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MANAGEMENT OF BIRD STRIKE HAZARDS AT AIRPORTS: A HABITAT APPROACH

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ABSTRACT

Management of bird strike hazards is costly and time consuming, yet effectiveness is limited to special circumstances and short intervals. The best opportunities for developing robust approaches to management must be built on a careful integration of the needs of air operations with the biological factors regulating the interaction of bird populations and the airport environment. This project examined bird associations at an airport (ACY) typical of north-eastern USA. Our goals were to: (1) identify bird strike hazards; (2) understand their biological basis; and (3) develop management approaches specific to ACY while holding the potential for application at a regional level.

ACY provides unique and attractive habitats that support a diverse avian community of at least 127 species. Breeding Laughing Gulls (*Larus atricilla*) caused the greatest bird strike hazard because their high numbers occurred over the short interval when they provisioned young in colonies 18 k away. Gulls at ACY foraged for insects (60-80% of diet), mainly Japanese beetles (*Popillia japonica*). Foraging opportunities provided mainly by abundant Japanese beetles were the primary attractant for Laughing Gulls at ACY. This occurred because emergence of Japanese beetles coincided with the period of peak food demand by nestlings. We are developing a management approach for Laughing Gulls based on reducing the foods that attract them to ACY - Japanese beetles. Our approach modifies habitats to reduce availability of plant species required by Japanese beetles for growth and reproduction.

Keywords: Laughing Gull, habitat modification, Japanese beetle

1. INTRODUCTION

Each year collisions of aircraft with birds cause millions of dollars in damage and in some instances loss of human lives. The threat of bird strikes can also result in troublesome and expensive disruptions in air service when air operations must be stopped or curtailed because of high bird activity. The natural appeal of airports with large open areas suitable for foraging and loafing can be a compelling attractant for many bird species. However, birds have proven very resistant to most efforts directed at removing or relocating them from hazardous areas.

Current management approaches are costly, time consuming, and often require highly trained technicians. Techniques such as harassment and scare tactics are generally effective only under very special circumstances and only over very short intervals. Furthermore, development of better management strategies is often complicated when bird problems are influenced by factors operating on a scale much larger than the immediate airport environment.

Land use patterns well beyond airport boundaries can have a direct impact on the magnitude of bird strike hazards. Dispersion of highly mobile birds like gulls is often influenced by regional landscape features, with local habitat patches at or near airports far less important. As a result, the best opportunity for developing robust approaches for the management of bird hazards requires an understanding of the biological basis for the association of birds with the airport. This broad approach leads naturally to a consideration of the regional factors influencing avian pest populations. The best management techniques carefully integrate the needs of air operations with the biological factors regulating the interaction of bird populations and the airport environment.

We undertook a 3 year research project at Atlantic City International Airport (ACY) in Pomona, New Jersey, USA in an effort to develop robust approaches to managing bird problems that would be broadly applicable on a regional basis. We had 3 specific goals: (1) identify bird strike hazards at the airport; (2) understand the biological basis for the most important problems; and (3) develop management approaches that address the specific needs of ACY while holding the potential for broad application at airports across the northeastern region of the USA.

2. METHODS

2.1. Bird Surveys at ACY and at Off-Airport Control Sites.

We estimated species composition and populations sizes for birds at and near ACY by conducting regular surveys from June 1991 when this study began through 1 September 1993. Our bird surveys were based on a modified variable circular-plot method (Reynolds et al. 1980. A variable circular-plot method for estimating bird numbers. Condor 82:309-313). This technique not only estimates numbers of birds, but by recording the distance from a fixed point to each observation it also provides an estimate of bird density. In 1991 we established a series of 23 survey sites (a 24th site was added in 1992) on and near the operations area at ACY. All survey sites were visited in sequence, alternating starting sites with each successive survey.

2.2 Color-marking Laughing Gulls.

We color-marked about 2,000 Laughing Gulls in each of 2 years (1991, 1992) at nesting colonies located on salt marshes off the Atlantic Coast approximately 18 km east of ACY. We marked gulls with rhodamine-B, a dye that produces a bright pink color on the gulls' white feathers. Our dye-mixture consisted of Vaseline brand petroleum jelly mixed with 5% of rhodamine-B by weight. We located nests with eggs and placed approximately 0.5 to 1.0 ml of the Vaseline-dye mixture in the nest. When adult Laughing Gulls returned to incubate their eggs the dye-mixture was transferred to the feathers of their breast and abdomen. When wet, the dye dissolved and produced a bright pink stain on the feathers. We located the marked birds by searching during our regular bird surveys and by soliciting aid from the public.

2.3. Nesting Chronology of Laughing Gulls.

We monitored the breeding and nesting status of Laughing Gulls at 2 colony sites on the coastal salt marshes located 15-20 km east of ACY. Both colonies were in areas dominated by *Spartina alterniflora* at the lower elevations and *Spartina patens* at higher elevations. They were subjected to flooding of 5-15 cm at high tides depending on elevation and moon phase. Before the onset of egg laying we erected an observation blind at each site and marked nests with individually numbered survey flags. We visited the colony two to five times per week throughout the nesting season and conducted surveys within our study areas. During these surveys we counted the number of eggs in each marked nest, and monitored the hatching, development, and fledging of chicks. In addition to these individually marked nests we conducted general surveys of the study areas to monitor nesting chronology and estimate the total number of nests.

2.4 Diet of Laughing Gulls.

Studies of Laughing Gull diet were based on specimens we obtained from the Bird Hazard Reduction Force (USDA/APHIS) which maintains a dawn to dusk vigil (June -mid August) to remove by shooting any Laughing Gulls posing a hazard to air operations at ACY. Our sample consisted of 748 birds in 1991, and 642 in 1992.

Birds were frozen soon after collection and subsequently processed. Specimens were aged on the basis of plumage, sexed, weighed and the stomach and complete esophagus were removed and preserved in 70% alcohol for later analysis. Stomach contents were separated into arthropods (non marine), foods of marine origin (mainly fish and crustaceans), fruit (mainly blueberries), anthropogenic, digested material (mainly unidentified insect fragments) and other. The volume of each category was determined by water displacement.

Arthropods were separated into individual taxa and counted. Biomass estimates were based on samples of individual insects (5-20 individuals) from the 23 most common taxa which were obtained from a representative series of stomachs. We also developed an estimate of biomass in the less abundant taxa. We separated all arthropods, other than the 23 common taxa, from a different series of 10 stomachs. These were combined to provide a single estimate of average biomass for the uncommon taxa. Samples were dried to constant weight and weighed. Mean weight per individual insect was used to construct an index to biomass for each common taxa. The collective sample was used to estimate an index to biomass per insect for each of the remaining taxa. We used the same collective estimate for all the uncommon taxa (<5 % total biomass). The index was calculated as the number of insects recovered per stomach times the mean dry weight for the respective taxon (or the collective sample for the uncommon taxa). This value we took to be proportional to the energetic contribution of each respective taxon, minimizing the effect of vastly different body sizes when only counts are used to evaluate diet composition.

2.5. Population Dynamics Of Japanese Beetles.

In 1992 we established two study areas at ACY where we conducted several experiments on the management of Japanese beetles (*Popillia japonica*) through habitat manipulation. Both sites contained two cover types: grass dominated and mixed-oak scrub. We established 4 plots at each site consisting of an experimental and control plot for each cover type. At site A the grass plot was 1.20 ha and the mixed-oak scrub plot was 3.35h. At site B the grass plot was 8.18 ha and the mixed-oak scrub plot was 1.12 ha. At both sites adjacent areas of similar size and cover type served as controls. The treatment we applied to our experimental plots was a regime of frequent mowing (once per month) designed to discourage or eliminate plant species favored by adult Japanese beetles for foraging. The adjacent control plots were mowed at the same intervals normally employed by grounds maintenance operations at the airport (mowing grass at 6-10 wk intervals; mowing once per year in mixed-oak scrub).

We used the line intercept method to estimate plant species composition in each of our experimental plots. Each of 4 transects was 30.5 m long, and all were radially arranged (90° intervals) from a center point. Plant species were identified at 100 evenly spaced locations along each transect.

To determine foraging substrate preferences for Japanese beetles, we performed surveys (between 0900 and 1200 hrs) within the experimental and control plots twice a week from 9 July to 27 August 1992, and three times a week from 28 June to 30 August 1993. Surveys within each plot consisted of 4 transects (72 meters long) begun at randomly determined locations. We walked each transect pushing a measuring wheel with a meter stick attached perpendicularly to the direction of travel. We searched the area subtended by the meter stick as the transect was walked. We counted all beetles we encountered, recording their activity (foraging, mating, loafing) and the plant species they were on.

3. RESULTS AND DISCUSSION

3.1. What Bird Species Are Present at ACY?

From June 1991 to September 1993 we conducted 5,093 individual bird surveys distributed among our 25 survey sites at ACY. In the course of these surveys we encountered a total of 127 bird species. Among these were two species on the New Jersey list of Endangered and Threatened Wildlife (Upland Sandpiper, *Bartramia longicauda*; Grasshopper Sparrow, *Ammodramus savannarum*). In summer the 4 most abundant species at ACY were the European Starling, Laughing Gull, Eastern Meadowlark, and American Crow - all potentially serious bird strike hazards (Figure 1, Table 1). In winter the Canada Goose became the fourth most common species at ACY (Figure 1, inset). Laughing Gulls declined in winter because they migrate south in winter.

Laughing Gulls were only the second most abundant species, overall, at ACY, but they clearly posed the greatest threat to air safety. This was because their numbers were concentrated into a relatively short time interval. In each year of our study we recorded the largest numbers of Laughing Gulls within the 7-week interval from the first week in June through mid July (Figure 2). In 1992 there was an apparent influx of gulls in late May, but this early peak was only a sampling artifact. On the day of our only survey in that week a storm front came through the area bringing a temporary influx of gulls to the airport. More typically, there was little Laughing Gull activity at the airport until early to mid June and by August gull numbers were again low.

3.2 Laughing Gull Movements between Nesting Colonies and ACY.

Nesting colonies for Laughing Gulls were located 15-20 km east of ACY on coastal salt marshes. We suspected that the birds appearing at ACY were coming from these sites so we undertook a color marking study to identify movement patterns for these birds.

Our color-marking in 1991 provided our first indication that breeding Laughing Gulls from coastal colonies moved inland to forage. By September 1991 we had conducted 52 surveys which along with sightings from the public resulted in a total of 35 sightings of color-marked birds. Most sightings were from the Atlantic County area, but 1 came from John F. Kennedy International Airport 145 km north. At ACY there were 18 color-marked Laughing Gulls shot as part of the Bird Hazard Reduction Project. This is over half of the color-marked birds spotted, suggesting that a fairly high percentage of the birds from the colonies traveled to ACY.

In 1992 we had 119 sightings of color-marked Laughing Gulls. Most were in Atlantic County and Long Beach Island within 10 to 15 km from the colony (Figure 3). The frequency of observations of color-marked Laughing Gulls seen during regular surveys was greatest 6-11 km from the colony. The mean distance flown was 16.0 km and the modal distance was 8.3 km. We had sightings as far as 24.2 km directly inland and 45.1 kilometers out over the Atlantic Ocean (from a fishing boat). The Bird Hazard Reduction Force at ACY shot 10 Laughing Gulls in 1992 that we had color-marked. Overall our results from color-marking and banding demonstrated that ACY is well within the typical foraging range of Laughing Gulls nesting at the coastal colonies, and showed that nesting birds from nearby colonies were the main cause of Laughing Gull problem at ACY.

3.4 Laughing Gull Nesting Chronology.

Population dynamics of Laughing Gulls at ACY was closely linked to their nesting chronology at the colonies. The increase in abundance of Laughing Gulls visiting the airport followed a nearly identical increase in the proportion of Laughing Gull eggs hatching at the coastal colonies (Figure 2). Similarly, as the proportion of young remaining in the colony declined, the number of Laughing Gulls at ACY also declined. Thus, when food demands of young in the nests began to increase the number of Laughing Gulls at ACY increased, and as food demands declined when the young fledged the number of gulls at ACY also declined.

3.5 Laughing Gull Behavior at ACY.

We recorded five major types of Laughing Gull behavior during our general avian population surveys at ACY. Three of these behaviors are directly associated with active foraging. Foraging behavior included observed feeding (e.g., hawking insects, searching on the ground) as well as low and medium flight. Similarly, we considered loafing birds to have recently fed. High flying birds mainly represented transient birds moving past or out of the area.

For all 3 years, behaviors associated with foraging increased during June and early July (Figure 4). This period coincided with the time when most young were present in the colonies, and, therefore, represented a period when food demands of young in the colony were highest.

3.6 Diet of Laughing Gulls from ACY.

We analyzed stomach contents by volume for the 4 major components: arthropods (mainly insects), fruit (mainly blueberries), marine (mainly fish and crustaceans), and anthropogenic foods (e.g., french fries, fried chicken). Overall, insects made up the largest portion of the diet in both years (Figure 5). However, we did find some notable differences. In 1991, gulls took more than twice as much fruit as they did in 1992, while marine foods were nearly absent from the diet in 1991. The contribution of anthropogenic foods to the diet was similar in both years.

Japanese beetles were the most important food item in the diet of Laughing Gulls from ACY (Figure 6). In 1991 they contributed about 3 times as much biomass to the diet as oriental beetle (Scarabaeidae), dung beetle (Scarabaeidae) and ants (Formicidae). In 1992 Japanese beetles were about 3 times more abundant than ants and nearly 8 times more abundant than the next most common beetle (oriental beetle). Stink bugs (Pentatomidae) and dung beetles (Scarabaeidae) were important in 1991, but neither contributed much to the diet in 1992.

Japanese beetles played a uniquely important role in the diet of Laughing Gulls at ACY because they become available as food just when foraging demands were greatest for breeding gulls. In the years we measured Japanese beetle abundance at ACY (1992 and 1993) the period of beetle emergence closely coincided with the period when nestling Laughing Gulls were being fed in nests at the colonies (Figure 2). At this time foraging demands on breeding Laughing Gulls were highest, and emerging Japanese beetles represented a very attractive food at a critical period for the gulls. These observations are consistent with our hypothesis that Laughing Gulls forage at the airport mainly to secure insects to feed their developing young in nearby nesting colonies.

3.7 Ecological Relationships Of Japanese Beetles At ACY.

The importance of Japanese beetles as an inland food source for Laughing Gulls at ACY lead us to undertake a series of studies to understand the factors influencing the size and distribution of Japanese beetle populations at ACY. With this information we hoped to devise management strategies based on habitat manipulations that would effectively reduce population sizes of Japanese beetles at ACY without use of any chemical control agents.

Chemicals could not be used at ACY because a residential water supply in the form of a large open reservoir is within the ACY boundaries. Furthermore, use of chemicals would require annual treatments while a management strategy based on habitat modification held promise of a permanent solution based on rather minor maintenance activities.

Japanese beetles select oviposition sites in grass dominated areas where their larva feed primarily on subterranean grass roots through most of the year (July - June). At ACY the areas around structures and the air movement area are maintained in grass providing ample oviposition habitat. Japanese beetle adults emerge in June, the females mate, and then they must feed on the foliage of a select variety of plants in order to produce eggs. Most of the plants they rely on are woody perennials that are abundant in the mixed-oak scrub habitats at ACY. Japanese beetle move alternately between grass they emerge and subsequently deposit eggs and the mixed-oak scrub habitats where they feed.

Experimental Design. - We undertook a series of field evaluations and experiments to determine the potential for managing Japanese beetle populations in and near the air movement area at ACY. Our objective was to provide long term efficacy with a minimal amount of maintenance and without the use of chemical control agents. Our approach was based the habitat modifications that removed the food plants adult Japanese beetles need for successful reproduction. Our specific goals were to: (1) determine the species of host plants used by Japanese beetles at ACY, (2) determine the effect of host plant removal on population dispersion of Japanese beetle, (3) develop a practical technique for host plant removal, and (4) evaluate the effect of diminished numbers of Japanese beetle on the attractiveness of ACY to Laughing Gulls.

We established two study sites each of which included four plots: (1) experimental grass, (2) control grass, (3) experimental mixed-oak scrub, and (4) control mixed-oak scrub. We mowed the experimental plots at approximately monthly intervals throughout the growing season and left the control plots to normal maintenance practices at the airport (mowing grass at 6-10 wk intervals; mowing once per year in mixed-oak scrub). Our short term goal was to evaluate the effect of increased mowing on the dispersion of Japanese beetles and our long term goal was to evaluate the effect of frequent mowing on vegetation composition.

Foraging Substrate Use by Adult Japanese Beetles at ACY, 1992. - We found differences in substrate utilization by Japanese beetle adults between grass habitats and mixed-oak scrub habitats (Figure 7). In the grass häbitats Japanese beetles were found on slender bush clover (*Lespedeza hirta*) most often, followed by grape (*Vitis labrusca*). The other taxa were either used infrequently as substrates (e.g., grass) or were used while in transit to somewhere else (e.g., airborne).

We found Japanese beetles on more plant species in the mixed-oak scrub habitats. Sassafras (*Sassafras albidum*) was used most often, followed by grape, oak (*Quercus spp.*), and cherry (*Prunus spp.*). We also found them on bracken fern (*Pteridium aqullinum*), sumac (*Rhus spp.*), and grass, but these plants probably were not important food sources.

The large differences between availability of plant species and utilization suggests that Japanese beetles were showing strong preferences for some of the plant species. For example, in the mixed grass habitats slender bush clover made up at most 13% of the plant cover, but 77% of all Japanese beetles found in grass habitats were on this species.

Similarly, in the mixed-oak scrub areas sassafras made up only about 8% of the plant cover, but nearly 60% of the beetles were on that species.

Effect of Frequent Mowing on Vegetation Composition. - We compared vegetation composition between experimental and control areas in September 1993. This was after two years of frequent mowing on the experimental plots. We found significant differences between experimental and control plots for both grass and mixed-oak scrub habitats (X^2 = 194.63, df = 11, $p < 0.0001$). This indicated that the mowing treatments resulted in changes in vegetation composition between the experimental and control plots. We examined these changes by calculating the differences in percent plant cover (experimental - control) for each of the major plant categories (Figure 8). In the experimental mixed-oak scrub plots, grass/sege, and bare ground increased in area as a result of mowing while rubus, oaks, sassafras, and legumes decreased. In the grass plots there was a small increase in the other herbs and legumes categories, while the slender bush clover category decreased. The remaining categories in the grass plots were essentially unchanged as a result of the mowing treatments. In both the grass and mixed-oak scrub areas the mowing treatments resulted in decreases in the plants preferred by Japanese beetles.

3.8 Management of Japanese Beetles by Habitat Modification.

Japanese beetles must feed as adults to produce a full complement of eggs. In contrast many scarabs (e.g., oriental beetle) do little or no feeding as adults. ACY provides near optimal habitat for Japanese beetle growth and reproduction because the large grass dominated areas are available for mating, oviposition, and grub development while the mixed-oak scrub areas provide plants that meet the foraging requirements of adult beetles. In 1993 we completed the second year of a study designed to test the hypothesis that removal of plants used most often as forage by adult beetles would reduce Japanese beetle populations at ACY. Above we provided results showing that mowing reduces abundance of the plants most preferred by adult Japanese beetles. Below we report results showing that in these same experimental plots abundance of Japanese beetles declined as a result of the habitat manipulations we employed.

In 1992 and 1993 we regularly performed transects in our experimental and control plots to measure the abundance of Japanese beetles. We transformed our data before analysis (square root of the beetle density per transect plus 0.5) because zero densities occurred on some transects, particularly early and late in the season in the season when beetles were uncommon. For both years the results of the ANOVA's were significant for the experimental treatment (1992 - F = 16.82, df = 3/31, $p < 0.0001$; 1993 - F = 28.19, df = 3/43, $p < 0.0001$), weeks 1992 - F = 7.92, df = 7/31, $p < 0.0001$; 1993 - F = 4.46, df = 10/43, $p < 0.0001$) and the week by treatment interaction (1992 - F = 3.92, df = 21/31, $p < 0.0001$; 1993 - F = 3.39, df = 30/43, $p < 0.0001$). The significant week-by-treatment interaction terms required that we examine effects independently among weeks (Figure 9). Significance among each treatment within individual weeks is indicated at the top of Figure 9. We used Tukey's test to compare means when within week ANOVA's were significant.

For 1992 the pattern in our results suggest a movement of beetles from the grass areas were they emerged to the mixed-oak scrub areas where most feeding occurred. In the week of 16 July most beetles were in the grass areas. In the following week numbers of beetles in the

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control mixed-oak scrub increased as beetles moved to feed in these areas. Numbers of beetles in the control mixed-oak scrub were very high in the week of 30 July, but because of high variability we were unable to detect significance among treatments. In each of the succeeding 3 weeks we found significant treatment effects with numbers of beetles in the control mixed-oak scrub highest of the four treatments. In the final week numbers of beetles collapsed as the season ended and again we found no significant treatment effect.

With an increased sample size in 1993 we were able to show significant differences between treatments within more individual weeks over the course of the season (Figure 9). Our results for 1993 show significant treatment effects as early as the week of 3 July with more beetles found in the control mixed-oak scrub. Numbers of beetles in the control and experimental grass also increased slightly during this week. However, beetle numbers in the experimental grass remained consistently low throughout the season. We found no significant difference between treatments for the week of 10 July. Then, as in 1992, the pattern of our results suggested movement of beetles from the grass to the control mixed-oak scrub. During the week of 17 July beetle numbers in the control grass crashed and remained low throughout the remainder of the season, whereas numbers of beetles in the control mixed-oak scrub continued to increase and to show significant treatment effects. In each of the succeeding four weeks we found beetle numbers to be significantly higher in the control mixed-oak scrub when compared to our other treatments. As the season ended we found no significant differences between treatments for the final three weeks of our survey period.

It is noteworthy that although the patterns in both 1992 and 1993 are very similar, the peak differences between control and experimental areas in 1992 developed approximately two weeks later than in 1993. This occurred because of a two week delay in emergence of adult Japanese beetles due to lower average temperatures in the spring and early summer of 1992.

There are several conclusions that may be drawn from this experiment. (1) Frequent mowing results in a decline in the favored food plants of adult Japanese beetles. (2) Japanese beetles migrate from grass areas where they emerge (few food plants are available) to unmowed mixed-oak scrub areas where food plants are abundant. (3) Numbers of beetles in frequently mowed grass and frequently mowed mixed-oak scrub areas are lower than in either control area. Together these results provide a strong indication that Japanese beetle numbers can be reduced through habitat manipulations based on changes in the vegetation available to adult beetles.

4. CONCLUSIONS

Atlantic City International Airport supports a rather rich and diverse avian community. Such diversity is surprising considering that ACY is located in the midst of the New Jersey Pine Barrens, an area generally without rich and complex avian communities. Nonetheless, most of the species we found at ACY are present in similar habitats beyond the airport boundary. The airport habitats also supported relatively large populations of two species on the New Jersey list of Endangered and Threatened Wildlife (Upland Sandpiper and Grasshopper Sparrow) indicating that the habitats at ACY represent a valuable resource that can be successfully exploited by species that do not interfere with air operations.

Our observations of Laughing Gull numbers at ACY, combined with their diet, and behavior strongly suggested that the most prevalent bird strike hazards are caused by Laughing Gulls. The worst problems occurred when abundant insect foods (mainly Japanese beetles) became available at precisely the same time foraging demands peaked for breeding gulls feeding young in distant nesting colonies. There was a variety of insects at ACY that may on occasion be sufficiently abundant to attract Laughing Gulls to ACY, yet Japanese beetles were uniquely suited to the foraging needs of breeding Laughing Gulls. Characteristics of Japanese beetles leading to their easy exploitation by Laughing Gulls include: (1) emergence of adult beetles during the nestling period for Laughing Gulls, (2) a diurnal activity cycle (most other scarab beetles are nocturnal), (3) a highly synchronous emergence resulting in the rapid development of peak populations, and (4) dependence on 2 plant cover types widely available at ACY (managed grass and mixed-oak scrub) allowing for the maintenance of large populations that can on occasion grow to "outbreak" proportions.

Our approach to managing the Laughing Gull problem at ACY is based on habitat modifications designed to lower the abundance of the main insect foods that attract the Laughing Gulls - Japanese beetles. Our management strategies are based on habitat manipulations that reduce the availability of plants on which the adult beetles feed. We have conducted experiments that: (1) identify which plants at ACY Japanese beetles require, (2) show mowing reduces abundance of the plants beetles require, and (3) show mowed areas sustain few beetles. Our results suggest that removal of the forage plants used by Japanese beetles will have a significant depressing effect on the abundance of beetles at ACY.

We have only indirect evidence that a reduction in Japanese beetle abundance will result in a decrease in the use of ACY by breeding Laughing Gulls. Our evidence comes from the observation that sustained high numbers of Laughing Gulls occur only during periods of Japanese beetle emergence. It remains to be shown whether, in the absence of Japanese beetles, the other insect foods available at ACY will prove sufficient to attract large numbers of breeding Laughing Gulls in June and July. Such direct evidence can only come from a sustained management program for Japanese beetles maintained over many years.

Table 1. Scien

American Crow
American Gold
American Kestr
American Robi
Barn Swallow
Black-bellied P
Blue Jay
Brown Thrashe
Brown-headed
Bufflehead
Canada Goose
Carolina Chick
Chipping Sparr
Common Grac
Common Yello
Double-crested
Eastern Bluebi
Eastern Kingbi
Eastern Meado
European Starl
Field Sparrow
Grasshopper S
Gray Catbird
Herring Gull
Hooded Merga
Horned Lark
Killdeer
Laughing Gull
Lesser Snow G
Mourning Dove
Northern Bobw
Northern Mocki
Red-tailed Haw
Red-winged Bl
Ring-billed Gull
Rock Dove
Rufous-sided T
Savannah Spa
Tree Swallow
Upland Sandpi

Table 1. Scientific and common names for birds appearing in Figure 1.

American Crow	*Corvus brachyrhyncos*
American Goldfinch	*Carduelis tristis*
American Kestrel	*Falco sparverius*
American Robin	*Turdus migratorius*
Barn Swallow	*Hirundo rustica*
Black-bellied Plover	*Pluvialis squatarola*
Blue Jay	*Cyanositta cristata*
Brown Thrasher	*Toxostoma rufum*
Brown-headed Cowbird	*Molothrus ater*
Bufflehead	*Bucephala albeola*
Canada Goose	*Branta canadensis*
Carolina Chickadee	*Parus carolinensis*
Chipping Sparrow	*Spizella passerina*
Common Grackle	*Quiscalus quiscula*
Common Yellowthroat	*Geothlypis trichas*
Double-crested Cormorant	*Phalacrocorax auritus*
Eastern Bluebird	*Sialia sialis*
Eastern Kingbird	*Tyrannus tyrannus*
Eastern Meadowlark	*Sturnella magna*
European Starling	*Sturnus vulgaris*
Field Sparrow	*Spizella pusilla*
Grasshopper Sparrow	*Ammodramus savannarum*
Gray Catbird	*Dumetalla carolinensis*
Herring Gull	*Larus argentatus*
Hooded Merganser	*Lophodytes cucullatus*
Horned Lark	*Eremophila alpestris*
Killdeer	*Charadrius vociferus*
Laughing Gull	*Larus atricilla*
Lesser Snow Goose	*Chen caerulescens*
Mourning Dove	*Zenaida macroura*
Northern Bobwhite	*Colinus virginianus*
Northern Mockingbird	*Mimus polyglottos*
Red-tailed Hawk	*Buteo jamaicensis*
Red-winged Blackbird	*Agelaius phoeniceus*
Ring-billed Gull	*Larus delawarensis*
Rock Dove	*Columba livia*
Rufous-sided Towhee	*Pipilo erythrophthalmus*
Savannah Sparrow	*Passerculus sandwichensis*
Tree Swallow	*Tachycineta bicolor*
Upland Sandpiper	*Bartramia longicauda*

FIGURE LEGENDS

Figure 1. The 30 most abundant species (mean number of birds/survey) encountered at ACY. Means are based on all surveys conducted at all survey sites during the summer (4 June - 9 September 1991, 7 May - 7 October 1992, and 21 May - 1 September 1993, n=2920). Inset shows abundance for the 30 most abundant species encountered at ACY during the fall, winter and spring (10 September 1991 - 6 May 1992 and 8 October 1992 to 20 May 1993, n=2173).

Figure 2. Seasonal patterns in abundance of Laughing Gulls and Japanese beetles in 1992 and 1993. Top graphs are mean densities of Laughing Gulls per biweek at ACY. Middle graphs show nesting chronology of Laughing Gulls at nesting colonies based on percent eggs hatched and percent of fledglings remaining at the colony. Bottom graphs are mean densities of Japanese beetles per biweek at ACY.

Figure 3. Distance from the nesting colony of colored-marked Laughing Gulls observed in 1992. Insert indicates number of survey points relative to number of gull observations.

Figure 4. Mean percent of Laughing Gulls at ACY engaged in foraging behaviors, non-foraging behaviors, and in transit. Study ran 3 June 1991 through 1 September 1993.

Figure 5. Diet composition (percent volume) of major food categories for Laughing Gulls from ACY.

Figure 6. Contribution of major arthropod taxa (index to biomass) to the diet of Laughing Gulls at ACY.

Figure 7. Foraging substrate of adult Japanese beetles in grass habitats and mixed-oak scrub habitats at ACY, 1992.

Figure 8. A comparison in abundance of plant taxa between experimental and control plots at the Japanese beetle study sites, September 1993. Values are calculated as difference in abundance between control and experimental plots. Histograms to the right indicate a relative increase in abundance and to the left, a decrease.

Figure 9. Weekly densities of Japanese beetle populations in the experimental and control plots, 1992 and 1993. Symbols above figures represent within week significance as determined by ANOVAs, ** $p<0.01$, ns = not significant.

FIGURE 1. The 30 Most Abundant Species Encountered at ACY.

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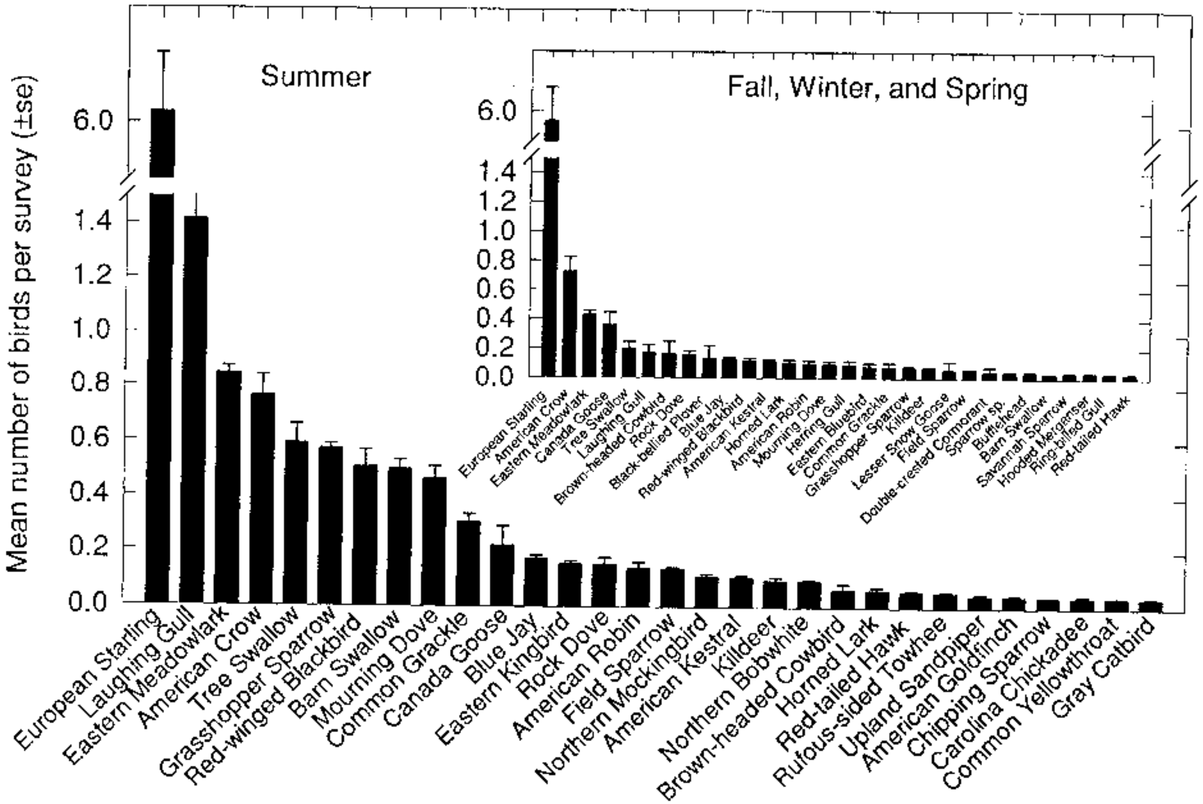

FIGURE 2. Seasonal Patterns in Abundance of Laughing Gulls and Japanese Beetles at ACY.

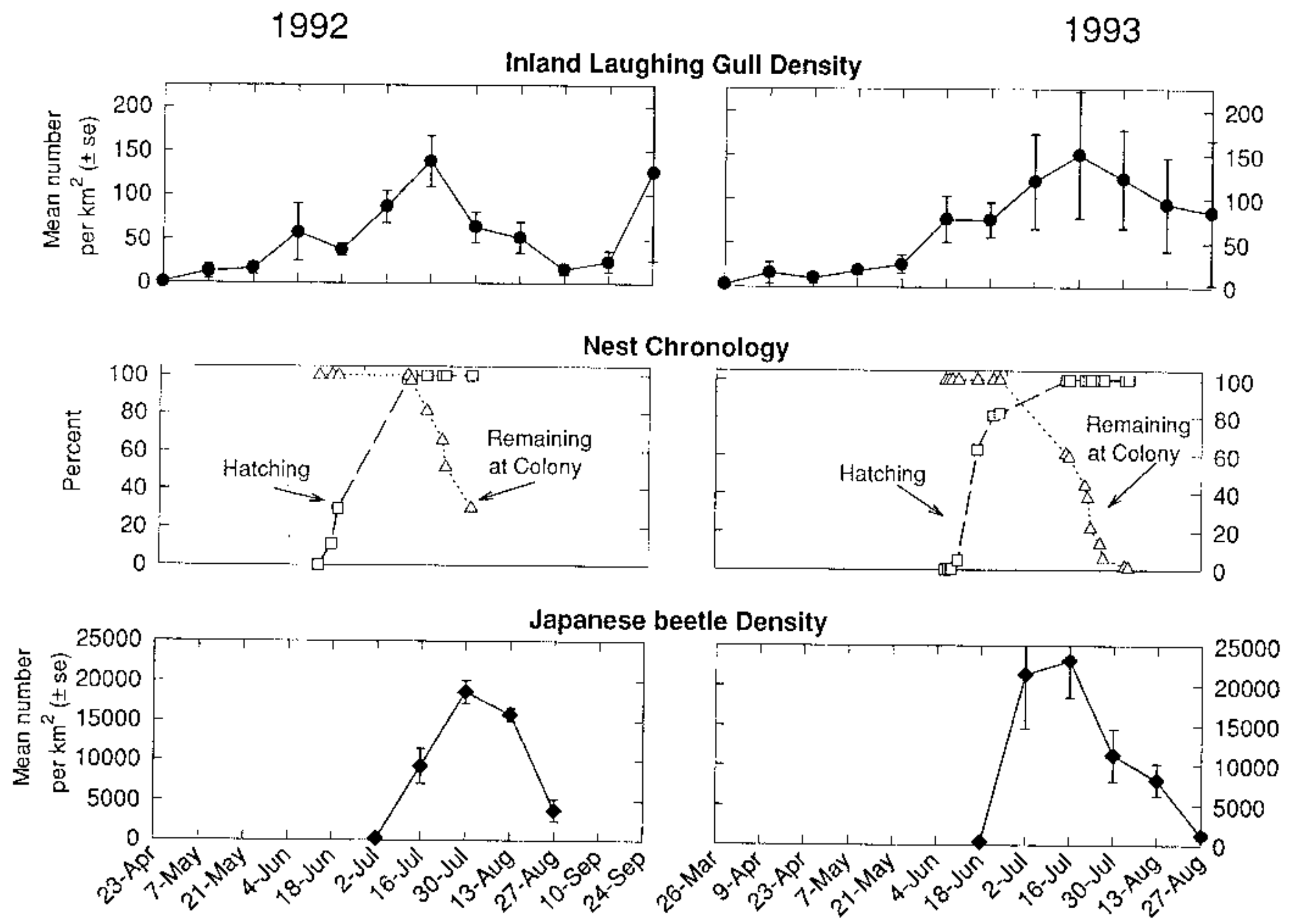

FIGURE 3. Distance from the Nesting Colony of Colored-Marked Laughing Gulls.

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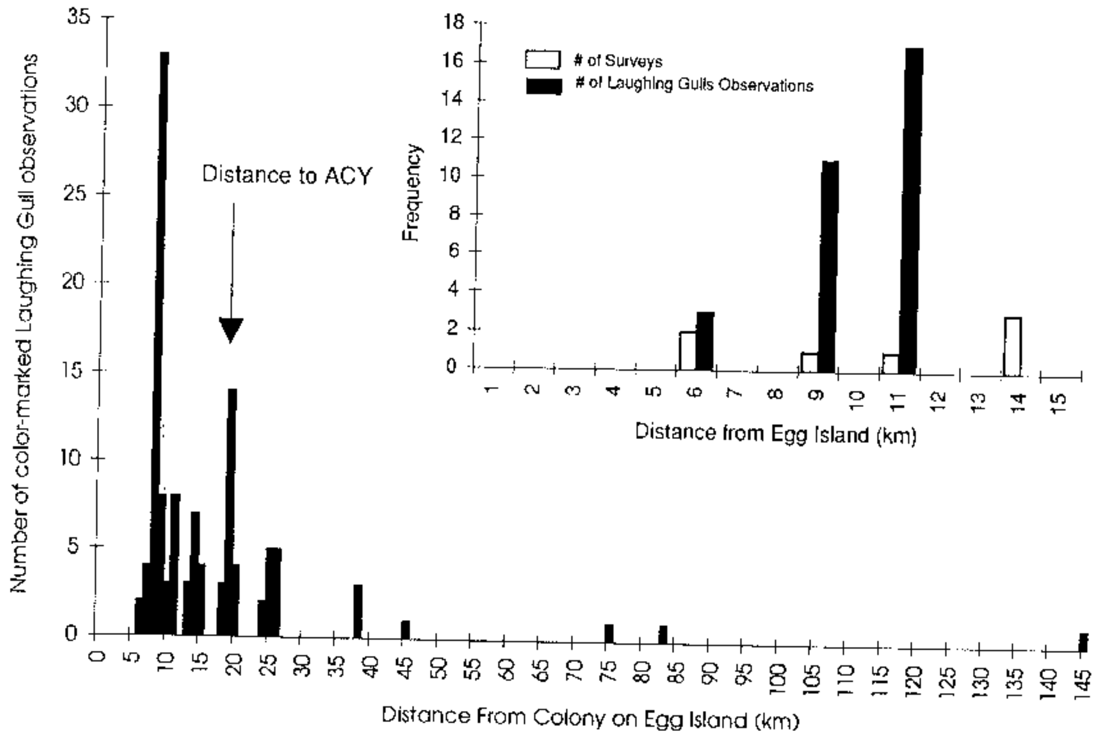


FIGURE 4. Behavior of Laughing Gulls at ACY.

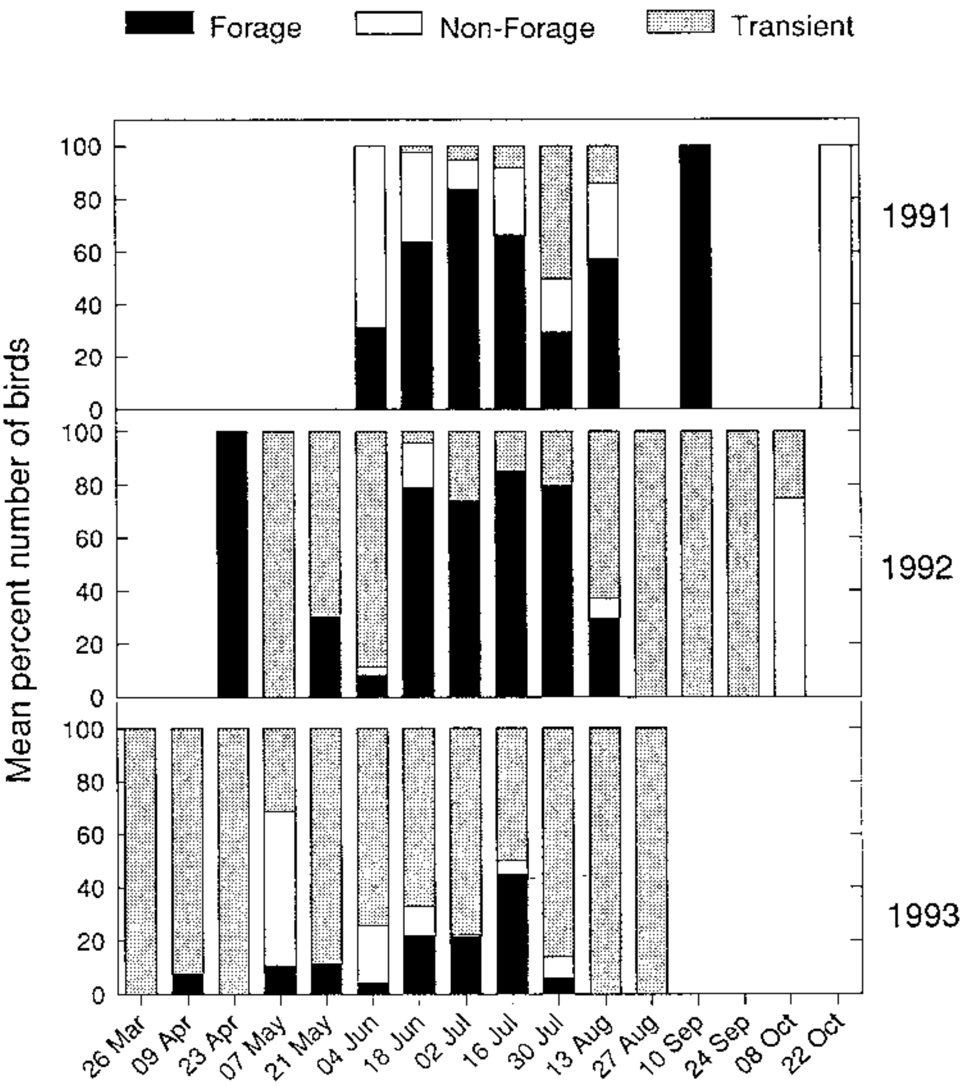


FIGURE 5. Diet of Laughing Gulls from ACY.

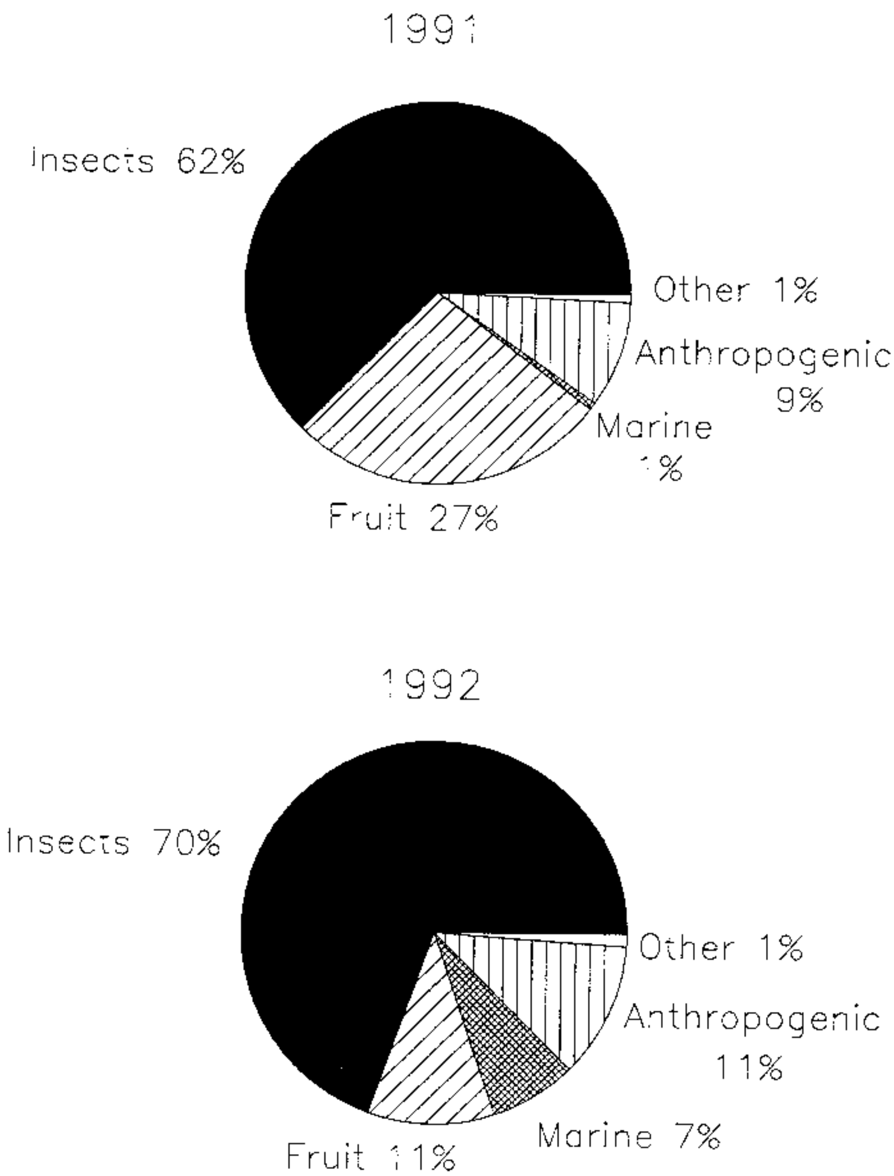


FIGURE 6. Relative Contribution of Insect Taxa to the Diet of Laughing Gulls from ACY.

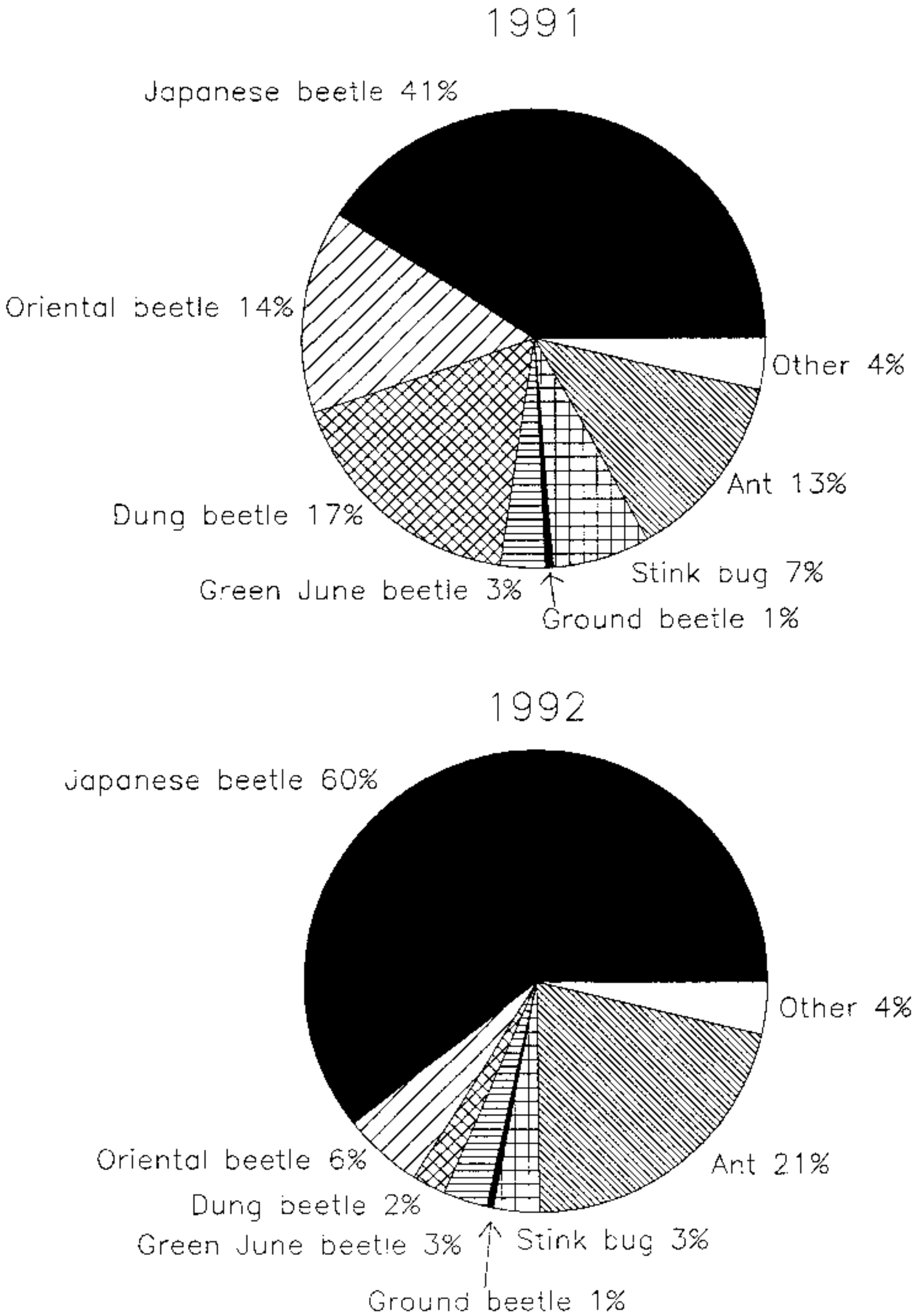
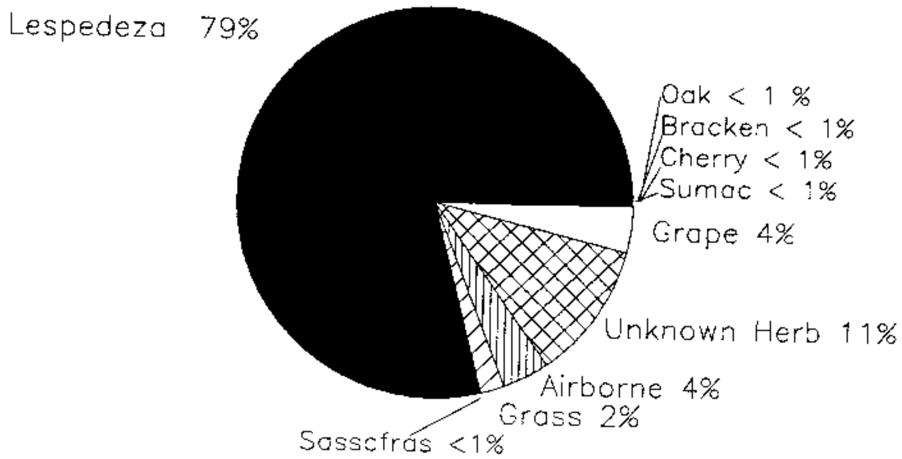


FIGURE 7. Foraging Substrate of Adult Japanese Beetles at ACY.

Mixed Grass Habitats



Mixed-oak Scrub Habitats

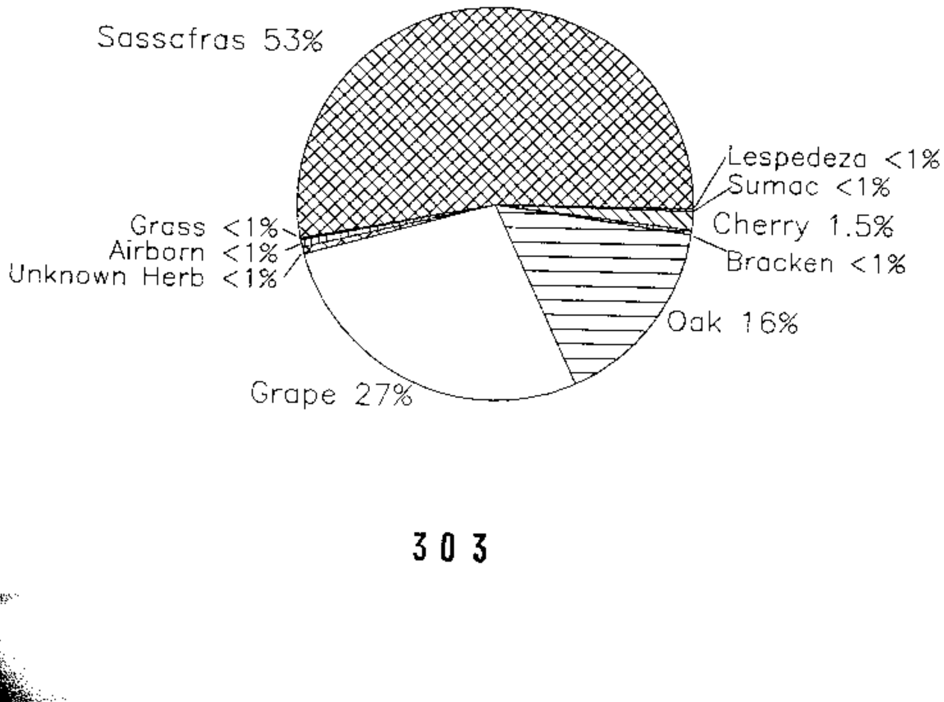


FIGURE 8. Effects of Mowing on Vegetation Composition in Japanese Beetle Study Sites.

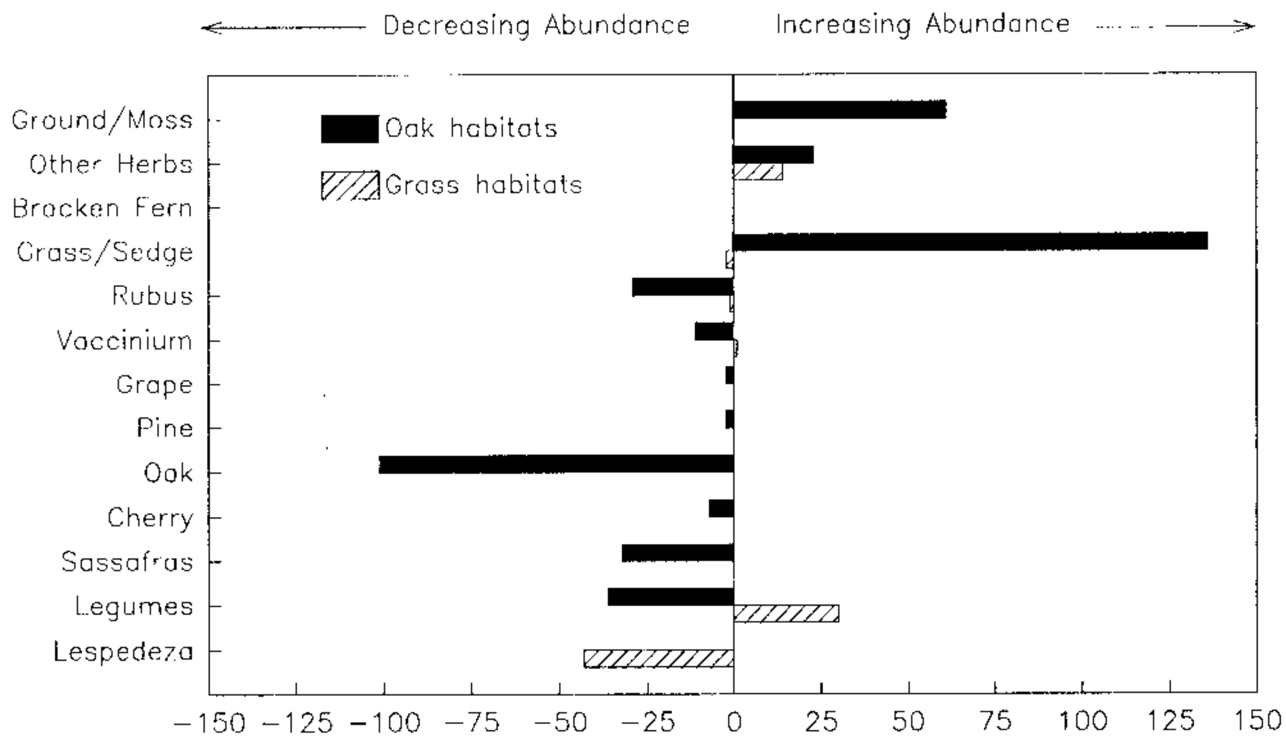


FIGURE 9. Japanese Beetle Abundance in Experimental and Control Plots.

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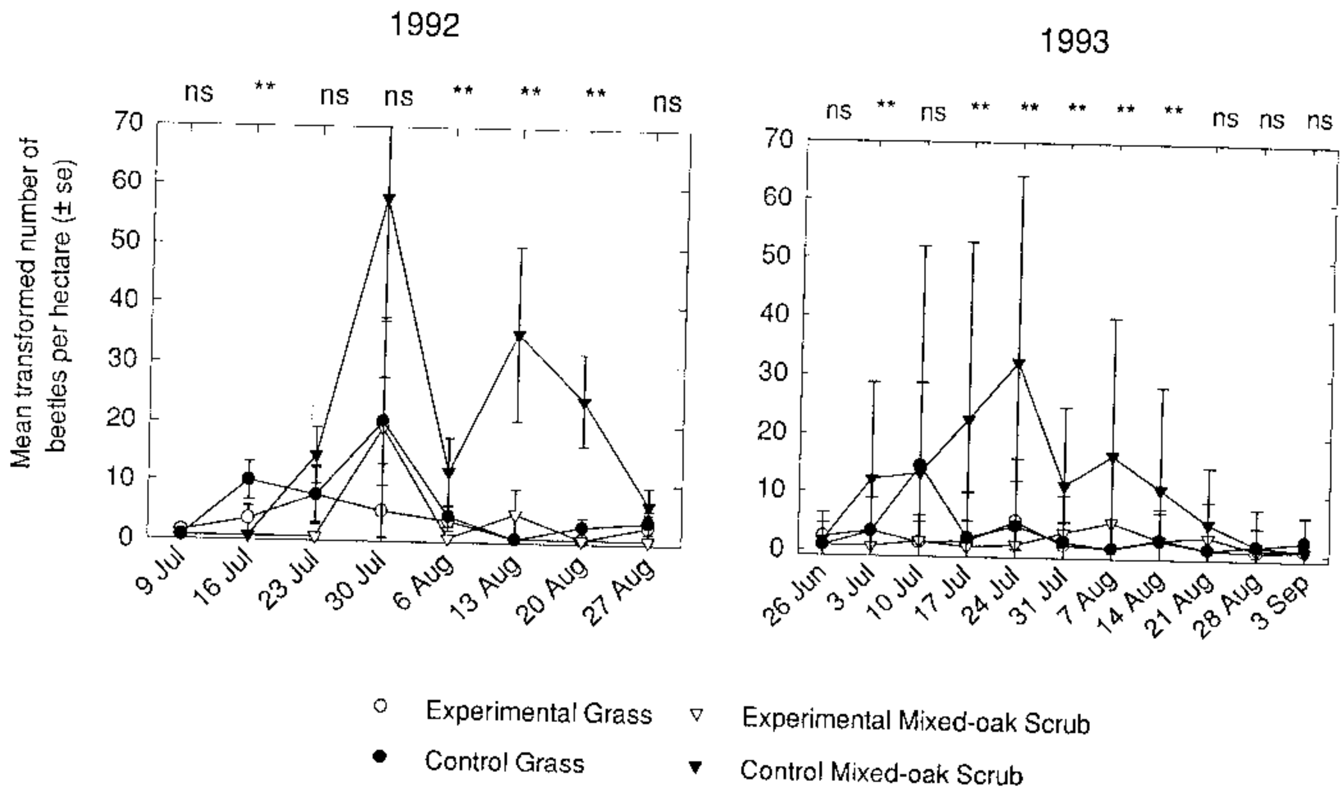

5. ACKNOWLEDGMENTS

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