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Short communication

Accumulation of wind-dispersed trash in desert environments

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ABSTRACT

Detrimental effects of plastic debris and other trash have been well-studied in marine and coastal environments, but the extent and severity of the threat to terrestrial ecosystems are largely unknown. I used distance-sampling methods to quantify density of wind-dispersed trash in two protected areas of the Sonoran Desert in southern Arizona. Densities of plastic bags ranged from 5.6/km^2 to 35.4/km^2, and densities of balloon clusters ranged from 39.2/km^2 to 62.7/km^2. Density of balloon clusters was greater than the density of desert tortoises, *Gopherus morafkai*, and western diamond-backed rattlesnakes, *Crotalus atrox*, in both study areas. Results of this study provide evidence that wind can disperse substantial amounts of trash >2 km into protected natural areas and suggest that accumulation of trash poses a potential threat to desert ecosystems.

1. Introduction

Anthropogenic effects on natural areas are ubiquitous, even in areas established to minimize human impacts, such as marine protected areas, national parks, or wilderness areas. One of the most apparent deleterious impacts is the accumulation of water- or wind-dispersed plastic debris and other trash (Coe and Rogers, 1997; Derraik, 2002), the effects of which are likely to worsen as urban areas expand and distances between urban and protected areas decrease (McDonald et al., 2009). In marine and coastal environments, the geographic scope and severity of this problem have been well studied (Coe and Rogers, 1997; Derraik, 2002). Concentrations of pelagic debris, particularly microscopic plastic fragments, have been detected in multiple ocean gyres (Law et al., 2010; Moore et al., 2001), and aggregations of larger plastic materials and other trash have become common in coastal areas throughout the world (Coe and Rogers, 1997; Nakashima et al., 2011; Santos et al., 2009).

Besides the aesthetic and economic costs, trash threatens wildlife inhabiting these areas. Physical entanglement in or ingestion of trash may reduce body condition or growth rates, reduce reproductive rates, or increase mortality in affected wildlife species (Azzarello and Van Vleet, 1987; Mrosovsky et al., 2009). Although effects of trash on marine species, particularly seabirds, sea turtles, and cetaceans, have been studied extensively (Derraik, 2002), effects on terrestrial species are largely unknown. The lack of studies detailing effects on wildlife in terrestrial environments is due, at least in part, to an absence of information regarding abundance and distribution of trash, particularly in desert regions.

Numerous techniques have been employed to estimate abundance and distribution of plastic debris and other trash in marine and coastal environments (e.g., Moore et al., 2001; Nakashima et al., 2011; Santos et al., 2009). In these environments, most trash can be detected with ground surveys, aerial photographs, or net tows or trawls. In contrast, quantifying trash in desert environments requires methods that account for imperfect detection because observers are likely to overlook trash that is beneath or entangled in vegetation. Despite logistical challenges, quantifying trash in terrestrial environments is imperative to gauge the scope and severity of threats to ecosystem function and wildlife species and to provide reliable data to inform management and policy decisions. To quantify wind-dispersed trash in a protected desert area, I used distance-sampling methods to estimate density of plastic bags and balloons in a National Park in southern Arizona.

2. Materials and methods

2.1. Study areas

I estimated density of trash in the Sonoran Desert of southern Arizona, a region with high diversity of woody plants and limited annual rainfall of 240–300 mm that falls in a seasonally bimodal pattern (Turner and Brown, 1982). I surveyed areas in Saguaro National Park, which is comprised of two districts that are

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separated by the city of Tucson, Arizona (see Online supplement). In 2005, I studied a 43-km^2 area in the Rincon Mountains that ranged in elevation from 800 m to 1150 m and was characterized by Arizona Upland vegetation (Turner and Brown, 1982). A low-density residential area (minimum lot size = 1.3 ha) bordered the western edge of the study area, and a single, 12.9-km long paved road traversed the lower elevations. In 2006, I studied a 78-km^2 area in the Tucson Mountains that ranged in elevation from 675 m to 1150 m and was located on the edge of a transition zone between Arizona Upland and Lower Colorado River Valley subdivisions of the Sonoran Desert. The Tucson Mountain study area was bordered on several sides by low- to medium-density housing (minimum lot size = 0.3–1.7 ha) and was bisected by 13.9 km and 15.4 km of paved and unpaved roads, respectively.

2.2. Field surveys

I used distance-sampling methods (Buckland et al., 2001) to estimate density of plastic bags and balloons in the Rincon Mountains in 2005 and the Tucson Mountains in 2006. I randomly located 60 1-km transects in each study area, with ≤20 transects in each study area >500 m from hills because I was sampling concurrently for reptiles that occur primarily in areas with greater topographic complexity (Zylstra et al., 2010). Each transect was composed of 4 250-m linear segments connected to form a square. I did not locate transects in areas where they crossed roads, were too steep to access or survey safely, or overlapped >50% with other transects. Two people surveyed each transect between early July and mid-October and recorded the perpendicular distance from each plastic bag and balloon encountered to the transect centerline. Although balloons were occasionally found in clusters, surveyors treated each cluster as a single observation and measured the perpendicular distance to the nearest balloon. Surveyors detected trash of varying states, from fully-intact bags or balloons to fragments of plastic or dried latex. All detections were included in analyses after eliminating fragments in close proximity to each other that were assumed to originate from the same balloon or bag.

2.3. Analysis

I used hierarchical models to estimate abundance of plastic bags and balloon clusters, which allowed me to evaluate covariates that influenced abundance and the detection process explicitly (Royle et al., 2004). Within a distance-sampling framework, the number of objects observed on each transect is a function of both local abundance, which is governed by underlying ecological and physical processes, and the ability of surveyors to detect the objects, which is governed by the distance between objects and the transect centerline (i.e., the detection process). I modeled transect-level abundance, N_i, with a Poisson distribution, where the log of mean abundance, log (λ_i), was assumed to vary linearly with transect-specific covariates. In these types of models, λ_i represents the density of objects per sample unit (Royle et al., 2004). I truncated observations of wind-dispersed trash >15 m from the transect line (5% of all observations) to reduce bias and improve precision of estimates (Buckland et al., 2001), and grouped remaining plastic bags and balloon clusters observed on each transect into five distance classes, each 3-m wide. I modeled the number of objects observed in each class with a Multinomial distribution. I assumed that detection probability decreased with distance from the transect centerline, and modeled this relationship with a half-normal function.

To establish models for inference, I evaluated an identical set of candidate models for both plastic bags and balloon clusters separately, where I allowed abundance to vary by study area, with standardized distance from each transect to the nearest road, or both. I assessed goodness-of-fit with parametric bootstrap methods for a fully-parameterized model and compared models using Akaike's Information Criterion (AIC), choosing for inference the model with the lowest AIC. I implemented all models with the R package "unmarked" (Fiske and Chandler, 2011).

3. Results

Field crews surveyed 120 1-km transects (60 in the Rincon Mountains and 60 in the Tucson Mountains) and observed ≥1 plastic bag on 42 transects (35%), ≥1 balloon cluster on 66 transects (55%), and ≥1 plastic bag or balloon cluster on 81 transects (68%). Crews detected a total of 56 plastic bags, most of which were disposable grocery bags made of polyethylene, and >94 balloons, most of which were latex. Plastic bags and balloons were located an average of 1.01 km and 1.09 km, respectively, from the nearest road (plastic bags: range = 0.03–2.68 km; balloons: 0.11–2.66 km).

Fully-parameterized models fit the data well (plastic bag: $\chi^2 = 535.8$, $P = 0.88$; balloon: $\chi^2 = 636.7$, $P = 0.12$). In the highest-ranking model for both plastic bags and balloons, density varied with study area but not with distance to nearest road (Table 1). Density of plastic bags was 35.4/km^2 in the Rincon Mountains (95% CI = 21.2–49.6) and 5.6/km^2 in the Tucson Mountains (95% CI = 1.1–10.2). Densities of balloon clusters in the Rincon and Tucson Mountains were 62.7/km^2 (95% CI = 42.9–82.5) and 39.2/km^2 (95% CI = 24.4–54.0), respectively.

4. Discussion

I found evidence that discarded plastic bags and balloons accumulate to high densities in protected desert areas and could pose a threat to these arid environments. In each study area, density of balloon clusters was greater than the density of western diamond-backed rattlesnakes (*Crotalus atrox*; E. Zylstra, *unpublished data*) and desert tortoises (*Gopherus morafkai*; Zylstra et al., 2010; Fig. 1), vertebrates encountered commonly during the summer monsoon season in the lower Sonoran Desert. The desert tortoise, listed as a candidate species under the Endangered Species Act (U.S. Fish and Wildlife Service, 2010), is vulnerable to effects of wind-dispersed trash through ingestion of latex balloons or entanglement in balloon strings (Walde et al., 2007). Trash could pose similar risks to other desert species, and may pose additional threats if rare and isolated water sources in desert canyons that are critical for the persistence of many wildlife species become contaminated by plastics as they degrade.

In addition to the potential effects of wind-dispersed trash on wildlife, trash could affect ecosystem function if the accumulation of these materials alters processes such as nutrient cycling and decomposition or alters water flow or quality in desert canyons. Plastic bags made of polyethylene are photodegradable but not

Table 1
Hierarchical models describing mean transect-level abundance (λ) of plastic bags and balloons on distance-sampling transects surveyed in 2005 and 2006 in the Sonoran Desert near Tucson, Arizona. ΔAIC = difference in Akaike's information criterion from the most parsimonious model in each candidate model set (in bold); w_i = AIC model weight. All models are based on a half-normal detection function.

Model	ΔAIC (w_i)	
	Bag	Balloon
λ (.)	27.91 (0.00)	2.89 (0.11)
λ (Study area)	**0.00 (0.69)**	**0.00 (0.49)**
λ (Road)	29.53 (0.00)	0.39 (0.40)
λ (Study area + Road)	1.60 (0.31)	42.68 (0.00)

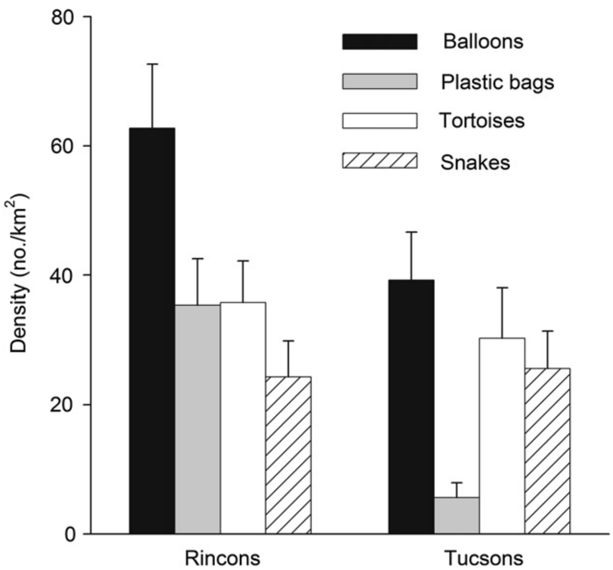

Fig. 1. Estimates of density, ±1 SE, for balloon clusters, plastic bags, desert tortoises, and western diamond-backed rattlesnakes in the Rincon and Tucson Mountains near Tucson, Arizona in 2005–2006.

biodegradable (Clapp and Swanston, 2009; Klemchuk, 2000). Therefore, microscopic plastic fragments may persist in the environment for centuries and long-term effects of these synthetic materials on water and soils are unknown (Clapp and Swanston, 2009). Given the persistence of these materials in the environment, they pose a potential threat to ecosystems over the long-term, even if production, distribution, or dispersal of plastic bags and balloons are curtailed.

I evaluated whether density of passively-dispersed trash in desert areas dissipated with distance from a potential source of origin, the nearest road. Contrary to expectations, there was no evidence that densities of plastic bags and balloons increased near roads; in fact, density of balloon clusters increased farther from roads in models that included road as a covariate. Further, densities of both plastic bags and balloon clusters were greater in the Rincon Mountains than the Tucson Mountains despite higher densities of roads and surrounding developments in the Tucson Mountains. Over the range of distances evaluated, I found that trash densities were largely independent of road proximity, suggesting that wind can disperse plastic bags and balloons >2 km into remote, wilderness areas. Although prevailing winds in southern Arizona blow from the southeast, stronger winds tend to blow from the west (U.S. Department of Agriculture, Natural Resources Conservation Service, http://www.wcc.nrcs.usda.gov/ climate/windrose.html), which could explain increased trash densities in the Rincon Mountains that are located directly east of Tucson.

The survey and analytical methods I used in this study are time- and cost-efficient, and could likely be incorporated into existing environmental or wildlife monitoring programs in many protected areas. In fact, in addition to plastic bags and balloons, the distance-sampling surveys in this study were used to concurrently estimate densities of desert tortoises, western diamond-backed rattlesnakes, and other reptile species. Moreover, the benefits of quantifying and monitoring trash in protected areas are substantial given the potential ecological, economic, and aesthetic costs associated with accumulation of trash in these areas, and the need to assess threats for wildlife species of conservation concern (Lawler et al., 2002).

In the United States, many coastal cities and municipalities, particularly in California, have banned the use of disposable plastic bags and created rules for mass releases of balloons (Clapp and Swanston, 2009), but few inland areas have implemented these types of policies. Without reliable data regarding the scope and severity of the problem in terrestrial environments, however, the ability of policy-makers to justify restrictions on the use of disposable plastics and balloons is limited. This study demonstrates both the ease with which relevant data can be obtained and the magnitude of the threat, at least in the protected desert areas I studied.

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Appendix A. Supplementary material

Supplementary material related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2012.10.004.

References

Azzarello, M.Y., Van Vleet, E.S., 1987. Marine birds and plastic pollution. Marine Ecology Progress Series 37, 295–303.
Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, Oxford, UK.
Clapp, J., Swanston, L., 2009. Doing away with plastic shopping bags: international patterns of norm emergence and policy implementation. Environmental Politics 18, 315–332.
Coe, J.M., Rogers, D.B., 1997. Marine Debris: Sources, Impacts, and Solutions. Springer, New York.
Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin 44, 842–852.
Fiske, I.J., Chandler, R.B., 2011. Unmarked: an R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43, 1–23.
Klemchuk, P.P., 2000. Environmental degradation of polymers. In: Hamid, S.H. (Ed.), Handbook of Polymer Degradation, second ed. Marcel Dekker Inc., New York, pp. 461–484.
Law, K.L., Morét-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M., 2010. Plastic accumulation in the North Atlantic subtropical gyre. Science 329, 1185–1188.
Lawler, J.J., Campbell, S.P., Guerry, A.D., Kolozsvary, M.B., O'Connor, R.J., Seward, L.C.N., 2002. The scope and treatment of threats in endangered species recovery plans. Ecological Applications 12, 663–667.
McDonald, R.I., Forman, R.T.T., Kareiva, P., Neugarten, R., Salzer, D., Fisher, J., 2009. Urban effects, distance, and protected areas in an urbanizing world. Landscape and Urban Planning 93, 63–75.
Moore, C.J., Moore, S.L., Leecaster, M.K., Weisberg, S.B., 2001. A comparison of plastic and plankton in the North Pacific central gyre. Marine Pollution Bulletin 42, 1297–1300.
Mrosovsky, N., Ryan, G.D., James, M.C., 2009. Leatherback turtles: the menace of plastic. Marine Pollution Bulletin 58, 287–289.
Nakashima, E., Isobe, A., Magome, S., Kako, S., Deki, N., 2011. Using aerial photography and *in situ* measurements to estimate the quantity of macro-litter on beaches. Marine Pollution Bulletin 62, 762–769.
Royle, J.A., Dawson, D.K., Bates, S., 2004. Modeling abundance effects in distance sampling. Ecology 85, 1591–1597.
Santos, I.R., Friedrich, A.C., Ivar do Sul, J.A., 2009. Marine debris contamination along undeveloped tropical beaches from northeast Brazil. Environmental Monitoring and Assessment 148, 455–462.
Turner, R.M., Brown, D.E., 1982. Sonoran desertscrub. Desert Plants 4, 181–221.
U.S. Fish and Wildlife Service, 2010. Endangered and threatened wildlife and plants; 12-month finding on a petition to list the Sonoran population of the desert tortoise as endangered or threatened. Federal Register 75, 78094–78146.
Walde, A.D., Harless, M.L., Delaney, D.K., Pater, L.L., 2007. Anthropogenic threat to the desert tortoise (*Gopherus agassizii*): litter in the Mojave Desert. Western North American Naturalist 67, 147–149.
Zylstra, E.R., Steidl, R.J., Swann, D.E., 2010. Evaluating survey methods for monitoring a rare vertebrate, the Sonoran Desert tortoise. Journal of Wildlife Management 74, 1311–1318.