BULLETIN

of the

FLORIDA
MUSEUM OF
NATURAL HISTORY

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Volume 41 No. 1, pp. 1-68 **1997**

UNIVERSITY OF FLORIDA GAINESVILLE

Numbers of the **BULLETIN OF THE FLORIDA MUSEUM OF NATURAL HISTORY** are published at irregular intervals. Volumes contain about 300 pages and are not necessarily completed in any one calendar year.

Communications concerning purchase or exchange of the publications and all manuscripts should be addressed to: Managing Editor, Bulletin; Florida Museum of Natural History; University of Florida; P. O. Box 117800, Gainesville FL 32611-7800; U.S.A.

This journal is printed on recycled paper.

ISSN: 0071-6154 CODEN: BF 5BA5

Publication date: December 31, 1997 Price: $ 6.50

WILDLIFE IN SOUTHERN EVERGLADES WETLANDS INVADED BY MELALEUCA (*Melaleuca quinquenervia*)

Nancy K. O'Hare and George H. Dalrymple[1]

ABSTRACT

In the Everglades region of southeastern Florida, invasion of graminoid/herbaceous wetlands by the invasive, non-native tree melaleuca (*Melaleuca quinquenervia*) results in a closed-canopy forested wetland, with a sparse understory. Intermediate stages in this transformation include a savannah with scattered mature melaleuca trees, and mature dense melaleuca heads surrounded by areas with moderate to low levels of melaleuca. Intermediate levels of melaleuca invasion have not received any attention and were the rationale for our study. Wildlife was surveyed monthly for two years to determine species richness and abundance in wetlands with different melaleuca coverages. Wildlife included all vertebrate classes, as well as selected macro-invertebrates such as crayfish (*Procambarus alleni*) and grass shrimp (*Paleomonetus paludosus*).

Species richness was highest in areas with moderate melaleuca coverage. Higher species richness is typical of sites with greater vegetative structural diversity, i.e., as in the savannah stage of invasion, as well as areas in an early stage of disturbance. The higher species richness was primarily the result of an increased number of migratory, upland birds. Many of these transient and winter-resident birds occurred at much lower abundances than in native forested habitats such as cypress swamps (*Taxodium distichum*), tropical hardwood hammocks, and pine (*Pinus elliottii* var. *densa*) rocklands.

In contrast to the birds, number of species and the abundance of herpetofauna varied little across the melaleuca gradient. There was no shift in species composition from wetland to upland species as the melaleuca coverage increased. The number of fish species was similar across the melaleuca gradient. Unlike the herptiles, fishes were less abundant in the closed-canopy melaleuca forests, indicating poorer habitat quality. Complex patterns of hydrology and gapping in the forest canopy due to wind storms and fires permitted light penetration and the persistence of productive pockets of aquatic life even within dense stands of melaleuca.

The mosaic of areas with low to moderate infestations of melaleuca surrounding mature dense melaleuca stands allowed higher numbers of individuals and species to persist in or seasonally use mature dense melaleuca stands. This interspersion of habitats resulted in stands of melaleuca with ecotonal edges that provided marginal habitat for species characteristic of natural communities. Higher degree of interspersion (more edge) may also mean that the natural areas experience higher exposure to melaleuca seed source, which may result in a faster rate of spread of melaleuca.

The results demonstrated that animal populations persisted in areas with disturbed vegetation, as long as critical abiotic factors (in this case hydrology) remained in operation. Areas with moderate levels of melaleuca retained species composition and productivity typical of the natural wetland community. The dominant characteristic of the faunal shifts along the gradient of increasing melaleuca coverage was increased numbers of upland, arboreal, and/or forest species, not the loss of wetland species. Regional

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O'Hare, N. K., and G. H. Dalrymple. 1997. Wildlife in southern Everglades wetlands invaded by melaleuca (*Melaleuca quinquenervia*). Bull. Florida Mus. Nat. Hist. 41(1):1-68.

permitting and natural resource agencies should recognize that lands with moderate levels of melaleuca may retain significant habitat quality. Restoration of such lands will demonstrate higher levels of success if the method used for melaleuca removal allows for retention of the *in situ* wildlife community.

RESUMEN

La invasión de los humedales graminoides/herbáceos en la región de los Everglades del sureste de la Florida por el árbol no nativo melaleuca (Melaleuca quinquenervia) resulta en un humedal forestado de dosel cerrado y de sotobosque ralo. Los estados intermedios de esta transformación incluyen una savana con melaleucas maduras y dispersas y bosquetes maduros y densos de melaleuca rodeados de areas con moderados a bajos números de melaleucas. Estos estados intermedios han sido poco estudiados, y por esto, fueron el foco de nuestro estudio. Con el objeto de determinar el número de especies y su abundancia en humedales con diferentes coberturas de melaleuca, se realizaron reconocimientos mensuales de vida silvestre durante dos años. La vida silvestre estudiada incluyó todas las clases de vertebrados, así como algunos invertebrados tales como dos especies de camarón (Procambarus alleni y Paleomonetus paludosus).

El mayor número de especies se encontró en áreas con una cubierta moderada de melaleuca. Un mayor número de especies es típico de áreas con una mayor diversidad estructural vegetal, como por ejemplo, en el estado de invasión tipo savana, así como también en áreas con un estadio de perturbación más temprana. El mayor número de especies fue primariamente el resultado de un mayor número de aves migratorias de tierras más altas. Muchas de estas epecies de aves en tránsito o residentes invernales se encontraron en abundancias mucho menores que en bosques nativos, como pantanos de ciprés (Taxodium distichum), bosquetes de madera dura y bosques de pino (Pinus elliottii var. densa). En contraste a las aves, el número de especies y la abundancia de anfibios y reptiles varió poco a través del gradiente de melaleuca. No hubo cambio en la composición de especies a medida que la cobertura de melaleuca aumentó. El número de especies de peces también fué similar a medida que la cobertura de melaleuca aumentó. A diferencia de los anfibios y reptiles, los peces fueron menos abundantes en bosques de melaleuca de dosel cerrado, indicando una calidad de habitat más pobre. La presencia de claros en el bosque producidos por tormentas de viento y fuegos, así como la compleja hidrología, permitieron la penetración de luz y la persistencia de bolsones de productividad de vida acuática, incluso dentro bosques densos de melaleuca.

El mosaico de áreas con infestaciones de melaleuca moderada a baja rodeando bosquetes maduros y densos de melaleuca permitieron la persistencia o uso estacional en éstos últimos de un número mayor de individuos y especies. El entrelazamiento de habitats resultó en bosquetes de melaleuca con bordes ecotonales, los cuales proveyeron habitats marginales para especies características de comunidades naturales. Un mayor nivel de entrelazamiento (más bordes) también significa que las áreas naturales tienen una mayor exposición a las fuentes de semillas de melaleuca, lo cual puede resultar en una tasa de avance mayor para la melaleuca.

Los resultados demostraron que las poblaciones animales persistieron en áreas con vegetación alterada, siempre y cuando factores abióticos críticos (en este caso hidrología) continúen operando. Las áreas con una cobertura moderada de melaleuca mantuvieron la composición de especies y la productividad típica de la comunidad natural del humedal. La característica dominante de los cambios faunísticos a lo largo del gradiente de melaleuca fue el incremento del número de especies de tierras altas, arbóreas, o de especies del bosque; no la pérdida de especies de humedal. Las agencias que administran recursos naturales deben reconocer que áreas con niveles moderados de melaleuca pueden retener niveles significtivos de calidad de habitat. La restauración de estas áreas puede resultar mas exitosa si el método usado para remover melaleuca permite la retención de la comunidad silvestre presente en dicha área.

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INTRODUCTION

In the Everglades region of southern Florida, invasion of an open canopy, graminoid/herbaceous wetland by the non-native pest tree melaleuca (*Melaleuca quinquenervia*) results in a closed-canopy forested wetland, with a sparse understory. Intermediate stages in this transformation may include a savannah with scattered mature melaleuca trees and mature dense melaleuca heads surrounded by areas with moderate to low levels of melaleuca. Previous surveys of wildlife in melaleuca-infested areas have focused on either a few species of mammals (Mazzotti et al. 1981; Sowder and Woodall 1985) or surveyed only dense melaleuca stands (Schortemeyer et al. 1981; Repenning 1986). Each of these studies was of short duration (few months). Therefore, relatively little is known regarding the use of melaleuca-invaded wetlands by native wildlife.

Disturbance of natural communities typically results in an increase in species richness as "weed" species, non-native, migratory and/or species uncommon to the natural community increase in numbers (Odum 1983). Furthermore, areas with higher vegetative structural diversity, such as the intermediate stages of melaleuca invasion of graminoid wetlands, are likely to have higher species diversity compared to areas with lower vegetative structural diversity (c.f. Cody 1985a). Therefore, the number of species (species richness) and the number of individuals (species abundance) are not, by themselves, a good measure of the environmental value of a habitat (Van Horne 1983). Which species are using a habitat and the manner in which they use the habitat (foraging, breeding) are more important to final evaluation of habitat quality (Stauffer and Best 1980; Keller et al. 1993). A fair analysis of habitat quality of disturbed areas should evaluate the types of species (e.g., wetland versus upland animals, native versus non-native), as well as their abundances.

Our goal in this study was to determine species richness and relative abundance along the single gradient of melaleuca coverage, without presuming to explain between-taxa differences, or variation within a single cover type. Wildlife was broadly defined to include selected macro-invertebrates and all vertebrates. Some of these groups are not traditionally included in wildlife assessments. However, they were included in this study since the abundance of these animals indicates the ability of a habitat to support higher trophic level animals, such as wading birds, alligators, snakes, and mammals.

ACKNOWLEDGMENTS

We thank Kenneth L. Krsyko for his dedication to the field work for two wet years. Joseph A. Wasilewski, Carlos Pages, and Doug Barker also assisted in the field during various times. We also thank Sue M. Alspach, Frank S. Bernardino, and Jean Evoy of the Dade County Department of Environmental Resources Management and the members of the South Florida Limestone Mining Coalition. Funding was provided by South Florida Limestone Mining Coalition, U. S. Army Corps of Engineers, South Florida Water Management District, and Metro-Dade Water and Sewer Department. Project management, technical support, and publication costs were provided by Dade County Department of Environmental Resources Management.

DESCRIPTION OF STUDY AREA AND COVER TYPES

The study was performed in northwest Dade County in a 19,400 ha region known as the Lake Belt Study Area (LBSA). The area is bounded by the Dade-Broward County line on the north, the Homestead Extension of Florida's Turnpike on the east, Tamiami Trail (US 41) on the south, and Krome Avenue on the west (Fig. 1). The area is the single, largest tract of land in the South Florida Water Management District's proposed East Coast Buffer/Water Preserve Areas between the urban areas and the remaining Everglades. The western one-third of the study (between the Dade-Broward Levee and Krome Avenue) is commonly referred to as the Pennsuco wetlands or Pennsuco Everglades.

The classic vegetation survey by Davis (1943) characterized most of the area as "saw-grass marshes (medium dense to sparse)," with the southeastern corner characterized as "saw-grass marshes (with wax myrtle thickets)." Reconstruction of pre-drainage conditions by Everglades National Park, the Army Corps of Engineers, and the South Florida Water Management District include most of the LBSA as part of the long hydro-period marsh of northeastern Shark River Slough (also see Fennema et al. 1994). Recent hydrological records demonstrate that the Pennsuco wetlands (west of the Dade-Broward Levee) are still flooded for more than six months a year under "normal rainfall" (e.g., 1986; Davis et al. 1994). Soils in the region are classified as muck or peat soils, with depths up to 1 m (EAS Engineering, Inc. 1995).

A map of existing cover types in the LBSA was generated from 1992 1:300 aerial photographs (Fig. 2; EAS Engineering, Inc. 1995). The region included approximately 3000 ha of sawgrass marshes with little to no invasion by melaleuca, 3300 ha of low to moderate coverage by melaleuca (10% to 75% melaleuca) and 7000 ha with greater than 75% coverage by melaleuca. The remaining 6100 ha were composed of lakes, littoral zones, agricultural lands, canals, levees, correctional facilities, electrical power facilities, and power line right-of-way (EAS Engineering, Inc. 1995).

There was a geographical gradient in the density of melaleuca within the study area. Areas with the highest coverage by melaleuca tended to be located in the eastern two-thirds of the region, while areas with lower melaleuca coverage were located in the western one-third (Pennsuco Everglades). Many of the areas with highest melaleuca coverage were adjacent to developed lands or near structures that alter local hydrology. In the eastern one-third of the study area, land uses included a municipal well field and rock-mining. Both of these uses affected adjacent lands by altering hydro-period, albeit the type of effects differed. The municipal well field had little effect on the ground surface topography. However, associated canals and the effect of ground water pumping altered local hydrology. The manner in which hydrology was altered was not predictable based upon seasonal weather patterns, but rather was determined by water supply needs. Therefore, the region may have standing water during the traditional "dry" season of southern Florida. In contrast, rock-mining substantially altered surface topography, creating permanent aquatic habitats up to 20 m deep. While the lakes draw water from surrounding areas, shortening their hydro-period, annual hydrological patterns fluctuated with normal seasonality of wet-dry periods.

Five cover types were designated for sampling based upon percent coverage by melaleuca. The following abbreviations were used in the text, tables, and figures.

1) DMM: 75-100% mature dense melaleuca coverage; DBH of trees>8 cm; stem density of 5000/ha (Hofstetter, unpubl. as cited by Hofstetter 1991)
2) SDM: 75-100% sapling dense melaleuca coverage; DBH of trees<8 cm; stem density of 250,000/ha (Alexander and Hofstetter 1975)
3) P75: 50-75% melaleuca coverage
4) P50: 10-50% melaleuca coverage
5) MAR (Marsh): 0-10% melaleuca coverage

The detailed vegetation map referenced above was not available when site selection for the Wildlife Studies began. Potential study sites were identified from the vegetation map in Larsen (1992) and 1992 aerial photographs. Actual site selection was determined by ground-truthing. Cover types with intermediate levels of melaleuca coverage (10%-50% and 50%-75%) were the most difficult to delineate on the ground and also occurred in smaller, less discrete parcels relative to the other three cover types. The spatial distribution of melaleuca in these areas usually consisted of a heterogenous mix of melaleuca heads, and savannahs. Since the minimum extent for cover type designation in the vegetation mapping was 0.40 ha (one acre), sites selected for wildlife sampling, were a minimum of 0.40 ha of homogenous melaleuca coverage, embedded in a matrix that we judged to be of the same cover type based upon ground-truthing. For each of the five cover types, ten sites were selected (50 sites total).

Each site selected for sampling had to be readily accessible on foot from an existing grade (e.g., up to 1 km from a levee, or right of way). Areas with melaleuca seemed to be related to developed areas or areas with altered hydrology. Approximately 75% of the area available for sampling (excluding cover types not sampled, such as lakes or agriculture areas) was within 1 km of some type of human disturbance (e.g., a primary or secondary road, existing grade, building, canal or lake). Approximately 20% of the available area that was greater than 1 km from a grade was MAR. Thus only 5% of available area was more than 1 km from a disturbance, and it was distributed unequally among four cover types. Primary and secondary roads were located only on the boundaries of the study area. Vehicular travel within the study area was confined to narrow gravel grades. Access to these grades was restricted by locked gates at all entry points. The major north-south grade was the Florida Power & Light (FPL) powerline right-of-way. Portions of the FPL right-of-way were flooded during the wet season.

SAMPLING METHODS

Drift Fence Arrays

Drift fence sampling required intensive site preparation and permanent installation of the trapping arrays (see below). Therefore, three sites for each cover type were repeatedly sampled each month from January 1994 through December 1995. Preliminary surveys of the entire region indicated that a hydrological gradient might exist from north-south. Hydrological data to either support or refute these field observations were unavailable. Since sample sizes were low (three sites per cover type), these sites were located in the northern one-third of the study area to minimize variation in factors other than melaleuca coverage (e.g., hydrology) as a precautionary measure.

Drift fence arrays were checked four days per month, generally, every other day over an eight day period, beginning the second week of each month. All 15 arrays were checked on the same days.

In studies of the amphibians and reptiles of the Everglades National Park, drift fences designed to trap amphibians and reptiles also regularly trapped high numbers of aquatic macro-invertebrates (e.g., crayfish, *Procambarus alleni*; grass shrimp, *Paleomonetus paludosus*; and fishes (Dalrymple 1988; G.H. Dalrymple and F.S. Bernardino, unpubl. data; Dalrymple 1994). Therefore, drift fence trapping in this study was used as a sampling method for all aquatic, semi-aquatic and terrestrial vertebrate animals (including fishes), as well as selected aquatic macro-invertebrates.

Drift fences were constructed of shade or ground cloth. Each array had four 15-m-long by 1-m-high arms arranged as a cross [+], with a total of four funnel traps per array. Traps and funnels were constructed of 1/8" gauge (approximately 3 mm) galvanized hardware cloth, with two funnels at one end of each trap. One trap was placed at the end of each arm of the array, so that one funnel rested on each side of the fence (as done by Dalrymple 1988). Pitfall traps were not feasible since most sites were flooded six to nine months each year.

Arrays were maintained so that the fencing remained upright and no gaps developed between the fencing material and the ground. Funnel traps were repaired or replaced as needed. When the traps were not being checked, they were removed from the end of the fence and the funnels were blocked to prevent animals from entering the traps.

Standing water did not preclude trapping. However, when traps were completely underwater, the time period between trap-check days was modified to minimize mortality of amphibians and reptiles, i.e., traps were checked four consecutive days rather than every other day for eight days. The number of check days remained the same (4 days per month). Trap rates were calculated using the number of days the arrays were open (array days), not the number of times the traps were checked.

Bird Strip Transects

Bird transects did not require site preparation and, therefore, allowed sampling to occur in a random subset of 3 of the 10 sites in each cover type each month. This procedure permitted a wider range of sites to be sampled. Transects were a fixed length of 100 m. The width of each transect was determined by the farthest distance to a bird observed during the transect. If the bird was flying overhead or could not be positively identified, it was not recorded. Sampling of the 15 sites occurred over a 2 -3 day period during the third week of each month. All data were collected between sunrise and 11 a.m. The order in which cover type sites were sampled was randomly chosen each month. Sites were sampled regardless of standing water conditions.

Strip transects for birds in this study were designed to focus on the birds that have limited daily cruising radii and, therefore, were most likely to reflect habitat preferences based on vegetative cover rather than hydrology. Perching birds (blackbirds, shrikes, warblers, cardinals), other land birds (doves, woodpeckers), some smaller wading birds (snipe, rails), and some birds of prey usually are studied to evaluate between habitat differences in vegetative cover (Stauffer and Best 1980). Such surveys also allow assessment of habitat use by migratory and/or transient birds versus resident breeders (Keller et al. 1993).

Mammal Surveys

Mammals were surveyed using Sherman live traps and scent and bait stations on a quarterly basis, with one replicate per cover type. Oats were used to bait 30 Sherman live traps, 15 *Sigmodon*-, and 15 *Peromyscus*-sized traps, laid out in a grid, and checked for three consecutive nights. In addition, one scent (mammal urine) and one bait station (oily tuna pet food) were also checked the same three consecutive nights. Sampling generally occurred the first week of the second month in each quarter (February, May, August, and October). In some quarters, sampling was either delayed until later in the quarter or simply not feasible due to high standing water levels.

Incidental Observations

To generate a complete species list for the LBSA, incidental observations of species within the five defined cover types as well as species noted along roadways were recorded. This information is presented in Appendix I.

HYDROLOGICAL ASSESSMENT

As a general rule, hydro-pattern (timing, depth, and duration) is a strong determinant of wetland species diversity and abundance (Mitsch and Gosselink 1986; Campbell and Christman 1982; Dalrymple 1988). Therefore, evaluation of biological resources in wetlands must consider hydrological conditions. As a preliminary assessment of gross hydrological patterns, two data sets were gathered through the Water Resources Section of DERM. The first data set was the 11-year period (1985 to 1995) of ground water levels measured at USGS wells in the LBSA. Two gages were randomly selected for more detailed analyses. One gage was located west of the Dade-Broward Levee (G-975) and the other east of the Dade-Broward Levee (G-972; see Fig. 2). The second data set was the 1994 and 1995 average monthly ground water levels of the seven USGS gages located in the LBSA (G-594, G-968, G-972, G-975, G-976, G-1488, and G-3253).

STATISTICAL METHODS

Statistical analyses followed standard procedures outlined in Zar (1996), Sokal and Rohlf (1995), Gauche (1982), and Krebs (1989). All analyses were performed using STATISTICA 5.1 (StatSoft, 1995).

Drift Fences and Bird Transects

For the drift fencing data on macro-invertebrates, fishes, and amphibians and reptiles , the two year cumulative numbers (e.g., Sokal and Rohlf 1995; Zar 1996) from each of the 15 sites (3 replicates in the 5 cover types) were analyzed by ANOVA. Some of the raw data sets did not follow a normal distribution and neither log nor square root transformations (Krebs 1989) resulted in a normal distribution. Therefore, in all cases, the data were analyzed by non-parametric Kruskal-Wallis ANOVA.

For the bird transects, the two year cumulative numbers for each cover type were analyzed. Cumulative data generated by this sampling protocol could not be analyzed by ANOVA, because site-specific cumulative measures were not available. While ANOVA of each of the 24 monthly samples for each method was possible, most had such low sample sizes as to be or little or no value, and did not address the larger issue of general patterns of habitat use.

The above limitations are not critical to statistical analyses in ecological sciences. "In general, the framework of hypothesis testing has been largely overused by scientists..., especially in the context of environmental decision making" (Steidl et al., 1997: 278). Simple statistical tests for average differences between cover types in numbers of individuals, or numbers of species reveal a limited amount about the ecological nature of cover type differences (Krebs 1989). They are useful for recognizing gross differences in species richness or diversity, but say little about the species composition of the cover types. Therefore, multivariate techniques that simultaneously consider each species' contributions to cover type differences (and vice versa) were used (Gauche 1982).

Data sets collected at standard sites, such as drift fence data for fishes, amphibians and reptiles, or macro-invertebrates, were analyzed using the multivariate techniques of cluster analysis, factor analysis and/or multidimensional scaling. These analyses have the same three replicates for each cover type sampled each month, permit the monthly data to be accumulated for tests of total numbers, averages, or medians (e.g., see Sokal and Rohlf 1995, Box 9.8), and allow us to see more of the variation among sites within the same cover type. The plots of these analyses in the figures have three replicates for the five cover types, entered separately and plotted separately. These data sets had enough replicates to permit factor analyses as well as cluster analyses and multidimensional scaling. For example, the herptile drift fence data has a matrix of 34 rows (species) by 15 columns (locations), i.e., 34 x 15 matrix. All multivariate matrices were derived from the raw data sets to include the effects of differences in absolute sample sizes.

Cluster analyses were done using the unweighted pair-group average (UPGMA) amalgamation method of joining groups (Krebs 1989). The joining was done on a distance matrix generated as the subtraction of each Pearson's product moment correlation coefficient from unity (1.0 , i.e., 1-r), to generate the distances. If for example two cover type sites or species had a correlation coefficient of 0.91, then their distance is 1.0-0.91, or 0.09 (i.e., they cluster close together). The factor analysis method used was the unrotated matrix of principal components based on the same matrices of correlation coefficients. These methods are standard procedures, and incorporate the least manipulation of the original data (unlike, e.g., varimax rotations, etc.). Additionally, multidimensional scaling was used to corroborate the results of the factor analyses.

Data sets that were collected using randomly located sites do not have the same geographic locations in each sampling period. In these cases the data for each cover type were lumped together to represent the overall pattern for the cover type. For example the bird transect data had a matrix of 46 rows (species) by 5 columns (cover types), i.e., a 46 x 5 matrix. With only five columns, these matrices were analyzable by cluster analysis but not by factor analysis (the latter method requires more than five rows and/or columns).

Tests for Diversity, Evenness, and Patterns of Dispersion

Species diversity was calculated using the Shannon H diversity index (Zar 1996). Species' patterns of dispersion among cover types were characterized as uniform, random, or clumped (also called contagious or aggregated) using the Index of Dispersion. The Index of Dispersion (I) was calculated as the variance divided by the mean, of a sample of locations, where a species was recorded (Krebs 1989; I = variance/mean). The test statistic for this index was chi square (X^2), where df (degrees of freedom) = number of locations minus 1. Interpretations were based upon a two way test, in which the null hypothesis that the distribution was random was accepted if:

$$X^2_{0.975} < \text{Observed } X^2 > X^2_{0.025}$$

Significant differences less than 0.025 were interpreted as clumped, and greater than 0.975 were uniform.

Habitat Quality and Species Composition

Habitat requirements for all life history stages of each species were determined based on the literature and personal experience. Each species was then assigned to one of two categories based upon these life history traits. For the purpose of the analysis, species whose respiration, feeding mechanisms, diet, reproduction, or larval development require 1 to 12 months of standing water each year were termed "wetland dependent." Species whose respiration, feeding mechanism, diet, reproduction, or larval development are independent of standing water were termed "non-wetland." Animals described as "wetland dependent" use upland habitats, but a population could not persist without suitable wetland habitat. Conversely, animals described as "non-wetland" use wetland habitats, but their life history traits allow them to survive and successfully breed outside of wetlands. Within this group, some species may be highly tolerant of wetland conditions, while others are intolerant.

Species assigned to the same category may have different preferences with regard to timing, depth, and duration of flooding.

Some species designations were difficult due to insufficient information. Others, mainly birds, required consideration of the relationship between hydrology and vegetation. For example, most woodpeckers use forested wetlands, such as cypress swamps. However, use of cypress swamps is due to the presence of trees, not hydrological conditions, since woodpeckers also successfully live and reproduce in upland forested areas such as pinelands and hardwood forests. Therefore, all woodpeckers were categorized as non-wetland. In contrast, breeding common yellowthroats (*Geothlypis trichas*) are strongly associated with dense, graminoid vegetation. In this region, this habitat type is dependent upon hydrological conditions of standing water approximately six to nine months per year. Therefore, this species was categorized as wetland dependent. The current assigned wetland association of each species of amphibian, reptile, and bird is listed in Appendix I. Fishes were excluded because they are all, obviously wetland dependent and were trapped in very high numbers. Therefore, they would artificially bias the results toward the wetland dependent categorization in the evaluation of cover types.

Hydrological Assessment

Pearson product moment correlation coefficients (r) were calculated for each taxa group with water levels measured at USGS gages G972 and G975. In graphical analyses, the height of the water column and the number of individuals or species were plotted for each month.

RESULTS AND DISCUSSION

Macro-invertebrates from Drift fencing

During the 24 months of the study, macro-invertebrates were captured at each of the 15 sites over 160 array days. A cumulative number of 9490 individuals of 10 species of selected macro-invertebrates were trapped. At any one site, the number of species of macro-invertebrates trapped ranged from 6 to 10, and the number of individuals ranged from 199 to 2112 (Table 1). Overall, the most abundant species were *Procambarus alleni* and *Paleomonetus paludosus* (Table 2).

There were no significant differences in the number of individuals (Kruskal-Wallis H (df = 4, n=15) = 7.6, p=0.11), number of species (H (df = 4, n = 15) = 2.33, p=0.68), or diversity indices (H (df = 4, n = 15) = 2.73, p=6.03) of macro-invertebrates between cover types (Fig. 3).

In tests of dispersion using the Index of Dispersion, all macro-invertebrates showed random distributions among cover types (Table 2). This indicated that cover type, defined by melaleuca cover, was not as important in the dispersion of the species as were other variables, including standing water.

Cluster analyses revealed two main groupings of macro-invertebrates by cover types: *Paleomonetus paludosus*, *Pomacea paludosa*, *Romalea microptera* , Odonate larvae , and *Stagnicola* sp were predominantly found in MAR and some of the intermediate cover type sites (P50, P75; Fig. 4). *Procambarus alleni*, dytiscid beetles (*Dytiscidae*), gyrinid beetles (*Gyrinidae*), *Biomphalaria havanensis*, and *Lethocerus americanus* were predominant in DMM, SDM and other intermediate sites.

Fishes from Drift fencing

During the 24 months of the study, fishes were captured at each of the 15 sites over 160 array days. A cumulative number of 27 species and 8428 individuals of fishes were trapped. At any one site, the number of species of fishes trapped ranged from 10 (DMM site) to 18 (MAR site), and the number of individuals ranged from 156 (SDM site) to 1111 (P50 site; Table 1). Overall, the most abundant species were *Gambusia holbrooki* (3803 fishes), *Hemichromis letourneauxi* (1059 fishes) and *Fundulus confluentus* (1038 fishes; Table 2).

Rarefaction curves for fishes indicated that, after 24 months, sampling approached maximum species richness in some cover types (Fig. 5). The rarefaction curves for MAR and DMM indicated that new species could be expected with additional sampling. MAR had the highest species richness, with the greatest number of species trapped even though a higher number of individuals were trapped in other cover types. During the last quarter of trapping, two new species of fishes were trapped in three of the five cover types. The non-native cichlids *Astronotus ocellatus* and *Tilapia mariae* were trapped in DMM. *Lepomis punctatus* and *Clarias batrachus* were trapped in SDM, and *L. punctatus* and *T. mariae* were trapped in P50. No new species were trapped in P75 or MAR.

Kruskal-Wallis ANOVA was used to compare the average number of species and the average number of individuals trapped between cover types (Table 1). There were no differences between cover types in the average number of species trapped (H (df = 4, n = 15) = 4.03, p=0.40). However, there were higher average numbers of individuals captured in MAR, P50, and P75, than in SDM, and DMM (H (df = 4, n = 15) = 10.5, p=0.03; Fig. 6). This pattern of abundance of fishes helped to explain why the intermediate cover types were commonly used by foraging wading birds, and many fish-eating amphibians and reptiles (see below). The Shannon Index was not significantly different between cover types (H (df = 4, n = 15) = 2.27, p=0.69). There were no significant differences in the number of individuals, or species of non-native fishes found among the cover types (p's>0.05; Fig. 7).

Of the 27 species of fishes, 16 showed clumped distributions. However, only seven species showed this clumping within a single cover type (Table 2). *Lucania goodei*, *Lepomis punctatus* and *A. ocellatus* clumped in MAR. *Lepisosteus platyrhinchus* and *T. mariae* clumped in P75. *Belonesox belizanus* and *Etheostoma fusiforme* clumped in SDM. Each of the other taxa that showed clumped distributions, 9 of 16 (or 56%), were clumped in locations in more than one cover type. Since only 7 of 27 species (26%) showed clumped distribution within a single cover type, variables other than melaleuca density were equally important in determining species abundance. These variables would include variations in historical patterns of distribution, hydropattern, and access to deep water refugia.

Cluster analyses of the data for fishes showed the three MAR replicates tightly grouped together, but joined by a range of replicates from intermediate cover types, and even DMM. Four of the six dense melaleuca sites (DMM and SDM) clustered together with one P75 site (Fig. 8). This result demonstrated the wide overlap in fish community structure along the melaleuca gradient. In other words, most species of fish were found wherever there was standing water.

Seven species of non-native fishes were trapped or observed in the LBSA. These species were *Hemichromis letourneauxi* (1059 individuals), *Cichlasoma bimaculatum* (656 individuals), *B. belizanus* (106 individuals), *Cichlasoma managuense* (62 individuals), *A. ocellatus* (21 individuals), *Clarias batrachus* (12 individuals), and *T. mariae* (5 individuals). The 19 *A. ocellatus* trapped in MAR cover type were all juveniles, trapped on the same day in the same trap. Juveniles of five species were trapped (*H. letourneauxi*, *C. bimaculatum*, *A. ocellatus*, *C. managuense*, *T. mariae*). *Belonesox belizanus*, *C. managuense*, and *H. letourneauxi* are predaceous on small forage size fishes. These small to moderate size predators may have an impact on the natural recruitment of many forage fish species in the area. However, it is likely that they are preyed upon by higher level consumers (snakes, wading birds).

As was the case for the macro-invertebrates, the distribution of many fishes was not strongly related to the gradient of melaleuca coverage. However, their abundances were lower in dense melaleuca coverages. This translated into a lower forage base for many higher-level consumers (e.g., many amphibians and reptiles, wading birds, some mammals).

Amphibians and Reptiles from drift fencing

During the 24 months of the study, amphibians and reptiles were captured at each of the 15 sites over 160 array days. A cumulative number of 1265 individuals of 34 species of amphibians and reptiles were captured. At any one site, the number of species of herptile trapped ranged from 10 (DMM site) to 22 (two P75 sites). The cumulative number of individuals ranged from 33 (MAR site; trap rate of 0.21 amphibians and reptiles per array day) to 175 (SDM site; trap rate of 1.09 amphibians and reptiles per array day; Table 1). Overall, the most abundant amphibians were *Rana sphenocephala* (218 individuals), *Eleutherodactylus planirostris* (167 individuals), and *Bufo quercicus* (94 individuals; Table 2). The most abundant reptiles were *Nerodia floridana* (89 individuals), *Anolis sagrei* (83 individuals) and *Nerodia fasciata* (46 individuals).

Rarefaction indicated that the number of species trapped was near or at maximum levels (Fig. 9). During the last quarter of trapping, no new species of amphibians and reptiles were trapped in any of the cover types. Rarefaction curves were similar for all cover types. Furthermore, rarefaction curves for melaleuca invaded wetlands exceeded the short-hydroperiod prairies in Everglades National Park (Dalrymple 1988).

Kruskal-Wallis ANOVA was used to compare the average number of species and the average number of individuals trapped between cover types. There were no significant differences between cover types in the average number of species (H (df = 4, n = 15) = 7.68, p=0.11), average number of individuals (H (df = 4, n = 15) = 4.87, p=0.30), or Shannon diversity (H (df = 4, n = 15) = 3.77, p=0.44; Fig. 10).

Of the 34 species of amphibians and reptiles, 18 (54%) showed clumped distributions. However, only six species showed this clumping within a single cover type (Table 2). *Kinosternon bauri* and *Bufo terretris* clumped in MAR. *Thamnophis sirtalis* and *Eumeces inexpectatus* clumped in P75. *Anolis sagrei* and *Hyla cinerea* clumped in DMM. The other 12 taxa with clumped distributions were clumped in locations in more than one cover type. Since only 6 of 34 species (18%) showed clumped distributions within a single cover type, this indicated that variables other than melaleuca density were also important in determining species abundance. These variables may include variations in historical patterns of distribution, hydro-pattern, and access to either deep water refugia or high ground refugia (c.f. Campbell and Christman 1982).

When the numbers of individuals of each species were placed in a correlation matrix by cover types for cluster analyses, the sites that shared similar species composition were easily identified. In the cluster analysis by cover types, all three MAR sites separated out with one of the P50. The other two P50 grouped with the P75. The SDM and DMM separated as a third distinct group (Fig. 11). When the same matrix was analyzed by species composition, *Rana grylio*, *K. bauri*, *N. floridana*, *Regina alleni*, and *Acris gryllus* all clustered together as good indicators of MAR. The majority of snakes, lizards, frogs, and toads used the wide range of intermediate cover types (P50 and P75). This included fully aquatic species such as *Farancia abacura*, *Amphiuma means*, and *N. fasciata*. The non-native *Osteopilus septentrionalis*, *Eleutherodactylus planirostris*, and *Anolis sagrei*, together with the native *Gastrophryne carolinensis*, *Bufo quercicus*, and *Siren lacertina* grouped together in DMM and SDM. Factor analyses of the loadings of the taxon on the first two principal components showed a broad scattering (Fig. 12). Taxa at one extreme (left side of graph) were typical of MAR and P50. Taxa at the other extreme (right side of graph) were typical of DMM and SDM. The taxa with significant clumped distributions were shaded (I index p's<0.025; Table 2).

The presence of so many *S. lacertina* in DMM and SDM habitats was unexpected (Table 2). This salamander is fully aquatic, and, is unable to feed out of the water (Bishop 1962; personal observation). It quickly dies from desiccation on dry land and does not disperse over dry areas. It was trapped at 11 of the 15 drift fence sites. Of the 60 *S. lacertina* trapped by drift fencing, 22 were trapped in one DMM site which was isolated from areas of lower melaleuca density. This species has a rather limited home range and individuals were trapped as soon as standing water levels existed. Four individuals were trapped at this site two days after heavy rain resulted in flooding of this site. A fifth, large individual was trapped on the third day following flooding. These short intervals indicated subterranean refugia near the trapping sites. Another 11 *S. lacertina* were trapped at one SDM site. Refugia for this species are known to be subterranean moist soils, where they aestivate in a mucus covering (Bishop 1962). The substrate of porous limestone overlain with up to 1 m of muck soil was readily accessible via numerous crayfish burrows and natural crevices. A similar pattern of rapid exploitation of surface water was found for *A. means* by Machovina (1994).

Two species of non-native amphibians and one species of non-native reptile were trapped. All three species were typical of drier, ruderal or edificarian habitats (Duellman and Schwartz 1958; Dalrymple 1988). *Osteopilus septentrionalis* (10 individuals) was trapped in P75, DMM and SDM. This treefrog requires standing water for its egg/tadpole stage, yet these stages are of short duration (less than two months). *Eleutherodactylus planirostris* (167 frogs) was trapped in 8 separate sites representing DMM, SDM, and P75 habitats. However, 90% of these frogs were trapped at just two sites (109 frogs at a SDM site and 41 frogs at a DMM site). This frog has no aquatic egg/tadpole stage. *Anolis sagrei* is highly tolerant of disturbed settings (Wilson and Porras 1983). It was most abundant in DMM (52 lizards from 3 sites), although it was trapped in all cover types (83 lizards total across all habitats).

Birds from strip transects

When the strip transect data were analyzed as twenty-four month cumulative data, 518 individuals of 46 species were observed across all five cover types (Table 3). P75 had the highest number of species (29) and the highest number of individuals (146; Fig. 13). DMM had the lowest number of species (9) and individuals (39). Marsh had the second highest number of individuals (137) yet had a lower number of species (15) than SDM, P75 and P50 (22, 29, and 27 species, respectively). Species in P75 were a peculiar mix of typical wetland/prairie species and upland species. Species observed in DMM were characteristic forest/edge species. Species observed in Marsh were typical of Everglades wetlands (herons, egrets, red-winged blackbird (*Agelaius phoeniceus*), eastern meadowlark (*Sturnella magna*), and common yellowthroat (*Geothlypis trichas*); Robertson and Kushlan 1984). The Shannon Index was highest in SDM and lowest in Marsh (Fig. 13). Lower diversity indicated that a fewer number of species accounted for most of the individuals. Evenness was also highest in SDM. It was lowest in P75. Lower evenness indicated that some species were dominant, while others were rare (Odum 1983).

The rarefaction curves of all cover types still showed an upward trend, indicating that the maximum species richness was not sampled after 24 months (Fig. 14). The numbers of new species recorded in each cover type during the eighth quarter were: DMM, 0 species; SDM, 1 species; P75, 1 species; P50, 1 species; MAR, 1 species.

Of 46 species of birds observed during transects, 15 showed clumped distributions. Unlike the patterns seen in macro-invertebrates, fishes and amphibians and reptiles, most species (11 of 15 or 73%) clumped in a single cover type (Table 3). *Geothlypis trichas, Capella gallinago* and *A. phoeniceus* clumped in MAR. *Sayornis phoebe* and *Quiscalus major* clumped in P50. *Colaptes auratus, Mimus polyglottos, Dendroica coronata,* and *Dendroica discolor* clumped in P75. *Setophaga ruticilla* and *Pipilo erythrophthalmus* clumped in SDM. The remaining species clumped in adjacent seral stages. The 15 species (33% of total species) that had clumped distributions accounted for 76% of all individuals observed in transects (395 of 518). Many species did not show a clumped distribution simply because they occurred only a few times (e.g., *Troglodytes aedon, Melospiza georgiana*). These results indicated that cover type defined by degree of melaleuca density was very important in the distribution of the many bird species.

Cluster analysis demonstrated that the species composition of the cover types was dramatically different (Fig. 15).*Geothlypis trichas* (57 individuals), and *A. phoeniceus* (47) were characteristic of MAR. These two species are resident breeding species, typical of long-hydroperiod, marsh habitats. They accounted for 76% of all individuals seen in MAR sites during transects. The DMM sites were characterized by the presence of Carolina wren (*Thyrothorus ludovicianus*) and bluejay (*Cyanocitta cristata*). The majority of herons, egrets, perching birds, raptors, and woodpeckers used P50, P75, and SDM. These cover types had the most species represented, but no more individuals than MAR.

Of the 46 species observed during transect surveys, 29 were resident species and 17 were wintering species (designations based upon Robertson 1955, Robertson and Kushlan 1984, and Louhglin et al. 1990; see Appendix I). The percentage of individuals that were resident species was highest in MAR (93%) and lowest in SDM (49%; Fig. 16). Most migratory species were warblers, which prefer thickets or forested areas (Morse 1985).

The strip transect method used in this study targeted bird species with small daily cruising radii, which selected habitat based primarily upon vegetative cover (e.g., passerines, some raptors), not standing water conditions (e.g., many wading birds). Yet wading birds are frequently given high profile in wetland assessments in southern Florida. Again, sampling methods in this study were intended to provide gross information on all species. Wading birds observed during transects were generally solitary, foraging individuals.

Mammals

Cumulative results of small mammal live trapping and use of scent and bait stations are presented in Table 4. Since the data sets were small, only general statements on the distributions of each species within each cover type are presented below.

Dasypus novemcinctus sign was common in DMM. *Didelphis virginiana* and *Procyon lotor* tracks were noted in all cover types. Each of these species are abundant and common throughout their geographic ranges. *Sylvilagus palustris* tracks and scats were observed in all cover types. On two separate occasions, its scat was found on top of a drift fence funnel trap when sites had standing water. *Felis rufus* tracks were noted in P50, P75, SDM and DMM. *Urocyon cinereoargenteus* tracks were observed in P75, SDM and DMM. *Lutra canadensis* tracks were noted in MAR, and scat occasionally were found along a levee adjacent to MAR habitat. *Odocoileus virginianus* tracks were seen in each of the five cover types during the dry season. All of the above species were directly observed on one or more occasions.

Live-trapping captured *Sigmodon hispidus* in P50, P75, and SDM, *Oryzomys palustris* in all cover types, and *Peromyscus gossypinus* in SDM and DMM (Table 5). The cover type/habitat preferences of these three rodents observed in this study were similar to trapping results in mature dense melaleuca versus "mixed melaleuca-graminoid" (Mazzotti et al. 1981) and tree islands surrounded by sawgrass marsh (Smith and Vriese 1979).

Percent similarity in species composition

The species composition of the MAR cover type was used as a standard to evaluate species composition of the other four cover types. The number of species that occurred in both MAR and the comparison cover type was divided by the total number of species found in the two cover types combined. Separate comparisons were made for each major vertebrate group, in each cover type. For fishes and amphibians and reptiles, species composition of each of the four cover types overlapped between 50 and 70 percent with MAR. The mammals showed similarities in species overlap with MAR from 40 to 65 percent. The birds showed the greatest difference in species composition, with between 20 and 30 percent overlap in species composition to MAR (Fig. 17).

In general, as melaleuca invasion progressed, fishes and amphibians and reptiles retained a high degree of constancy in community composition. These faunal groups appeared to move in and out of local areas as water levels seasonally shifted, regardless of melaleuca density. The birds showed the most dramatic shift from typical marsh inhabitants to progressively greater numbers of forest dwelling species. The mammals showed a progressive change from wetland to upland species as forest cover increased.

The percent of taxa that occurred in all of the five cover types varied widely between faunal groups (Fig. 18). Eighty percent of the 10 invertebrate taxa trapped by drift fencing were found in all cover types. Only 2 of the 46 birds observed in strip transects were found in all cover types (*Geothlypis trichas* and *Dendroica palmarum*).

Changes in species composition

There were two principal physical gradients in the Lake Belt Study Area environment: tree density and water levels. Tree density was a geographic gradient, with density varying primarily from east to west. Water level was primarily a temporal gradient, varying with seasonal rainfall.

While it has been anecdotally noted in the literature that melaleuca invasion causes secondary increase in ground surface elevation, we observed little evidence of this in the study area. Most sites in the study area were flooded regularly according to existing patterns of rainfall, topography, and water management.

The dominant characteristic of the faunal shifts along the gradient of increasing melaleuca coverage was increased numbers of upland, arboreal, and, or forest species, not the loss of wetland species. As melaleuca coverage increased, the habitat became suitable to non-wetland species at a faster rate than it became unsuitable to wetland species. The result was a pattern of increasing species diversity and abundance in the intermediate cover types. Increased use of areas by savannah and forest birds, and mammals played a significant role in creating this gradient.

The dominant characteristic of the faunal shifts along the gradient of water level was seasonal variation in abundance of wetland species. The majority of fully aquatic species (the aquatic macro-invertebrates, all the fishes, and some amphibians and reptiles, birds, and mammals) did use habitat with increased canopy cover, primarily as an effect of standing water. The existence of this prey base (invertebrates and forage sized fishes, in particular) permitted higher consumers to use these habitats.

Canopy closure occurred when melaleuca cover increased beyond 75%, reducing sunlight penetration and primary productivity of the periphyton, submerged and emergent vegetation. This had a dramatic effect on the primary consumers and detritovore macro-invertebrates (e.g., *Pomacea*, *Procambarus*), resulting in overall lower abundance and productivity in the understory. However, complex patterns of hydrology, and gapping in forest canopy due to wind storms and fires permitted light penetration and the persistence of productive pockets of aquatic life even within dense stands of melaleuca.

Habitat preference and species composition

Gross comparisons of the numbers of species or numbers of individuals found in each cover type did not yield significant differences among the cover types. However, multivariate analyses, which considered the contribution of each species to overall community composition, demonstrated differences between cover types. Indices of dispersion indicated that many faunal groups were distributed along a gradient other than melaleuca density. To assist in evaluating community composition in terms of hydrology, each species of herpetofauna and bird was categorized based upon their requirement for a particular, gross hydrologic pattern (see Methods).

Kruskal-Wallis ANOVA was used to compare the 24 month cumulative number of species and individuals of wetland and non-wetland amphibians and reptiles trapped at the 15 drift fence sites. There was no significant difference between cover types in the number species of wetland and non-wetland amphibians and reptiles (Kruskal-Wallis H (df = 4, 15) = 6.489 and 6.210, p=0.1655 and 0.184, respectively; Table 5). There were also no differences in the number of individuals of wetland and non-wetland amphibians and reptiles (Kruskal-Wallis H (df = 4, 15) = 5.510 and 8.610, p=0.239 and 0.072, respectively). The one SDM and the one DMM site with a low percentage of wetland-dependent individuals were the two sites where the non-native *Eleuthrodactylus planirostris* was abundant (Table 2). As noted earlier, this species does not have a tadpole stage, does not require standing water during any life history stage, and therefore, is a non-wetland species.

In contrast to the amphibians and reptiles, when the 24 month cumulative strip transect data for birds were considered, the occurrence of wetland-dependent species of birds demonstrated a more dramatic shift. In MAR, wetland associated species accounted for 80% of the species and 97% of the individuals. DMM had the lowest percentage of wetland associated species (11%) and individuals (5%; Table 6).

It is important to recognize that species categorized as "wetland dependent" may require wetlands only during specific life history stages. Most anuran amphibians have an egg/tadpole stage that is dependent upon standing water, yet adults of some species preferentially use upland areas, only returning to water to breed. Many aquatic snakes and turtles are unable to feed out of water, yet require dry areas to lay eggs. Additionally, most species will have a preference for the timing, depth and duration of flooding. Both *Geothlypis trichas* and *Sturnella magna* generally have higher breeding densities when climatic conditions indicate low standing water levels during the breeding season (Cody 1985b). Most wetland vertebrates are adapted to using water depths of less than 25 cm (Fredrickson and Laubhan 1994). Fredrickson and Laubhan state (1994:645): "No single wetland or wetland type will provide all the resources needed by a single vertebrate during all of its life-history stages or for all vertebrates adapted to wetlands. Thus, wetland complexes are essential for successful management...".

Gross Hydrological Assessment

Animals experience interannual variation in abundances. These variations may be partly determined by climatic conditions, such as rainfall (Cody 1985b; Morrow et al. 1997). The South Florida Water Management District has described the 1994-1995 period of rainfall as a "25-year" high rainfall event throughout Dade County. While the timing, depth, and duration of standing water conditions are correlated with rainfall, this relationship may be altered in managed wetlands by regional patterns of water management. Pumpage for drinking water well fields, and/or water releases from basin to basin may affect the actual standing water levels in an unnatural manner. Therefore, we considered ground water levels as measured at USGS gages located within the study area as an indicator of hydrological conditions throughout the study area.

To determine if there were significant differences in the average monthly ground water levels in different regions (sub-basins) of the LBSA 1994 and 1995 data for seven gages were compared. There were significant differences among the mean monthly water levels of the seven gages (ANOVA: $F = 46.72$, $df = 152$, $p<0.0001$), with the lowest mean value at G3253; Fig. 19). Pearson Product-moment correlation coefficients of variation in monthly mean values of all seven gages were highly significant (all r's>0.79, and all p's<0.05), indicating that all gages followed the same pattern of timing and duration of seasonal water level fluctuation. However, surface water depth cannot be extrapolated since ground elevation data were not available.

Two wells were selected for more detailed analyses based upon their proximity to the majority of sampling sites. Ground water levels during the two years of the study were compared to the previous nine years for two USGS wells located within the study area (USGS G972 and G975). This 11 year period included years described as "low" (1989-1991), "average" (1986-1988), and "high" rainfall (1994-1995). Average annual water levels at G972 and G975 for the 11 year period showed significant differences (ANOVA; G972: $F = 10.586$, $df = 10, 114$, $p<0.0001$; G975: $F = 9.891$, $df = 10, 115$, $p<0.0001$; Fig. 20). For each well, Tukey's Honest Significant Difference Tests were done to determine which years were significantly different from 1994 and 1995. At G972, the average monthly water level in 1994 was only significantly higher than 1989-1991. In 1995 at G972, it was higher than 1989-1991, plus 1985 (Tukey's Honest Significant Difference Tests). At G975, the average monthly water level in 1994 was only significantly higher than 1989-1990, and 1985. In 1995 at G975, water level was only significantly higher than the three drought years, and 1985 (Tukey's Honest Significant Difference Tests). In summary, even though annual rainfall in 1994 and 1995 was "high," average annual ground water levels measured at two wells in the study area were not significantly higher than in years of "average" rainfall. However, there was less variation in water level during 1994 and 1995 (i.e., it was wet longer).

Correlations of Gauge Ground Water Level with Trap Rates

Major peaks in capture of macro-invertebrates, fishes, and amphibians and reptiles by drift fences were generally associated with changing water levels (either rising or falling; Fig. 21). When standing water existed over large areas, aquatic and semi-aquatic animals were more dispersed, and capture rates were generally lower.

Successional changes in vegetative structure and faunal implications

Melaleuca invasion of native graminoid/herbaceous wetlands changes the vegetational structure of the landscape. It is unclear to what extent melaleuca invasion also changes the hydrological characteristics of an area because variation and shifts in water management and human disturbance are so strongly correlated with the distribution of melaleuca. This study was designed to address only the impact of melaleuca coverage on wildlife species richness and abundance. Prior to the current study, the only information available was based upon either dense melaleuca stands only (Schortemeyer et al. 1981) or were short-term studies that considered only a few species (Mazzotti et al. 1981; Sowder and Woodall 1985; Repenning 1986).

As melaleuca coverage increases, a graminoid wetland with low structural diversity becomes a savannah (mix of open prairie/marsh and trees) with increased structural diversity. As melaleuca coverage continues to increase, the savannah becomes a closed canopy forest with sparse understory. Since little understory persists in the forest and most of the trees are of similar size, structural diversity of the forest is lower than existed in the savannah stage of melaleuca invasion. Some animals (e.g., many birds, c.f. Cody 1985a) select habitat based upon subtle differences in vegetational structure. However, other animals (e.g., amphibians and reptiles) are less sensitive to vegetative structure but select habitats based upon other characteristics (e.g., soil or hydrological characteristics; Campbell and Christman 1982).

The results of this study demonstrated a higher species richness and abundance of birds in the cover types that have moderate levels of melaleuca coverage. As discussed above, these were the cover types with the greatest structural diversity. Notably absent from these areas, though, were resident bird species that are selective about the types of trees they use (e.g., pine warbler (*Dendroica pinus*)). Many of the transient and winter-resident birds occurred at much lower abundances than in cypress swamps of the Big Cypress National

Preserve or the uplands of Long Pine Key, Everglades National Park (personal observations).

In contrast to the birds, a similar diversity of herpetofauna was found across all cover types. However, their abundances generally decreased in the closed-canopy melaleuca forest (DMM cover type). The lower abundances indicated poorer habitat quality. This was probably the result of the closed-canopy of the forest limiting the amount of sunlight reaching the water surface. With reduced sunlight, the algae forming the structure of the periphyton mat does not develop. Many species of amphibians and reptiles consume crayfish, grass shrimp, and smaller forage fishes which depend upon a well-developed periphyton mat. However, complex patterns of hydrology, and gapping in forest canopy due to wind storms and fires permit light penetration and the persistence of productive pockets of aquatic life even within dense stands of melaleuca. Changes in both structural and wildlife diversity are summarized in Figure 22.

Landscape effects

Habitat interspersion and melaleuca patch size were not explicitly considered in sampling designs because detailed maps of the area were unavailable at the start of the project. The only variable considered was melaleuca coverage. Random sampling of three replicates of each cover type per month did not permit testing of any variable other than melaleuca coverage. However, the mosaic of areas with low to moderate infestations of melaleuca surrounding mature dense melaleuca stands may allow higher numbers of individuals and species to persist in, or seasonally use, mature dense melaleuca stands. A single stand of melaleuca surrounded by prairie has less habitat interspersion than several, smaller stands of melaleuca which have the same total area as the single large, stand. The smaller stands have more "edge" habitat which is likely to provide at least marginal habitat for species characteristic of the prairie. However, higher degree of interspersion (more edge) may also expose surrounding natural areas to higher seedfall, since seedfall is generally limited to a distance less than 1.5 times tree height (Meskimen 1962).

Factors affecting the rate of spread of melaleuca have not been examined. The most widely cited paper on melaleuca expansion rate by Laroche and Ferriter (1992) did not explore causal relationships between melaleuca invasion and biotic or abiotic factors. In calculating expansion rate Laroche and Ferriter only considered land sections that had attained 100% melaleuca coverage. This approach was explicitly recognized by the authors as a constraint on the application of their results, yet their results have been widely cited as the single possible melaleuca expansion rate. Exclusion of sections that had some melaleuca coverage yet had resisted heavy infestation may have led to the calculation of the fastest possible expansion rate. Moreover, "invasion" was interpreted as the presence of one or more melaleuca trees in an acre. This has unfortunately been improperly interpreted as 100% dense melaleuca coverage, which was not the intended use of the authors. Additional studies should examine land sections that are exposed to melaleuca yet have resisted heavy infestation. Factors influencing the rate of melaleuca expansion, such as habitat interspersion, melaleuca patch size, soil, plant cover, human disturbance and hydrology, should also be considered.

While the interspersion of areas of varying melaleuca coverage may contribute to the abundance of animals (particularly fishes and semi-aquatic amphibians and reptiles) in dense melaleuca sites, it is unlikely that the Pennsuco marshes on the western edge of the area were the sole source of fishes and some fully aquatic amphibians and reptiles in the study area. High levees subdivide the LBSA along north-south (Dade-Broward Levee) and east-west axes (levees associated with Wellfield and Pennsuco Canals). These levees were dispersion barriers to fishes, and some fully aquatic amphibians and reptiles. Therefore, some species were confined to isolated sub-basins, which sustain local populations. The abundance of *Siren lacertina* (a fully aquatic salamander) in a DMM site isolated from areas with lower melaleuca coverages was a good example of this. The rapid rate at which fully aquatic amphibians and reptiles and fishes exploited standing water in many sites indicated that deep water or subterranean refugia were available even within areas of dense melaleuca. Likewise, the highly vagile mammals and birds were readily capable of exploiting small patches of suitable habitat throughout the entire region.

The numerous, recent reviews of the relationships between habitat quality, demographics, dispersal, and metapopulations that are being derived from landscape ecology are all relevant to future research on the impact of melaleuca (c.f. Hansson 1995). For example, to what extent do melaleuca invaded habitats function as marginal habitat?, and what effect does the ratio of optimal to marginal patch area (ROMPA hypothesis; see Hansson 1995) play in the dynamics of the various populations in the areas of melaleuca invasion?

Melaleuca continues to aggressively invade wetland habitats in southern Florida as well as upland habitats in southwestern Florida and parts of Broward and Palm Beach County. While the replacement of native vegetation with a monoculture of non-native species is undesirable, it is important to recognize that animal populations will persist in areas with disturbed vegetation. Therefore, these areas still retain some habitat value. Successful restorations must re-establish native animal communities as well as the native plant communities. Since many native animals may persist in areas with melaleuca, preference should be given to restoration methods that are sensitive to the existing on-site animal populations.

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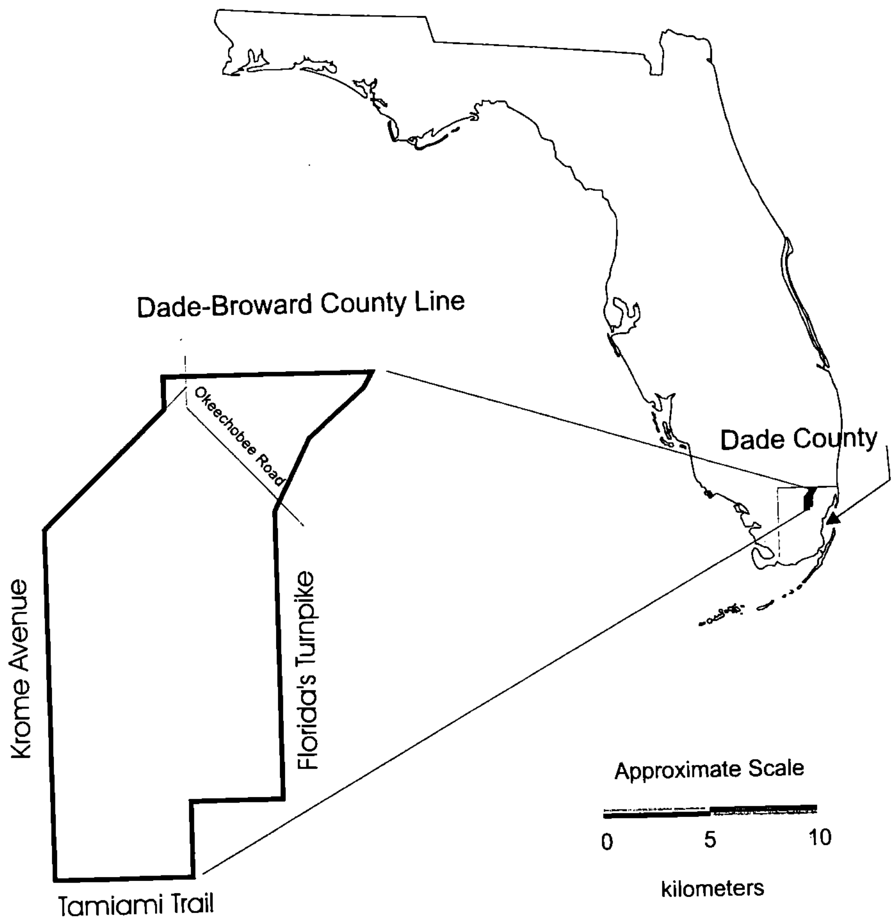

Figure 1. Location of study area in southern Florida.

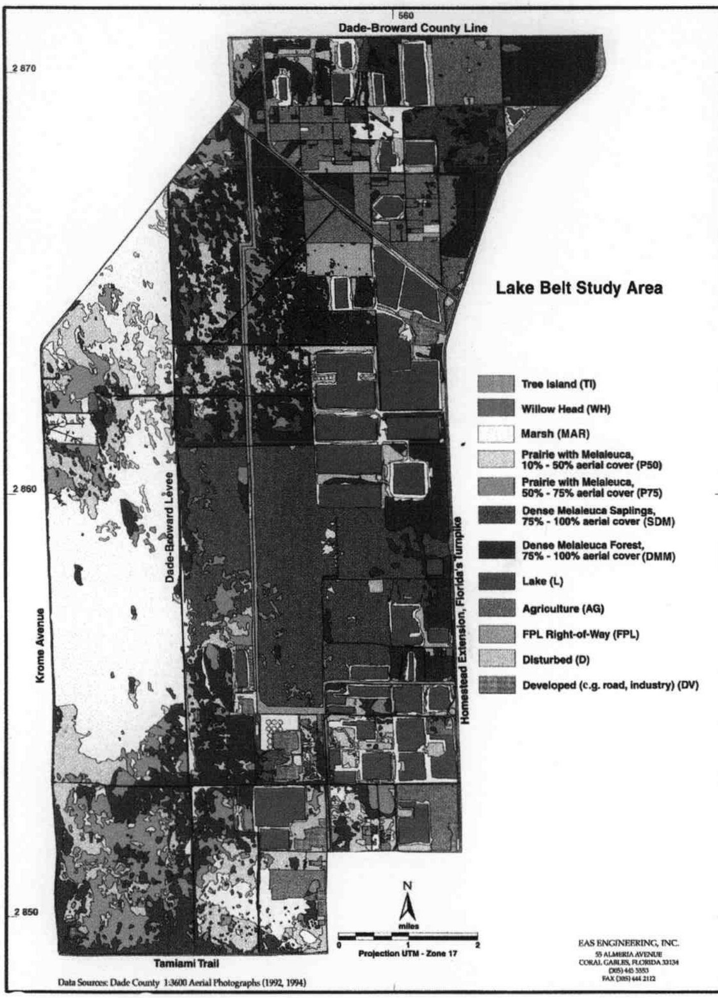

Figure 2. Map of vegetative cover types and man-made features within the study area, interpreted from 1992 1:300 aerial photographs.

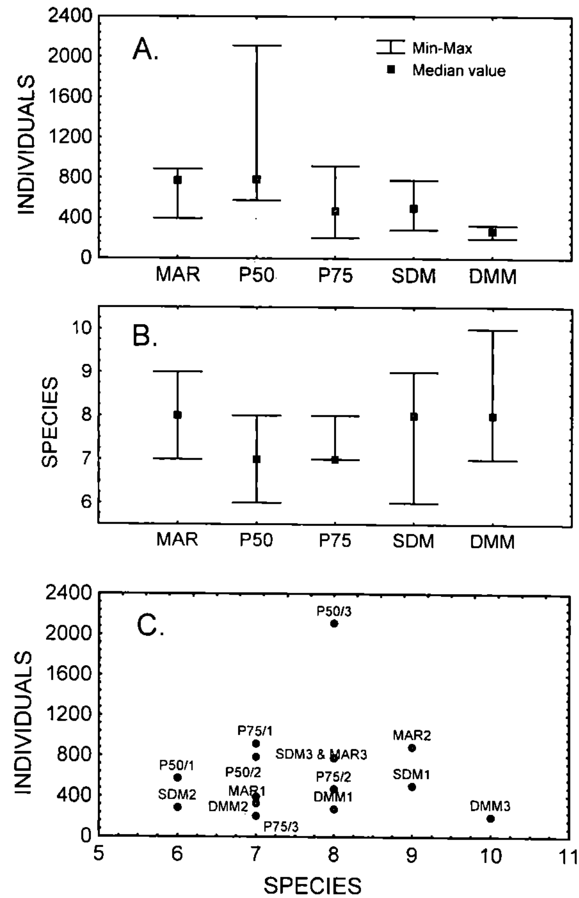

Figure 3. Box-whisker plot of cumulative number of individuals of macroinvertebrates trapped by drift fencing for each cover type. 3B. Box-whisker plot of cumulative number of species of macroinvertebrates trapped by drift fencing for each cover type. Kruskal-Wallis H (4, 15) = 6.6, p = 1.16. 3C. Plot of number of species versus number of individuals trapped for each cover type. Kruskal-Wallis H (4, 15) = 2.33, p = 1.68. Cover type abbreviations: MAR = <10% melaleuca coverage; P50 = 10% to 50% melaleuca coverage; P75 = 50% to 75% melaleuca coverage; SDM = >75% melaleuca coverage, sapling trees; DMM = >75% melaleuca coverage, mature trees.

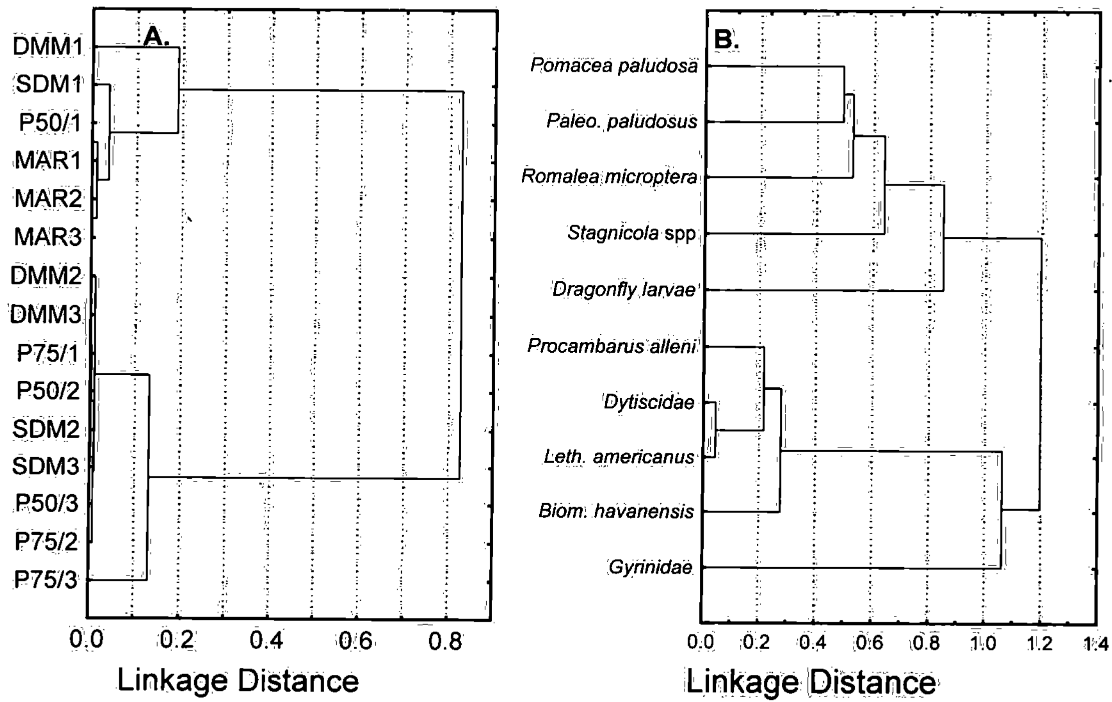

Figure 4. Cluster analyses by individual replicates and by taxa for macroinvertebrates. Based upon 24 month cumulative drift fence data from the 15 replicates (3 replicates per cover type). Cover type abbreviations as in Fig. 3.

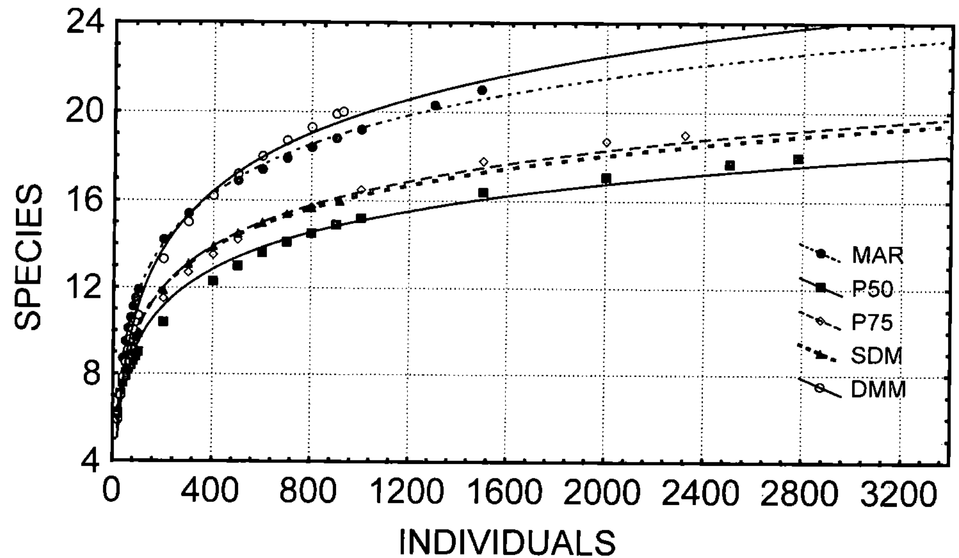

Figure 5. Rarefaction curves for fishes trapped in each cover type. Curves based upon 24 month cumulative data from drift fencing. Cover type abbreviations as in Fig. 3.

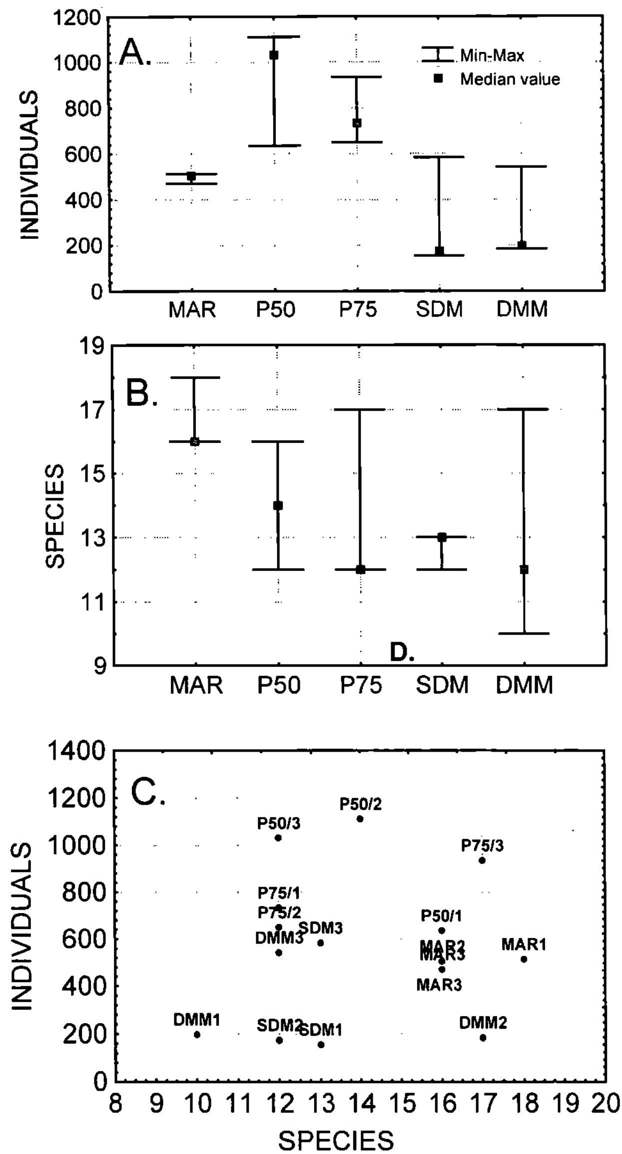

Figure 6A. Box-whisker plot of cumulative number of individuals of fishes trapped by drift fencing for each cover type. Krusal-Wallis H (4, 15) = 10.5, p = 0.03. 6B. Box-whisker plot of cumulative number of species of fishes trapped by drift fencing for each cover type. Kruskal-Wallis H (4, 15) = 4.03, p = 0.40. 6C. Plot of number of species versus number of individuals trapped for each of the 15 replicates (3 per cover type). Cover type abbreviations as in Fig. 3.

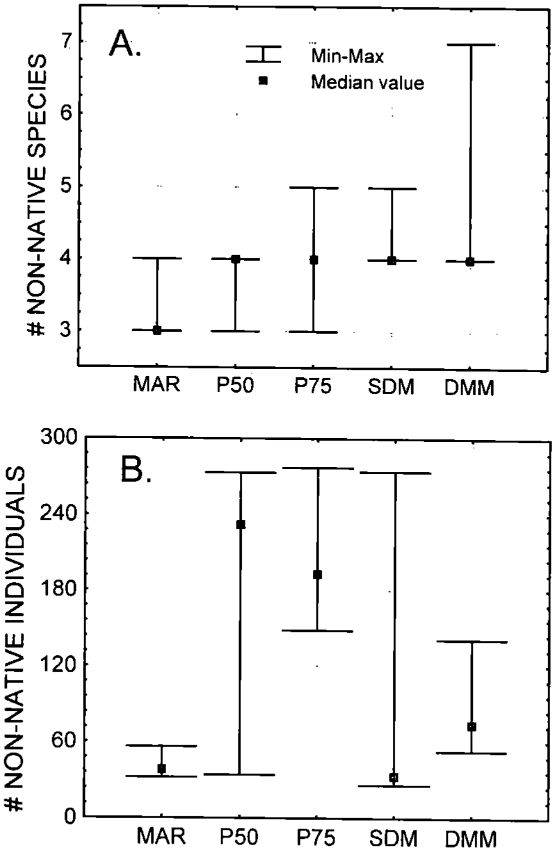

Figure 7A. Box-whisker plots of number of species of non-native fishes trapped in each cover type. Krukal-Wallis H (4, 15) = 4.76, p = 0.31. 7B. Box-whisker plots of number of individuals of non-native fishes trapped in each cover type. Krukal-Wallis H (4, 15) = 5.10, p = 0.28. Cover type abbreviations as in Fig. 3.

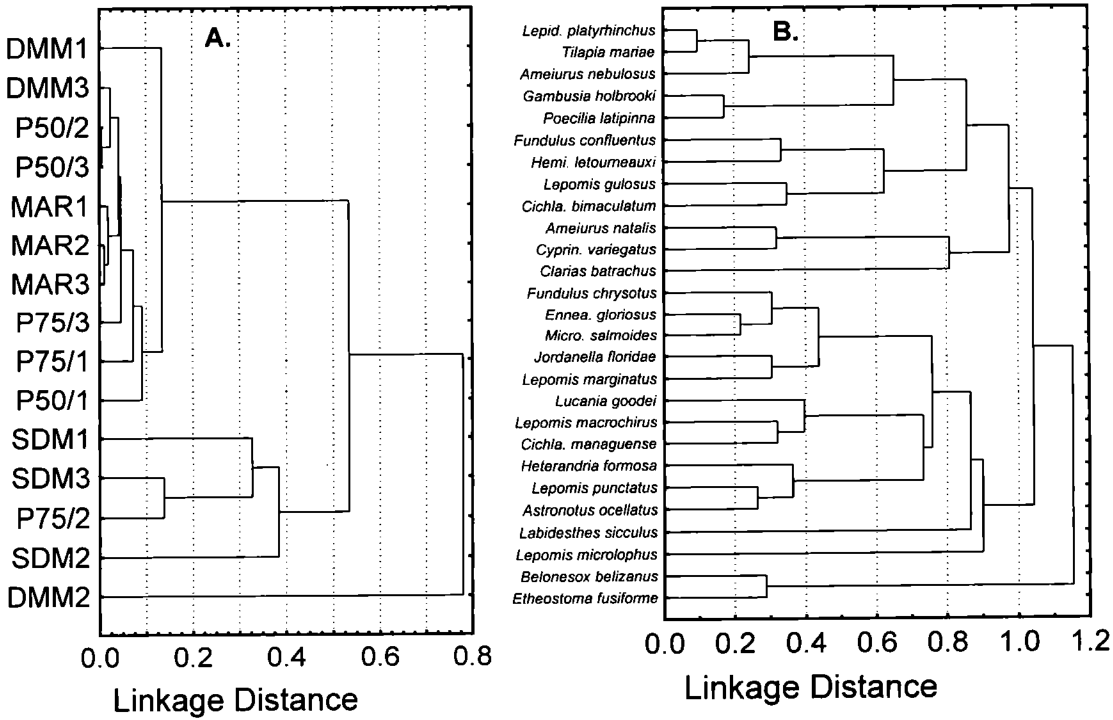

Figure 8. Cluster analyses by individual replicates and by taxa for fishes. Based upon 24 month cumulative drift fence data from the 15 replicates (3 replicates per cover type). Cover type abbreviations as in Fig. 3.

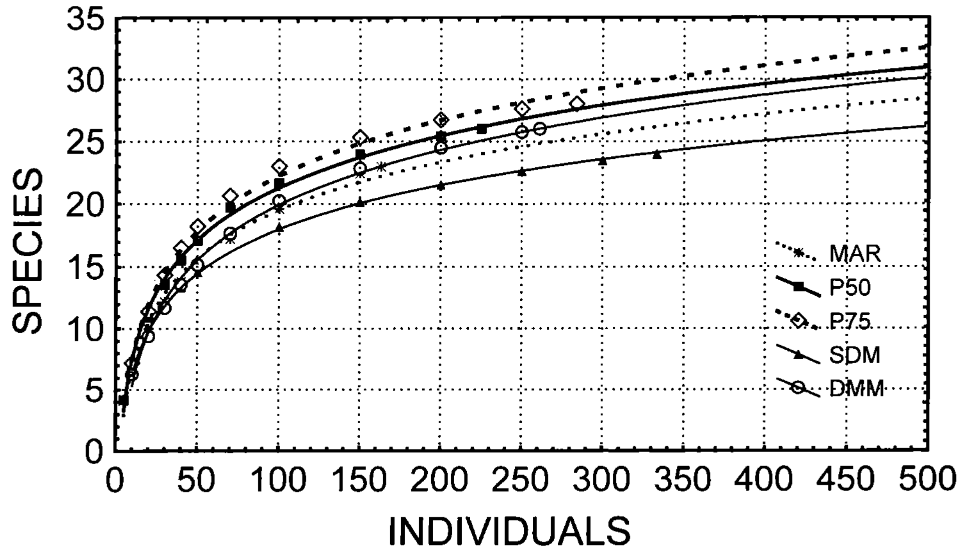

Figure 9. Rarefaction curves (number of species versus number of individuals sampled) for herptiles based upon drift fence data for each cover type; 24 month cumulative data collection. Cover type abbreviations as in Fig. 3.

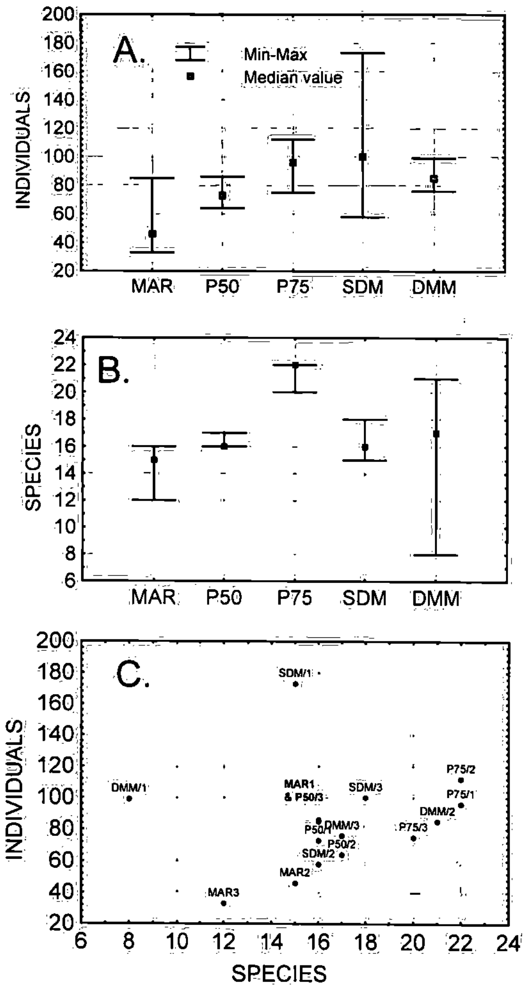

Figure 10A. Box-whisker plot of cumulative number of individuals of herptiles trapped by drift fencing for each cover type. Kruskal-Wallis H (4, 15) = 4.87, p = 0.30. 10B. Box-whisker plot of cumulative number of species of herptiles trapped by drift fencing for each cover type. Kruskal-Wallis H (4, 15) = 7.58, p = 0.11. 10C. Plot of number of species versus number of individuals trapped for each of the 15 replicates (3 per cover type). Cover type abbreviations as in Fig. 3.

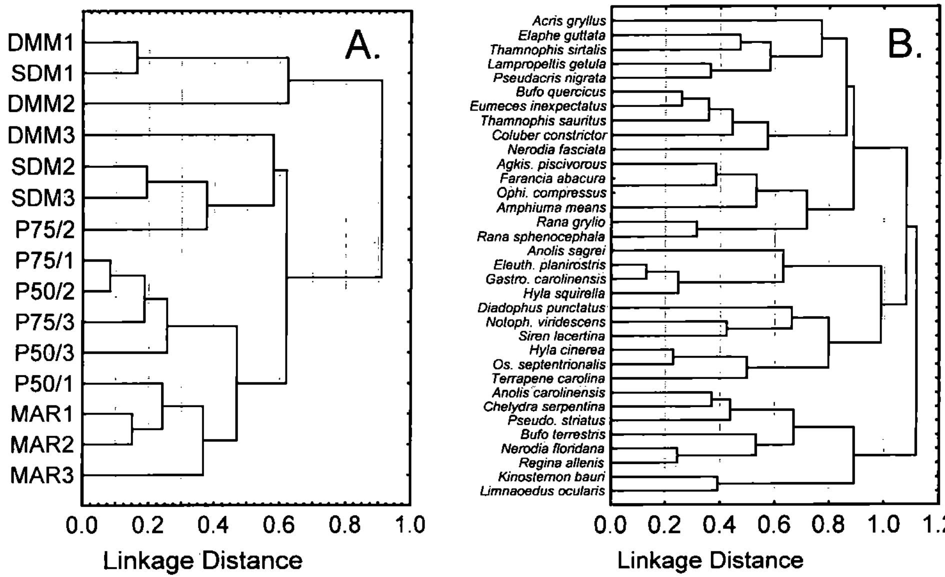

Figure 11. Cluster analyses by individual replicates and by taxa for herptiles. Based upon 24 month cumulative drift fence data from the 15 replicates (3 replicates per cover type). Cover type abbreviations as in Fig. 3.

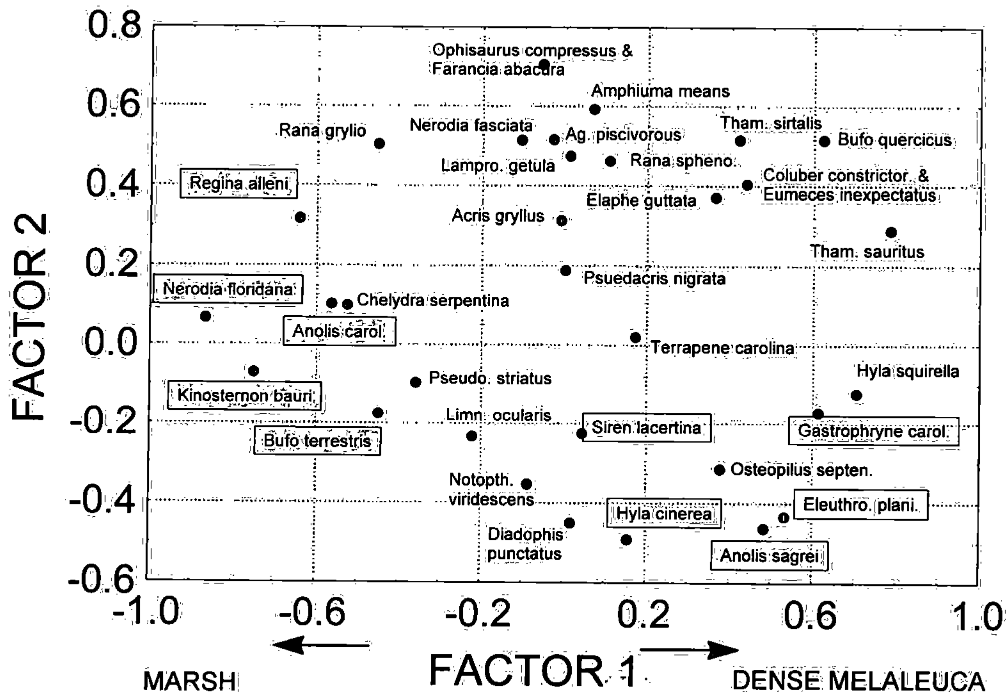

Figure 12. Plot of the first two factor loadings for herptiles. Based upon 24 month cumulative drift fence data from the 15 replicates (3 replicates per cover type). Taxa with significant clumped distributions are outlined (I index p 's > 0.025).

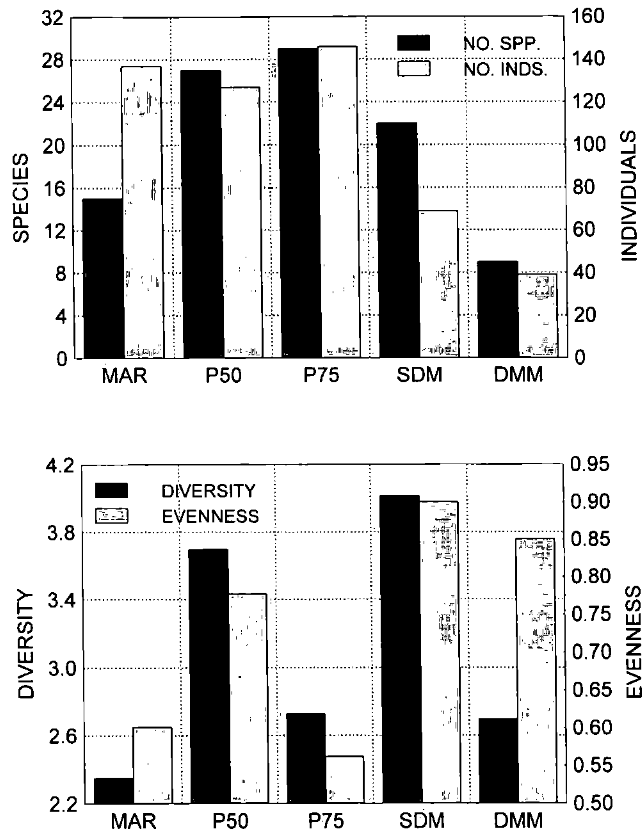

Figure 13. Abundance, species richness, and diversity of birds observed during strip transects in the five defined cover types. Cover type abbreviations as in Fig. 3.

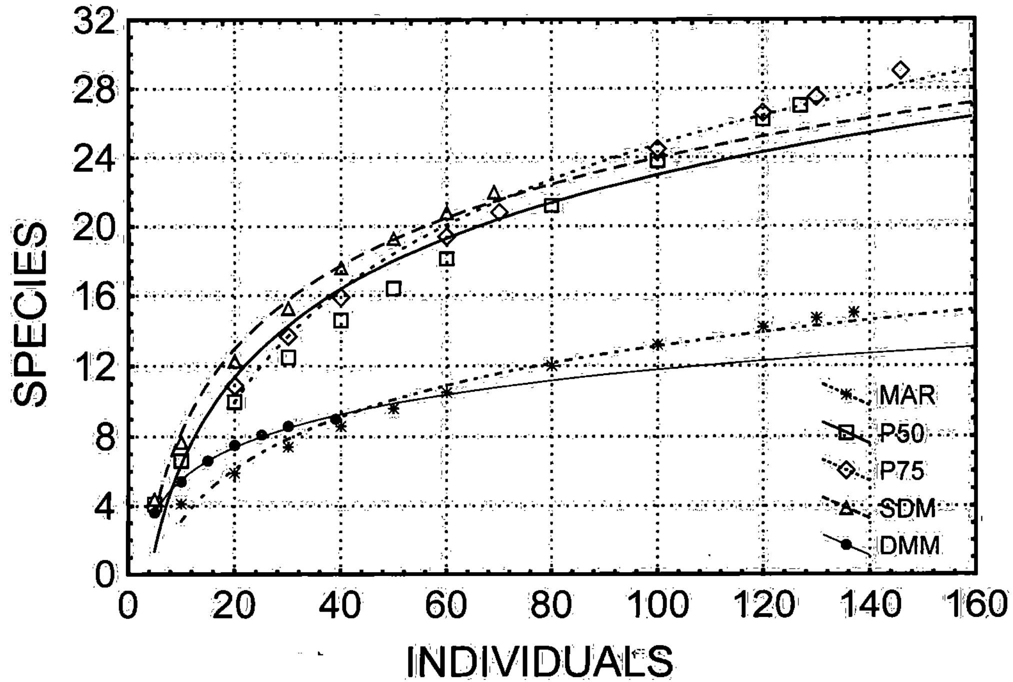

Figure 14. Rarefaction curves (number of species versus number of individuals sampled) for birds based upon strip transect data for each cover type; 24 month cumulative data collection. Cover type abbreviations as in Fig. 3.

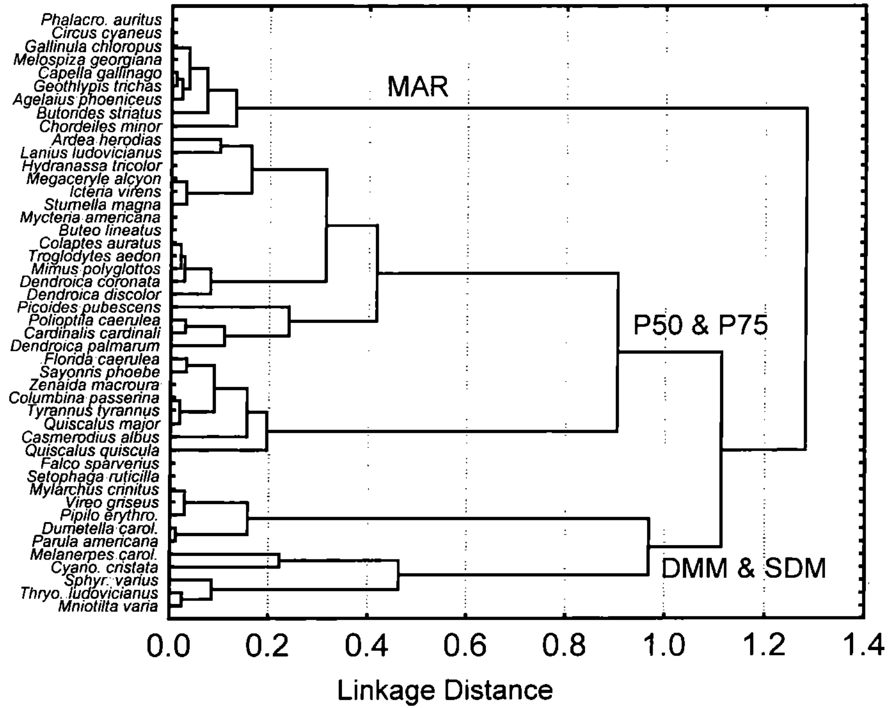

Figure 15. Cluster analyses by cover type and by taxa for the strip transect data for birds. Based upon 24 month cumulative strip transect data from the five cover types (data from the three replicates per cover type combined). Cover type abbreviations as in Fig. 3.

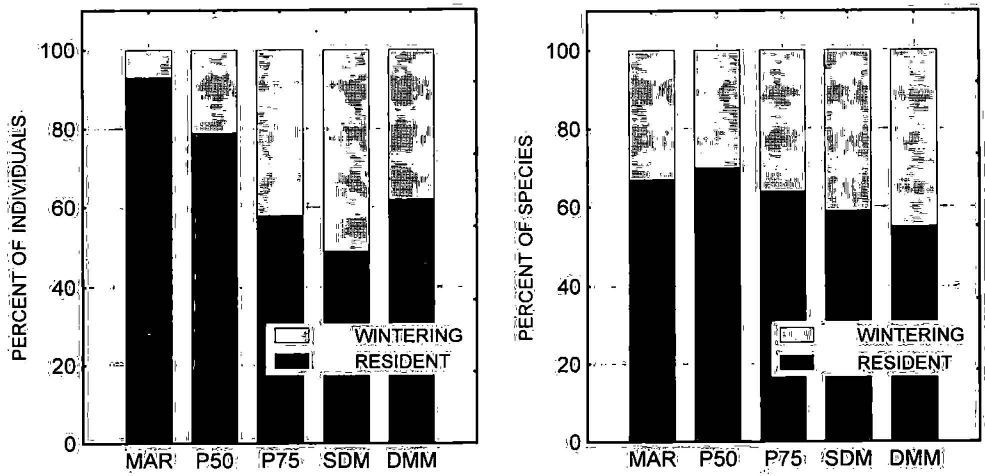

Figure 16. Plot of the percentage of individuals and species of resident and wintering bird species. Based upon 24 month cumulative strip transect data from the five cover types (data from the three replicates per cover type combined). Cover type abbreviations as in Fig. 3.

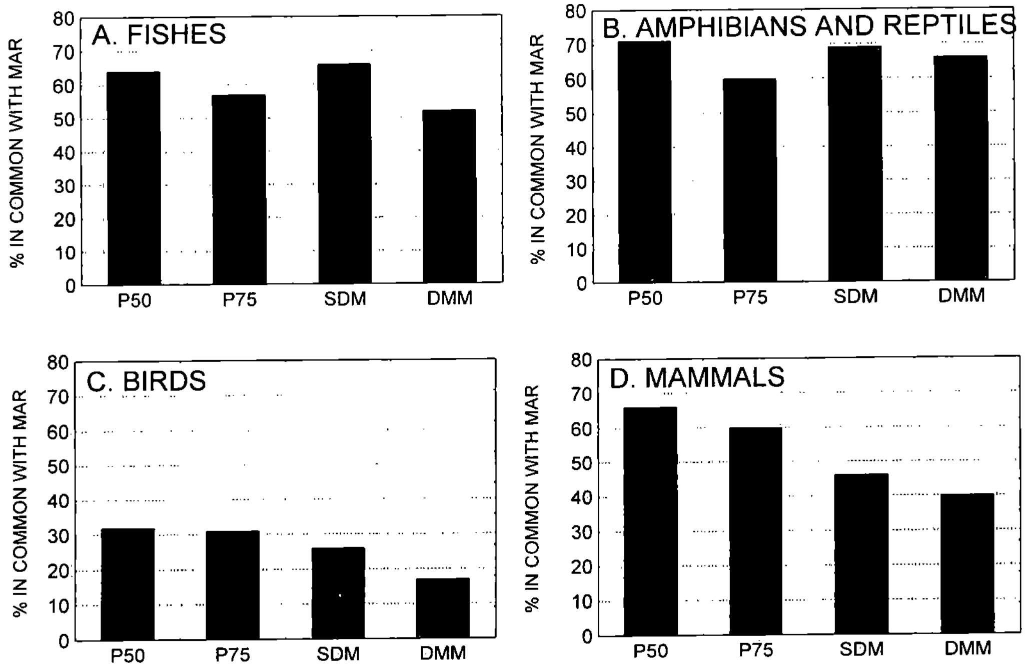

Figure 17. Percent of species in common between Marsh and each other cover type for fishes, herptiles, birds, and mammals. Cover type abbreviations as in Fig. 3.

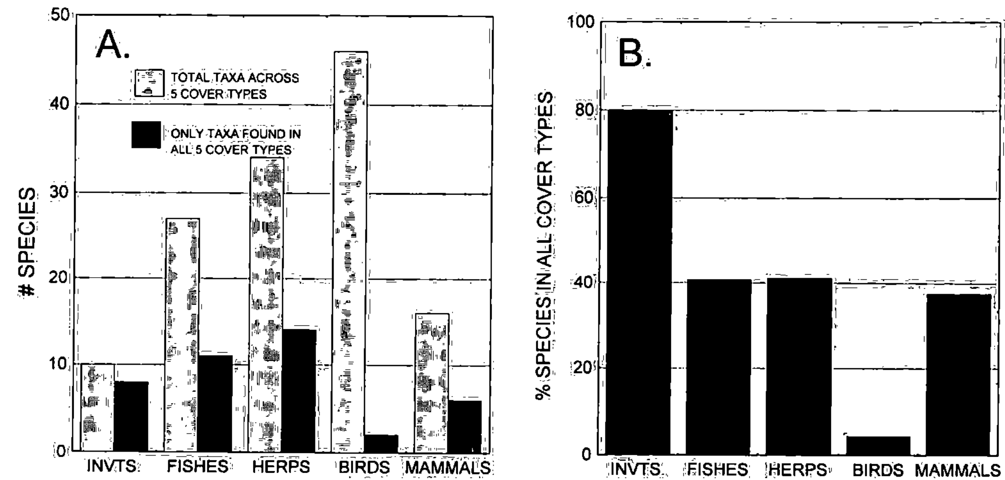

Figure 18. Total taxa for each faunal group and percent of taxa found in all of the five defined cover types.

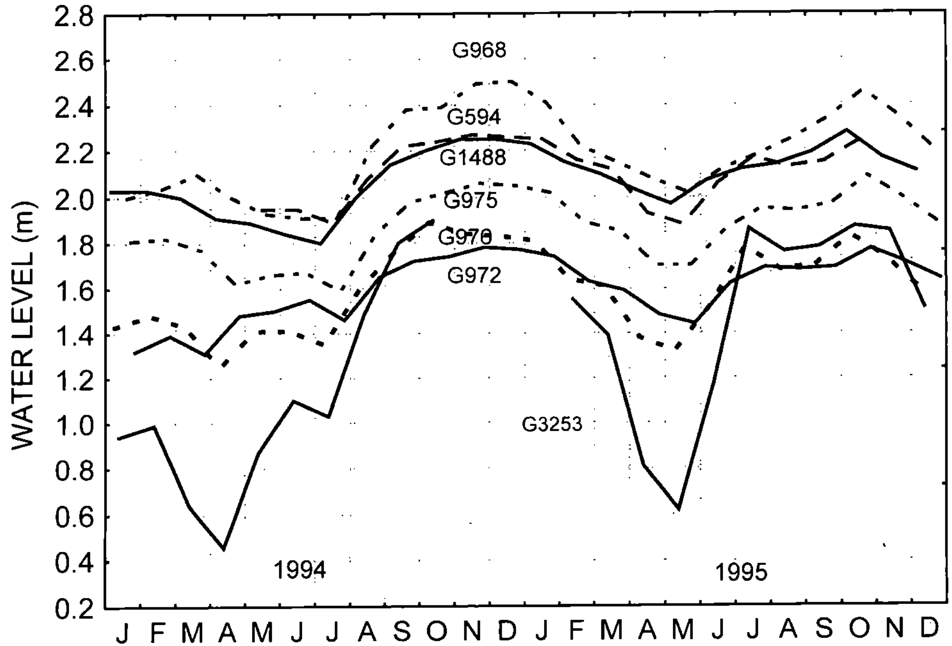

Figure 19. Plot of the average monthly water level for the seven USGS gages located within the Lake Belt Study area for 1994-1995.

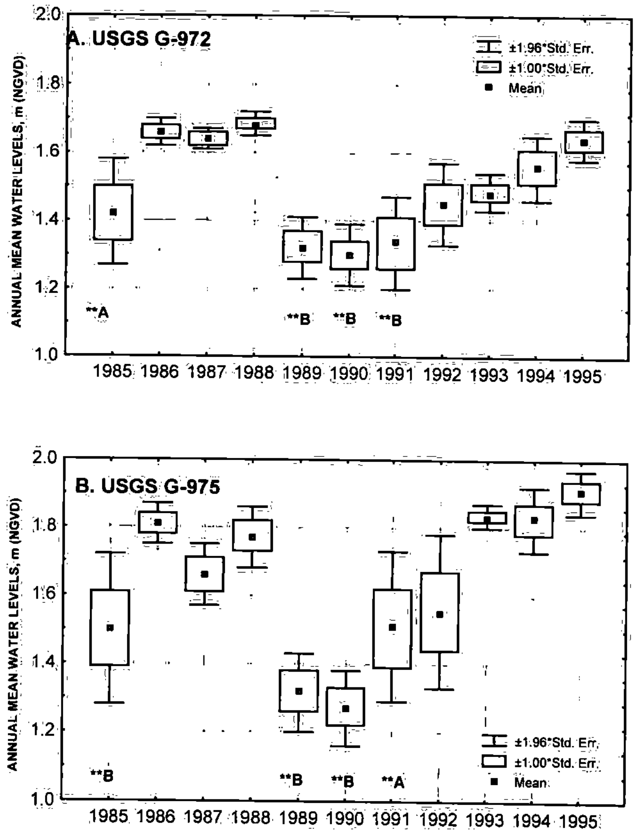

Figure 20A. Plot of monthly average water level at G-972 for the period 1985-1995. 20B. Plot of the monthly average water level at G-975 for the period 1985-1995. Each plot is intended to demonstrate the range of conditions for the 11 year period, rather than to compare specific years. **A = Year significantly different from 1995 only. **B = Year significantly different from both 1994 and 1995.

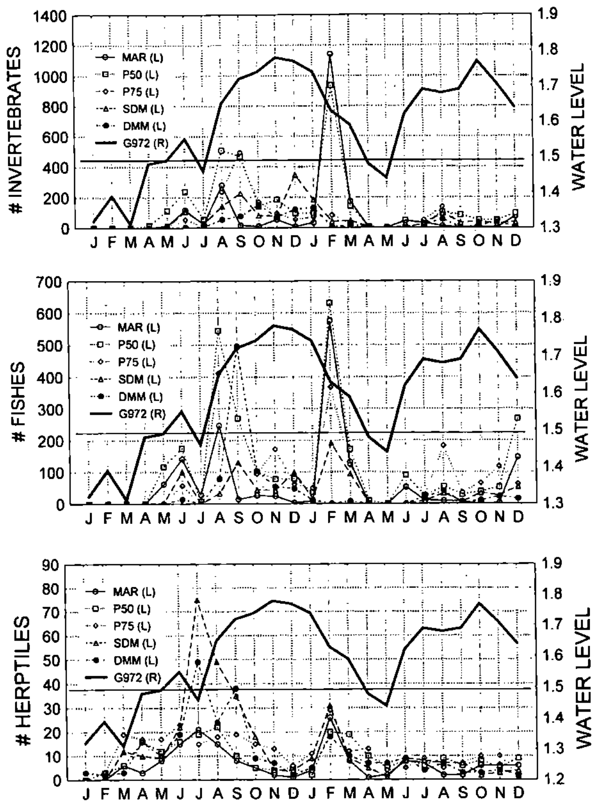

Figure 21. Plot of the monthly number of individuals of macroinvertebrates, fishes, and herptiles trapped in each cover type by drift fencing (Jan, 1994 thru Dec, 1995). Also plotted is the average monthly water level at USGS gage G-972 for the same period. The horizontal line represents the LSD elevation for the gage (1.5 m, NGVD). Actual ground surface elevation is likely to be lower. Cover type abbreviations as in Fig. 3.

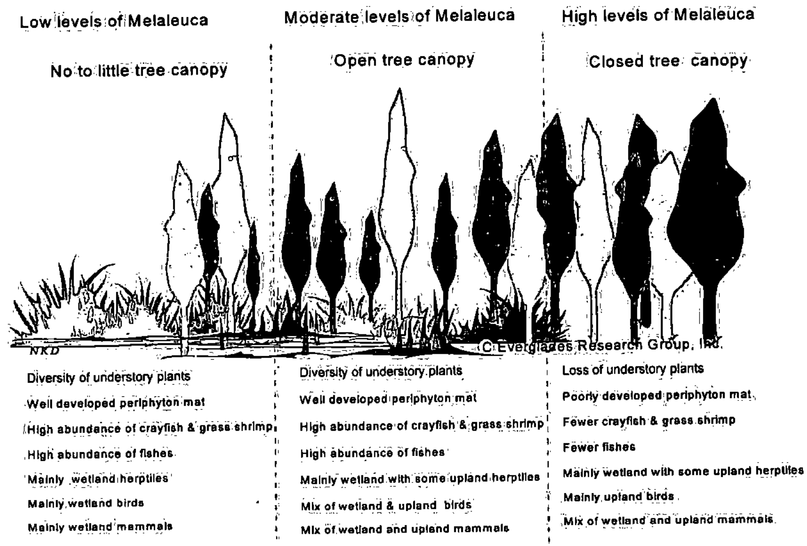

Figure 22. Summary of changes in vegetation structural diversity and wildlife diversity in native graminoid wetland habitats with increasing coverage by melaleuca.

Table 1. Summary of drift fence trapping results for each site (15 sites total), 24-month cumulative numbers. Cover type abbreviations: MAR=<10% melaleuca coverage, P50=10% to 50% melaleuca coverage; P75=50% to 75% melaleuca coverage; SDM=>75% melaleuca coverage, sapling trees; DMM=>75% melaleuca coverage, mature trees.

	MAR			P50			P75			SDM			DMM		
Site:	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Invertebrates															
Odonate larvae	12	6	2	—	1	8	—	—	—	1	3	—	1	—	1
Romalea microptera	4	14	1	3	—	—	—	1	—	15	3	5	4	4	4
Lethocerus americanus	6	9	15	1	66	87	66	40	39	9	17	39	4	1	17
Dytiscid beetles	7	25	7	7	84	86	78	68	52	17	12	45	5	5	14
Gyrinid beetles	—	—	—	—	—	—	—	4	—	2	—	1	—	1	1
Biomphalaria havanensis	—	1	5	—	4	14	3	1	6	—	—	1	—	—	1
Stagnicola sp	—	6	—	—	1	1	1	1	3	1	—	1	5	—	1
Pomacea paludosa	2	11	4	1	—	1	3	—	2	1	—	—	1	6	6
Paleomonetus paludosus	295	748	690	459	3	19	4	5	10	319	9	17	130	19	1
Procambarus alleni	68	67	50	104	626	1896	763	352	94	136	243	669	124	292	153
Fishes															
Lepisosteus platyrhinchus	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—
Ameiurus natalis	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Ameiurus nebulosus	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—
Clarias batrachus	—	—	—	1	—	3	1	—	1	—	1	—	—	2	3
Cyprinodon variagatus	1	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Fundulus chrysotus	30	29	34	76	29	35	33	16	14	4	—	34	—	—	3
Fundulus confluentus	32	43	16	99	62	80	85	164	132	37	118	121	26	11	12
Jordanella floridae	79	43	40	99	55	53	6	17	75	1	7	11	25	—	13
Lucania goodei	18	11	10	7	4	2	1	—	12	1	1	2	1	—	9

Table 1 Continued.

*Belenosox belizanus**	—	—	—	—	—	—	—	12	—	43	3	31	10	7	—
Gambusia holbrooki	296	264	281	264	598	556	344	130	429	35	17	98	81	10	400
Heterandria formosa	3	12	2	4	2	—	—	5	10	—	—	—	—	3	—
Poecilia latipinna	16	46	50	39	82	62	38	24	113	1	1	—	2	1	30
Labidesthes sicculus	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Enneacanthus gloriosus	1	2	2	3	1	—	—	—	—	—	—	—	—	—	—
Lepomis gulosus	1	1	—	1	2	5	—	2	2	1	1	5	—	2	2
Lepomis macrochirus	2	1	1	—	—	—	1	—	1	1	—	1	—	—	—
Lepomis marginatus	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Lepomis microlophus	11	3	10	11	6	5	33	3	5	—	1	8	1	4	6
Lepomis punctatus	3	5	1	3	—	—	—	—	—	—	—	1	—	1	—
Micropterus salmoides	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—
Etheostoma fusiforme	1	—	—	—	—	—	—	1	—	3	—	—	—	—	—
*Astronotus ocellatus**	—	19	—	—	—	—	—	—	—	—	—	—	—	2	—
*Hemichromis letourneauxi**	6	19	7	15	132	148	150	234	96	18	18	133	7	35	41
*Cichlasoma bimaculatum**	5	5	13	12	135	80	41	42	36	10	5	105	42	102	23
*Cichlasoma managuense**	8	2	2	—	2	2	1	—	3	1	2	34	3	1	1
*Tilapia mariae**	—	—	—	—	1	—	—	—	3	—	—	—	—	1	—
Amphibians															
Pseudobranchus striatus	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Siren lacertina	2	1	2	5	—	2	3	—	3	2	7	11	—	22	—
Amphiuma means	2	—	1	1	4	10	4	3	3	3	6	8	—	1	4
Notophthalmus viridescens	—	2	1	—	—	—	—	—	1	—	—	—	—	3	—
Bufo terrestris	7	2	—	—	—	—	—	—	—	—	1	3	—	—	4
Bufo quercicus	2	—	—	—	6	9	6	24	5	15	10	12	2	—	3
Gastrophryne carolinensis	1	1	—	—	3	—	—	5	6	14	—	3	8	1	—
*Eleutherodactylus planirostris**	—	—	—	—	—	—	1	2	1	109	—	1	41	10	2
Pseudacris nigrita	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—

Table 1. Continued.

Limnaoedus ocularis	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Acris gryllus	—	4	1	—	2	2	1	3	—	—	—	—	—	1	—
Hyla cinerea	—	1	—	1	—	—	—	—	—	2	—	—	—	2	5
Hyla squirella	—	—	—	—	—	—	—	1	—	1	—	—	1	—	—
Osteopilus septentrionalis	—	—	—	—	—	—	2	—	—	2	1	—	—	2	3
Rana sphenocephala	13	9	3	15	16	15	34	15	15	9	6	19	17	13	19
Rana grylio	5	4	2	12	8	7	14	2	7	—	1	6	—	—	7
Reptiles															
Kinosternon bauri	7	5	8	2	1	4	1	1	3	—	—	—	1	1	1
Terrapene carolina	—	—	—	—	—	—	1	—	1	—	1	—	—	1	1
Chelydra serpentina	—	—	1	1	—	—	1	—	—	—	—	—	—	—	—
*Anolis sagrei**	1	—	—	6	—	—	1	7	—	6	4	6	25	10	17
Anolis carolinensis	5	1	—	5	—	—	—	2	3	—	—	1	—	—	—
Ophisaurus compressus	—	—	—	1	4	2	1	1	—	—	—	—	—	—	—
Eumeces inexpectatus	—	—	—	—	—	1	—	12	—	—	3	—	—	1	—
Nerodia fasciata	6	2	4	2	1	3	3	8	4	2	2	5	1	1	2
Nerodia floridana	19	8	7	15	4	11	2	1	6	1	5	7	—	3	—
Regina alleni	10	4	—	2	4	9	1	1	2	—	1	2	—	1	—
Thamnophis sirtalis	2	—	—	—	5	3	8	6	3	4	2	3	—	6	1
Thamnophis sauritus	—	1	1	1	1	2	3	5	3	3	4	2	4	2	1
Diadophis punctatus	1	—	—	—	—	—	—	—	—	1	—	—	—	1	—
Farancia abacura	—	—	—	—	—	3	1	1	2	—	—	—	—	—	—
Coluber constrictor	—	—	1	2	1	—	4	6	1	1	4	7	1	2	1
Elaphe guttata	—	—	—	—	2	—	—	2	—	—	—	1	—	1	—
Lampropeltis getula floridana	—	—	—	—	2	—	2	—	1	—	—	—	—	—	—
Agkistrodon piscivorous	—	1	—	1	1	3	2	2	8	—	—	3	—	—	4
Mammals															
Blarina carolinensis	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—

Table 1 Continued.

Sigmodon hispidus	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
Oryzomys palustris	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
All animals															
Number of species	40	40	37	39	39	36	41	42	45	38	35	40	28	45	39
Number of individuals	991	1,438	1,278	1,284	1,962	3,229	1,748	1,232	1,220	832	521	1,463	573	598	818
Trap rate	6.19	8.99	7.99	8.03	12.26	20.18	10.93	7.70	7.63	5.20	3.26	9.14	3.58	3.74	5.11
Invertebrates only															
Number of species	7	9	8	6	7	8	7	8	7	9	6	8	8	7	10
Number of individuals	394	887	774	575	785	2,112	918	472	206	501	287	778	274	328	199
Trap rate	2.46	5.54	4.84	3.59	4.91	13.20	5.74	2.95	1.29	3.13	1.79	4.86	0.93	1.34	0.83
Fishes only															
Number of species	18	16	16	16	14	12	12	12	17	13	12	13	10	17	12
Number of individuals	514	505	471	636	1,111	1,031	734	650	935	156	175	584	198	185	543
Trap rate	3.21	3.16	2.94	3.98	6.94	6.44	4.59	4.06	5.84	0.98	1.09	3.65	0.91	1.16	0.59
Amphibians & Reptiles only															
Number of species	15	15	13	17	18	16	22	22	20	16	16	18	10	21	16
Number of individuals	83	46	33	73	66	86	96	110	78	175	58	100	101	85	75
Trap rate	0.52	0.29	0.21	0.46	0.41	0.54	0.60	0.69	0.49	1.09	0.36	0.63	0.63	0.53	0.47

Table 2. Results of drift fencing trapping, summarized for each species by cover type (3 replicates in each cover type), 24 month cumulative numbers. Also indicated, for each species, are the Index of Dispersion (I), Chi-square value (χ^2), and whether distribution was clumped in any cover type. Cover type abbreviations as in Tab. 1.

	MAR	P50	P75	SDM	DMM	I Index	x2	Cover types		
Invertebrates										
Odonate larvae	20	9	-	4	2	5.49	76.86			
Romalea microptera	19	3	1	23	12	5.65	79.069			
Lethocerus americanus	30	154	145	65	22	26.80	375.18			
Dytiscid beetles	39	177	198	74	24	29.01	406.16			
Gyrinid beetles	-	-	4	3	2	2.10	29.33			
Biomphalaria havanensis	6	18	10	1	1	5.94	83.17			
Stagnicola sp	6	2	5	2	6	2.43	34.00			
Pomacea paludosa	17	2	5	1	13	3.77	52.79			
Paleomonetus paludosus	1733	481	19	345	150	375.90	5262.55			
Procambarus alleni	185	2626	1209	1048	569	618.64	8660.99			
Fishes										
Lepisosteus platyrhinchus	-	-	2	-	-	2.00	28.00	Clumped	P75	
Ameiurus natalis	-	-	-	-	1	1.00	14.00			
Ameiurus nebulosus	-	-	1	-	1	0.93	13.00			
Clarias batrachus	-	4	2	1	5	1.46	20.50			
Cyprinodon variagatus	1	-	-	-	1	0.93	13.00			
Fundulus chrysotus	93	140	63	38	3	18.73	262.15	Clumped	MAR	P50
Fundulus confluentus	91	241	,381	276	49	34.85	487.93	Clumped	P75	SDM
Jordanella floridae	162	207	98	19	38	28.49	398.90	Clumped	MAR	P50

Table 2 Continued.

Lucania goodei	39	13	13	4	10	5.84	81.82	Clumped	MAR		
Belenosox belizanus	-	-	12	77	17	23.88	334.38	Clumped	SDM		
Gambusia holbrooki	841	1418	903	150	491	142.44	1994.13	Clumped	MAR	P50	P75
Heterandria formosa	17	6	15	-	3	5.20	72.78	Clumped	MAR	P75	
Poecilia latipinna	112	183	175	2	33	33.22	465.01	Clumped	MAR	P50	P75
Labidesthes sicculus	1	-	-	-	-	1.00	14.00				
Enneacanthus gloriosus	5	4	-	-	-	1.62	22.67				
Lepomis gulosus	2	8	4	7	4	1.43	20.00				
Lepomis macrochirus	4	-	2	2	-	0.77	10.75				
Lepomis marginatus	1	1	-	-	-	0.93	13.00				
Lepomis microlophus	24	22	41	9	11	8.91	124.73	Clumped	MAR	P50	P75
Lepomis punctatus	9	3	-	1	1	2.52	35.29	Clumped	MAR		
Micropterus salmoides	1	1	-	-	-	0.93	13.00				
Etheostoma fusiforme	1	-	1	3	-	2.00	28.00	Clumped	SDM		
*Astronotus ocellatus**	19	-	-	-	2	17.12	239.71	Clumped	MAR		
*Hemichromis letourneauxi**	32	295	480	169	83	73.85	1033.96	Clumped	P50	P75	SDM
*Cichlasoma bimaculatum**	23	227	119	150	167	45.92	642.92	Clumped	P50	SDM	DMM
*Cichlasoma managuense**	12	4	4	7	5	1.80	25.19				
*Tilapia mariae**	-	1	3	-	1	2.00	28.00	Clumped	P75		
Amphibians											
Pseudobranchus striatus	-	1	-	-	-	1.00	14.00				
Siren lacertina	5	7	6	20	22	9.43	132.04	Clumped	SDM	DMM	
Amphiuma means	3	15	10	17	5	2.47	34.60	Clumped	P50	SDM	
Notophthalmus viridescens	3	-	1	-	3	1.80	25.14				
Bufo terrestris	9	-	-	4	4	3.77	52.71	Clumped	MAR		
Bufo quercicus	2	15	35	37	5	7.42	103.87	Clumped	P75	SDM	

Table 2 Continued.

Gastrophryne carolinensis	2	3	11	17	9	5.72	80.14	Clumped	SDM	DMM
*Eleutherodactylus planirostris**	-	-	4	110	53	75.79	1061.11	Clumped	SDM	DMM
Pseudacris nigrita	-	1	-	-	-	1.00	14.00			
Limnaoedus ocularis	1	-	-	-	-	1.00	14.00			
Acris gryllus	5	4	4	-	1	1.76	24.57			
Hyla cinerea	1	1	-	2	7	2.62	36.73	Clumped	DMM	
Hyla squirella	-	-	1	1	1	0.86	12.00			
Osteopilus septentrionalis	-	-	2	3	5	1.64	23.00			
Rana sphenocephala	25	46	64	34	49	3.44	48.15	Clumped	P50	P75
Rana grylio	11	27	23	7	7	3.74	52.40	Clumped	P50	P75
Reptiles										
Kinosternon bauri	20	7	5	-	3	2.99	41.88	Clumped	MAR	
Terrapene carolina	-	-	2	1	2	0.17	10.00			
Chelydra serpentina	1	1	1	-	-	0.86	12.00			
*Anolis sagrei**	1	6	8	16	52	9.42	131.88	Clumped	DMM	
Anolis carolinensis	6	5	5	1	-	2.82	40.35	Clumped	MAR	P50
Ophisaurus compressus	-	7	2	-	-	1.80	25.14			
Eumeces inexpectatus	-	1	12	3	1	8.56	119.77	Clumped	P75	
Nerodia fasciata	12	6	15	9	4	1.48	20.67			
Nerodia floridana	34	30	9	13	3	5.21	72.97	Clumped	MAR	P50
Regina alleni	14	15	4	3	1	3.99	55.84	Clumped	MAR	P50
Thamnophis sirtalis	2	8	17	9	7	2.24	31.30	Clumped	P75	
Thamnophis sauritus	2	4	11	9	7	0.92	12.91			
Diadophis punctatus	1	-	-	1	1	0.86	12.00			
Farancia abacura	-	3	4	-	-	1.80	25.14			
Coluber constrictor	1	3	11	12	4	2.31	32.39	Clumped	P75	SDM

Table 2 Continued.

Elaphe guttata	-	2	2	1	1	1.36	19.00			
Lampropeltis getula floridana	-	2	3	-	-	1.57	22.00			
Agkistrodon piscivorous	1	5	12	3	4	2.89	40.40	Clumped	P50	P75
Mammals										
Blarina carolinensis	-	-	-	1	-					
Sigmodon hispidus	-	-	1	-	1					
Oryzomys palustris	-	-	-	1	-					
All animals										
Number of species	53	53	57	52	57					
Number of individuals	3707	6475	4200	2816	1989					
Trap rate	7.72	13.49	8.75	5.87	4.14					
Macroinvertebrates only										
Number of species	9	9	9	10	10					
Number of individuals	2055	3472	1596	1566	801					
Trap rate	4.28	7.23	3.33	3.26	1.67					
Fishes only										
Number of species	21	18	19	16	20					
Number of individuals	1490	2778	2319	915	926					
Trap rate	3.10	5.79	4.83	1.91	1.93					
Amphibians and Reptiles only										
Number of species	23	26	28	24	26					
Number of individuals	162	225	284	333	261					
Trap rate	0.34	0.47	0.59	0.69	0.54					

Table 3. Results of bird strip transects summarized by cover type, 24-month cumulative numbers. Within each cover type, there were three replicates. Also indicated for each species are the Index of Dispersion, Chi-square value, and whether distribution was clumped in any cover type. Cover type abbreviations as in Table 1.

	MAR	P50	P75	SDM	DMM	I Index	2	Cover types		
Phalacrocorax auritus	1	-	-	-	-	1.00	4.00			
Ardea herodias	1	1	2	-	-	0.88	3.50			
Butorides striatus	3	1	1	1	-	1.00	4.00			
Florida caerulea	-	2	1	-	-	1.33	5.33			
Casmerodius albus	3	6	-	-	-	4.00	16.00	Clumped	MAR	P50
Hydranassa tricolor	-	1	1	-	-	0.75	3.00			
Mycteria americana	-	-	1	-	-	1.00	4.00			
Buteo lineatus	-	-	2	-	-	2.00	8.00			
Circus cyaneus	1	-	-	-	-	1.00	4.00			
Falco sparverius	-	-	-	1	-	1.00	4.00			
Gallinula chloropus	1	-	-	-	-	1.00	4.00			
Capella gallinago	5	1	1	-	-	3.07	12.29	Clumped	MAR	
Zenaida macroura	-	1	-	-	-	1.00	4.00			
Columbina passerina	-	1	-	-	-	1.00	4.00			
Chordeiles minor	2	-	1	-	-	1.33	5.33			
Megaceryle alcyon	-	2	2	-	-	1.50	6.00			
Colaptes auratus	-	-	4	-	-	4.00	16.00	Clumped	P75	
Melanerpes carolinus	-	1	3	1	3	1.13	4.50			
Sphyrapicus varius	-	-	-	-	2	2.00	8.00			
Picoides pubescens	-	1	1	1	-	0.50	2.00			
Tyrannus verticalis	-	1	-	-	-	1.00	4.00			
Mylarchus crinitus	-	-	-	2	-	2.00	8.00			
Sayornis phoebe	-	4	1	-	-	3.00	12.00	Clumped	P50	

Table 3 Continued.

Cyanocitta cristata	-	1	5	5	5	1.94	7.75			
Troglodytes aedon	-	-	1	-	-	1.00	4.00			
Thryothorus ludovicianus	-	-	1	4	13	8.42	33.67	Clumped	SDM	DMM
Mimus polyglottos	-	1	5	-	-	3.92	15.67	Clumped	P75	
Dumetella carolinensis	-	-	2	3	-	2.00	8.00			
Polioptila caerulea	-	3	7	7	2	2.55	10.21			
Lanius ludovicianus	1	3	6	1	-	2.59	10.36			
Vireo griseus	-	-	-	1	-	1.00	4.00			
Mniotilta varia	-	-	-	1	2	1.33	5.33			
Parula americana	-	-	1	2	-	1.33	5.33			
Dendroica coronata	-	2	18	4	-	11.92	47.67	Clumped	P75	
Dendroica discolor	-	-	10	4	-	6.86	27.43	Clumped	P75	
Dendroica palmarum	2	11	22	13	9	4.59	18.35	Clumped	P75	SDM
Geothlypis trichas	57	20	12	4	2	26.42	105.68	Clumped	MAR	
Icteria virens	-	1	1	-	-	0.75	3.00			
Setophaga ruticilla	-	-	-	3	-	3.00	12.00	Clumped	SDM	
Sturnella magna	8	26	28	-	-	15.23	60.90	Clumped	P50	P75
Agelaius phoeniceus	47	11	-	1	-	34.64	138.54	Clumped	MAR	
Quiscalus major	4	21	-	-	-	16.60	66.40	Clumped	P50	
Quiscalus quiscula	-	2	-	1	-	1.33	5.33			
Cardinalis cardinalis	-	1	5	4	1	2.14	8.55			
Pipilo erythrophthalmus	-	1	1	5	-	3.07	12.29	Clumped	SDM	
Melospiza georgiana	1	-	-	-	-	1.00	4.00			
Number of species	15	27	29	22	9					
Number of individuals	137	127	146	69	39					

Across all five cover types

Number of species	46
Number of indivduals	518

Table 4. Scent and bait stations and small mammal live trapping results by cover type, 24-month cumulative numbers. Cover type abbreviations as in Table 1.

	MAR	P50	P75	SDM	DMM
Bait stations					
Didelphis virginiana	+	+	+	+	+
Sigmodon hispidus	-	-	-	+	-
Procyon lotor	+	+	+	+	+
Urocyon cinereoargenteus	-	-	-	+	+
Canis familiaris	+	-	+	-	+
Felis rufus	-	-	-	+	+
Number of species	3	2	3	5	5
Scent stations					
Didelphis virginiana	-	-	-	+	+
Sigmodon hispidus	-	-	-	-	+
Procyon lotor	+	+	+	+	+
Canis familiaris	-	+	+	-	+
Felis rufus	-	-	-	+	+
Odocoileus virginianus	+	-	+	-	-
Number of species	2	2	3	3	5
Sherman live traps					
Sigmodon hispidus	-	7	4	1	-
Oryzomys palustris	3	4	2	2	1
Peromyscus gossypinus	-	-	-	3	2
Mus musculus	-	-	-	-	1
Rattus rattus	-	-	-	-	1
Number of species	1	3	2	3	5
Number of individuals	3	11	6	6	5
All three methods combined					
Number of species	5	5	6	7	10
	Across all five cover types				
Number of species			11		

Table 5. Habitat association and species composition of amphibian and reptiles in each cover type based upon the cumulative totals of number of species and number of individuals trapped by drift fencing. Cover type abbreviations as in Table 1.

	MAR			P50			P75			SDM			DMM		
Site	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Number of species															
Wetland dependent	12	14	12	13	15	14	18	15	17	12	13	13	7	15	13
Non-wetland	3	1	1	4	3	2	4	7	3	4	3	5	3	6	3
% Wetland dependent	80	93	92	76	83	88	82	68	85	75	81	72	70	71	81
Number of individuals															
Wetland dependent	76	45	32	59	59	83	89	78	73	58	47	84	34	60	55
Non-wetland	7	1	1	14	7	3	7	32	5	117	11	16	67	25	20
% Wetland dependent	92	98	97	81	89	97	93	71	94	33	81	84	34	71	73

Table 6. Habitat association and species composition of birds in each cover type based upon the cumulative totals of number of species and number of individuals observed during strip transects. Cover type abbreviations as in Table 1.

	MAR	P50	P75	SDM	DMM
Number of species					
Wetland dependent	12	11	10	4	1
Non-wetland	3	16	19	18	8
% Wetland dependent	80%	41%	34%	18%	11%
Number of individuals					
Wetland dependent	132	92	59	10	2
Non-wetland	5	35	87	59	37
% Wetland dependent	96%	72%	40%	14%	5%

APPENDIX I

Glossary of the scientific and common names of each vertebrate species found during the 24 months of the surveys in the Lake Belt Study Area, including areas otehr than the five defined cover types (e.g. canals, levees). Within each class, species are listed alphabetically by scientific name. The Status column indicates whether a species is considered non-native in southern Florida. The GFC column indicates whether a species is listed as Endangered (E), Threatened (T) or Species of Special Concern (SSC) by the State of Florida Department of Game and Freshwater Fish Commission. The FWS column indicates whether a species is listed as Endangered (E), Threatened (T) or Candidate for Listing (C1 or C2) by the United States Fish and Wildlife Service. For amphibians, reptiles, birds, and mammals only, the Habitat Assoc. column lists whether the species requires wetland habitats at some point in its life history for either reproduction, respiration, feeding mechanism or diet. For birds only, it is also indicated whether the species occurs in southern Florida all year (Resident), only during certain seasons (Winter or Summer), or passes through during spring and/or fall migration (Transient). In general, species designated "Resident" or "Summer" breed in southern Florida, although exceptions do exist.

Scientific Name	Common Name	Status	GFC	FWS	Habitat Association	Season
Fishes						
Ameiurus natalis	Yellow bullhead catfish					
Ameiurus nebulosus	Brown bullhead catfish					
Amia calva	Bowfin					
Astronotus ocellatus	Oscar	Non-native				
Belonesox belizanus	Pike killifish	Non-native				
Cichla ocellaris	Peacock bass	Non-native				
Cichlasoma bimaculatum	Black acara	Non-native				
Cichlasoma managuense	Nicaraguan cichlid	Non-native				
Clarias batrachus	Walking catfish	Non-native				
Cyprinodon variegatus	Sheepshead minnow					
Enneacanthus gloriosus	Bluespotted sunfish					
Etheostoma fusiforme	Swamp darter					
Fundulus chrysotus	Golden topminnow					
Fundulus confluentus	Marsh killifish					
Gambusia holbrooki	Mosquito fish					
Hemichromis letourneauxi	Jewelfish	Non-native				
Heterandria formosa	Least killifish					
Jordanella floridae	Flagfish					
Labidesthes sicculus	Brook silverside					
Lepisosteus platyrhinchus	Florida gar					
Lepomis gulosus	Warmouth					
Lepomis macrochirus	Bluegill					
Lepomis marginatus	Dollar sunfish					
Lepomis microlophus	Redear sunfish					
Lepomis punctatus	Spotted sunfish					
Lucania goodei	Bluefin killifish					

Scientific Name	Common Name	Status	GFC	FWS	Habitat Association	Season
Micropterus salmoides	Large mouth bass					
Mugil cephalus	Striped mullet					
Poecilia latipinna	Sailfin molly					
Tilapia mariae	Spotted tilapia	Non-native				
Amphibians						
Acris gryllus	Southern cricket frog				Wetland	
Amphiuma means	Two-toed amphiuma				Wetland	
Bufo quercicus	Oak toad				Wetland	
Bufo terrestris	Southern toad				Wetland	
Eleutherodactylus planirostris	Greenhouse frog	Non-native			Non-wetland	
Gastrophryne carolinensis	Eastern narrowmouth toad				Wetland	
Hyla cinerea	Green treefrog				Wetland	
Hyla squirella	Squirrel treefrog				Wetland	
Limnaoedus ocularus	Little grass frog				Wetland	
Notophthalmus viridescens	Peninsula newt				Wetland	
Osteopilus septentrionalis	Cuban treefrog	Non-native			Wetland	
Pseudacris nigrita	Florida chorus frog				Wetland	
Pseudobranchus striatus	Dwarf siren				Wetland	
Rana grylio	Pig frog				Wetland	
Rana sphenocephala	Southern leopard frog				Wetland	
Siren lacertina	Greater siren				Wetland	
Reptiles						
Agkistrodon piscivorous	Cottonmouth				Wetland	
Alligator mississippiensis	American alligator		SSC	T	Wetland	
Anolis carolinensis	Green anole				Non-wetland	
Anolis sagrei	Brown anole	Non-native			Non-wetland	
Apalone ferox	Florida softshell turtle				Wetland	

Scientific Name	Common Name	Status	GFC	FWS	Habitat Association	Season
Chelydra serpentina	Florida snapping turtle				Wetland	
Coluber constrictor	Black racer				Non-wetland	
Deirochelys reticularia	Chicken turtle				Wetland	
Diadophis punctatus	Southern ringneck snake				Non-wetland	
Elaphe guttata	Red rat snake				Non-wetland	
Elaphe obsoleta	Yellow rat snake				Non-wetland	
Eumeces inexpectatus	Southeastern five-lined skink				Non-wetland	
Farancia abacura	Mud snake				Wetland	
Gopherus polyphemus	Gopher tortoise		SSC	C2	Non-wetland	
Kinosternon baurii	Striped mud turtle				Wetland	
Lampropeltis getula floridana	Florida kingsnake				Wetland	
Nerodia fasciata	Florida water snake				Wetland	
Nerodia floridana	Florida green water snake				Wetland	
Nerodia taxispilota	Brown water snake				Wetland	
Opheodrys aetivus	Rough green snake				Non-wetland	
Ophisaurus compressus	Island glass lizard			C2	Non-wetland	
Pseudemys floridana	Peninsula cooter				Wetland	
Pseudemys nelsoni	Florida redbelly turtle				Wetland	
Regina alleni	Striped crayfish snake				Wetland	
Terrapene carolina bauri	Florida box turtle				Wetland	
Thamnophis sauritus	Peninsula ribbon snake				Wetland	
Thamnophis sirtalis	Eastern garter snake				Wetland	
Birds						
Agelaius phoeniceus	Red-winged blackbird				Wetland	Resident
Ajaia ajaia	Roseate spoonbill		SSC		Wetland	Resident
Anas fulvigula	Mottled duck				Wetland	Resident
Anhinga anhinga	Anhinga				Wetland	Resident

Scientific Name	Common Name	Status	GFC	FWS	Habitat Association	Season
Archilochus colubris	Rubythroated hummingbird				Non-wetland	Winter
Ardea herodias	Great blue heron				Wetland	Resident
Bubulcus ibis	Cattle egret				Non-wetland	Resident
Buteo jamaicensis	Red-tailed hawk				Non-wetland	Resident
Buteo lineatus	Red-shouldered hawk				Non-wetland	Resident
Buteo regalis	Swainson's hawk				Non-wetland	Winter
Butorides striatus	Green heron				Wetland	Resident
Cairina moschata	Muscovy	Non-native			Wetland	Resident
Capella gallinago	Common snipe				Wetland	Winter
Cardinalis cardinalis	Northern cardinal				Non-wetland	Resident
Casmerodius albus	Great egret				Wetland	Resident
Cathartes aura	Turkey vulture				Non-wetland	Resident
Catharus guttatus	Hermit thrush				Non-wetland	Winter
Catoptrophorus semipalmatus	Willet				Wetland	Winter
Charadrius vociferus	Killdeer				Non-wetland	Resident
Chordeiles minor	Common nighthawk				Non-wetland	Resident
Circus cyaneus	Northern harrier				Wetland	Winter
Cistothorus palustris	Marsh wren				Wetland	Winter
Colaptes auratus	Northern flicker				Non-wetland	Resident
Colinus virginianus	Bobwhite quail				Non-wetland	Resident
Columbina passerina	Ground dove				Non-wetland	Resident
Coragyps atratus	Black vulture				Non-wetland	Resident
Cyanocitta cristata	Bluejay				Non-wetland	Resident
Dendroica coronata	Yellow rumped warbler				Non-wetland	Winter
Dendroica nigrescens	Black throated green warbler				Non-wetland	Winter
Dendroica caerulescens	Black throated blue warbler				Non-wetland	Winter
Dendroica discolor	Prairie warbler				Wetland	Resident

Scientific Name	Common Name	Status	GFC	FWS	Habitat Association	Season
Dendroica palmarum	Palm warbler				Non-wetland	Winter
Dendroica striata	Blackpoll warbler				Non-wetland	Transient
Dendroica tigrina	Cape may warbler				Non-wetland	Winter
Dryocopus pileatus	Pileated woodpecker				Non-wetland	Resident
Dumetella carolinensis	Gray catbird				Non-wetland	Winter
Egretta thula	Snowy egret		SSC		Wetland	Resident
Eudocimus albus	White ibis		SSC		Wetland	Resident
Falco columbarius	Merlin				Independent	Winter
Falco sparverius	American kestrel				Non-wetland	Winter
Florida caerulea	Little blue heron		SSC		Wetland	Resident
Fulica americana	American coot				Wetland	Resident
Gallinula chloropus	Common moorhen				Wetland	Resident
Geothlypis trichas	Common yellowthroat				Wetland	Resident
Himantopus mexicanus	Black necked stilt				Wetland	Resident
Hirundo rustica	Barn swallow				Non-wetland	Transient
Hydranassa tricolor	Tricolor heron		SSC		Wetland	Resident
Icteria virens	Yellowbreasted chat				Non-wetland	Resident
Lanius ludovicianus	Loggerhead shrike			C2	Non-wetland	Winter
Lophodytes cucullatus	Hooded merganser				Wetland	Winter
Megaceryle alcyon	Belted kingfisher				Wetland	Winter
Melanerpes carolinus	Red-bellied woodpecker				Non-wetland	Resident
Melosdittacus undulatus	Budgegriar	Non-native			Non-wetland	Resident
Melospiza georgiana	Swamp sparrow				Wetland	Winter
Mimus polyglottos	Northern mockingbird				Non-wetland	Resident
Mniotilta varia	Black white warbler				Non-wetland	Winter
Mycteria americana	Wood stork		E	E	Wetland	Resident
Myiarchus crinitus	Great crested flycatcher				Non-wetland	Resident

Scientific Name	Common Name	Status	GFC	FWS	Habitat Association	Season
Nyctanassa violacea	Yellow crowned night heron				Wetland	Resident
Nycticorax nycticorax	Black crowned night heron				Wetland	Resident
Pandion haliaetus	Osprey				Wetland	Resident
Parula americana	Northern parula warbler				Non-wetland	Winter
Passerculus sandwichensis	Savannah sparrow				Wetland	Winter
Phalacrocorax auritus	Double crested cormorant				Wetland	Resident
Picoides pubescens	Downy woodpecker				Non-wetland	Resident
Piranga rubra	Summer tanager				Non-wetland	Transient
Pipilo erythrophthalmus	Rufous-sided towhee				Non-wetland	Resident
Plegadis falcinellus	Glossy ibis				Wetland	Resident
Podilymbus podiceps	Pied billed grebe				Wetland	Resident
Polioptila caerulea	Blue-gray gnatcatcher				Non-wetland	Winter
Prothonotaria citrea	Prothonotary warbler				Non-wetland	Transient
Quiscalus major	Boat tailed grackle				Wetland	Resident
Quiscalus quiscula	Common grackle				Non-wetland	Resident
Rallus elegans	King rail				Wetland	Resident
Sayornis phoebe	Eastern phoebe				Non-wetland	Winter
Seiurus aurocapillus	Ovenbird				Non-wetland	Winter
Setophaga ruticilla	American redstart				Non-wetland	Winter
Sphyrapicus varius	Yellow-bellied sapsucker				Non-wetland	Winter
Sterna albifrons	Least tern		T		Wetland	Summer
Streptopelia decaocto	Eurasian collared-dove	Non-native			Non-wetland	Resident
Sturnella magna	Eastern meadowlark				Wetland	Resident
Sturnus vulgaris	European starling	Non-native			Non-wetland	Resident
Thryothorus ludovicianus	Carolina wren				Non-wetland	Resident
Tringa flavipes	Lesser yellowlegs				Wetland	Winter
Tringa melanoleuca	Greater yellowlegs				Wetland	Winter

Scientific Name	Common Name	Status	GFC	FWS	Habitat Association	Season
Troglodytes aedon	House wren				Non-wetland	Winter
Turdus migratorius	American robin				Non-wetland	Winter
Tyrannus tyrannus	Eastern kingbird				Non-wetland	Resident
Tyrannus verticalis	Western kingbird				Non-wetland	Winter
Vireo griseus	White eye vireo				Non-wetland	Resident
Vireo philadelphicus	Philadelphia vireo				Non-wetland	Transient
Zenaida macroura	Mourning dove				Non-wetland	Resident
Mammals						
Blarina carolinensis	Southern short-tailed shrew				Non-wetland	
Canis familiaris	Domestic dog	Non-native			Non-wetland	
Dasypus novemcinctus	Nine-banded armadillo	Non-native			Non-wetland	
Didelphis virginiana	Virginia opossum				Non-wetland	
Felis domesticus	Domestic cat	Non-native			Non-wetland	
Felis rufus	Bobcat				Non-wetland	
Lutra canadensis	River otter				Wetland	
Mus musculus	House mouse	Non-native			Non-wetland	
Odocoileus virginianus	White-tailed deer				Non-wetland	
Oryzomys palustris	Marsh rice rat				Wetland	
Peromyscus gossypinus	Cotton mouse				Non-wetland	
Procyon lotor	Raccoon				Non-wetland	
Rattus rattus	Black rat	Non-native			Non-wetland	
Sigmodon hispidus	Hispid cotton rat				Non-wetland	
Sylvilagus palustris	Marsh rabbit				Wetland	
Urocyon cinereoargenteus	Gray fox				Non-wetland	

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