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ARTICLE

# Isolated Wetland Loss and Degradation Over Two Decades in an Increasingly Urbanized Landscape

**Lisa A. McCauley · David G. Jenkins · Pedro F. Quintana-Ascencio**

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**Abstract** Urbanization is a leading cause of species loss in the United States because of habitat destruction and fragmentation. Wetlands can be affected by urbanization and the condition of wetlands can be compared across land use categories. Cypress domes are isolated wetlands dominated by cypress (*Taxodium distichum*) and often remain in urban areas. The purpose of this study was to quantify the effects of urbanization on cypress dome number, size and spatial pattern through two decades of rapid urbanization in Orlando, Florida, a large city in the southeastern US. Over 3,000 cypress domes, in a region typical of urban growth in the cypress range, were identified in images from 1984. Over a 20-year period, 26 % were destroyed or degraded (i.e., no longer cypress-dominated) and almost half in managed forests were degraded, destroyed, or became surrounded by urban or agricultural land uses. The smallest and largest cypress domes were lost, leaving only medium-sized wetlands and decreasing landscape-level diversity. Despite the fact that these wetlands are common and partially protected by legislation, cypress in isolated wetlands may be at risk from urbanization.

**Keywords** Cypress dome · Florida · Fragmentation · Habitat loss · Southeastern US · Urbanization

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L. A. McCauley (✉) · D. G. Jenkins · P. F. Quintana-Ascencio
Department of Biology, University of Central Florida,
4000 Central Florida Blvd,
Orlando, FL 32816-2368, USA
e-mail: lmccauley@usgs.gov

*Present Address:*
L. A. McCauley
Northern Prairie Wildlife Research Center, U.S. Geological Survey/South Dakota State University, 8711 37th St SE,
Jamestown, ND 58401, USA

## Introduction

Urbanization is one of the leading causes of species loss in the United States (Czech et al. 2000). It can decrease native species diversity directly by eliminating habitat (McDonald et al. 2008) and indirectly by increasing fragmentation and isolating natural habitat (McKinney 2002, 2006). Unlike some other disturbances driven by human land use (McCauley and Jenkins 2005), urbanization is essentially permanent, increasing at rates faster than the acquisition of lands as parks or conservation areas (McKinney 2002), and leading to thorough and widespread land-use changes and increasing demands on regional natural resources (Jenerette and Potere 2010).

Urbanization is driven by human population growth in metropolitan areas, and has occurred globally; the majority of people worldwide now live in urban areas (United Nations Population Fund 2007). Within the U.S., metropolitan populations have increased rapidly (30 % since 1990) to include nearly 84 % of the U.S. population in 2009 (U.S. Census Bureau 2000, 2010). The southeastern United States, and especially Florida, has experienced greater population growth than other US regions and has many rapidly expanding urban areas (Fig. 1).

While urbanization causes rapid conversion of natural habitat to urban areas, pockets of natural areas, and biodiversity may often remain within the urban areas. Wetlands often remain in urban areas because many are legally protected and may be too expensive to develop. However, “isolated” wetlands are not protected as fully as “navigable”, riverine wetlands in the USA (SWANCC v. U.S. Army Corps of Engineers 2001; Craig 2002) and are particularly susceptible to urbanization because these are located within an upland matrix, which can be more readily urbanized and drained than riverine areas. The risk to isolated wetlands exists despite the fact that they provide unique habitat for multiple species, are numerous, and typically sum to the greatest area among all wetland types in any given region

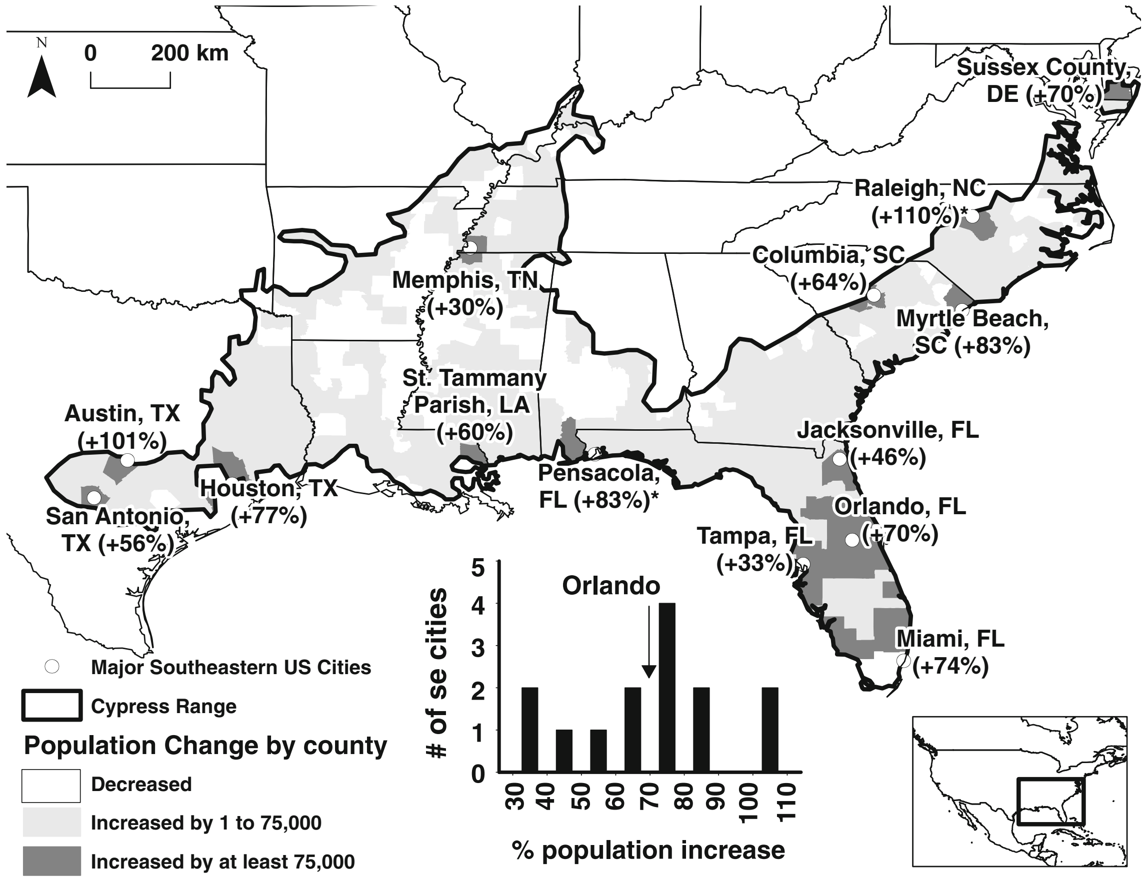


**Fig. 1** Population change in the southeast U.S. from 1990 to 2009 and species range of cypress. Cities shown are those where the city (or surrounding counties) had population growth greater than 75,000 people. Counties that grew >75,000 people but lacked a major city nearby are also indicated. Embedded graph is histogram of city/county population growth

(Haag and Lee 2010; Herault and Thoen 2009; Leibowitz 2003; Semlitsch and Bodie 1998; van der Valk and Pederson 2003). We note that "isolated" here is a common, legally-based term that refers only to the absence of a permanent, navigable, surficial hydrological connection to other waters; connections in surface or subsurface hydrology (Whigham and Jordan 2003) or among biological populations (Leibowitz 2003) exist nonetheless.

Isolated, forested wetlands are at risk in the rapidly urbanizing southeastern U.S. and can often represent a majority of the wetlands in an area (Haag and Lee 2010). These wetlands are often dominated by cypress (*Taxodium distichum*) trees and, in Florida, are called "cypress domes" because trees are taller in the middle and shorter around the edge of the wetland. Cypress is a deciduous conifer which has a range across much of the Southeast U.S. coastal plain (Fig. 1). Two varieties of cypress have been recognized, baldcypress and pondcypress (Lickey and Walker 2002; Tsumura et al. 1999). In central Florida, we frequently found morphological characteristics associated to each of the varieties occurring in the same wetland and even on the same individual. Because we had difficulty distinguishing between the two varieties, in this study, we consider them together under cypress. Cypress domes are important habitat for a large number of species, including multiple rare, threatened and endangered species (Brandt and Ewel 1989; Ewel 1998; McKinney 2002) and provide valuable ecosystem services including flood water storage, sediment filtration, and nutrient and pollutant removal (Ewel and Odum 1985; Haag and Lee 2010; Xu et al. 2009). Urban development may alter cypress domes and reduce their ability to provide such services. Thus, understanding the effects of urbanization on cypress domes is essential to maintaining and improving the ecosystem services they provide and conserving their biodiversity.

The purpose of this study was to classify cypress domes into a land cover category based on surrounding land and to quantify the effects of urbanization on cypress dome number, size and spatial pattern through two decades (1984–2004) of rapid urbanization. We expected that during the 20-year period, urbanization caused the loss of some smaller (more easily drained) cypress domes but that many cypress domes remained among the newly urban areas. We had three main predictions for this study: (1) there would be a loss in cypress domes surrounded by natural land uses and an increase in cypress domes neighboring urban land uses over the 20-year period; (2) cypress domes in 2004 would be more spatially clustered in urban areas than in 1984; and (3) cypress domes in urban areas would be, on average, larger than cypress domes in managed forests. We expected ranchlands to be intermediate to managed forests and urban areas in all predictions.

## Methods

### Study Area

We studied Orange and Seminole counties in the Orlando region of central Florida, USA (28°36′N, 81°18′W; Fig. 2). Human population growth in Orlando was very similar to the mean growth rate of major cities in the Southeast U.S. (Fig. 1; U.S. Census Bureau 2000; 2010). This area includes numerous extant wetlands (about half of which are forested, non-riverine wetlands), many of which remain in these urban areas (Haag and Lee 2010). Assuming typical urbanization pattern with similar population growth in other cities, this study should indicate the effects of urbanization on isolated cypress wetlands throughout their range.

### Detecting Cypress Domes

Cypress domes have a distinct spectral appearance making them readily detectable in color infrared (CIR) images (Online Resource 1; Blazquez 1992a, b). Because urbanization in Orlando has been rapid and recent, CIR images were used to describe individual wetlands through decades and at spatial scales that would otherwise be challenging. CIR photographs also made it possible to identify individual cypress domes and distinguish cypress dome "degradation" (i.e., increase of upland, forested vegetation) from cypress dome destruction (loss of the entire wetland).

Color-infrared aerial photos from 1984 were acquired from St. John's River Water Management District (St. Johns River Water Management District 1984) and 2004 aerial photos were acquired from U.S. Department of Agriculture (U.S. Department of Agriculture-Natural Resource Conservation Service 2004). The 1984 photos had lower resolution (1.5 m cell size) than the 2004 photos (1 m cell size) and the methodology used to capture the images differed but even small cypress domes can be detected with these resolutions. Moreover, all cypress domes found in 2004 photos were also found in 1984 photos, showing the resolution differences did not substantially affect results.

Land cover data from 1990 to 2004 were acquired for Orange and Seminole counties (St. Johns River Water Management District 1990, 2006). Land cover from 1984 was unavailable so 1990 land cover data was substituted; the 1990 land cover was created from 1986 to 1989 photos. To account for the slight differences between years, 1990 wetland landcover polygons were manually edited to match the boundaries shown on the1984 aerial photos. In addition, land cover was generalized (see *Quantifying urbanization* below) and the use of 1990 land cover instead of 1984 to assign wetlands to land cover categories led to a more conservative estimate of the urbanization changes by 2004. A small portion (10 %) of the study area in the southwestern part of Orange County was not included in the analysis because color-infrared aerial photos from 1984 were unavailable for those areas (this area was not part of the St. John's River Water Management District in 1984).

Using ArcGIS v9.2 (ESRI 2006), all forested wetland polygons were exported from the total land cover database and overlain onto the aerial photos. Landcover data were manually corrected to match aerial photos by examination at a 1:12,000 scale; forested wetlands were removed, added, or modified as necessary to obtain an accurate coverage of cypress domes. Automated selection procedures were attempted but lacked sensitivity so that results were inaccurate relative to manual processing. Subsequent field studies (McCauley et al. 2012) have shown this method to be very accurate and able to distinguish even very small cypress domes in both years. Polygons in close proximity to riverine habitats were removed so that only "isolated" cypress domes were chosen for analyses.

### Quantifying Urbanization

In order to quantify the urbanization intensity of each cypress dome, we categorized land cover surrounding each cypress dome in 1984 and 2004. For 1984, we again used 1990 land cover (created from photographs dated 1986–1989) for a conservative estimate of land cover changes. While the methodology used to create the 1990 land cover differs slightly from the 2004 land cover (St. Johns River Water Management District 1990, 2006), we found these differences to be negligible because our procedure generalized the land cover surrounding each wetland.

We first created a buffer in ArcGIS v.9.2 (ESRI 2006) around each cypress dome equal to the average nearest neighbor distance (245 m for 1984 and 263 m for 2004). Based on descriptions provided with the land cover data layer, five potential land cover categories were identified: natural, agriculture, low-intensity urban, medium-intensity urban, or high-intensity urban. For example, land cover descriptions such as golf courses, recreation, and low density housing were classified as low-intensity urban and descriptions such as cattle operations, crops, and citrus groves were classified as agricultural (see Online Resource 2 for full list of land cover descriptions). Principal Component Analysis (PCA) was used to reduce the proportions of each of the 5 land cover categories

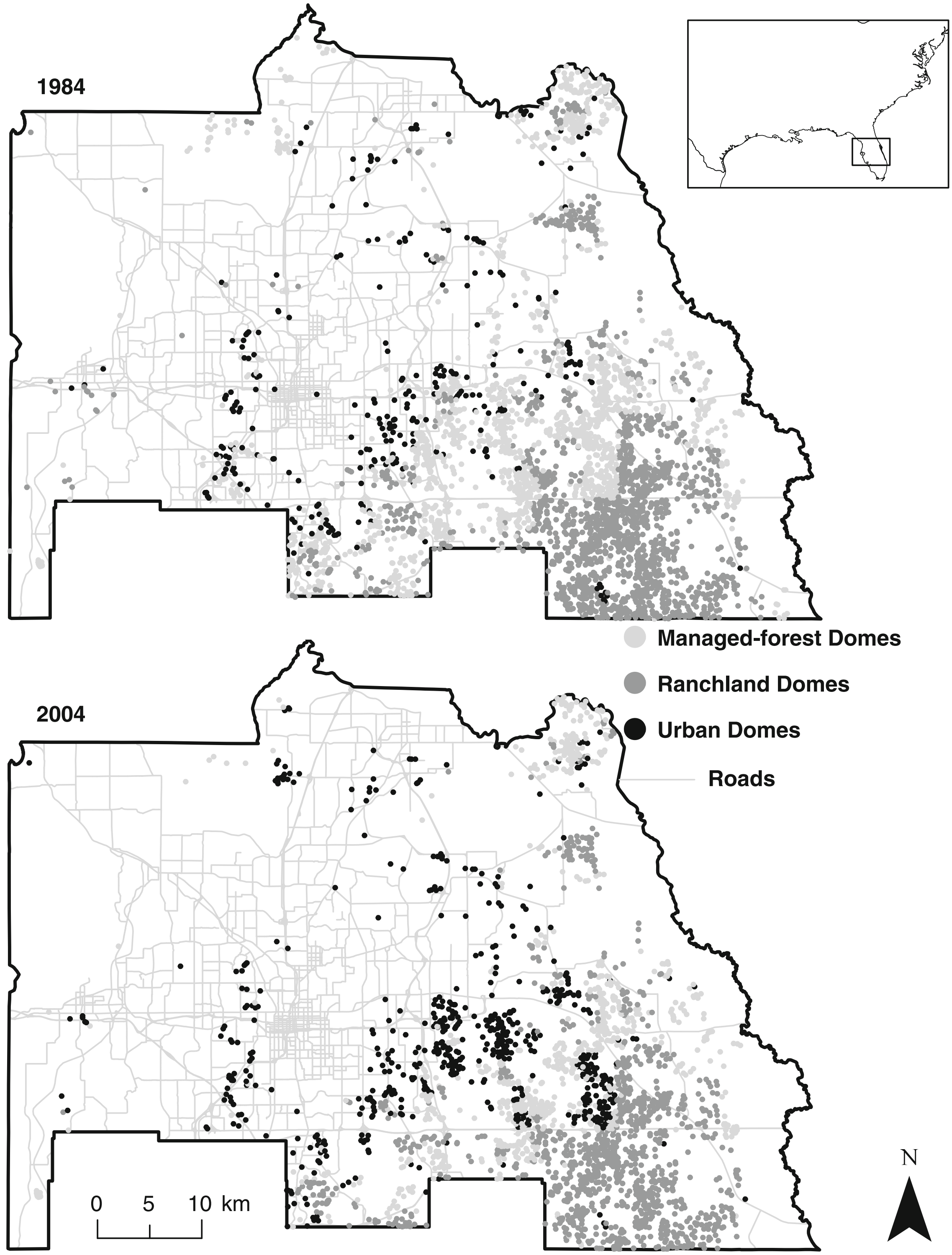


**Fig. 2** Cypress dome polygons in the Orlando metropolitan area in 1984 and 2004. Low-, medium-, and high-urban dome categories have been combined and displayed as "Urban Domes" for visual simplicity. High road density represents the more urbanized portions of the study area (i.e. downtown Orlando)

within the buffer to two multivariate axes. Each axis was then plotted against each of the 5 original land cover proportions. Each graph was evaluated and a range of axis values that represented that category was estimated, based on where the majority of points fell on the graph. For example, when each axis was plotted against the agricultural proportions in each buffer, the majority of points that were high in agriculture were less than −0.5 for axis 1 and between −1 and 1 on axis 2.

We used the ranges obtained from the graphs to assign each cypress dome into one of the 5 categories. Natural cypress domes were called managed-forest and agricultural cypress domes were called ranchland because those land uses strongly dominated those categories. Canonical Discriminant Analysis was used to test the assignments and 95 % (for 1984) and 92.4 % (for 2004) of the cases were classified correctly, which we considered sufficient to represent the urbanization gradient (see McCauley et al. 2012). To ensure the accuracy of dome categorization between years, we also evaluated differences in assignment between years for all cypress domes. Any cypress dome identified as becoming less urban (an unlikely event) during the 20-year time period was re-evaluated using land cover and imagery to verify its land cover category. Only ~5 % of the 1984 polygons were re-categorized by this data-quality processing.

### Cypress Dome Destruction vs. Degradation

Cypress domes that were present in 1984 but judged as absent in 2004 were evaluated further in GIS to determine if the loss was due to habitat destruction or habitat degradation. Habitat destruction was apparent because vegetation had been removed and the wetland was destroyed (e.g., replaced by constructed roads or buildings). Habitat degradation was assumed in those cypress domes that existed in 1984 but could no longer be distinguished from photographs in 2004 though there was no evidence that the habitat had been destroyed (Online Resource 3). In most of these cases, non-flood tolerant vegetation had encroached so that the cypress trees could no longer be distinguished from the surrounding upland vegetation. Natural fire and hydrology regimes would typically prevent competition and displacement from upland vegetation (Casey and Ewel 2006; Penfound 1952), so habitat degradation was assumed when this appeared. Losses by destruction or degradation were recorded separately.

### Urbanization Effects on Cypress Dome Pattern

Changes in cypress dome spatial patterns were calculated by evaluating statistical descriptors of spatial position and size. We used ArcGIS v9.3 (ESRI 2009a) to calculate three measures of cypress dome spatial pattern by land cover category in 1984 and 2004. We used Ripley's K to evaluate spatial clustering of dome locations. Ripley's K evaluates spatial clustering of locations, relative to Monte Carlo randomizations, where an observed Ripley's K value greater than expected indicates spatial clustering of cypress domes (ESRI 2009b). Ripley's K values were calculated for each land cover category in 1984 and 2004 with 20 distance classes and 99 permutations representing approximately a 99 % confidence interval. Significant clustering was indicated by an observed Ripley's K value greater than the upper 99 % confidence limit of the expected Ripley's K under the hypothesis of random distribution (ESRI 2009b).

A Spatial Isolation index was calculated for each cypress dome by drawing a buffer equal to twice the mean nearest neighbor distance of the 1984 cypress domes (490 m) and using Hawth's Tools (Beyer 2004) to count the number of other cypress domes present within each buffer in both 1984 and in 2004. Monte Carlo permutation tests (10,000 permutations) in R (R Development Core Team 2011) were used to evaluate significant differences between Spatial Isolation index values across land cover categories within each year. To account for positive spatial autocorrelation, we adjusted the Type I error rate, α, to 0.01 for Spatial Isolation index analyses (Dale and Fortin 2002).

### Urbanization Effect on Cypress Dome Size

Cypress dome areas were calculated for all categories across both years. Monte Carlo permutation tests (10,000 permutations) in R (R Development Core Team 2011) were used to evaluate significant differences between areas across categories within each year. To account for positive spatial autocorrelation, we adjusted the Type I error rate, α, to 0.01 for area (Dale and Fortin 2002).

## Results

### Cypress Dome Loss and Land Cover Category Conversions

A total of 3,393 cypress domes (6,363.4 ha) were detected from the 1984 aerial photos. Of these, 92 % were categorized as managed forest or ranchland (Fig. 2, Table 1). By 2004, the total number of cypress domes dropped to 2,498 (4,677.3 ha), for a loss of 26 % in number and area. Nearly half of the managed-forest cypress domes were destroyed, degraded, or re-categorized because surrounding land use had changed (Fig. 2, Table 1). The number of cypress domes categorized as urban increased substantially from 1984 to 2004, and within the urban subcategories, low-urban cypress domes increased three-fold, medium-urban cypress domes increased by 50 %, and high-urban cypress domes increased two-fold (Table 1). Similarly, from 1984 to 2004, total cypress dome area was significantly reduced in managed forest and ranchland categories and significantly increased in urban categories (Table 1). This was a result of increased urban land use surrounding cypress domes in 2004.

Overall, almost four times more cypress domes were lost to habitat degradation (encroachment of upland vegetation)

**Table 1** Number and percent change of cypress domes for each year. Change from 1984 to 2004 represent loss, degradation, and re-categorization to another category. Estimates were made using ArcGIS

| | | 1984 | % of 1984 domes | 2004 | % of 2004 domes | Change from 1984 to 2004 | % change from 1984 to 2004 |
|---|---|---|---|---|---|---|---|
| Managed- Forest | Number | 1517 | 45 % | 767 | 31 % | −750 | −49 % |
| | Area | 2925.9 | 46 % | 1379 | 29 % | −1546.9 | −53 % |
| Ranchland | Number | 1588 | 47 % | 1110 | 44 % | −478 | −30 % |
| | Area | 2782.9 | 44 % | 1927.6 | 41 % | −855.3 | −31 % |
| Low-Urban | Number | 98 | 3 % | 294 | 12 % | 196 | 200 % |
| | Area | 167.2 | 3 % | 602 | 13 % | 434.8 | 260 % |
| Med-Urban | Number | 109 | 3 % | 169 | 7 % | 60 | 55 % |
| | Area | 290.2 | 5 % | 421.9 | 9 % | 131.7 | 45 % |
| High-Urban | Number | 81 | 2 % | 158 | 6 % | 77 | 95 % |
| | Area | 197.2 | 3 % | 346.8 | 7 % | 149.6 | 76 % |
| Total | Number | 3393 | | 2498 | | −895 | −26 % |
| | Area | 6363.4 | | 4677.3 | | −1686.1 | −26 % |

than were lost to habitat destruction and this general pattern was true for all land cover categories (Table 2). Although degradation was most pronounced in urban areas, surprisingly, the proportion of cypress domes that degraded in managed forests was also high. Degradation in managed forests exceeded the number that were destroyed and exceeded the rate of conversion to urban land use. This was likely the result of land management practices suppressing fires and allowing encroachment of upland vegetation that degraded the cypress domes.

Many cypress domes that were formerly surrounded by managed forests became surrounded by low-urban land use. This conversion occurred mainly at the periphery of Orlando, especially in the southeast portion of the study area, indicating urban sprawl (Fig. 2). In contrast, most of the extant ranchland cypress domes that changed land use categories were re-categorized to managed-forest domes. These were mainly in large tracts of land which were taken out of agricultural production and put into management as natural lands. The cypress domes which were classified as urban in 1984 tended to become more urban or disappear/degrade. No cypress dome classified as urban in 1984 was converted back to a managed-forest or ranchland category by 2004 (Table 2).

## Cypress Dome Spatial Pattern

Urban-categorized cypress domes became more clustered from 1984 to 2004, as indicated by Ripley's K values (Fig. 3). In 1984, both low-urban and medium-urban cypress domes were not significantly clustered at large distances (10,000–12,000 m) but by 2004 both categories were significantly clustered at all distances (Fig. 3). Similarly, the spatial isolation index showed increased clustering in all urban groups from 1984 to 2004 ($p<0.0001$ in all urban categories). Low-urban cypress domes were less clustered (i.e., more spatially isolated) in 1984, closer to other urban categories, but by 2004 low-urban cypress domes were significantly more clustered ($p<0.0001$), grouping with managed-forest and ranchland domes ($p<0.0001$; Fig. 4). It is important to note that increased clustering was not caused by cypress domes being created or moved, but was due to the conversion of surrounding land cover that caused cypress domes to be re-categorized. Thus, cypress domes that were spatially clustered within managed forests in 1984 were more likely to be spatially clustered within urban land cover in 2004; cypress domes were more likely to be surrounded by urban land uses in 2004 than they were in 1984.

## Size Distributions

Across all categories, cypress domes that were lost from 1984 to 2004 were significantly smaller ($p=0.0001$) than cypress domes that remained indicating that during urbanization the smaller cypress domes are likely to be destroyed. Our data were not enough (1984: $p=0.208$; 2004: $p=0.048$) to conclude on significant differences between urban and managed-forest cypress domes but urban cypress domes tended to be larger than managed-forest cypress domes (by 0.44 ha in 1984 and by 0.19 ha in 2004). Urban cypress domes were significantly larger than ranchland domes in 1984 (by 0.41 ha; $p=0.005$) and 2004 (by 0.11 ha; $p=0.007$). Similarly, the smallest (<0.1 ha) and largest (>50 ha) managed-forest and ranchland cypress domes were lost or degraded between 1984 and 2004, while medium-sized domes (0.1–50 ha) were converted to the urban land cover categories (Fig. 5). With the smallest and largest

**Table 2** Square matrix of urbanization category changes, loss and degradation of cypress domes (number and area) from 1984 to 2004.[a] Left-most column is condition in 1984 and top row is condition in 2004. Numbers on the diagonal are cypress domes that remained in the same land cover category from 1984 to 2004. Other numbers (not on the diagonal) are cypress domes that changed land cover categories from 1984 to 2004. For example, 220 cypress domes and 420 $m^2$ (Column 5, rows 1 and 2) were managed-forest in 1984 and became low-urban by 2004, representing 14.5 % and 14.4 % of the 1984 amount, respectively

| | | Managed forest in 2004 | Ranchland in 2004 | Low-urban in 2004 | Med-urban in 2004 | High-urban in 2004 | Disappeared | Degraded |
|---|---|---|---|---|---|---|---|---|
| Managed-forest | Number | 629 (41.5 %) | 130 (8.6 %) | 220 (14.5 %) | 79 (5.2 %) | 92 (6.1 %) | 122 (8.0 %) | 245 (16.2 %) |
| in 1984 | Area ($m^2$) | 1326.6 (45.3 %) | 244.1 (8.3 %) | 420 (14.4 %) | 196.9 (6.7 %) | 294.5 (10.1 %) | 129.9 (4.4 %) | 313.8 (10.7 %) |
| Ranchland | Number | 140 (8.8 %) | 992 (62.5 %) | 24 (1.5 %) | 20 (1.3 %) | 5 (0.3 %) | 37 (2.3 %) | 370 (23.3 %) |
| in 1984 | Area ($m^2$) | 230.4 (8 %) | 1877.9 (67.5 %) | 37.9 (1.4 %) | 38 (1.4 %) | 8.7 (0.3 %) | 47.4 (1.7 %) | 542.5 (19.5 %) |
| Low-urban | Number | 0 | 0 | 49 (49.5 %) | 11 (11.1 %) | 12 (12.1 %) | 6 (6.1 %) | 21 (21.1 %) |
| in 1984 | Area ($m^2$) | 0 | 0 | 72.8 (43.5 %) | 34.4 (20.6 %) | 16.9 (10.1 %) | 10.2 (6.1 %) | 32.9 (19.7 %) |
| Med-urban | Number | 0 | 0 | 0 | 55 (50.5 %) | 14 (12.8 %) | 10 (9.2 %) | 30 (27.5 %) |
| in 1984 | Area ($m^2$) | 0 | 0 | 0 | 181.2 (62.4 %) | 18.3 (6.3 %) | 29.3 (10.1 %) | 61.4 (21.2 %) |
| High-urban | Number | 0 | 0 | 0 | 0 | 35 (43.2 %) | 11 (13.6) | 35 (43.2 %) |
| in 1984 | Area ($m^2$) | 0 | 0 | 0 | 0 | 87.1 (44.2 %) | 27 (13.7 %) | 83 (42.1 %) |
| Total | Number | | | | | | 186 (5.5 %) | 701 (20.7 %) |
| | Area ($m^2$) | | | | | | 243.8 (3.83 %) | 1033.6 (16.24 %) |

[a] Any differences in numbers from Table 1 are a result of merging of multiple domes into one and splitting of one dome into multiple domes from 1984 to 2004

cypress domes mostly lost, medium-sized domes dominated the landscape.

## Discussion

Urbanization can lead to the progressive degradation, loss, and homogenization of wetlands in only a matter of decades. This study revealed changes among isolated cypress wetlands in Orlando from 1984 to 2004. Although urbanization began in the Orlando metropolitan region in the 1960's (Gladstone 1998), almost all (92 %) of the cypress domes remaining in 1984 were surrounded by managed forests or ranchland. However, half of the managed-forest cypress domes and 30 % of the ranchland cypress domes were lost, degraded or re-categorized by 2004, mostly due to the conversion of managed forests to urban uses.

During the study period, a number of conservation and wetland protection programs (e.g., Florida Forever, P2000; FDEP 2007) were established to preserve natural lands or convert lands into conservation areas. This effort is demonstrated in the re-categorization of 140 cypress domes (230 ha) from ranchland to managed forest. However, these efforts cannot equal the urbanization that has surrounded and affected many cypress domes. Urbanization appears to be permanent because no urban cypress domes in greater Orlando were restored to a more natural land cover category.

During the 20 years examined in this study, one fifth of cypress domes were degraded (Table 2), in which the wetland remained but was encroached by upland vegetation so that cypress trees were no longer detected on aerial photos. Degradation will alter the ecosystem by allowing encroachment of upland vegetation that may out-compete native vegetation, including cypress, reducing the quality of the habitat for wetland species. Beyond potential effects on cypress population structure and habitat quality for other wetland species, degradation alone may cause the habitat to lose protection under wetland regulations (University of Florida/IFAS Extension 2006) making subsequent, legally permitted destruction of the wetland more probable.

Degradation in urban categories is likely due to urbanization-driven alterations in hydrology and/or fire regime in the cypress dome and surrounding matrix. Cypress domes in urban areas are either drained completely to avoid flooding of real estate or permanently flooded to retain stormwater. This is different from the natural hydrology regime of cypress domes that includes periodic flooding followed by subsequent drawdown. Flooding is the primary mechanism for dispersal of seeds between cypress populations (Middleton 1999) by allowing sheet flow across uplands in which seeds float between wetlands. Drawdown allows seed germination and seedling survival (Burns and Honkala 1990; Demaree 1932; Middleton 1999). Urbanization also reduces fire frequency because fires are immediately suppressed, which is an especially pronounced change from the natural fire regime that prevents succession of cypress domes into hardwood swamps, prevents encroachment of upland vegetation, and maintains conditions suitable for recruitment (Casey and Ewel 2006; Penfound 1952).

While degradation is frequent in urban areas, degradation is also occurring in managed forests and decreased fire frequency may also be the mechanism causing the degradation. Natural fire regimes prevent encroachment of upland vegetation (Casey and Ewel 2006; Penfound 1952) so substantial degradation in managed forests would suggest altered fire regimes. Managers of forests have used fire breaks around wetlands to avoid muck or peat fires that can generate persistent smoke and lead to reignition risk for several weeks (Leeds et al. 2009; Reardon et al. 2007). McCauley et al. (2012) found fire-breaks around managed-forest cypress domes and this is likely the cause of the degradation and encroachment of upland vegetation seen in managed forests.

Some (5.5 %) cypress domes were completely destroyed during the 20-year period. Loss of entire cypress domes causes remaining cypress domes to be more isolated and leads to increased dispersal distances among remaining patches (Hanksi and Gilpin 1991; Hanski 1998). In addition, because cypress domes are now more likely to be surrounded and clustered in urban land uses, such dispersal will include travel across an often unsuitable urban matrix. Fragmentation may contribute to further decline of wetland diversity in urban cypress domes.

Land use changes appear to have caused the loss of the smallest and largest cypress domes in managed forests and ranchlands, leaving only medium-sized (~1 ha) cypress domes. Loss of small populations, while seemingly unimportant demographically, can lead to a decrease in overall genetic diversity because some small populations can be particularly valuable genetically, potentially containing rare alleles (Fleishman et al. 2001; Godt et al. 1995). In addition, small wetlands can support populations of plants and waterbirds not found in other, larger wetlands (Herault and Thoen 2009; Ma et al. 2009) and often lack predatory fish and alligators that help support populations of invertebrates and amphibians (Semlitsch and Bodie 1998). Small, isolated wetlands also contribute to high landscape-level species diversity because they differ greatly from larger wetlands and from one another (Scheffer et al. 2006). Considering cypress wetlands provide habitat for many other species (Brandt and Ewel 1989; Ewel 1998), loss of habitat heterogeneity can affect a substantial variety of species groups. Species-area relationships and island biogeography theory (MacArthur and Wilson 1967) suggest that large wetlands are also important to maintenance of regional biodiversity. Oertli et al.

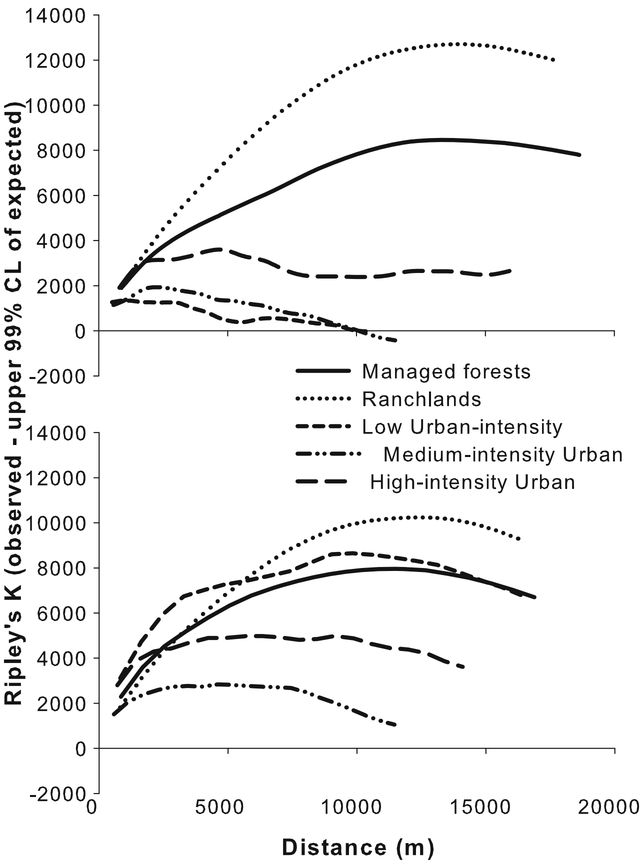


**Fig. 3** Ripley's K values for 1984 (top) and 2004 (bottom) cypress domes at distance classes. Values in the above plots represent [observed values – (upper 99 % confidence limit of expected values)]. Thus, values greater than 0 indicate significant clustering

(2002) measured diversity in 80 similarly sized ponds and found that while some species were most frequent in small wetlands and some species were more numerous in large

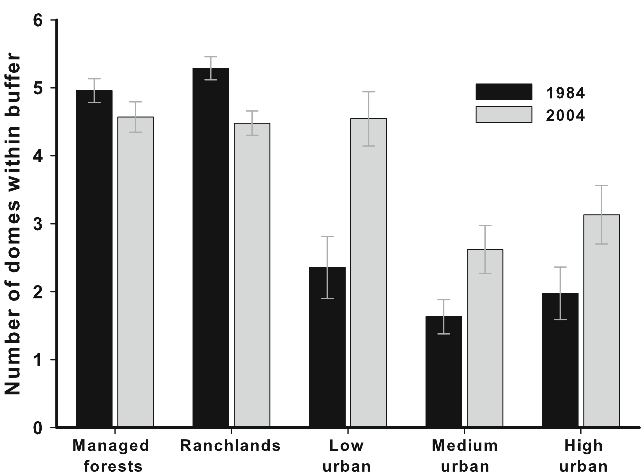


**Fig. 4** Spatial Isolation Index of cypress domes. The Spatial Isolation Index was calculated by creating a buffer around each cypress domes and counting the number of other cypress domes within the buffer. Black bars are numbers from 1984 and grey bars are numbers from 2004. Error bars represent 95 % confidence intervals

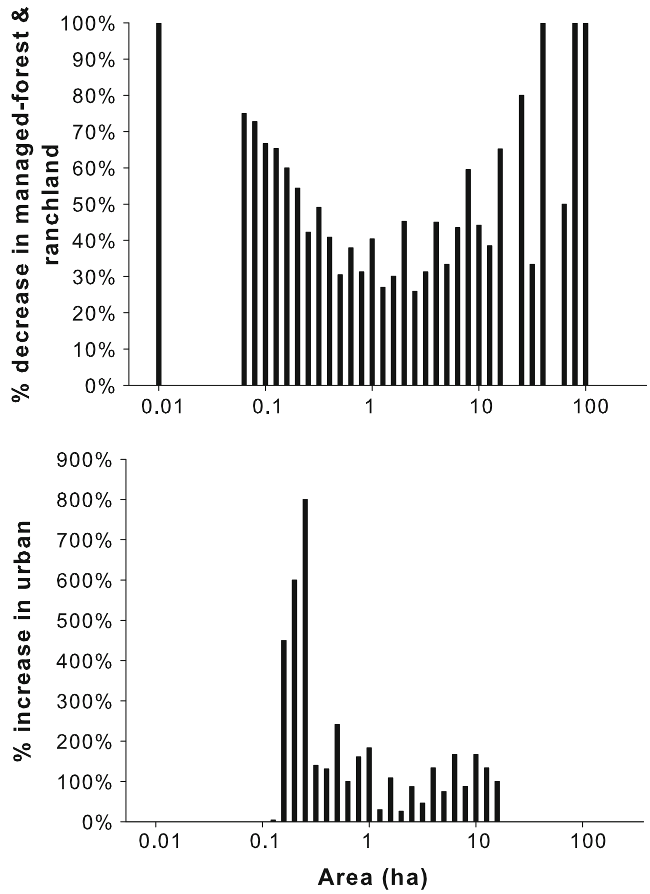


**Fig. 5** Histograms showing changes in cypress dome numbers in different categories. Top graph displays percent *decrease* in managed-forest and ranchland categories while bottom graph shows percent *increase* in urban category. Bars visible in the top graph but missing from the bottom graph represent wetland size classes that were lost or degraded from 1984 to 2004. Bars visible in both graphs represent wetland size classes that were either converted to urban uses or lost/degraded

wetlands, none of the 64 examined taxa preferred medium-sized ponds. Homogenized wetland size during the course of 20 years' urbanization in central Florida could have contributed to a decrease in both species-level genetic diversity and regional biodiversity in remaining cypress domes.

Assuming Orlando urbanization is typical of the southeastern United States, our results indicate that similar range-wide effects of degradation and fragmentation could be occurring in isolated cypress wetlands in other urban areas. If this trend continues, natural populations of *T. distichum* may persist only in riparian zones and species that depend on cypress dome habitats will likely be affected. In addition, urban areas have lower recruitment (McCauley et al. 2012), fragmentation may limit dispersal, and urban activities degrade water quality. Also, urban wetlands may harbor less regional species diversity and more upland and invasive species (Biamonte et al. 2011; Duguay et al. 2006). Despite the current commonality of cypress throughout its range and the fact these wetlands are partially protected by legislation, cypress in isolated wetlands of urban areas may be at risk.

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