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Authors: Lamb, Juliet S., Hall, C. Scott, Kress, Stephen W., and Griffin, Curtice R.

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Comparison of Burning and Weed Barriers for Restoring Common Tern (*Sterna hirundo*) Nesting Habitat in the Gulf of Maine

JULIET S. LAMB^{1,3,*}, C. SCOTT HALL^{2,4}, STEPHEN W. KRESS² AND CURTICE R. GRIFFIN¹

¹Department of Environmental Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA, 01003, USA

²National Audubon Society Seabird Restoration Program, 159 Sapsucker Woods Road, Ithaca, NY, 14850, USA

³Current address: South Carolina Cooperative Fish and Wildlife Research Unit, G-27 Lehostky Hall, Clemson University, Clemson, SC, 29678, USA

⁴Current address: National Fish and Wildlife Foundation, 1133 15th Street NW, Suite 1100, Washington, D.C., 20005, USA

*Corresponding author; E-mail: jslamb@clemson.edu

Abstract.—As seabird nesting colonies have become concentrated on fewer managed islands, available nesting habitat for open-ground nesters such as Common Terns (*Sterna hirundo*) has rapidly become overgrown by guano-fertilized vegetation, leading managers to try various methods of vegetation control to open usable nesting habitat. Two of these methods, burning and synthetic weed barrier treatments, were tested in the summers of 2009 and 2010 to assess their ability to open and maintain Common Tern nesting habitat on two nearshore seabird nesting islands in Maine. Treatments were applied to overgrown habitat pre-nesting, and vegetation regrowth and Common Tern nest and fledging success were monitored in treated plots, untreated vegetation plots and occupied Common Tern nesting habitat. Burned areas did not remain open for the full nesting season, but regrew shortly after egg-laying, creating unsuitable vegetation structure and leading to near-complete nest failure in these plots. However, vegetation characteristics produced by the two different weed barrier treatments—one a layer of muslin fabric overlaying newspaper mulch and the other a mosaic of synthetic turf and open ground—were similar to vegetation in pre-existing Common Tern nesting habitat throughout the season. Common Tern nest and fledging success was similar in weed barrier plots (1.37 chicks/pair) and pre-existing Common Tern nesting habitat (1.38 chicks/pair). While burning may not be a useful technique for creating nesting habitat, synthetic weed barriers offer a promising short-term solution to vegetation overgrowth in nesting habitat of Common Terns and species with similar habitat requirements. Received 12 February 2014, accepted 19 March 2014.

Key words.—Common Tern, Gulf of Maine, habitat, island, management, restoration, *Sterna hirundo*, vegetation.

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Although botanists and ornithologists frequently direct their attention toward the effects of seabird guano on island vegetation communities (Anderson and Polis 1999; Sánchez-Piñero and Polis 2000; Ellis 2005), few studies have addressed the loss of nesting habitat that results from these vegetation changes. Seabird colonies supply nutrient-rich guano and biological materials to islands that typically have few outside nutrient sources (Polis and Hurd 1996; McMaster 2005; Wait *et al.* 2005). By elevating levels of nutrients, seabirds can alter vegetation, although the effect (positive or negative) varies by plant species (Wainright *et al.* 1998; Rajakaruna *et al.* 2009). Seabirds also disperse many agents, including plant seeds (Gillham 1956) and pollutants (Blais *et al.* 2005; Evenset *et al.* 2007), that can affect

the composition and spatial distribution of island vegetation communities (Ellis 2005).

Vegetative cover limits breeding habitat for many ground-nesting tern species (Severinghaus 1982; Houde 1983; Saliva and Burger 1989; Ramos and del Nevo 1995). Common Terns (*Sterna hirundo*) prefer to nest on open ground with ~10-40% vegetation cover (Blokpoel *et al.* 1978; Burger and Gochfeld 1991; Nisbet 2002). However, most islands in the Gulf of Maine available for nesting seabirds have central grassy meadows surrounded by open rock, with thin margins of rock-vegetation interface (Conkling 1999). Thus, most protected habitat is not suitable for Common Tern nesting, and breeding populations of this species are concentrated on a small number of islands managed for nesting seabirds (Kress *et al.* 1983; Anderson and Devlin 1999).

As numbers of breeding seabirds on managed islands increased in recent years, tall, dense vegetation has overgrown former nesting areas, making these habitats increasingly unsuitable (Austin 1934; Conkling 1999). Curbing the spread of vegetation on these islands may improve habitat suitability for Common Terns. However, traditional weed management methods, such as mowing, herbicide application and soil sterilization, are generally difficult to apply to island seabird colonies due to difficulties of equipment transport, concerns surrounding the effects of chemical treatments on terrestrial and marine systems (Relyea 2005), and the high level of disturbance required to conduct vegetation control measures while nesting birds are present (Kress and Hall 2004).

To date, experimental vegetation manipulations of nesting habitat for various species of terns have focused on nest site selection (e.g., Severinghaus 1982; Richards and Morris 1984; Saliva and Burger 1989; Cook-Haley and Millenbah 2002), but few have tested vegetation control techniques over a full nesting season or assessed nesting productivity in modified habitat. Spendlow (1982) found that overgrown Roseate Tern (*S. dougallii*) nests that had been modified by placing boards over tall vegetation at access points had higher nest success than those that had not been manipulated. On Coquet Island, United Kingdom, numbers of nesting Roseate Terns increased following the installation of a cobblestone terrace covering overgrown habitat (Morrison and Gurney 2007). In the Gulf of Maine, Burbidge (2008) found that small plots that had been hand-weeded or treated with glyphosate were used as nest sites by Common and Roseate terns within the year of application; however, she did not measure productivity of either species in the manipulated habitat and suggested that the significant amount of labor involved in these techniques may make them impractical.

We tested whether areas unsuitable for Common Tern nesting can be managed to provide suitable habitat for a full nesting season and on a large scale using burning and weed barriers, both of which are non-chem-

ical management techniques that can be applied prior to the breeding season. Burning has long been used to manage inland plant communities for wildlife (e.g., Lewis and Harshbarger 1976; Moog *et al.* 2002) and has been used in recent years to create nesting habitat for Common and Roseate terns on at least one island in the Gulf of Maine (S. Williams, pers. commun.). Weed barriers kill rhizomes and seeds by limiting light and nutrient passage into the soil (Martin *et al.* 1991; Benoit *et al.* 2006), and the authors have observed Common Terns using weed barriers as nesting habitat within several weeks of application.

METHODS

Study Area

We conducted our study on two islands in the Gulf of Maine, Outer Green Island (OGI) and Eastern Egg Rock (EER) (Fig. 1). Both islands are restored seabird nesting colonies owned by the Maine Department of Inland Fisheries and Wildlife and managed in cooperation with the National Audubon Society's Seabird Restoration Project. Both islands have a history of livestock grazing, with vegetation communities dominated by in-

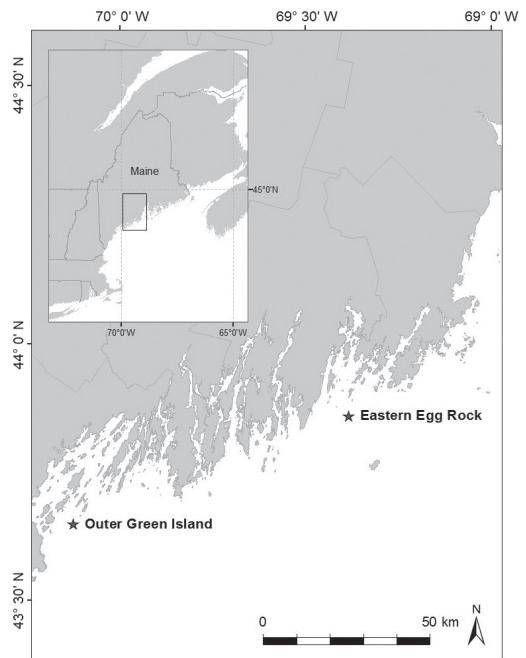


Figure 1. Map showing study islands in the Gulf of Maine, relative to the state of Maine (inset).

troduced pasture grasses including quackgrass (*Elymus repens*) and timothy (*Phleum pratense*).

OGI is located in Casco Bay, Maine, ~9 km off the coast of Portland in Cumberland County (43° 39' N, 70° 7.5' W). Composed of metamorphic schist, the 2.1-ha island has a vegetated interior surrounded by a narrow rocky perimeter and sheer cliffs. The center of the island contains a high density of large-leaved plants such as great burdock (*Arctium lappa*) and cow parsnip (*Heraclium maximum*), as well as introduced pasture grasses. While this center meadow is unsuitable for Common Tern nesting, it is often used for nesting by Common Eiders (*Somateria mollissima*). Since restoration in 2002, the island has supported a colony of 700-900 pairs of Common Terns and up to 70 pairs of Roseate Terns on ~0.22 ha of nesting habitat, concentrated along the transition zone between the interior meadow and the rocky perimeter. The dominant vegetation along these edges includes seaside goldenrod (*Solidago sempervivens*) and annuals such as Indian mustard (*Brassica juncea*). Laughing Gulls (*Larus atricilla*) do not breed on OGI.

EER lies 9 km off the coast of Knox County, Maine, at the mouth of Muscongus Bay (43° 52' N, 69° 22' W). The perimeter of the 2.9-ha island is composed primarily of granite boulders. Its interior is flat, with shallow peat soil ~0.5 m deep, and contains a high density of introduced pasture grasses and wild red raspberry (*Rubus idaeus*). This habitat supports 100-300 breeding pairs of Common Eiders and a colony of Laughing Gulls that reached a peak of > 2,000 breeding pairs in 2009. Laughing Gulls are predators of seabird eggs and sometimes compete with Common and Roseate terns for nest sites, although they generally prefer denser vegetation than either species. Closer to the edges, New York aster (*Aster novae-belgii*) and bittersweet nightshade (*Solanum dulcamara*) dominate. Along the transition zone between the interior meadow and rocky perimeter, approximately 0.51 ha of suitable nesting habitat annually supports around 1,000 pairs of Common Terns and 100 pairs of Arctic Terns (*S. paradisaea*) and, with 100-120 pairs, is the largest Roseate Tern colony in the Gulf of Maine.

Experimental Design

On each of the two islands, we selected and marked with rebar six 10-m x 10-m plots, in overgrown areas currently unused for nesting, ensuring that all plots were separated from one another by at least 20 m on all sides. All plot locations were contiguous with Common Tern nesting habitat occupied during the previous (2008) breeding season because pioneering birds prefer to nest near conspecifics (Kress 1983). We visually assessed species composition pre-treatment, choosing plots that contained a mixture of both annual forbs and perennial graminoids and appeared to represent the overall plant composition of each island. We numbered each plot and assigned plot numbers by random draw to one of three treatments (burning, barrier, or no treatment), with each treatment represented in two plots on each island.

To compare treated plots to pre-existing suitable Common Tern nesting habitat, we also monitored veg-

etation in areas already occupied by nesting Common Terns. We used a pre-existing census grid to select two numbered grid squares by random draw from all 10-m x 10-m grid squares containing Common Tern nests. We monitored vegetation in these grid squares according to the same protocols used for study plots, restricting sampling transects to portions of the selected grid squares occupied by Common Terns.

Treatments

No treatment. Untreated vegetation plots were located in vegetated areas unsuitable for Common Tern nesting. They did not receive any experimental treatment and were visited only for monitoring during the period of vegetation growth (May-August).

Burn treatments. On 16 and 17 September 2008, once nesting birds left the islands, we treated all burn plots with Matran EC, a post-emergent clove-oil herbicide (EcoSMART Technologies) to dry existing grasses. We then burned all plots assigned to the burn treatment using a drip torch from 22 to 24 September 2008. From 15 to 18 April 2009, before nesting birds arrived, we conducted a second burn on these plots using a Red Dragon heavy-duty vapor torch (Flame Engineering). In September 2009, we again cut all vegetation in the burn plots at their base using a brush cutter, but did not conduct a burn. We returned and burned the burn plots from 13 to 15 April 2010 using both drip and jet torches.

Barrier treatments. From 15 to 18 April 2009, we used a string trimmer to clear the plots assigned to the weed-barrier treatment and, on 19, 20 and 24 May 2009 (after Common Terns had begun arriving, but before they initiated nesting), installed a single 0.5-cm layer of newspaper mulch covered by 2-m-wide strips of unbleached muslin fabric anchored with 15.2-cm U-shaped landscape staples. Since patchy vegetation can significantly improve Common Tern productivity compared to bare ground (Richards and Morris 1984), we allowed margins of 5 cm of clear soil between muslin strips to allow vegetation to grow through.

In September 2009, we removed the newspaper and muslin layers from the weed barrier plots. On 17 and 21 May 2010, once again preceding nest initiation, we applied a layer of polypropylene artificial turf, obtained second-hand from golf courses. Sections of turf averaged ~5 m² in size and were generally rectangular in shape. We laid pieces to allow a margin of ~5 cm of clear soil between each section and anchored them in place with 25.4-cm galvanized steel spikes with 0.95-cm heads, using two nails per square meter of turf. Although weed barrier materials differed between seasons, the overall matrix of covered and uncovered soil did not change.

Common Tern habitat. Common Tern habitat transects were located in areas currently used for nesting by Common Terns, along the edges of grid squares used to conduct nest censuses. Transects were chosen by randomly drawing two grid square numbers per sampling period from among all grid squares on the island containing occupied Common Tern nesting habitat.

Monitoring

Vegetation monitoring. During the 2009 and 2010 Common Tern nesting seasons (May to August), we did not conduct any further treatment of plots, but monitored two indices of treatment success: vegetation regrowth and Common Tern nesting success. We conducted vegetation monitoring during three sampling periods: egg-laying, chick hatch, and fledging. To allow for weather and differences in phenology between the two islands, we chose 7-day sampling periods based on peak egg-laying (28 May to 3 June), hatching (15 to 24 June) and fledging (6 to 15 July) dates recorded in previous years. We did not sample when vegetation was wet or wind speed was excessive (> 15 kmph) because these factors could influence height and cover measurements and nest survival.

We used the point-centered quarter method (Cottam and Curtis 1956) adapted for use in grasslands (Dix 1961) to measure vegetation. Although this method is demonstrably weak in its estimates of species-specific density in clumped grasslands (Risser and Zelder 1968), this method takes less time than other commonly-used vegetation sampling techniques, which is advantageous in disturbance-sensitive seabird nesting colonies (Penfound 1963).

Before entering a plot, we randomly selected two 10-m transects by drawing two numbers between 1 and 18; numbers 1-9 were north-south transects 1 m from the plot edges numbered from west to east, and numbers 10-18 were west-east transects 1 m from the plot edges numbered from north to south. In nesting habitat plots, we restricted our selection to transect numbers known to contain Common Tern nests. Along each transect, 10 sample points were selected at 1-m intervals with the first sample point located 0.5 m inside the plot. We divided the area around each sample point into four quadrants and recorded the species and distance from the sample point to the nearest living vegetation stem in each quadrant. At each sample point, we also estimated percent canopy cover using a quadrat frame (1,250-cm² rectangular frame with cross-strings at 5-cm intervals) centered on the sample point, recording percent cover by counting the number of squares where the ground was completely obstructed by vegetation (Daubenmire 1959). Average vegetation height was recorded using a Robel pole, a 2-m length of PVC marked by alternating 10-cm bands of dark tape around the white pole (Robel *et al.* 1970). One observer held the pole in place at the sample point while a second observer stood 4 m away and, looking from the height of a second 1-m tall PVC pole, recorded the lowest visible 5-cm mark.

Newcomb (1989) and Brown (1979) were used for all plant identifications. We also collected and pressed samples of plants and sent samples to Cornell University botanists for identification. When we could not immediately identify shoots, we took photos, collected samples where possible and attempted to identify plants as they grew.

Nest monitoring. All plots were monitored for Common Tern nests. We numbered each nest upon encounter and recorded its final clutch size before hatching.

We checked nests every 3-4 days until the first hatched egg was encountered, after which we checked nests every other day, banded newly-hatched chicks with U.S. Geological Survey aluminum leg bands and recorded whether chicks banded on previous occasions were present or absent. After chicks became mobile (5 days of age), we also checked for banded chicks from portable blinds situated around plot edges and recorded band numbers using spotting scopes. Chicks that were present at 15 days of age were considered fledged unless they were recovered or found again. Island-wide hatching and fledging success were determined using the same methods from nests in long-term fenced plots (Kress and Hall 2004), representing ~5-10% of the island-wide populations.

Analysis

We analyzed the following plant community variables: mean height, mean percent cover, mean density, relative density of annuals, relative density of introduced species and relative density of forbs. Since plant species could be included in multiple categories, we screened for correlation between variables before including them. These individual variables were not normally distributed, so we used non-parametric statistical tests for the bulk of our analysis. Using these variables, we conducted a principal components analysis (Dunteman 1989) for all plots and sampling periods to assess differences in plant communities between plots and compared to Common Tern occupancy. We then conducted non-parametric multi-response permutation procedures (MRPP) using Euclidean distance and column-normalized data to test for differences between plots with and without Common Tern nests (Clarke 1993; Mielke *et al.* 2001). We tested for differences in individual metrics between treated plots, untreated vegetation plots and Common Tern nesting habitat using the non-parametric Kruskal-Wallis test. Since clutch size, hatch success, and fledging success did not appear to significantly violate assumptions of normality, we used unpaired *t*-tests to compare Common Tern nest productivity measures in plots to island averages. All statistical analyses were conducted in R (R Development Core Team 2011), including the RDA and MRPP functions from the VEGAN library.

RESULTS

Vegetation

In the study plots, we identified 51 vascular plant species, of which 17 occurred only on EER, 16 only on OGI and 18 on both islands. Of these plants, 25 were perennials, 23 were annuals, two (*Persicaria maculosa* and *Potentilla norvegica*) were species that could be either annuals or perennials and one was a biennial. Twenty-one species were native

plants and 30 were introduced. Eight were graminoid species, 42 were forbs or vines and one (*Rubus idaeus*) was a shrub.

Vegetation growth. Mean vegetation height, cover and density increased during the breeding season in both treated plots and untreated vegetation plots. However, in occupied Common Tern nesting habitat, these values decreased between egg-laying and hatch, suggesting that nesting Common Terns affected vegetation structure (Table 1). Proportions of annuals, introduced plants and forbs generally remained constant throughout the season in all plots. Vegetation growth followed the same pattern on both islands and in both years, although height and density of vegetation were higher in 2010 than in 2009 (2009: Fig. 2A-C; 2010: Fig. 2D-F). In general, untreated vegetation plots and burn plots had similar high values for height, density and cover, whereas Common Tern nesting habitat and weed-barrier plots had similar low values of all three parameters.

Burn treatment. We found no differences in any vegetation parameter in burn plots between 2009 and 2010, except for an increase in proportion of annuals in 2010 (Table 2). At laying, burn plots had shorter vegetation, lower vegetation density and less cover than untreated vegetation plots. However, at hatch, burn plots did not differ from untreated vegetation plots in either vegetation height or cover and were significantly denser than control plots (Fig. 2). Compared to Common Tern nesting habitat, burn plots had taller vegetation and greater cover and density during all sampling periods (Table 3).

Barrier treatment. Vegetation communities in weed-barrier plots differed in all parameters between years (Table 2). Further, vegetation in barrier plots differed from that in untreated vegetation plots for all parameters during all sampling periods. In contrast, vegetation in Common Tern nesting habitat was similar to that in barrier plots in vegetation height (hatch and fledge sampling periods) and cover (all sampling periods), but all other parameters differed between these plots (Table 3). In 2009, muslin fabric treatment plots had lower vegetation height, cover and density than Common Tern nesting habitat, whereas artificial turf treatment plots had greater height and cover than Common Tern nesting habitat in 2010 (Fig. 2).

Common Tern Nesting

Nesting habitat selection. We conducted principal component analysis (PCA) on 48 samples to compare vegetation communities between treatment types, representing three sampling periods for each of four plot types on EER and four on OGI in each of two years. The first two axes of the resulting PCA explained 79% of variance (PC1: Eigenvalue = 3.350, proportion of variance = 0.558; PC2: Eigenvalue = 1.376, proportion of variance = 0.229). Percent cover had the strongest structural correlation with PC1 (0.88), followed by proportion of introduced species (0.787), proportion of forbs (-0.735), proportion of annuals (-0.730), mean height (0.691) and density (0.637). We then characterized each sample as either occupied or unoccupied by nesting Common Terns and

Table 1. Mean values for vegetation parameters by study plot during Common Tern breeding season for Eastern Egg Rock and Outer Green Island, Maine (combined), 2009-2010.

	Burn			Barrier			Untreated Vegetation			Common Tern Habitat		
	Lay	Hatch	Fledge	Lay	Hatch	Fledge	Lay	Hatch	Fledge	Lay	Hatch	Fledge
Cover (%)	79.5	94.8	98.3	11.9	24.5	40.7	89.4	94.6	97.9	25.1	22.6	46.4
Height (mm)	241	555	728	22.5	106	427	412	615	625	96.3	56.9	331
Density (shoots m ⁻²)	451	837	556	4.7	4.2	3.8	490	626	562	20.1	14.0	9.0
Annuals (%)	24	23	29	25	24	30	4	7	5	68	68	62
Introduced (%)	76	76	81	35	58	59	87	85	88	49	40	58
Forbs (%)	38	37	39	37	49	47	22	24	23	77	79	70

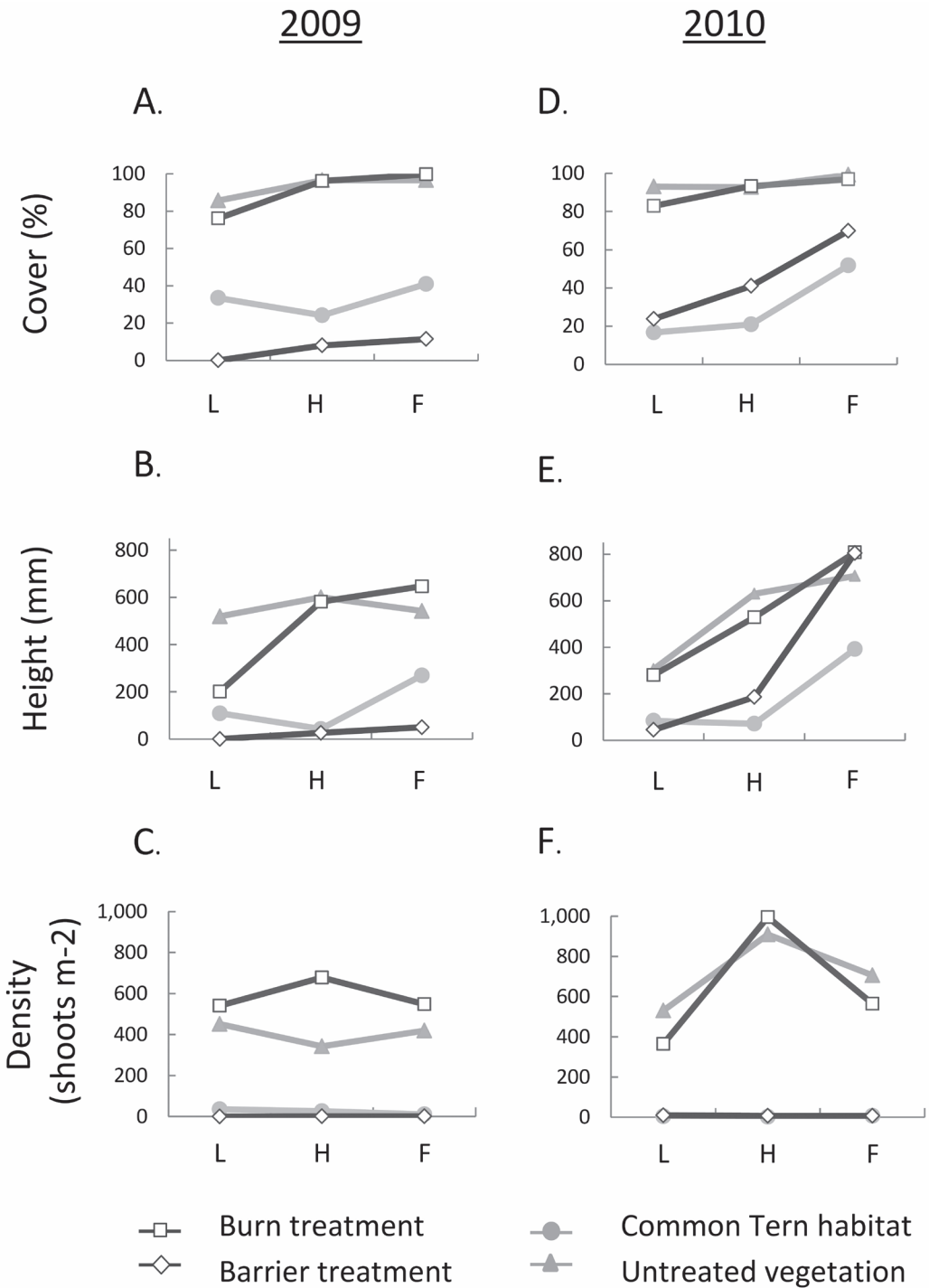


Table 2. Kruskal-Wallis scores (df = 1) comparing vegetation characteristics in 2009 and 2010 for burned plots and weed-barrier plots for Eastern Egg Rock and Outer Green Island, Maine (combined).

	Burn	Weed Barrier
Cover (%)	2.28, $P = 0.13$	87.3, $P < 0.001$
Height (mm)	0.31, $P = 0.58$	59.2, $P < 0.001$
Density (shoots m ⁻²)	0.60, $P = 0.44$	87.3, $P < 0.001$
Annuals (%)	4.50, $P = 0.03$	71.2, $P < 0.001$
Introduced (%)	0.00, $P = 1.00$	238.5, $P < 0.001$
Forbs (%)	2.52, $P = 0.11$	41.6, $P < 0.001$

ences in vegetation communities (Fig. 3). Occupied plots had lower vegetation height, density and percent cover, but higher proportions of annuals, forbs and native species than unoccupied plots. The MRPP test confirmed a significant distance between plots with and without Common Tern nests (observed delta = 1,821, predicted delta = 2,045, $A = 0.1094$, $P < 0.001$, 1,000 permutations).

Nesting in burn treatment. On OGI, no Common Terns nested in burn plots in 2009, but there was a single nest in one burn plot in 2010 that fledged three chicks (Table 4). On EER, 33 pairs of Common Terns nested in burn plots during the 2009 and 2010 seasons. Nests in burn plots had a mean clutch size of 2.18 eggs (SD = 0.78), similar to the average of 2.34 (SD = 0.51, $n = 258$) in Common Tern habitat (unpaired t -test, $t_{33} = 1.2$, $P = 0.23$). However, 85% of nests in burn plots ($n = 28$) were abandoned pre-hatch and hatch success was 0.35 (SD = 0.58) chicks/nest, much lower than the average of 2.10 (SD = 0.69) in Common Tern habitat ($t_{33} = 35.2$, $P < 0.001$). Consequently, fledging success was 0.09 (SD = 0.06) chicks/nest, much lower than the average of 1.38 (SD = 0.67) chicks/nest in Common Tern habitat ($t_{33} = 38.3$, $P < 0.001$) (Fig. 4).

Nesting in barrier treatment. Common Terns nested in weed-barrier plots on OGI in both years. The difference in fledging success on barrier plots between 2009 (1.0 chick/nest, SD = 0.67, $n = 8$ nests) and 2010 (1.8 chicks/nest, SD = 0.91, $n = 9$ nests) was not significant ($t_{15} = 2.0$, $P = 0.065$). There were no successful Common Tern nests in weed-barrier plots on EER, with no nests initiated in 2009 and a single unhatched egg in 2010. Fledg-

Table 3. Kruskal-Wallis scores (df = 1) for vegetation parameters in burned plots and weed barrier plots compared to untreated vegetation and Common Tern nesting habitat during lay, hatch and fledge for Outer Green Island and Eastern Egg Rock, Maine (combined), 2009-2010.

	Untreated Vegetation			Common Tern Nesting Habitat		
	Lay	Hatch	Fledge	Lay	Hatch	Fledge
Burn						
Cover (%)	7.32, $P = 0.007$	0.22, $P = 0.636$	2.81, $P = 0.094$	126.52, $P < 0.001$	186.47, $P < 0.001$	189.62, $P < 0.001$
Height (mm)	38.39, $P < 0.001$	0.95, $P = 0.329$	4.99, $P = 0.026$	48.85, $P < 0.001$	172.79, $P < 0.001$	72.54, $P < 0.001$
Density (shoots m ⁻²)	3.30, $P = 0.069$	8.64, $P = 0.003$	0.76, $P = 0.383$	82.07, $P < 0.001$	127.76, $P < 0.001$	104.86, $P < 0.001$
Weed Barrier						
Cover (%)	136.93, $P < 0.001$	229.51, $P < 0.001$	124.15, $P < 0.001$	0.00, $P = 0.978$	0.63, $P = 0.428$	1.82, $P = 0.177$
Height (mm)	114.91, $P < 0.001$	186.80, $P < 0.001$	3.96, $P = 0.047$	0.52, $P = 0.472$	2.60, $P = 0.107$	8.46, $P = 0.004$
Density (shoots m ⁻²)	92.71, $P < 0.001$	182.39, $P < 0.001$	153.71, $P < 0.001$	7.09, $P = 0.008$	15.69, $P < 0.001$	17.00, $P < 0.001$

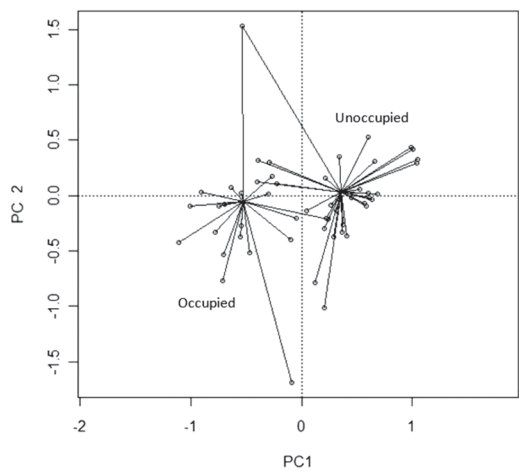


Figure 3. Position of samples (one experimental plot during one sampling period) occupied and unoccupied by nesting Common Terns on the first two axes of a principal component analysis for Outer Green Island and Eastern Egg Rock, Maine, 2009-2010.

ing success on weed-barrier plots on OGI in both years combined (1.37 chicks/nest, SD = 1.17) was similar to island-wide fledging success (1.38 chicks/nest, SD = 0.67) ($t_{272} = 0.03$, $P = 0.98$) (Fig. 4). Nest densities were lower in treated plots than in pre-existing nesting habitat (Table 4).

Accounting for differing island-wide fledging rates between years on OGI, barrier type did not affect fledging success (χ^2_1

= 0.047, $P = 0.828$). However, the nearly two-fold increase in nest numbers in barrier plots between 2009 ($n = 41$) and 2010 ($n = 74$) on OGI was substantially greater than the small increase in island-wide Common Tern nest numbers (1,036 in 2009, 1,151 in 2010). Thus, Common Terns appeared more apt to nest on artificial turf barriers in 2010 than on the muslin barriers in 2009 ($\chi^2_1 = 6.026$, $P = 0.014$). Although carry-over effects from the 2009 breeding season may have influenced settlement decisions in 2010, we did not find any significant difference between years for the rate at which Common Terns nested in burn plots on either island (OGI: $n_{2009} = 0$, $n_{2010} = 1$, $\chi^2_1 = 0.003$, $P = 0.958$; EER: $n_{2009} = 20$, $n_{2010} = 13$, $\chi^2_1 = 0.337$, $P = 0.561$).

DISCUSSION

Our analysis indicated that percent cover was the vegetation parameter most strongly affecting occupation of plots by nesting Common Terns, which agrees with the literature on Common Tern nest site selection (Severinghaus 1982; Houde 1983; Richards and Morris 1984; Cook-Haley and Millenbah 2002). Cover in all occupied plots was similar on OGI and EER at egg-laying, within the 10 to 40% range previously reported (Blok-

Table 4. Mean (SD) clutch sizes, hatch success and fledging success of Common Terns by island and year for burn (B), weed barrier (W) and tern habitat (T) plots for Eastern Egg Rock (EER) and Outer Green Island (OGI), Maine, 2009-2010.

Year	Island	Type	Total	Nests m ⁻²	<i>n</i> ^a	Clutch ^b	Hatch ^c	Fledge ^d
2009	EER	B	20	0.10	20	2.2 (0.48)	0.3 (0.24)	0
		W	0	0.00	0	—	—	—
		T	837	0.16	73	2.3 (0.66)	2.0 (0.84)	0.7 (0.58)
	OGI	B	0	0.00	0	—	—	—
		W	41	0.21	6	2.2 (0.28)	1.3 (0.83)	1.0 (0.67)
		T	1,036	0.47	61	1.9 (0.38)	1.7 (0.59)	1.7 (0.62)
2010	EER	B	13	0.07	13	2.1 (0.43)	0.2 (0.39)	0.2 (0.21)
		W	1	0.01	1	1.0 (0)	0	0
		T	714	0.14	56	2.4 (0.59)	2.1 (0.72)	1.1 (0.67)
	OGI	B	1	0.01	1	3.0 (0)	3.0 (0)	3.0 (0)
		W	76	0.38	9	2.8 (0.25)	2.1 (0.44)	1.8 (0.91)
		T	1,151	0.52	68	2.8	2.6	2.1

^aNumber of nests sampled for productivity.

^bTotal eggs/total nests.

^cTotal hatched eggs/total nests.

^dTotal chicks surviving to 15 days/total nests.

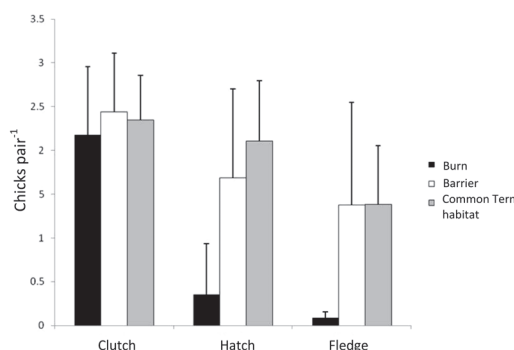


Figure 4. Means and standard deviations of Common Tern clutch size, hatch success and fledging success by treatment for Outer Green Island and Eastern Egg Rock, Maine (combined), 2009-2010.

poel *et al.* 1978; Burger and Gochfeld 1991; Nisbet 2002) for Common Terns throughout their breeding range. Despite the separation of occupied and unoccupied plots in the PCA (Fig. 3), a few plots overlapped. We attribute this overlap to the confounding effects of Laughing Gulls nesting on EER. Specifically, Laughing Gulls used cleared areas in barrier plots on EER for loafing, excluding Common Terns from these plots. In contrast, Common Terns nested in barrier plots on OGI, an island where no Laughing Gulls occur.

Although burn treatments altered vegetation structure, they did not effectively create productive Common Tern nesting habitat. Despite initial reduction of vegetation by burning, the height, percent cover and density of vegetation in burn plots at hatch were similar to those of vegetation in control plots and were much greater than those of vegetation in Common Tern nesting habitat. Thus, burning effectively created an ecological trap (Schlaepfer *et al.* 2002) for nesting Common Terns, providing apparently suitable habitat at laying, but becoming too thickly vegetated for adults to gain access to their nests and feed chicks after hatch. While clutch sizes were similar in burned plots and Common Tern nesting habitat, both hatch success and fledging success declined as vegetation overgrew. However, burning did alter species composition of treated plots, increasing relative density

of annual forbs (23 to 29%) over perennial graminoids. Although annual forbs did not increase to levels we measured in Common Tern nesting habitat (62 to 68%), burning did seem to be effective in reducing graminoids, particularly when applied over consecutive years. This indicates that burning could be a useful tool in combination with another vegetation management technique that specifically targets annual seeds. For example, pre-emergent herbicides offer a promising non-chemical alternative to traditional herbicides in preventing the germination of annual seeds, but do not affect the root systems of mature grasses (Bingaman and Christians 1995). Managers could follow a burn treatment with herbicide application to target both perennial graminoids and annual forbs.

Although burning offers a cost-effective means of removing vegetation from overgrown nesting habitat, its effectiveness varies based on soil and vegetation characteristics (Moog *et al.* 2002) and, in our study, plots that were burned did not support nesting Common Terns for a full season. Additionally, burning may reduce nesting success by creating sites with preferred characteristics at nest initiation which then become unsuitable after laying. This is highly dependent on site characteristics, however. In areas where deep peat soils are present, such as the study islands, burning may affect only seeds close to the soil surface, allowing annual seeds to persist in the seed bank; however, in shallower or sandier soils, burning is more likely to penetrate deeply enough to affect all seeds in the soil (Whelan 1995). At other sites in the region, particularly Petit Manan Island, burning has been used to create Common Tern nesting habitat for several years (Lamb 2011).

Between 2009 and 2010, we changed our weed barrier treatment from muslin fabric to artificial turf. This decision was prompted by several observed deficiencies in the muslin fabric treatment. It did not completely block light and allowed vegetation to grow under and distort the fabric, constricting the space available between fabric pieces for standing vegetation cover; in addition, it be-

gan wearing out well before the end of the nesting season. Although these factors did not appear to influence Common Tern productivity, we hoped that artificial turf might prove a heavier and more durable substrate. In addition, while muslin must be purchased from fabric suppliers, second-hand artificial turf is readily available from athletic fields and miniature golf courses who discard the material after 2-3 years, at which point it is unsuitable for athletic use but is still in good condition. Although we changed the weed barrier material between years, we did not alter the proportions of bare and covered soil in weed barrier plots.

Of the two barrier treatments we tested, artificial turf was selected at a higher rate than muslin fabric and replicated Common Tern nesting habitat conditions more successfully throughout the breeding season. Since we did not observe between-year differences in Common Tern settlement on burn plots, we attribute the increased number of nesting Common Terns on barrier plots in 2010 to the change in barrier materials rather than to between-year effects. Artificial turf is inexpensive, durable and readily available, and can support nesting Common Terns in the season of application with productivity rates comparable to those in natural habitat. This technique could be applied or adapted to create habitat for other tern species with similar habitat requirements: for example, by adding nest boxes to cleared areas to create Roseate Tern habitat (Morrison and Gurney 2007). One concern surrounding the use of polypropylene materials is that these substrates may absorb solar radiation, resulting in temperature increases that negatively affect egg or chick development (Martin *et al.* 1991; Burbidge 2008). In this respect, synthetic turf, which is designed to be used on athletic fields in full sunlight without increasing to dangerous temperatures, represents a more suitable option than materials such as landscape fabric or plastic sheeting. Although we did not measure surface temperature on synthetic turf plots, our results suggest that surface temperature increases did not negatively affect Common Tern productivity compared to island-wide averages.

However, in warmer climates, the potential for increased surface temperature should be taken into account when considering the use of synthetic turf for nesting.

We were not able to include all available vegetation management techniques in our study, but we recommend that the variety of vegetation management treatments (e.g., saltwater pumping, halite application, soil removal by pressure hose and livestock grazing) reviewed by Kress and Hall (2004) and Lamb (2011) be tested experimentally.

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