The use of artificial floating nest platforms as conservation measure for the common tern *Sternula hirundo*: a case study in the RAMSAR site Druznó Lake in Northern Poland

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(Received 16 September 2021; accepted 1 February 2022)

Abstract
Artificial nesting sites with floating platforms may effectively support local breeding populations of waterbirds (enhancing productivity and survival) when natural sites are unavailable. In this study, we installed three artificial floating nest platforms (one in 2017, two in 2020) and we evaluated their use as a conservation measure for the common tern *Sternula hirundo* breeding at a RAMSAR site in Northern Poland with limited natural nesting habitat. We analyzed local population dynamics based on direct census in the study area from 2013 to 2021 and using data from literature dating back to 1923, with emphasis on the effects of three artificial nest platforms. We found that the local common tern population exhibited steep decline during the period 1999–2021 (−92%). Birds accepted artificial nesting platforms in the first year of their installation. The number of pairs breeding in artificial nests in 2017–2021 made up 53–100% of the breeding population in the study area. The nest density, clutch size and mean breeding output were similar in all platforms during all seasons. In 2020, the water level in the lake rapidly increased (ca 50 cm in 24 h) and completely destroyed common tern nests in the natural islets, while the floating platforms were the only places in the nature reserve where common terns were able to nest and breed successfully. We conclude that artificial breeding platforms may be a good conservation measure for common terns in natural areas with limited access to breeding habitat (but with optimal foraging areas). Based on our experiences from the present case study and on experience of other authors we propose recommendations for constructing, placing, and maintenance of nest platforms for common terns.

Keywords: Reproductive success, artificial nest, colonial waterbirds, population dynamics, floating rafts

Introduction
Breeding distribution and reproduction success of birds are limited by environmental and population factors (Newton 1998). These factors are traditionally grouped into extrinsic [i.e., food-supply, availability of nest-sites, nest density, level of predation and parasitism and disease, competition for nesting sites by other species of birds, human impacts (disturbance or landscape fragmentation)] and intrinsic (i.e., birth and death rates, prior breeding success and movements like immigration, emigration or dispersion) (Morris & Hunter 1976; Furness & Birkhead 1984; Danchin & Wagner 1997; Newton 1998; Tims et al. 2004). Some extrinsic factors affect intrinsic factors and thus affect the changes in population level (Newton 1998). Some extrinsic factors like disappearance of breeding habitat and extreme weather events (e.g., sudden weather events, such as flood or storm) are especially important for ground-nesting colonial waterbirds (Demongin et al. 2010). Level of water surface and weather conditions can affect reproductive rates through egg loss and low survival of chicks (Parnell et al. 1988; Anctil et al. 2014; Gach et al. 2018). These factors can cause complete colony abandonment (Nisbet 2000), which may affect the population size at the regional scale.

Terns (*Laridae, Sterninae*) are a group of waterbirds usually breeding colonially on the ground.
They are characterised by a long lifespan (usually 10–20 years) and low fecundity (usually one brood per year with 1–3 eggs) (Cramp 1983; Weimerskirch 2002; Braby et al. 2012). Terns return to the same breeding colonies over many years (Szostek et al. 2014). Breeding site fidelity is usually high (ca 90%), but depends on the site, predation rate, disturbance level, and distance to other colonies (Spedelow et al. 1995; Lebreton et al. 2003; Devlin et al. 2008; Braby et al. 2012). The common tern Sterna hirundo is one of the most common tern species breeding in Europe with a population estimated at 316,000–605,000 breeding pairs (BirdLife International 2017) with 6,000–8,000 of those pairs nesting in Poland (Sikora et al. 2007). In Europe, the population trend is increasing (BirdLife International 2017), while declining in Poland by 30% since the early 1990s (Sikora et al. 2007) with large interannual fluctuations (Chylarecki et al. 2018). The occurrence of this species is determined primarily by the availability of suitable nesting sites (marine, coastal, inland areas including lakes, fishponds, artificial bodies of water), mostly on Islands and peninsulas with open sandy and gravelly substrates with little or no vegetation (Del Hoyo et al. 1996; Chylarecki et al. 2015). Habitat loss and disturbance decrease common tern reproductive success and may result in a decline in the colony size (Dunlop et al. 1991). Tern nests are prone to substantial water-level fluctuations from nesting on the ground (Morris & Hunter 1976). Ongoing climate change is leading to more extreme weather and events like floods are becoming more frequent, which may result in higher bird mortality (McKechnie & Wolf 2010).

Multiple studies conducted since the 1970s have revealed that terns usually accept artificial nesting sites like floating nest platforms (Eades 1970; Turrian 1980; Dunlop et al. 1991; Lampman et al. 1996; Molina et al. 2009). Artificial nesting site supplementation may support local breeding populations when natural sites are unavailable (Molina et al. 2009). Floating nest platforms are less prone to mammalian predation, are not susceptible to erosion, and are isolated from human disturbance (Dunlop et al. 1991; Lampman et al. 1996; Quinn & Sirdevan 1998; Jenniges & Plettner 2008). Thus, artificial nest platforms may enhance productivity and survivorship in some species (Dunlop et al. 1991; Lampman et al. 1996; Molina et al. 2009) and may be considered as a conservation measure for species such as common terns.

Our study objectives were to:

1. Evaluate the use of artificial floating nest platforms as a conservation measure for the common tern based on a case study from the RAMSAR site, Druzzo Lake, a reserve in Northern Poland. As part of this effort, we investigated:

A) population trends for common terns breeding at Druzzo Lake with emphasis on artificial nest platforms effects on the local population dynamics. Given limited availability of the natural nesting habitats, we expected that birds will nest using artificial platforms (Beaud 2001).

B) latency from the nesting platforms installation to occupancy by nesting common terns; we expected fast colonization considering limited access for the natural nesting habitat and tendency of this species for very fast colonization (24 h after installation) of newly established floating platforms in another study (Dunlop et al. 1991).

C) whether nest density and offspring productivity differed between platforms and years; given differences in platform size and availability of alternative breeding habitats, we expected some interannual differences in the studied variables.

2. Formulate recommendations for constructing, placing, and maintenance of nest platforms for common terns based both on our experience from the present case study and the literature.

Material and methods

Study area

We performed the study in the Druzzo Lake reserve in Northern Poland (54.05 N, 19.45 E). The Druzzo Lake is a large and eutrophic very shallow water body (average depth is 1.2 m) (Nitecki 2013). The lake lies in a depression (part of the Vistula delta region in Northern Poland). The lowest point below sea level is ~1.8 m. As a result of strong north and north-west winds, connection with the Vistula Lagoon, and heavy rainfall in the lake basin, the water level often rises to 1.5 m (Fac-Beneda 2013). The large fluctuations in water level pose a threat during the breeding season for birds nesting in rushes, reedbeds and on floating vegetation (authors’ unpublished data). The reserve is an important breeding and stop-over site for some waterbird species and is protected as a RAMSAR and Natura 2000 site.

The common tern population size

To study common tern population dynamics, we collected literature data about the breeding population size at the Druzzo Lake reserve (Lüttschwager 1925;
Nesting platforms provision

We installed two types of floating nesting platforms for common terns. Platform A measured 4.3 × 4.3 m providing approximately 18.5 m² of potential nesting area (Figure 1A). Two platforms B measured 4.4 × 2.4 m providing approximately 10.5 m² of potential nesting area (Figure 1B). Given that the common tern prefers flat, sandy and gravelly beaches for nesting (Chylarecki et al. 2015), we supplied a layer of about 5 cm sand on to the platforms surface. We placed dry branches and pieces of driftwood and shrubs on top of the sand layer to create a natural appearance and provide shelter and shade for chicks. The boards of the platforms were submerged in water and protected with graphite-colored galvanized steel sheet against mammalian predators, such as the American mink Neogale vison common in the reserve (Ciechanowski et al. 2013). The species predation on bird colonies can be devastating and can cause their large-scale abandonment (Craik 1997). The bottom of the platforms was made of wooden planks fixed to metal structure frame. Holes were drilled through the boards and gaps were created in each corner of the platform to provide rainwater drainage. The boards of the structure were made of wooden planks to prevent chicks from falling out. The platforms were mounted on floats (nine 200 litre and four 565 litre plastic barrels were fitted underneath the platform A, and B, respectively). The platforms were anchored with a metal chain connected to four concrete blocks to avoid uncontrolled movement due to frequent water level changes in the lake.

Given the breeding season of the common tern in Poland begins the last decade of April (Bukaciński & Bukacińska 1994; authors’ unpublished data) but older individuals may start to breed earlier (Nisbet 1978), platform A was positioned in the beginning of April on 04.04.2017 (Figure 1A). Two of platform type B were installed on 14.04.2020 in two locations (Figure 1B). All floating platforms were

Figure 1. Nesting floating platforms, A (A), and B (B), and general view of all platforms location (C) in the Drużno Lake reserve (photos by authors).
situated in the southern part of the lake, with negligible human disturbance (Figure 1C).

One of the B platforms (B1) was located 127 meters from platform A. The other B platform (B2) was located 136 meters from A (Figure 1C). Platform B1 and A are separated with a strip of reedbeds about 45 m wide. Platform B2 and A are separated by an open water surface (Figure 1C).

Field study

We surveyed the platforms contents remotely using a spotting scope 200 meters from land, or by using binoculars from a boat from 20 to 100 meters in 2017–2018. In 2019, we tested terns’ reaction to use of an unmanned aerial vehicle UAV (hereafter drone) to survey the nest content. We performed five subsequent flights in short time intervals differing in drone height over the colony. During the first trial adults fled after the drone appeared at a height of 15 meters. During the second flight (after about 4–5 minutes) at the same altitude birds behaved similarly. During the third flight, after following 4–5 min, the birds escaped only when the drone lowered its height to about 3 meters above the platform. During subsequent two flights, adult common terns did not escape from the nests in the presence of the flying drone (Figure 2). Based on the results of these observations, we decided to use the drone to perform our research during the 2019–2021 seasons. We used a DJI Mavic 2 Pro DJIIM0258 drone with a 20 Mpix camera for all aerial controls. We controlled the platform each 10–15 days in all studied years. The number of eggs and chicks (1–2 week of life) in each nest on platforms were counted visually from the boat (2017–2018) and from drone aerial images (2019–2021) from a height of 5–6 meters above the platform surface. Due to the movement of chicks within the colony it was not possible to assign specific chicks to specific nests hence we could only calculate the average productivity of common terns on each platform.

Statistical analyses

We calculated a population trend of common terns breeding at the Drużno Lake reserve during 1999–2021 using the TRIM (TRenDS & Indices for Monitoring data) software (Pannekoek & van Strien 2005), version 3.53. It implements a Poisson regression for estimating yearly indices and trends of the considered populations to analyse time-series counts (log-linear models) and produce two estimates describing trends: 1) multiplicative reflecting the changes in terms of average percentage change per year, and 2) additive which is natural logarithm of the multiplicative parameter. These parameters are different descriptions of the same estimates. Between-year changes in abundance are represented as indices, using the first year as a base year (1999). We employed a linear trend model with stepwise selection of changepoints. TRIM first estimated the model with changepoints in all studied years (Wald test, P < 0.03) and then implemented selection procedure removing from analysis one changepoint (year 2011 – Wald test = 0.01, p = 0.93). We have no population estimates for 2003 but TRIM can analyze time-series of counts with missing observations (Pannekoek & van Strien 2005).

We used a G test to compare the nest density per square meter and mean breeding output per nest on the individual floating platforms between 2020 and 2021.

Results

Population dynamics of common terns in the Drużno Lake reserve

Common terns in the Drużno Lake reserve usually nest in small colonies on small islets without dense vegetation. The first published record of breeding from the 1920s reported 100 pairs nesting on the lake islets (Lüttschwager 1925). In the 1950s, about 300 birds were recorded during the breeding season (Krzanowski & Pinowski 2006), while from the mid-1970s to the end of the 1990s, the number of nesting pairs was estimated at 70–110 (Nitecki et al. 2013). Between 1999 and 2016 a gradual decrease in the size of the breeding population from 110 to 10 pairs was observed (Nitecki et al. 2013; author’s unpublished data). The number of breeding colonies decreased from six in 1999 to one in 2013 (Figure 3). Moreover, starting in 2016, small islets with little or no vegetation where common terns nested in the past have been occupied and monopolized by breeding and/or roosting great cormorants Phalacrocorax carbo (Nitecki et al. 2013; author’s unpublished data).

A long-term population trend of the common tern in natural habitat colonies at Drużno Lake reserve between 1999 and 2021 after stepwise selection of changepoints was classified by TRIM software as a “steep decline” with the additive slope ± SE between 1999 and 2021 −0.08 ± 0.0005, corresponding to 92 ± 0.0005% annual decrease.
Nesting on artificial platforms

The first installed floating platform (A) was occupied by common terns in the first year after establishment in 2017. A single pair laid there three eggs, all hatched, and the chicks fledged successfully (Table 1). In the same year, 14 pairs of common terns nested within a colony of black-headed gulls Chroicocephalus ridibundus on natural islets in the lake. In the following year (2018), three common tern nests were observed on the floating platform (Table 1). We found no other nests in other parts of the Druzno Lake reserve (on 1 of 20 artificial nesting platforms designed for black tern Chlidonias niger), none found in the natural islets. In 2019, we observed 33 breeding pairs in the black-headed gull breeding colony and 37 pairs on the platform Type A. The number of all breeding pairs (nesting both on the platform and in natural islets) in 2019 reached 63.6% (N = 70) of the maximal documented population size in the Druzno Lake reserve (110 nests in 1999). In 2020, we recorded 34 nests on all three platforms (Table 1). We found only one other nest in other parts of the Druzno Lake reserve (on 1 of 20 artificial nesting platforms designed for black tern Chlidonias niger), none found in the natural islets. In 15.05.2020, the water level in the lake increased by 50 cm in 24 hours. The water level remained high for several weeks destroying black-headed gulls nests and submerging all potential nesting sites for common terns on the natural islets. After this flood event, two pairs of black-headed gulls nested on platform A. Aggressive behaviour towards common terns was not
In 2021, we recorded 47 nests on all three platforms (Table I). In the same year, 3 pairs common terns pairs nested within the black-headed gull colony on natural islets in the lake, and 18 pairs nested on the artificial nesting platforms for black terns. In 2021 the water level

![Figure 3](image)

**Figure 3.** The population dynamics of common terns breeding in the Druzno Lake reserve in 1999–2021. No data available for 2003 [indicated with X in the graph]. The red arrow indicates the construction of a one floating platform Type A, the purple arrow – two platforms Type B, for common terns bars indicate number of pairs, dots number of colonies.

| Year | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Number of colonies | [indicated with X in the graph]. The red arrow indicates the construction of a one floating platform Type A, the purple arrow – two platforms Type B, for common terns bars indicate number of pairs, dots number of colonies.

| Platform type | 2017 | 2018 | 2019 | 2020 | 2021 |
|---------------|------|------|------|------|------|
| Number of nests | A: 1, B1: - | B2: - | 3, 11, 15 | 37, 22, 14 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Nest density per m² | A: 0.05, B1: - | B2: - | 0.16, 0.10, 1.71 | 2.0, 2.10, 1.33 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Mean clutch size ± SD | A: 3.0 ± 0.0, B1: - | B2: - | 2.3 ± 0.47, 3.0 ± 0.0, 2.4 ± 0.83 | 2.2 ± 0.90, 2.3 ± 1.05, 2.14 ± 0.95 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Hatching success (%) | A: 100.0, B1: - | B2: - | 100.0, 67.1, 48.0 | 0.0, 75.5, 1.82 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Mean breeding output per nest | A: 3.0, B1: - | B2: - | 2.33, 6.7, 1.82 | 1.49, 1.09, 1.82 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

| Year | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Number of colonies | [indicated with X in the graph]. The red arrow indicates the construction of a one floating platform Type A, the purple arrow – two platforms Type B, for common terns bars indicate number of pairs, dots number of colonies.

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| Nest density per m² | A: 0.05, B1: - | B2: - | 0.16, 0.10, 1.71 | 2.0, 2.10, 1.33 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Mean clutch size ± SD | A: 3.0 ± 0.0, B1: - | B2: - | 2.3 ± 0.47, 3.0 ± 0.0, 2.4 ± 0.83 | 2.2 ± 0.90, 2.3 ± 1.05, 2.14 ± 0.95 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Hatching success (%) | A: 100.0, B1: - | B2: - | 100.0, 67.1, 48.0 | 0.0, 75.5, 1.82 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Mean breeding output per nest | A: 3.0, B1: - | B2: - | 2.33, 6.7, 1.82 | 1.49, 1.09, 1.82 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
in the lake was stable. We observed 11 black-headed gull nests on the floating platforms (3 on A, 7 on B2 and 1 on B1).

**Breeding performance of birds nesting on the platforms**

We found that the nest density ranged from 0.05 to 2.1 per m² (mean ± SD: 1.08 ± 0.76, N = 122) (Table I) and was similar in 2020 and 2021 on all three platforms (G test, G₂ = 2.24, p = 0.59), and on the platform A in 2017–2021 (G test, G₁ = 2.62, p = 0.62).

The clutch size on all floating platforms during 2017–2021 ranged from one to four eggs in all study years (mean ± SD, 2.41 ± 0.88, N = 122) (Table I).

We found that mean breeding output per nest ranged from 0 to 2.33 (mean ± SD: 1.66 ± 0.82, N = 190) (Table I) and was similar on all three platforms in 2020 and 2021 (G test, G₂ = 1.90, p = 0.39), and on the platform A in 2017–2021 (G test, G₁ = 0.59, p = 0.96).

**Discussion**

We found a steep decline in the common tern population at the Druzzo Lake reserve between 1999 and 2021. This result is consistent with the population trend of this species in Poland which had a 30% decline between the 1990s and 2000s (Sikora et al. 2007) and a decrease in abundance index between 2007 and 2016 (Monitoring of Birds of Poland; online [https://monitoringptakow.gios.gov.pl/raporty.html](https://monitoringptakow.gios.gov.pl/raporty.html)). In other European countries, a decrease in population size has been reported in southern Norway (BirdLife International 2017), Mediterranean populations in France (Dubois et al. 2000; Siblet 2002), three of most important breeding sites in the Netherlands (Van Dijk et al. 2002), Croatia, Moldova and Albania (BirdLife International 2017) and Lithuania (Kurlavicius & Raudonikis 2001). The steep decline in the local population of this species at Druzzo Lake reserve may not be related to a lack of food resources because this site is a productive eutrophic water body (Nitecki et al. 2013). It can be attributed to interspecies competition over nesting or resting availability at the site. In recent years, locations that could be used for nesting by common terns (small islets with little or no vegetation) have been occupied and changed by great cormorants (Nitecki et al. 2013; author’s unpublished data). Declines in the Druzzo Lake reserve population (where the common tern is a priority species of conservation) followed by the inter-specific competition over nesting sites with cormorants encouraged us to implement conservation measures in the form of installation of artificial nesting sites.

We found positive effects of the measures taken with common terns colonizing the floating nesting platforms in the Druzzo Lake reserve within the first-year installation. Rapid colonization has been also reported in other locations for this species (Dunlop et al. 1991) and other species of terns (Lampman et al. 1996; Molina et al. 2009). In addition, we showed an increasing population trend during 2017–2021 (after platform installation; Figure 3).

The number of common tern pairs breeding on the platforms in the Druzzo Lake reserve accounted for up to 53–100% of all breeding pairs in the Druzzo Lake reserve. In 2020, when all natural nests were flooded, common terns nested successfully solely on artificial platforms. The total number of breeding pairs on platform in 2020 was higher than annual number of pairs breeding in the reserve from 2010 to 2018. Increased number of nesting pairs observed in subsequent years after platform installation was likely a consequence of successful breeding there, since low success often results in abandonment of nests on artificial platforms (Molina et al. 2009). It has been found that the breeding success of common terns on artificial platforms is higher than in natural habitats because of lower mammalian predation (Norman 1987) and are not flooded (Dunlop et al. 1991).

Nest density on the platforms ranged from 0.05 to 2.1 per m² throughout our study. Our results are consistent with the literature reporting 0.3–2.1/m² (Sudmann 1998) and 0.5–1.0/m² (Szostek et al. 2014), on artificial-nesting rafts, and 0.03–5.2/m² (Neubauer 1998), 0.06–0.5/m² (Nisbet 2002) in natural habitat. Due to the lack of nesting sites in their natural habitat, and that area on platforms limits the number of pairs that can nest at a given location (Molina et al. 2009), common terns in our study nested in all available microhabitats including sites in proximity of branches or boards, and open sand zone. Other studies have found that when the preferred nest habitat (i.e., bare ground or short grass) is unavailable, common terns may also breed in areas covered with sparse grass or shrubs or even in areas of dense or tall vegetation (Becker & Ludwigs 2004). However, too high nest density may negatively affect the breeding success of the entire colony (Molina et al. 2009) by the transmission of pathogens (Brown & Brown 1996), increased intraspecific aggressions (Butler & Trivelpiece 1981; Sudmann 1998), and deterioration of both adult (Coulson et al. 1982) and offspring body condition (Tella 1996).

In our study, the clutch size on all floating platforms ranged from one to four eggs (mean 2.41) which is generally in concordance with results of other studies on common terns breeding on floating
platforms [2.8 (Dunlop et al. 1991) and 2.4–2.8 (Martinović et al. 2019)] and in natural habitats [2.5–2.7 (Becker & Sudmann 1998), 2.2–2.7 (Nisbet 2002)]. Our results found the mean breeding output per nest on platforms ranged from 0 to 3 chicks per nest (weighed mean 1.63 chicks per nest). In other studies based on five common tern colonies breeding on artificial structures (disused piers, breeding rafts) the average number of fledglings per pair ranged from 1.1 to 1.5 (Dunlop et al. 1991), 0.85 to 1.29 (Szostek et al. 2014) and 0.6 to 0.9 (Martinović et al. 2019).

Recommendation for platforms installation

Based on our and others experience with constructing and maintaining platforms designed for nesting terns we have many recommendations (summarized in Table II). The construction of the nesting raft should be heavy to prevent being buffeted by the strong winds at the exposed sites (Babcock & Booth 2020a). We recommend constructing high sides on the platform to minimize substrate erosion and protect nests and chicks against waves. The anchors must be properly secured because strong winds and storms can damage them and

Table II. Recommendations for constructing and placing nest platforms for common terns.

| Recommendation | Note | Reference |
|----------------|------|-----------|
| **Construction** | | |
| Heavy construction of the platform with high buoyancy | prevention of the raft being buffeted by the strong winds at the exposed sites | Babcock & Booth 2020a |
| High sides/boards | minimize substrate erosion, protect nests and chicks against waves | Dunlop et al. 1991; Molina et al. 2009 |
| Fine anchoring (e.g., concrete blocks) | strong winds and storms can damage platforms and/or pull them off the ground/move/rotate them | Dunlop et al. 1991; Molina et al. 2009 |
| Chain connecting platform and anchor should be long enough to secure anchoring | protection against water level fluctuations | Dunlop et al. 1991 |
| Drainage holes in the platform | protection against flooding of nests due to rainfall | Dunlop et al. 1991; Shealer et al. 2006 |
| At least a 5 cm sand/gravel layer on the top of the platform | PCV sheet on the construction will prevent from sand spread | this study |
| Sides covered with metal sheets or a clear polycarbonate screen with a smooth surface | protection against mammalian predators; a smooth surface offers no footholds for the mammalian predators to climb | this study; Babcock & Booth 2020a |
| Boards of the platform should be secured to prevent chicks fall from the platform (but see the next point) | chicks that jumped to water are unable to climb back onto the platform | Dunlop et al. 1991; Lampman et al. 1996; Gach et al. 2018 |
| A hinged flap fixed to the edge of the nest platform providing a shallow gradient which can be climbed by chicks | allowing unfledged chicks to climb back on the platform if they fall out, and being able to access water in hot weather; hide from avian predators, excessive sunlight or strong wind; shelters shaped as a tunnel should be positioned at an angle away from the prevailing wind to maximise protection | Molina et al. 2009; Babcock & Booth 2020a |
| Shelter structures for chicks (e.g., dry tree branches, small rocks) and/or deep, long and low chick shelters made of wood of PVC | this study; Richards & Morris 1984, Dunlop et al. 1991, Burness & Morris 1992, Babcock & Booth 2020a, 2020b |
| **Location** | | |
| Close to other platforms/natural colonies | social attracting | this study; Dunlop et al. 1991 |
| Far from places exposed to human disturbance | minimize risks associated with human disturbance | this study; Babcock & Booth 2020a |
| Within the cost-effective distance from foraging areas | securing effective foraging and feeding chicks | this study; Babcock & Booth 2020a |
| **Maintenance** | | |
| Covering the platform, with e.g. a tarpaulin, until the common terns arrive | minimize risks associated with overcompeting terns by larger gulls | Babcock & Booth 2020a |
| Remove vegetation from the platforms before the breeding period onset | to maintain a comfortable open area with soft substrate | this study; Ramos & Del Nevo 1995; Denac & Božič 2019 |
| Ongoing maintenance, e.g., repair of construction damage, sand replenishment | to maintain bird safety and attractiveness of the substrate | this study; Babcock & Booth 2020a |
| **Monitoring** | | |
| Remote control should be used, e.g., using drone, motion-activated cameras or camera | to minimize bird disturbance | this study; Chabot et al. 2015; Guilfoyle et al. 2017 |
pull them off the ground and move them (Dunlop et al. 1991; Molina et al. 2009). We recommend that the chain connecting the platform and anchor should be long enough to secure anchoring regardless of water-level fluctuations (Dunlop et al. 1991). The boards and the bottom of the platform should allow rainwater (e.g., heavy rainfall) to run off to prevent possible flooding of the eggs or chicks (Dunlop et al. 1991; Shealer et al. 2006; Gach et al. 2018). At least a 5 cm sand layer should be placed on the platform surface (PCV sheet on the construction will prevent sand spread). In areas where mammalian predators like the American mink may swim out to a raft, high sides covered with metal sheets or a clear polycarbonate screen with a smooth surface may act as effective anti-predatory barriers (Babcock & Booth 2020a). Sheltering structures for chicks (e.g., dry tree branches, wooden or PVC tunnel-like structures) to provide shelter from predators, excessive sunlight, or strong wind should be installed on the platform (Richards & Morris 1984; Dunlop et al. 1991; Burness & Morris 1992; Babcock & Booth 2020a). The boards or edges of the platform should be secured so that chicks cannot fall off as they are unable to climb back onto the platform and will die (Dunlop et al. 1991; Lampman et al. 1996; Gach et al. 2018). However, securing boards of the platform to prevent this results in lack of access to water for the chicks. Frequent foot and body soaking are important thermoregulatory behaviours for adult larids and their young in maintaining normal body temperature via evaporative cooling (Molina et al. 2009). In hot weather, this solution may negatively affect chick thermoregulation putting young at risk of mortality. However, as we have demonstrated, breeding success on platforms and in natural habitats was often similar, so perhaps the lack of access to lake water did not affect chick survival considerably. An additional advantage of high boards is the shade they can provide for chicks to shelter from the sun. Installing a hinged flap fixed to the edge of the nest platform can provide a shallow gradient allowing chicks a possible return to the nesting site in the case of falling out (Molina et al. 2009; Babcock & Booth 2020a). However, this feature may provide mammalian predators access to the platform. Thus, such ramps are not suitable for sites with a high mammalian predation risk (Babcock & Booth 2020a).

When installing a few platforms, locating them close other platforms or natural colonies is recommended to facilitate social attraction (Dunlop et al. 1991). Locating platforms close to foraging areas to securing effective foraging and feeding chicks (Babcock & Booth 2020a) is also recommended. Artificial breeding sites must be regular maintained and protected against terrestrial predators and human disturbance in order to provide suitable nesting habitat in the long-term (Becker & Ludwigs 2004).

We suggest covering the platform until the common terns arrive to minimize risks associated with nest competition with larger gulls (Babcock & Booth 2020a) and removing the vegetation from the platforms before the following breeding season (no later than in March), because nests of common terns are usually placed in open areas with soft substrates (Denac & Božič 2019; Ramos & Del Nevo 1995; this study). Floating nesting platforms will need ongoing maintenance, e.g., repair of construction damage and sand replenishment (Babcock & Booth 2020a; this study).

We recommend monitoring the platform contents using a drone or motion-activated camera, as it minimizes bird disturbance (Chabot et al. 2015; Guilfoyle et al. 2017; this study). Other studies based on monitoring using drones have reported that common terns are able to habituate to disturbance by small, unmanned aircraft systems. Adults were initially alarmed by a novel stimulus but subsequently stopped reacting and rapidly habituated because it did not cause adverse consequences to the colony (Chabot et al. 2015). Considering that floating nesting platforms without may allow chicks to jump into the water (Dunlop et al. 1991), aerial monitoring of common tern nest contents is recommended (Chabot et al. 2015). However, care must be taken when working with a drone in bird colonies of other species, as the use of drones in species that are particularly sensitive to colony disturbance may cause adult birds to abandon their nests (e.g., the elegant tern Thalasseus elegans; Thompson 2021). Drones should only be used by experienced and properly licensed personnel since illegal, or recreational drone use can carry catastrophic wildlife consequences (Thompson 2021).

To conclude, we found a positive effect of installing floating nest platforms in the Druzno Lake reserve on the local breeding population of common terns. The declining trend stopped and population size started to increase during our study. In one of year of our study, a flood resulted in all pairs breeding exclusively on the artificial platforms. Thus, we recommend installing artificial nesting platform in areas with limited access to natural nesting habitats (but with optimal foraging areas) and declining population trends for common terns. Even though this work is focused on population dynamics of a local population of common terns, we believe that conclusions of our study
have very broad implications and by share a large list of recommendations for the construction and maintenance of nesting platforms.

Acknowledgements
We are grateful to Mateusz Barcikowski for help with the first metal frame platform construction. This construction and initial monitoring of the platform were supported by the Special Research Facility grants (SPUB) of the Polish Ministry of Science and Higher Education [No. 203733/E-335/SPUB/2016/5 and 203733/E-335/SPUB/2018/1]. The study was performed with the permissions from the General Inspectorate for Environmental Protection, Poland (GDOŚ DZP-WP.6205.9.2017.LR.2) and from Regional Directorate of Environmental Protection in Olsztyn, Poland (RDOŚ: WOPN.6401.30.2019.MJ, WOPN.6205.1.5.2019.AK.2, WOPN.6401.50.2020. AWK, WOPN.6205.1.32.2020.TB). The drone operator had a licence for using UAVO, BVLOS and UAV of the weight exceeding < 5kg (licence number: PL.47266.UAVO). We appreciate the improvements in English usage made by Pamela Denmon through the Association of Field Ornithologists’ program of editorial assistance.

Funding
This work was supported by the Special Research Facility grants (SPUB) of the Polish Ministry of Science and Higher Education [203733/E-335/SPUB/2016/5, 203733/E-335/SPUB/2018/1].

Disclosure statement
No potential conflict of interest was reported by the author(s).

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References
Anctil A, Franke A, Béty J. 2014. Heavy rainfall increases nesting mortality of an Arctic top predator: Experimental evidence and long-term trend in peregrine falcons. Oecologia 174 (3):1033–1043. DOI:10.1007/s00442-013-2800-y.
Babcock M, Booth V. 2020a. Tern conservation best practice. Habitat: Rafts and structures. Roseate Tern Life Project Report 30(12):2021. http://roseatetern.org.
Babcock M, Booth V. 2020b. Tern conservation best practice. Chick shelters. Roseate Tern Life Project Report 30 (12):2021. http://roseatetern.org.
Beaud M. 2001. Quelques experiences dans le domaine de la protection de la Sterne pierregarin Sterna hirundo en periode de nidification. Nos Oiseaux Suppl. 5:73–80.
Becker PH, Ludwigs JD. 2004. Sterna hirundo Common Tern. BWP Update 6:91–137.
Becker PH, Sudmann SR. 1998. Quo vadis Sterna hirundo? Schlußfolgerungen für den Schutz der Flußseschwalbe in Deutschland. Vogelwelt 119:293–304.
BirdLife International. 2017. European birds of conservation concern: Populations, trends and national responsibilities. Cambridge, UK: BirdLife International.
Braby J, Braby SJ, Braby RJ, Altweg R. 2012. Annual survival and breeding dispersal of a seabird adapted to a stable environment: Implications for conservation. Journal of Ornithology 153(3):809–816. DOI:10.1007/s10336-011-0798-7.
Brown CR, and Brown MB. 1996. Coloniality in the cliff swallow: the effect of group size on social behavior. Chicago: University of Chicago Press. p. 580.
Bukaciński D, Bukacińska M. 1994. Czynniki wpływające na zmiany liczebności i rozmieszczenie mew, rybiów i siewczeż gniazdujących na środkowej Wiśle. Notatki Ornitoligiczne 35:79–97.
Burness GP, and Morris RD. 1992. Shelters decrease gull predation on chicks at a common tern colony. Journal of Field Ornithology 63:186–189.
Butler RG, Trivelpiece W. 1981. Nest spacing, reproductive success, and behavior of the Great Black-backed Gull (Larus marinus). The Auk 98:99–107.
Chabot D, Craik SR, Bird DM. 2015. Population census of a large common tern colony with a small unmanned aircraft. PLoS ONE 10(4):e0122588. DOI:10.1371/journal.pone.0122588.
Chylarecki P, Chodkiewicz T, Neubauer G, Sikora A, Meer W, Woźniak B, Wylegala P, I. L, Marchowski D, Betleja J, Bzoma S, Cenian Z, Görski A, Korniuk M, Moczarска J, Ochocińska D, Rubacha S, Wieloch M, Zieleńska M, Zieliński P, Kuczyński L. 2018. Trendy liczebności ptaków w Polsce. Warszawa: GIOŚ.
Chylarecki P, Sikora A, Cenian Z, Chodkiewicz T, eds. 2015. Monitoring ptaków lęgowych. Poradnik metodyczny. Warszawa: Wydanie 2, GIOŚ.
Ciechanowski M, Cieśliński R, Kamińska K, Kaszuba S, Komar J, Mączyńska M, Saath S, Zwolicki A. 2013. [The Mammalian fauna of “Jezioro Drużno” Nature Reserve]. In: Nitecki C, editor. Lake Drużno – Natural Monograph. Olsztyn: Wyd. Mantis. pp. 191–230 [in Polish with English summary].
Couls.on JC, Duncan N, Thomas C. 1982. Changes in the breeding biology of the herring gull (Larus argentatus) induced by reduction in the size and density of the colony. Journal of Animal Ecology 51(3):739–756. DOI:10.2307/4002.
Craik C. 1997. Long-term effects of North American Mink Mustela vison on seabirds in western Scotland. Bird Study 44 (3):303–309. DOI:10.1080/00063659709461065.
Cramp S. 1985. Handbook of the birds of Europe, the Middle East and Africa. The birds of the western Palearctic vol IV: Terns to woodpeckers. Oxford: Oxford University Press.
Danchin E, Wagner RH. 1997. The evolution of coloniality: The emergence of new perspectives. Trends in Ecology & Evolution 12(9):342–347. DOI:10.1016/S0169-5347(97)01124-5.
Del Hoyo J, Elliott A, Sargatal J. 1996. Handbook of the Birds of the World, vol. 3: Hoatzin to Auks. Barcelona, Spain: Lynx Edicions.

Demongin L, Poiacheau M, Strange IJ, Quillfeldt P. 2010. Effects of severe rains on the morality of Southern Rockhopper Penguin (Eudyptes chrysocephalus) chicks and its impact on breeding success. Ornithologia Neotropical 21:439–443.

Denac D, Božič L. 2019. Breeding population dynamics of Common Tern Sterna hirundo and associated gull species with overview of conservation management in continental Slovenia. Acrocephalus 40(180–181):5–48. DOI:10.1515/acro-2019-0001.

Devlin GM, Diamond AW, Kress SW, Hall CS, Welch L. 2008. BREEDING DISPERSAL AND SURVIVAL OF Arctic TERNS (Sterna paradisaea) NESTING IN THE GULF OF MAINE. The Auk 125(4):850–859. DOI:10.1525/auk.2008.07060.

Dubois Pj, Le Marechal P, Olioso G, Yesou P. 2000. Inventaire des Oiseaux de France—Avifaune de la France m’empolitique. Paris: Nathan.

Dunlop CL, Blokploel H, Jarvis S. 1991. Nesting rafts as a management tool for a declining common tern (Sterna hirundo) colony. Colonial Waterbirds 14(2):116–120. DOI:10.2307/1521499.

Eades R. 1970. An artificial raft as a nesting site for terns on the Dee. In: Bourne WRP, editor. Seabird Report. Bedford, United Kingdom: Henry Burt & Son Ltd. pp. 45

Fac-Beneda J. 2013. The hydrological characteristics of Lake Druzzo. In: Nitecki C, editor. Lake Druzzo – Natural monograph. Olsztyn: Wyd. Mantis. pp. 15–52 [in Polish].

Furness RW, Birkhead TR. 1984. Seabird colony distributions suggest competition for food supplies during the breeding season. Nature 311(5957):655–656. DOI:10.1038/311655a0.

Gach K, Janiszewski T, Włodarczyk R, Lerner B, Minias P. 2018. Age- and Condition-dependent Mortality of Common Tern (Sterna hirundo) Chicks during a heavy rainfall event. Waterbirds 41(1):63–67. DOI:10.1675/063.041.0108.

Guilfoyle MP, Ruby RJ, Suedel BC, Fredette TJ, Bijhouwer P, Hannes A, Adair K, Banks CJ, and Friona AM. 2017. Creating nesting habitat for the Common Tern (Sterna hirundo) on the repaired Ashtabula breakevent: Lessons learned 2014–2016. ERDC/TN EWN-17-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center. https://doi.org/10.1675/1524-4695(2008)31[274:LTNAHC]2.0.CO;2 Accessed on 30.12.2021.

Jennes Jj, Plettenberg RG. 2008. Least Tern nesting at human created habitats in central Nebraska. Waterbirds 31 (2):274–282. DOI:10.1675/1524-4695(2008)31[274:LTNAHC]2.0.CO;2.

Krzanowski A, Pinowski J. 2006. Ptaki środowiska wodnego jeziora Drużno. Drozdowskie Zeszyty Przyrodnicze 3:53–79.

Kurlavičius P, Raudoniškis L. 2001. Lietuvos paukščių vietinių perinčiu populiacijų gausa 1999–2001. Ciconia 9:92–97.

Lampman KP, Taylor ME, Blokploel H. 1996. Caspian Terns (Sterna caspia) breed successfully on a nesting raft. Colonial Waterbirds 19(1):135–138. DOI:10.2307/1521819.

Lebretom JD, Hines J, Pradel R, Nichols JD, Spendelow JA. 2003. Estimation by capture-recapture of 2003 and dispersal over several species, Oiseaux 102(2):253–264. DOI:10.1034/j.1600-0706.2003.11848.x.

Lättschwager H 1925. Der Drausensee bei Elbing, eine Entstehungsgeschichte und seine Tierwelt zu gleich ein Beitrag für die Tiergeographie des Weichsel-Nogatdeltas. Danzig, I–99

Martinović M, Kralj J, Rubinić T, Jurinović L, Petrović A, Svetličič I. 2019. First data on breeding success of Croatian inland colonies of Common Tern Sterna hirundo. Sterna Hirundo. Acrocephalus 40(180–181):97–103. DOI:10.1515/acro-2019-0007.

McKechnie AE, Wolf BO. 2010. Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. Biology Letters 6(2):253–256. DOI:10.1098/rsbl.2009.0702.

Molina KC, Ricca MA, Miles AK, Schoneman C. 2009. Use of a nesting platform by gull-billed terns and black skimmers at the Salton Sea, California. Western Birds 40:267–277.

Morris RD, Hunter RA. 1976. Factors influencing desertion of colony sites by Common Terns (Sterna hirundo). Canadian Field-Naturalist 90:137–143.

Neubauer W. 1998. Habitatwahl der Flusseeschwalbe Sterna hirundo in Ostdeutschland. Vogelwelt 119:169–180.

Newton I. 1998. Population Limitation in Birds. San Diego: Academic Press.

Nisbet ICT. 1978. Dependence of fledging success on egg-size, parental performance and egg-composition among common and roseate terns, Sterna hirundo and S. dougallii. S. Dougallii. Ibis 120(2):207–215. DOI:10.1111/j.1474-919X.1978.tb06777.x.

Nisbet ICT. 2000. Disturbance, habituation, and management of waterbird colonies. Waterbirds 23:312–332.

Nisbet ICT. 2002. Common tern Sterna hirundo. In: Poole A, and Gill F, editors. The Birds of North America, No. 618, pp. 1–40. Philadelphia: The Birds of North America.

Nitecki C. (eds.). 2013. [Lake Druzzo – Natural monograph]. Wyd. Mantis, Olsztyn [In Polish with English summary].

Nitecki C, Jakubas D, Typiak J. 2013. [The avifauna of the Lake Druzzo]. In: Nitecki C, editor. Lake Druzzo – Natural Monograph. Olsztyn: Wyd. Mantis. pp. 113–190 [in Polish with English summary].

Norman D. 1987. Are common terns successful at a man-made nesting site? Ringing and Migration 8(1):7–10. DOI:10.1080/03078698.1987.9673895.

Pannekoek J, van Strien A. 2005. TRIM 3 Manual. (TRends and Indices for Monitoring data). Project nr: 100384. Voorburg: Statistics Netherlands.

Parnell JF, Ainley DG, Blokploel H, Cain B, Custer TW, Dusi JL, Kress S, Kushlan JA, Southern WE, Stenzel LE, Thompson BC. 1988. Colonial waterbird management in North America. Colonial Waterbirds 11(2):129–169. DOI:10.2307/1520996.

Quinn JS, Sierdan J. 1998. Experimental measurement of nesting substrate preference in Caspian terns, Sterna caspia, and the successful colonisation of human constructed Islands. Biological Conservation 85(1–2):63–68. DOI:10.1016/S0006-3207(97)00142-0.

Ramos JA, Del Nevo AJ. 1995. Nest-site selection by Roseate Terns and Common Terns in the Azores. The Auk 112:580–589.

Richards MH, Morris RD. 1984. An experimental study of nest site selection in common terns. Journal of Field Ornithology 55:457–466.

Shelar DA, Buzzell JM, Heiar JP. 2006. Effect of floating nest platforms on the breeding performance of Black Terns. Journal of Field Ornithology 77(2):184–194. DOI:10.1111/j.1557-9263.2006.00040.x.

Siblet JP. 2002. Sterne pierregarin Sterna hirundo. In: Cadiou B, Pons J-M, Ye sou P, editors. Oiseaux marins nicheurs de France mc tropolitaine (1960–2000). Paris: Report direction de la nature et des paysages. pp. 103–107.

Skóra A, Rohde Z, Gromadzki M, Neubauer G, Chylarecki P, eds. 2007. Atlas rozmieszczenia ptaków lęgowych Polski 1985-2004. Poznań: Bogucki Wyd. Nauk.
Spendelow JA, Nichols JD, Nisbet ICT, Hays H, Cormons GD, Burger J, Safina C, Hines JE, Gochfeld M. 1995. Estimating annual survival and movement rates of adults within a metapopulation of Roseate Terns. Ecology 76 (8):2415–2428. DOI:10.2307/2265817.

Sudmann SR. 1998. How densely can Common Terns Sterna hirundo breed? Extreme situations of rafts. Vogelwelt 119:181–192.

Szostek KL, Becker PH, Meyer BC, Sudmann SR, Zintl H. 2014. Colony size and not nest density drives reproductive output in the Common Tern Sterna hirundo. Sterna Hirundo. Ibis 156(1):48–59. DOI:10.1111/ibi.12116.

Tella JL. 1996. Ecological constraints, costs and benefits of coloniality in the Lesser Kestrel. PhD Dissertation Unpublished. University of Barcelona, Barcelona, Spain.

Thompson J 2021. A drone crash caused thousands of Elegant Terns to abandon their nests. Intern Audubon Magazine. Accessed on 30.12.2021. https://www.audubon.org/news/a-drone-crash-caused-thousands-elegant-terns-abandon-their-nests/

Tims J, Nisbet ICT, Friar MS, Mostello C, Hatch JJ. 2004. Characteristics and performance of Common Terns in old and newly-established colonies. Waterbirds 27(3):321–332. DOI:10.1675/1524-4695(2004)027[0321:CAPOCT]2.0.CO;2.

Weimerskirch H. 2002. Seabird demography and its relationship with the marine environment. In: Schreiber EA, Burger J, editors. Biology of Marine Birds. Washington, D.C: CRC Marine Biology Series, CRC Press. pp. 115–135.