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A Comparison Of Shorebird Habitat Use Between Living Shorelines And Natural Fringing Marshes

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A Comparison of Shorebird Habitat Use Between Living Shorelines and Natural Fringing
Marshes

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A thesis presented to the Graduate Faculty of The College of William & Mary in
Candidacy for the Degree of Master of Science

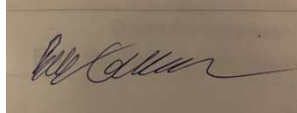
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APPROVAL PAGE

This Thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Science



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COMPLIANCE PAGE

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ABSTRACT

We examined the use of fringing marshes by herons and shorebirds in the southern portion of Chesapeake Bay. From 13 pairs of natural fringing marshes and nearby, constructed living shoreline marshes, we completed analysis of videos recorded at discrete, 30-minute intervals (dawn, dusk, high tide, low tide) throughout the 2018 and 2019 field seasons (May through August). A total of 684 hours of recording yielded 91 individual observations of birds comprising six species. Spotted Sandpipers (*Actitis macularius*) were observed most frequently (25), but only at living shoreline marshes. Likewise, 15 of 16 observations of Green Herons (*Butorides virescens*) were at living shoreline marshes. Great Blue Herons (*Ardea Herodias*; 19), Great Egrets (*Ardea alba*; 16), and Yellow-crowned Night Herons (*Nyctanassa violacea*; 14) were observed at both living shoreline and natural fringing marshes, and a single Willet (*Tringa semipalmata*) was observed at a living shoreline marsh. Bird species richness was significantly higher at living shoreline marshes relative to natural fringing marshes (2.2 ± 0.26 vs 1.0 ± 0.20 , respectively; Wilcoxon signed-rank test, $V = 45$, $p = 0.008$). Spotted Sandpipers spent significantly more time on average at living shoreline marshes relative to natural fringing marshes (514 s vs 0 s, respectively; $V = 36$, $p = 0.008$), as did Green Herons (341 s vs 4 s; $V = 36$, $p = 0.008$). We found, however, no difference in time spent between marsh types for Great Blue Herons, Great Egrets or Yellow-crowned Night Herons. From generalized linear modeling, no models that included time of day, time since high tide, year, or marsh type fit the observational data better than the null model for any species. For Spotted Sandpipers, the model including Julian day yielded a better fit with a positive slope, indicating increased use of living shoreline marshes later in the season of observation. The rocky sills placed in front of constructed living shoreline marshes appear to provide refuge and/or foraging habitat for both Spotted Sandpipers and Green Herons. Because use of living shoreline marshes by other heron and egret species was similar to natural fringing marshes, we conclude that living shorelines as coastal management features provide habitat support for herons and shorebirds at least as well as natural fringing marshes.

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INTRODUCTION

Relative sea level in the Chesapeake Bay is rising at a faster rate of over 5 mm/year (Boon 2012; Boon and Mitchell 2015; Ezer & Atkinson 2015), compared to the global average between 1.7 – 3.2 mm/year (U.S. Geological Survey 2013). The bay has over 19,000 km of shoreline fringed by tidal marshes, mudflats, and developed shorescapes (Center for Coastal Resources Management [CCRM] 2019). In addition to drowning when soil accretion rates cannot keep up with inundation (Morris et al 2016), fringing tidal marsh ecosystems in Chesapeake Bay and other estuaries are lost to coastal erosion exacerbated by sea level rise (Kirwan and Megonigal 2013).

Perhaps the greatest economic impact of coastal erosion is land loss (Nicholls and Cazenave 2010). As seas rise and low-lying areas are inundated, landowners face a dilemma: Do not make any changes to coastal property and slowly lose land, or; pay marine contractors to combat the effects of coastal erosion. In past decades, the typical management approach was to harden eroding shorelines in a process called “shoreline armoring” (Gittman et al. 2015; Prosser et al. 2018). Armoring consists of engineered structures, like bulkheads or riprap revetments, built on the shore to deflect wave energy. Armoring protects landowners’ property by preventing the loss of sediment to wave action. Shoreline armoring, however, leads to a variety of negative effects on coastal ecosystems, including habitat fragmentation (Peterson and Lowe 2009, Dugan et

al. 2011), prevention of natural landward migration of habitats in accordance with sea level rise, and declines in fish, invertebrate, and shorebird diversity (Bilkovic et al. 2006, Bilkovic and Roggero 2008, Prosser et al. 2017).

The negative consequences of shoreline armoring have led managers of coastal systems to seek better methods to protect these critical coastal habitats. One recently developed alternative to shoreline armoring is the living shoreline. Living shorelines are typically composed of a rock sill or other offshore breakwater combined with a shoreward backfilling of coarse sediment and native marsh grasses, typically *Spartina alterniflora* and *Spartina patens* in the Chesapeake Bay (Bilkovic et al. 2017). With the planting and growth of native marsh grasses, living shorelines are designed to mimic the ecological functions associated with natural fringing marshes. Natural fringing marshes, which are composed of very narrow bands of vegetation, help to dissipate wave action, provide nursery habitat for a variety of coastal taxa (Minello et al. 2012), filter water (Valiela & Cole 2002), and accrete sediment that can mitigate the effects of coastal erosion. A large number of fish and invertebrate species in estuarine ecosystems use tidal waters at or near the marsh fringe for feeding and refuge (Baltz et al. 1993, Peterson and Turner 1994, Glancy et al. 2003). In addition, these fringing marshes can act as corridors that connect more extensive marsh habitats (Rudershausen et al. 2018).

Living shorelines are a relatively new management strategy, and thus the degree to which these constructed intertidal marsh habitats mimic the functioning of natural fringing marshes is relatively unknown (Bilkovic et al. 2017), particularly with respect to bird use. Notably, living shorelines that include a rock sill feature fronting the marsh to reduce wave energy have additional structural heterogeneity that is not present in natural fringing marsh sites. For herons and shorebirds, the rock sill could provide refuge from land-based predators or harsh weather. Rock sills could also provide both important microhabitats for prey species and an elevated platform from which birds can forage during higher tidal levels when other foraging habitat is inundated.

Both tidal cycle and time of day are environmental variables known to affect the foraging ecology of many shorebirds and herons (Watts 1988, Riegner 1982, Maccarone & Brzorad 2005, Watts 2011, McCrimmon et al. 2011, Vennesland & Butler 2011, Davis Jr. et al. 2011), but the foraging response to rock sills has not been investigated. Especially for smaller herons and shorebirds in general, tidal stage and depth of flooding can limit foraging to those areas a bird is able to access. Additionally, some species preferentially forage in the morning or at dusk (Watts 2011, Vennesland & Butler 2011).

As a part of a larger project examining other ecosystem-level differences in soils, plants, fish and invertebrates, we determined the extent to which living shorelines

mimic natural fringing marshes with respect to use by large- and small-bodied herons and shorebirds. We analyzed video recordings to test the following hypotheses regarding bird use of living shoreline and natural fringing marshes: 1) species richness will be greater at living shoreline marshes because of bird use of rocky sills; 2) total time spent at each marsh type will vary by species; 3) behaviors by species will be similar at each marsh type; and 4) effects of environmental variables (marsh type, time of day, time of year, year and tide) on time spent in fringing marshes will vary by species. By examining bird use at both living shoreline and natural fringing marsh locations, we assessed bird use of natural fringing marshes and the relative importance of living shorelines for herons and shorebirds.

METHODS

Site Selection

Thirteen living shoreline (LS) and natural fringing marsh (NFM) pairs in the lower Chesapeake Bay were selected for our study on the basis of similarity in shoreline exposure, proximity, and site accessibility (Fig. 1). This design, with each NFM located within 349 m (SD = 229 m) of its living shoreline pair, allowed us to assess marsh use by shorebirds and herons as measured by their presence and time spent in each marsh type. Three of the LS-NFM pairs were located farther south in a highly populated, more urban setting; the other 10 marsh pairs were located farther north in a more rural setting (Fig. 1).

Bird Surveys

We surveyed each site between one to three times from May until August in 2018 and 2019, or a total of 3 to 6 times during the two years of sampling, with equal survey effort within each LS-NFM pair (Table 1). Although point counts are commonly used to characterize avian communities (Royle & Nichols 2003, Shriver et al. 2004, Conway 2011), we found this technique yielded few shorebird and heron detections in a pilot season in 2017, because herons and egrets often would flush at distances over 200 m as observers approached point-count locations either on foot or in a canoe (R. Galvin, pers. observation).

To eliminate the potential disturbance effect of observers on time spent by birds on study sites, we recorded bird activities remotely using Raspberry Pi cameras (Naturebytes Wildlife Cam Kit; <https://shop.naturebytes.org/product/naturebytes-wildlife-cam-kit/>) powered by a custom Raspberry Pi model A+ script (Raspberry Pi Foundation, 37 Hills Rd., Cambridge, UK). In 2018, between three and five Raspberry Pi cameras were placed on the rock sill of a LS and also at the edges of the paired NFM. At LS sites, the cameras were positioned on the left and right end of the rock sill facing the center of the sill. For sites where the rock sill was exceptionally long or sharply angled, additional cameras were set up in the middle of the two end cameras to capture the entirety of the rock sill. At NFM sites, the cameras were positioned at both ends of the leading edge of the fringing marsh, facing towards the center. The same number of cameras was used within each living shoreline and natural fringing marsh pair to standardize sampling effort among pairs. Cameras were covered in weatherproof casings and mounted atop tripods to ensure that they would not be submerged by high tides. The cameras were programmed to record 4 30-minute segments in a day near the expected peak activity times for shorebirds and herons, i.e., sunrise and sunset, as well as high tide and low tide (Burger et al. 1997). Because light levels are too low at sunrise or sunset, recordings were timed an hour after sunrise and before sunset to ensure birds would be visible in playback.

During the 2018 field season, camera performance was negatively affected by high air temperatures, leading to fewer and lower-quality segments being recorded. Thus, during 2019, we replaced the camera recording system to GoPro Hero 5 (GoPro, Inc., San Mateo, California, USA) cameras in conjunction with a BlinkX Time Lapse Controller (CamDo Solutions, 1200-555 West Hastings Street, Vancouver, BC, Canada) and DryX Weatherproof Enclosure (CamDo Solutions, 1200-555 West Hastings Street, Vancouver, BC, Canada). In 2019, either two or three cameras were set up at each living shoreline site, with an equal number at the paired NFM-LS marshes. Fewer cameras were needed in 2019 due to the better video clarity of the GoPros. Because the battery life of the cameras was increased in 2019, two additional 30-minute recording time periods were added— an hour before and an hour after high tide. We added these times because many of our observations from recordings from 2018 were of shorebirds foraging on the rock sills around high tide.

Data Analysis

Video footage was initially scanned at between 2x and 4x speed to detect and identify herons and shorebirds present in each 30-minute video segment, and to record the time in the video the bird entered and exited the viewing frame. Once that initial pass was completed, we re-reviewed all of the video segments with birds present and recorded how long they were present in the marsh, where in the marsh they were located, and whether they were stationary (i.e., standing on

one or two legs crouched or with extended neck), moving (i.e.,), or conducting maintenance behavior (i.e.,) like preening (behavior classification follows Kushlan 1976 and Kelly et al. 2003). Because maintenance behavior constituted <1% of total time spent in only one recording, this behavior was combined into the stationary category for behavioral analysis. For instances when an observed bird briefly left the field of view of the camera and did not fly or walk off the marsh, but became visible later in the 30-minute video segment, the time unseen was counted toward the total time a shorebird or heron was present in the marsh. When birds were visible on two different cameras in the same marsh, we recorded time and activity only from the camera closer to the bird. For each behavioral observation, we logged factors potentially influencing bird observations including marsh type (LS vs NFM), year (2018 vs 2019), Julian date, time of day, and time to nearest high tide in order to run further analyses (Burger et al. 1997).

Species richness and time spent at a given marsh type – To address our first two hypotheses, we tested for differences in species richness and total time spent by each species in the two marsh types. Because we observed species < 2% of the time, our sample size included only those synchronized video segments when a given species was observed in one or both marshes in a LS or NFM pair. In other words, we excluded from analyses all synchronized video segments when no species were observed. In cases for which a species was observed at only one

of the paired sites, the site with no observation received a zero for species count or time observed. Because our data were not normally distributed, we used a non-parametric equivalent to the paired t-test, the Wilcoxon signed-rank test (Wilcoxon 1945, Benayas et al. 2009, Arnold and Owens 1999) for comparisons between marsh types.

Behaviors by species - When comparing time spent moving and stationary in either marsh type, we focused on the Great Blue Heron (*Ardea Herodias*), Great Egret (*Ardea alba*), and Yellow-crowned Night Heron (*Nyctanassa violacea*), as these species had sufficient numbers of observations at both LS and NFM sites. Because observation duration for each behavior during a given 30-min video segment was our sampling unit, and because behavior time was not normally distributed, we use Mann-Whitney U tests (Zar 1999) to compare average time spent for a given behavior between marsh types.

Marsh use in relation to environmental variables – For each species, we evaluated total time spent per 30-min video segment for every recorded observation as a function of year, time to nearest high tide, Julian date, time of day, and marsh type, using general linear models with a negative-binomial error structure (Zuur et al. 2007). Our sample size included only those 30-min video segments in which we observed a given species. Because of small sample sizes, we only ran univariate models to avoid overfitting and did not include a random

site effect. For each species, we included an intercept only model (i.e., null model) in the candidate set of models to evaluate if the addition of a given predictor variable resulted in better models. We compared model rankings on the basis of AIC_c (Burnham et al. 2011). If a null model for a given species was within $2 \Delta AIC_c$ of top models with predictor variables, we considered all predictor variables unimportant. We also considered any predictor variable unimportant if ΔAIC_c values were > 10 (Burnham et al. 2011). All statistical analyses were run in R (R Core Team 2017). Where applicable, we report means (\pm SEM).

Results

We reviewed 316 hrs and 368 hrs of video footage in 2018 and 2019, respectively, for a total of 684 hours between both years. We observed a total of 91 individuals across sites for roughly 10 hours, i.e., about 1.5% of the footage included either a heron or shorebird. All observation and time data were collected for individual birds.

We documented four species of herons and two species of shorebirds over the two-year study period at the 13 paired sites, with all six species observed at LS sites and four species only observed at NFM sites (Table 2). All four heron species were observed at both LS and NFM sites. Great Blue Herons were found at 38.5% of LS sites (n = 5 sites; total number of observations = 8) and NMF sites (n = 5 sites; total number of observations = 11). Great Egret observations were distributed similarly, occurring at 30.8% of LS sites (n = 4 sites; total number of observations = 6) and at 38.5% of NMF sites (n = 5 sites; total number of observations = 10). Yellow-crowned Night Herons were found at 23.1% of LS sites (n = 3 sites; total number of observations = 8) and at 15.4% of NFM sites (n = 2 sites; total number of observations = 6). Finally, Green Herons (*Butorides virescens*) were found at 61.5% of LS sites (n = 8 sites; total number of observations = 15) and at one NFM site (n = 1 observation). Both shorebird species were found exclusively at LS sites. Spotted Sandpipers (*Actitis macularius*) and Willets (*Tringa semipalmata*) were found at 61.5% of LS sites (n

= 8 sites; total number of observations = 25) and one LS site, respectively, but at no natural fringing marsh sites. We included the Willet observation in the richness analysis but excluded it from the marsh use and behavioral analyses.

Does species richness differ between marsh types?

Over the two years of observation, average species richness was significantly higher at LS relative to NFM sites ($V = 45$, $p = 0.008$). Mean species richness was twice as high (2.2 ± 0.26) in LS marshes compared to NFM sites $1.0 (\pm 0.20)$.

Does time spent differ between marsh types?

Total time spent between LS and NFM sites differed among species (Table 2).

Two species spent significantly more time at LS than NFM sites: Green Heron ($V = 36$, $p = 0.008$; LS mean total time = 341 s [± 109], NFM mean total time = 4 s [± 3]) and the Spotted Sandpiper ($V = 36$, $p = 0.008$; LS mean total time = 514 s [± 314], NFM mean total time = 0 s). We found three heron species for which time spent did not differ between LS and NFM sites: Great Blue Heron ($V = 7$, $p = 0.30$; LS mean total time = 159 s [± 72], NFM mean total time = 243 s [± 120]), Great Egret ($V = 7$, $p = 0.22$; LS mean total time = 142 s [± 93], NFM mean total time = 363 s [± 213]), and Yellow-crowned Night Heron ($V = 5$, $p = 0.50$; LS mean total time = 593 s [± 337], NFM mean total time = 192 s [± 163]).

Do species behaviors relate to marsh type?

There were no statistically significant behavioral differences between LS and NFM for the Great Blue Heron, Great Egret, or Yellow-crowned Night Heron. For both marsh types, similar amounts of time were spent moving by the Great Blue Heron ($W = 29$, $p = 0.79$; LS mean total time = 85 s [± 26], $n = 8$ video segments; NFM mean total time = 161 s [± 48], $n = 11$ video segments), Great Egret ($W = 15$, $p = 0.23$; LS mean total time = 42 s [± 17], $n = 6$ video segments; NFM mean total time = 168 s [± 65], $n = 10$ video segments), and Yellow-crowned Night Heron ($W = 3$, $p = 0.70$; LS mean total time = 79 s [± 28], $n = 8$ video segments; NFM mean total time = 114 s [± 47], $n = 6$ video segments). Likewise, in both marsh types, similar amounts of time also were spent stationary by the Great Blue Heron ($W = 38$, $p = 0.56$; LS mean total time = 191 s [± 84], $n = 8$ video segments; NFM mean total time = 121 s [± 59], $n = 11$ video segments), Great Egret ($W = 9$, $p = 0.16$; LS mean total time = 219 s [± 154], $n = 6$ video segments; NFM mean total time = 294 s [± 114], $n = 11$ video segments), and Yellow-crowned Night Heron ($W = 7$, $p = 0.40$; LS mean total time = 844 s [± 226], $n = 8$ video segments; NFM mean total time = 342 s [± 116], $n = 6$ video segments).

Is marsh use by birds affected by environmental variables?

For the Spotted Sandpiper, the Julian date best explained the variation in total time spent at a given marsh type. All other predictor variables for this species

had ΔAIC_c values > 10 (Table 3). The slope was positive, indicating that later in the season of observation (May – August), Spotted Sandpipers were seen spending more time at the sites. For all other bird species, none of the models performed better than the null model (Table 3).

Discussion

This is the first study comparing bird use of natural fringing marshes and living shoreline marshes that, relative to bulkheads or riprap, are increasingly used as a “soft” defense against coastal erosion and rising seas. Prior research has documented heron use of more extensive marshes (Chavez-Ramirez & Slack 1995, Darnell & Smith 2004, Maccarone & Brzorad 2005, Raposa et al. 2009). From our results, herons and other shorebirds use constructed living shoreline marshes at least as much as natural fringing marshes. In this study, significantly more bird species used living shoreline marshes, although the diversity difference largely was due to the occurrence of Green Herons and Spotted Sandpipers on rocky sills placed in front of the marsh. All 25 observations of Spotted Sandpipers and 15 of 16 observations of Green Herons were at living shorelines. Not surprisingly, we found that Green Herons and Spotted Sandpipers spent significantly more time at living shoreline sites, relative to natural fringing marshes.

Sills provide structure that often is exposed even during high tides, giving Green Herons and Spotted Sandpipers habitat for refuge and/or foraging. These two smaller species are more limited by tidal flooding in their potential use of natural fringing marshes relative to larger Great Blue Herons and Great Egrets. Green Herons typically forage by waiting for prey at the edge of the water or in very shallow water (Davis Jr. & Kushlan 1994) and consume a much more limited size

range of fish than larger herons and egrets (Davis Jr. & Kushlan 1994). In contrast, Spotted Sandpipers mostly consume invertebrates, but will also consume small fish if locally abundant (Oring & Reed 2013). We suggest that rocky sills must house prey that are available to Green Herons and Spotted Sandpipers and account for their almost ubiquitous occurrence at living shoreline marshes.

For the other herons, however, we found no difference in their total time spent at living shoreline and natural fringing marshes. Great Blue Herons, Great Egrets and Yellow-crowned Night Herons comprised 49 of 91 total observations of individual birds, and all three species were observed at two or more of each of the 13 living shoreline-natural marsh pairs (Table 2). Great Blue Herons are the largest birds found in these marshes, and are relatively sedentary hunters, typically standing in wait of prey or slowly walking along the marsh edge looking for food (Vennesland & Butler 2011). In addition, they are opportunistic feeders – they are primarily piscivorous, but will also eat invertebrates and many other organisms (Vennesland & Butler 2011). Great Egrets are similarly generalist predators, tending to prey on what is locally available rather than any specific size or type of prey (McCrimmon et al. 2011). Great Blue Herons and Great Egrets are larger and can forage in deeper water during high tide. The relatively smaller Yellow-crowned Night Herons are the most specialized feeders of the herons we saw, exclusively feeding on crustaceans (Watts 2011). The presence

of all three species at both living shoreline and natural fringing marshes suggests relevant prey items are present in both marsh types.

Unlike Green Herons and Spotted Sandpipers, Great Blue Herons, Great Egrets and Yellow-crowned Night Herons were observed mostly along marsh fringes and not on rocky sills. In comparing behaviors of herons between marsh types, we detected no difference in average time spent either stationary or moving in living shoreline or natural fringing marshes. We observed, however, a general but non-significant trend of more time on average spent moving in natural fringing marshes than in living shoreline marshes for Great Blue Herons (161 vs 85 s), Great Egrets (168 vs 42 s) and Yellow-crowned Night Herons (114 vs 79 s). Bird movements could be related to searching for or actively stalking prey, and we do not know whether these temporal differences in movement are the result of habitat differences between marsh types.

Interestingly, bird use of living shoreline and natural fringing marshes did not vary in relation to time of day or time to high tide. From prior studies, we expected to see that bird use would be higher in either mornings or evenings, or at low tide relative to high tide (Watts 1988, Riegner 1982, Maccarone & Brzorad 2005, Watts 2011, McCrimmon et al. 2011, Vennesland & Butler 2011, Davis Jr. et al. 2011). When grouping all the data from both marsh types, however, the fitted model of bird use was not improved over the null model by including time of day

or tide for any of the five species (the single observation of a Willet was not included in the analysis) (Table 3). Further, we detected no differences by year of observation (2018 vs 2019) or by marsh type (living shoreline vs natural fringing marsh). We note that our prior, non-parametric rank analysis indicated more time spent by both Green Herons and Spotted Sandpipers at living shoreline marshes. The non-parametric test ranks differences in time spent between living shoreline and natural fringed marsh pairs by a given species, which includes zeros for when a given species was absent at one of the two marshes, whereas the GLM model regresses time spent at a marsh by a given species in relation to environmental factors. Only for the Spotted Sandpiper did the model including time of year (Julian day) fit the data better than the null model, indicating that the use of marshes by sandpipers increased later in the season of observation, May through August.

Other unmeasured environmental variables could help explain the observed spatial variation in bird use of different LS-NFM pairs. Herons and shorebirds in particular tend to have variable, species-specific reactions to anthropogenic disturbance (Burger & Gochfeld 1998, Peters & Otis 2006). In our study, Spotted Sandpipers were found exclusively at more rural sites (Table 2; Fig. 1), suggesting they may be sensitive to anthropogenic disturbance that might be greater at the three more urban LS-NFM pairs. In contrast, our observations of Yellow-crowned Night Herons were exclusive to those three most southern

marsh pairs found in urban areas. Because others have indicated that Yellow-crowned Night Herons are fairly sensitive to disturbance (Peters & Otis 2006, Prosser et al. 2017), their occurrence in our more urban marsh regions may be the result of other factors. Perhaps night heron rookeries are located nearer to our southern sampling sites and thus observations are concentrated in marshes there. Alternately, night herons may be sensitive to disturbance in urban regions, but if the availability of marsh area for foraging is limited, they may concentrate their efforts in lower-quality (i.e., more disturbed) marshes that may be all that is available regionally. In this regard, living shoreline marshes in urbanized estuaries could be important constructed habitat for herons faced with limited feeding resources.

Relative to hardened shorelines, constructed living shoreline marshes are viable alternatives to be used in the ongoing management of estuarine ecosystems and conservation of shorebird diversity. A recent study found that since 1970, bird populations in North America have lost a net 3 billion birds, or 29% of 1970 abundance (Rosenberg et al. 2019). The study estimated that the Scolopacidae, or Sandpiper, family decreased in abundance by roughly 38%, and 72% of the 32 species in the Sandpiper family show a negative trajectory (Rosenberg et al. 2019). The Ardeidae, or Heron, family experienced a 29% decrease in abundance from 1970 levels, and 58% of the 12 species in that family show a negative trajectory (Rosenberg et al. 2019). These birds are further threatened

by habitat loss; for example, fringing marshes constituted much of the marsh loss in one subestuary of the Chesapeake Bay since the 1970s (Mitchell et al. 2017). Providing habitat to these at-risk shorebird species will be critical for their survival in the future, and this study demonstrates that living shorelines are providing comparable, or even increased, quality habitat for herons and other shorebirds compared to natural fringing marshes.

Appendix

Table 1: Number of times each site pair was surveyed (LS = living shoreline, NFM = natural-fringed marsh). Site pairs are sorted from south to north, where 1 is the southernmost pair of marshes and 13 the northernmost pair (Fig. 1).

LS & NFM Pair	2018	2019	Total
1	2	3	5
2	1	3	4
3	1	2	3
4	2	3	5
5	4	2	6
6	4	2	6
7	3	2	5
8	1	2	3
9	2	3	5
10	2	3	5
11	2	2	4
12	1	2	3
13	1	2	3
Total	26	31	57

Table 2: Time spent in seconds by six species of wading birds by site. Site pairs are sorted from south to north, where 1 is the southernmost pair of marshes and 13 the northernmost pair (Fig. 1). Unshaded rows represent living-shoreline sites (a) and shaded boxes represent natural fringing marsh sites (b). Scientific names for each species are listed in Methods and Results.

Site	Great Blue Heron	Great Egret	Green Heron	Yellow-crowned Night Heron	Willet	Spotted Sandpiper
1a	0	0	203	1594	0	0
1b	0	1126	0	291	0	0
2a	0	294	0	4181	0	0
2b	0	0	0	0	0	0
3a	0	24	0	1939	0	0
3b	578	0	0	2208	0	0
4a	0	0	739	0	792	204
4b	0	391	0	0	0	0
5a	863	0	0	0	0	17
5b	1424	0	0	0	0	0
6a	432	281	1156	0	0	583
6b	0	24	0	0	0	0
7a	473	1249	55	0	0	309
7b	0	2797	0	0	0	0
8a	0	0	954	0	0	656
8b	0	0	0	0	0	0
9a	0	0	225	0	0	509
9b	0	377	0	0	0	0
10a	127	0	427	0	0	0
10b	231	0	40	0	0	0
11a	178	0	669	0	0	0
11b	893	0	0	0	0	0
12a	0	0	0	0	0	4355
12b	0	0	0	0	0	0
13a	0	0	0	0	0	55
13b	34	0	0	0	0	0
Σ a	2073	1848	4428	7714	792	6688
Σ b	3160	4715	40	2499	0	0

Table 3: Results of total time spent by each species in relation to marsh type (LS vs NFM) (Type), time since high tide (Tide), time of day (Time), date (Date), and year (Year). For each species we included an intercept model (null model) to evaluate if the addition of a predictor resulted in a better model. Shown for each model are degrees of freedom (Df), loglikelihood estimate (logLik), Akaike Information Criterion adjusted for small sample size (AIC_c), delta AIC (ΔAIC_c), and AIC weight (Weight). Scientific names for each species are listed in Methods and Results.

Species	Model	Df	logLik	AIC_c	ΔAIC_c	Weight
Great Blue Heron	Null	2	-126.36	257.47	0	0.38
	Tide	3	-125.65	258.91	1.44	0.18
	Time	3	-125.74	259.08	1.61	0.17
	Date	3	-126.36	260.29	2.82	0.09
	Year	3	-126.35	260.31	2.83	0.09
	Type	3	-126.36	260.32	2.85	0.09
Great Egret	null	2	-112.26	229.43	0	0.37
	time	3	-111.04	230.08	0.643	0.27
	type	3	-111.95	231.90	2.46	0.11
	date	3	-112.22	232.43	2.99	0.08
	tide	3	-112.23	232.45	3.02	0.08
	year	3	-112.22	232.45	3.02	0.08

Green Heron	time	3	-104.23	216.45	0	0.34
	null	2	-106.03	216.99	0.53	0.26
	type	3	-104.66	217.32	0.87	0.22
	year	3	-106.01	220.02	3.57	0.06
	tide	3	-106.02	220.04	3.59	0.06
	date	3	-106.03	220.05	3.60	0.06
Yellow-crowned Night Heron	null	2	-106.30	217.68	0	0.42
	type	3	-105.04	218.47	0.79	0.28
	date	3	-105.91	220.22	2.53	0.12
	tide	3	-106.08	220.56	2.88	0.10
	time	3	-106.29	220.98	3.29	0.08
Spotted Sandpiper	date	3	-153.16	313.53	0	0.99
	tide	3	-158.92	325.03	11.50	0.003
	time	3	-158.94	325.08	11.55	0.003
	type	3	-158.99	325.13	11.60	0.003
	year	3	-159.56	326.27	12.74	0.003
	null	2	-163.08	330.71	17.18	0.0002

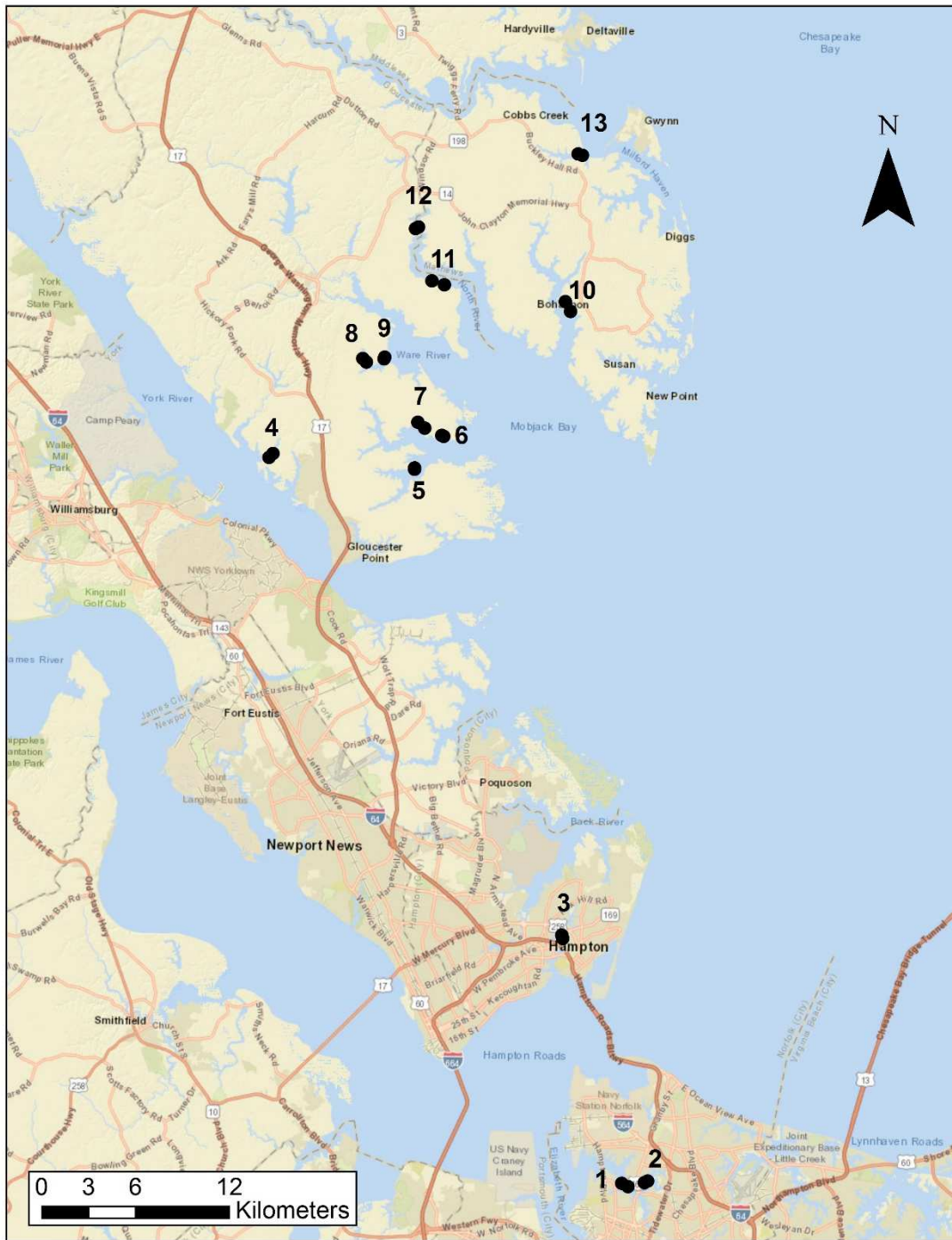


Figure 1: Location of paired study sites in southeastern Virginia.

References

- Albanese, G., & Davis, C. A. (2013). Broad-Scale Relationships between Shorebirds and Landscapes in the Southern Great Plains. *The Auk*, 130(1), 88–97. <https://doi.org/10.1525/auk.2012.11240>
- Arnold, K. E., & Owens, I. P. F. (1999). Cooperative breeding in birds: The role of ecology. *Behavioral Ecology*, 10(5), 465–471.
<https://doi.org/10.1093/beheco/10.5.465>
- Baltz, D. M., Rakocinski, C., & Fleeger, J. W. (1993). Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fishes*, 36(2), 109–126. <https://doi.org/10.1007/BF00002790>
- Benayas, J. M. R., Newton, A. C., Diaz, A., & Bullock, J. M. (2009). Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *Science*, 325(5944), 1121–1124. <https://doi.org/10.1126/science.1172460>
- Bentley, E. (1994). *Use Of A Landscape-Level Approach To Determine The Habitat Requirements Of The Yellow-Crowned Night-Heron, Nycticorax Violaceus, In The Lower Chesapeake Bay*. <https://doi.org/10.25773/V5-YKDF-GQ95>
- Bilkovic, D. M., Mitchell, M., Toft, J., & La Peyre, M. (2017). *A Primer to Living Shorelines*. CRC Press, Taylor & Francis Group.
- Bilkovic, D. M., Roggero, M., Hershner, C. H., & Havens, K. H. (2006). Influence of land use on macrobenthic communities in nearshore estuarine habitats.

Estuaries and Coasts, 29(6), 1185–1195.

<https://doi.org/10.1007/BF02781819>

- Bilkovic, D. M., & Roggero, M. M. (2008). Effects of coastal development on nearshore estuarine nekton communities. *Marine Ecology Progress Series*, 358, 27–39. <https://doi.org/10.3354/meps07279>
- Boon, J. D. (2012). Evidence of Sea Level Acceleration at U.S. and Canadian Tide Stations, Atlantic Coast, North America. *Journal of Coastal Research*, 1437–1445. <https://doi.org/10.2112/JCOASTRES-D-12-00102.1>
- Boon, J. D., & Mitchell, M. (2015). Nonlinear Change in Sea Level Observed at North American Tide Stations. *Journal of Coastal Research*, 1295–1305. <https://doi.org/10.2112/JCOASTRES-D-15-00041.1>
- Burger, J., & Gochfeld, M. (1998). Effects of ecotourists on bird behaviour at Loxahatchee National Wildlife Refuge, Florida. *Environmental Conservation*, 25(1), 13–21. <https://doi.org/10.1017/S0376892998000058>
- Burger, J., Niles, L., Clark, K. E. (1997). Importance of beach, mudflat and marsh habitats to migrant shorebirds on Delaware Bay. *Biological Conservation* 79 (2-3): 283-292.
- Burnham, K. P., Anderson, D. R., & Huyvaert, K. P. (2011). AIC model selection and multimodel inference in behavioral ecology: Some background, observations, and comparisons. *Behavioral Ecology and Sociobiology*, 65(1), 23–35. <https://doi.org/10.1007/s00265-010-1029-6>
- Center for Coastal Resources Management (CCRM). (2019). Chesapeake Bay

Shoreline Inventory Database. Virginia Institute of Marine Science, William & Mary, Gloucester Point, Virginia.

<http://www.vims.edu/ccrm/research/inventory/index.php>

Chavez-Ramirez, F., & Slack, R. D. (1995). Differential Use of Coastal Marsh Habitats by Nonbreeding Wading Birds. *Colonial Waterbirds*, 18(2), 166–171. <https://doi.org/10.2307/1521477>

Conway, C. (2011). Standardized North American Marsh Bird Monitoring Protocol. *Waterbirds: The International Journal of Waterbird Biology*, 34(3), 319–346.

Darnell, T. M., & Smith, E. H. (2004). Avian Use of Natural and Created Salt Marsh in Texas, USA. *Waterbirds: The International Journal of Waterbird Biology*, 27(3), 355–361. Retrieved from JSTOR.

Davis, Jr., W. E., & Kushlan, J. A. (1994). Green Heron (*Butorides virescens*). *The Birds of North America Online*. <https://doi.org/10.2173/bna.129>

Dugan, J., Airoidi, L., Chapman, M., Walker, S., & Schlacher, T. (n.d.). Estuarine and Costal Structures: Environmental Effects, A Focus on Shore and Nearshore Structures. In *Treatise on Estuarine and Coastal Science* (Vol. 8, pp. 17–41). Waltham: Academic Press.

Ezer, T. and L. Atkinson (2015), Sea level rise in Virginia-causes, effects and response. *Virginia Journal of Science*, 66(3), 355-359, Publication of the Virginia Academy of Science. (n.d.). Retrieved November 12, 2019, from ResearchGate

website: https://www.researchgate.net/publication/313139836_Ezer_T_and_L_Atkinson_2015_Sea_level_rise_in_Virginia-causes_effects_and_response_Virginia_Journal_of_Science_663_355-359_Publication_of_the_Virginia_Academy_of_Science

Fretwell, S. D., & Lucas, H. L. (1969). On territorial behavior and other factors influencing habitat distribution in birds. *Acta Biotheoretica*, 19(1), 16–36. <https://doi.org/10.1007/BF01601953>

Gittman, R. K., Fodrie, F. J., Popowich, A. M., Keller, D. A., Bruno, J. F., Currin, C. A., ... Piehler, M. F. (2015). Engineering away our natural defenses: An analysis of shoreline hardening in the US. *Frontiers in Ecology and the Environment*, 13(6), 301–307. <https://doi.org/10.1890/150065>

Glancy, T. P., Frazer, T. K., Cichra, C. E., & Lindberg, W. J. (2003). Comparative patterns of occupancy by decapod crustaceans in seagrass, oyster, and marsh-edge habitats in a Northeast Gulf of Mexico estuary. *Estuaries*, 26(5), 1291–1301. <https://doi.org/10.1007/BF02803631>

Isdell, R.E. (2018). Predominate land use around NSF Coastal SEES award #1600131 study sites.

Kelly, J. K., Gawlik, D. E., Kieckbusch, K. D. (2003) An Updated Account of Wading Bird Foraging Behavior. *The Wilson Journal of Ornithology*, 115(1), 105-107.

Kirwan, M.L. Megonigal, J.P. (2013). Tidal wetland stability in the face of human activity and sea level rise. *Nature* 504:53-60.

- Koch, S. L., & Paton, P. W. C. (2014). Assessing anthropogenic disturbances to develop buffer zones for shorebirds using a stopover site. *The Journal of Wildlife Management*, 78(1), 58–67. <https://doi.org/10.1002/jwmg.631>
- Kushlan, J. A. 1976. Feeding behavior of North American herons. *Auk* 93:86–94.
- Lowther, P. E., Douglas, lii, H. D., & Gratto-Trevor, C. L. (2001). Willet (*Catoptrophorus semipalmatus*). *The Birds of North America Online*. <https://doi.org/10.2173/bna.579>
- Maccarone, A. D., & Brzorad, J. N. (2005). Foraging Microhabitat Selection by Wading Birds in a Tidal Estuary, with Implications for Conservation. *Waterbirds*, 28(3), 383–391. [https://doi.org/10.1675/1524-4695\(2005\)028\[0383:FMSBWB\]2.0.CO;2](https://doi.org/10.1675/1524-4695(2005)028[0383:FMSBWB]2.0.CO;2)
- Mann, H. B., & Whitney, D. R. (1947). On a Test of Whether one of Two Random Variables is Stochastically Larger than the Other. *The Annals of Mathematical Studies*, 18(1), 50-60. <https://doi.org/10.1214/aoms/1177730491>
- Mccrimmon, Jr., D. A., Ogden, J. C., & Bancroft, G. T. (2011). Great Egret (*Ardea alba*). *The Birds of North America Online*. <https://doi.org/10.2173/bna.570>
- McKinney, R. A., Raposa, K. B., & Kutcher, T. E. (2010). Use of urban marine habitats by foraging wading birds. *Urban Ecosystems*, 13(2), 191–208. <https://doi.org/10.1007/s11252-009-0111-1>
- Minello, T. J., Rozas, L. P., & Baker, R. (2012). Geographic Variability in Salt Marsh Flooding Patterns may Affect Nursery Value for Fishery Species.

Estuaries and Coasts, 35(2), 501–514. <https://doi.org/10.1007/s12237-011-9463-x>

Mitchell, M., Herman, J., Bilkovic, D. M., & Hershner, C. (2017) Marsh persistence under sea-level rise is controlled by multiple, geologically variable stressors. *Ecosystem Health and Sustainability*, 3(10), 1379888. <https://doi.org/10.1080/20964129.2017.1396009>

Morris, J.T., Barber, D.C., Callaway, J., Chambers, R., Hagen, S.C., Johnson, B.J., Megonigal, P., Neubauer, S.C., Troxler, T. and Wigand, C. (2016) Contributions of organic and inorganic matter to sediment volume and accretion in tidal wetlands at steady state. *Earth's Future* 4:110-121.

Nicholls, R., & Cazenave, A. (2010). Sea-Level Rise and Its Impact on Coastal Zones. *Science*, 328(5985), 1517–1520.

Oring, L. W., Gray, E. M., & Reed, J. M. (2013). Spotted Sandpiper (*Actitis macularius*). *The Birds of North America Online*. <https://doi.org/10.2173/bna.289>

Peters, K. A., & Otis, D. L. (2006). Wading Bird Response to Recreational Boat Traffic: Does Flushing Translate into Avoidance? *Wildlife Society Bulletin*, 34(5), 1383–1391. [https://doi.org/10.2193/0091-7648\(2006\)34\[1383:WBRTRB\]2.0.CO;2](https://doi.org/10.2193/0091-7648(2006)34[1383:WBRTRB]2.0.CO;2)

Peterson, G. W., & Turner, R. E. (1994). The value of salt marsh edge vs interior as a habitat for fish and decapod crustaceans in a Louisiana tidal marsh. *Estuaries*, 17(1), 235–262. <https://doi.org/10.2307/1352573>

- Peterson, M. S., & Lowe, M. R. (2009). Implications of Cumulative Impacts to Estuarine and Marine Habitat Quality for Fish and Invertebrate Resources. *Reviews in Fisheries Science*, 17(4), 505–523.
<https://doi.org/10.1080/10641260903171803>
- Prosser, D. J., Jordan, T. E., Nagel, J. L., Seitz, R. D., Weller, D. E., & Whigham, D. F. (2017). Impacts of Coastal Land Use and Shoreline Armoring on Estuarine Ecosystems: An Introduction to a Special Issue. *Estuaries and Coasts*, 41, 2–18.
- Prosser, D. J., Nagel, J. L., Howlin, S., Marbán, P. R., Day, D. D., & Michael Erwin, R. (2018). Effects of Local Shoreline and Subestuary Watershed Condition on Waterbird Community Integrity: Influences of Geospatial Scale and Season in the Chesapeake Bay. *Estuaries and Coasts*, 41(1), 207–222. <https://doi.org/10.1007/s12237-017-0288-0>
- Raposa, K. B., McKinney, R. A., & Beaudette, A. (2009). Effects of Tide Stage on the Use of Salt Marshes by Wading Birds in Rhode Island. *Northeastern Naturalist*, 16(2), 209–224. <https://doi.org/10.1656/045.016.0204>
- Riegner, M. F. (1982). Prey Handling in Yellow-Crowned Night Herons. *The Auk*, 99(2), 380–381.
- Rodgers, J. A. (1983). Foraging Behavior of Seven Species of Herons in Tampa Bay, Florida. *Colonial Waterbirds*, 6, 11–23.
<https://doi.org/10.2307/1520962>
- Rosenberg, K. V., Dokter, A. M., Blancher, P. J., Sauer, J. R., Smith, A. C.,

- Smith, P. A., ... Marra, P. P. (2019). Decline of the North American avifauna. *Science*, 366(6461), 120–124.
<https://doi.org/10.1126/science.aaw1313>
- Royle, J. A., & Nichols, J. D. (2003). Estimating Abundance from Repeated Presence–Absence Data or Point Counts. *Ecology*, 84(3), 777–790.
[https://doi.org/10.1890/0012-9658\(2003\)084\[0777:EAFRPA\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2003)084[0777:EAFRPA]2.0.CO;2)
- Rudershausen, P., Merrell, J., & Buckel, J. (2018). Fragmentation of habitat affects communities and movement of nekton in salt marsh tidal creeks. *Marine Ecology Progress Series*, 586, 57–72. <https://doi.org/10.3354/meps12385>
- Shriver, G., Hodgman, T. P., Gibbs, J. P., & Vickery, P. D. (2004). Landscape context influences salt marsh bird diversity and area requirements in New England. *Biological Conservation*, 119(4), 545–553. <https://doi.org/10.1016/j.biocon.2004.01.016>
- U.S. Geological Survey. (2013). Sea-Level Rise and Chesapeake Bay. Retrieved from Science Summary Sea-Level Rise and Chesapeake Bay website: <https://www.usgs.gov/centers/cba/science/sea-level-rise-and-chesapeake-bay>
- Valiela, I., & Cole, M. L. (2002). Comparative Evidence that Salt Marshes and Mangroves May Protect Seagrass Meadows from Land-derived Nitrogen Loads. *Ecosystems*, 5(1), 92–102. <https://doi.org/10.1007/s10021-001-0058-4>

- Vennesland, R. G., & Butler, R. W. (2011). Great Blue Heron (*Ardea herodias*). *The Birds of North America Online*. <https://doi.org/10.2173/bna.025>
- Watts, B. D. (1988). Foraging Implications of Food Usage Patterns in Yellow-Crowned Night-Herons. *The Condor*, *90*(4), 860–865.
<https://doi.org/10.2307/1368843>
- Watts, B. D. (2011). Yellow-crowned Night-Heron (*Nyctanassa violacea*). *The Birds of North America Online*. <https://doi.org/10.2173/bna.161>
- Wilcoxon, F. (1945). Individual Comparisons by Ranking Methods. *Biometrics Bulletin*, *1*(6), 80–83. JSTOR. <https://doi.org/10.2307/3001968>
- Zar, J. H. (1999). *Biostatistical Analysis*, 4th Ed. Prentice Hall Inc., Upper Saddle River, NJ.
- Zharikov, Y., & Milton, D. A. (2009). Valuing coastal habitats: Predicting high-tide roosts of non-breeding migratory shorebirds from landscape composition. *Emu - Austral Ornithology*, *109*(2), 107–120.
<https://doi.org/10.1071/MU08017>
- Zuur, A. F., Ieno, E. N., & Smith G. M. 2007. *Analysing ecological data*. Springer Verlag, New York, NY, USA.