November 1979

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INTRODUCTION

The bird-aircraft strike hazard is a world-wide problem resulting in human fatalities and aircraft damage. Although the exact cost of bird damage is difficult to obtain, United States Air Force losses are estimated at over $10 million per year (Harrison 1976). Collisions between birds and aircrafts occur either enroute or when planes are landing or taking off at airports. Most of these collisions are due to large flocks of birds attracted to the vicinity by food, shelter, or water (Solman 1971). Solid waste disposal sites are an abundant food source for many hazardous bird species, especially gulls and blackbirds; and if these sites are located near airports, they constitute a major cause of bird-aircraft collisions (Davidson et al. 1971). Thus information on the attractiveness of birds to solid waste disposal sites is important and may lead to a reduction in the number of bird-aircraft collisions.

To date most studies have been conducted on open dumps and sanitary landfills because these were the commonest method of waste disposal. (See Forsythe (1976) for reviews of these studies.) However, the technique of milling or shredding solid waste has recently begun to replace other methods; and this trend will probably continue in the future. With the exception of a survey of 22 milling sites in Europe (Ham and Reinhardt 1973), little is known about the attractiveness of shredded material to birds potentially hazardous to aircraft. Hence data are needed on the attractiveness of shredded refuse to birds, so that a potentially hazardous bird-aircraft collision problem can be avoided if plans are made for the placement of shredded solid waste sites near airports.

The Charleston, South Carolina area offers a unique opportunity to obtain information on the attractiveness of shredded garbage to birds. Data are available from a prior study (Forsythe 1974) on avian populations and movement patterns (especially gulls) related to waste disposal sites and the bird air-craft strike hazard at Charleston Air Force Base. Further, the Charleston County Health Department closed all dumps and landfills and replaced them with a solid waste shredder in June 1974. Hence information can be obtained about the attractiveness of shredded solid waste to birds and about changes in populations and movement patterns resulting from the reduction and closing of disposal sites and their replacement by a shredding plant.

The objectives of this study were: (1) to determine the attractiveness to birds of shredded garbage as a food source; and (2) to determine what changes have occurred in gull populations and movement patterns and the bird-aircraft strike hazard at Charleston AFB when all dumps and landfills are closed and replaced by a single shredding plant and landfill.

STUDY AREA

Observations were made in a 500-mi^2 section of Charleston, Berkeley, and Dorchester counties, South Carolina. About 15% of the area was coastal marsh or barrier island; 40% was urban habitat; and 45% was farmland, swamp, or forest. The area is part of the coastal plain region; hence it is flat and low with the highest elevation 50 ft. above sea level (Fig. 1).

Since 1974, the only solid waste disposal site was the Charleston County Solid Waste Reduction Center located at the east end of Romney Street adjacent to the Cooper River and Drum Island (Fig. 1). This approximately 73-acre complex consisted of a shredding plant and adjacent landfill. The shredding plant, a corrugated steel structure with concrete floor, contained three Heil Company shredding units. Two units milled at the rate of 20 tons per hour; and one, 40 tons per hour. Once milled, the material was carried on conveyor belts to trucks, which transported the shredded refuse to the landfill. In May, 1975, a ferrous metal recovery unit was added to the complex.

The landfill was a former dredge-materials disposal site, whose last pumping operations terminated approximately 20 years ago. Initially it was covered with a dense stand of vegetation, chiefly red mulberry *(Morus rubrus)* and *Baccharis halimifolia,* with an understory of lamb's quarters *(Chenopodium album)* and pokeberry *(Phytolacca americana).* The majority of the vegetation was removed as the landfill was used. No other dump or landfill was operating in Charleston during the study.

METHODS AND MATERIALS

Determination of the Attractiveness of Shredded Garbage to Birds

This study was conducted from 1 January through 31 December 1976 at the Charleston County Solid Waste Reduction Center, Romney Street, Charleston, South Carolina. A total of 26 dawn-to-dusk counts were made at the site to determine daily use patterns of birds. At least two counts were made each month, and the days were selected to determine what variables influenced daily use. In addition, one-hour counts were made at the shredder a minimum of three days a week. On each count, data were collected on species present, sex and age ratios, feeding behavior, and loafing sites. Area weather and tidal information were also recorded. Once a week, particle size of shredded refuse was measured by samples taken from the shredder in a pre-weighed 10-gal. garbage pail. The samples were processed through a series of wire sieves which discriminated among 6-in, 4-in., and 2-in. sized particles. From these, the proportion by weight, of each particle size class in the sample was determined. The amount of solid waste processed daily was obtained from the records of the reduction center.

Determination of Current Gull Populations and Movement Patterns In the Charleston Area

Gull populations and movement patterns were determined by aerial surveys conducted monthly during May-September and bi-weekly during January-April and October-December. Emphasis was placed on herring gull *(Larus argentatus)* and ring-billed gull *(L. delawarensis)* populations, as these were the main hazardous species (Forsythe 1974). A total of 19 surveys, flown in a Cessna 150 or 172 single-engine aircraft, were made. Flights averaged four hours and were made in the morning over the same course at altitudes of 500-800 ft. Clear weather with light winds and good visibility but variable tidal conditions occurred on all censuses. On each count, the species, number, locations, and movement patterns of all gulls were recorded. Aerial photographs, taken with a 35-mm camera using fine-grain, black-and-white film, were made on the first three counts. These were compared with the results of ground counts as well as the aerial surveys. Ground censuses were made in conjunction with each aerial survey. Additional ground counts were made to areas of gull concentrations when necessary but at

least once a month. Bird-aircraft strike records for Charleston Air Force Base were obtained from the Flight Safety Officer. All data were compared with those of the previous study (Forsythe 1974) to evaluate the changes which have occurred since 1971-72. To facilitate this comparison, the methods of the previous study were used whenever possible.

RESULTS AND DISCUSSION

Species Present and Population Size at the Charleston County Solid Waste Reduction Center, Romney Street

About 88 species of birds were observed at Romney Street during 1976. Of these 50% were passerines associated with the shrub and tree-covered dikes bordering the landfill. Only seven species occurred in large enough numbers to be considered the main components of the Romney Street avian community. These included: herring gull, ring-billed gull, laughing gull (*L. atricilla*), boat-tailed grackle (*Quisculus major*), cattle egret (*Bubulcus ibis*), common crow (*Corvus brachyrhnchos*), and fish crow (*C. ossifragus*). The herring gull, ring-billed gull, and the crows occurred in large enough numbers to become a major hazard to aircraft if the landfill were located near an airport. The seasonal abundance of these four species is shown in Figures 2-4. For each species, a weekly average was determined by finding the mean number observed for at least three weekday counts during periods of peak bird activity. Only counts taken when the shredder was operating were used for these figures. Because of the difficulty in separating the two crow species, their numbers were pooled and reported as crow species (Figure 4). Up to 1,000 herring gulls, 300 ring-billed gulls, and 800 crows were present with peak numbers in winter for all species.

Age Structure of Gulls at Romney Street

Herring gulls were divided into three age classes: one-year old or less; intermediates, 2-3 years old; and adults, over three years. The mid-winter population (December, January) averaged 72% chicks, 3.5% intermediates, and 24.5% adults. After January, the proportion of chicks declined until none was present in May. Adults, after an initial increase in February-March, rapidly declined to zero in May. Intermediates, on the other hand, increased to 100% in May-June. When gulls returned in late October, they were mostly chicks. The normal winter ratio was re-established in December. The age ratio and its seasonal trends were similar to those observed at the Charleston Naval Base-Spruill Avenue dump in 1971-72 (Forsythe 1974).

The majority of ring-billed gulls were immatures, less than one year old. The largest proportion of adults (10-17%) were present in February-April, the period when the highest concentration of post-breeding ring-bills from the Great Lakes Region are present along the South Atlantic Coast (Southern 1974). Similar age ratio trends were observed at dumps and landfills in Charleston during 1971-72 (Forsythe 1974).

Laughing gull age ratio trends were the reverse of those for the previous two species, as this species is a summer resident and the other two are winter visitors. As is typical for a species in the northern part of its winter range, all winter and spring birds were adults, over one year of age. Immatures appeared in May and reached a peak (70%) in the last week of May. The summer population averaged 22% immatures with a migration peak in early October.

Observations suggest immature gulls may concentrate at disposal sites and other artificial food sources, while adults feed mainly on natural sources (Drury 1965). To determine if such age preferences did exist in Charleston, I compared age ratios for gulls present at the shredder with those found in natural areas of the study area using a Chi-square test of independence. Herring, ring-billed and laughing gulls all showed significant differences in the proportion of immatures present at the shredder as compared with the remainder of the Charleston area. Immature herring and ring-bills concen-

trated at the shredder (herring gull: X^2 = 253.00, 36df; significant at 0.05 level; ring-billed gull: x^2 = 331.61, 16df, significant at 0.05 level). This may have been due to either an exclusion from natural areas by adults, as Drury and Smith (1968) found for New England birds, or because immatures were inexperienced in food procuring. For example, Cooke and Ross (1972) found young spent more time foraging for food at dumps than did adults. If immature gulls frequent disposal sites because of lack of feeding experience, they may be inexperienced in other areas such as aircraft avoidance. Thus positioning solid waste disposal sites near airports may increase the potential bird-aircraft strike hazard because of inexperienced immatures attracted to the area. Laughing gulls exhibited the reverse age distribution pattern found for the other species with fewer young present at the shredder than the region as a whole. Unlike the others, laughing gulls were summer residents breeding on islands in the Charleston area. The tendency for young to remain near breeding colonies on the coast may account for the higher proportion of young observed away from the shredder.

Daily Movement Patterns of Gulls and Crows at the Romney Street Shredder

A total of 33 all-day counts were made. Attempts were made to divide the counts equally among the seasons and to divide counts equally between weekdays and weekends. The typical weekday pattern in mid-winter is shown in Figure 5. The three gull species were combined as ring-bills and herrings made up the majority of the population and exhibited similar movement patterns. Laughing gulls, with a different pattern, occurred in such low numbers, less than 1%, as to not alter the dominant pattern. Herring and ring-billed gulls began arriving shortly after sunrise and continued until a peak occurred in mid-morning. After this, numbers declined until late afternoon, when a second peak occurred. Numbers then declined until all birds had left prior to sunset.

Crow patterns were similar to those of gulls, with a morning and afternoon high and a mid-day low. However, crows arrived more quickly in the morning, with the majority arriving in one large flock within 20 minutes after sunrise (Fig. 5). The population peaked earlier in the morning and later in the afternoon than did gulls. Crows quickly left in large flocks just prior to sunset. This basic bimodal pattern was characteristic of gulls and crows at Romney Street throughout the year.

Daily movements of Saturdays and Sundays differed in some details from those seen during the week. Gull numbers were reduced 50-60% on Saturdays and 70-90% on Sundays from those present on week days. Morning and afternoon peaks were observed on Saturdays, with the afternoon peak being lower. This trend continued for Sundays, with the afternoon peak even lower or, in spring and fall, absent altogether. Crow populations were less influenced by the lack of dumping on weekends. Saturday and Sunday numbers were usually within 10-15% of weekday levels, and there was no noticeable reduction in the morning and afternoon peaks. In these species, dumping activities did not influence the daily movement patterns but did influence the numbers present. Gulls were more sensitive to changes in dumping patterns than were crows.

Influence of Shredding on Avian Species Abundance and Behavior

During 1976, approximately 163,172 tons of solid waste were brought to the Solid Waste Reduction Center. About 127,144 tons (77.9%) were shredded; the remaining 36,028 tons (22.1%) consisting of dry trash, were dumped directly on the landfill. Little variation was seen in the amount of refuse shredded weekly. Amounts averaged 2,587 tons per week, with a normal range of 2,000-2,900 tons. The amount of refuse received and processed varied with the days of the week. Lowest amounts were processed on Wednesdays and Saturdays. The highest amounts were on Mondays and Tuesdays and resulted from garbage accumulated over the weekend.

An attempt was made to correlate bird numbers with the volume of shredded refuse (Fig. 6), but no relationship was found. Other attempts to correlate gull numbers with either amount of solid waste dumped or the surface area covered by refuse have been inconclusive (Cogswell 1974).

There may be a correlation between shredded particle size and food availability for birds. Ham (1975) suggested if material were ground so at least 90% passed through a 3-inch screen, little or no food would be available for refuse-feeding birds. However, birds were present and fed on refuse at Romney Street when an average of 81 % of the refuse passed through a 2-inch sieve, and no correlation between particle size and bird numbers was found (Fig. 7).

Relative Attractiveness of Various Solid Waste Disposal Techniques to Potentially Hazardous Bird Species

At present, solid waste is disposed either at open dumps or sanitary landfills. At open dumps the material is piled and left uncovered, or it may be burned; while at sanitary landfills, the waste is placed in trenches, then covered with dirt. Several techniques are used to reduce the volume of material prior to disposal, including metal recovery, compression, baling, and shredding. The last technique has become increasingly popular.

All presently used techniques attract birds potentially hazardous to aircraft. Direct comparisons of the relative attractiveness to birds was not possible because they were not all operating during the same period in Charleston. Also comparisons were difficult as a variety of other factors influenced the attractiveness of a site (Forsythe 1976). However, if all other factors were constant, my studies indicated open dumps in Charleston attracted about 50% more gulls than did sanitary landfills. The shredder also attracted gulls and other birds and seemed to be as attractive as a sanitary landfill.

Changes in Gull Populations for the Charleston Area between 1971-72 and 1976.

To see if the consolidation of disposal sites reduced gull populations, herring and ring-billed gull numbers for 1971-72 were compared with those for 1976 by a paired t-test. For each species, January-June 1972 populations were compared with those for 1976; July-December 1971, with those for 1976. The results (Table 1-4) showed numbers of both species were reduced in 1976 from the 1972 levels, but no similar trends were seen between 1976 and 1971. The weather in 1972 and 1976 was normal and similar for both years; however, the winter of 1976 was abnormally severe, while that of 1971 was not (U.S. Dept. Commerce 1971, 1972, 1976). These data suggest the reduction in numbers of disposal sites aid reduce the gull population, but severe weather could cause short-term population increases. Similar reduction in bird numbers with the removal of dumps and landfills was observed by van Tets (1965) in Australia.

Changes in Gull Daily Movement Patterns and Feeding Sites in Charleston between 1971-72 and 1976.

The main herring and ring-billed gull roosting sites are shown in Figure 8. All sites were isolated islands or beaches along the coast, with little or no vegetation and few ground predators. A few gulls roosted on water in the harbor and the leeward side of the jetties. No noticeable differences in roosting site selection between 1971-72 and 1976 were found (Fig. 9).

Herring and ring-billed gull daily movement patterns are shown in Figure 8. Gulls left roosts near sunrise and flew singly or in small flocks to feeding and loafing areas. In the evening, birds returned to the roosting area, using the same pathways that were used in the morning. No differences in flight paths were observed between January-April and September-December 1976. However, differences were noted between 1971-72 and 1976 (Figs. 8, 9): during 1976, most gull movements were along the coast, with few short-distance flights up the major estuaries; during 1976 no overland flights or long-distance flights up rivers were observed. This concentration of gulls along the coast and lack of inland flights in 1976 was the direct result of the elimination of inland dumps and landfills.

Figure 10 shows the main gull loafing and feeding sites in 1976. Most feeding areas were on beaches or mud flats along the coast, except for the Romney Street site and the Plum Island Sewage Treatment Plant. All loafing areas were within 0.5 mile of feeding or roosting sites. Unlike in 1971-72, few gulls were seen during 1976 at sewer outlets, because the county had eliminated all open sewers in 1972 when Plum Island was started (Fig. 11). There was a marked reduction in the number of birds feeding in in-

land areas, and no birds were present at disposal sites closed since 1974. The result of these changes was a reduction in the number of gull-feeding areas within metropolitan Charleston and a concentration of gulls at natural sites along the ocean and Charleston Harbor.

Bird-aircraft Strikes at Charleston Air Force Base, 1971-1976

In June 1970-31 May 1971, a serious bird-aircraft strike hazard existed at Charleston Air Force Base with at least 33 reported strikes (Forsythe 1974, Table IX). The strike rate was reduced to 14 strikes (41% of 1970-71) during June 1971-May 1972 (Forsythe 1974, Table X) with the closing of the Reward Street dump next to the air base. No bird-aircraft strike records are available for the period June 1972-December 1973, but records are available for 1974-76. These show an additional reduction in bird strikes from the 1971-72 high. In 1974, when all dumps were closed and replaced with the Romney Street shredder, four strikes were reported. This was a 71% reduction from the 1971-72 level. Six strikes were reported in 1975 and only two in 1976. These results show that solid waste site consolidation and effective zoning (Forsythe 1974, Fig. 24) can minimize the bird-aircraft strike hazard at airports.

CONCLUSIONS

This study showed that shredded solid waste attracted a variety of avian species in large enough numbers to create a bird-aircraft strike hazard if the site were situated near an airport. The major species present were the same species you would expect at an open dump or sanitary landfill located in a topographically similar area in Charleston. The population levels were about the same as those of a similarly located sanitary landfill. Seasonal and daily movement patterns, as well as loafing and feeding sites, were similar to those observed previously at dumps and landfills in Charleston.

The elimination of all dumps and landfills and their replacement with a shredder greatly changed gull populations and movement patterns in the greater Charleston area. Both herring and ring-billed gull populations were reduced significantly after consolidation, although variations in weather obscured the magnitude of the reduction of July-August 1976. Inland movements were reduced and most birds remained close to the coast in 1976. The proportion of refuse-feeding birds also was reduced. Most birds feed around shrimp trawlers and on natural foods in the intertidal zone. All these changes were reflected in about an 80% reduction from 1971-72 in the number of bird strikes experienced at Charleston Air Force Base. This reduction supported the previous recommendations for the zoning of dump sites in Charleston to reduce the bird-aircraft collision hazard at Charleston Air Force Base.

This study indicates that no presently used solid waste disposal technique is bird-proof. Therefore airport managers and air base flight safety officers must be concerned and involved with their communities solid waste disposal program. Present guidelines for determining when landfills are incompatible with airport safety requirements (Vitale no date) must be considered the minimum needed by airport personnel in reducing the bird-aircraft collision problem. A more positive approach would include an ecological survey prior to the creation of a disposal and the participation by airport personnel in the establishment of county and region-wide solid waste disposal zoning plans. Such plans can locate disposal sites so that they not only keep birds away from airports but also concentrate birds in regions away from airports, thus reducing the hazard. In such programs guidance should be obtained from biologists knowledgeable of bird-aircraft strike hazards and the biology of the avian species. Airport personnel should cooperate with solid waste disposal personnel and participate in programs of landfill and dump consolidation, recycling planning, and any other technological improvements that would reduce the attractiveness of disposal sites to potentially hazardous birds.

ACKNOWLEDGEMENTS

This study was funded by grants number 14-16-0008-612 and 14-16-0008-2024 from the Animal Depredation Control Section., U.S. Dept. of the Interior with funds by the BASH program, Tyndall AFB, Florida, U.S. Air Force.

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TABLE 1. Comparison of herring gull populations in the Charleston study area between 1972 and 1976.

Month	Number of Birds Present	
	1972★	1976★★
January	2780	1300
February 1-15	2900	2100
16-28	2600	1900
March	3200	1700
April	1100	650
May	300	60
June	75	24

★ During 1972 there were eight active dumps and landfills.
★★ During 1976 there was only one active landfill.
t= 3.47 with 6 df, significant at the 0.05 level.

TABLE 2. Comparison of herring gull populations in the Charleston study area between 1976 and 1971.

Month	Number of Birds Present	
	1971★	1976★★
July	75	14
August	80	14
September	100	166
October	700	1345
November	2590	1627
December	2720	2256

★ During 1971 there were eight active dumps and landfills.
★★ During 1976 there was only one active landfill.
t= 0.64 with 5 df, not significant.

TABLE 3. Comparison of ring-billed gull populations in the Charleston study area between 1972 and 1976.

Month	Number of Birds Present	
	1972★	1976★★
January	2400	900
February 1-15	3400	2700
16-28	3100	2500
March	3200	1735
April	1900	900
May	600	200
June	50	118

★ During 1972 there were eight active dumps and landfills.
★★ During 1976 there was only one active landfill.
t= 3.72 with 6 df, significant at the 0.05 level.

TABLE 4. Comparison of ring-billed gull populations in the Charleston study area between 1971 and 1976.

Month	Number of Birds Present	
	1971★	1976★★
July	100	69
August	100	26
September	120	110
October	600	519
November	3700	1257
December	2100	1576

★During 1971 there were eight active dumps and landfills.
★★During 1976 there was only one active landfill.
t= 2.78 with 5 df, not significant.

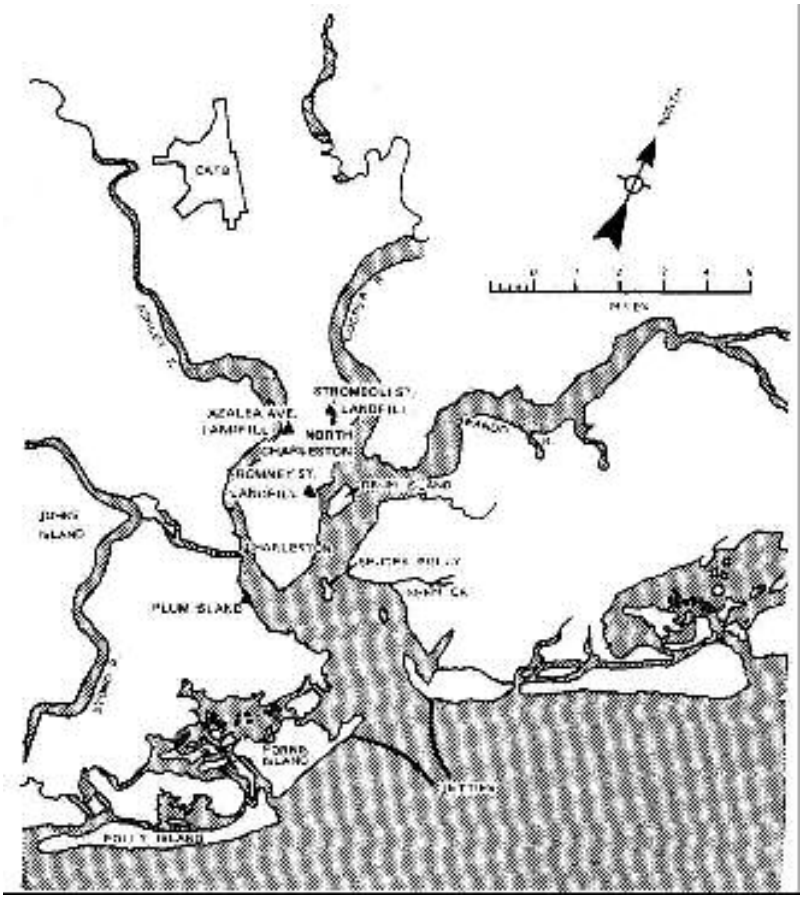

FIGURE 1. Metropolitan Charleston area within which most intensive field work was conducted.

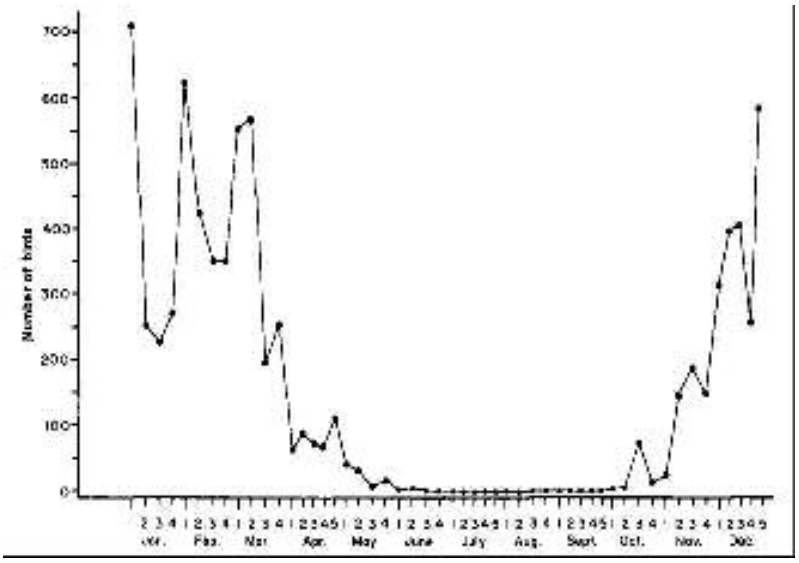

FIGURE 2. Number of Herring Gulls at Charleston County Solid Waste Reduction Center, Jan. 1-Dec. 31, 1976.

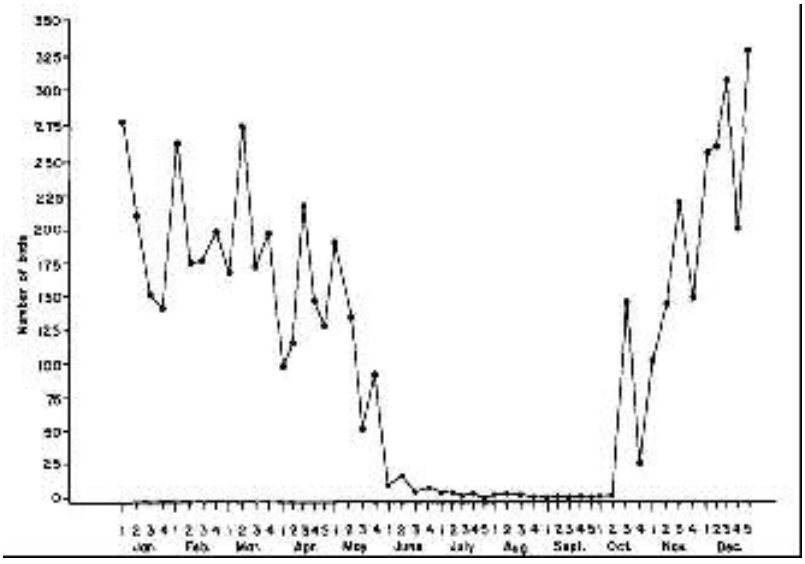

FIGURE 3. Number of Ring-billed Gulls at the Charleston County Solid Waste Reduction Center, Jan. 1-Dec. 31, 1976.

FIGURE 4. Number of crows at the Charleston County Solid Waste Reduction Center, Jan. 1-Dec. 31, 1976.

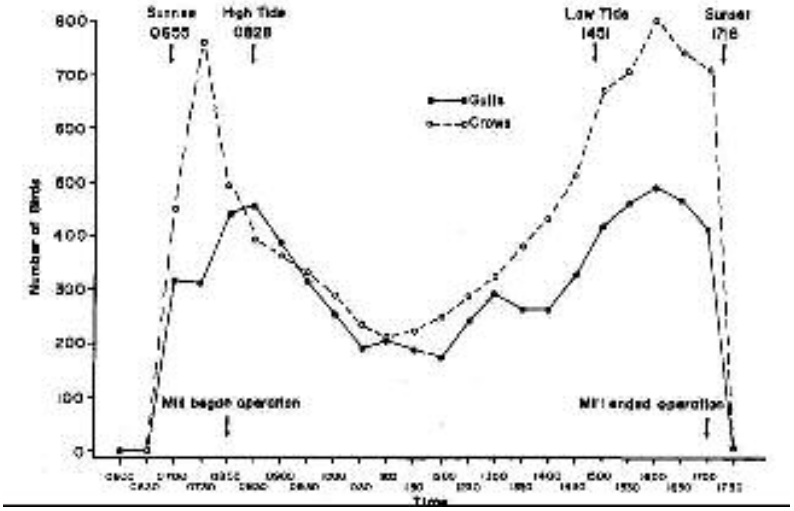

FIGURE 5. Normal weekday movement pattern of crows and gulls at Charleston County Waste Reduction Center, Romney Street, Charleston, S.C., Nov. 20, 1975.

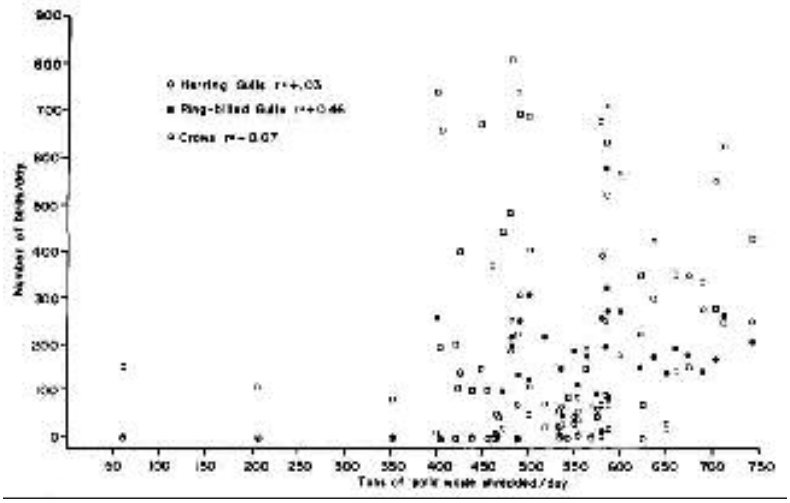

FIGURE 6. A comparison of birds present with respect to volume of solid waste processed at the Charleston County Solid Waste Reduction Center in 1976.

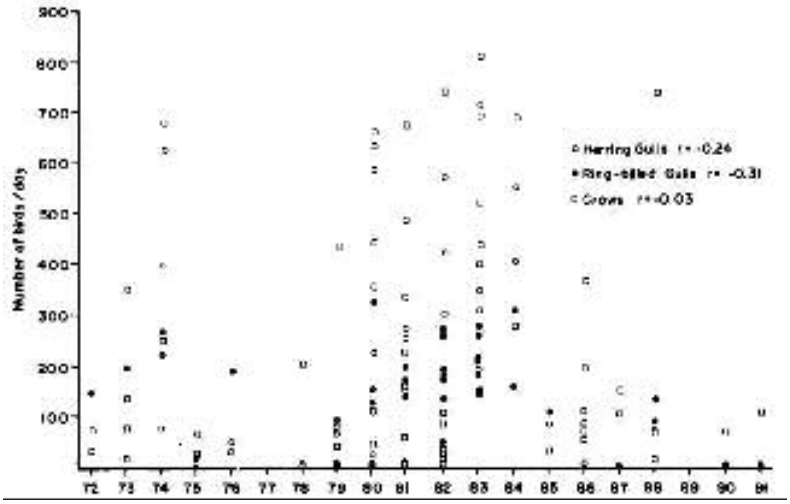

FIGURE 7. A comparison of number of birds present and shredded solid waste particle size at the Charleston County Solid Waste Reduction Center in 1976.

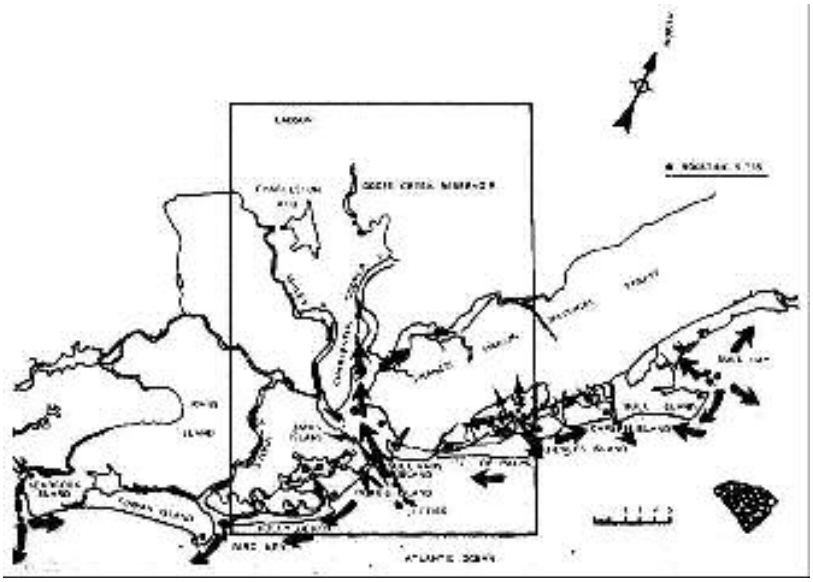

FIGURE 8. Roosting sites and daily movement of gulls Jan.-April and Sept.-Dec.

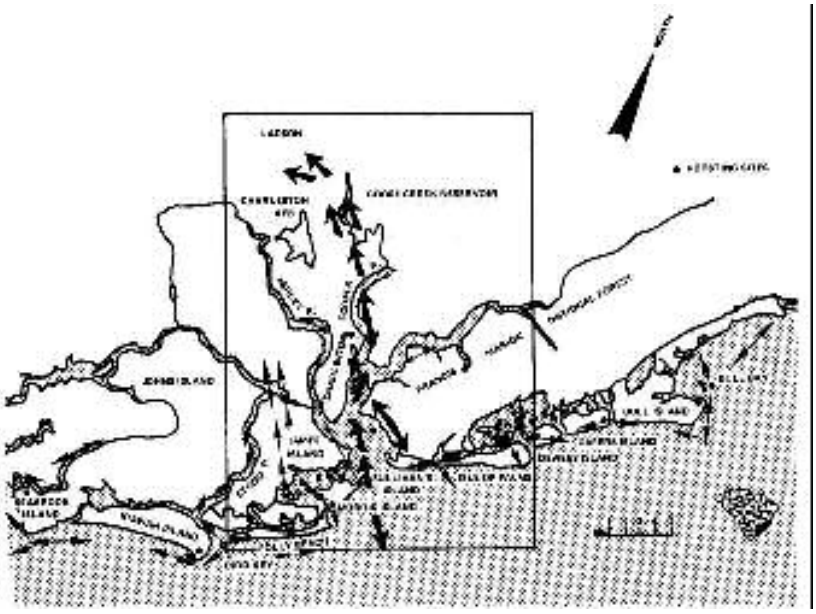

FIGURE 9. Roosting sites and daily movement of gulls from Oct. 1971-April 1972.

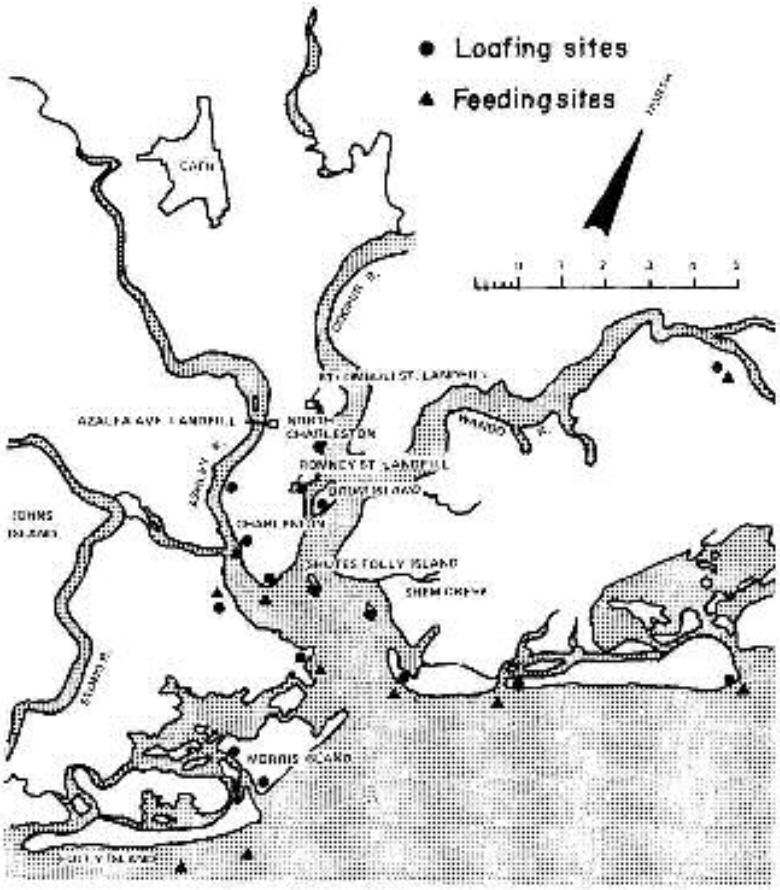

FIGURE 10. Major loafing and feeding sites of Herring and Ring-billed Gulls during Jan.-April and Sept. Dec. 1976. Each dot represents a minimum of 30 gulls.

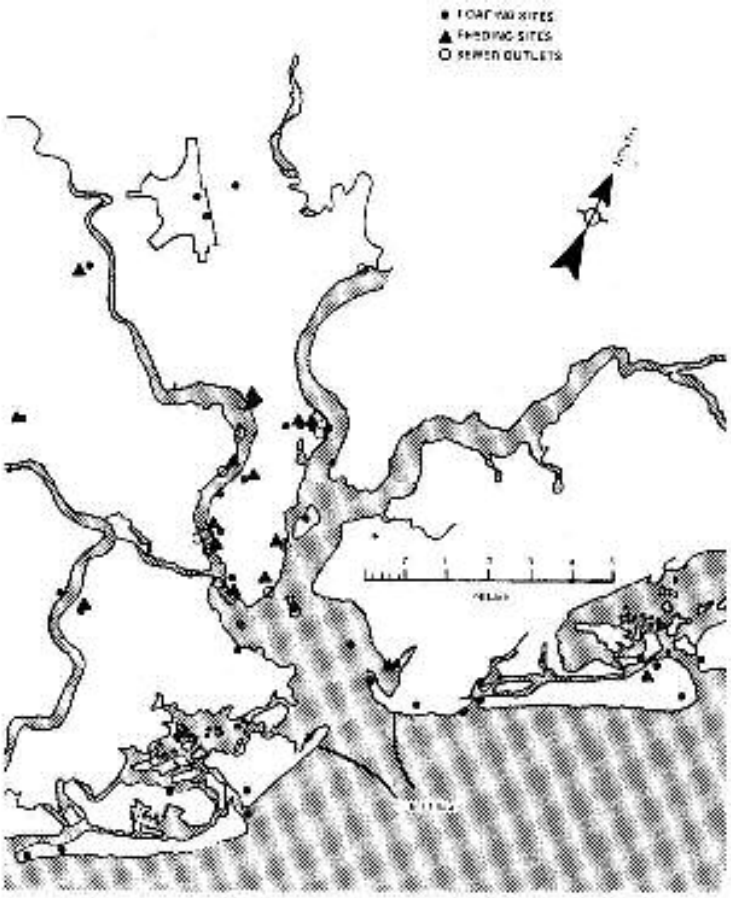

FIGURE 11. Major loafing and feeding sites of Herring and Ring-billed Gulls during Oct. 1971-April 1972.