Review of vegetation management in breeding colonies of North Atlantic terns

Juliet S. Lamb[1,2*]

[1]Department of Environmental Conservation, University of Massachusetts, Amherst, MA, USA
[2]Current affiliation: Department of Forestry and Environmental Conservation, G-27 Lehotsky Hall, Clemson University, Clemson, SC, 29634, USA

SUMMARY

Although guano from nesting seabirds is known to fertilize vegetation in nesting colonies, resulting in increased vegetation height and cover, little published research addresses the loss of nesting habitat that may result from this overgrowth. Terns, which nest in limited areas of predator-free, undeveloped coastal habitat, are especially vulnerable to nesting habitat loss due to vegetation overgrowth, but very little information in the scientific literature is applicable to management efforts in seabird nesting habitat. I gathered information on vegetation management effort and success at tern nesting colonies from a survey of colony managers throughout the temperate North Atlantic, as well as from published and unpublished literature. I identified twelve applicable techniques in three categories: vegetation control during the period of plant growth, vegetation control prior to the period of plant growth, and habitat construction. Although the effectiveness of all techniques varied widely across locations and application methods, habitat construction techniques were the most likely to provide nesting habitat for a full season without vegetation re-growth. I summarize general factors likely to influence the effectiveness of management efforts and offer guidelines for choosing different techniques for managing vegetation.

BACKGROUND

Six species of terns (Sternidae) breed in the temperate North Atlantic between 33° and 55° north latitude (Nisbet *et al.* 2013). As a group these species are primarily coastal, particularly during the breeding season when they rely on nearshore islands or mainland beaches for breeding activity. Most terns nest in open areas easily accessed from the air (Burger & Gochfeld 1988, Ramos & del Nevo 1995) with sparse vegetative cover to provide protection from conspecific aggression, aerial predation and severe weather (Severinghaus 1982, Houde 1983, Nisbet 2002). However, seabird guano increases the biomass, height, and cover of island vegetation by adding nitrogen and phosphorous to otherwise nutrient-poor systems (Anderson & Polis 1999, Sánchez-Piñero & Polis 2000, Ellis 2005), meaning that the presence of a tern colony at a breeding site for several years can begin to reduce the suitability of nesting habitat. Historically, when individual sites became unsuitable, breeding terns would relocate to nearby sites with open habitat (Austin 1934, Erwin *et al.* 1981). As human populations increase at coastal breeding habitats, viable alternatives are less likely to be available (Drury 1973, Allen 2010).

In order to maintain population levels and sufficient breeding habitat, vegetation structure at existing sites must be managed with greater intensity. However, vegetation management at seabird colonies presents challenges. Tern nesting coincides with the growing season for most North Atlantic plant species, meaning that mowing, grazing and most herbicides cannot be applied during plant growth when they are most effective. Additionally, the inaccessibility and ecological sensitivity of seabird colonies often prevent the use of vegetation management techniques that require heavy equipment, bulky materials, or noxious chemicals. Information on management of island vegetation is sparse in the scientific literature. My goal was to collect and synthesize information on vegetation management practices used in existing tern nesting colonies in the temperate North Atlantic. Specifically I sought to identify vegetation management methods that could be applied at breeding colonies, determine the frequency and distribution of techniques used by surveying colony managers, and compare the success of different techniques across sites. Such an approach does not replace experimental approaches to the study of conservation interventions as it involves multiple subjective assessments. However it allows the rapid assessment of management interventions across multiple sites and provides a context for decisions about research requirements.

ACTIONS

To identify available management techniques, I surveyed the scientific literature through Web of Knowledge using a combination of the search terms “island”, “vegetation management”, “tern” and “seabird”. I also surveyed the Journal of Weed Science for articles on weed control in agricultural contexts. I selected techniques that could be used on offshore islands, and could be applied without harming nests and chicks.

Once I had identified appropriate techniques, I created a survey questionnaire asking respondents to report which of the techniques they had used, the approximate cost and area of application for each intervention, and whether or not the managed habitat had remained open for a full tern nesting season (nest initiation through to fledging). I surveyed managers of 38 breeding colonies in total, using the Gulf of Maine Seabird Working Group for North American contacts and the LIFE Project Database for European contacts, obtaining additional contact details thorough agency websites and referrals. For islands or organizations for which I was unable to obtain survey information I relied on written or telephone contact with managers (indicated by pers.comm.). I also obtained work plans, written presentations, and other unpublished materials from contacts.

Based on the information provided in the surveys, I divided the number of instances of each treatment that provided tern nesting habitat during a full nesting season by the total number

* To whom correspondence should be addressed: jslamb@clemson.edu

ISSN 1758-2067

of applications reported, to give an overall index of treatment success.

CONSEQUENCES

In the scientific literature I identified 12 suitable techniques in three categories: post-emergent (vegetation management during the growing season), pre-emergent (vegetation management prior to the growing season), and construction (covering existing soil and vegetation with new substrate) (Table 1).

I received survey responses from managers of 35 breeding sites in North America and Europe (Table 2). Each of the 12 management techniques had been used on at least one site. Although the survey included space for additional management methods, no other techniques were reported. Managers typically described plant communities broadly based on their suitability for nesting terns, e.g. "broad-leafed weeds", "European pasture grasses", or "rank vines". Generally, tall vegetation that holds moisture, entangles birds, or grows in stands with high shoot density and high canopy cover was considered undesirable for tern nesting. Managers focused on physical characteristics of vegetation rather than native status, and target plants included both native and introduced species. Specific target plants included a combination of annuals (9 species) and perennials (24 species). I refer to specific sites using the three-letter codes listed in Table 2.

Effectiveness

Post-emergent vegetation removal: Post-emergent techniques were used on 83% of colonies and were effective for a full nesting season in 46% of applications (Figure 1). Advantages of these techniques identified by survey respondents include low costs, large areas of application, ease of access, and that they only required limited and readily-available equipment. The main drawback of these techniques is short duration of effect, as they must be applied annually at a minimum. Most post-emergent applications occurred in spring and were supplemented by spot-treatments during the breeding season.

Grazing by large or small mammals was the most successful of the four post-emergent techniques reported (60%; Figure 2), although effects varied depending on species. Of three colonies that used large mammals to control vegetation in tern habitat, only one (MET, which has a resident population of sheep *Ovis aries*) reported effects on tern habitat (Adrienne Leppold, pers. comm.). Habitat resulting from natural colonization by voles *Microtus* spp. did not persist past the first season, as voles consumed grasses but not the weedy annuals that replaced them (Helen Hays pers. comm., Ted d'Eon pers. comm.). Following natural die-offs of rabbits *Sylvilagus floridanus* and *Oryctolagus cuniculus* at two colonies, broad-leafed weeds overgrew nesting habitat, and rabbit re-introduction is being considered on at least one colony (Paul Morrison pers. comm.).

Manual control created nesting habitat for a full season in 50% of applications (Figure 2). The same success rate applied to both hand-weeding (17 instances) and mechanical cutting (21 instances). Herbicide had a success rate of 38%. One pre-emergent herbicide, corn gluten meal, was used unsuccessfully. Burning had a 36% success rate, although in some cases controlled burns had not actually been used in about 100 years. Autumn burning appeared to be less effective than spring, but was sometimes necessary due to weather or fuel loads.

Pre-emergent vegetation removal: Pre-emergent techniques were used on 34% of colonies surveyed, with 16% of applications effectively providing habitat for a full nesting season (Figure 1). Advantages of these techniques include long duration and large areas of application. The main drawbacks are high costs and difficulty obtaining permissions, as most require either heavy equipment or specialized chemicals and applications.

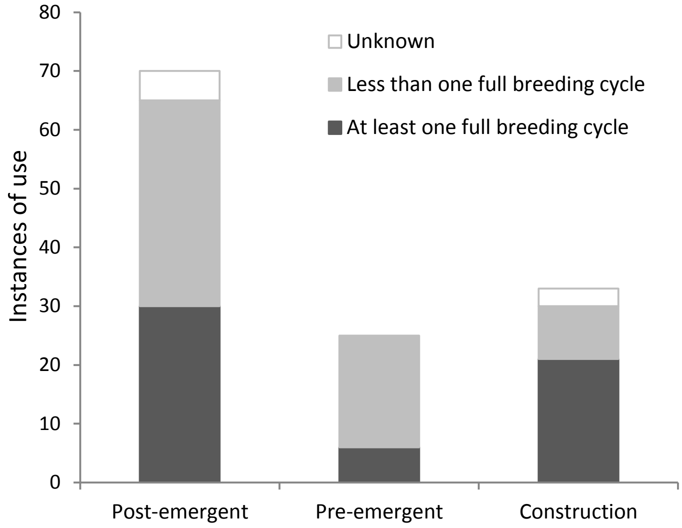

Figure 1. Reported effectiveness of management techniques by type.

Soil removal had the highest success rate in this category (75%; Figure 2). Manual removal of soil did not successfully create habitat for a full breeding season. Soil removal using heavy equipment lasted for a full season, although managers repeated the treatment annually to maintain open habitat. Mulching successfully created habitat in two instances (29%), although at least one of these (OGI) experienced lower fledging success than pre-existing habitat. Mulches were re-applied annually in spring, as mulches left in place over the winter became degraded due to weather. Salt treatment successfully provided habitat for a full nesting season in one instance. The single successful treatment (GGI) involved flooding an area of cleared soil and repeating the treatment annually. Finally,

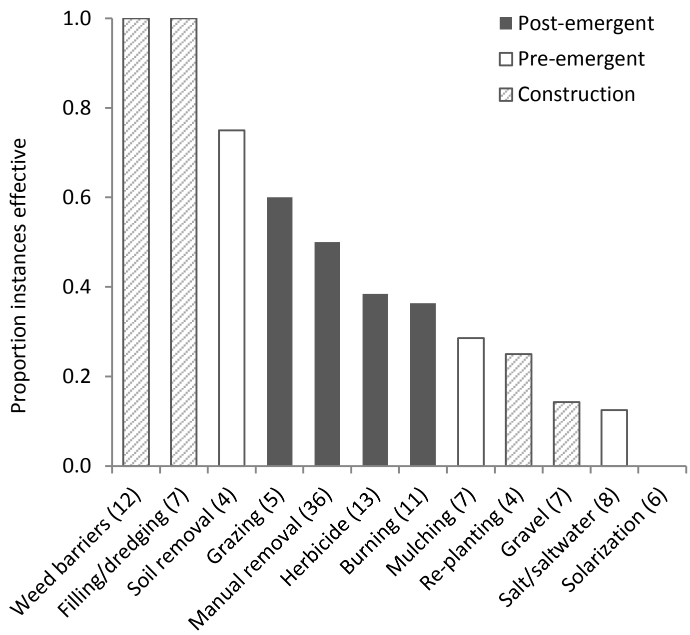

Figure 2. Proportion of uses of each intervention providing suitable breeding habitat for at least one full breeding season. Total numbers of applications are listed in parentheses.

ISSN 1758-2067

Table 1. Vegetation management techniques used in tern breeding habitat

		Description	Materials	Cost ($/year)	References
Post-emergent	**Herbicide**	Targeted application of chemicals to control growth of unwanted plant species	Roundup, Rodeo, Accord, Matran EC, Garlon 3A, corn gluten meal	<200	Worsham *et al.* (1974) Cook-Haley & Millenbah (2002)
	Manual removal	Removal of plants by hand or using cutting tools	hand tools, string trimmer, brushcutter, rotary tiller, disc harrow	0-100	Austin (1934) Burbidge (2008)
	Burning	Controlled application of fire to remove emergent plant growth and damage sub-surface rootstock and seeds, reducing likelihood of re-sprouting	drip torch, jet torch	<500	Simmons (2006) Sparks *et al.* (1998)
	Grazing	Allowing herbivorous mammals to damage and remove vegetation and	sheep, goats, rabbits, voles	0-200	Fallon (1991) Seliskar (2003)
Pre-emergent	**Soil removal**	Displacement of soil and seeds, using hand tools or machinery, to remove propagules or expose bare rock	(a) hand tools (b) pressure hose, bulldozer	(a) 0-200 (b) 500-1000	Hölzel & Otte 2003
	Solarization	Application of a fully sealed clear plastic barrier over soil, so that temperatures underneath the plastic rise high enough to kill buried seeds (40-55° C)	clear plastic	500	Upadhyaya & Blackshaw (2007) El-Keblawy & Al-Hamady (2009)
	Salt/ saltwater	Application of concentrated salt or seawater to mimic storm overwash, causing root-inhibiting stress	(a) halite, rock salt (b) seawater	(a) 1000 (b) 0-200	Kress (1986)
	Mulching	Application of a cover material to reduce weed seed viability by blocking access to light and nutrients. Cover is removed or biodegrades over time.	opaque plastic, unbleached muslin, newspaper, bark chips, hay	500	Skroch *et al.* (1992) Teasdale & Mohler (2000)
Construction	**Weed barriers**	Application of porous synthetic or organic sheet materials to create habitat immediately following application. Cover is left in place throughout breeding.	landscape fabric, tarpaulin, synthetic turf	0-500	Martin *et al.* (1991) Teasdale & Mohler (2000)
	Gravel	Covering unsuitable ground with a layer of stones to suppress weed growth and create usable habitat	beach cobble, shell shingle, sand, commercial gravel, flagstones	1000	Morrison & Gurney (2007)
	Filling	Dumping of sand and silt dredged from shipping channels to cover or extend existing habitat	sand, dredge spoils	> 1500	Maun & Lapierre (1984)
	Re-planting	Removing unsuitable vegetation and re-seeding with species more likely to provide suitable nesting habitat	fescue *Festuca* spp., seaside bentgrass *Agrostis maritima*, goldenrod *Solidago* spp.	500	Kress (1988)

solarization using clear plastic, which is most commonly used at tropical latitudes, was unsuccessful (Figure 2). Managers on OGI found that temperatures under the clear plastic barrier never reached more than 32° C, well below the critical level of 40-55° C, and plant shoots grew underneath the plastic cover (Lamb 2007).

Construction: Construction techniques were used on 63% of colonies surveyed, with 70% effectiveness (Figure 1). Managers cited immediate habitat creation and long duration as the main advantages of the techniques (most lasted at least 3-5 years), but recognized the need to identify and maintain appropriate materials. Managers improved habitat suitability by interspersing cleared areas with naturally-growing vegetation and by adding cobble, thatch, and nest boxes. Two of the four techniques in this category, weed barriers and dredge spoil deposits, successfully created habitat for at least one year in 100% of applications (Figure 2). Weed barrier materials could be saved and re-applied until they degraded, and the maximum lifespan of the treatment depended on the durability of materials. Dredge spoils naturally succeed to grass and shrub habitat within 2-3 years, requiring maintenance using hand tools and new deposits every 3-5 years. Replanting and transplanting vegetation to replace unwanted species had a 25% rate of success. With maintenance, successful treatments lasted 2-4 years. Finally, stone and gravel treatments had the lowest rate of success among construction techniques (Figure 2). The single successful application (COQ) used large flagstones and maintained the area with annual post-emergent herbicide and weeding treatments.

Multiple techniques: Seven islands used multiple techniques in combination (i.e. on the same area in a single season). In five cases, a pre-emergent technique (e.g. manual removal, herbicide) preceded a construction technique (e.g. weed barriers, re-planting). Only two islands surveyed (MON and SEV) used

ISSN 1758-2067

Table 2. Physical and management details of tern colony sites surveyed.

Colony site	Code	Location	Area (ha)	Distance offshore (km)	Elev-ation (m)	Primary substrate	Tern Species[1]	Managing Agencies[2] and Respondents[3]
The Brothers	BRO	CAN (NS)	451	1	3	rock	ARTE, COTE, ROST	a, 3
Country Island	COU	CAN (NS)	1,635	5	10	rock	ARTE, COTE, ROST	a, 15
Machias Seal Island	MSI	CAN (NB)	8,170	16	12	rock	ARTE, COTE	a, w, 18
Petit Manan Island	PMI	USA (ME)	7	4	5	rock	ARTE, COTE	c, 29, 30
Matinicus Rock	MAT	USA (ME)	8.9	29	4	rock	ARTE, COTE	c, p, 5
Seal Island	SEL	USA (ME)	26.3	35.4	11	rock	ARTE, COTE	c, p, 5, 25
Metinic Island	MET	USA (ME)	130	8	8	rock	ARTE, COTE	c, 14, 29
Eastern Egg Rock	EER	USA (ME)	2.95	9.7	6	rock	ARTE, COTE, ROST	f, p, 5, 13
Pond Island	PON	USA (ME)	4	2.4	30	rock	COTE, ROST	c, p, 5
Jenny Island	JEN	USA (ME)	1.2	2.4	2	rock	COTE, ROST	f, p, 1, 5
Outer Green Island	OGI	USA (ME)	2.1	8	84	rock	COTE, ROST	f, p, 5
Stratton Island	STR	USA (ME)	9.7	4.8	5	sand/cobble	COTE, ROST, LETE	p, 5
Appledore Island	APP	USA (NH)	38	16	7	rock	COTE, ROST	u, 4
Seavey Island	SEV	USA (NH)	3	9.7	4	rock	COTE, ROST	q, 2, 7
Beach and dredge sites	MAB	USA (MA)	varies	<1	0	sand/cobble	LETE	o, 11
Tern Island	TER	USA (MA)	28	0.1	1	sand/cobble	COTE, ROST	o, 22
Bird Island	BII	USA (MA)	0.6	0.8	0	sand/cobble	COTE, ROST	g, 17, 20
Ram Island	RAM	USA (MA)	1.2	0.7	2	sand/cobble	COTE, ROST	g, 17, 20
Penikese Island	PEN	USA (MA)	30	22.5	16	sand/cobble	COTE, ROST	g, 17, 20
Monomoy Island	MON	USA (MA)	600	1	1	sand/cobble	COTE, ROST	c, 9, 12
Falkner Island	FAL	USA (CT)	1.8	5	0	sand/cobble	COTE, ROST	c, 21, 27
Great Gull Island	GGI	USA (NY)	6.9	0.6	7	sand/cobble	COTE, ROST	k, 6
Cape Island	CAP	USA (NJ)	725	0.1	6	sand/cobble	LETE	r, 28
Dredge spoils	NCD	USA (NC)	varies	<1	0	sand/cobble	LETE, ROYT, SATE	h, 26
Bird Key	BIK	USA (SC)	14.2	0.5	0	sand/cobble	LETE, ROYT, SATE, COTE, GBTE	e, j, 24
Tomkins Island	TOM	USA (SC)	2	3.2	1	sand/cobble	ROYT, SATE	e, j, 24
Coquet Island	COQ	UK	6	1.2	15	rock	ARTE, COTE, ROST, SATE	s, 16
Rockabill	ROC	IRE	0.9	6	25	rock	ARTE, COTE, ROST	l, 19
Lady's Island Lake	LIL	IRE	4	0.1	10	rock	ARTE, COTE, ROST, SATE	l, 19
Kilcoole	KIL	IRE	0.1	0	0	sand/cobble	LITE	l, 19
Île de la Colombière	IDC	FRA	0.1	1.5	12	rock	COTE, ROST, SATE	m, n, 8, 10, 23
Île aux Dames	IAD	FRA	0.9	1	19	rock	COTE, ROST, SATE	m, n, 8, 10, 23
Île de Trevorc'h	IDT	FRA	0.8	1	24	rock	COTE, ROST, SATE, LITE	m, n, 8, 10, 23
Île aux Moutons	IAM	FRA	3	8	9	rock	COTE, ROST, SATE	m, n, 8, 10, 23
Petit Veizit	PET	FRA	0.4	0.9	24	rock	COTE, ROST, SATE	m, n, 8, 10, 23

[1] **Tern Species** (Pyle & de Sante 2003)**: ARTE:** Arctic tern *Sterna paradisaea*; **COTE:** Common tern *Sterna hirundo*; **GBTE:** Gull-billed tern *Gelochelidon nilotica*; **LETE:** Least tern *Sternula antillarum*; **LITE:** Little tern *Sternula albifrons*; **SATE**: Sandwich tern *Thalasseus sandvicensis*; **ROST:** Roseate tern *Sterna dougallii*; **ROYT:** Royal tern *Thalasseus maximus*

[2] **Managing Agencies:** ***Government – National***: a. Canadian Wildlife Service, b. Environment Canada, c. U.S. Fish and Wildlife Service, d. U.S. Geological Survey, e. U.S. Army Corps of Engineers. ***Government – Regional***: f. Maine Department of Inland Fisheries and Wildlife, g. Massachusetts Department of Fish and Game, h. North Carolina Wildlife Resources Commission, i. Nova Scotia Department of Natural Resources, j. South Carolina Department of Natural Resources. ***NGO/Charitable***: k. American Museum of Natural History, l. BirdWatch Ireland, m. Bretagne Vivante, n. LIFE-Dougall, o. Massachusetts Audubon Society, p. National Audubon Society, q. New Hampshire Audubon Society, r. New Jersey Audubon Society, s. Royal Society for the Protection of Birds. ***Academic***: t. Antioch University New England, u. Cornell University, v. Tufts University, w. University of New Brunswick. ***Consultancies***: x. I.C.T. Nisbet & Company, y. Terns LLC

[3] **Survey Respondents**: 1. Brad Allen[f], 2. Susie Burbidge[t], 3. Ted d'Eon, 4. Julie Ellis[v], 5. Scott Hall[p], 6. Helen Hays[k], 7. Dan Hayward[y], 8. Stéphanie Hennique[m,n], 9. Kate Iaquinto[o], 10. Yann Jacob[m,n], 11. Ellen Jedrey[o], 12. Stephanie Koch[c], 13. Stephen Kress[p,u,] 14. Adrienne Leppold[c], 15. Julie McKnight[a,b], 16. Paul Morrison[s], 17. Carolyn Mostellog, 18. Reg Newell[i,w], 19. Stephen Newton[l], 20. Ian Nisbet[x], 21. Richard Potvin[c], 22. Bob Prescott[o], 23.Gaëlle Quemmerais-Amice[m,n], 24. Felicia Sanders[j], 25. Susan Schubel[p], 26. Sara Schweitzer[h], 27. Jeffrey Spendelow[d], 28. Suzanne Treyger[r], 29. Linda Welch[c], 30. Sara Williams[c]

ISSN 1758-2067

multiple post-emergent vegetation removal techniques in combination (herbicide and burning). In both cases, the resulting habitat remained open for a full nesting season.

DISCUSSION

Efforts to manage vegetation in tern nesting habitat are widespread throughout the North Atlantic. Of 35 tern nesting colonies surveyed, 31 (88%) reported some attempt to manage vegetation, 25 (71%) employed at least two different techniques, and 17 (49%) used four or more techniques.

Vegetation management during the growing season, which includes some of the most readily available, least expensive and most widely used of the treatments, was effective in 36-50% of applications. Vegetation management prior to the growing season included the least frequently used, most cost- and equipment-intensive techniques. Only one of the four techniques in this category (soil removal) was effective in more than 30% of applications, and only when heavy equipment was used. Finally, construction techniques included both the two most effective (weed barriers, filling: 100% success) and two of the least effective (gravel, re-planting: <30% success) treatments reported.

Variation in reported treatment effectiveness appeared to have five principal components:

1. Nesting substrate. Most post-emergent techniques reduced perennial grasses, but treated areas were then invaded by herbaceous annuals. In areas where herbaceous vegetation is low-growing, particularly sandy soils dominated by beachgrass *Ammophila* spp., these treatments alone can create suitable nesting habitat. However, in deeper peat soils a single post-emergent technique is unlikely to reduce herbaceous growth and may create an ecological trap, in which habitat that appears suitable at nesting becomes unsuitable before chicks fledge (Burbidge 2008, Lamb *et al.* 2014).
2. Climate. Year-round temperature and humidity affect the application and intensity of burn treatments, and was likely responsible for the failure of solarization, which requires sustained temperatures of at least 40 °C (Uphadyaya & Blackshaw 2007). .
3. Suitability of materials. The effectiveness of herbicide applications and re-planting were particularly prone to the specific chemicals or plant species used. Re-planting can replace unwanted vegetation species; however, if the replacement species was also unsuitable for tern nesting (e.g., red fescue *Festuca rubra* on OGI, which grew too tall and dense to create tern habitat), the treatment failed.
4. Treatment intensity. Stone/gravel, saltwater, mulch, and burn treatments were highly sensitive to the length of time and depth of application. Effective applications were applied over a long period of time, for example up to one year for plastic mulch. Increased thickness of application (e.g. stone or gravel) and duration of exposure (e.g, saltwater) increased the likelihood that a treatment would last a full nesting season. Burning was most effective when fuel levels were high and moisture low, increasing the intensity of the burn.
5. Maintenance. The frequency of maintenance treatments (e.g. trimming, hand-weeding, or spot treatment with herbicides during breeding) was not controlled or measured, so it is difficult to determine the effect of within-season maintenance on treatment success.

Management considerations

Ecological impact: Managers reported trade-offs between ensuring treatment effectiveness and minimizing ecological impacts. Organic herbicides have minimal impact on surrounding land and aquatic communities (Tworkoski 2002) but may be less effective than traditional treatments (Scott Hall, pers. comm.). Grazing by large mammals can cause erosion (Seliskar 2003) and can negatively affect eggs and chicks through trampling and production of animal waste (Adrienne Leppold pers. comm., Williamson & Schubel 1995). Small mammal populations could attract predators, adversely affect the structure of soils and root systems or occupy burrows used by nesting seabirds (Helen Hays, pers. comm.). While non-biodegradable mulches and weed barriers appear to be more effective than biodegradable alternatives, they risk blowing away from target areas (Lamb *et al*. 2014). Dredge materials may contain high levels of contaminants, which are transferred to the colony and could enter the food chain and eventually be ingested by foraging birds (Winger *et al.* 2000).

Communication: Managers cautioned that the public can be highly sensitive to the environmental implications of vegetation management (Brad Allen, pers. comm., Scott Hall, pers. comm.). Fischer and van der Wal (2007) found that the public's perceptions, attitudes, and values strongly influenced their response to different vegetation management scenarios in UK seabird colonies, particularly to treatments involving chemical application or species introductions. They suggested that communication across the range of stakeholders be considered when developing management policies.

Effect on other seabirds: Most of the islands included in the survey hosted several tern species (Table 1), as well as other marine bird species with varying habitat requirements. Survey respondents generally agreed that dense vegetation has detrimental effects on open-rock nesters, neutral effects on boulder and cliff nesters, neutral or positive effects on grassland nesters, and neutral or negative effects on burrowing species. Vegetation management can affect both relative species abundances and competition between species for limited nesting areas (Kress & Hall 2004, Schwarzer & Koch 2004). If necessary, open-ground habitat can be modified for other tern species by supplementing it with artificial structures or habitat components such as nest boxes, stone substrate, or transplanted vegetation (e.g. Morrison & Gurney 2007, Grinnell 2010).

Recommendations

Future vegetation management efforts depend on minimizing costs so that management can be widely applied and repeated as necessary, testing multiple techniques in combination, and instituting standardized pre- and post-treatment monitoring to determine what management techniques are most effective given the variety of ecological characteristics of seabird islands across the North Atlantic.

Minimizing costs. Respondents identified several cost-minimizing measures. Volunteers can be used for procedures that do not require scientific training (Stephen Kress pers. comm.). Organizations that own equipment such as fire management tools, saltwater pumps, and heavy machinery, may provide their equipment at reduced or no cost as part of their staff training programs or routine maintenance (Helen Hays pers. comm.). Recycled materials offer a low-cost source of mulching and habitat construction supplies (Lamb et al. 2014). On islands with suitable grass communities, haying may provide a means of augmenting income (Stephanie Hennique pers. comm.).

Multiple and novel techniques. Managers that applied more than one technique in combination reported that effectiveness was greater than for either technique alone (Schwarzer & Koch 2004,

ISSN 1758-2067

Burbidge 2008). Dedicated experiments would help to describe how colonies with different substrates respond to different combinations of techniques. Novel techniques not tested on seabird islands in this study that may be targets of future study include soil fumigants, coconut matting, and cellulose sheeting.

Monitoring. In order to more effectively describe the factors contributing to treatment success, vegetation and tern productivity monitoring should be regularly incorporated into vegetation management efforts. Fixed-plot vegetation monitoring (e.g. Smart *et al.* 2003) and transect monitoring (Schwarzer & Koch 2004, Lamb *et al.* 2014) of untreated control plots and tern-nesting habitat provide a basis for assessing vegetation change following treatment.

ACKNOWLEDGEMENTS

In addition to survey respondents (see Table 1), I thank the following for support and information: Christine Bogdanowicz, Jessica Bolker, Rosalie Borzik, Andrew Boyne, Tony Diamond, Julie Ellis, Mitch Hartley, Colin MacKinnon, Craig Watson, and Hal Weeks. Scott Hall provided significant logistical support in obtaining contacts and responses, and he, Stephen Kress, Curtice Griffin, Patrick Jodice, and an anonymous reviewer provided helpful comments on earlier drafts of this manuscript. Yvan Satgé translated the survey and helped establish contacts with European researchers. Funding was provided by the Garden Club of America, National Audubon Society, and Friends of Maine Seabird Islands.

REFERENCES

Allen B. (2010) *Minutes of the Gulf of Maine Seabird Working Group.* Maine Department of Inland Fisheries and Wildlife.

Anderson W.B. & Polis G.A. (1999) Nutrient fluxes from water to land: seabirds affect plant nutrient status on Gulf of California islands. *Oecologia*, **118**, 324-332.

Austin O.L. (1934) The status of Cape Cod terns in 1934. *Bird-Banding*, **5**, 155-171.

Burbidge S. (2008) Nest-site selection and response to habitat manipulation by Roseate Terns (Sterna dougallii) on Seavey Island, New Hampshire. M.S. Thesis. Antioch University.

Burger J. & Gochfeld M. (1988) Source nest-site selection and temporal patterns in habitat use of Roseate and Common Terns. *The Auk*, **105**, 433-438.

Cook-Haley B. S. & Millenbah K. F. (2002) Impacts of vegetative manipulations on common tern nest success at Lime Island, Michigan. *Journal of Field Ornithology*, **73**, 174-179.

Drury W.H. (1973) Population changes in New England seabirds. *Bird-banding*, **44**, 267–313.

El-Keblawy A. & Al-Hamadi F. (2009) Assessment of the differential response of weeds to soil solarization by two methods. *Weed Biology and Management*, **9**, 72-78.

Ellis J.C. (2005) Marine Birds on Land: A Review of plant biomass, species richness, and community composition in seabird colonies. *Plant Ecology*, **181**, 227-241.

Erwin R. M., Galli J. & Burger J. (1981) Colony site dynamics and habitat use in Atlantic coast seabirds. *The Auk*, 550-561.

Fallon, K. (1991) *Island sheep raising*. Island Institute, Rockland, ME.

Fischer A. & van der Wal R. (2007) Invasive plant suppresses charismatic seabird—the construction of attitudes toward biodiversity management options. *Biological Conservation*, **135**, 256-267.

Grinnell C. (2010) Behavior and habitat use of Roseate Terns (*Sterna dougallii*) before and after construction of an erosion control revetment. MSc Thesis. University of Massachusetts.

Hölzel N. & Otte A. (2003) Restoration of a species-rich flood meadow by topsoil removal and diaspore transfer with plant material. *Applied Vegetation Science*, **6**, 131-140.

Houde A.E. (1983) Nest density, habitat choice, and predation in a Common Tern colony. *Colonial Waterbirds*, **6**, 178-184.

Kress S.W. (1986) *Egg Rock Update. Newsletter of the Fratercula Fund*. National Audubon Society.

Kress S.W. (1988) *Egg Rock Update. Newsletter of the Fratercula Fund*. National Audubon Society.

Kress S. W. & Hall C. S. (2004). *Tern Management Handbook - Coastal Northeastern United States and Atlantic Canada*. U.S. Department of Interior, Fish and Wildlife Service, Hadley.

Lamb J.S. (2007) *Outer Green Island Season Report*. National Audubon Society Seabird Restoration Program & Maine Department of Inland Fisheries and Wildlife.

Lamb J.S., Hall C.S., Kress S.W. & Griffin C.R. (2014). Comparison of Burning and Weed Barriers for Restoring Common Tern (*Sterna hirundo*) Nesting Habitat in the Gulf of Maine. *Waterbirds*, **37**, 286-297.

Martin C.A., Ponder H.G. & Gilliam C.H. (1991) Evaluation of landscape fabrics in suppressing growth of weed species. *Journal of Environmental Horticulture*, **9**, 38-40.

Maun M.A. & Lapierre J. (1984) The effects of burial by sand on *Ammophila Brevigulata*. *Journal of Ecology*, **72**, 827-839.

Morrison P. & Gurney M. (2000) Nest boxes for roseate terns *Sterna dougallii* on Coquet Island RSPB reserve, Northumberland, England. *Conservation Evidence*, **4**, 1-3.

Nisbet I.C.T. (2002) Common Tern. In: A. Poole (ed) *The Birds of North America Online*. Cornell Lab of Ornithology, Cornell. http://bna.birds.cornell.edu/bna/species/618

Nisbet, I. C.T., Veit R.R., Auer S.A. & White T.P. (2013). Marine Birds of the Eastern United States and the Bay of Fundy: Distribution, Numbers, Trends, Threats, and Management. *Nutall Ornithological Monographs* **29**, 1-188.

Pyle P. & DeSante D. F. (2003) Four-letter and six-letter alpha codes for birds recorded from the American Ornithologist's Union check-list area. *North American Bird Bander*, **28**, 64-79.

Ramos J.A. & del Nevo A.J. (1995) Nest-site selection by Roseate Terns and Common Terns in the Azores. *The Auk*, **112**, 580-589.

Sánchez-Piñero F. & Polis G.A. (2000) Bottom-up dynamics of allochthonous input: direct and indirect effects of seabirds on islands. *Ecology*, **81**, 3117-3132.

Schwarzer A. & Koch S. (2004) *Monomoy National Wildlife Refuge: Summary of Field Activities in 2004*. U.S. Fish and Wildlife Service.

Seliskar D.M. (2003) The response of *Ammophila brevigulata* and *Spartina patens* (Poaceae) to grazing by feral horses on a dynamic mid-Atlantic barrier island. *American Journal of Botany*, **90**, 1038-1044.

ISSN 1758-2067

Severinghaus L.L. (1982) Nest site selection by the Common Tern (Sterna hirundo) on Oneida Lake, New York. *Colonial Waterbirds*, **5**, 11-18.
Simmons T. (2006) Habitat Management Tools: Using prescribed fire to manage habitats in the Northeast. Pages 79-86 in: Oehler J.D., Covell D.F., Capel S., & Long B (eds.) *Managing Grasslands, Shrublands, and Young Forest Habitats for Wildlife: A Guide for the Northeast*. Northeast Upland Habitat Technical Committee.
Skroch W.A., Powell M.A., Bilderbuck T.E. & Henry P.H. (1992) Mulches: durability, aesthetic value, weed control, and temperature. *Journal of Environmental Horticulture*, **10**, 43-45.
Smart S.M., Clarke R.T., van de Poll H.M., Robertson E.J., Shield E.R., Bunce R.G.H. & Maskell L.C. (2003) National-scale vegetation change across Britain; an analysis of sample-based surveillance data from the Countryside Surveys of 1990 and 1998. *Journal of Environmental Management*, **67**, 239-254.
Sparks J.C., Masters R.E., Engle D.M., Palmer M.W. & Bukenhofer G.A. (1998) Effects of late growing-season and late dormant-season prescribed fire on herbaceous vegetation in restored pine-grassland communities. *Journal of Vegetation Science*, **9**, 133–142.
Teasdale J.R. & Mohler C.L. (2000) The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Science*, **48**, 385-392.
Tworkoski T. (2002) Herbicide effects of essential oils. *Weed Science*, **50**, 425–431.
Upadhyaya M.K. & Blackshaw R.E. (2007) *Non-chemical weed management: principles, concepts, and technology*. CABI, Cambridge.
Williamson K. & Schubel S. (1995) *Evaluation of the impacts of livestock grazing and habitat restoration on tern nesting islands in the Gulf of Maine*. Petit Manan National Wildlife Refuge.
Winger P.V., Lasier P.J., White D.H. & Seginak J.K. (2000) Effects of contaminants in dredge material from the lower Savannah river. *Environmental Contamination and Toxicology*, **38**, 128-136.
Worsham A.D., Soots R.F. & Parnell J.F. (1974) Herbicides for vegetation management in restoring dredge islands for nesting sites for coastal nesting birds. *Proceedings Southern Weed Scientific Society*, **27**, 298.

ISSN 1758-2067