

Prepared in cooperation with the San Francisco Bay Bird Observatory

Evaluation of Social Attraction Measures to Establish Forster's Tern (*Sterna forsteri*) Nesting Colonies for the South Bay Salt Pond Restoration Project, San Francisco Bay, California—2017 Annual Report



Open-File Report 2018–1090

Cover: Photograph showing Forster's tern (*Sterna forsteri*) decoys deployed on Island 15 in Pond A16, Don Edwards San Francisco Bay National Wildlife Refuge, California, March 8, 2017. Photograph by Alex Hartman, U.S. Geological Survey.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)

Abbreviations

DENWR	Don Edwards San Francisco Bay National Wildlife Refuge
SBSP	South Bay Salt Pond
SE	standard error

Evaluation of Social Attraction Measures to Establish Forster's Tern (*Sterna forsteri*) Nesting Colonies for the South Bay Salt Pond Restoration Project, San Francisco Bay, California—2017 Annual Report

By C. Alex Hartman¹, Joshua T. Ackerman¹, Mark P. Herzog¹, Yiwei Wang², and Cheryl Strong³

Executive Summary

Forster's terns (*Sterna forsteri*), historically one of the most numerous colonial-breeding waterbirds in South San Francisco Bay, California, have had recent decreases in the number of nesting colonies and overall breeding population size. The South Bay Salt Pond (SBSP) Restoration Project aims to restore 50–90 percent of former salt evaporation ponds to tidal marsh habitat in South San Francisco Bay. This restoration will remove much of the historical island nesting habitat used by Forster's terns, American avocets (*Recurvirostra americana*), and other waterbirds. To address this issue, the SBSP Restoration Project organized the construction of new nesting islands in managed ponds that will not be restored to tidal marsh, thereby providing enduring island nesting habitat for waterbirds. In 2012, 16 new islands were constructed in Pond A16 in the Alviso complex of the Don Edwards San Francisco Bay National Wildlife Refuge, increasing the number of islands in this pond from 4 to 20. However, despite a history of nesting on the four historical islands in Pond A16 before 2012, no Forster's terns have nested in Pond A16 since the new islands were constructed.

In 2017, we used social attraction measures (decoys and electronic call systems) to attract Forster's terns to islands within Pond A16 to re-establish nesting colonies. We maintained these systems from March through August 2017. To evaluate the effect of these social attraction measures, we also completed waterbird surveys between April and August, where we recorded the number and location of all Forster's terns and other waterbirds using Pond A16, and monitored waterbird nests. We compared bird survey and nest monitoring data collected in 2017 to data collected in 2015 and 2016, prior to the implementation of social attraction measures, allowing for direct evaluation of social attraction efforts on Forster's terns.

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To increase the visibility and stakeholder involvement of this project, we engaged in multiple outreach activities, including the development of a project web site (<https://apps.usgs.gov/shorebirds/>) and educational video (<https://www.youtube.com/watch?v=-IaZD0YlAvM&feature=youtu.be>); publication of a popular article (<http://www.sfestuary.org/estuary-news-caspian-push-and-pull/>); and public presentations to relay findings to managers, stakeholders, and the general public.

The relative number of Forster's terns using Pond A16, after adjusting for the overall South San Francisco Bay breeding population each year, was higher during the nesting period in 2017 (after social attraction was used) than in 2015 and 2016 (before social attraction was used). Furthermore, in 2017, more Forster's terns were observed in the areas of Pond A16 where decoys and call systems were deployed during the pre-nesting and nesting periods. Although no Forster's tern nests were recorded in Pond A16 before (2015, 2016) or after (2017) implementation of social attraction measures, bird survey results indicate that Forster's terns were attracted to areas within Pond A16 where decoys and call systems were deployed, suggesting that terns may have been prospecting for future breeding sites. As social attraction efforts often benefit from multiple years of decoy and call system deployment, these first-year results suggest that continued implementation of social attraction measures could help to re-establish Forster's tern breeding colonies in Pond A16 and other areas of South San Francisco Bay.

Introduction

The South Bay Salt Pond (SBSP) Restoration Project aims to restore 50–90 percent of former salt evaporation ponds to tidal marsh habitat in South San Francisco Bay, California, including many wetlands within Santa Clara County (Goals Project, 1999). This restoration is expected to benefit the South San Francisco Bay ecosystem, including improved water quality, fish habitat, and flood protection. However, numerous waterbirds use former salt ponds for nesting and foraging habitat, and islands within these managed ponds are critically important nesting habitat (Strong and others, 2004; Hartman, Ackerman, and Herzog, 2016; Hartman, Ackerman, Takekawa, and others, 2016). For this reason, the remaining 10–50 percent of former salt ponds that are not being restored to tidal marsh habitat are being enhanced to support breeding, migratory, and wintering birds.

The primary pond enhancement feature has been the construction of islands to attract and support nesting birds. As part of the SBSP Restoration Project, 30 islands were constructed at Ravenswood Pond SF2 (near the west end of the Dumbarton Bridge) in 2010 at a cost of \$9 million, and 16 islands were constructed at Alviso Pond A16 in 2012 at a cost of \$4 million. Previous work has established the preferred location, size, shape, slope, and other features of islands that are well suited for nesting waterbirds (Hartman, Ackerman, and Herzog, 2016; Hartman, Ackerman, Takekawa, and others, 2016). However, since new island construction, there has been little use of these 50 newly constructed islands by nesting waterbirds, and no use by nesting Forster's terns (*Sterna forsteri*) at Pond A16, an at-risk species in San Francisco Bay that was a target species of the island construction.

Project Goals

Social attraction is a wildlife restoration technique whereby decoys of nesting birds, along with bird sound recordings, are deployed to look and sound like a real nesting colony in order to attract birds to nest at specific sites (Arnold and others, 2011; Jones and Kress, 2012). Because of their colonial nature, terns and many other seabirds are attracted to nesting sites by the presence of conspecifics, making the deployment of decoys and colony sound recordings a promising method for establishing new breeding colonies and re-establishing historical breeding colonies (Kress, 1983; Roby and others, 2002). We previously showed the effectiveness of social attraction measures (decoys and call systems) in establishing Caspian tern (*Hydroprogne caspia*) breeding colonies at locations in South San Francisco Bay where they had never bred previously (Hartman and others, 2017). In just 3 years, we increased the number of Caspian tern nests between two sites on the Don Edwards San Francisco Bay National Wildlife Refuge (DENWR) from zero to at least 664 nests following implementation of social attraction measures. The objective of this project was to implement similar social attraction measures targeting Forster's terns to re-establish the historically large breeding colony at Pond A16.

Forster's terns are an at-risk species in San Francisco Bay. In recent years, the breeding population of Forster's terns in South San Francisco Bay has decreased greatly, from more than 1,600 nests in 2010 to fewer than 500 nests in 2017 (J.T. Ackerman, M.P. Herzog, and C.A. Hartman, U.S. Geological Survey, unpub. data, 2018). Moreover, the number of large Forster's tern breeding colonies in South San Francisco Bay has decreased from 10–20 colonies historically to only 4 colonies in 2017. Some of these losses can be traced to loss of historical island nesting habitat due to changes in pond management associated with the SBSP Restoration Project. For example, large colonies of Forster's terns previously nested in Ponds A7 and A8 of the Alviso pond complex, but the islands in these ponds are now flooded, preventing nesting. Pond A16, also in the Alviso pond complex, historically supported about 200–300 Forster's tern nests annually (Ackerman and Herzog, 2012). However, in 2012, Pond A16 was temporarily drained to construct 16 new nesting islands, and no Forster's terns have nested in the pond since. Instead, Forster's terns have been nesting in New Chicago Marsh, which is directly adjacent to Pond A16 (fig. 1). However, New Chicago Marsh is a shallow-water marsh habitat that does not afford the same protection from terrestrial predators as islands within deep-water ponds, and waterbird nest success in New Chicago Marsh typically is low (Ackerman and others, 2014).

The colonial nature of Forster's terns, the fact that Pond A16 historically supported large numbers of breeding terns, and the large potential source population of terns in adjacent New Chicago Marsh make social attraction a viable restoration option for re-establishing Forster's tern breeding colonies in Pond A16. After nesting is established, these colony sites likely will be used for decades. Additionally, because the presence of nesting Forster's terns can attract other nesting waterbirds such as American avocets (*Recurvirostra americana*; Hartman, Ackerman, Takekawa, and others, 2016), re-establishing Forster's tern breeding colonies to Pond A16 also could increase use of Pond A16 by other nesting waterbirds.

In 2017, we implemented Forster's tern social attraction measures (decoys and call systems) in Pond A16 to re-establish breeding colonies. The objectives of this project were to:

1. Deploy and maintain social attraction measures (decoys and call systems) for Forster's terns on six islands within Pond A16;
2. Monitor and evaluate prospecting and nesting by Forster's terns and other waterbird species in Pond A16;
3. Conduct outreach activities to advertise the project and promote social attraction efforts as a tool for waterbird management in South San Francisco Bay, and to relay findings to managers, stakeholders and the general public.

Methods

Outreach to Stakeholders and the General Public

We did multiple outreach activities to promote our social attraction efforts as a tool for waterbird management in South San Francisco Bay, and to relay findings to managers, stakeholders, and the general public. These activities included the development of a project web site hosted by the U.S. Geological Survey, three public presentations, one publication of a popular article in a local outlet highlighting project activities, and two visits with local elementary school classes to explain the project and enlist students in painting tern decoys.

Social Attraction Measures for Forster's Terns

In early March 2017, we deployed Forster's tern social attraction measures (decoys and call systems) on six islands at the south end of Pond A16 of the DENWR (fig. 1). We chose these six islands based on their nearness to New Chicago Marsh, a site that in recent years has had numerous nesting Forster's terns but where nest success has been low because of easy access to nest sites by terrestrial predators. Thus, by placing decoys and call systems close to the adjacent New Chicago Marsh, Forster's terns nesting there may be attracted to nest instead in Pond A16. In addition to their nearness to New Chicago Marsh, we selected islands based on their size and shape. Forster's terns prefer linear-shaped and elongated islands to more rounded islands (Hartman, Ackerman, and Herzog, 2016). Five of the six islands in which we deployed decoys and call systems were elongated and highly linear (fig. 1).

We arranged 50 Forster's tern decoys spaced 1–1.5 m apart on each of the six islands (300 total decoys; figs. 2–4). Decoys (Duck Trap Woodworking, Lincolnville, Maine) were carved of wood and painted to resemble Forster's terns in an incubation posture (fig. 2). We installed a call system (Murremaid Music Boxes, South Bristol, Maine) on each of the six islands with decoys and broadcasted Forster's tern colony calls continuously through two omnidirectional outdoor speakers. Each call system was powered by two 6-volt Optima® AGM batteries and charged by a 135 W Kyocera® solar panel, enabling it to broadcast continuously throughout the breeding season. Call box and solar panels were deployed about 20 m from the decoy arrangement. The two omnidirectional speakers were deployed amongst the decoys and connected to the call box by speaker wire. We used a 30-minute recording of a Forster's tern colony recorded at Pond A16 in 2009 (Borker and others, 2014). Decoys and call systems, broadcasting on a continuous loop, remained on each island until they were retrieved in August.

In 2015, 2016, and 2017, we also deployed Caspian tern and western snowy plover (*Charadrius alexandrinus nivosus*) decoys and call systems on three islands on the north end of Pond A16 (fig.1).

Evaluating Forster's Tern Response to Social Attraction Implementation

Bird Surveys

We did biweekly bird surveys at Pond A16 beginning in early March 2017 (shortly after decoy and call system deployment) and continuing through August 2017. Surveys occurred in the early morning or early afternoon, with the time of day alternating during consecutive surveys (that is, one survey in the morning, and one survey in the afternoon each week). Each survey consisted of driving around the levee surrounding Pond A16 and stopping at five set vantage points (fig. 5) to record the number and location of all Forster's terns and other prominent waterbirds known to nest in South San Francisco Bay. Surveys were done using binoculars and a 20–60× spotting scope. We recorded bird locations by assigning each observation to 1 of 26, 250×250-m grid cells within Pond A16 (fig. 5). Each survey was completed within 60 minutes to limit double-counting of individuals and avoid biasing abundance estimates at each pond.

Nest Monitoring

We visited 18 of the 20 islands in Pond A16 weekly during the nesting season (April–June) to record nesting activity of Forster's terns, American avocets, and other waterbirds. We did not visit two islands (Island 11 and Island 12) at the north end of the pond owing to our ongoing study of Caspian terns on these islands (Hartman and others, 2017). During each island visit, we systematically searched for nests. For each new nest found, we recorded Universal Transverse Mercator coordinates and marked the nest with a uniquely numbered aluminum tag held in place just outside the nest bowl with a garden staple and a 40-cm flag placed 2 m north of the nest. We then revisited nests weekly until failure or hatch, and documented if the nest was active or inactive (abandoned or depredated), recorded the number of eggs in the nest, and floated eggs to determine the stage of development (Ackerman and Eagles-Smith, 2010).

Statistical Analyses

Forster's Tern Use of Pond A16 Before and After Social Attraction Implementation

For all analyses, we compared 2 years of data collected prior to implementation of Forster's tern social attraction measures (2015, 2016) to 1 year of data collected after implementation of Forster's social attraction measures (2017). From our bird-survey data, we calculated the high count of Forster's terns and American avocets observed in Pond A16 during each week of the breeding season (April–August) of 2015, 2016, and 2017. We then used general linear models to examine the fixed effects of month (April, May, June, July, and August) and year (2015, 2016, and 2017) on the number of Forster's terns or American avocets observed in Pond A16. However, we observed a substantial decrease in the total number of Forster's tern nests in South San Francisco Bay in 2017 relative to 2015 and 2016 (see section, “Results and Discussion”). Because the number of birds using Pond A16 in any given year is dependent on the number of birds present in South San Francisco Bay, we needed to account for the overall decrease in the Forster's tern population in South San Francisco Bay. We, therefore, adjusted the

number of Forster's terns observed during each survey by multiplying this value by the number of Forster's tern nests in South San Francisco Bay in 2017 divided by the total number of nests observed in South San Francisco Bay in each year. By making this adjustment, we examined the relative abundance of Forster's terns in Pond A16 after accounting for annual differences in the overall breeding population in South San Francisco Bay. As with terns, we adjusted the number of American avocets observed each year. We then evaluated the fixed effects of month, year, and a month \times year interaction on the adjusted number of Forster's terns and American avocets in Pond A16. Additionally, we compared the years 2015 and 2016 to 2017 during each of the months of April, May, June, July, and August, enabling us to test for differences in Forster's tern and American avocet numbers in Pond A16 before (2015, 2016) compared to after (2017) implementation of social attraction measures. Adjusted number of Forster's tern and American avocet values were not normally distributed, so we used a natural log data transformation to meet the assumption of normality.

Forster's Tern Use of Pond A16 Locations with and without Social Attraction

We did a second analysis in which we examined if Forster's tern use of the eight 250 \times 250-m grid cells within Pond A16 with decoys and call systems (fig. 5) varied before (2015, 2016) versus after (2017) implementation of social attraction measures. First, we assigned each grid cell in Pond A16 to one of two treatments: (1) with social attraction (grid cell included one or more islands with decoys and call systems deployed in 2017), or (2) without social attraction (grid cell did not include islands with decoys and call systems in 2017). We then tested whether the number of Forster's terns within grid cells varied by year (2015, 2016, or 2017), treatment (with social attraction or without social attraction in 2017), and a year \times treatment interaction. For this analysis, we only included April–June survey data, as this represents the pre-nesting and nesting periods for Forster's terns and other waterbirds in San Francisco Bay. We again adjusted the number of Forster's terns observed during a survey by the nesting population for that year. We also included two individual covariates (pond area and island area) that we hypothesized could influence Forster's tern use of a given grid cell, but we could not control for it in our experimental design. Although each grid cell was 250 \times 250 m, not all grid cells were solely within Pond A16 (fig. 5). Because we did not count Forster's terns outside Pond A16, grid cells with little area within Pond A16 could be expected to have fewer Forster's terns within them than grid cells completely within Pond A16. Additionally, the amount of island area may influence Forster's tern use of a particular grid cell, as cells with more island area may offer more nesting and roosting opportunities for terns. By including the pond area and island area of each grid as covariates, we accounted statistically for these differences. Grid cell survey data were not normally distributed and data transformation was not possible because of the large number of zeros. We, therefore, used a generalized linear mixed model with a Poisson distribution with the adjusted number of Forster's terns as the response variable and year, treatment, a year \times treatment interaction, and pond area (continuous covariate) and island area (continuous covariate) as fixed effects, and the individual grid cell as a random effect. We did two additional identical analyses, with either the adjusted number of American avocets as the response variable or the adjusted number of American avocet nests as the response variable. For the analysis of American avocet nests, we omitted 2015 data because only four nests, all in one grid cell, were recorded in that year. All analyses were done using SAS/STAT software (release 9.4, SAS Institute, Cary, North Carolina). We report back-transformed least squares means and estimated standard errors using the delta method (Seber, 1982).

Spatial Distribution of Forster's Tern Observations within Pond A16

We summed the total number of Forster's terns observed within each grid cell in Pond A16 between April and June (pre-nesting and nesting periods). We then calculated the proportion of all observations that occurred within each grid cell and plotted these proportions using ArcGIS™ 10.4.1 (Environmental Research Systems Institute, Redlands, California) to create maps of Forster's tern activity. In this way, we could ascertain whether Forster's tern distribution within Pond A16 during the pre-nesting and nesting periods was affected by the presence of social attraction measures.

Results and Discussion

Outreach to Stakeholders and the General Public

We engaged in eight outreach activities for this project, including development of a web site and an outreach video, three public presentations, one publication of a popular article, and two visits with local elementary school classes.

In June 2017, the story map web site entitled “Re-establishing Waterbird Breeding Colonies in San Francisco Bay” was published, and is accessible to the general public (<https://apps.usgs.gov/shorebirds/>; fig. 6). In addition to a detailed description of the Forster's tern social attraction project at Pond A16, the web site serves to place those efforts in the broader context of waterbird research, conservation, and management in South San Francisco Bay and the SBSP Restoration Project. The story map includes an overview of the benefits and challenges of the SBSP Restoration Project to breeding waterbirds, recommendations for the construction of nesting islands, descriptions and results of our social attraction efforts for Forster's terns and Caspian terns, as well as population changes and management of American avocets and California gulls (*Larus californicus*). Included in the Forster's tern social attraction component of the web site is an educational outreach video describing the need for the project and how it was implemented (available at <https://www.youtube.com/watch?v=IaZD0YIAvM&feature=youtu.be>).

We gave three presentations associated with our tern social attraction efforts in South San Francisco Bay. On March 23, 2017, we presented at the SBSP Restoration Project researchers and management team meeting at the DENWR where we gave updates on ongoing efforts to promote nesting by waterbirds in the SBSP Restoration Project area. On October 11, 2017, we presented an invited talk at the 13th Biennial State of the San Francisco Estuary Conference, entitled “Waterbird Nesting Ecology and Management in San Francisco Bay”. This conference focused on management and health of the San Francisco Bay-Delta Estuary and was attended by more than 800 people. Our presentation focused on the urgency of addressing the decreasing waterbird nesting populations in San Francisco Bay, the importance of island nesting habitat to waterbirds, and how social attraction can be an effective tool for establishing nesting colonies. On November 16, 2017, we presented a talk entitled “Using Social Attraction to Establish Tern Breeding Colonies in South San Francisco Bay” at the San Francisco Bay Bird Observatory Science Talk forum. This forum was attended by San Francisco Bay Bird Observatory staff, members, and the general public. Our presentation focused on our efforts in establishing Forster's tern and Caspian tern breeding colonies on the DENWR.

In February 2017, we visited two elementary schools to talk to students about waterbird conservation in San Francisco Bay and how social attraction can be used to attract birds to nest. We then worked with students in a hands-on activity of repainting tern decoys that were used in our Caspian tern social attraction efforts in 2017. This outreach effort gave young students a unique opportunity to contribute to waterbird conservation efforts close to home.

In June 2017, the article “Caspian Push and Pull” was published in Estuary News, a publication of the San Francisco Estuary Partnership (<http://www.sfestuary.org/estuary-news-caspian-push-and-pull/>). This article focused on our successful efforts using social attraction to establish tern nesting colonies in South San Francisco Bay, and our engagement of local schoolchildren in repainting decoys for our social attraction efforts.

Forster’s Tern Use of Pond A16 Before and After Social Attraction Implementation

We completed a total of 40 bird surveys at Pond A16 between April and August of 2017 and compared these data to surveys done over the same period in 2015 and 2016. The adjusted weekly high count of Forster’s terns observed in Pond A16 varied significantly by month ($F_{4, 56} = 2.97, P = 0.03$) and by the month \times year interaction ($F_{8, 56} = 4.09, P = 0.0007$). Least squares mean comparisons indicated that adjusted Forster’s tern numbers were greater ($F_{1, 56} = 7.50, P = 0.008$) after the implementation of social attraction measures (2017) than before implementation (2015, 2016) in May (fig. 7), the month during which Forster’s tern first begin nesting. Adjusted Forster’s tern numbers also were higher in April (fig. 7), but this difference was not statistically significant ($F_{1, 56} = 3.51, P = 0.07$). In contrast, adjusted Forster’s tern numbers were lower in 2017 during the post-nesting period in July ($F_{1, 56} = 7.61, P = 0.008$) and August ($F_{1, 56} = 8.91, P = 0.004$; fig. 7), likely due to the substantially smaller South San Francisco Bay nesting population in 2017 producing fewer juvenile terns, compared to 2015 and 2016.

The adjusted weekly high count of American avocets observed in Pond A16 varied by month ($F_{4, 53} = 9.41, P < 0.0001$) and year ($F_{2, 53} = 15.77, P < 0.0001$), but not by the month \times year interaction term ($F_{8, 53} = 1.99, P = 0.07$). Least squares mean comparisons indicated that adjusted American avocet numbers were lower after implementation of Forster’s tern social attraction measures (2017) than before (2015, 2016) in May, July, and August ($F_{1, 53} \leq 6.50, P \leq 0.01$; fig. 8).

Forster’s Tern Use of Pond A16 Locations with and without Social Attraction

We completed a total of 23 bird surveys at Pond A16 between April and June of 2017 (pre-nesting and nesting periods) and compared these data to surveys done over the same period in 2015 and 2016. The adjusted number of Forster’s terns observed within individual grid cells of Pond A16 during April–June varied by treatment (with social attraction in 2017 compared to without social attraction in 2017, $F_{1, 44} = 5.88, P = 0.02$) and by the amount of pond area within the grid cell ($F_{1, 44} = 5.84, P = 0.02$), but did not vary by year ($F_{2, 44} = 2.34, P = 0.11$), the amount of island area within the grid cell ($F_{1, 44} = 0.39, P = 0.54$), or the year \times treatment interaction ($F_{2, 44} = 2.61, P = 0.08$). Least squares mean comparisons indicated that in 2017, Forster’s tern numbers were 567 percent greater in grid cells where social attraction measures

were implemented than in grid cells where they were not implemented ($F_{1,44} = 8.20$, $P = 0.006$; fig. 9). However, Forster's terns also were more numerous during 2015 in grid cells where social attraction would be implemented in the future ($F_{1,44} = 5.09$, $P = 0.03$), but not during 2016 ($F_{1,44} = 0.02$, $P = 0.90$; table 1, fig. 9). A comparison of the spatial distribution of Forster's tern observations among years showed that birds occupied a smaller area closer to islands with social attraction measures in 2017 than they did in years prior to social attraction implementation (fig. 10).

The adjusted number of American avocets observed within individual grid cells of Pond A16 during April–June varied by year ($F_{2,42} = 11.96$, $P < 0.0001$), treatment ($F_{1,42} = 7.99$, $P = 0.007$), the year×treatment interaction ($F_{2,42} = 7.17$, $P = 0.002$), and the amount of island area within the grid cell ($F_{1,42} = 11.87$, $P = 0.001$), but not by the amount of pond area within the grid cell ($F_{1,42} = 0.00$, $P = 0.97$). Least squares mean comparisons indicated that in 2017, American avocet numbers were 326 percent greater in grid cells where Forster's tern social attraction measures were implemented than in grid cells where they were not ($F_{1,42} = 4.31$, $P = 0.04$; fig. 11). American avocets also were more numerous in grid cells where social attraction would be implemented in 2017 during the 2015 ($F_{1,42} = 15.32$, $P = 0.0003$) but not during the 2016 breeding seasons ($F_{1,42} = 3.43$, $P = 0.07$; table 1, fig. 11).

Waterbird Nests in Pond A16

No Forster's tern nests were recorded in Pond A16 before (2015, 2016) or after (2017) implementation of Forster's tern social attraction measures. There were four American avocet nests in Pond A16 in 2015, 89 nests in 2016 (before social attraction implementation) and 79 nests in 2017 (after social attraction implementation). During 2015–17, American avocets nested on all 6 islands where Forster's tern social attraction was implemented in 2017, and on 7 of the 14 islands where Forster's tern social attraction was not implemented in 2017, as well as on some mudflats between islands (in 2016 only; fig. 12). The adjusted number of American avocet nests within individual grid cells of Pond A16 varied by treatment ($F_{1,23} = 10.37$, $P = 0.004$), the year×treatment interaction ($F_{1,23} = 9.38$, $P = 0.006$), and the amount of island area within the grid cell ($F_{1,23} = 14.68$, $P = 0.0009$), but not by year ($F_{1,23} = 3.20$, $P = 0.09$) or the amount of pond area within the grid cell ($F_{1,23} = 0.43$, $P = 0.52$). Least squares mean comparisons indicated that before implementation of Forster's tern social attraction measures in 2016, the number of American avocet nests was 40 times greater within grid cells that would later receive Forster's tern decoys and call systems (2.8 ± 1.6 nests per grid cell) than within grid cells that would not receive them (0.07 ± 0.06 nests per grid cell, $F_{1,23} = 13.40$, $P = 0.001$). Similarly, after implementation of Forster's tern social attraction measures in 2017, the number of American avocet nests was 16 times greater within grid cells with Forster's tern decoys and call systems (1.3 ± 0.8 nests per grid cell) than within grid cells without them (0.08 ± 0.8 nests per grid cell; $F_{1,23} = 7.34$, $P = 0.01$). However, the number of American avocet nests within grid cells with Forster's tern social attraction was lower after implementation (2017— 1.3 ± 0.8 nests per grid cell) than before implementation (2016— 2.8 ± 1.6 nests per grid cell; $F_{1,23} = 10.26$, $P = 0.004$). Thus, although more American avocets nested in grid cells at the south end of Pond A16 before (2016) and after (2017) Forster's tern decoys and call systems were deployed, fewer American avocets nested overall after implementation. Additional years of social attraction implementation would help to determine if this decrease was due to the presence of the Forster's tern decoys and call systems or natural annual variation in nesting numbers.

Conclusions

Implementation of Forster's tern (*Sterna forsteri*) social attraction measures in 2017 led to changes in Forster's tern use of, and distribution within, Pond A16, in the Alviso complex of the Don Edwards San Francisco Bay National Wildlife Refuge, South San Francisco Bay, California. Compared to 2015 and 2016 (before implementation), the relative abundance of Forster's terns was higher in 2017 during May when Forster's terns first begin prospecting for nest sites and initiating nests. Moreover, Forster's terns were much more prevalent in the areas of Pond A16 where social attraction measures were implemented during the pre-nesting and nesting periods in 2017 than in areas where it was not implemented. Furthermore, the overall distribution of Forster's terns within Pond A16 was more localized to the areas of the pond where social attraction was implemented (the southern and southeastern ends of the pond) in 2017, whereas Forster's terns were more dispersed throughout the pond in 2015 and 2016. Taken together, these results suggest that implementation of social attraction measures was successful in attracting prospecting Forster's terns to Pond A16, and specifically to the areas of Pond A16 where decoys and electronic call systems were present.

We observed little evidence of changes in American avocet (*Recurvirostra americana*) use of or distribution within Pond A16 following implementation of Forster's tern social attraction measures in 2017. However, we observed differences in the number of and distribution of American avocet nests. First, the nesting population of American avocets in Pond A16 decreased slightly from 2016 to 2017. Second, there were fewer avocet nests per grid cell with Forster's tern decoys and call systems after implementation (1.3 nests per grid cell) than before implementation (2.8 nests per grid cell). However, even with this decrease observed after implementation, there were still considerably more avocet nests per grid cell with Forster's tern decoys and call systems (1.3 nests per grid cell) than without them (0.8 nest per /grid cell). American avocets in San Francisco Bay often are drawn to areas where there are nesting Forster's terns, and the presence of Forster's tern decoys and calls in Pond A16 may have had a similar effect.

Although Forster's tern decoys and calls were not successful in establishing Forster's tern breeding colonies in the first year (2017) of this effort, the observed changes in Forster's tern use of Pond A16 are encouraging and suggest that continued deployment of social attraction measures can help to establish breeding colonies. Establishment of waterbird breeding colonies using social attraction does not typically occur immediately, and often benefits from multiple years of effort. For example, in coastal Maine, social attraction measures (decoys and calls) were first deployed in 1978 in an attempt to re-establish arctic tern (*Sterna paradisaea*), as well as common tern (*S. hirundo*), nesting colonies on Eastern Egg Rock, a major historical nesting site on which terns had not bred since the 1930s. In the first year of the effort, tern sightings on Eastern Egg Rock nearly doubled, but the first nests were not recorded until 1980, the third year of the effort. By 1983, 5 years after the project started, more than 1,000 terns were nesting on Eastern Egg Rock, making it the largest common tern breeding colony in Maine. Repeatedly exposing Forster's terns to social attraction efforts in subsequent years may similarly lead to the re-establishment of breeding colonies at Pond A16.

In 2017, we observed a substantial decrease in the number of large Forster's tern breeding colonies (from 10 to 20 in previous years to only 4 in 2017) and the overall Forster's tern breeding population (from more than 1,600 in 2010 to fewer than 500 in 2017) in South San Francisco Bay. Some of this decrease may be linked to the loss of historical island nesting habitat due to the conversion of managed ponds to tidal action as part of the South Bay Salt Pond (SBSP) Restoration Project. As future phases of the SBSP Restoration Project convert more managed ponds to tidal action, and the islands within these ponds are lost, Forster's tern nesting opportunities will become even more limited, potentially reducing the breeding population further. The decreasing Forster's tern breeding population, and the projected loss of additional nesting habitat, highlights the urgency in re-establishing colonies at historical nesting sites such as Pond A16 that will continue to be managed as ponds into the future. Increased Forster's tern uses of Pond A16 after only 1 year of social attraction, as well as the successful establishment of Caspian tern (*Hydroprogne caspia*) breeding colonies in a related effort, suggest that social attraction is a viable means for re-establishing Forster's tern breeding colonies in South San Francisco Bay.

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Table 1. Back-transformed least squares mean number of Forster's terns, adjusted number of Forster's terns, number of American avocets, adjusted number of American avocets, and adjusted number of American avocet nests observed April–June per 250-by-250-meter grid cell in Pond A16, Don Edwards San Francisco Bay National Wildlife Refuge, California, before (2015, 2016) and after (2017) implementation of Forster's tern social attraction measures.

[Least squares means were generated from a generalized linear mixed model with a Poisson distribution in which year, treatment (grid cell contained islands with Forster's tern social attraction measures in 2017 or grid cell did not contain islands with Forster's tern social attraction measures in 2017), a year×treatment interaction, the amount of pond area within each grid cell (continuous covariate) and the amount of island area within each grid cell (continuous covariate) were fixed effects, and grid cell was a random effect. The estimated breeding population size was used to calculate the adjusted number of birds (see body text for details).]

Per grid cell	¹ 2015		¹ 2016		² 2017	
	Social attraction in 2017	No social attraction in 2017	Social attraction in 2017	No social attraction in 2017	Social attraction in 2017	No social attraction in 2017
Number of Forster's terns	0.87	0.06	0.54	0.36	1.02	0.12
Adjusted number of Forster's terns	0.47	0.05	0.24	0.22	1.11	0.17
Number of American avocets	1.45	0.09	2.69	0.79	1.87	0.45
Adjusted number of American avocets	2.44	0.15	2.97	0.87	1.86	0.44
Adjusted number of American avocet nests	³ 0.50	³ 0	2.85	0.07	1.33	0.08

¹Year before Forster's tern social attraction implemented.

²Year after Forster's tern social attraction implemented.

³These are not least-squares mean estimates, but rather raw averages per grid cell. Only four American avocet nests were recorded in Pond A16 in 2015, all on one island where Forster's tern social attraction would be deployed in 2017.



Figure 1. Location of New Chicago Marsh, and Alviso Pond 16 where 50 Forster's tern decoys and one electronic call system were deployed on each of six islands (islands 14–18 and 20, shown in blue), Don Edwards San Francisco Bay National Wildlife Refuge, California, 2017 breeding season. Decoys and call systems for Caspian terns were deployed on islands 11 and 12, shown in orange) and for western snowy plovers were deployed on island 3 (shown in brown), 2015–17.



Figure 2. Forster's tern decoys deployed on Island 15 in Pond A16 (see fig. 1 for location), Don Edwards San Francisco Bay National Wildlife Refuge, California, 2017. Photograph by Alex Hartman, U.S. Geological Survey, March 8, 2017.



Figure 3. Forster's tern decoys and electronic call system with solar panel array deployed on Island 15 in Pond A16 (see fig. 1 for location), Don Edwards San Francisco Bay National Wildlife Refuge, California, 2017. Photograph by Alex Hartman, U.S. Geological Survey, March 8, 2017.



Figure 4. Forster's tern decoys and electronic call system with solar panel array deployed on Island 17 in Pond A16 (see fig. 1 for location), Don Edwards San Francisco Bay National Wildlife Refuge, California, 2017. Photograph by Crystal Shore, U.S. Geological Survey, March 13, 2017.

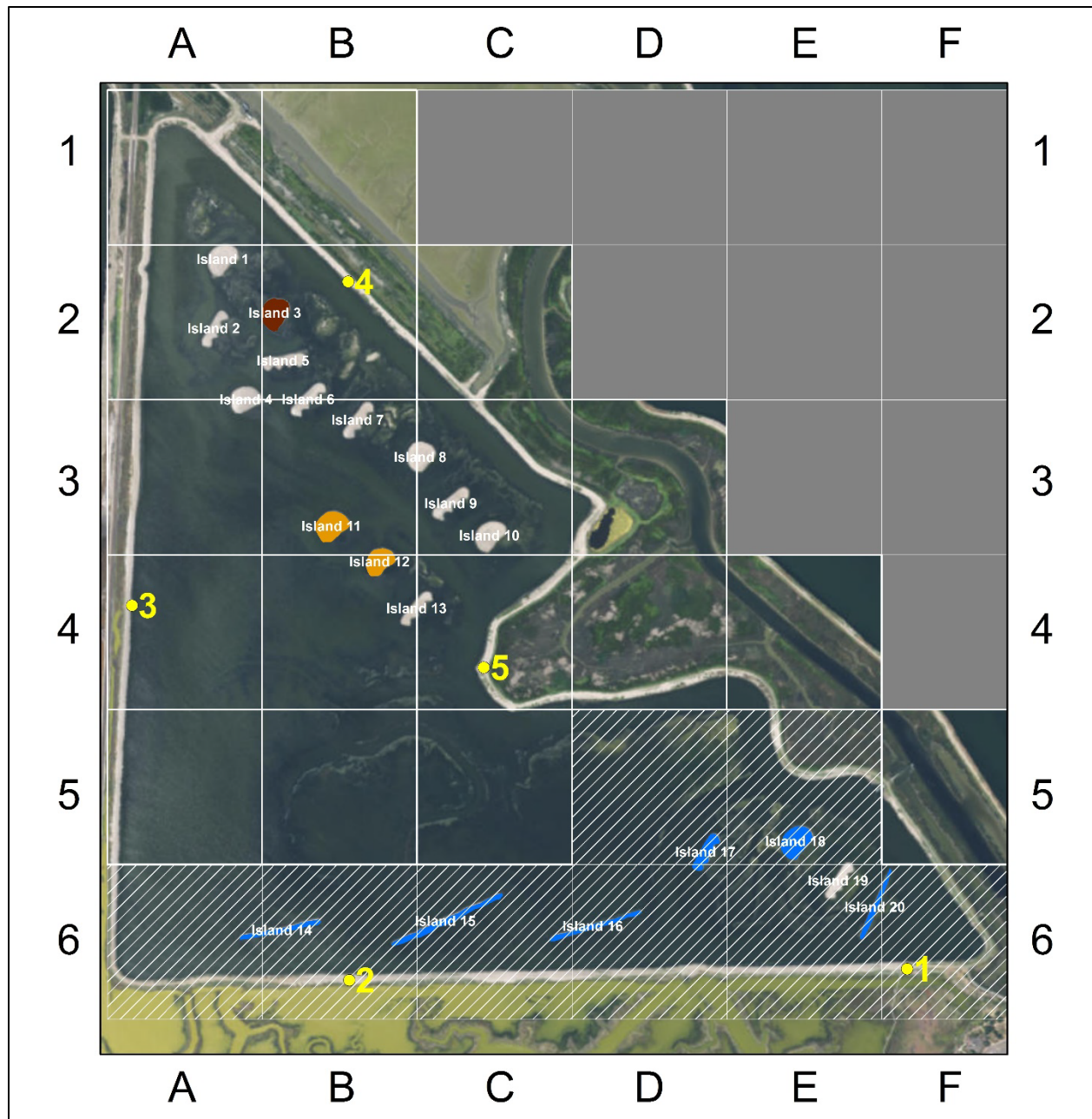


Figure 5. Location of five vantage points (numbered yellow dots) used to count number and location of Forster's terns during pond surveys, in Pond A16, Don Edwards San Francisco Bay National Wildlife Refuge, California, 2017 breeding season. Square grid cells are 250 by 250 meters. Islands 11 and 12 (shown in orange) were used for Caspian tern social attraction, and island 3 (shown in brown) was used for western snowy plover social attraction. Grid cells with white hatching indicate those containing islands with Forster's tern decoys and call systems in 2017. Observations in grid cells completely outside Pond A16 (shown in gray, upper right side) were not included.

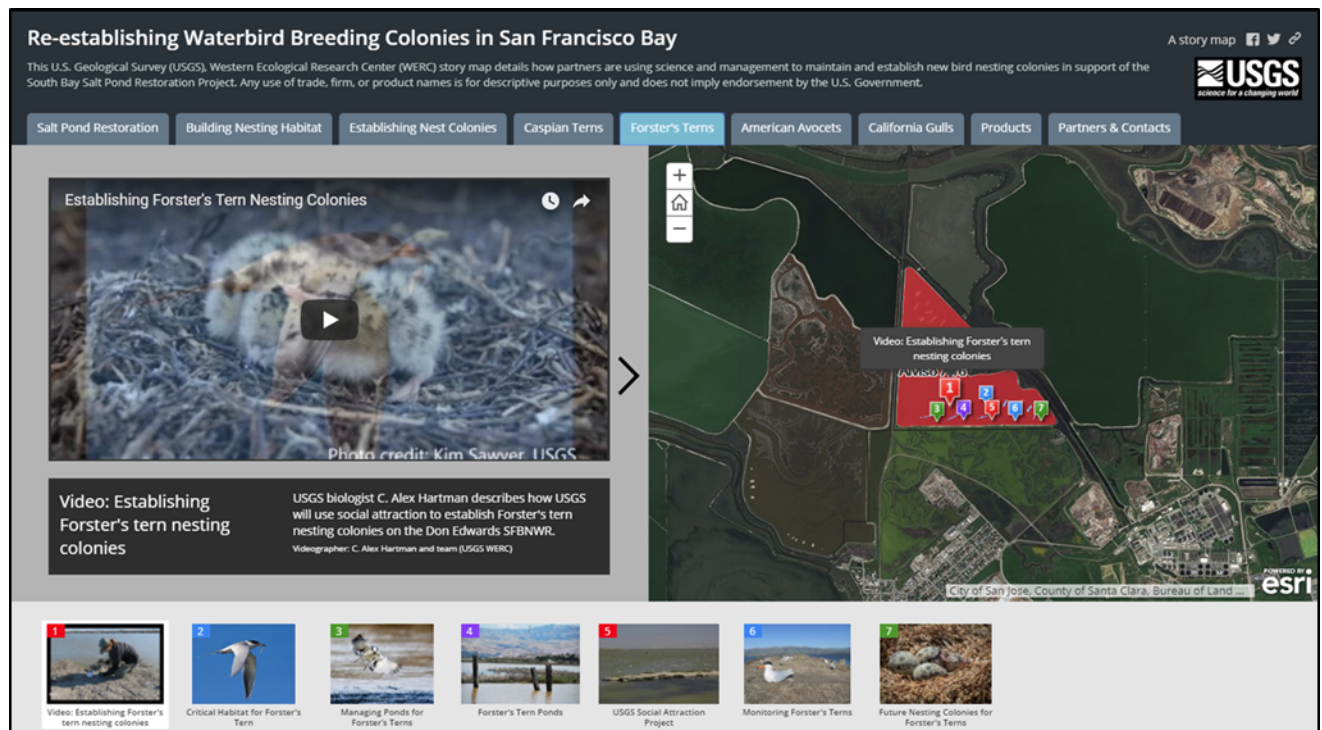


Figure 6. U.S. Geological Survey story map web site (<https://apps.usgs.gov/shorebirds/>) and imbedded video documentary detailing the Forster's tern social attraction project in the broader context of breeding waterbird research and management in South San Francisco Bay, California.

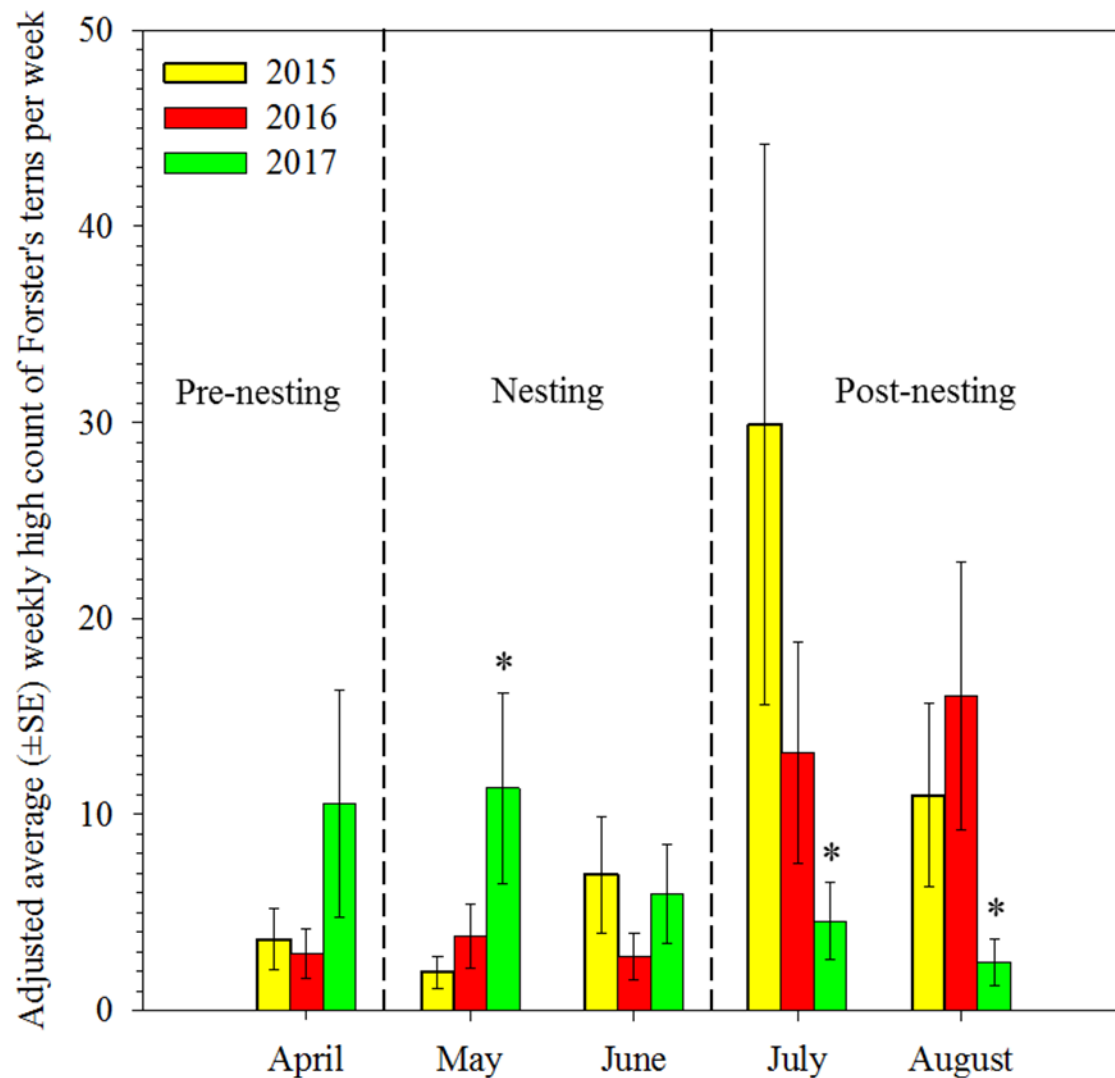


Figure 7. Adjusted average (plus or minus standard error [\pm SE]) weekly high count of Forster's terns at Pond A16 before (2015, 2016) and after (2017) implementation of social attraction measures (Forster's tern decoys and calls) by month during the pre-nesting, nesting, and post-nesting periods, Don Edwards San Francisco Bay National Wildlife Refuge, California. Asterisks denote months in which the average number of Forster's terns was significantly different after implementation of social attraction measures.

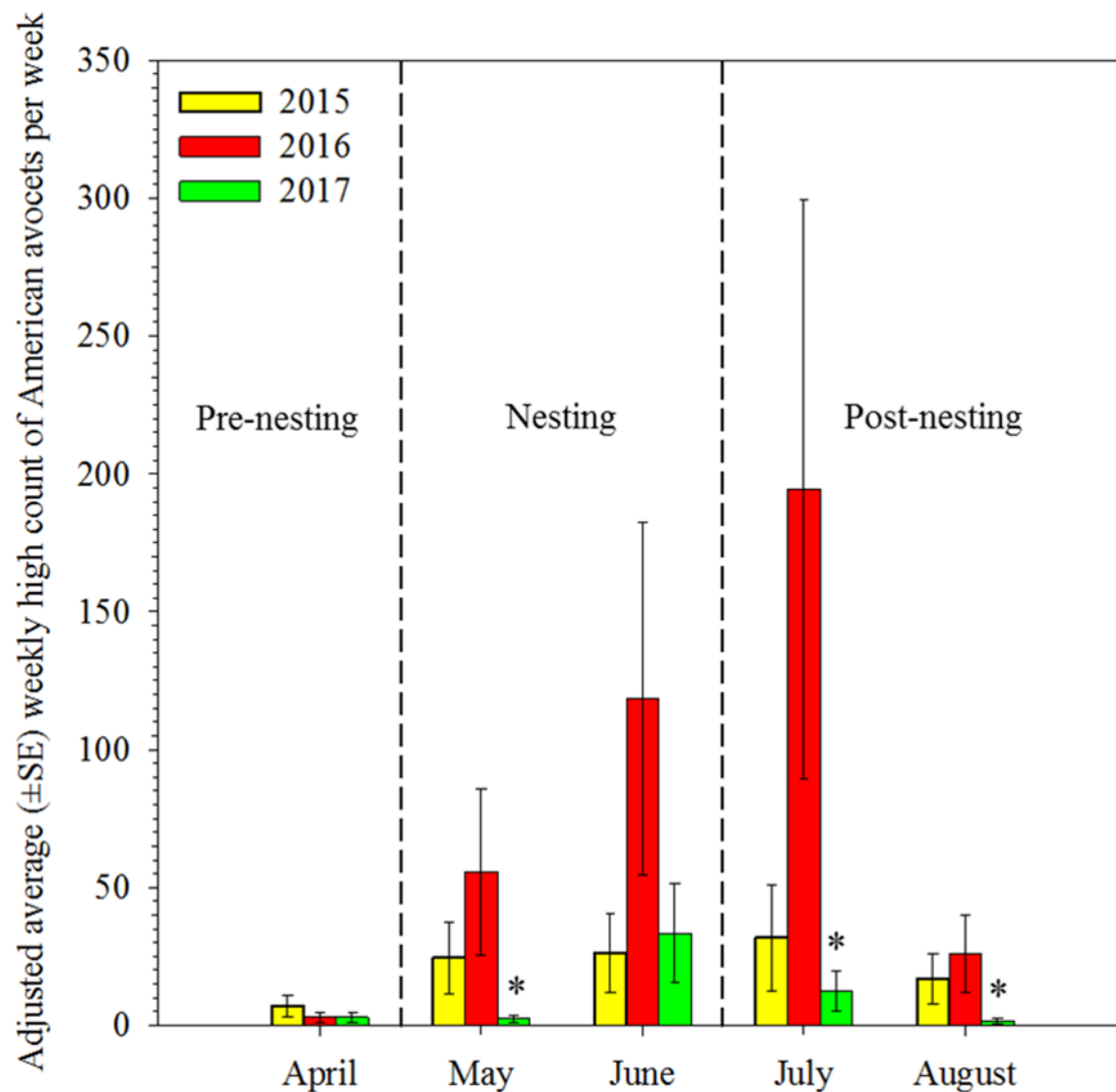


Figure 8. Adjusted average (plus or minus standard error [\pm SE]) weekly high count of American avocets at Pond A16 before (2015, 2016) and after (2017) implementation of social attraction measures (Forster's tern decoys and calls) by month during the pre-nesting, nesting, and post-nesting periods, Don Edwards San Francisco Bay National Wildlife Refuge, California. Asterisks denote months in which the average number of American avocets was significantly different after implementation of social attraction measures.

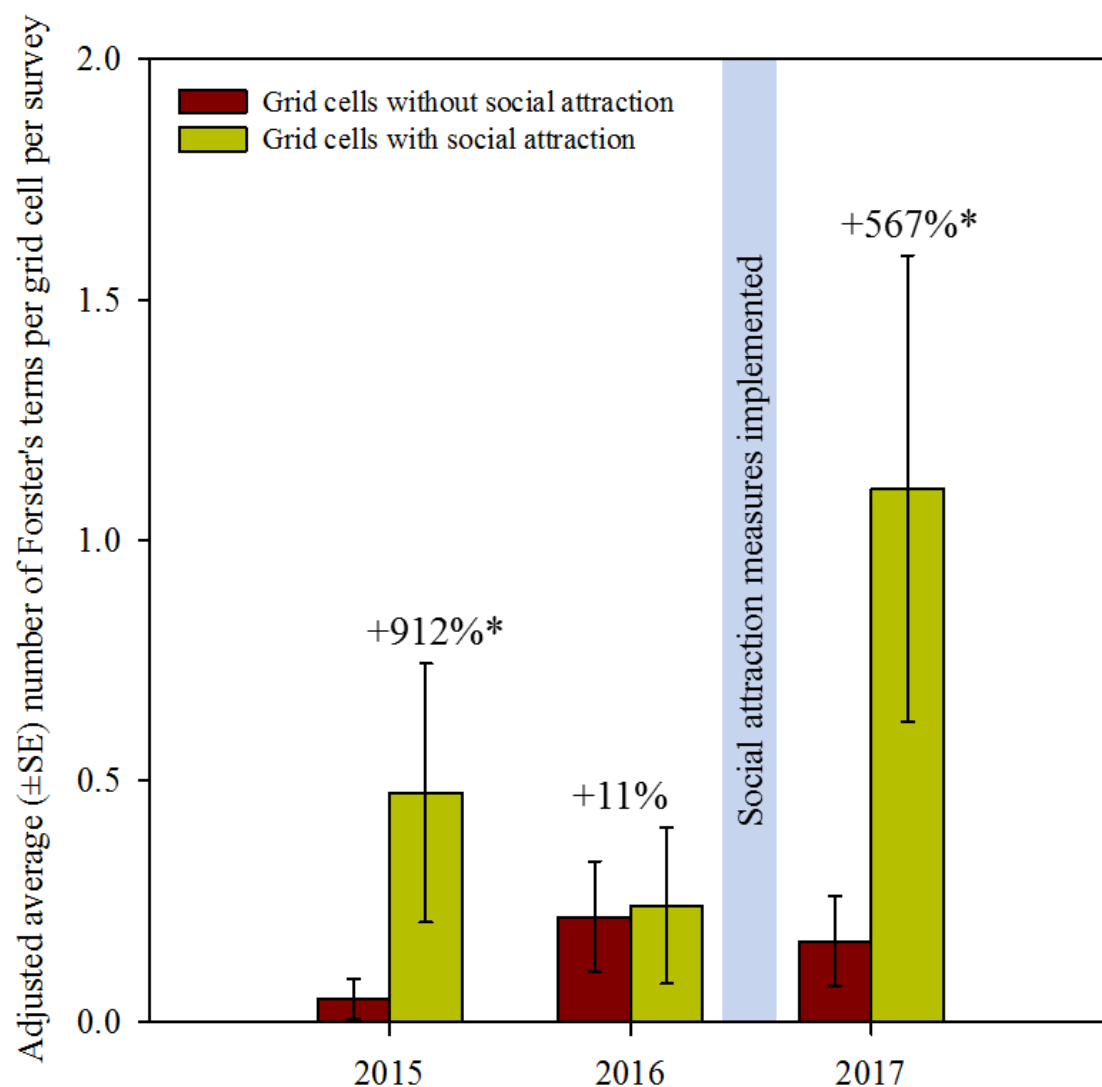


Figure 9. Adjusted average (plus or minus standard error [\pm SE]) number of Forster's terns per grid cell per survey at Pond A16 before (2015, 2016) and after (2017) implementation of social attraction measures (Forster's tern decoys and calls) during the pre-nesting and nesting periods (April–June), Don Edwards San Francisco Bay National Wildlife Refuge, California. Asterisks denote years in which the number of Forster's terns in grid cells that received social attraction measures in 2017 was significantly different from grid cells that did not.

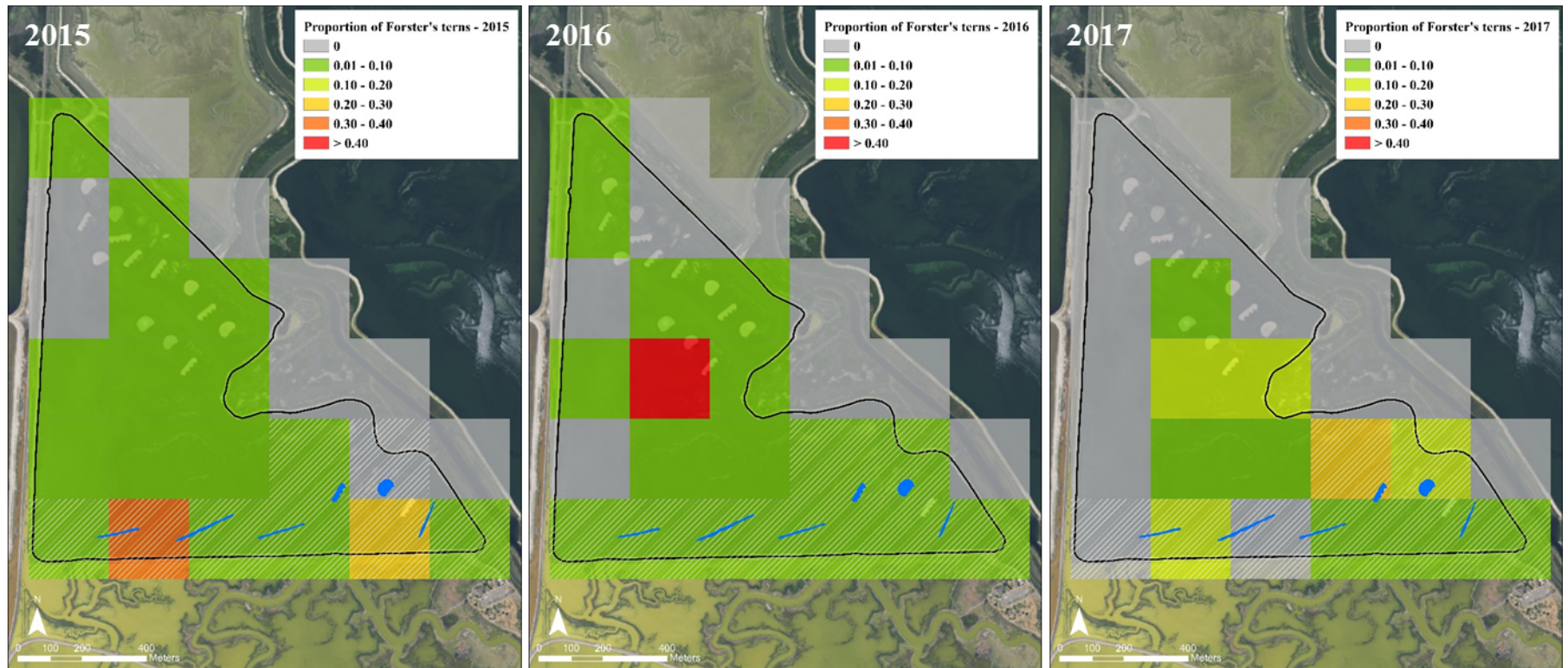


Figure 10. Proportion of all Forster's terns observed within each individual 250-by-250-meter grid cell in Pond A16 during the pre-nesting and nesting periods (April–June) before (2015, 2016) and after (2017) implementation of Forster's tern social attraction measures (decoys and calls) on six islands (shown at bottom of each image), Don Edwards San Francisco Bay National Wildlife Refuge, California. The black line denotes the Pond A16 boundary. Grid cells with white hatching (at south end of the pond) denote those cells containing islands where Forster's tern social attraction measures were implemented in 2017.

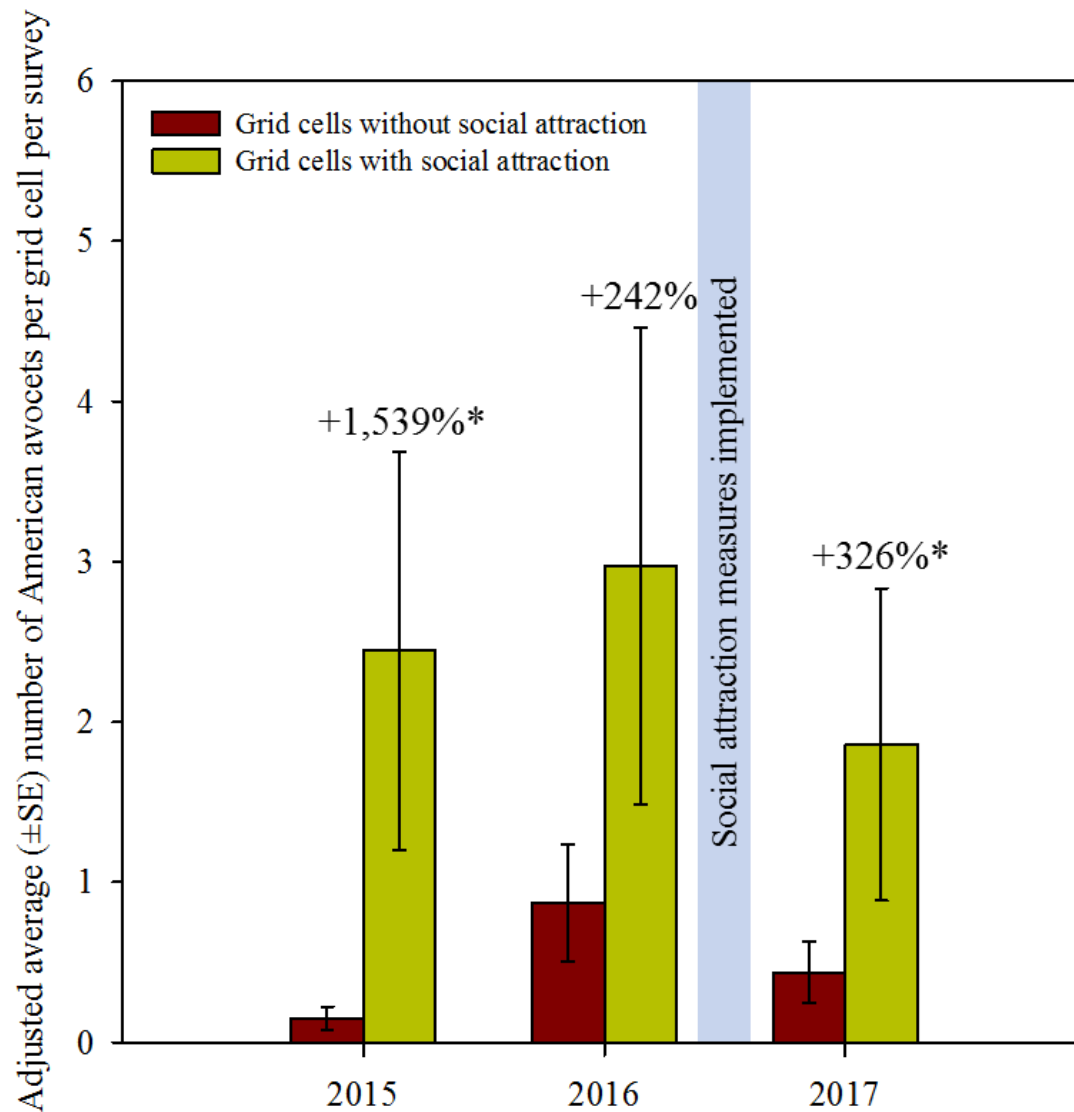


Figure 11. Adjusted average (plus or minus standard error [\pm SE]) number of American avocets per grid cell per survey at Pond A16 before (2015, 2016) and after (2017) implementation of social attraction measures (Forster's tern decoys and calls) during the pre-nesting and nesting periods (April–June), Don Edwards San Francisco Bay National Wildlife Refuge, California. Asterisks denote years in which the number of American avocets in grid cells that received social attraction measures in 2017 was significantly different from grid cells that did not.

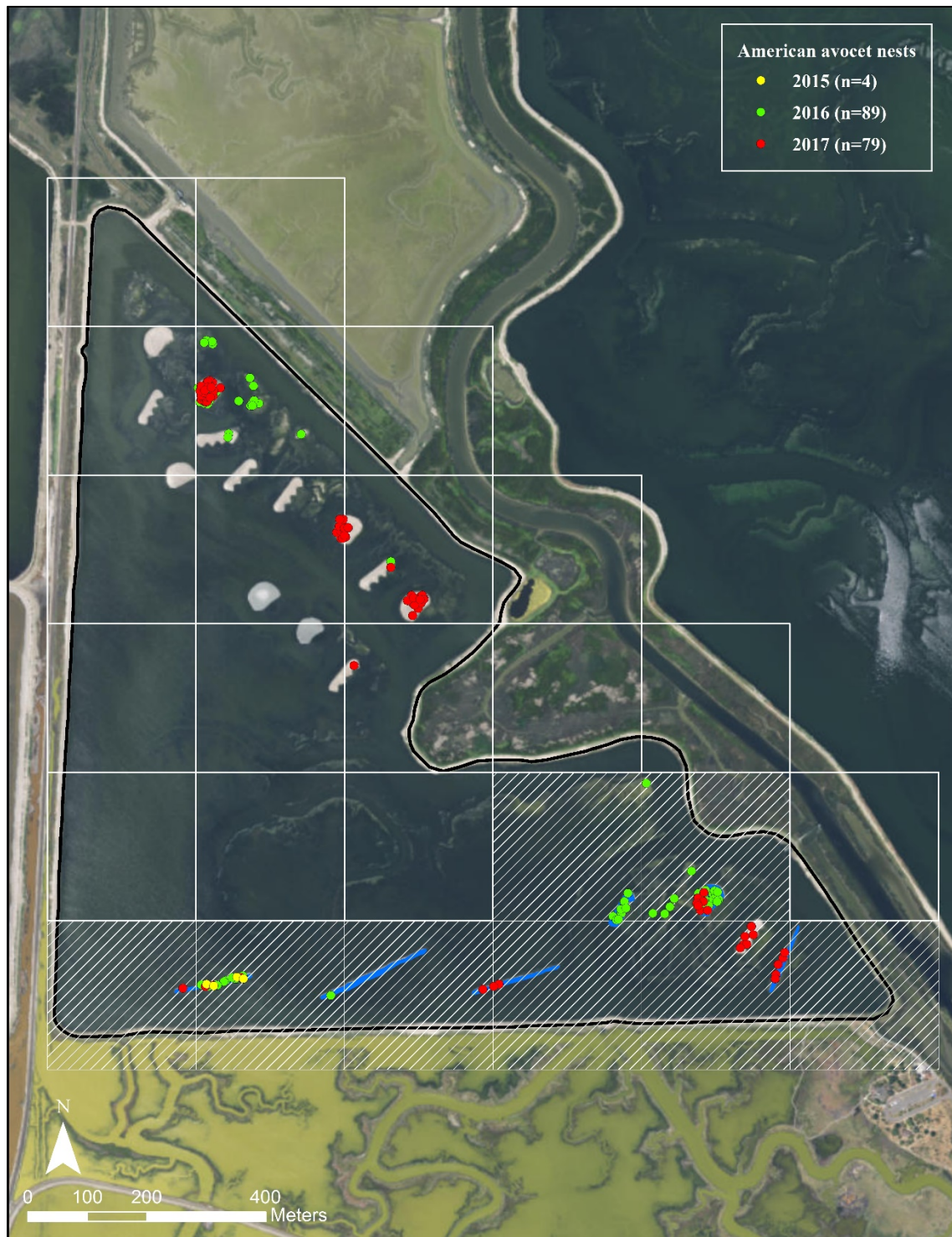


Figure 12. American avocet nest locations in Pond A16 before (2015, 2016) and after (2017) implementation of Forster's tern social attraction measures (decoys and calls), Don Edwards San Francisco Bay National Wildlife Refuge, California. Grid cells with white hatching (at south end of the pond) denote those containing islands where Forster's tern social attraction measures were implemented in 2017.

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