–0.405)	0.355 (0.119–0.591)	66 (23)
2004							
	Platform	27	0.708 (0.536–0.880)*	0.686 (0.505–0.867)*	0.450 (0.262–0.638)*	0.539 (0.334–0.744)*	27 (9)
	Natural	51	0.333 (0.204–0.462)	0.392 (0.247–0.537)	0.214 (0.101–0.327)	0.240 (0.102–0.378)	31 (12)

Causes of nest failure. Causes of nest failure included abandonment, infertility, eggs that had rolled out of the nest, drowned chicks, predation, and weather-related losses (Table 4). Nest failure due to weather (storms and flooding) was clearly the single most important assigned cause in both years, particularly during the high-water season of 2004. With one exception, however, all weather-related losses were restricted to nests on natural substrates. Causes of failure to nests on platforms were evenly distributed in both years, with predation being highest in 2003 and abandonment highest in 2004.

DISCUSSION

Nest platforms versus natural substrates. Our 2-yr study supports the hypothesis that the quality of available nesting habitat limits reproductive success of Black Terns at Grassy Lake. In 2003, when drought conditions created abundant natural nesting habitat for terns, breeding performance of terns nesting on platforms was equal to that of terns using natural substrates. However, during the flood year of 2004, platform nests were occupied earlier (Fig. 2) and had greater hatching success (Table 2) and a higher overall survival probability (Fig. 3) than natural nests. In fact, the hatching success estimates generated from the platform nests in 2003 and 2004 are among the highest reported for Black Terns in North America (Dunn and Agro 1995) and compare favorably to an earlier study that compared hatching success between nests on artificial platforms (0.652) and those on natural substrates (0.443) along the Upper Mississippi River (Faber 1996). Hatching success of platform nests was consistent between the 2 yr. In contrast, success of nests on natural substrates varied predictably with environmental conditions, suggesting that this technique may be an effective management tool for Black Terns in areas prone to flooding such as river edges or unmanaged wetlands (Gilbert and Servello 2005).

Because floating platforms have been successful in improving reproductive success of aquatic birds such as loons (Hancock 2000, Piper et al. 2002) and other species of terns (Techlow and Linde 1983, Dunlop et al. 1991, Lampman et al. 1996), the technique would appear to have general applicability to a variety of wetland-dependent species. However,

Table 3. Linear growth rates of Black Tern nestlings reared on artificial platforms and on natural substrates at Grassy Lake, 2003–2004. Sample size (no. chicks) given in parentheses.

	Linear growth rate (g d^{-1})[a]		
Nest type	2003	2004	Combined years
Platform	4.66 ± 0.98 (5)	4.66 ± 0.76 (10)	4.66 ± 0.81 (15)
Natural	4.00 ± 0.92 (25)	5.03 ± 0.48 (10)	4.29 ± 0.94 (35)
Combined nest types	4.11 ± 0.95 (30)	4.84 ± 0.65 (20)	

[a] Mean ± 1 SD.

use of nest platforms by Black Terns in other areas has been sporadic. In the Netherlands, platforms are an important component of the overall management of Black Terns, and about 50% of the breeding population nests exclusively on them (van der Winden et al. 1996). Conversely, nest platforms installed at established breeding sites in Indiana (Rabenold 1988) and Ontario (Weseloh et al. 1996) were ignored by prospecting terns. Such results suggest that Black Terns will nest on platforms at established sites where natural substrate is limited in availability or of poor quality, but will largely ignore artificial structures at sites where nesting habitat is abundant (Rabenold 1988, Hands et al. 1989).

We identified Grassy Lake as a candidate wetland for the platform study only after four seasons of work at several colony sites in southeastern Wisconsin. Grassy Lake was deemed most appropriate because of its persistent use by terns, despite chronically poor reproductive success that we attributed to sparse vegetative cover on the lake rather than predation. At most other sites, we were concerned that nesting platforms would attract predators. In particular, we were concerned that the PVC poles and perch sites erected at each nesting platform would provide hunting sites for raptors. In two seasons prior to the nest platform study, however, the only known predator of Black Terns identified at Grassy Lake was mink (*Mustela vison*). Mink are attracted to floating rafts, and rafts have been used in England to monitor mink populations and to control them by trapping (Reynolds et al. 2004). The effects of mink predation on bird colonies can be devastating and can cause large-scale abandonment (Craik 1997), and we suspect that mink predation was partly responsible for the low estimates of chick survival and low reencounter frequency of chicks once they left the nest (Table 2). However, we found no evidence of mink predation during the incubation and early chick-rearing periods, when platforms were expected to be most effective. Nest losses attributed to predation and abandonment were lower for platform nests compared to those on natural substrates (Table 4). We occasionally observed turtles using some platforms as basking sites and found fresh cuttings of marsh vegetation by muskrats (*Odontra zibethecus*) on others. Muskrats and turtles may have been responsible for eggs rolling off the platforms, but we suspect that any egg losses due to turtles and muskrats were similar to those on natural substrates.

The total number of clutches initiated at Grassy Lake in 2003 ($N = 84$) and 2004 ($N = 79$) was higher than the number of nests recorded in 2001 ($N = 45$) and 2002 ($N = 52$, Shealer 2002). The number of clutches found on the platforms ($N = 29$) in 2003 accounts for the difference between 2002 and 2003, suggesting that the size of the breeding population at

Table 4. Assigned causes of nest failure among Black Terns nesting on floating platforms and those using natural substrates at Grassy Lake, 2003–2004.

	2003		2004	
Cause of failure	Platform (%)	Natural (%)	Platform (%)	Natural (%)
Weather related	1 (7.7)	8 (40.0)	0 (0.0)	15 (51.7)
Predation	5 (38.4)	6 (30.0)	2 (22.2)	6 (20.7)
Abandoned	0 (0.0)	4 (20.0)	5 (55.5)	3 (10.3)
Egg/chick death	3 (23.1)	0 (0.0)	2 (22.2)	4 (13.8)
Eggs rolled from nest	4 (30.8)	2 (10.0)	0 (0.0)	1 (3.4)

Grassy Lake is limited by availability of breeding habitat and that the addition of the nest platforms in 2003 allowed more birds to breed there than would have otherwise. However, alternative explanations for the population increase have not been explored fully, so this interpretation is tentative. Lacking in particular is a clear understanding of why the size of the breeding population remained stable between 2003 and 2004 despite differences in the availability of natural nesting substrate and why there was no compensatory use of nest platforms in 2004.

Two results from our study suggest that platforms were occupied by high-quality individuals. Eggs laid on platforms were significantly larger than eggs laid on natural substrates both in 2003 and 2004, and early season clutch initiations in 2004 progressed at a higher rate on platforms compared to natural substrates. Chick growth rates did not differ between the two nest types in either year, but sample sizes were small. By the end of the 2004 season, a substantial fraction of the breeding population had been color-banded and this should enable us to address questions pertaining to habitat selection and parental quality in the future.

Comparison of nest survival estimates. Estimates of hatching success and chick survival derived from the ANS method were similar to those calculated from the unbiased Kaplan–Meier method, with point estimates differing by no more than 9%, and in most cases less than 5% (Table 2). The main criticism of the ANS method is that it tends to overestimate nest success (Hensler and Nichols 1981, Nur et al. 2004) because each nest is not adjusted according to its period of exposure to risk of failure (Mayfield 1961) and because successful nests have a higher probability of detection than failed nests (Jehle et al. 2004). However, as Johnson and Shaffer (1990) argued, the apparent estimator may be preferred when catastrophic nest losses occur (violating the assumption of constant daily survival probability) or when nests are easily visible or detectable, as is the case with Black Terns. Our results indicate a tendency to be conservative in our determination of nest fate when the nest was empty at the predicted time of hatching, as indicated by the consistent underestimates generated by the ANS method for chick survival to day 12 (Table 2), but the discrepancies all were minor. Our main conclusion, that nest platforms provide consistency in reproductive success of Black Terns, appears robust regardless of which estimator is used.

ACKNOWLEDGMENTS

We thank the U.S. Fish and Wildlife Service and the Wisconsin Department of Natural Resources for the permits and logistical support necessary to conduct our research on Black Terns at Grassy Lake and elsewhere. Funding for this project was provided by the U.S. Fish and Wildlife Service, the R.J. McElroy Trust (Iowa College Foundation), and Loras College. We gratefully acknowledge the thoughtful comments of the two referees, E. H. Dunn and W. Piper.

LITERATURE CITED

BATTIN, J. 2004. When good animals love bad habitats: ecological traps and the conservation of animal populations. Conservation Biology 18: 1482–1491.

BEINTEMA, A. J. 1997. European Black Terns (*Chlidonias niger*) in trouble: examples of dietary problems. Colonial Waterbirds 20: 558–565.

BERGMAN, R. D., P. SWAIN, AND M. W. WELLER. 1970. A comparative study of nesting Forster's and Black Terns. Wilson Bulletin 82: 435–444.

CRAIK, C. 1997. Long-term effects of North American mink *Mustela vison* on seabirds in western Scotland. Bird Study 44: 303–309.

CUTHBERT, N. L. 1954. A nesting study of the Black Tern in Michigan. Auk 71: 36–63.

DAHL, T. E. 1990. Wetlands losses in the United States, 1780s to 1980s. U.S. Fish and Wildlife Service, Washington, D.C.

DELIBES, M., P. GAONA, AND P. FERRERAS. 2001. Effects of an attractive sink leading into maladaptive habitat selection. American Naturalist 158: 277–285.

DUNLOP, C. L., H. BLOKPOEL, AND S. JARVIE. 1991. Nesting rafts as a management tool for a declining Common Tern (*Sterna hirundo*) colony. Colonial Waterbirds 14: 116–120.

DUNN, E. H. 1979. Nesting biology and development of young in Ontario Black Terns. Canadian Field-Naturalist 93: 276–281.

———, AND D. J. AGRO. 1995. Black Tern (*Chlidonias niger*). In: The Birds of North America, no. 147 (A. Poole, and F. Gill, eds.). Academy of Natural Sciences, Philadelphia, PA, and the American Ornithologists' Union, Washington, D.C.

FABER, R. A. 1996. Impacts of artificial nest platforms and water levels on hatching success in Black Terns (abstract). Colonial Waterbird Society Bulletin 20: 53.

GILBERT, A. T., AND F. A. SERVELLO. 2005. Water level dynamics in wetlands and nesting success of Black Terns in Maine. Waterbirds 28: 181–187.

HANCOCK, M. 2000. Artificial floating islands for nesting Black-throated Divers *Gavia arctica* in Scotland: construction, use and effect on breeding success. Bird Study 47: 165–175.

HANDS, H. M., R. D. DROBNEY, AND M. R. RYAN. 1989. Status of the Black Tern in the northcentral United States. U.S. Fish and Wildlife Service, St. Paul, MN.

HENLSER, G. L., AND J. D. NICHOLS. 1981. The Mayfield method of estimating nest success—a model, estimators and simulation results. Wilson Bulletin 93: 42–53.

HOYT, D. F. 1979. Practical methods of estimating volume and fresh weight of bird eggs. Auk 96: 73–77.

JEHLE, G., A. A. YACKEL ADAMS, J. A. SAVIDGE, AND S. K. SKAGEN. 2004. Nest survival estimation: a review of alternatives to the Mayfield estimator. Condor 106: 472–484.

JOHNSON, D. H., AND T. L. SHAFFER. 1990. Estimating nest success: when Mayfield wins. Auk 107: 595–600.

KAPLAN, E. L., AND P. MEIER. 1958. Nonparametric estimation from incomplete observations. Journal of the American Statistical Association 53: 457–481.

KRISTAN, W. B., III. 2003. The role of habitat selection behavior in population dynamics: source–sink systems and ecological traps. Oikos 103: 457–468.

LAMPMAN, K. P., M. E. TAYLOR, AND H. BLOKPOEL. 1996. Caspian Terns (*Sterna caspia*) breed successfully on a nesting raft. Colonial Waterbirds 19: 135–138.

MARUBINI, E., AND M. G. VALSECCHI. 1995. Analysing survival data from clinical trials and observational studies. John Wiley, Chichester, UK.

MATTESON, S. W., AND M. J. MOSSMAN. 2000. Changes in Wisconsin Black Tern populations, 1980–1997. U.S. Fish and Wildlife Service and Wisconsin Department of Natural Resources, Madison, WI.

MAYFIELD, H. F. 1961. Nesting success calculated from exposure. Wilson Bulletin 73: 255–261.

———. 1975. Suggestions for calculating nest success. Wilson Bulletin 87: 456–466.

NUR, N., A. L. HOLMES, AND G. R. GEUPEL. 2004. Use of survival time analysis to analyze nesting success in birds: an example using Loggerhead Shrikes. Condor 106: 457–471.

PIPER, W. H., M. W. MEYER, M. KLICH, K. B. TISCHLER, AND A. DOLSEN. 2002. Floating platforms increase reproductive success of Common Loons. Biological Conservation 104: 199–203.

POLLOCK, K. H., S. R. WINTERSTEIN, C. M. BUNCK, AND P. D. CURTIS. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53: 7–15

RABENOLD, P. P. 1988. 1988 Survey of Black Terns (*Chlidonias niger*) breeding in Indiana. Indiana Department of Natural Resources, Indianapolis, IN.

REYNOLDS, J. C., M. J. SHORT, AND R. J. LEIGHT. 2004. Development of population control strategies for mink, *Mustela vison*, using floating rafts as monitors and trap sites. Biological Conservation 120: 533–543.

SAUER, J. R., J. E. HINES, AND J. FALLOON. 2004. The North American Breeding Bird Survey, results and analyses 1966–2003. Version 2004.1. USGS, Patuxent Wildlife Research Center, Laurel, MD.

SHEALER, D. A. 2002. Population dynamics of Black Terns nesting in southeastern Wisconsin: 2002 field season report. U.S. Fish and Wildlife Service, Horicon National Wildlife Refuge, Mayville, WI.

SHEALER, D. A. 2003. Annual survival, breeding site fidelity, and natal recruitment of Black Terns breeding in southeastern Wisconsin, 1999–2003. U.S. Fish and Wildlife Service, Horicon National Wildlife Refuge, Mayville, WI.

SHUFORD, W. D. 1999. Status assessment and conservation plan for the Black Tern in North America. U.S. Fish and Wildlife Service, Denver, CO.

TECHLOW, A. F., III, AND A. F. LINDE. 1983. Forster's Tern nest platform study for 1983. Wisconsin Endangered Resources Report 7, Bureau of Endangered Resources, Madison, WI.

VAN DER WINDEN, J., W. HAGEMEIJER, AND R. TERLOUW. 1996. Heeft de Zwarte Stern *Chlidonias niger* een toekomst als broedvogel in Nederland? Limosa 69: 149–164.

WESELOH, D. V., H. BLOKPOEL, P. J. EWINS, AND M. RICHARDSON. 1996. Black Terns in southern Ontario: breeding biology, contaminants and management efforts (abstract). Colonial Waterbird Society Bulletin 20: 57.

WESTERKOV, K. 1950. Methods for determining the age of game bird eggs. Journal of Wildlife Management 14: 56–57.