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Hypersaline spray increases habitat heterogeneity and nesting density in an island-nesting seabird

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Abstract

Seabirds introduce aquatically-derived nutrients into their terrestrial nesting environments, often leading to vegetative overgrowth that degrades nesting habitat suitability over time. In this study we capitalized upon the process of salt suppression that naturally occurs in salt-spray plant communities in order to reintroduce habitat heterogeneity (the mix of open substrate and plant cover) on a common tern (*Sterna hirundo*) breeding colony in the Gulf of Maine. In 2019, we randomly assigned hypersaline spray and control treatments within 10 experimental blocks across the site, and recorded plant community and seabird reproductive responses. We compared the habitat heterogeneity resulting from salt treatment to estimates of optimal habitat heterogeneity measured within productivity monitoring areas at this site during 2016–2020. We observed an average reduction of approximately 24% plant cover in hypersaline plots relative to control plots ($t_{18} = -5.56$, $p < 0.001$), constituting a substantial increase in nesting habitat heterogeneity. Common tern nesting density was 80% higher in treatment plots relative to controls ($t_{18} = 2.6$, $P = 0.020$), yielding 88% more chicks hatched per square meter ($t_{18} = 3.3$, $P = 0.004$). We suggest that the application of hypersaline spray may serve as an effective and practical habitat management technique in management-dependent systems such as tern nesting colonies.

KEYWORDS
common tern, Gulf of Maine, habitat management, plant cover, salt, *Sterna hirundo*

Colonial waterbirds, including island-nesting seabirds, introduce large quantities of aquatically-derived nutrients into their terrestrial nesting environments. Nutrient introduction occurs through the deposition of feces, discarded prey items, and carcasses of dead adults and chicks at the nesting colony. Introduction of allochthonous nutrients can alter community and ecosystem structure, including shifts in plant and arthropod communities and soil pH and moisture (Anderson and Polis 1999, Sanchez-Pinero and Polis 2000, Ellis 2005, Craig et al. 2012). In many instances, the introduction of nitrogen and phosphorous leads to fertilization of plant growth and resulting increases in above ground biomass.

Ground-nesting seabirds rely on islands and mainland beaches and marshes for nesting habitat during the breeding season. Among ground-nesting seabirds, terns (Sternidae) nest in open or heterogenous nesting environments (consisting of a mix of open substrate and vegetative cover) in order to successfully raise young. Common terns (*Sterna hirundo*) are ground-nesting seabirds that require low-lying vegetation or bare substrate on which to lay their eggs, relying on open habitat structure to allow for aerial access to the nest during the breeding season (Burger and Gochfeld 1988, Ramos and del Nevo 1995). During the chick-rearing period in June and July, however, developing chicks rely on nearby vegetative cover to provide protection from predators and shade for thermoregulation (Severinghaus 1982, Nisbet et al. 2017). As such, a heterogenous nesting environment consisting of a mix of open or bare substrate and vegetation is most suitable for many ground-nesting seabirds like terns.

Across the common tern's breeding range in North America, declines in available nesting habitat have occurred largely due to coastal development and competition with other species for limited islands and protected coastal marshes and beaches (Kress and Hall 2004, Nisbet et al. 2017). Conservation efforts are currently focused on protecting and improving the productivity of a few existing tern colony sites, as colonies can no longer easily relocate to new islands if conditions deteriorate (namely from the attraction of predators and overgrowth of vegetation). Conservation management action has resulted in sustained nesting activity at the same colony sites over successive years or decades in many cases, yielding large cumulative inputs of nutrients over time. Resulting changes in nesting habitat can produce unsuitable nesting conditions with regards to plant cover and height (Anderson and Polis 1999, Sanchez-Pinero and Polis 2000, Ellis 2005) in which terns experience difficulty accessing the nest to incubate eggs and provision chicks, eventually leading to nest failure. To allow for ongoing reproductive success at protected colony sites, the nesting environment must be occasionally or regularly managed to reduce vegetative growth and cover and thereby reestablish the nesting habitat heterogeneity that these seabirds require.

Managers have employed a diversity of habitat management techniques in order to maintain optimal breeding conditions and alleviate space limitation and competition at seabird colony sites (Kress and Hall 2004). A recent survey of seabird colony managers in North America and Europe reported the use of 12 distinct management techniques (including herbicide, manual removal, burning, grazing, weed-blocking, filling, and replanting), resulting in varying degrees of effectiveness (Lamb 2015). Management methods also exhibit trade-offs with regards to expense, intensiveness of time and effort, environmental impact, and disruptiveness to nesting activity during the breeding season. However, a lack of consistent pre- and post-treatment documentation has made it difficult to directly compare the efficacy of management methods. Nesting colonies occur in environments with a wide range of substrates and topography, ranging from low-lying marshes and sandy beaches to rocky offshore islands, and environmental variability leads to further differences in the effectiveness and suitability of habitat management techniques. Although managers must select amongst management alternatives to fit individual colony conditions on a site-by-site basis, the application of a combination of methods at a single site results in greater effectiveness than any one technique used in isolation (Burbidge 2008, Lamb 2015).

The influence of salt spray on the makeup and distribution of coastal plant communities has been well documented in coastal Atlantic environments and worldwide (Wells and Shunk 1938, Boyce 1954, Boden 1977, Du and Hesp 2020). Salt spray communities, much like lower lying salt marsh habitats, exhibit patterns linked to soil salinity regimes that typically follow predictable gradients. Salt stressed soils suppress the growth of plants by impacting beneficial soil microorganisms (Paul 2012). Salinity also impacts germination success of many coastal plant species (Burdick et al. 2017) and the combined effects of soil salinization from salt spray and prevailing wind selects for low growing or

prostrate growth forms seen in coastal maritime islands (Wells and Shunk 1938, Griffiths 2006, Nichols and Nichols 2008). Plants of lower elevation, coastally exposed areas tend to have lower overall height and limited species richness compared to interior sites (Boden 1977, McMaster 2005). Soil salinity has been shown to affect coastal plant cover, growth, and form (Boyce 1954, Howes et al. 1986, Chambers et al. 2003) and further experimental work has shown that artificially increasing salinity decreases stem height and stem density in tidal marshes (Burdick et al. 2017). Building upon environmental factors already influencing plant communities, anthropogenic introduction of saline and hypersaline water can be used to bolster natural vegetative suppression processes. Given the natural vegetation suppression effects of salt spray on coastal plant communities, the anthropogenic introduction of salt inland from existing rocky barrens and salt spray communities may serve as an effective, inexpensive, and low impact means of enhancing habitat heterogeneity in coastal nesting environments. We are aware of at least one occasion upon which salt application was employed to manage nesting habitat at a tern colony, although the results of the management action were not quantified in terms of the plant community response (Kress 1986, Lamb 2015).

In our study we evaluated the effectiveness of applying hypersaline seawater spray on a tern colony that has been consistently active for over 20 years. Our goals were to enhance nesting habitat heterogeneity by increasing the relative proportion of unvegetated, open habitat in treated areas, to evaluate the quality of managed nesting habitat by monitoring reproductive output of terns nesting in those areas, and to evaluate the management outcomes in the context of optimal nesting habitat heterogeneity at this site.

STUDY AREA

We conducted our study on White and Seavey Island, NH, USA (42°58′06.9″N 70°37′29.5″W), an approximately 2.5 ha island at the southern extent of the Isles of Shoals archipelago, located approximately 12 km from the mouth of the Piscataqua River in the Gulf of Maine (Figure 1). The island is owned by the New Hampshire Department of

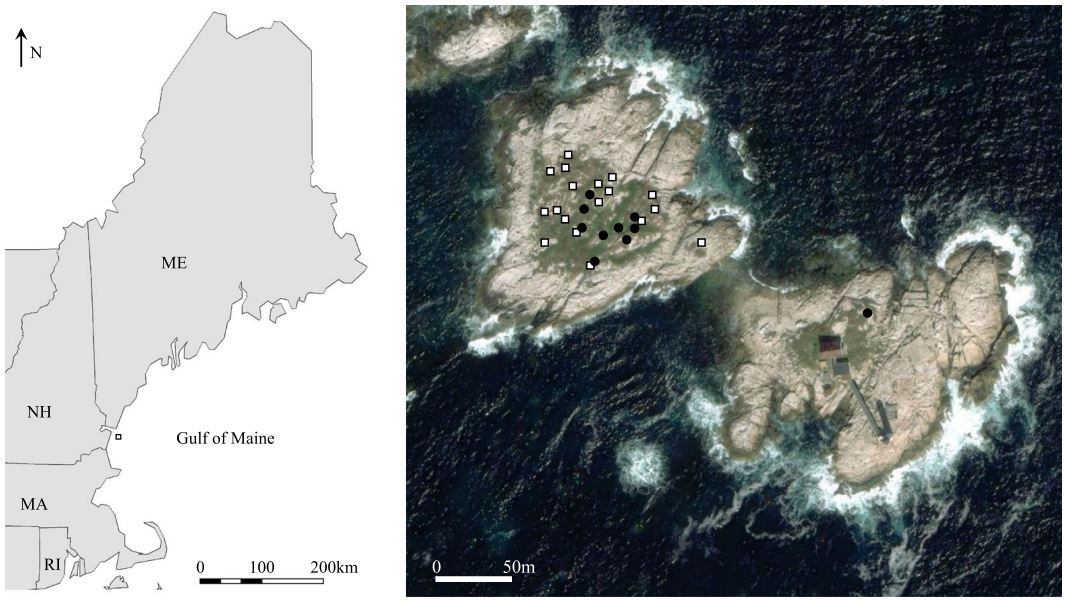

FIGURE 1 Left: map of the Gulf of Maine region with White and Seavey Island, NH, USA located within the open box. Right: aerial image of White and Seavey Island with locations of common tern (*Sterna hirundo*) habitat management blocks indicated by black circles and productivity-monitoring areas indicated by white squares.

Natural and Cultural Resources and is managed and protected as an endangered species nesting area by the New Hampshire Fish and Game Department's Nongame and Endangered Wildlife Program. Since 1997, the island has supported a mixed-species breeding colony of terns, which currently includes common terns (*Sterna hirundo*; listed as threatened in NH; 2,900 nesting pairs in 2019), roseate terns (*S. dougallii*; listed as endangered federally and in NH; 61 nesting pairs in 2019), and Arctic terns (*S. paradisaea*; listed as special concern in NH; one nesting pair in 2019).

White and Seavey Island contains 3 natural community types, including maritime intertidal rocky shore, rocky barren, and meadow habitats (Nichols and Nichols 2008), the latter 2 of which contain vascular plants and support tern nesting activity. Research by Nichols and Nichols (2008) revealed that this island hosts a total of 58 vascular taxa, comprised of 8 shrub and 50 herbaceous species split evenly between native (29) and nonnative plant species (29). Although there has been no direct evaluation of native vs. nonnative plant species at the site with regards to preferability or quality as nesting habitat for terns, maintenance of the native plant community and reduction in invasive plant growth have been identified as management goals alongside the restoration of tern nesting habitat on White and Seavey Island (Burbidge 2008).

METHODS

During the summer of 2019 we assigned habitat treatments using a randomized block design. We established 10 blocks in vegetated areas of the nesting colony that had been observed during the previous breeding season to exhibit low nesting density of common terns. Blocks were also limited to areas with no recent nesting activity of roseate terns, as we aimed to enhance nesting conditions for common terns without disturbing roseate tern nesting habitat. Common tern nesting areas consisted primarily of meadow habitat and meadow/rocky barren interface. Treatment types included a control treatment and a hypersaline seawater treatment, described below. We randomly assigned experimental plots of 0.5 m^2 within each block, with one replicate of each treatment type per block. Each plot was located a minimum of 1-m distance from any other plot to minimize the potential for salt intrusion on neighboring plots (Figure 1).

We applied hypersaline spray in May 2019 before terns established nests on the colony site. At each plot, we mechanically removed any existing vegetative growth within 2.5 cm of the ground using pruning shears or a motorized string trimmer. For the hypersaline treatment, we sprayed approximately 7.5 L (15 L/m^2) of saltwater with salinity of 100 (created by adding 700 g of table salt to 7.5 L of seawater) directly onto the confines of each treatment plot using a hand-pressurized sprayer. We selected the salinity applied in this treatment as a result of a pilot trial conducted at our study site in 2018 using ambient salinity seawater (salinity of 30–33) and hypersaline seawater (salinity of 70), both of which led to minor but not statistically significant reductions in plant growth relative to control plots (E. C. Craig and G. E. Moore, University of New Hampshire, unpublished data). We repeated hypersaline spray applications once per week for 2 weeks (2 applications in total), after which time terns began to establish nests on the island, and any further spraying activity would have been disruptive to the colony.

We monitored plots weekly throughout the nesting season to document the nesting density of terns in each plot (nests/m^2), and the clutch size (number of eggs) and hatch rate (proportion of eggs hatched) of each nest. We measured habitat responses (percent cover of each plant species established within the plot) in July 2019, corresponding with the peak of the chick-rearing season. Given our use of salt in our experimental approach, we categorized plant species as halophytes or non-halophytes (Haines 2011) in order to evaluate plant response with respect to expected salt tolerance. We further categorized plant species as native or nonnative (Nichols and Nichols 2008) to evaluate the effect of salt treatment on the island's native plant community. We summarized habitat variables for each plot, including total percent plant cover (the sum of percent cover of each plant species), plant species richness (the total number of plant species), plant community composition (the categorical list of plant species), and percent cover for each plant category (the sum of percent cover of halophyte, non-halophyte, native, and nonnative species).

We conducted statistical analyses using JMP Pro version 15 (SAS Institute Inc., Cary, NC, USA). To evaluate differences in plant responses between treatment types, we conducted blocked t-tests (2-tailed t-tests with mean-centered blocks; Hansen and Bowers 2008) for the continuous variables of percent plant cover and plant species richness. Percent plant cover and plant species richness were reported for the plant community as a whole, for individual plant categories, and for post-hoc analysis of specific plant species. Blocked t-tests were also used to evaluate differences in tern nesting response metrics (nesting density, clutch size, and hatch rate) between treatment types. We used a blocked chi-square test to compare overall plant community composition across treatment types (Cochran-Mantel-Haenszel tests; Mantel 1963).

To evaluate optimal nesting habitat heterogeneity for terns at our study site, we compared the overall reproductive output response of terns to the percent plant cover within common tern productivity-monitoring areas on the island observed from 2016 to 2020. As part of the annual monitoring work conducted at the site, we established fenced productivity-monitoring areas in representative habitat types (including meadow habitat and meadow/rocky barren interface) across the island, encompassing variation in vegetative cover, topography, and exposure (Figure 1). We monitored each area throughout each nesting season to document tern nest density, clutch size, and hatch rate (as described for experimental plots above). The addition of fencing around the productivity-monitoring areas constrained the movement of older, more mobile chicks, allowing us to observe fledge rate (the number of chicks per nest surviving to 15 days of age), which we were unable to measure in the unfenced habitat management plots. We estimated percent cover from photographs taken of each area during the month of May. Individual productivity-monitoring areas averaged 12.7 (2.8) m^2 and totaled 558.9 m^2 monitored over the 5-year period.

RESULTS

When measured in July 2019, average percent plant cover in hypersaline treatment plots was 23.7% lower relative to control plots ($t_{18} = -5.56$, $P < 0.001$; Figure 2). The control plots exhibited average (standard deviation) percent cover of 92.3 (5.3)%, with values ranging from 85–100%. In comparison, the hypersaline treatment exhibited average percent cover of 68.6 (19.8)%, with values ranging from 31–95%.

We observed 15 plant species in total across all the plots (Table 1). Chi-square analysis revealed no significant difference in plant community composition between treatment types ($\chi^2_{14} = 12.1$, $P = 0.594$). Plant species richness did not differ significantly between treatment types ($t_{18} = 0.0$, $P = 1.000$; Table 2), exhibiting an average of 4.8 (1.6)

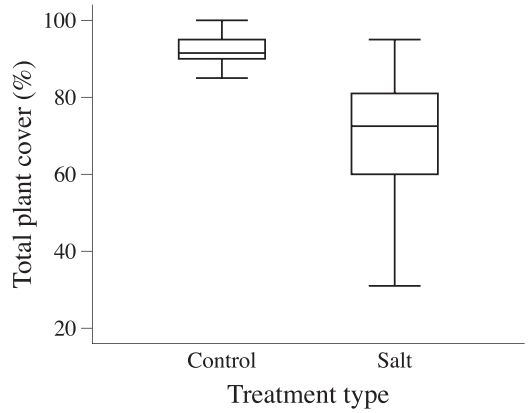

FIGURE 2 Box and whisker plot (with lines indicating minimum, first quartile, median, third quartile, and maximum values) of percent plant cover measured within control and salt treatment plots (treated with hypersaline spray) measured in summer 2019 on White and Seavey Island, NH, USA.

TABLE 1 Plant species observed within management plots on White and Seavey Island, New Hampshire, USA, in July 2019, with species categorized by salt tolerance and native status.

Plant species	Native status	Salt tolerance
Achillea millefolium	Native	Non-halophyte
Ambrosia artemisiifolia	Native	Non-halophyte
Anagallis arvensis	Nonnative	Non-halophyte
Calystegia sepium	Native	Non-halophyte
Ligusticum scoticum	Native	Non-halophyte
Lolium perenne	Nonnative	Non-halophyte
Persicaria maculosa	Nonnative	Non-halophyte
Raphanus raphanistrum	Nonnative	Non-halophyte
Stellaria media	Nonnative	Non-halophyte
Trifolium repens	Nonnative	Non-halophyte
Agrostis stolonifera	Nonnative	Halophyte
Plantago maritima	Native	Halophyte
Solidago sempervirens	Native	Halophyte
Spartina alterniflora	Native	Halophyte
Teucrium canadense	Native	Halophyte

plant species/plot overall, with values ranging from 2–8 species/plot. We categorized 5 plant species as halophytes, 10 as non-halophytes, 8 as native, and 7 as nonnative (Table 1). When considering the effects of salt tolerance, only halophytes experienced significant declines in percent cover in salt treatments relative to controls (Table 2). Halophyte species richness, however, was elevated in salt treatment plots (1.3 [1.4] halophyte species/plot) relative to control plots (0.7 [0.5] halophyte species/plot; $t_{18} = 2.1$, $P = 0.048$). Non-halophyte species exhibited no significant change in species richness ($t_{18} = -1.7$, $P = 0.106$) or percent cover ($t_{18} = -1.6$, $P = 0.130$) across treatments. With regards to native vs. nonnative plant distribution, nonnative species richness was significantly lower in salt treatment plots (1.7 [0.8] nonnative species/plot) relative to control plots (2.1 [1.0] nonnative species/plot; $t_{18} = -2.1$, $P = 0.048$). The same pattern was observed for nonnative percent cover (18.0 [21.8]% in treatment plots in comparison to 37.6 [23.3]% in control plots; $t_{18} = -4.2$, $P < 0.001$). In comparison, native plants exhibited no significant change in species richness (3.1 [1.4] species in treatment plots relative to 2.7 [0.9] species in controls; $t_{18} = 1.9$; $P = 0.081$) or percent cover (48.4 [24.2]% in treatment plots relative to 51.7 [19.1] % in controls; $t_{18} = -0.7$; $P = 0.482$) between treatment types (Table 2).

In addition to these overall plant community trends, there were also significant changes in the relative percent cover of a handful of individual species examined post-hoc. The non-halophyte grass species *Lolium perenne* exhibited significantly lower percent cover in treatment plots (14.9 [21.8]%) relative to controls (27.6 [22.0]%; $t_{18} = -2.9$, $P = 0.010$). Of the 2 halophyte grasses, *Agrostis stolonifera* exhibited significantly lower percent cover in treatment plots (1.9 [3.6]%) relative to controls (11.0 [15.4]; $t_{18} = -2.6$, $P = 0.018$), whereas *Spartina alterniflora* was only ever observed in treatment plots (2.1 [3.4]% cover). In addition to the grasses, wild radish (*Raphanus raphanistrum*) exhibited significantly lower percent cover in treatment plots (1.7 [2.7]%) relative to controls (5.8 [6.5] %; $t_{18} = -2.7$, $P = 0.015$).

Terns established nests at a greater density in treatment plots (1.8 [1.1] nests/m^2) relative to control plots (1.0 [1.1] nests/m^2; $t_{18} = 2.6$, $P = 0.020$). Average clutch size (2.1 [0.9] eggs/nest in treatment plots; 1.8 [0.4] eggs/nest in controls) and hatch rate (83.6 [24.7]% in treatment plots; 90.0 [22.4]% in controls) did not differ significantly

TABLE 2 Percent cover and plant species richness (mean with standard deviation in parentheses) observed within control and salt treatment plots (treated with 100 ppt hypersaline spray) on White and Seavey Island, New Hampshire, USA, in July 2019, including overall change and change within species categorized by salt tolerance and native status. Comparisons between control and hypersaline treatment plots reported as *t*-statistics and associated probabilities.

	Control	Salt treatment	*t*-statistic	*P*-value
Plant cover (%)				
Overall	92.3 (5.3)	68.6 (19.8)	−5.56	<0.001
Halophyte	18.0 (20.6)	6.6 (7.0)	−2.73	0.014
Non-halophyte	71.3 (19.3)	59.8 (21.4)	−1.58	0.130
Native	51.7 (19.1)	48.4 (24.2)	−0.72	0.482
Nonnative	37.6 (23.3)	18.0 (21.8)	−4.18	<0.001
Plant species richness (species/plot)				
Overall	4.9 (1.7)	4.9 (1.6)	0.00	1.000
Halophyte	0.7 (0.5)	1.3 (1.4)	2.12	0.048
Non-halophyte	4.1 (1.4)	3.5 (1.0)	−1.70	0.106
Native	2.7 (0.9)	3.1 (1.4)	1.85	0.081
Nonnative	2.1 (1.0)	1.7 (0.8)	−2.12	0.048

between treatment and control plots ($t_{18} = 0.7$, $P = 0.487$ and $t_{18} = -0.7$, $P = 0.721$, respectively). Due to the difference in nesting density between treatment types, the total number of chicks hatched in treatment plots (3.0 [2.2] chicks/m^2) was nearly twice the number in control plots (1.6 [1.8] chicks/m^2; $t_{18} = 3.3$, $P = 0.004$), despite the lack of a significant difference in hatch rate.

Within fenced common tern productivity-monitoring areas, total plant cover ranged from 12–100% (84.6 [21.8]%) over the 5 years of sampling. When examined post-hoc, the relationship between total plant cover and measures of tern reproduction (including nests/m^2, hatched chicks/m^2, and fledged chicks/m^2) were all consistent with a quadratic regression ($R^2 = 0.56$, $F_{2,41} = 26.3$, $P < 0.001$ for nests/m^2; $R^2 = 0.53$, $F_{2,41} = 23.4$, $P < 0.001$ for hatched chicks/m^2; $R^2 = 0.48$, $F_{2,41} = 18.8$, $P < 0.001$ for fledged chicks/m^2; Figure 3). Peak nesting density was observed at 22% plant cover. Peak reproductive output was observed at 45% plant cover for hatched chicks/m^2 and 43% plant cover for fledged chicks/m^2.

DISCUSSION

Quantifying the effects of habitat management techniques with regards to vegetative response is critical for the conservation of management-dependent systems such as tern nesting colonies. Our study found that application of hypersaline spray increased nesting habitat heterogeneity (as measured by a 24% reduction in average vegetation cover within treatment plots) and resulted in nearly doubled reproductive output of common terns (hatched chicks/m^2) when compared to control plots at the same site. The annual application of hypersaline spray should therefore be considered as a potential option in the suite of habitat management techniques employed by managers of ground-nesting seabird colonies.

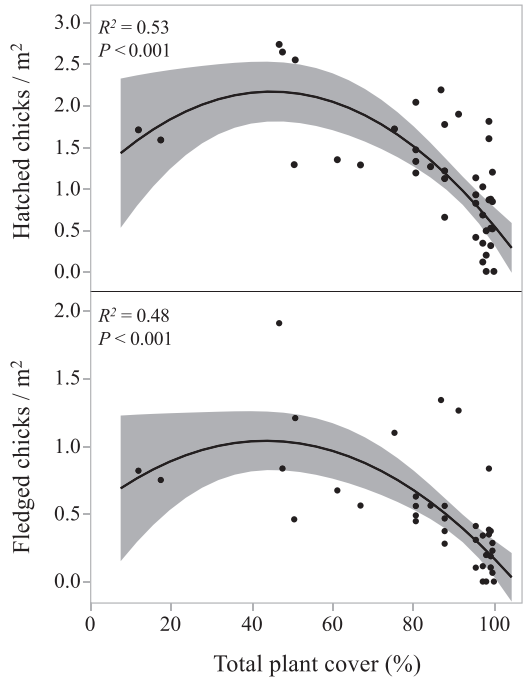

FIGURE 3 Quadratic regression (assessed post-hoc, with 95% confidence interval shaded in gray) of common tern (*Sterna hirundo*) reproductive output in terms of chicks hatched per square meter (above) and chicks fledged per square meter (below) relative to percent plant cover measured within productivity-monitoring areas on White and Seavey Island, NH, USA from 2016–2020.

Plant community composition was similar between control and treatment plots, with a few significant differences corresponding with shifts towards higher salt tolerance. The most notable example was the increase in species richness of halophytes within hypersaline treatment plots. Hypersaline plots also exhibited a reduction in the species richness and percent cover of nonnative plant species, but this is also likely attributable to differences in salt tolerance, as salt-sensitive non-halophytes constituted 86% of the nonnative plant community, but only 50% of the native plant community. In addition to shifts in overall plant community composition, we observed some notable differences in several individual plant species. Relative to the control treatment, salt treatment plots exhibited significant reductions in the non-halophyte grass *L. perenne*, and a significant increase in the halophyte grass *S. alterniflora*, suggesting that grass species may be particularly susceptible to this habitat management technique. There was also significantly lower percent cover of wild radish in treatment plots relative to controls, which is particularly notable as wild radish is a nonnative species that is considered to provide poor nesting habitat quality for terns (Leahy and Camp 2006).

With regards to the response of nesting terns to our habitat manipulations, we observed more nests and hatched chicks in treatment plots relative to control plots. The elevated nest density indicates that nesting habitat conditions within the hypersaline treatment plots were perceived as preferable by terns at the time of nest establishment, and that salt treatment had no measurable negative effect on the ability of terns to protect and incubate their eggs to the point of hatching. Although the fledging success of chicks (defined as survival to 15 days of age) would have been a more informative measure of reproductive response to nesting habitat manipulation, we were unable to measure fledging success consistently in our experimental treatment plots, as they were not fenced and therefore allowed older, more mobile chicks to leave the plot.

Analysis of the relationship between tern reproductive output and nesting habitat heterogeneity examined within fenced productivity-monitoring areas revealed that peak reproductive output of common terns at our site was achieved at 43 to 45% plant cover when calculated for fledged and hatched chicks, respectively. Given that optimal nesting habitat heterogeneity was similar (within 2% plant cover) when estimated using hatch and fledge rates, there appears to be no major shift in nesting habitat conditions required for eggs to hatch (equivalent to observations in experimental plots in 2019) and for chicks to fledge. Given that the hypersaline treatments yielded an average of approximately 66% plant cover, the average managed condition fell somewhat short of optimal nesting habitat heterogeneity for common terns nesting at our site, but nevertheless constituted a marked improvement from control conditions. Notably, we estimated nesting habitat heterogeneity within productivity-monitoring areas from photographs taken in the month of May (as opposed to July in the case of the habitat management plots), and we presume that if we had made these estimates in July, the percent plant cover would be higher overall, including the estimate of optimal percent plant cover.

Conservation managers at this site have employed a variety of habitat management techniques over the 20 years of nesting activity, including hand pulling of vegetation, herbicide application, prescribed burning, and deployment of weed-blocking mats (Burbidge 2008, Craig 2019). Management efforts have varied in their extent of pre- and post-treatment documentation, with the best-documented study to date reporting approximately 9% reduction in plant cover in response to hand pulling of vegetation, and 2% reduction in plant cover in response to herbicide treatment relative to control plots (Burbidge 2008). In comparison, the hypersaline spray treatment employed in our study yielded approximately 24% reduction in plant cover relative to controls. In the case of prescribed burning, pre- and post-prescribed burn responses were not well documented at our site. However, it has been observed that in the summer following a prescribed burn, burned areas remain bare during the nest-establishment period (early May), but vegetation grows quickly in subsequent weeks to the point of overgrowing nests by the peak of the chick-rearing period in July (Kress and Hall 2004, Craig 2017). Although application of hypersaline spray yielded significant results when used on its own at our site, we suggest that application of the hypersaline spray management method in combination with others (for instance, application after a prescribed burn to suppress post-burn vegetative resurgence) may result in a greater magnitude of habitat response.

When considering the application of this management method, we found evaluation of optimal nesting habitat conditions to be a critical component in determining management targets and recommend evaluation of optimal nesting habitat conditions specific to individual seabird species and management sites. To determine whether the addition of salt is likely to be effective and produce beneficial changes at a particular site (in terms of improvements to wildlife habitat and maintenance or enhancement of native plant communities), managers should consider the salt tolerance of the plant community at each site. Particular attention should be paid to the salt tolerance of native species, invasive or noxious species, and species that are particularly beneficial as wildlife habitat. We recommend that managers who are considering application of this management method on islands in freshwater systems evaluate treatment salinity, as plant communities in freshwater systems are likely to exhibit lower salt tolerances than observed on islands in marine systems. Finally, we have limited our discussion to island-nesting seabirds, as this management method may not be suitable for seabird colonies located on beaches or in marsh environments considering the marked differences in plant communities and hydrology, and the potential for different habitat selection pressures experienced by birds nesting in these environments.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

No ethical information provided.

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