



Research article

Influence of the Conservation Reserve Program (CRP) and playa wetlands on pollinator communities in the Southern High Plains, USA

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ABSTRACT

Numerous studies have documented that invertebrate pollinator services are critical to the world economy. Factors including habitat loss and agricultural practices, however, threaten pollinator populations. Many counties in the Southern High Plains were identified as at risk for a shortage of pollination service from wild bees. This region also has one of the highest concentrations of Conservation Reserve Program (CRP) contracts in the US. The CRP is the largest, voluntary, private lands conservation program in the US and was targeted as a program to improve pollinator habitat. Our objective was to determine how the predominant land uses in the SHP (native grassland, CRP, and cropland) affect pollinator abundance and species richness, and more specifically if the CRP can provide quality habitat for pollinators. We also examined how the keystone habitat, playa wetlands, embedded within these land uses contribute to pollinator habitat (land type: uplands vs. wetland). We used blue vane traps placed in playa basins and adjacent uplands to determine Hymenoptera abundance and richness from April to October in 2013 and 2014. The CRP had lower abundance than cropland and native grassland, and generally less richness. Uplands and playa wetlands had little difference in Hymenoptera abundance and richness. Patch size negatively influenced abundance but had a positive influence on richness. The interaction of vegetation height and percent bare ground positively influenced abundance in cropland and native grasslands, and positively influenced richness in all land uses. In the CRP, vegetation height negatively influenced Hymenoptera abundance and percent bare ground had a positive influence. The years sampled in this study were during a severe extended drought; therefore, these results may be reflective of poor floral resources. The CRP has potential to create valuable habitat for pollinators if land managers incorporate a diversity of native grasses and native forbs into plantings to enhance pollinator foraging and nesting habitat.

1. Introduction

In the 1990s, scientists became aware that many species of native invertebrate pollinators were in long-term decline, or their services were scarce (National Research Council, 2007). Potential causes for this decline come from a combination of factors, including habitat degradation and fragmentation (Cane and Tepedino, 2001; Potts et al., 2010; Hadley and Betts, 2012) and agricultural practices (Cane and Tepedino, 2001; Ghazoul, 2005). The concern over pollinator declines reached a critical status in 2006 when beekeepers in the United States began reporting massive die-offs of honeybees (*Apis mellifera*) (Stokstad, 2007, Environmental Protection Agency, 2017).

Invertebrates provide the bulk of pollination service (Kevan and Phillips, 2001; Abrol, 2012; Calderone, 2012). Most insect pollinators

are members of four orders (Willmer, 2011a; Abrol, 2012; Rader et al., 2016): Hymenoptera (ants, bees, wasps), Diptera (flies) (Larson et al., 2001; Clement et al., 2007; Jauker and Wolters, 2008; Saeed et al., 2008; Inouye et al., 2015; Orford et al., 2015), Coleoptera (beetles) (Bernhardt, 2000; Graham et al., 2012), and Lepidoptera (butterflies and moths) (Willmer, 2011c). For this paper, we focused on insects in the order Hymenoptera because bees are the most important pollinators (Kevan and Baker, 1983; Willmer, 2011b; Abrol, 2012). The value of their service to the United States agricultural economy is \$ 14.2–23.8 billion (Chopra et al., 2015). Crops dependent upon insect pollination include alfalfa, cucurbits, almonds, stone fruit, *Brassica* spp., clover, and strawberries (Abrol, 2012). Additionally, studies show that major self-pollinated crops such as cotton and soybeans demonstrated increased yields when pollinated by insects (Monasterolo et al., 2015;

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Cusser et al., 2016). There is also evidence that wind-pollinated crops such as corn and sorghum may benefit from insect pollination (Saunders, 2018).

In response to the pollination crisis, the White House released a Presidential Memorandum - Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators (The White House, 2014). The Pollinator Research Action Plan: Report of the Pollinator Health Task Force (The White House, 2016a) and National Strategy to Promote the Health of Honey Bees and Other Pollinators: Report of the Pollinator Health Task Force (The White House, 2016b), identified the Conservation Reserve Program (CRP) as a focal program to enhance and expand more than 2.8 million ha pollinator habitat. The CRP is the federal government's largest land conservation program (Stubbs, 2014). The purpose of the CRP is to provide rental payments and cost-share assistance to producers in exchange for voluntarily taking highly erodible land out of production and replacing it with permanent vegetation cover (Stubbs, 2014). The CRP provided almost \$2 billion annually for enrolled landowners since 1985 (Stubbs, 2014). In 2016, over 9.63 million ha were enrolled in the United States (Farm Service Agency, 2017). The Farm Service Agency and Natural Resource Conservation Service are the agencies tasked with identifying and expanding CRP plantings beneficial to pollinators. The Southern High Plains of Texas is an important area to determine the CRP effects on pollinators as it has some of the highest concentrations of CRP acreage in the country (Farm Service Agency, 2017), and it was identified as an area with potential for future pollination shortage (Koh et al., 2016).

The Southern High Plains is one of the most intensively cultivated regions in the Western Hemisphere (Smith, 2003). The original native upland habitat was shortgrass prairie, and livestock grazed land not cultivated (Smith and Haukos, 2002). Major crops are cotton, wheat, sorghum, and corn (National Agricultural Statistics Service, 2016). Because of intensive agriculture and high erosion potential, the Southern High Plains receives considerable funding for USDA conservation programs, primarily through the CRP. Early CRP contracts in the Texas High Plains consisted of mostly non-native grasses (Berthelsen et al., 1989), and many of these plantings remain in the landscape.

Playa wetlands are keystone habitats in the Southern High Plains (Haukos and Smith, 1994). They are shallow, depression, recharge wetlands (Smith, 2003). Playa wetlands occupy approximately 3% of the Southern High Plains, providing biodiversity refugia (Smith and Haukos, 2002). These wetlands are primarily under threat from watershed erosion and sediment deposition (Luo et al., 1997). Johnson et al. (2012) determined that 60% of original playa wetlands were lost from the Southern High Plains between 1970 and 2008 from erosion caused sedimentation fill and loss of visible depression. Playa wetlands are a source of diverse floral resources (O'Connell et al., 2012) and as such, they may be an important source of forage for pollinators, especially during drought. Loss of these wetlands to sedimentation and agricultural conversion has the potential to isolate pollinators and plant populations by habitat fragmentation in an already heavily altered landscape.

The CRP and playa wetland conservation efforts provide an opportunity to enhance pollinator habitat in a region identified as "at-risk" for a shortage of pollination service. Therefore, our objectives were:

- 1.) to determine how the predominant land uses in the Southern High Plains (native grassland, CRP lands, and cropland) influenced pollinator abundance and richness;
- 2.) to determine if land type (upland or wetland embedded in the land use) influenced invertebrate pollinator abundance and richness;
- 3.) to determine if landscape characteristics such as patch size, distance from nearest land use, vegetation height, and bare soil cover influenced pollinator abundance and richness;
- 4.) make recommendations for potential management actions to improve upland and wetland habitat for pollinators based on our findings.

2. Materials and methods

2.1. Study location

The study area encompassed nine counties in the Southern High Plains of Texas (Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher) between Amarillo and Lubbock, and approximately 2,353,522 ha (United States Census Bureau, 2007) (Fig. 1).

The climate is dry steppe (Smith, 2003). The mean daily temperatures from April–September in Amarillo, TX, the northern portion of the sampling area, was 13.5 °C–20.8 °C, and average precipitation for April–September was 4.88 cm–5.33 cm (National Weather Service, 2017a). Lubbock, TX is in the southern portion of the sampling area and April–September temperature ranged from 15.8 °C–22 °C, and average precipitation for April–September was 3.58 cm–6.38 cm (National Weather Service, 2017b). When sampling began in April 2013, the area was in moderate to exceptional drought (National Drought Mitigation Center, 2017). At the end of September, several significant rain events toward the end of the season eased drought conditions, and only a small portion of the area was in extreme drought with the remaining moderate to severe (National Drought Mitigation Center, 2017). Extended dry conditions persisted into 2014. These conditions maintained a drought trend that started in March 2011 (National Drought Mitigation Center, 2017).

2.2. Site selection

We selected the nine counties for the project because they were the location of study sites involved in long-term CRP and playa wetland research. The geographical range of counties allowed us to sample across temperature and precipitation variation. Each county had three sampling sites consisting of an accessible wetland embedded within the three land uses studied: cropland, CRP land, and native grassland. At each site, we established six permanent sets of parallel belt transects, 25 m long by 2 m wide, three sets in the uplands and three sets in the wetland (Fig. 2a).

Transect belts were established to collect vegetation data and determine locations for insect traps. To determine placement, we trisected each wetland from the center. With an online random number generator, we selected a random azimuth bearing in each section, (1°–120°, 121°–240°, 241°–360°) and placed the transect on that bearing. We positioned upland transects similarly by extending the azimuth bearing to a starting point at least 25 m from the wetland edge.

Reference sites were native grassland wetlands and their uplands that had not been plowed or restored. Landowners managed all native grassland sites as rangeland for cattle with varying levels of grazing intensity. In addition to grazing, persistent drought conditions influenced the quality of the native vegetation. Cropland was the land use state to which native landscapes were converted. All of our cropland sites were near ditches and unmaintained, relatively undisturbed areas that supported populations of flowers that were outside of our sampling transects (Begosh, 2018). Seven of nine cropland sampling sites had wetlands that were unplowed with wetland vegetation present. There were two types of upland directly adjacent to these wetlands; unmanaged de facto vegetated buffer strips or plowed but unplanted soil. The crops surrounded these vegetated or soil buffers rather than being directly adjacent to the wetland. The crops bordering these sites varied. In 2013, landowners planted five sites in grain sorghum, three sites had cotton, and one site had winter wheat. In 2014, landowners planted four sites in cotton, three sites had grain sorghum, one site had wheat and one site had corn. At these sites, upland transects were not in the crop, rather, they were placed on the perimeter of the crop. The last two cropland sites had plowed and cropped wetlands and all transects were placed in the crop. In both years, one was planted in cotton, and one in sorghum. It was possible for the landowner to plant in the wetland because playa wetlands are often dry during planting season. All CRP

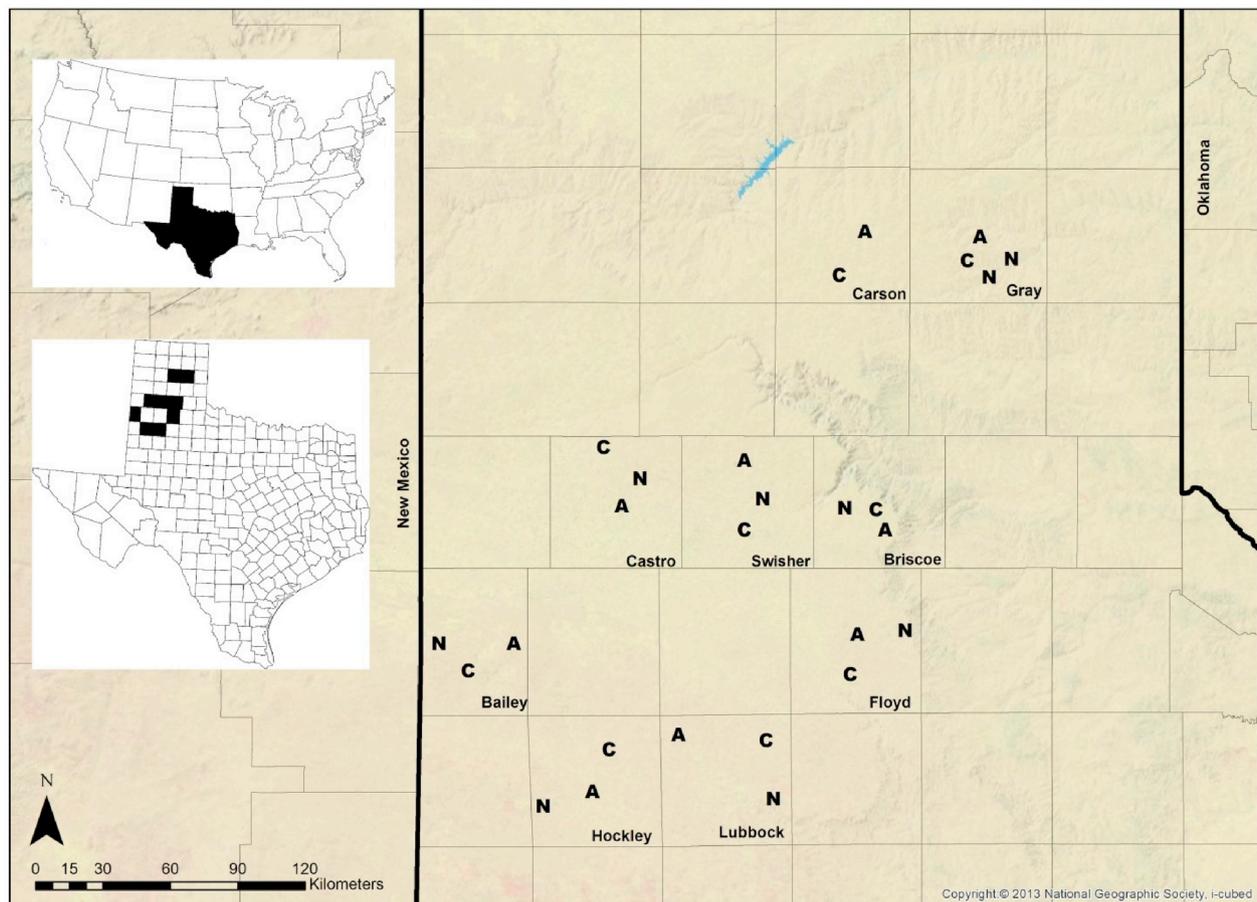


Fig. 1. Carson, Gray, Castro, Swisher, Briscoe, Bailey, Floyd, Hockley and Lubbock counties in the Southern High Plains of Texas, USA, where pollinator and vegetation sampling took place in April–September 2013 and 2014. Land uses represented are cropland (A), CRP (C), and native grassland (N). Each county had one land use represented except Gray, which had two native grassland sites because we were unable to obtain access to a native grassland site in Carson County. The location of each site is an approximation. We are unable to disclose the exact location due to confidentiality issues with landowners and USDA Farm Service Agency. Map created using ArcMap 10.7 (Environmental Systems Research Institute, 2019). Inset map created with mapchart.net.

sites in this study were seeded in a mix of grasses, primarily non-natives (Berthelsen et al., 1989) that were denser than native vegetation (O'Connell et al., 2012). The wetlands were not included in the CRP contract, however, some had been dry for several years and upland plants were present.

2.3. Sampling methods

We collected data from April–September in 2013 and 2014 for 26 weeks with 13 sampling periods. A bi-weekly rotation of sampling sites allowed us to capture variation in insect presence based on weather differences, all blooming periods for flowers, and varying flight times for pollinators. Daily sampling occurred between 0800 and 1800. We sampled sites in each county on the same day when weather and driving conditions permitted. We collected pollinators with Springstar™ blue vane traps (Stephen and Rao, 2005; Rao and Ostroverkhova, 2015). They are a visual attractant, not baited, and contain no killing agents or additives (Stephen and Rao, 2005). Halfway down each transect (12.5 m), we placed a 1.25 m wooden post with a wire to hang a trap. We adjusted the wire height so the traps were visible and hung in line with the height of the surrounding vegetation. We placed six traps at each site, three in the wetland, and three in the uplands. Each site representing each land use had two sampling units determined by land type; an upland sample and a wetland sample, each consisting of the respective three trap contents pooled. Traps were set out each day and collected the following day as close to 24 h as possible. We killed specimens in the field by transferring the contents of the traps into a

mesh vegetable bag and then placed the bag in a killing jar soaked with 99% ethyl acetate. Invertebrates collected from traps were stored in a Whirl-Pak collection bag representing each trap for that sampling period. Insects were stored in freezers at -20 C and identified at Oklahoma State University and the United States Geological Survey Northern Prairie Wildlife Research Center (USGS NPWRC). We confirmed insect identification by consulting reference collections built with input from taxonomic specialists.

2.4. Landscape metrics

We did not have grazing intensity data for the native grassland sites we sampled. Grazing can result in reduced vegetation height and stress on vegetation that causes reduced grass cover and increased bare ground percentage (Natural Resource Conservation Service, 2017). Conversely, livestock are excluded from CRP lands except for emergency grazing exemptions that did not occur during the study. To estimate the effects of vegetation by grazing in native grasslands and exclusion of livestock in CRP, we used mean vegetation height and mean percent bare ground cover in late season (September 1–14, 2013 and August 31–September 13, 2014) determined by the line-point intercept method (Herrick, 2009). We collected all data from one 25-m tape pulled taut against the ground, anchored on each end with rebar stakes. We recorded bare ground present at each meter with a dropped pin flag. Vegetation height was recorded at 2 m intervals starting at 1, 10 cm from the edge of the tape.

We used Google Earth (2018) to determine the distance from the trap

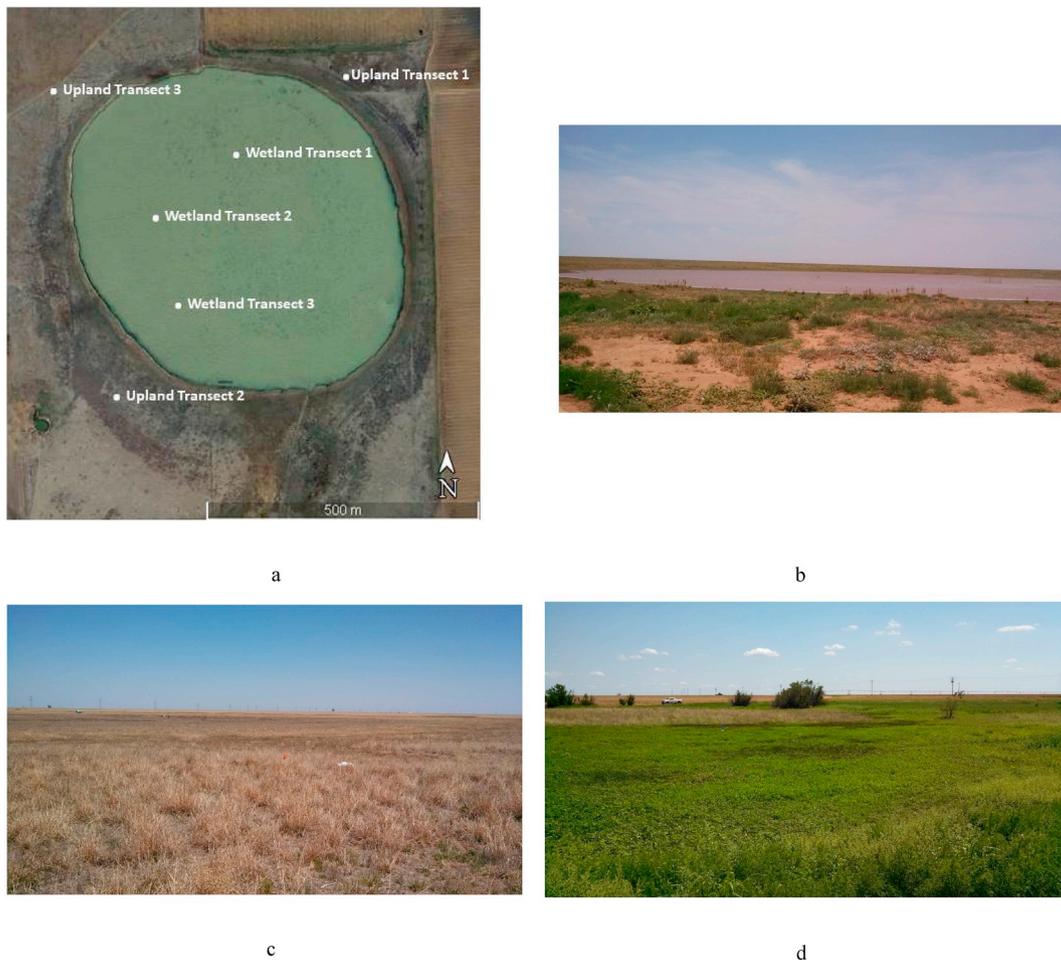


Fig. 2. a. Example of where transects were located for blue vane trap placement in playa basin and uplands in 2013 and 2014. We placed traps in nine counties in Texas (Bailey, Briscoe, Carson, Castro, Floyd, Hockley, Lubbock and Swisher), three sampling sites per county, representing native grasslands (Fig. 2b), CRP (Fig. 2c) and cropland (Fig. 2d) land uses. Each site had two sampling units; there were three traps in the wetland basin and three traps in the upland. The combined catch of the three traps in the upland represented the upland sampling unit and the combined trap collection in the wetland represented the wetland sampling unit. Source: Map showing an example of a Texas playa. *Google Earth*, earth.google.com/web/. Fig. 2b. Example of a native grassland sampling site in the Southern High Plains of Texas where potential pollinators and vegetation data were collected in 2013 and 2014. This site shows a wetland recently inundated from a rain event. Fig. 2c. Example of a CRP sampling site in the Southern High Plains of Texas where potential pollinators and vegetation data were collected in 2013 and 2014. This site shows a dry wetland which was typical of many CRP sites because dense grasses prevented water runoff into and inundation of the wetland. Fig. 2d. Example of a cropland sampling site in the Southern High Plains of Texas where potential pollinators and vegetation data were collected in 2013 and 2014. Although active agricultural operations surrounded cropland wetlands, many were protected from disturbance because it was difficult to cultivate the land when they were inundated. As a result, many had relatively undisturbed vegetation cover. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

in each sampling unit to the nearest adjacent land use and for the estimation of patch size. We determined patch size as the area of continuous land use where we located the sampling site, including the area surrounding the unit to which landowners granted us access. We used online records to determine the percentage of land uses in each county (Farm Service Agency, 2017; Texas Land Trends, 2018) (Table 1).

2.5. Statistical analysis

We used R version 3.5.3 (R Core Development Team, 2019) for statistical analysis. We pooled the thirteen biweekly trap collections each year by county so we could have a complete measure of total richness and abundance for each land use and land type over the growing season without the influence of sampling period. We examined the data and checked for outliers and heterogeneity. We applied a log₁₀ transformation to patch size, distance to nearest land use, and mean vegetation height to correct for skew. We then checked for collinearity using pairwise scatterplots, correlation coefficients and variance inflation

factors (VIF) (Zuur et al., 2009). The estimated correlation coefficient between distance from nearest differing land use and patch size was high (0.7) and the VIF for distance (2.09 for abundance and 2.06 for richness) was above a recognized conservative threshold for land use variables of ≥ 2 (Cusser et al., 2016). Therefore, we excluded distance to nearest land use as an explanatory variable. We tested for overdispersion. The data was highly overdispersed for abundance, and slightly overdispersed for richness. We standardized the continuous variables so they were on similar scales.

To determine the best predictors for pollinator richness and abundance, we built global models for both candidate sets using R package *lme4* (Bates et al., 2015). The *bbmle* package (Bolker and R Core Development Team 2017) was used to rank models. *MuMIn* (Barton, 2019) has a dredge function that we used to rank all possible combinations of an existing global model. We used the dredge function to avoid having a candidate set of models that were arbitrary. These models included the explanatory variables land use (LU), native grassland, CRP, cropland), land type (LT), wetland and upland), year

Table 1

Landscape metrics for sampling sites in Southern High Plains of Texas where we placed blue vane traps to collect insect specimens in 2013 and 2014. Patch size included the sampling unit and same contiguous land use. The total of each land use may exceed the area of county due to calculation methods based on centroids of independent school districts (Texas Land Trends, 2018). CRP percentages were confirmed with Farm Service Agency data (Farm Service Agency, 2017).

County	Land Use	Patch size (ha)	Estimated % land use in county	Land Type	Distance to nearest differing land use (m)	Land Type	Distance to nearest differing land use (m)
Bailey	crop	1750	36	wetland	909	upland	744
	CRP	260	24	wetland	416	upland	408
	native	129	58	wetland	422	upland	215
Briscoe	crop	408	42	wetland	375	upland	164
	CRP	263	8	wetland	157	upland	90
	native	664	24	wetland	583	upland	560
Carson	crop	28,507	57	wetland	1667	upland	1625
	CRP	263	10	wetland	545	upland	695
	native	101	46	wetland	2021	upland	1422
Castro	crop	270	13	wetland	1877	upland	1728
	CRP	201	19	wetland	341	upland	400
	native	6660	72	wetland	3272	upland	3237
Floyd	crop	72	22	wetland	72	upland	72
	CRP	78	21	wetland	221	upland	287
	native	2358	74	wetland	855	upland	733
Gray	crop	692	57	wetland	1027	upland	1667
	CRP	141	5	wetland	221	upland	340
	native	72	27	wetland	258	upland	258
Hockley	crop	1207	15	wetland	1567	upland	1570
	CRP	79	18	wetland	370	upland	271
	native	11,029	69	wetland	4413	upland	4422
Lubbock	crop	618	3	wetland	391	upland	318
	CRP	195	7	wetland	501	upland	450
	native	118	74	wetland	627	upland	640
Swisher	crop	522	30	wetland	276	upland	218
	CRP	249	19	wetland	372	upland	294
	native	688	61	wetland	714	upland	566

Table 2

Generalized linear mixed-effect models tested by AICc model selection to determine the best predictors of Hymenoptera abundance in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Southern High Plains of Texas in 2013–2014. Year = Year that we collected data (2013 or 2014), VegHt.T = Mean vegetation height with log transformation, Patch.T = Patch size with log transformation, Bare = mean percent bare ground cover, LU = Land use (crop, CRP, native grassland), and LT = Land type (upland or wetland). Models were derived from dredged global model. All three-way interactions include lower level effects.

Abundance Models	k	AICc	ΔAICc	ω _i	loglik
Year + Patch.T + LU x VegHt.T x Bare	7	8255.0	0	1	-4111.5
Year + LU x VegHt.T x Bare	6	8336.0	75	<0.001	-4150.4
Year + Patch.T + LU + VegHt.T x Bare	7	8659.1	398.1	<0.001	-4318.4
LU + VegHt.T x Bare	5	9215.7	954.8	<0.001	-4599.1
VegHt.T x Bare	4	9217.9	956.9	<0.001	-4602.5
Patch.T + LU + VegHt.T + Bare + LT + Year	8	9291.0	1030.1	<0.001	-4634.4
Year + VegHt.T + Bare + Patch.T + LU	7	9296.9	1035.9	<0.001	-4638.5
Year + VegHt.T + Bare + Patch.T + LT	7	9297.4	1036.5	<0.001	-4640.0
Year + VegHt.T + Patch.T + LU + LT	7	9297.6	1036.6	<0.001	-4638.9
Null Model	2	10,628.8	2367.8	<0.001	-5311.3
LU	3	10,629.6	2368.7	<0.001	-5309.5

sampled (Year), patch size (Patch), distance to nearest land use (Distance), mean vegetation height (VegHt) and mean bare ground cover (Bare). We used the interaction of vegetation height x bare ground cover as a proxy for the condition of vegetation at the sampling sites resulting from presence or lack of grazing. We then dredged those models and selected and tested all models with a delta AICc <7.0 (Burnham and Anderson, 2002). We used Akaike Information Criteria corrected for small sample size (AICc) as our model selection criteria (Zuur et al.,

2009; Burnham and Anderson, 2002). We created interaction plots using R packages *ggplot2* (Wickham, 2016), *interplot* (Solt and Yue, 2018), *plyr* (Wickham, 2011), and *dplyr* (Wickham et al., 2019).

3. Results

3.1. Hymenoptera collected

In 2013, 2014, we collected 72,633 insects in blue vane traps. Hymenoptera comprised 64% of the specimens (46,211) and 43,034 were native bees (Begosh, 2018). A detailed list of all insects captured and abundance numbers are found at (Begosh, 2018). The most abundant bee genera were *Melissodes* spp., *Diadasia* spp., *Lasioglossum* spp. and *Agapostemon* spp.

3.2. Abundance

Our top model suggests that patch size, land use, vegetation height, and bare ground cover influence Hymenoptera abundance (Table 2). Land use, vegetation height and bare ground positively influenced Hymenoptera abundance, while patch size was negatively associated with abundance. We found that crop and native grassland (NG) land uses had higher Hymenoptera abundances than CRP (Fig. 3). In these two land uses, vegetation height and percent bare ground positively influenced abundance; although in CRP, vegetation height negatively influenced abundance and percent bare ground positively influenced abundance. The highest abundances in CRP land uses were in areas with either low vegetation height or with a higher percentage of bare ground (Fig. 4). The model also shows that we had a higher abundance of Hymenopterans collected in 2014 than in 2013. None of the models incorporating land type were considered competitive, suggesting little difference in Hymenoptera abundances between wetland and uplands.

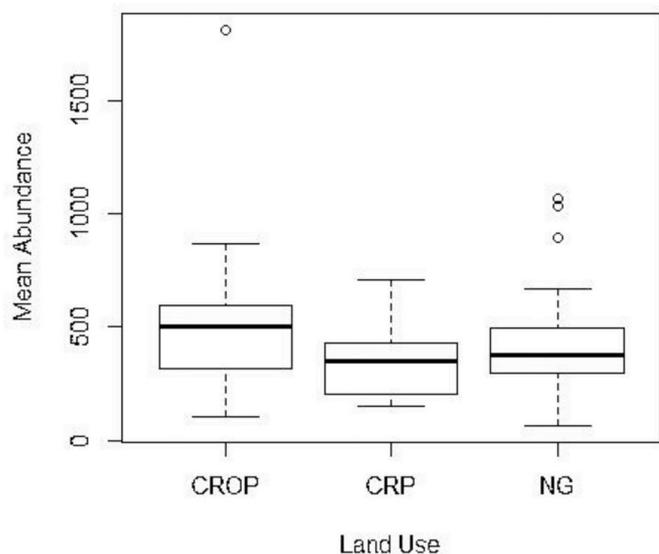


Fig. 3. Mean abundance of hymenopterans for cropland, CRP, and native grassland land uses collected with blue vane traps in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Southern High Plains of Texas in 2013–2014. Crop (M = 492.36, SD = 293.80), CRP (M = 338.69, SD 134.64), NG (M = 430.19, SD = 221.64). We tested eleven models for abundance (Table 2).

3.3. Richness

We tested sixteen models for richness (Table 3).

Our top model suggests that patch size, land use, vegetation height, and bare ground cover influences Hymenoptera richness (Table 3). Native grasslands and patch size both positively influenced Hymenoptera richness, whereas CRP land uses generally had less richness (Fig. 5). An interaction of bare ground and vegetation height positively affected richness, and areas with high or moderate bare ground and taller vegetation had the highest Hymenoptera richness (Fig. 6). The model also suggests that richness was higher in the second year of sampling. None of the competitive models incorporated land type, suggesting little differences in Hymenoptera richness between wetlands and uplands.

4. Discussion

4.1. Influence of land use

4.1.1. Native grassland

A high percentage of grassland cover in a landscape has been associated with supporting a higher diversity and abundance of some pollinators (Bennett and Isaacs, 2014; Pisanty and Mandelik, 2015). We expected that native grasslands would have a positive effect on pollinator abundance and richness, and our data support this. Croplands, however, did not vary greatly from native grasslands in abundance, and this was unexpected. Previous studies have demonstrated that in order

Table 3

Generalized linear mixed-effect models tested to determine the best predictors of Hymenoptera richness in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Southern High Plains of Texas in 2013–2014. Year = Year that we collected data (2013 or 2014), VegHt.T = Mean vegetation height with log transformation, Patch.T = Patch size with log transformation, Bare = mean percent bare ground cover, LU = Land use (crop, CRP, native grassland), and LT = Land type (upland or wetland). Models were derived from dredged global model.

Richness Models	k	AICc	ΔAICc	ω _i	loglik
Year + Patch.T + LU + VegHt.T x Bare	7	829.4	0	0.894	-403.6
Year + LU x VegHt.T x Bare	6	834.3	4.9	0.077	-399.6
Year + Patch.T + LU x VegHt.T x Bare	7	836.5	7.0	0.027	-399.2
Year + LT + LU + VegHt.T	6	844.3	14.9	<0.001	-413.4
Year + LU + VegHt.T	5	845.5	16	<0.001	-415.2
Year + LT + LU + VegHt.T + Patch.T	7	846.0	16.6	<0.001	-413.1
Year + Bare + LT + LU + VegHt.T	7	846.1	16.6	<0.001	-413.1
Year + LU + VegHt.T + Patch.T	6	847.2	17.8	<0.001	-414.9
Year + LU + VegHt.T + Bare	7	847.6	18.2	<0.001	-415.1
Year + Patch.T + LU + VegHt.T + Bare + LT	8	847.8	18.4	<0.001	-412.8
Year + LU + VegHt.T + Patch.T	6	849.4	19.9	<0.001	-414.8
Year + LT + LT + VegHt.T	6	850.6	21.2	<0.001	-418.9
LU + VegHt.T x Bare	5	862.0	32.5	<0.001	-422.3
VegHt.T x Bare	4	868.6	39.1	<0.001	-427.9
Null Model	2	931.0	101.6	<0.001	-462.4
LU	3	931.2	101.8	<0.001	-460.3

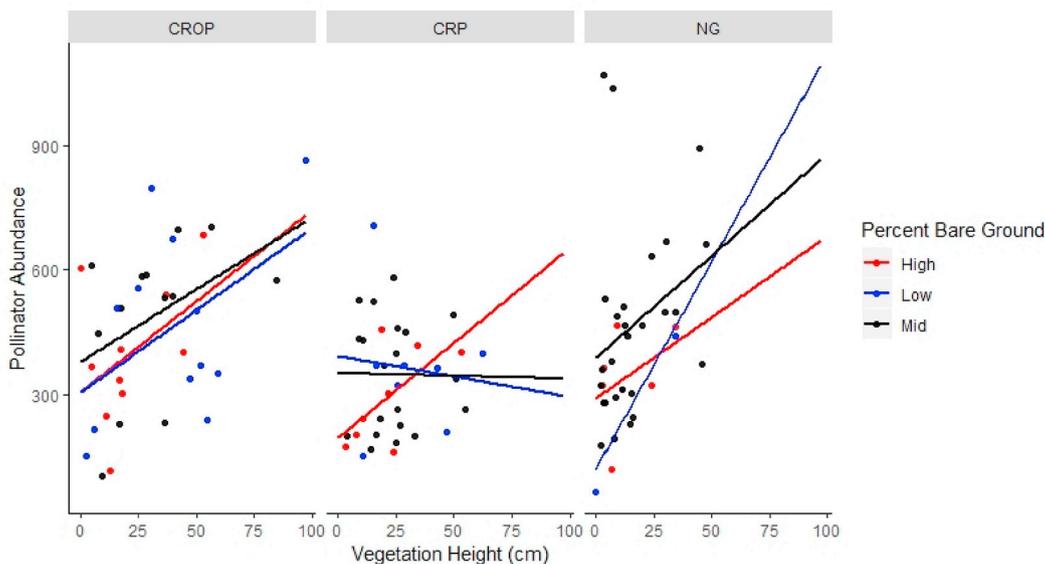


Fig. 4. Interactions between land use (crop, CRP, or native grasslands), vegetation height, and percent bare ground on Hymenoptera abundance. For graphical purposes we displayed percent bare ground as 3 categories: High (1 SD + x), Mid (x), and Low (x - 1 SD). Vegetation height was measured in centimeters. Summary tables are included as supplementary information (Table F4S).

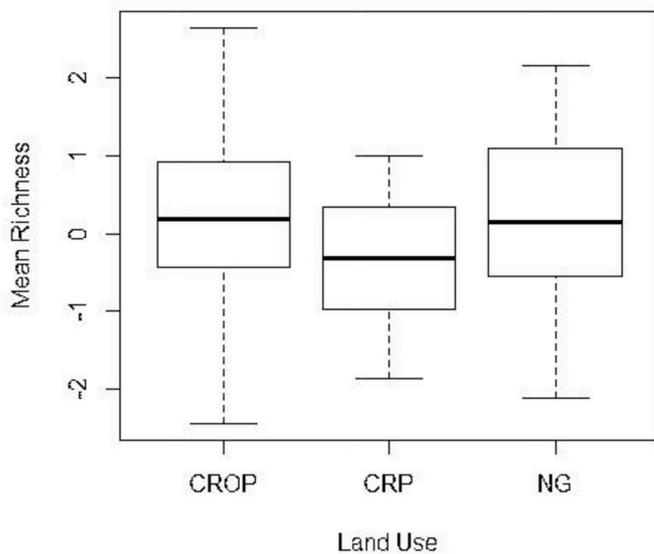


Fig. 5. Mean richness of hymenopterans for cropland, CRP, and native grassland land uses collected with blue vane traps in Bailey, Briscoe, Carson, Castro, Floyd, Gray, Hockley, Lubbock and Swisher counties in the Southern High Plains of Texas in 2013–2014. Crop (M = 49.33, SD = 12.31), CRP (M = 43.42, SD = 9.27), NG (M = 50.58, SD = 13.29).

for grasslands to support a diverse pollinator community, they must have high floral diversity and abundance (Potts et al., 2003; Dauber et al., 2010; Fründ et al., 2010; Blaauw and Isaacs, 2014), and provide adequate nesting habitat (Black et al. 2011, 2014).

Landowners managed all native grassland sites in our study as grazing lands, and this likely played a role in influencing our results (Gibson and New, 2007). Effects of grazing on pollinators are mixed, but there is evidence it changes the way pollinators select plants for visitation (Vázquez and Simberloff, 2003; Vanbergen et al., 2014). Research supports that grazing at an intensity appropriate for the habitat can enhance bee and flower richness and diversity (Vulliamy et al., 2006; Yoshihara et al., 2008; Wilkerson et al., 2013) and can be used as a tool to enhance biodiversity (Darkoh, 2003). However, overgrazed (Darkoh, 2003), heavily grazed (Vulliamy et al., 2006), and intensively managed

grassland pastures (Kruess and Tschamtkke, 2002; Cole et al., 2015) can result in poor floral resources and corresponding low diversity of plants and pollinators (Darkoh, 2003; Vulliamy et al., 2006; Cole et al., 2012). Our models show that vegetation height had a positive effect on hymenopteran abundance and richness in native grasslands, and grazing can decrease mean vegetation height, potentially reducing pollinator abundance and richness. For the sites we sampled, the dual stressors of grazing and exceptional drought conditions in the Southern High Plains starting in 2011 resulted in degraded habitat because of lack of adequate regrowth of grass and forbs. Mean vegetation height in cropland playa wetlands and uplands was significantly higher than vegetation height in native grasslands (Begosh, 2018). The deteriorated condition of the habitat likely contributed to native grasslands not having a much stronger positive influence on Hymenoptera abundance and richness.

4.1.2. Cropland

Agricultural conversion is correlated with the loss of biodiversity (Kennedy et al., 2013; Bennett and Isaacs, 2014; Chateil and Porcher, 2015; De Palma et al., 2015), and it can change the fundamental structure of plant-pollinator networks (Vanbergen et al., 2014). It was expected that cropland would have a negative effect on pollinator abundance and richness in our study, however, our models show that cropland had a positive influence on Hymenoptera abundance. Blue vane traps have been shown to be a strong attractant for non-Apis bees, even in the presence of rich floral resources (Stephen and Rao, 2007). Stephen and Rao (2005) found that the reflected light from the traps diverted female bees on their flight to floral resources. In this study, this likely resulted in artificially high abundance and richness numbers for cropland sites. Another factor that could contribute to high Hymenoptera abundance in cropland traps is that there are species and communities of wild bees that are not negatively affected by intensive agriculture (Winfrey et al., 2007; Cariveau et al., 2013; Mogren et al., 2016). Homogenization of the landscape, however, may result in a shift to more generalist or common bee species (Carré et al., 2009; Mogren et al., 2016). Generalist species are more tolerant of disturbance associated with land use and not as prone to extinction as pollinators with more specialized resource needs (Weiner et al., 2014). Mogren et al. (2016) demonstrated that northern Great Plains agricultural landscapes had mostly degraded habitat outside of crop monocultures, including less intensively managed forage crops and wetlands, which resulted in a

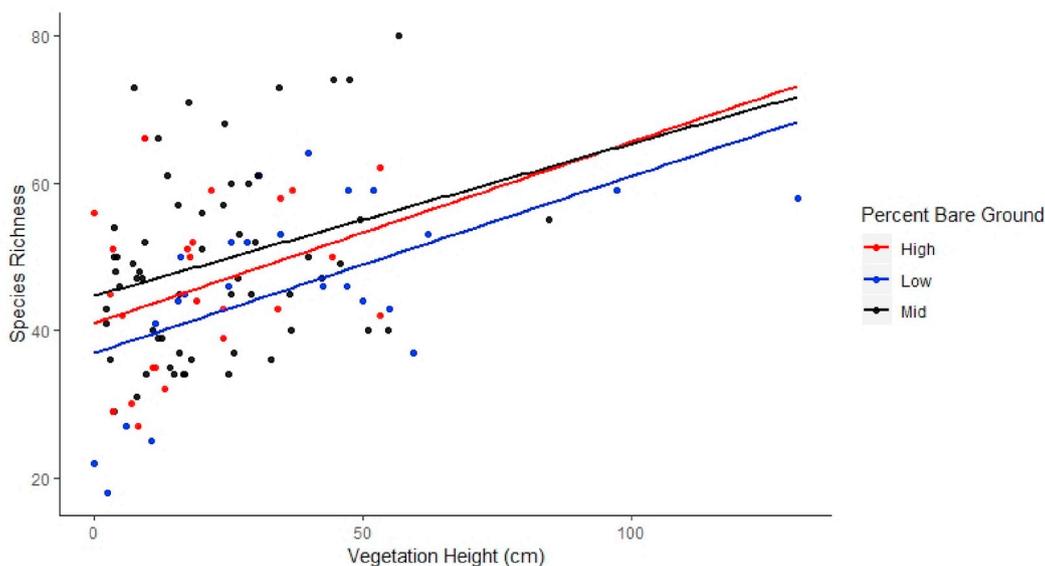


Fig. 6. An interaction of percent bare ground and vegetation height on Hymenoptera richness. For graphical purposes, we displayed percent bare ground as 3 categories: High (1 SD + x), Mid (x), and Low (x - 1 SD). Vegetation height was measured in centimeters. Summary tables are included as supplementary information (Table F6S).

predominance of generalist genera such as *Melissodes* spp. and halictid bees. Our results were similar in the Southern High Plains. We documented high abundance and richness of *Melissodes* spp. with 18 species, eight species of *Agapostemon* spp., and four species and one subgenus of *Lasioglossum* spp. (Begosh, 2018). Although *Melissodes* was species-rich, most of the species within the genera share similar functional roles in the landscape by feeding primarily on composite flowers (Asteraceae) (Ascher and Pickering, 2018). These three genera represented just over half of the bees collected during our study (Begosh, 2018).

4.1.3. The CRP

There is little information on how the CRP affects native pollinators. Most research has focused on game birds (Matthews et al., 2012a, 2012b; Blank, 2013) and grassland birds (Herkert, 2007; Osborne and Sparling, 2013). Although recent studies have concentrated on honeybees (Gallant et al., 2014; Otto et al., 2018), these studies cannot reliably predict the response of native bees. In our study, the CRP had a negative effect on Hymenoptera abundance and generally lower richness. All CRP sites in this study were seeded in a mix of grasses, primarily non-natives (Berthelsen et al., 1989) that were denser than native vegetation (O'Connell et al., 2012), and had higher total non-native grass cover and lower floral cover than the other land uses (Begosh, 2018). These plantings likely resulted in a lack of floral foraging resources and suitable nesting sites (Gilbert and Vaughan, 2011; Roulston and Goodell, 2011; Black et al., 2014) due to the characteristics of the dense tallgrass, non-native grass plantings.

In Europe, agri-environmental schemes (AES) are similar to the CRP in that farmers are provided payments to implement practices that enhance environmental quality. These practices have delivered variable results relative to pollinators (Carvell et al., 2007; Scheper et al., 2013). AESs have been most effective in intensively farmed areas and habitat-poor landscapes (Carvell et al., 2007; Pywell et al., 2011). Higher pollinator abundance and richness in these systems were because of the contrast between simple and complex habitats (Scheper et al., 2013). In our sampling area, CRP sites have the potential for increased Hymenoptera abundance and richness if seed mixes are high in forbs and use native grasses, and provide higher quality and quantity of floral forage and nesting sites for bees than native grasslands and cropland.

4.2. Influence of land type

There was little difference in abundance and richness in uplands and wetlands. This is likely because in this semi-arid landscape, pollinators rely on floral resources in both the uplands and wetlands, especially during drought years.

4.3. Influence of vegetation characteristics

The interaction of mean vegetation height and mean percent bare ground cover suggest that there may be specific vegetation characteristics of each site independent of land use that are drivers of pollinator abundance and richness. Kruess and Tscharntke (2002) and Ryder et al. (2005) found that vegetation height is a primary determiner of variation in insect diversity among habitats. Most native bees (70%) are ground nesters, and in addition to a rich floral resource, need sunny, well-drained areas with access to the soil (Vaughan and Black, 2008). Cropland sites had a higher mean vegetation height than native grassland and the CRP which were similar (Begosh, 2018), and this could have been a contributing factor for higher abundance in cropland sites. With vegetation height and percent bare soil interactions, both variables had a positive effect on abundance in cropland and native grasslands and richness in all land uses. In the CRP, however, increased vegetation height had a negative influence on abundance. Tall, dense, non-native grasses at these sites (Berthelsen et al., 1989; O'Connell et al., 2012) likely contributed to the negative effect of vegetation height on Hymenoptera abundance found only in the CRP. Exposed soil will benefit

ground nesting bees by providing nesting sites, and our models showed that percent bare soil had a positive influence on abundance and richness in all land uses, including the CRP.

4.4. Other landscape metrics

When studying land use effects on pollinators, it is important to consider the foraging range of native bees and the distance between land uses. Through translocation studies, Gathmann and Tscharntke (2002) determined that the average range of solitary bees was 150–600 m, and varies based on body length. Osborne et al. (1999) studied the foraging range of *Bombus terrestris* L. with harmonic radar and found the foraging range to vary from 70 to 631 m. Ideally, patch size of sampling units should be sufficiently large enough or far enough from a competing land use to accommodate the longest flights. In Texas, 95% of land is in private ownership (Texas Land Trends, 2014), and it can be challenging to secure consistent access to sampling sites. Additionally, over 50% of the CRP contracts in Texas in 2017 were 100 acres or less (Farm Service Agency, 2017). Although many of our sites did not meet minimum patch size or distance from other land uses (Table 1) to exceed the foraging distance of the largest native bees, this study represented land use as it is typically distributed in this region of Texas. Patch size had a positive influence on richness which was expected (Blaauw and Isaacs, 2014), but it had a negative influence on abundance. Gathmann and Tscharntke (2002) concluded that local scale landscape structure was more important than large-scale landscape structure for native bee survival. Vegetation structure differences in our smaller patches and presence of adequate floral resources may be more important.

5. Conclusion

This is the first study in the Southern High Plains to examine the effect the CRP has had on native pollinators relative to other land uses in the region. Our data show that the CRP in its current form in the Southern High Plains had a negative influence on pollinator abundance and is generally less rich than other land uses. The dense, introduced tall grasses in the uplands and low floral abundance in the wetlands and uplands reduced potential forage for pollinators.

The Southern High Plains has one of the highest concentrations of CRP in the country and has potential to become valuable as pollinator habitat primarily because of the amount of land enrolled. Future CRP plantings should emphasize pollinator health and be designed to incorporate native shortgrass prairie grasses and a variety of native, nectar-rich flowers into the landscape with the goal to enhance overall plant and insect biodiversity. This can be accomplished by emphasizing enrollment in the CRP's CP42 Pollinator Habitat practice and a focus on plantings that establish native grasses, especially around playa wetlands. Wetlands within these CRP plantings have the potential for restored hydrologic function when native grasses allow inundation previously reduced by dense introduced grasses. Restored hydrologic function can in turn, encourage the persistence of wetland flowers that can provide additional forage for pollinators, especially during drought conditions. In a landscape where most of the native shortgrass prairie experiences varying levels of disturbance from grazing cattle, the CRP could provide pockets of minimally disturbed habitat to serve as refugia for more specialized pollinators (Basu et al., 2016).

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Author contributions

Angela Begosh: Writing: Original draft preparation, investigation, data collection, statistical analysis, Loren M. Smith: Conceptualization, methodology, writing: review and editing, fund acquisition, Scott T. McMurry: Conceptualization, methodology, writing: review and editing, fund acquisition, Jonathan P. Harris: Statistical analysis, writing: review and editing.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jenvman.2019.109910>.

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