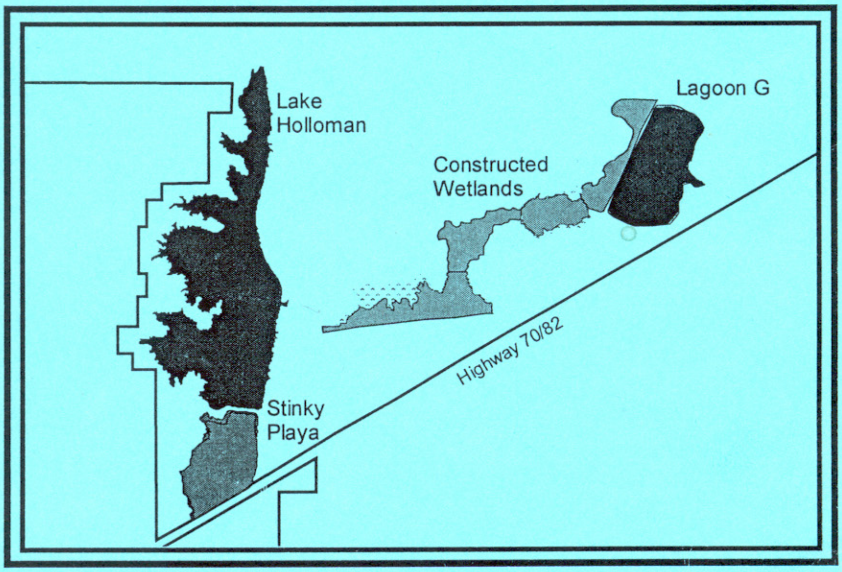
Shorebird Foraging and Invertebrate Occurrence at the Holloman Wetlands, Holloman Air Force Base, 1996-1998



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INTRODUCTION

Arctic-nesting shorebirds make two yearly migrations, to breeding grounds in the spring and wintering areas in the fall. They typically stop en route to forage and replenish fat reserves necessary to complete their migration and (in the spring) begin breeding. Quality stopover habitat is typified by a wetland in partial drawdown, containing a combination of unvegetated mudflat and shallow water with high invertebrate abundance (Eldridge 1992).

Since they were constructed in the late 1960s, the Holloman wetlands at Holloman Air Force Base (HAFB), New Mexico (Fig. 1) have been used as stopover habitat by migrating shorebirds, waterfowl, waders, and other bird species. In 1996, HAFB contracted to US Fish and Wildlife Service (FWS) for development and construction of a wetland (CW) complex. In 1997, FWS constructed a water delivery ditch to the CW. This ditch and an additional outfall to Lagoon G were fully operational by November 1997. These new wetlands, along with Lake Holloman and Stinky Playa, provide shorebird stopover and breeding habitat and hold the increased flow from a new sewage treatment plant.

The purpose of this study was to evaluate foraging behavior and habitat use by migrating and breeding wetland birds at the Holloman wetlands. We sampled the invertebrate food base, surveyed wetland birds by habitat, and conducted detailed bird foraging observations. In 1996, we focused on habitats in Lake Holloman, Stinky Playa, and Lagoon G. With the construction of the water delivery system to the CW in 1997, our efforts shifted to more detailed sampling of habitats in the CW. The aim of the data collection was to provide an empirical foundation for a wetlands management program at HAFB.

STUDY AREA

Historical Context

The decline of wetlands in the U. S. since the 1780s includes a loss of one-third of New Mexico's wetlands (Dahl 1990). Representing less than 1% of the state's surface area, wetlands are disproportionately important as wildlife habitat. Efforts to protect existing wetlands, restore historic wetland sites, or create new wetland habitat are noteworthy and can have large impacts on biodiversity. Existing wetlands in the Tularosa Basin are scattered and some are ephemeral. The successful creation or restoration of a wetland complex in the Tularosa Basin would be a significant conservation achievement. We are not aware of other constructed wetland projects in southern New Mexico.

Addressing efforts to reverse the loss of wetlands, Laubhan and Fredrickson (1993) caution that "the pattern of wetland distribution has been altered and the type of wetlands being restored or created are dissimilar from those being lost". The question -- Is the wetland under development at HAFB similar to former wetlands in the Tularosa Basin? --

is difficult to answer. Europeans did not settle the area until the 1860s and there are few historical descriptions of the vegetation or landscape. When the first settlers began farming in 1862, the site of present-day Tularosa was described as "marshy land where the Tularosa [River] fanned out and lost itself among reeds and marsh grass a mile from the canyon" (Sonnichsen 1960:11). This description may represent pre-1900 conditions along the eastern margin of the Tularosa Basin, where streams from Sierra Blanca and the Sacramento Mountains met the basin floor.

Springs and seeps line the fault along the interface between the Alamogordo Sub-Basin within the Tularosa Basin. MacBride (1905) remarked on the "great springs" that emerged from the southern margin of the Carrizozo lava flow, where "all the plain is saturated with salt and alkali" and characterized by *Suaeda* and *Allenrolfea*. Malpais Spring and its marshy drainage basin, well known as the type locality for the White Sands pupfish (Miller and Echelle 1975), is a present-day example of a spring-fed wetland that may have been more common in the Tularosa Basin.

Historical accounts of wetlands on or near HAFB are limited. Garton Lake, 4 km southwest of Lake Holloman and now part of White Sands National Monument, was a large marsh with several acres of open water. Although not a natural marsh, it developed in 1916 when a well drilled for oil opened an artesian flow of warm, highly mineralized water (Dodge 1971). It was investigated in 1935-1938 as a potential bird sanctuary. The marsh area was 4 feet deep and surrounded by cattail, saltgrass, bulrush and other wetland plants. Migrating waterfowl, waders, and shorebirds frequented the site (A. E. Borell 1938, cited by Schneider-Hector 1993). The marsh has been dry since the 1980's, when the upper part of the well casing was removed (J. Mangimelli, WSNM Chief of Interpretation, personal communication). The existence of this wetland for at least 50 years bodes well for the prospect of creating wetland habitats in the Tularosa Basin.

Description of Study Area

Lake Holloman and Stinky Playa are remnants of a Pleistocene lake bed that was divided by construction of an earthwork dam in 1968. These water bodies have also been altered by the construction of U.S. Highway 70 and the use of Holloman Lake as a reservoir for treated sewage effluent (US Army Corps of Engineers 1996).

The construction of a new sewage treatment plant at HAFB provided the impetus to create an artificial wetland that could receive treated effluent. When filled to capacity, the constructed wetland adds approximately 40-50 ha of wetland bird habitat to the Holloman complex. As one of the largest permanent water sources in the Tularosa Basin, the new wetland provides important stopover habitat for migrating shorebirds and waterfowl, as well as increased breeding habitat for resident species. The wetland is designed to add large areas of shallow water and mudflat habitat to pre-existing mudflat, playa, and deep-water habitats.

Lake Holloman

Prior to the construction of the CW, Lake Holloman (Fig. 1) had a mean depth of 1.4 m, with a maximum depth of 2.0-2.5 m when water was near spillway height. Seasonal variation of evaporation and precipitation caused water-level fluctuations of about 30 cm annually (see Cole et al. 1984, for a detailed description of the lake).

The primary purpose of Lake Holloman was to retain runoff from a HAFB sewage treatment facility. The water has traditionally been brackish because of groundwater influences (12,000 - 17,000 mg/l in the 1980s, a period of very high flows), and total dissolved solids have increased in recent years (up to 46,000 mg/l in 1998). The lake has been too saline for most freshwater fish species and not saline enough for saltwater fishes. No amphibians occur there and only one species of fish, *Gambusia affinis*, survives in the lake (Cole et al. 1984). High input of nutrients, especially phosphorus and nitrogen, has resulted in very high productivity, also enhanced by high solar radiation and shallow water depths. Community metabolism causes diurnal fluctuation in oxygen concentration, and high productivity frequently causes oxygen depletion (Cole et al. 1984). In addition, periodic blooms of a purple sulfur bacterium have resulted in severe oxygen depletion and a striking pink coloration in the lake, most recently in August, 1997.

Creation of the new sewage treatment plant has altered Lake Holloman in several ways. In 1996 and 1997, before the CW was operational, effluent from the plant was sent to Lake Holloman at a rate of one million gallons/day, increasing the volume of water in the lake and greatly decreasing the area of shorebird foraging habitat on Holloman's shore (see Availability of Mudflat Habitat, below). In addition, the new effluent contains less organic matter, which decreases the likelihood of forming nutrients. However, with less effluent going directly into Lake Holloman, its salinity may increase, potentially affecting the aquatic invertebrate community.

Stinky Playa

Stinky Playa is likely the most natural water body in the wetland complex, most closely resembling the playas present before the construction of Lake Holloman and the lagoons. The surface area of Stinky Playa is 12 ha between the dam and the highway. Through the annual cycle, Stinky Playa may range from being entirely filled with water to a potential depth of 1.5 m (Davis et al. 1996), to being almost completely dry, with a crusty, saline surface. The water in Stinky Playa can be turbid from algal or bacterial blooms.

The water in Stinky Playa is typically quite alkaline, with high concentrations of sodium and chloride (3,870 mg/l and 7,650 mg/l, respectively, Davis et al. 1996). The playa can be classified as eutrophic to hyper-eutrophic, based on phytoplankton community composition, total nitrogen, and total phosphorus (Davis et al. 1996). Shorebirds forage on invertebrates in the shallow water and saltflat habitats (see Habitats, below) at Stinky.

Lagoon G

Lagoon G is approximately 19 ha in area, with an average water depth of about 1m (EBASCO and Radian Corp. 1995). Wastewater from the old plant originally flowed into seven lagoons, including Lagoon G, then into Lake Holloman and Stinky Playa. All lagoons except Lagoon G were closed by the end of 1997, due to hazardous levels of toxic organic compounds. Although organochlorides and heavy metals were detected at Lagoon G, levels were not above legal limits (EBASCO and Radian Corp. 1995), and the lagoon remains open. The treated wastewater from the new facility flows by gravity into Lake Holloman, and in a separate pipeline is pumped to the north end of Lagoon G.

Constructed Wetlands

The CW began operation in early November 1997 with the opening of an open-water ditch, approximately 1.6 km long, from a splitter box to Pond 2 (Fig. 2). The splitter box allows for control of water delivery between Lake Holloman and the CW. The CW adds 40-50 ha of aquatic and wetland bird habitat to the wetlands at HAFB. The water in the CW is impounded in four ponds or cells, contained by a system of earthen berms, and connected by a series of control structures (Fig. 2). Control structures consist of a half culvert drop inlet design (Payne 1992) with a vertical riser that accommodates stoplogs. Water level of a cell is regulated by the height of the stoplogs, and a cell can be drained by removing the stoplogs. Water flow in the CW is by gravity.

In November 1997, we conducted a vegetation survey at the site of Pond 2 before it was inundated by the opening of the surface ditch. The site comprised 11 vegetation plots of various sizes in which the coverage by plant species was estimated. Each plot was centered with a GPS reference point and the boundaries were measured. The vegetation in this area falls within the saltgrass (*Distichlis spicata*) community type of Muldavin et al. (1997), but there is considerable variation in species coverage classes among the plots. Six plant species are represented (in decreasing order of importance): *D. spicata* (saltgrass), *Cressa truxillensis* (silky cressa), *Allenrolfea occidentalis* (pickleweed), *Suaeda moquinii* (seepweed), *Tamarix chinensis* (saltcedar), and *Scirpus maritimus* (alkali bulrush). This area was an important shorebird foraging site in the spring of 1997 and 1998 (see below). It was expected to develop into a saltgrass wetland that would increase as the CW developed; however, recent observations indicate dominance by alkali bulrush (H. Reiser, personal communication, Nov. 1998).

Habitats

At the Holloman wetlands we delineate five general habitat types that are variously distributed among the four water bodies (Table 1). Saltflat habitat occurs at all four water bodies, emergent vegetation occurs primarily at the CW, and deep water is present at all water bodies except Stinky Playa.

We define saltflat as being relatively flat and unvegetated, with a dry, crusty soil surface. Mudflat is also relatively flat with little vegetation and soils ranging from moist to those having less than 2 cm of standing water. Shallow water is 2-15 cm deep. Emergent vegetation habitat includes areas with substantial growth of saltgrass, alkali bulrush, or other wetland vegetation. Deep water is over 15 cm in depth.

BIRD CENSUSES

Methods: We conducted monthly bird censuses from April through November, 1996, during a 4-5 day period in the second or third week of each month. Using binoculars and a spotting scope, we censused eight survey points at three water bodies: Stinky Playa (1), Lake Holloman (4), and Lagoon G (3) (Fig. 1). Surveys began 30 minutes after sunrise on two non-consecutive days of the field period and lasted 20 minutes at each point. We counted the number of individuals of each species seen from each point and assigned each to one of the following habitat types: saltflat, mudflat, emergent vegetation, shallow water, and deep water. For each census, numbers of individuals of each species were summed over all census points at each water body. For each monthly census, we selected the census with the largest number of individuals and reported that as the peak number of individuals (see Appendix A). Here we use American Ornithologists' Union common names; scientific names are listed in Appendix B.

In 1997, we conducted bird censuses at the end of January and once monthly from March through June and August through October at Lake Holloman, Stinky Playa, and Lagoon G, using the survey points and habitat types developed in 1996. We established three survey points in the constructed wetlands (CW, Fig. 1). In April we initiated censuses at the CW site and incorporated them into the census schedule.

In 1998, we added one survey point to the three CW points established in 1997, as bird numbers increased at the CW. We eliminated points 1, 2, and 4 at Lake Holloman, due to the time required to survey the CW and collect detailed foraging data.

Results: We observed 50 species of wetland birds at the four water bodies over the three years (Appendix A). The most abundant category of birds was waterfowl, including 17 species of ducks, two grebe species, two goose species, and the American Coot. Second in abundance were shorebirds, comprising 17 species of sandpipers, four plover species, and avocets and stilts. We detected six species of waders.

The majority of ducks were present during spring and fall migration, although smaller numbers of a few species were detected in the winter and summer (Appendix A). Their presence during the summer months suggests that some individuals nested there, but we did not find any duck nests.

The two main plover species were Western Snowy Plover and Killdeer. Western Snowy Plovers were present as stopover migrants and also as breeders (Fig. 3 and see Individual Species, below). Killdeer, on the other hand, were present year-round and are therefore considered residents (Fig. 4). Sandpipers tended to be primarily stopover migrants, for example Wilson's Phalarope (Fig. 5), but a handful of Western Sandpipers also overwintered (Fig. 6).

Avocets and stilts appeared to be mostly stopover migrants, but individuals of both species were present all summer, and are known to nest at the wetlands (Fig. 7 and see Individual Species, below). Waders were uncommon. White-faced Ibis were the most abundant waders, with 78 seen in one census at the CW (May, 1998). Most waders were observed as single individuals.

SHOREBIRDS BREEDING AT THE HOLLOMAN WETLANDS

Western Snowy Plover (*Charadrius alexandrinus nivosus*)
The Western Snowy Plover (*C. a. nivosus*) is presently a US Fish and Wildlife Service Species of Concern. There are breeding records for the species at the Holloman wetlands beginning in 1991, and the NMNHP has detected evidence of Snowy Plovers nesting there in 1994 and 1995 (NMNHP 1996). In mid-May, 1996, at the beginning of this study, we observed one group of three chicks with a pair of adults on Stinky Playa.

Two Snowy Plover nests were found and monitored in 1997, both occurring on Lake Stinky. On 15 May we found a nest with three eggs at the western margin of the playa; two chicks fledged by the first week of June. On 10 June we discovered a second nest in the center of the playa south of Highway 70. It contained 3 eggs and was attended by a male. The site was checked for several weeks thereafter by other observers. No chicks were seen and the nest was considered to be a failure.

Other evidence of Snowy Plover breeding in 1997 was inferred from observations of young birds consistently seen with a pair of adults. In May and June, we observed one group (1 male, 1 female, 2 juveniles) at Lagoon G and its adjacent wetland and another group (1 male, 1 female, 2 juveniles) at control structure 3 (see Fig. 2) in the CW.

The mudflats and shoreline at the northern end of Lake Holloman were also searched for plover nests in April, May, and June (approximately one 8h day of effort per month), but none was found. A pair of adults (male and female) was seen foraging in this area in June, but no young birds were present. Areas at Lake Holloman where nests were found in 1995 and 1996 by Mr. Mark Proctor were inundated in 1997.

Our observations provide a conservative estimate of Snowy Plover breeding in 1997 of 4 breeding pairs, with the possibility of a fifth pair at northern L. Holloman. Mark Proctor has been noting Snowy Plover nesting at HAFB in his daily bird observations in the vicinity of Lake Holloman. He reports 14 breeding pairs and a total of 26 chicks at Lagoon G and 2 pairs at Lake Holloman in 1997. He also found 2 nests at Stinky Playa south of Highway 70, both subsequently destroyed by predators (M. Proctor, personal communication, Dec. 1997). One of these was probably the nest that we found in June.

On 14 April, 1998, we discovered a scrape containing one egg on the western edge of Stinky Playa. The nest was still there on 6 May and during June, suggesting that the nest was abandoned. On 6 May, 1998, a second nest containing three eggs was found on the northwest corner of the playa, and a male was observed on the nest on 8 May. The eggs were still present on 12 and 21 May. On 30 May and 19 June only one egg remained. No chicks were seen on Stinky Playa in June, but it is possible that two chicks hatched.

[As of 19 June, 1999, there were 12 plover nests on the mudflat of the northeast shoreline of L. Holloman. No nests were detected on Stinky Playa or other areas in the CW. (H. Reiser and M. Proctor, personal communication)]

American Avocet (*Recurvirostra americana*)
American Avocets are present at the Holloman wetlands during the spring and fall migrations and also during the summer breeding season (Fig. 7). In 1998, we found the first evidence of avocets breeding at the new CW. On 19 June, we found a nest containing three hatched eggs on the southwest edge of Pond 2. On 20 June, 1998 a nest on the north edge of Pond 4 contained 4 eggs. As the CW develops, we expect increased nesting by avocets. [This has occurred in 1999, when at least 10 avocet/stilt nests were found. Most of the nests were located along the edge of earthen berms in the CW. The majority of these nests (>90%) failed because of predation, primarily by coyotes. (H. Reiser and M. Proctor, personal communication)]

Other Water-Associated Species
The majority of shorebird species at the Holloman wetlands are stopover migrants. Aside from Snowy Plovers and American Avocets, two other species are typically present at Holloman during the breeding season (Appendix A). Killdeer almost certainly breed at the wetlands (Fig. 4) and Black-necked Stilts are also present in small numbers throughout the summer. Other species that have nested in the CW are Black-crowned Night Heron and Green Heron. [In 1999, for the first time, two Snowy Egret pairs nested and fledged at least 7 young. Also, a small flock (5 individuals) of White-faced Ibis remained in the CW from November 1998 through summer 1999. One nesting attempt was also documented for the first time. (H. Reiser and M. Proctor, personal communication)] Numbers of individuals of wetland species breeding at Holloman will likely increase as the CW continues to develop.

INVERTEBRATES

Invertebrates in Shorebird Habitats

Methods
Permanent stations and transects for invertebrate sampling were established in 1996 at the three original water bodies (Fig. 1). Transects bisected the major wetland and aquatic habitat types adjacent to each sampling station: mudflat, shallow water (2 to 15 cm depth), open water, and saltgrass meadow. With the prospect of the constructed wetland becoming operational in 1997, we identified preliminary sampling points at the site in spring 1997. We collected samples there when runoff and rainfall events created temporary habitats for shorebird foraging. In 1998, invertebrate sampling was restricted to the constructed wetland, with the dual objectives of quantifying invertebrate abundance in conjunction with shorebird foraging studies (see Shorebird Foraging and Habitat Use) and providing baseline data on the invertebrates in the newly-created wetland habitats.

After 1996, the main purpose of our invertebrate studies was to identify potential food items in shorebird habitats, limiting our methods to the collection of macroinvertebrates (≥0.5 mm in length). Special methods for collecting zooplankton (microinvertebrates) were not employed. Larger crustaceans (cladocerans, copepods, and ostracods) were collected by our methods. Samples were taken at sites where shorebirds were actually foraging or had been observed feeding within 24 hr. Most of our sampling methods (summarized in Table 2) provide relative or index, measures of abundance, which allow a level of precision appropriate for invertebrate surveys of various habitat types (Murkin et al. 1996). For the foraging studies discussed later in this report, we used sampling methods (soil cores) that provide density estimates, i. e., counts of individuals per unit area. Although cores provide a volumetric sample of substrate, we follow the convention of presenting invertebrate densities as individuals per m^2 of surface area (using a specified core depth) for assessment of invertebrate abundance in moist-soil habitats (e. g., Eldridge 1992).

A lake kayak was used to facilitate sampling at Lake Holloman and Lagoon G. In addition to its use for net and sediment sampling in deep water, the kayak proved invaluable in providing access to near-shore areas where sediments would not support a person and sampling from the shoreline was not possible.

Preliminary processing occurred at HAFB before samples were transported to the laboratory. Sediment and soil-core samples were washed through a fine-mesh net (0.15 mm) or a #100 metal sieve to eliminate fine sediment particles. Samples were preserved in 10% formalin. Water column samples and contents of pitfall traps and aquatic traps were poured through a fine-mesh net and stored in 70% ethyl alcohol.

The manuals of Borror et al. (1989), Merritt and Cummins (1996), and Thorp and Covich (1991) were consulted for identification of invertebrates. Insects and gastropods are identified to family and, when possible, to genus. Dr. Boris Kondratieff (Colorado State University) provided identifications of chironomid and ceratopogonid larvae. Dr. Lee Herman (American Museum of Natural History) identified specimens of *Bledius*. Other groups are identified to the lowest functional taxonomic category appropriate to our objectives – crustaceans to order or subclass, arachnids to order.

Results

An overview of the distribution of invertebrate taxa shows that the mix of habitats present at Holloman contributes to the range of macroinvertebrates (Table 3). Not surprisingly, much of the taxonomic diversity is due to insects characteristic of aquatic habitats – water boatmen (Corixidae), five dipteran families with aquatic larvae, water scavenger beetles (Hydrophilidae), predaceous diving beetles (Dytiscidae), crawling water beetles (Haliplidae). Most of the taxa characteristic of the saltflats – ground beetles (Carabidae), tiger beetles (Cicindelidae), rove beetles (Staphylinidae), ants (Formicidae) – also occur in the mudflats, contributing to the prey base there. Deep water is dominated almost exclusively by corixids, with a relatively depauperate crustacean fauna. The latter group occurs in greater abundance in shallow water and emergent habitats.

Collections of deep-water sediments in 1996, both at L. Holloman and Lagoon G, yielded no specimens and this sampling was subsequently abandoned.

Importance of Invertebrates in Shorebird Diets

Both the taxonomic diversity (Table 3) and numbers (Tables 4, 5) of macroinvertebrates at the Holloman wetlands are indicative of the current and potential importance of these wetlands to shorebirds. Whether stopover migrants or breeding individuals, shorebirds require large numbers of invertebrates for food. Invertebrate availability throughout the migration and breeding seasons is a key factor in determining the suitability of shorebird habitat (Helmers 1992). All taxa in Table 3 (except the sun scorpions, Solpugida) have been identified as diet items for shorebirds, both on a continental scale (Skagen and Oman 1996) and in reviews of the biology of four of the most common species occurring at the Holloman wetlands: Wilson's Phalarope (Colwell and Jehl 1994), Snowy Plover (Page et al. 1995), American Avocet (Robinson et al. 1997), and Western Sandpiper (Wilson 1994).

Cole et al. (1984) analyzed shorebird stomach contents at L. Holloman. Their study provides limited data on the taxa and relative abundance of prey items for four shorebird species. Snowy Plovers (n=2) consumed corixids and hydrophilid beetles, Wilson's Phalaropes (n=7) ate chironomids and corixids, American Avocets (n=4) ate corixids predominantly, and Killdeer (n=4) preferred hydrophilids, followed by corixids.

We analyzed Snowy Plover fecal pellets collected at Stinky Playa in August, 1997. The most frequent prey category was the beetle *Bledius mandibularis* (Staphylinidae), occurring in more than 50% of the pellets (N = 50). Less frequent, but common, prey items included ground beetles (Carabidae), tiger beetles (Cicindelidae), *Corisella* sp. (Corixidae), ants (Formicidae), and shore flies (Ephydridae). All of these taxa are members of the invertebrate fauna at Stinky Playa and Lake Holloman (Table 3). (See Appendix C for a more extensive discussion of the Snowy Plover fecal analysis.)

Invertebrate Taxa of Special Interest

Corixidae (Hemiptera)

Corixids (water boatmen) forage on bottom sediments, consuming algae, bacteria, and other microorganisms. They are excellent swimmers, and, being dependent on atmospheric oxygen obtained at the water surface, they move vertically in the water column between the surface and the benthos. Most corixids overwinter as adults and lay eggs in the spring. The eggs are attached to the substrate, usually any available submerged surface. They hatch in 1 to 2 weeks, followed by five nymphal instars, each lasting a week to 10 days. The instars can be recognized by the progressive development of the wing pads. *Corisella* is one of the corixid genera common in saline lakes (Lauck 1979).

The temporal pattern of *Corisella* population structure at L. Holloman (Fig. 8) shows a rapid increase in nymphal stages in August, 1996, with peak abundance in October, and declining reproduction through January, 1997. Adult numbers (Fig. 9) peaked in August, 1996, and declined through January, 1997. Numbers of both nymphs and adults were low in the spring and summer of 1997 in comparison to the previous year. Population numbers were beginning to decrease in September, 1997 (Figs. 8, 9). The variation in the two years is probably characteristic of aquatic insect population fluctuations where physical conditions such as temperature and water levels fluctuate. A "typical" year may have been 1996, because the reproductive pattern is consistent with what is known about corixid biology. The depressed populations in 1997 may have been due to a combination of a colder than average late winter/early spring, causing a delay in adult reproduction. The water level was higher than in 1996, thus requiring a longer time for the lake to reach temperatures conducive to corixid reproduction and development.

Chironomidae (Diptera)

Chironomids (midges) spend most of their life cycle in the larval stage. The adult, which does not bite, lives at most several weeks, but usually only a few days. They frequently occur in large swarms at waterbodies. Eggs are usually deposited on the water surface, sometimes attached to emergent vegetation. Hatching occurs within several weeks, frequently after a few days, and is followed by four larval instars. Most chironomid larvae build tube-like or loosely constructed cases of fine substrate particles cemented together. Larvae are mostly microphagous, feeding on detritus and microorganisms. In warm environments emergence can occur throughout the season and many species are multivoltine. A *Dicrotendipes* sp. in Arizona can have up to 30 generations per year (Gray 1981).

Larvae are usually confined to surface layers of soft sediments, penetrating only a few centimeters of the surface. In habitats with soft bottoms, ~95% of larvae occur in the upper 10 cm of the substrate (Oliver 1971). The larvae of several common genera, including *Chironomus* and *Dicrotendipes*, are called "bloodworms" because of their bright red color, a consequence of having hemoglobin as a component of their hemolymph. Their bright color and abundance in warm, shallow, open water make them conspicuous prey for shorebirds.

Ceratopogonidae (Diptera)

Related to chironomids, these flies live in moist areas close to the larval habitat. The adults are known as "punkies" or "biting midges". For egg maturation, females of most species require a blood meal, obtained by an irritating or painful bite. Adults are often conspicuous in mating swarms. In *Culicoides* and related genera, the larval habit ranges from free-swimming aquatic forms to those that burrow in moist soil or benthic sediments. They are predominantly predaceous, and some are scavengers (Downes and Wirth 1981). Gray (1981) reported rapid development times (9-16 days), continuous reproduction, lack of diapause, and 35 potential generations per year for a ceratopogonid in a Sonoran Desert lowland stream.

At Holloman, chironomid larvae (primarily *Dicrotendipes* sp.) were most common in mudflat and shallow-water habitats. Density estimates from core samples (8 cm diam., 10 cm deep) ranged from 400 to 6700 individuals per m^2 in moist-soil habitats at the north end of L. Holloman and the constructed wetland, respectively (Table 4). At north

L. Holloman, the presence of chironomids was attributed to their downstream drift from the outflow basin at the upper end of the lake. Samples from sites adjacent to the channel had almost none. Net samples from the outflow pond and the channel flowing to the lake confirmed the presence of bloodworms in the bottom sediments. At the constructed wetland, total chironomid densities at shorebird foraging sites were 1300 larvae per m^2 in April and 6700 larvae per m^2 in May. High densities of biting midge larvae occurred at Stinky Playa (5600 larvae per m^2) and North Holloman (3800 larvae per m^2) in spring sampling (Table 4), but they did not occur at the CW in April and May. The absence of ceratopogonids at the CW sites suggests that they do not colonize new habitats as readily as chironomids, or that a microbial food base for biting midge larvae has not yet developed in the CW.

Bledius spp. (Coleoptera: Staphylinidae)

These beetles live in burrows on the mudflats and saltflats at Stinky Playa and Lake Holloman. Occurring in high densities (Table 5), they are present all year and are most abundant in pitfall traps during the period that coincides with shorebird migration at the Holloman wetlands (Fig. 10). In areas of new mudflat at the CW, *Bledius* burrows were present in relatively high abundance in spring, 1998, but few adult beetles were collected. These sites of high burrow density occurred in areas that were undergoing drawdown and rapid drying. Other, smaller areas of permanently moist soil supported small populations of *Bledius*, indicating that the CW may eventually become suitable habitat for this organism. See Appendix C for a discussion of the biology of *Bledius* and its occurrence in shorebird diets and habitats.

We found three species of *Bledius* at Stinky Playa and Lake Holloman during excavations of burrow sites and analysis of Snowy Plover fecal samples. *Bledius mandibularis* was the most abundant, and *B. ferratus* and *B. eximius* were far less common (Table 5, Appendix C). This pattern is similar to that found by Dr. Lee Herman of the American Museum of Natural History, who collected four *Bledius* species at Stinky Playa in May, 1968 – *mandibularis, ferratus, flavipennis, and playanus* (Herman 1972, 1976). He noted a large colony of *B. mandibularis* on the surface of the saltflat and later collected the four species with a light trap, *B. mandibularis* constituting 75% of the total individuals (L. Herman, personal communication). Thus, *B. mandibularis* has persisted both as the most abundant *Bledius* species and as a major component of the invertebrate fauna at Stinky Playa for at least 30 years. The present number of *Bledius* species has decreased by one with the loss of *playanus* and *flavipennis* and the addition of *eximius.* Herman (1972, 1976) found these five *Bledius* species (in various combinations and relative abundances) at saltflats and saline ponds in southern and central New Mexico. These observations suggest that this suite of species may be an indicator of playas and other saline habitats in New Mexico. Changes in *Bledius* species composition over a 30-year period would be expected at Stinky Playa. Differences in presence or absence of the less abundant species might be attributed to several causes, including competitive displacement, subtle changes in habitat suitability (salinity, amount or duration of flooding), random population fluctuations, or differences in collection methods. Nonetheless, persistence of *B. mandibularis* and the net decrease of *Bledius* species richness by 1 suggest that the saltflat at Stinky Playa has been a relatively stable habitat for these beetles.

SHOREBIRD FORAGING AND HABITAT USE

To assess the suitability of habitat for shorebirds at the constructed wetland, we collected data on habitat use and availability, and measured shorebird foraging and invertebrate abundance in mudflat habitat. We have classified the shorebirds of HAFB by shorebird group and foraging guild (Table 6), following the scheme of Helmers (1992). Guilds provide a functional basis for identifying and managing habitat in relation to the invertebrate prey base.

The shorebirds recorded from HAFB comprise 7 foraging guilds, each defined by a combination of habitat (terrestrial, aquatic, or pelagic) and method of foraging (probing or gleaning) (Table 6). The shorebird group name is used in the following sections as a descriptive term for its associated foraging guild, e. g., "plover" includes the 6 species that are terrestrial or aquatic gleaners. Of the 7 shorebird groups at HAFB, only three (plover, sandpiper, avocet/stilt) had sufficient numbers of individuals to be included in our analyses of foraging behavior in moist-soil habitat (see below), and a fourth (yellowlegs) was represented only in the water depth observations (next section). The phalaropes, although abundant at the Holloman wetlands, do not use moist-soil habitat for foraging, but prefer the deeper, open water at Lake Holloman and Lagoon G. The remaining two foraging guilds, represented by the godwit and curlew/turnstone groups, include the least abundant shorebirds and did not occur in our observations of foraging behavior and habitat use.

Water Depth Distribution of Foraging Shorebirds

Methods: We observed individual shorebirds throughout the constructed wetland in April and May of 1998. Species and water depth were recorded for each individual. Observations were confined to water depths less than 15 cm. It was not possible to measure water depth directly at the exact location that a bird was observed, because of topographical variation of the surface sediments and the inability of observers to walk or wade into the soft sediments. We estimated water depth by recording the anatomical region on an individual bird's leg that corresponded to the water height. We grouped water depths into five categories: above the toes; tarsus; heel; tibiotarsus; belly. For each species we used average tarsus lengths published in Ridgway (1919). For all other measurements (N = 3-5 specimens per species) we measured specimens at The University of New Mexico, Museum of Southwestern Biology. We then summed the relevant lengths to determine the water depth in which each individual was foraging.

Results: Ten shorebird species, comprising 4 foraging guilds, were represented in the observations (Fig. 11). All ten species foraged within the range of water depths we defined. As expected, long-legged species (avocets and stilts) consistently foraged in deeper water than the other species, without significant overlap. All other species foraged at depths of 2 cm or less.

Foraging Behavior of Shorebird Guilds

Methods: We observed shorebird foraging at 4 sites in the constructed wetland (Fig. 2). Designated T1, T2, T3, and T4, the 4 sites were selected to encompass representative habitat, i. e., a linear zone of shoreline, a rectangular area (20 m x 100 m) encompassing the shoreline. Observations were conducted over 8 days (April 14-17 and May 5-8, 1998), with 13 to 15 sampling periods at each site. Each sample consisted of a scan with a spotting scope (completed within 10 minutes) of all microhabitats available at each site. The species, method of foraging, and microhabitat were recorded for each bird encountered in the scan. Foraging behaviors were classified as glean (prey picked from the surface), chase and glean (prey pursued and picked from the surface), sweep and glean (bill swept from side to side through the water), and probe (bill inserted into substrate) (Remsen and Robinson 1990, Helmers 1992). Microhabitat was defined as dry soil (substrate light in color with a dry texture compared to the surrounding soil), saturated soil (water depth < 1 cm), shallow water (1 cm < water depth <15 cm), or deep water (water depth >15 cm).

Results: These observations reveal how the 3 guilds used the different microhabitats at the constructed wetland (Fig. 12). All guilds used shallow water and saturated soil for foraging. Sandpipers restricted their foraging to these substrates, with avocets/stilts additionally utilizing deep water, and plovers also using dry soil for foraging. Thus, although there were slight differences in foraging maneuvers among guilds, all foraged in mudflat, i. e., shallow water or saturated soil, where the main foraging behavior was gleaning.

Availability of Mudflat Habitat

Methods: In May, 1996, we began to monitor the change in exposed shore at a representative point at Lake Holloman. A reference point was established on the east side of the lake (point indicated on Fig.1). Here a stake was placed at the outer limit of the salt flat margin. At monthly intervals the distance to the water line was measured from the stake. The width of this band of both moist and dry substrate is used as an index of change in shorebird foraging during this period of lake level fluctuations.

In spring, 1998 we measured the area of potential mudflat habitat in the part of the constructed wetland where we conducted observations of shorebird foraging. On 25 March one researcher walked the perimeter of the shoreline in Ponds 2 and 4 (Fig. 2), using a GPS unit. These data were used to create an ArcView layer of the pond perimeters. The water levels were at or near their maximum on this date, and were subsequently allowed to draw down. On 6 May the shoreline perimeter was measured again. The GPS data were used to plot the perimeter and to calculate an estimate of shoreline length on the two dates.

Results: Due to a combination of influences (low rainfall, high evaporation, interrupted inflow during treatment plant construction), lake levels were lower than usual in July and August, 1996 (Fig. 13). Wastewater flow from the new plant began to enter Lake Holloman on 30 July, 1996. Levels gradually increased in the lake through April 1997, and remained relatively constant through the end of 1997. In November, 1997, water began to be diverted to the new CW, causing levels in the lake to decrease through June 1998. Thus, areas of mudflat habitat were quite small through 1997 and mudflat only began to reappear in the spring of 1998, due to the higher spring temperatures and the CW receiving a substantial portion of the effluent (Fig. 13).

Once the CW was filled, it was allowed to draw down over a two-month period between March and May, 1998. The stippled area of Fig. 2 shows the difference in the 2 shoreline locations between March and May. The figure delimits the area where we sampled invertebrates and observed shorebirds as the mudflat corridor moved with the receding water line. The shoreline perimeters for Ponds 2 and 4 combined were calculated to be 3640 m (March 25) and 3289 m (May 6). Using a 6-m width for the perimeter, a mudflat area of 2.18 ha (21,840 m^2) and 1.97 ha (19,734 m^2) was estimated for the two dates, respectively. Two hectares represents 1.4% of the total area of constructed wetland (140 ha). Thus, although the shoreline moved considerably, the actual area of mudflat habitat in the CW did not change appreciably during the drawdown.

Invertebrate and Shorebird Numbers

Methods: Mudflat sites, observation dates, and substrate descriptions are the same as in the methods for "Foraging Behavior of Shorebird Guilds". Here we use counts of shorebird numbers recorded on the scans. Invertebrates were collected in shallow water and saturated soil microhabitats using a core sampler. Three cores (8.2 cm diameter, 10 cm depth) were taken at each of 4 sites and 2 microhabitats (N= 24 samples) in both April and May. A 10-cm core depth included the maximum bill length of American Avocets, the species with the longest bill among the 3 foraging guilds that we studied (Robinson et al. 1997). The May sampling points were moved to correspond to the May location of the mudflat habitat. To minimize disturbance of foraging birds and to avoid creation of artificial feeding sites (depressions made by footprints) within the observation areas, all samples were collected on a single day after the foraging observations had been completed. The samples were processed on the day of collection by washing through a series of sieves and saving the fraction collected on a #35 standard sieve (pore opening = 0.5 mm). Each sample was preserved in 70% ethyl alcohol, stored in individually-labeled containers, and transported to the laboratory for identification and counting of invertebrates.

Results: The number of invertebrates in the constructed wetlands varied by month and site, but not systematically by habitat type (Fig. 14). At sites 1 and 2, there were no differences in invertebrate numbers between shallow water and saturated soil habitats in either April or May. At site 3 in May, there were significantly more invertebrates in saturated soil than in shallow water. In contrast, at site 4 in April, there were significantly more invertebrates in shallow water than saturated soil. A t-test combining all sites and dates showed no differences in invertebrate numbers between shallow water and saturated soil habitats (t=0.6, p=0.44, n=48).

For all sites combined, there were significantly more invertebrates in May than in April in both saturated soil and shallow water habitats (Appendix D: Table D1). Sites differed significantly in number of invertebrates in both habitats in May and shallow water in April. In all three tests, samples from sites 3 and 4 (which did not differ from each other) contained significantly more invertebrates than sites 1 and 2 (which also did not differ from each other: Appendix D: Table D2).

The number of birds in the constructed wetlands differed somewhat by month, site, and habitat, but no systematic patterns were evident. For avocets/stilts, there were more birds in all sites and all habitats combined in May than in April, while sandpipers were significantly more abundant in April than in May. No differences existed between months for plovers (Appendix D: Table D3). Monthly differences are probably more reflective of migration schedules than responses to invertebrate abundance, because avocets and stilts typically arrive later than migrating sandpipers.

Differences in bird numbers among sites occurred for avocets/stilts only in deep and shallow water during May. For sandpipers, differences among sites occurred only in shallow water in both months. For plovers, among-site differences occurred in shallow and saturated habitats in both months (Appendix D: Table D4).

Not surprisingly, all three guilds of shorebirds tended to use both types of mudflat habitat preferentially over dry soil and deep-water habitats. However, avocets and stilts significantly preferred shallow water to saturated soil in May (Fig. 15b; Appendix D: Table D5), while plovers preferred saturated soil to shallow water habitat in April (Fig. 15d; Appendix D: Table D5). This result is consistent with the species' foraging modes – avocets and stilts typically glean and sweep in mudflat and deeper water, while plovers tend to glean in mudflat and drier soils (Fig. 12). Sandpipers showed a preference for saturated soil over shallow water only at site 2 in April (Fig. 15c; Appendix D: Table D5), but there were no differences in the other seven sandpiper samples (Appendix D: Table D5). This is consistent with their foraging mode, which combines probing and gleaning in both types of mudflat habitat, while avoiding deeper water and dry soil (Fig. 12).

Simple regressions of number of birds on number of invertebrates at a site yielded no significant associations for sandpipers and plovers (Appendix D: Table D6). For avocets/stilts, however, when months and habitats were combined, the regression was significant. Also, when months were combined but shallow water and saturated soil habitats were examined separately, both saturated and shallow habitats showed significant regression of bird number on invertebrate number for this guild (Appendix D: Table D6). However, we suspect that this result was driven by between-month differences, because regressions in which habitats were combined but months were examined separately showed no relationship between invertebrates and birds (Appendix D: Table D6).

The absence of a clear relationship between the number of shorebirds and the number of invertebrates at a site is somewhat surprising. One possible explanation is that the numbers of invertebrates at all sites exceeded some abundance threshold, such that all guilds were able to acquire sufficient food at any site. Eldridge (1992) suggests that a minimum of 100 invertebrates per square meter is necessary to attract migrating shorebirds. Our samples greatly exceeded this density at the constructed wetlands (Table 4). Given that shorebird populations at the Holloman Lakes complex are small relative to many coastal or larger inland sites, shorebirds at Holloman may not be food limited. If invertebrates are so abundant at all mudflat sites that intake is limited only by probing rate, birds should have no reason to select among habitats. An ideal free distribution (Fretwell and Lucas 1970) and a resulting correlation between food abundance and predator number should only occur when food is limited and varies among foraging sites.

MANAGEMENT OF THE CONSTRUCTED WETLAND

The determining factor in the success of wetland creation and restoration is the correct application of hydrologic principles in the design of the site. Failure of constructed wetlands is often associated with improper hydrology. Unpredictable and rapidly fluctuating hydrologic conditions can lead to washouts, scouring, revegetation failure, and animal (including macroinvertebrate) emigration, resulting in decreased biodiversity and potential loss of water quality function (Mitsch and Wilson 1996, Mitsch et al. 1998). Problems at the Holloman CW caused by washed-out culverts and breached dikes underscore the importance of hydrologic-associated design factors in successful maintenance of the wetland. Although beyond the scope of our report, understanding the hydrologic basis for operation of the CW is essential for its future management.

In addition to hydrology, effective management of the constructed wetland should consider at least three biotic components: shorebirds, macroinvertebrates, and vegetation. Management for shorebird habitat should be the primary goal. Waterfowl are a secondary concern, given the availability of deepwater habitats at L. Holloman and Lagoon G. Waterfowl species with food habits similar to those of shorebirds (Green- and Blue-winged Teal, Northern Pintail, American Wigeon) will benefit directly from habitat management for shorebirds.

Depth and timing of flooding will influence shorebird use of the area. Moist-soil and shallow water habitats should be maintained during shorebird migration. However, the effects of such apparently simple hydrologic manipulations on the invertebrate fauna and vegetation are not well known for a man-made wetland in the northern Chihuahuan Desert. Moist-soil management techniques used at playa lakes in the Midwest for shorebirds (Eldridge 1992) and the Southern High Plains of Texas and New Mexico for waterfowl (Bolen et al. 1989, Haukos and Smith 1992) may be relevant to the Holloman CW. We use them as guidelines, but their application to the Holloman CW requires care and a willingness to be flexible, given the inherent differences in the systems.

Shorebirds in migration select stopover areas based on a specific combination of habitat characteristics, including (1) a *wetland in partial drawdown* with a combination of open mudflat and shallow water in a basin with gradually sloping sides, (2) *high invertebrate abundance*, and (3) *sparse vegetation* (Eldridge 1992). Invertebrates are the critical element; without them the birds do not remain at the site. The key to managing habitat for migrating shorebirds is to encourage invertebrate production and to make invertebrates available for foraging birds through drawdown. A proper regime of drawdown and flooding can stimulate plant growth and decomposition, creating a detrital food source for invertebrates. All three of the above conditions presently occur to varying degrees at the CW.

A *wetland in partial drawdown with a mixture of mudflat and shallow water habitats* provides a diversity of foraging habitats and a dependable food supply. Although different bird species forage at different water depths or substrates, 70-80% of shorebird species prefer depths of less than 10 cm (see Fig. 12 for shorebird species and water depths in which they foraged at the CW). Without drawdown, avian predators can deplete invertebrates at the mud-water interface. Chironomid larvae, for example, do not migrate in response to decreasing water level, and many species can survive moderate levels of desiccation (Pinder 1986). The larval midge population will be depleted through time along an unvarying shoreline unless drawdown is slow and continuous.

High invertebrate abundance is the critical component in determining suitability of wetlands for shorebirds. The importance of chironomid and other dipteran larvae for shorebird habitat has been emphasized for wetlands in other geographic areas (Eldridge 1992, Helmers 1992). Chironomid density at the CW (see previous discussion of "Chironomidae") has already exceeded the threshold of 100 individuals per m^2 proposed by Eldridge (1992). A diversity of other invertebrate taxa is present, and nearby habitats at L. Holloman and Lagoon G provide a source pool for invertebrate colonization of the CW. Colonization can occur through active dispersal of invertebrates and passive transport by birds moving among the water bodies.

Vegetation will be the most problematic aspect of maintaining shorebird habitat at the Holloman CW. At present the CW is dominated by saltgrass in Pond 1, alkali bulrush and saltgrass in Pond 2, and upland vegetation adapted to high soil salinities surrounding Ponds 3 and 4. There is a good mix of mudflat, shallow water, emergent, and deepwater habitats. One of the most common management problems in freshwater wetlands is the development of monotypic plant communities or nuisance exotics (Fredrickson and Laubhan 1996). The situation at Holloman is no exception. Saltcedar is already present. Its requirement of moist soil as a substrate for seed germination can have a confounding influence on schemes for drawdowns and other moist-soil management options (see next section on "Saltcedar Control"). Alkali bulrush may also become a problem in the constructed wetland. It is already the dominant emergent species in Pond 2 (H. Reiser, personal communication) and has the potential to render much of the wetland unsuitable as shorebird habitat through loss of bare areas preferred for foraging (see following section on "Alkali Bulrush Control").

Saltcedar Control

Management and control of saltcedar (*Tamarix* spp.) is currently in progress to a limited degree at HAFB. Bulldozing and mechanical clearing of some mature stands was undertaken during wetland construction. Potentially effective methods for saltcedar control at the CW include inundation of seedlings and young plants and herbicide application to young plants.

Killing *Tamarix* by flooding can be effective and efficient, but it requires good control over water levels. Smith and Kadlec (1983) found that maintaining water depth of a few centimeters prevented establishment of saltcedar in a Utah saltmarsh. Within the first few weeks after germination, seedlings can be killed by relatively short periods of flooding; they float to the surface (Gladwin and Roelle 1998). Later, within the first growing season, inundation of a month or two is required; adult plants can survive flooding of 3 months or more (J. Friedman, USGS, personal communication). Observations at Bosque del Apache National Wildlife Refuge indicate that first-year saltcedar does not survive well after fall flooding, but that seedlings can survive prolonged spring flooding in their second year (Gladwin and Roelle 1984, citing observations by J. Taylor). Seeds lose their viability within 4 weeks and cannot remain dormant in the soil. The most suitable substrate for germination is moist, fine silt deposits (Brock 1994). Thus, areas drawn down for shorebird foraging habitat are prime sites for saltcedar seed germination and establishment. The period of *Tamarix* seed dispersal (and presumably seedling establishment) occurs from early April through early October in the Southwest (Shafroth et al. 1998, Warren and Turner 1975). Seed dispersal will coincide with spring migration (April and May) and the first part of fall migration (late August and September), creating a conflict between management for shorebirds and control of saltcedar by flooding.

A new basal application technique (Parker and Williamson 1996) using the herbicide triclopyr (trade names: Remedy and Garlon 4) may prove useful for saltcedar control at the CW. Using a backpack sprayer, a mixture of the herbicide and a vegetable oil blend is applied to the lower 2 feet of each young saltcedar stem (i. e., those with reddish-brown, smooth bark). The most effective time for treatment appears to be during the period of active growth (May through September). Advantages of this method include its (1) selectivity for saltcedar, i.e., other vegetation that may help to retard saltcedar re-invasion can be maintained, (2) relatively low cost, (3) environmental compatibility. Triclopyr is a selective herbicide that has little or no effect on grasses. It binds quickly to the soil with little or no biological activity and breaks down rapidly, with no residual activity if the treated area is inundated. Remedy is registered for use on rangelands and pastures, Garlon 4 for forests and wildlife openings, and both for non-irrigation ditch banks. An important caveat is to avoid contamination of water by overapplication that results in runoff from the stems. A temporary barrier at the wetland perimeter would provide an additional safeguard against contamination of moist-soil or aquatic habitats from nearby treatment areas. This basal application technique has been used successfully in several riparian areas of the Southwest and is considered to be safe and effective in wetland habitats if the previous guidelines are followed (D. Parker, personal communication).

Alkali Bulrush Control

Cutting and burning are effective control techniques if flooding to a depth >20 cm follows the treatment. Deep flooding is required because heat penetration into the soil from fires is insufficient to cause belowground plant mortality. Inundation soon after burning or mowing will cause rapid oxygen consumption in the submerged plant parts, resulting in decay of the plant material and inhibiting its capacity to regenerate (Smith and Kadlec 1985).

If the lessons from wetland plant ecology in Great Basin salt marshes (Smith and Kadlec 1986, Kadlec and Smith 1989) can be applied to the same species occurring at Holloman, general patterns seen at the CW become clearer. In the Great Basin, alkali bulrush becomes dominant at sediment salinity levels of 10-20 mmhos and can tolerate soil salinity up to 18 mmhos for growth; saltgrass has a higher salinity tolerance (>20 mmhos) and is common in areas that dry periodically, with a resulting high salinity in the upper sediment layers; cattail is the least tolerant of salinity (<10 mmhos). The Mead series soils of the CW are characterized by salinities >16 mmhos/cm (Derr 1981), creating conditions conducive to further spread and dominance by alkali bulrush if inundated. Note that in areas of drawdown (prime sites for saltcedar colonization), sediment salinity can increase rapidly as periodic flooding and drying cause salts to return to the surface by capillary action, restoring conditions that promote bulrush establishment (Kadlec and Smith 1989). Thus, flooding and drawdown regimes designed to control saltcedar could promote proliferation of bulrush.

Management Recommendations

1) An ideal *drawdown schedule* for the CW would optimize the creation and maintenance of mudflat habitat during both spring and fall shorebird migrations. Conflicting conditions involving control of invasive plant species will require management strategies specific to these problems. The complex of wetland ponds provides the option to conduct drawdowns asynchronously with the objective to have at least one pond or cell available for nesting and migration periods.

2) Management and *control of saltcedar and alkali bulrush* are important for maintenance of shorebird habitat.

    a) *Bulrush control* by cutting and burning followed by flooding may be the only effective method, although there will be detrimental effects on shorebird habitat. Alkali bulrush management should be considered an ongoing maintenance requirement; otherwise, the plant will become the dominant component of the wetland.

        i) If done in the late fall or winter (and followed by flooding), effects on shorebirds and their habitat will be minimal, and promotion of saltcedar seedling establishment would be avoided.

ii) If bulrush control were necessary earlier in the year (March through mid-October), a schedule alternating among seasons or years among ponds would assure moist-soil habitat in some cells. However, *Tamarix* encroachment and subsequent control would require additional time and effort.

b) *Saltcedar* establishment is unavoidable in areas drawn down for shorebird habitat. Assuming that personnel are available, the basal application treatment discussed previously would be a control method compatible with maintenance of shorebird habitat. Otherwise, the area would have to be flooded at the end of shorebird migration.

3) *Protection of nesting shorebirds* from disturbance and predators. Both human disturbance and mammalian egg predators, primarily coyotes, can have detrimental effects on breeding success of Western Snowy Plovers and American Avocets (Grover and Knopf 1982, Page et al. 1985, Page et al. 1995, Robinson et al. 1997). The following actions would be effective.

a) Restrict access by people and accompanying dogs during nesting season. Gates already restrict vehicle access, but informative signs should warn humans. Closure to the public and roping or fencing of nesting areas may have to be considered if increasing shorebird reproductive success becomes a management goal.

b) Prohibit hunting in and adjacent to the CW from April through July.

c) Solar-powered electric fences have been used with some success in reducing coyote predation on Snowy Plover nests at saltflats in Oklahoma (Koenen et al. 1996). For relatively small nesting areas such as those occurring at the Holloman CW, movable electric fences may be an effective method to reduce mammalian nest predation. This method would probably be cost-effective. Estimated fence costs in the Oklahoma study were $0.85/m. Coyotes or their scat are commonly seen at the Holloman wetlands and are likely candidates as nest predators.

4) *Avian botulism* is a *potential* problem that should be considered in wetland management plans. Conditions at the Holloman wetlands correspond to those contributing to botulism outbreaks: large concentrations of waterfowl, fluctuating water levels, shallow ponds with gradually sloping margins, saline conditions, and warm temperatures (Wobeser 1997). American Avocets and Black-necked Stilts are the shorebird species most susceptible to botulism (Robinson et al. 1997). Drawdowns are essential in areas managed for shorebirds, and botulism control must focus on carcass cleanup (Locke and Friend 1987). At Holloman, monitoring and removal of bird carcasses (primarily avocets, stilts, and waterfowl) in late summer and early fall would be prudent and could be incorporated into shorebird surveys or a census program. Prevention and control of outbreaks is preferable to treating sick birds, which is labor-intensive and expensive. Botulism outbreaks often occur at the same wetland year after year. Once established, botulism-prone marshes persist and the disease is difficult to eradicate. Although avian botulism is not evident at the Holloman wetlands now, future management plans should consider its potential occurrence.

Recommendations for Future Research

1) *Document effects of natural change and management actions on vegetation, birds, and invertebrates in the wetlands*:

   a) Using remote sensing, create a GIS record of natural and managed vegetation changes.

   b) Document habitat use by shorebirds as the CW changes. Research would focus on habitat use in areas under different management actions or vegetation control regimes.

   c) Document changes in invertebrate populations and diversity in conjunction with water level manipulations or vegetation management.

2) *Shorebird nesting studies*:

Breeding surveys and nest monitoring of Western Snowy Plovers, American Avocets, and Black-necked Stilts would be useful in providing data on habitat suitability of the constructed wetland. Such studies would help to determine if predation on nests is a problem.

3) *Continuation of shorebird surveys or census program at the constructed wetland*:

Monitoring of wetland birds should be continued in order to provide baseline data on habitat use. The main public interest in the wetland is its avifauna, for recreational (birdwatching, photography, ornithological societies), educational (school groups. environmental education), and research purposes. These activities could also generate opportunities for monitoring the wetland's birds through volunteers or personnel associated with research projects at the wetland.

4) *Characterization of the constructed wetland for vegetation management*: Management activities designed to promote desirable species and restrict exotics may conflict. A study of the relationships among hydrology, hydraulics, salinity, and vegetation would provide baseline information necessary for vegetation management. Measurements should include conductivity and selected chemical parameters of surface and interstitial water, sediment characteristics, and water levels and flow rates under different hydrologic conditions (partial or complete drawdown, reflooding at various depths). If vegetation data (field measurements or remote sensing) were collected concurrently with physical measurements, information about plant salinity tolerances, water requirements, and succession in this unique constructed wetland could be investigated.

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Table 1 Wetland habitat types by water body at the Holloman wetlands.

Habitat	Water Body			
	Lake Holloman	Stinky Playa	Lagoon G	Constructed Wetland
saltflat	+	+	+ (n.s.)	+
mudflat	+	NA	+	
shallow water	+	~	+	+
emergent vegetation	(+)		(+)	+
deep water	+		+	+

+ = present; (+) = limited in extent; ~ = ephemeral; - = not present
n.s. = not sampled (see text); NA = not applicable

Table 2. Invertebrate sampling methods for the Holloman wetlands.

Method	Target fauna	Habitat	Site	Parameters (other than relative abundance)	Description
pitfall traps	*Bledius*	saltflat	S, H	phenology	10 traps per site
	terrestrial arthropods	saltflat	S, H		
burrow excavation	*Bledius*	saltflat	S, H	density	0.1 m^2 quadrat, to top of water table
soil core	dipteran larvae, benthos	mudflat	S, H, CW	density	diam = 8.2 cm or 10 cm
D-shaped net	corixids	shallow and deep water	H, L, CW	phenology, instars	diam = 30.5 cm (with 0.15 mm mesh bottom)
	dipteran larvae, ostracods	shallow water sediments	S, H, L		
	nekton	emergent	CW		
aquatic trap	nekton, neuston	shallow water, emergent	CW		standard design (Bioquip)
LaMotte sampler	ostracods, other benthos	shallow water	S, H		standard design (Bioquip)
Ekman dredge	benthos	deep water	H, L		(not used after 1996)

S = Stinky Playa, H = Lake Holloman, L = Lagoon G, CW = Constucted Wetland

nekton = free-swimming within water column
neuston = living on water surface
benthos = within or on bottom sediments and submersed surfaces

Table 3. Relative abundance of macroinvertebrate taxa in habitats at the Holloman wetlands.

Higher Taxa and Families*	Genus	adults, nymphs, larvae	Habitat					
			saltflat	mudflat	shallow water	emergent	deep water	other
GASTROPODA								+ CB**
Physidae	*Physella*							
CRUSTACEA								
(Cladocera)					+++	+	+	
(Copepoda)					+++	+	+	
(Ostracoda)				++	++			
(Isopoda)				+				
INSECTA								
Odonata								
Libellulidae		l			+	+		
Hemiptera								
Belostomatidae		a			+			
Corixidae	*Corisella*	a, n			+++	+	+++	
Diptera								
Ceratopogonidae	*Culicoides*	l		+++		+		
Chironomidae	*Dicrotendipes*	l/a		+++/+	+++/+	+		++ CB
Culicidae		l			++	+		
Ephydridae	*Ephydra*	l		++		+		
Syrphidae	*Eristalis*	l		++	+			
Hymenoptera								
Formicidae		a	+					
Coleoptera								
Anthicidae	*Ischyropalpus*	a	+					
Carabidae	*Bembidion*	a	++	++				
	other	a	++	+				
Cicindelidae	*Cicindela*	a	+					
Curculionidae		a	+			+		
Dytiscidae		a			+	+		
Haliplidae	*Haliplus*	a			+	+++		
Hydrophilidae	*Berosus*	a			+++	+++		
Staphylinidae	*Bledius*	a, l	+++	++				
	Carpelimus	a	+++	++				
ARACHNIDA								
(Araneae)			+			+		
(Solpugida)	*Eremochelis*		+					

Abundance categories: + = present, ++ = common, +++ = abundant

* Taxon names in parentheses are subclasses or orders.

** CB = catchment basin at north end of L. Holloman for outflow from treatment plant.

Table 4. Density estimates (individuals per m^2) of chironomid and ceratopogonid larvae.

Site	Date	Ceratopogonidae (biting midges)	Chironomids (midges)	Combined
Stinky Playa	May-97	5640		
North Holloman	Apr-97	3808	424	4232
Constructed Wetland	Apr-98		1297	
	May-98		6737	

Table 5. Numbers and density estimates of *Bledius* beetles from excavated burrows and core samples. Each sample is a 0.1 m2 quadrat excavated to the top of the water table, unless identified as a soil core.

Site	Date	Burrows		*Bledius* adults			
		Depth (cm)	No. of entrances	*Bledius mandibularis*	*Bl. eximius*	Total adults	Density (no./m^2)
Stinky	7/13/96	7.5	22	41	9	50	500
	7/16/96	7.5	8	13	1	14	140
	3/21/97	12.5	10	30	1	31	310
	4/16/97	12.5	12	38	3	41	410
	4/16/97	12.5	3	24	0	24	240
N Holl	11/19/96	12.5	?	3		4	40
N Holl	3/17/97	12.5	13	38	0	38	380
N Holl	5/15/97	12.5	40	16	0	16	160
CW	3/20/97	10 (core)	1	0	0		128
	3/20/97	10 (core)	2	0	0	1	128

Table 6. Shorebirds and shorebird foraging guilds at the Holloman wetlands.

Shorebird Group	Foraging Guild[a]	Common Name[b]	Scientific Name
Plover	terrestrial/aquatic gleaner	Black-bellied Plover	*Pluvialis squatarola*
		Snowy Plover	*Charadrius alexandrinus*
		Semipalmated Plover	*Charadrius semipalmatus*
		Killdeer	*Charadrius vociferus*
		American Golden Plover[c]	*Pluvialis dominica*
		Mountain Plover[c]	*Charadrius montanus*
Sandpiper	aquatic prober/gleaner	Semipalmated Sandpiper	*Calidris pusilla*
		Western Sandpiper	*Calidris mauri*
		Least Sandpiper	*Calidris minutilla*
		White-rumped Sandpiper	*Calidris fuscicollis*
		Baird's Sandpiper	*Calidris bairdii*
		Pectoral Sandpiper	*Calidris melanotus*
		Stilt Sandpiper	*Calidris himantopus*
		Long-billed Dowitcher	*Limnodromus scolopaceus*
		Common Snipe	*Gallinago gallinago*
		Red Knot[c]	*Calidris canutus*
		Dunlin[c]	*Calidris alpina*
		Sanderling[c]	*Calidris alba*
		Ruff[c]	*Philomachus pugnax*
		Short-billed Dowitcher[c]	*Limnodromus griseus*
Avocet/Stilt	aquatic gleaner/prober	Black-necked Stilt	*Himantopus himantopus*
		American Avocet	*Recurvirostra americana*
Phalarope	aquatic/pelagic gleaner	Wilson's Phalarope	*Phalaropus tricolor*
		Red-necked Phalarope[c]	*Phalaropus lobatus*
		Red Phalarope[c]	*Phalaropus fulicarius*
Yellowlegs	aquatic gleaner	Greater Yellowlegs	*Tringa melanoleuca*
		Lesser Yellowlegs	*Tringa flavipes*
		Solitary Sandpiper	*Tringa solitaria*
		Willet	*Catoptrophorus semipalmatus*
Curlew/Turnstone	terrestrial/aquatic gleaner/prober	Spotted Sandpiper	*Actitis macularia*
		Long-billed Curlew	*Numenius americanus*
		Whimbrel[c]	*Numenius phaeopus*
		Ruddy Turnstone[c]	*Arenaria interpres*
Godwit	aquatic prober	Marbled Godwit	*Limosa fedoa*
		Hudsonian Godwit[c]	*Limosa haemastica*

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[a] Includes all species in shorebird group (from Helmers 1992).

[b] Shorebird species from *Checklist of Birds, Holloman Air Force Base* (1996).

[c] Not observed during this study; all except Sanderling and Red-necked Phalarope are accidentals.

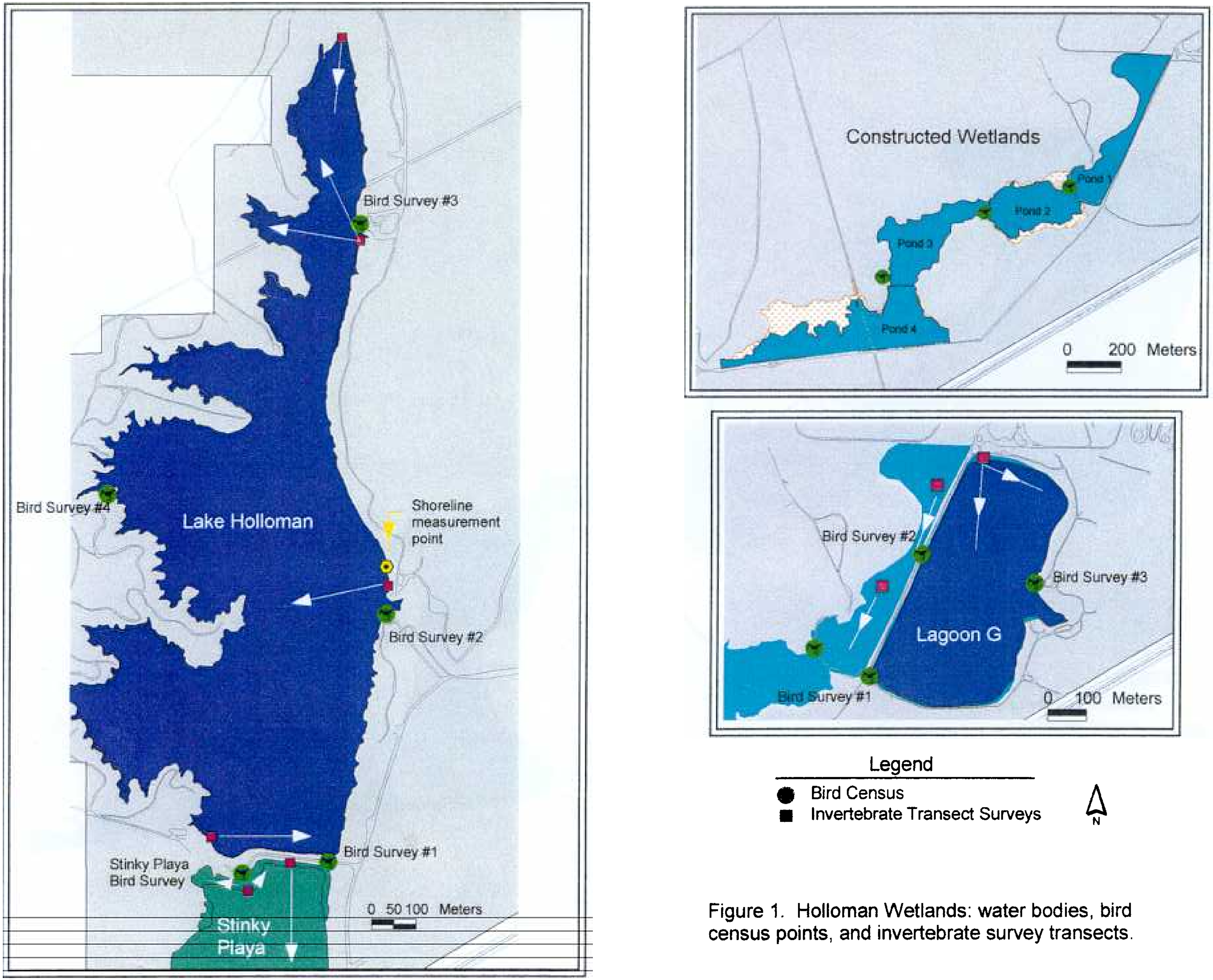


Figure 1. Holloman Wetlands: water bodies, bird census points, and invertebrate survey transects.

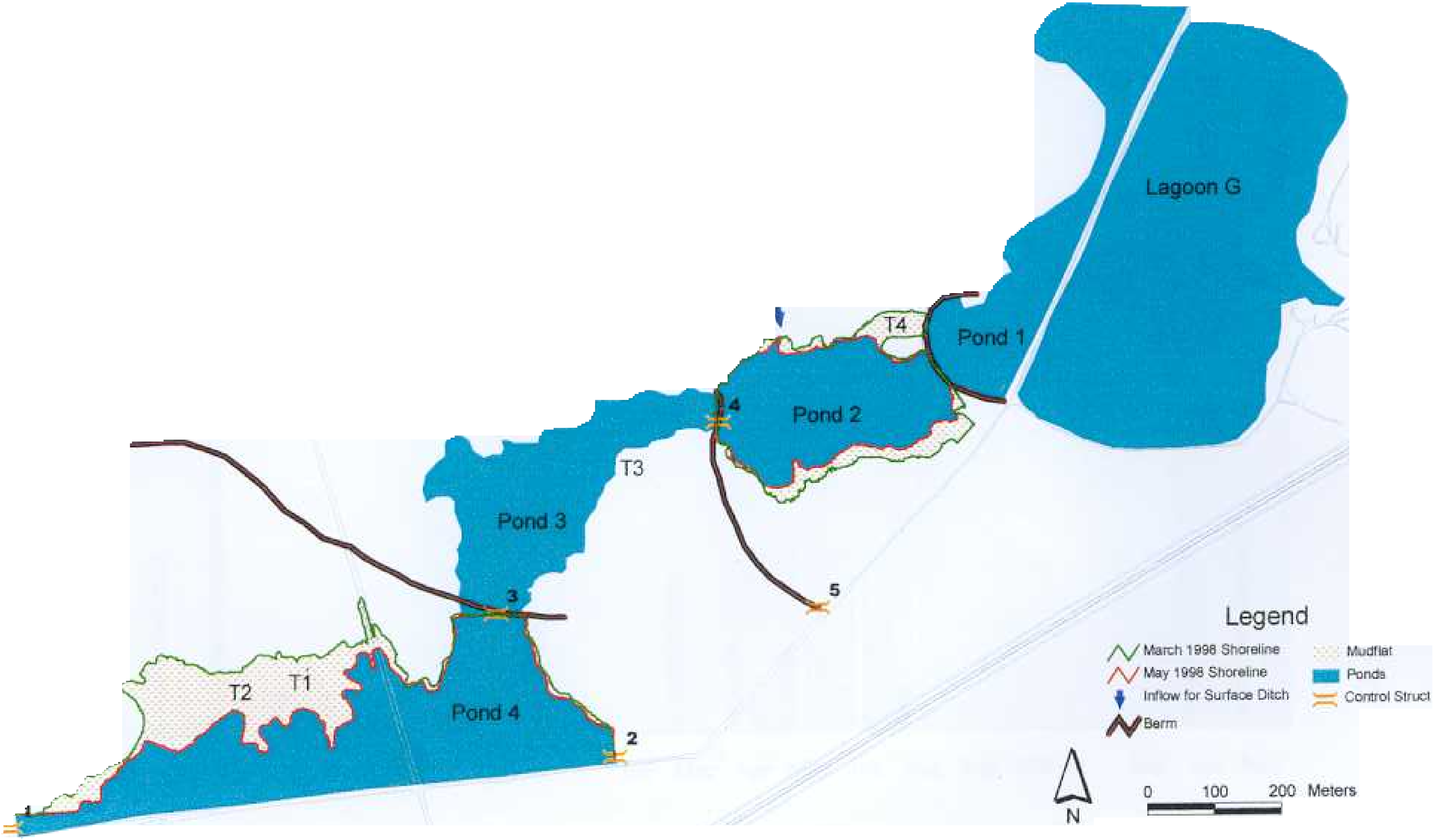


Figure 2. Constructed Wetlands: physical features with shorebird foraging and invertebrate sampling areas (T1-T4).

Figure 3. Snowy Plover Abundance by Waterbody

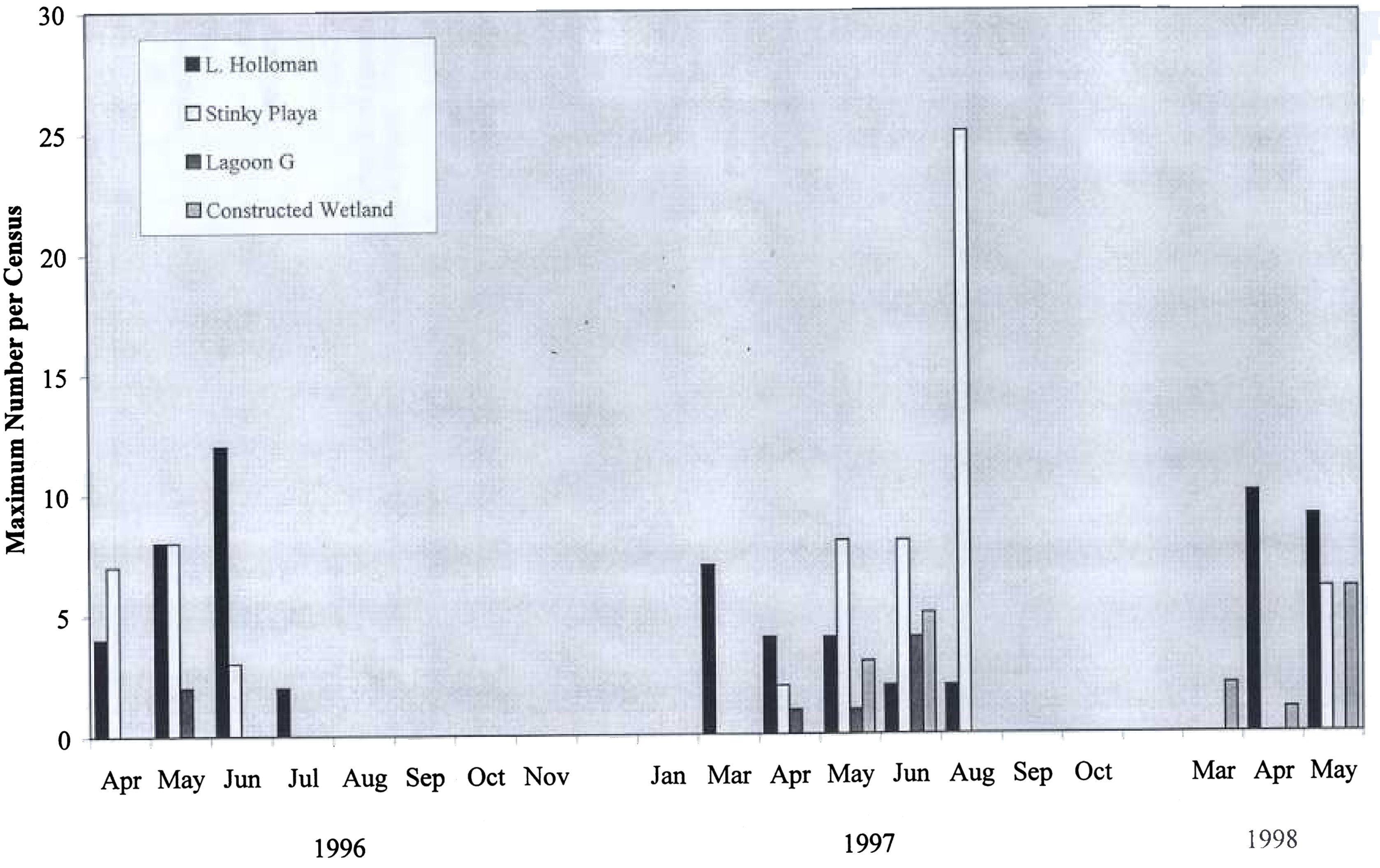


Figure 4. Killdeer Abundance by Waterbody

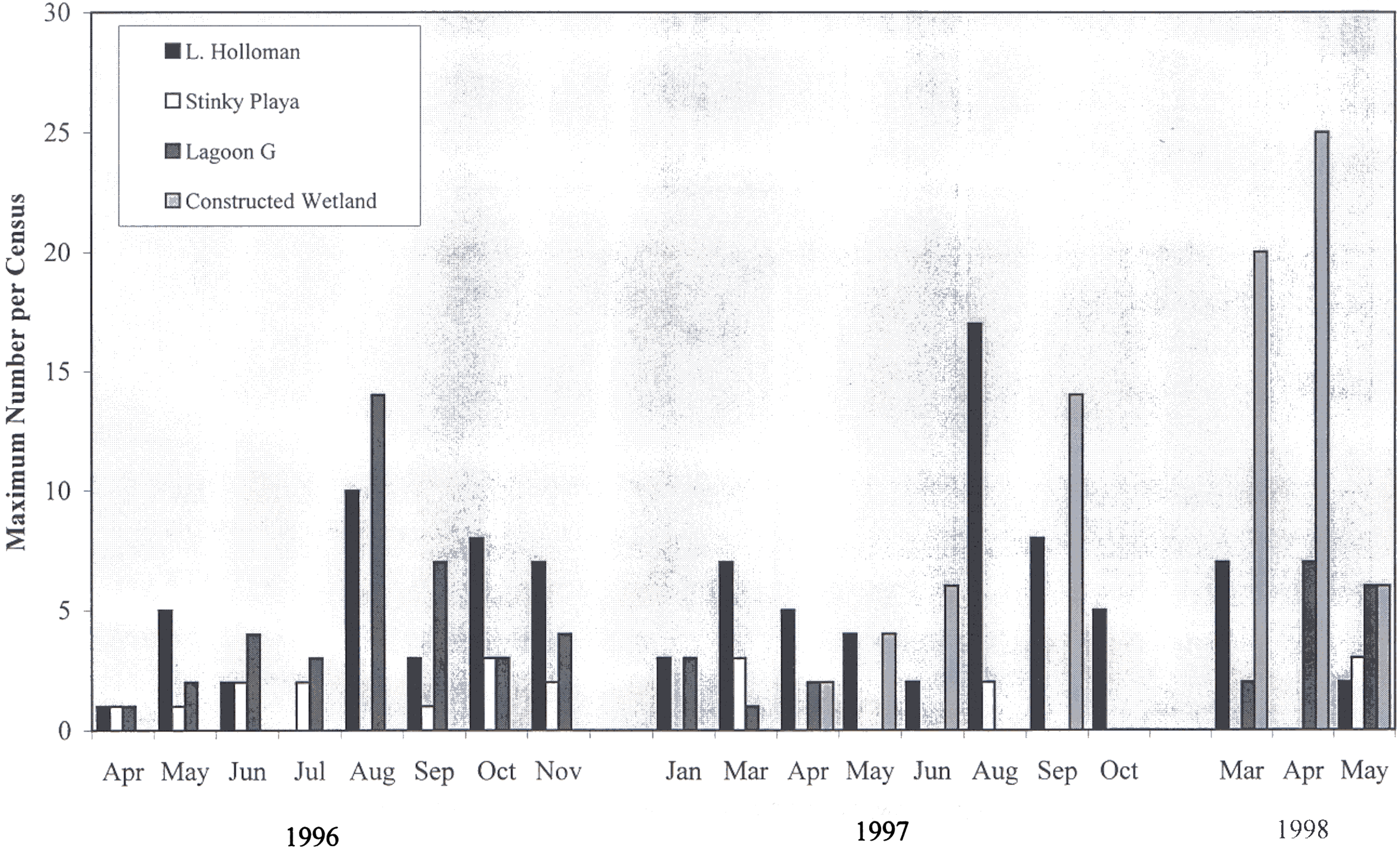


Figure 5. Wilson's Phalarope Abundance by Waterbody

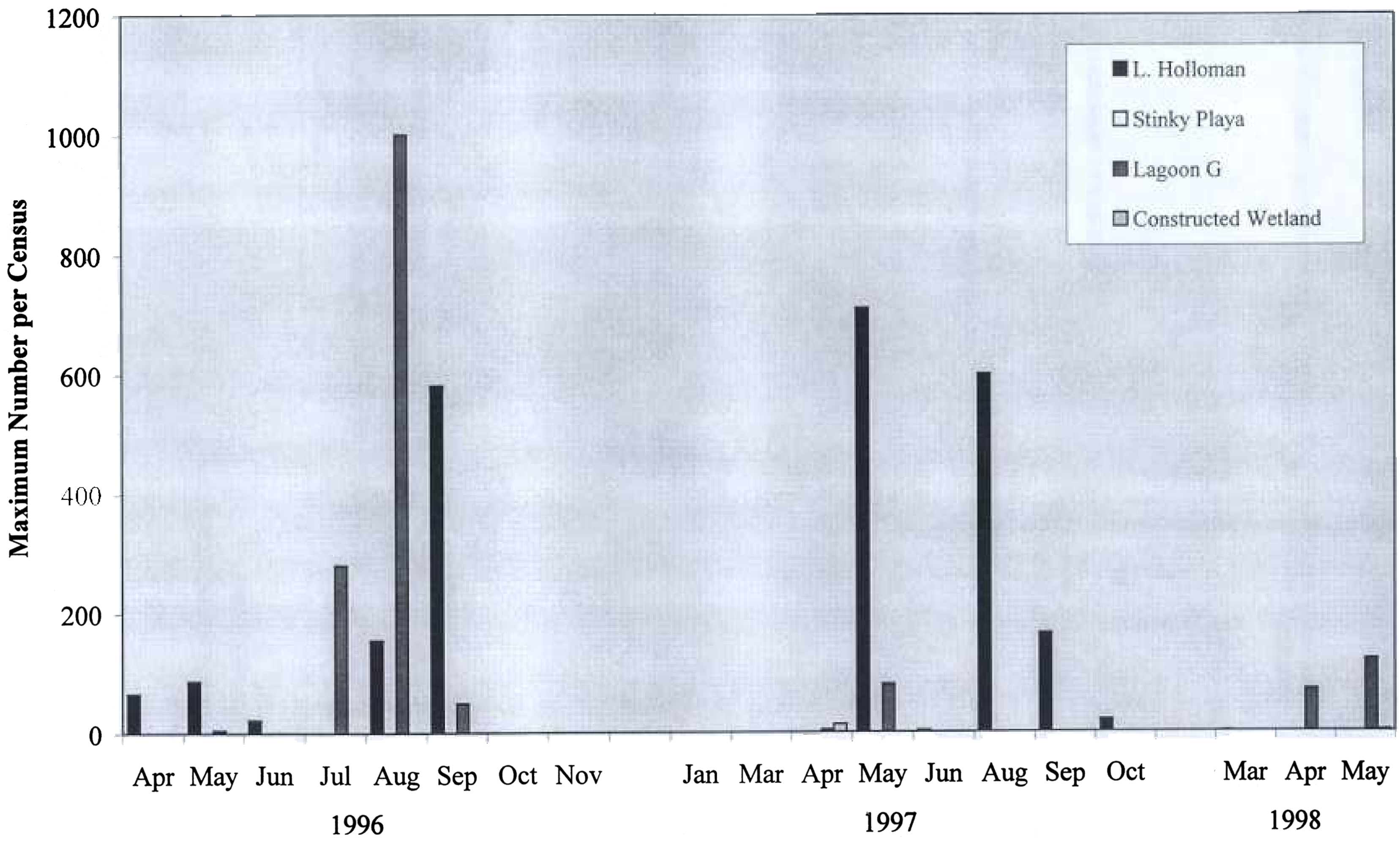


Figure 6. Western Sandpiper Abundance by Waterbody

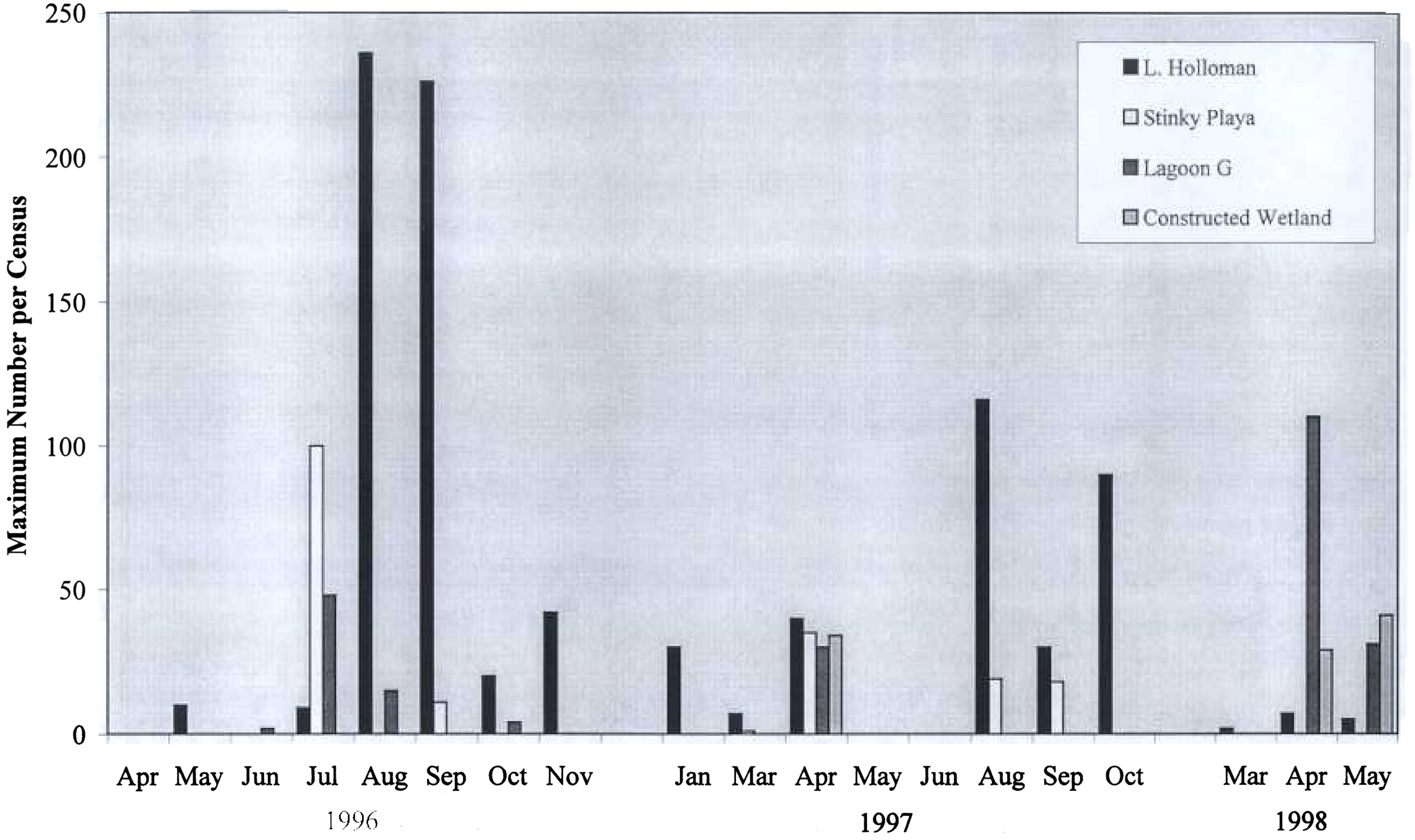
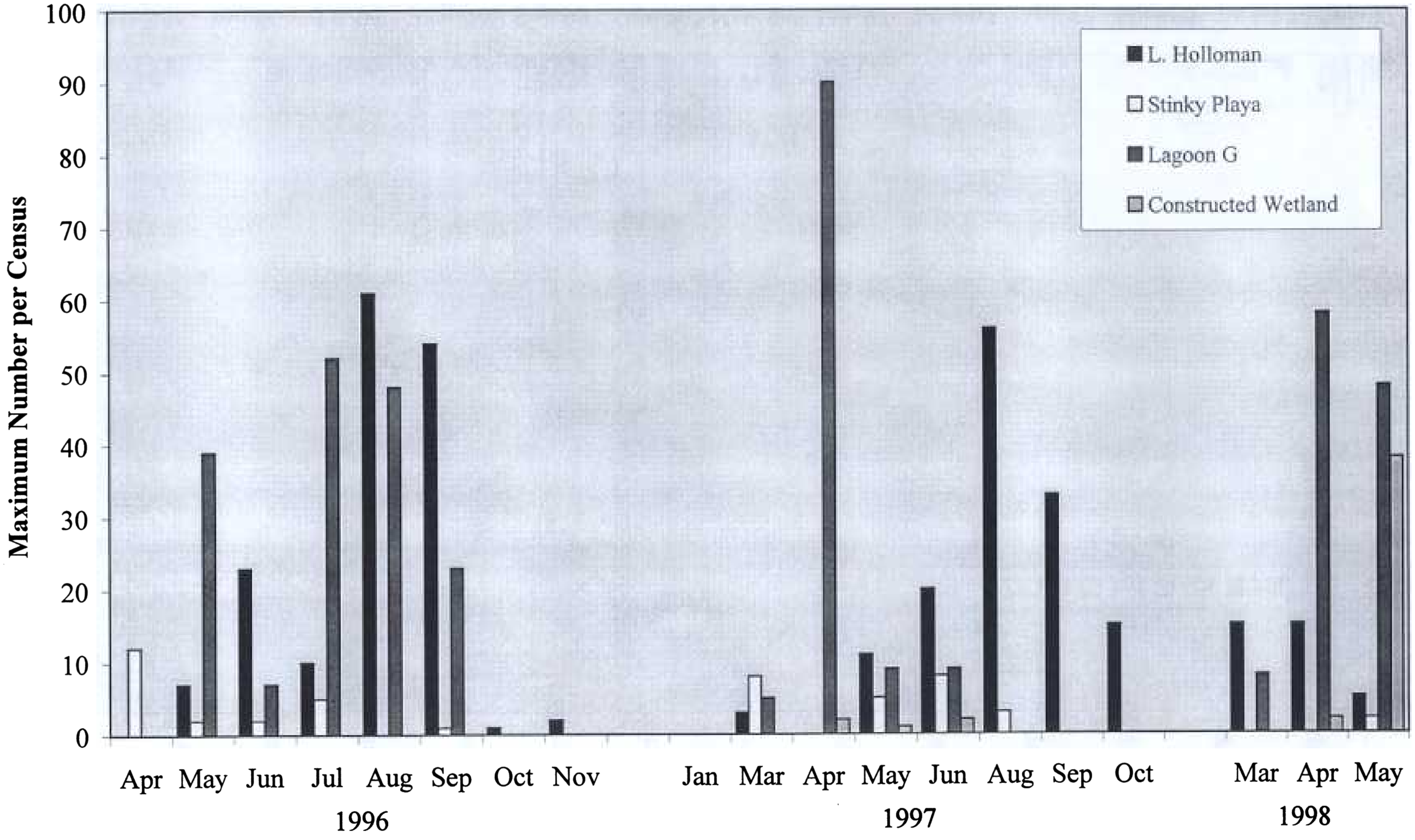


Figure 7. American Avocet Abundance by Waterbody



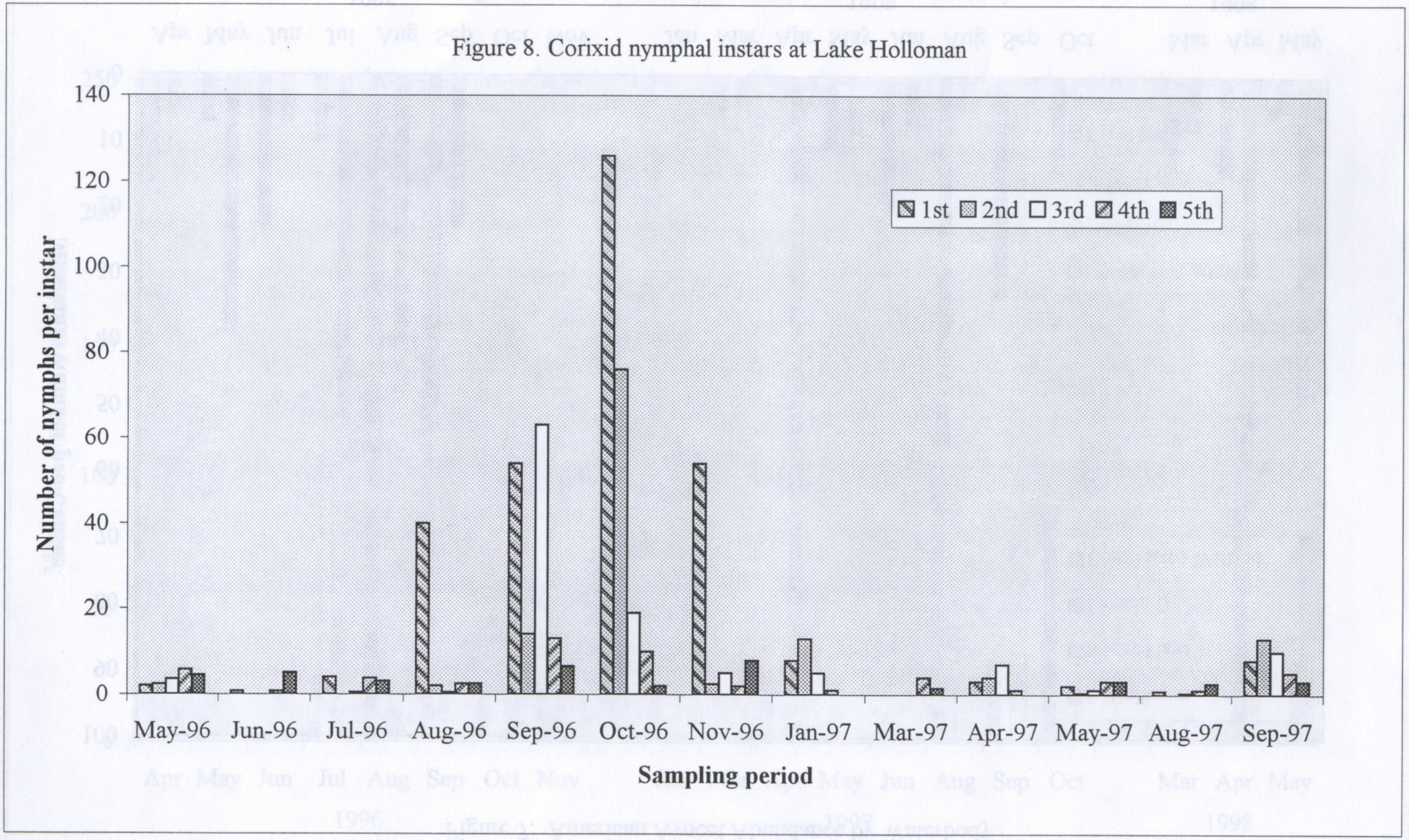


Figure 8. Corixid nymphal instars at Lake Holloman

Figure 9. Corixid abundance at Lake Holloman

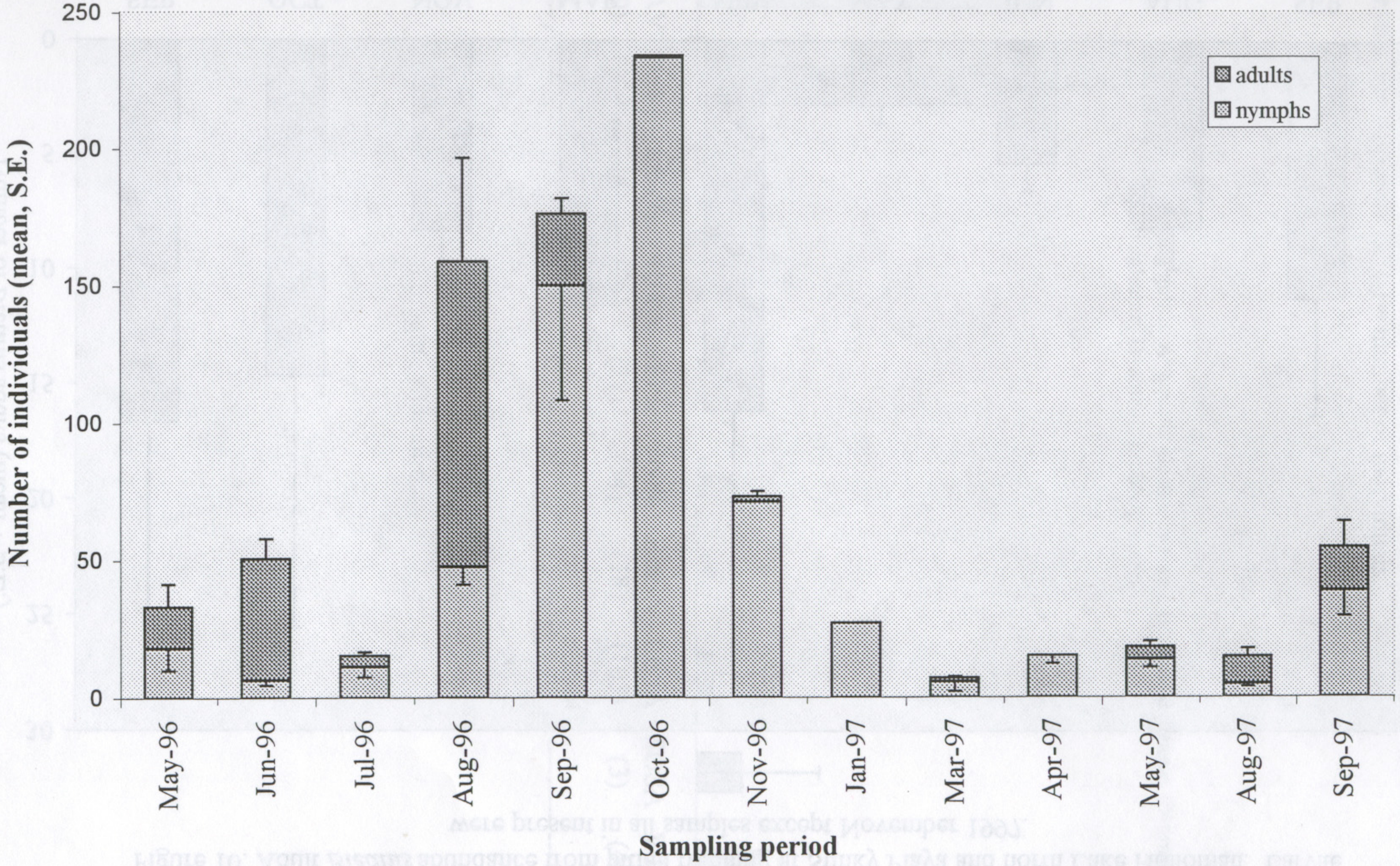


Figure 10. Adult *Bledius* abundance from pitfall trapping at Stinky Playa and north Lake Holloman. Larvae were present in all samples except November 1997.

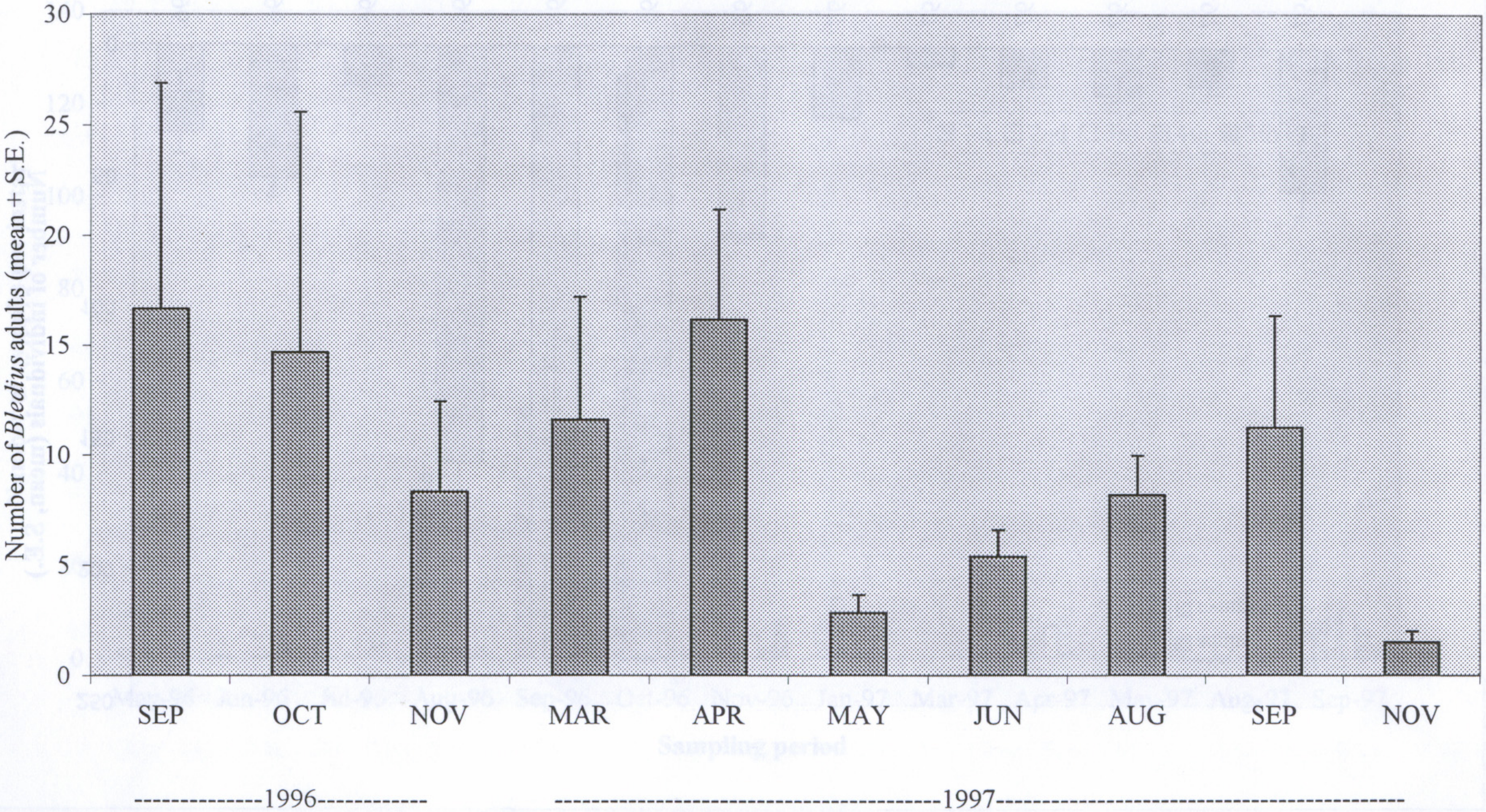


Figure 11. Mean water depth of foraging shorebirds at the constructed wetland (1998) was determined by level of water on the leg (see text for methods). For acronyms, see Appendix B. ( ) = number of individuals.

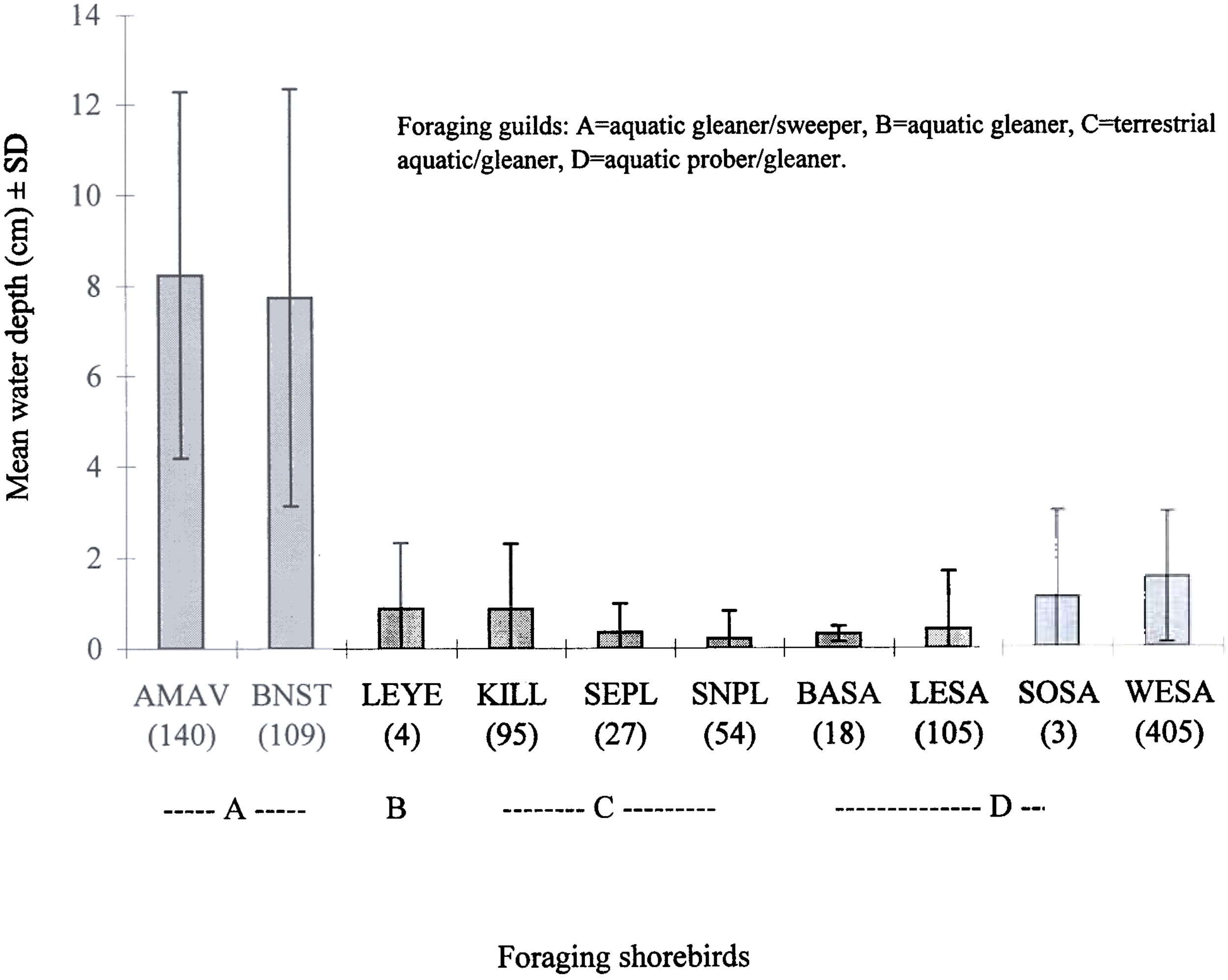
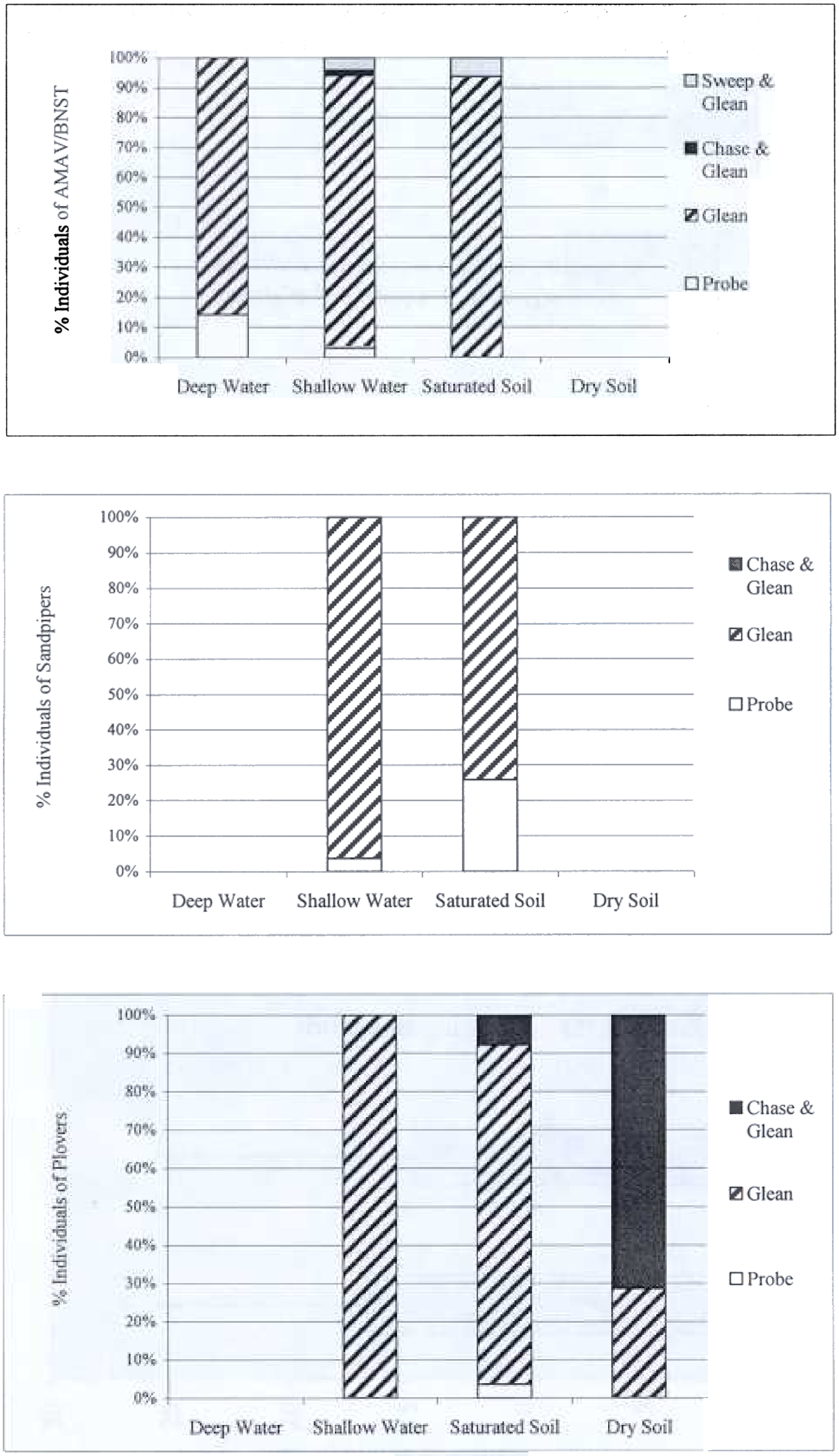


Figure 12. Foraging mode by habitat of three foraging guilds at the constructed wetland in 1997.



igure 13. Changes in amount of exposed shore at Lake Holloman, May 1996 to June 1998.

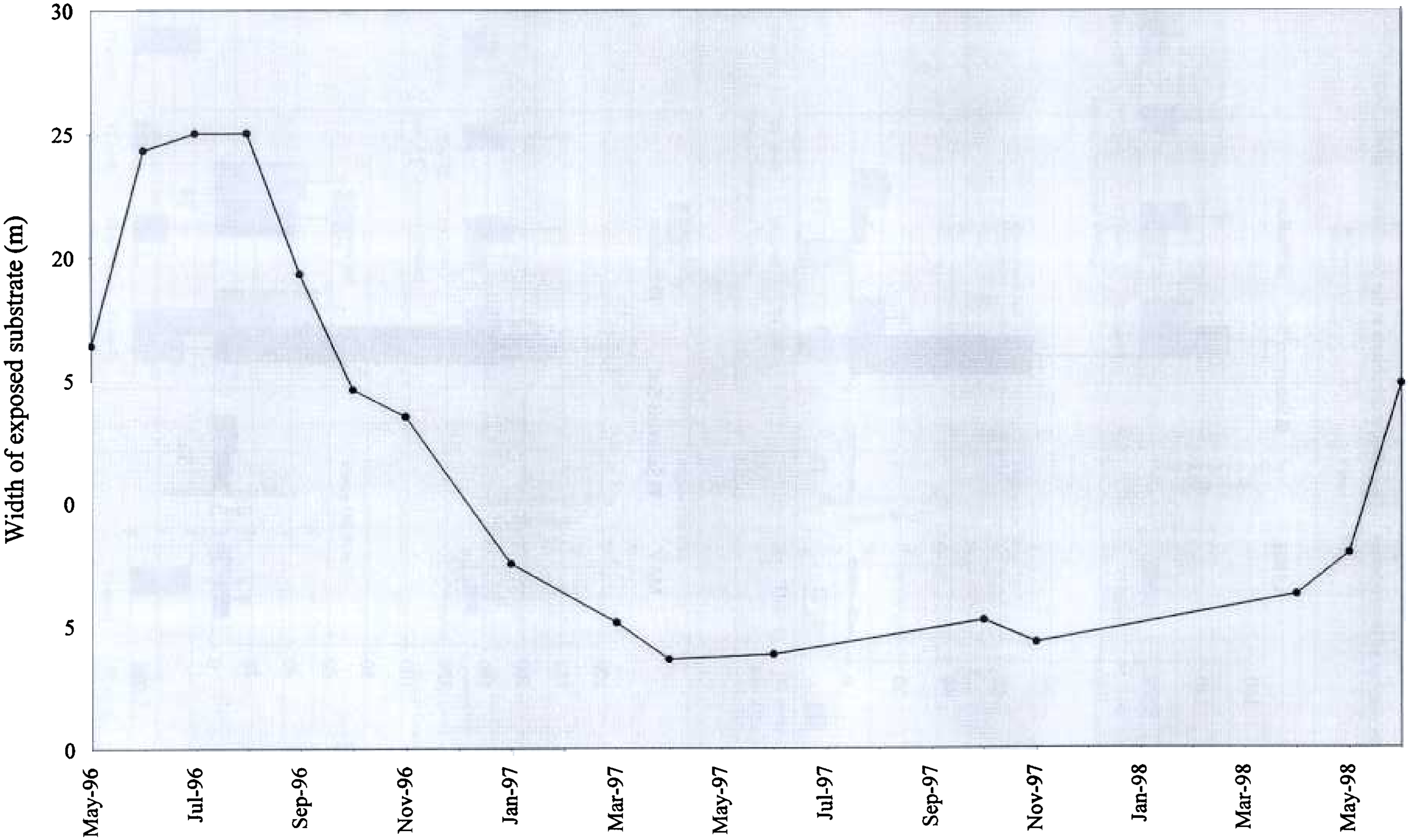
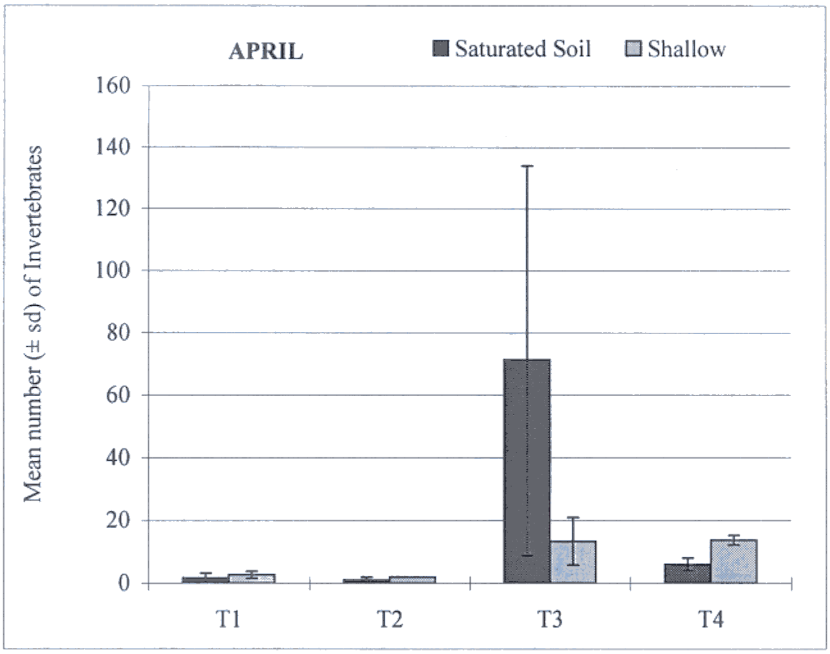


Figure 14. Mean number of invertebrates in four sites, two habitats at the constructed wetland, 1997.



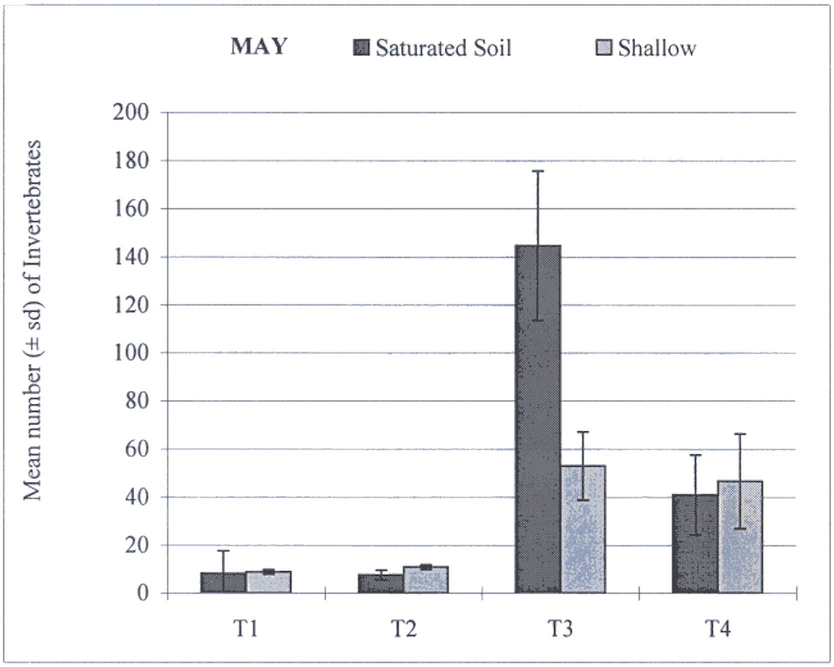
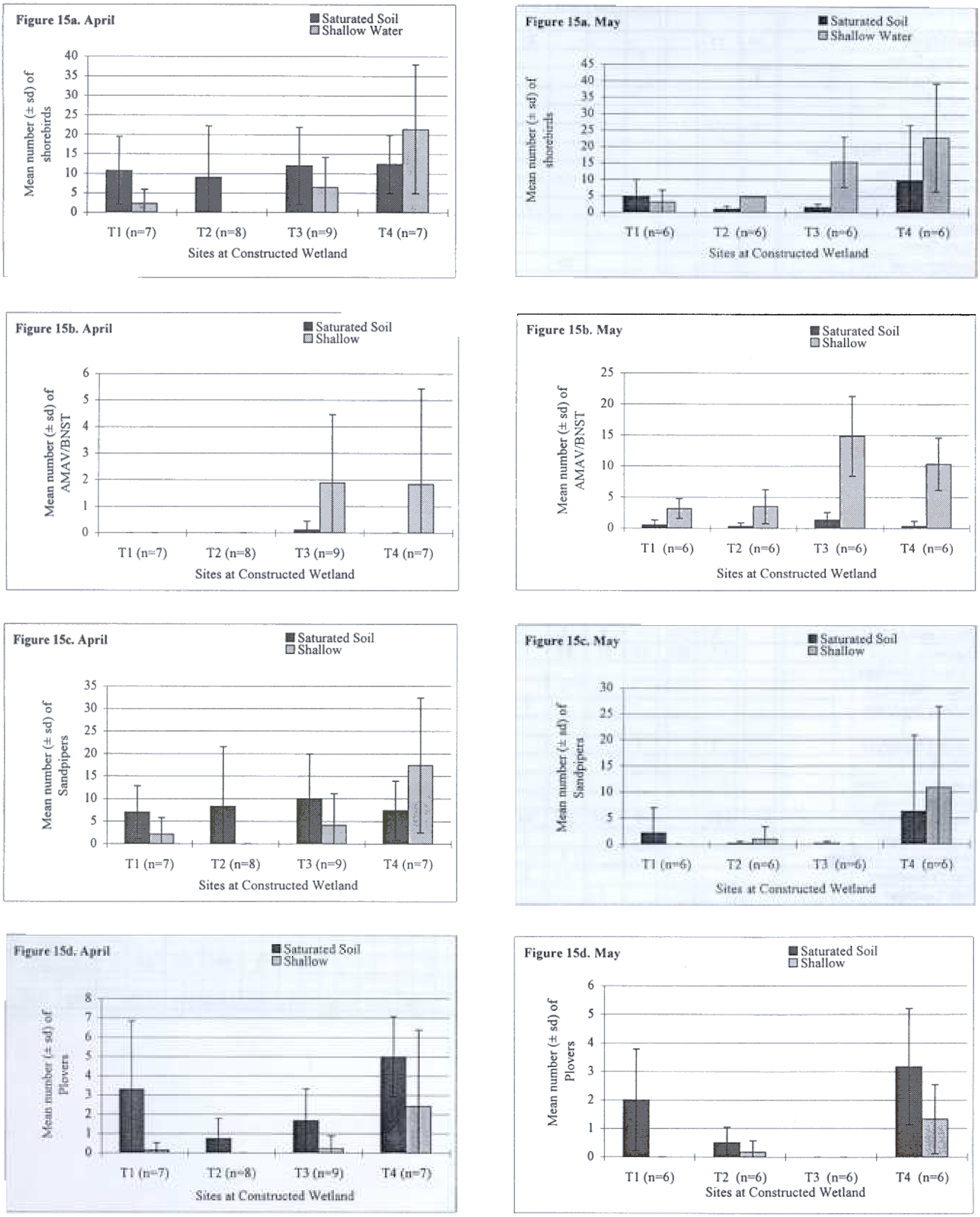


Figure 15a-d.. Mean number of shorebirds in four sites, two habitats at the constructed wetland , 1997 (shown by guild and as the three guilds combined).



APPENDIX A. Peak number of birds by waterbody.

LAKE HOLLOMAN -- Peak number of individuals by census period.

Common Name	1996								1997								1998		
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Mar	Apr	May	Jun	Aug	Sep	Oct	Mar	Apr	May
Eared Grebe	30	15					20	75	2	6	17	32	1	9	9	20	1		
Western Grebe				1				1			8	2							
Great Blue Heron	1				1											1			
Snowy Egret										2						1			
Cattle Egret														1	1				
Green Heron																			
Black-crowned Night Heron																			
White-faced Ibis																			
Fulvous Whistling-duck																			
Black-bellied Whistling-duck							2	2		3				1					
Ross's Goose																			
Snow Goose																			
Green-winged Teal		3				50				2					30				
Mallard			3		4			10		2			16	10	300	15			
Northern Pintail										2	3								
Blue-winged Teal		6				318	140	55				3	2	100	130	160			
Cinnamon Teal		2	2			4						11	2	11	6				
Northern Shoveler	47	66	56		30	700	210	110	195	2	40	23	109	215	60	470	85	40	3
Gadwall	2		1			20		1		13		10	10	70	4	40			
American Wigeon							10			8									
Canvasback																			
Redhead							8		6	24						20			
Ring-necked Duck							2			38			2	4					
Lesser Scaup		5						30		36	2					30			
Common Merganser																			
Bufflehead									2			2							
Ruddy Duck	40	2	2				210	95	2		12	29	80		50	600			
American Coot		1					40	1				6	24	7	9	185			
Black-bellied Plover																			
Snowy Plover	4	8	12	2						7	4	4	2	2				10	9
Semipalmated Plover																			
Killdeer	1	5	2		10	3	8	7	3	7	5	4	2	17	8	5	7		2
Black-necked Stilt		8	28	3	6	5					2	13	10	79	56				
American Avocet		7	23	10	61	54	1	2		3		11	20	56	33	15	15	15	5
Greater Yellowlegs										1				8	2	8			
Lesser Yellowlegs					24	2									1				
Solitary Sandpiper							1								4				
Willet																			
Spotted Sandpiper		5		1								2							6
Whimbrel																			
Long-billed Curlew												1		1					1
Marbled Godwit																			
Western Sandpiper		10		9	236	226	20	42	30	7	40			116	30	90	2	7	5
Least Sandpiper	8						9	5		62				6	8				
White-rumped Sandpiper						1									5				
Baird's Sandpiper						13	2					2		1				35	
Stilt Sandpiper					1			1											
Short-billed Dowitcher																	5		
Long-billed Dowitcher					10						4	5		2		10	6		
Common Snipe																			
Wilson's Phalarope	66	87	22		155	580						710	3	600	165	20	1		
TOTALS	199	230	151	26	538	1976	683	437	240	225	120	870	283	1316	911	1690	122	107	31

APPENDIX A. Peak numbers of birds by waterbody

STINKY PLAYA -- Peak number of individuals by census period.

	1996									1997									1998		
Common Name	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**		**Jan**	**Mar**	**Apr**	**May**	**Jun**	**Aug**	**Sep**	**Oct**		**Mar**	**Apr**	**May**
Eared Grebe																					
Western Grebe																					
Great Blue Heron																					
Snowy Egret																					
Cattle Egret																					
Green Heron																					
Black-crowned Night Heron																					
White-faced Ibis																					
Fulvous Whistling-duck																					
Black-bellied Whistling-duck						2															
Ross's Goose																					
Snow Goose																					
Green-winged Teal																					
Mallard																					
Northern Pintail																					
Blue-winged Teal																					
Cinnamon Teal																					
Northern Shoveler																					
Gadwall																					
American Wigeon																					
Canvasback																					
Redhead																					
Ring-necked Duck																					
Lesser Scaup																					
Common Merganser																					
Bufflehead																					
Ruddy Duck																					
American Coot																					
Black-bellied Plover															2						
Snowy Plover	7	8	3									2	8	8	25						6
Semipalmated Plover															2						3
Killdeer	1	1	2	2		1	3	2			3				2						3
Black-necked Stilt														2							
American Avocet	12	2	2	~~5~~		1					8		5	8	3						2
Greater Yellowlegs																					
Lesser Yellowlegs																					
Solitary Sandpiper																					
Willet																					
Spotted Sandpiper																					
Whimbrel																					
Long-billed Curlew	3													1	2						
Marbled Godwit																					
Western Sandpiper				~~100~~		11					1	35			19	18					
Least Sandpiper	8																				
White-rumped Sandpiper																					
Baird's Sandpiper				1										2							
Stilt Sandpiper																					
Short-billed Dowitcher																					
Long-billed Dowitcher																					
Common Snipe																					
Wilson's Phalarope																					
TOTALS	31	11	108	108	0	15	3	2		0	12	37	13	21	55	18	0		0	0	14

APPENDIX A. Peak numbers of birds by waterbody.

LAGOON G -- Peak number of individuals by census period.

	1996									1997									1998		
Common Name	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov		Jan	Mar	Apr	May	Jun	Aug	Sep	Oct		Mar	Apr	May
															[DRY]	[DRY]	[DRY]				
Eared Grebe	13	11				3	30			1	3	1								6	1
Western Grebe																					1
Great Blue Heron				1																	1
Snowy Egret		1			9	1														2	1
Cattle Egret					9								1								
Green Heron	1	1	2	2	1																1
Black-crowned Night Heron				1							1		2	1						1	
White-faced Ibis		1			16	2	1					4								55	13
Fulvous Whistling-duck													2								
Black-bellied Whistling-duck																				1	
Ross's Goose																					
Snow Goose																					
Green-winged Teal		2									8	21	9						130	20	
Mallard	8	11	4	20	18			3				2	5	4						2	3
Northern Pintail										16	6	2	2	1							
Blue-winged Teal	4	5	1			8	105						5							70	7
Cinnamon Teal		4	4		6			5		3	30	10	6						62	40	1
Northern Shoveler	60	160	12	30	20	35	170			20	350	450	30	10					355	85	
Gadwall		4	2			10					40		10	4					20	2	7
American Wigeon											5	2	1								
Canvasback							1			15											
Redhead																			2	4	4
Ring-necked Duck								10		20											
Lesser Scaup		5								10										5	2
Common Merganser								2													
Bufflehead																			15		2
Ruddy Duck	221	15	10	30	35	10	140			15	30	80							100	450	220
American Coot	40	8	10	12	25	8	30	25		27	40	50							9	55	37
Black-bellied Plover																					
Snowy Plover		2										1	1	4							
Semipalmated Plover																					
Killdeer	1	2	4	3	14	7	3	4		3	1	2							2	7	6
Black-necked Stilt		11	3	22	77	46					1	6	6	13					15	27	25
American Avocet		39	7	52	48	23					5	90	9	9					8	58	48
Greater Yellowlegs						2						3									
Lesser Yellowlegs					62	15															
Solitary Sandpiper																					
Willet																					1
Spotted Sandpiper		1											3								34
Whimbrel		1																			
Long-billed Curlew												1									
Marbled Godwit																					1
Western Sandpiper			2	48	15		4					30								110	31
Least Sandpiper	5									5										15	10
White-rumped Sandpiper																					
Baird's Sandpiper																					
Stilt Sandpiper						1															
Short-billed Dowitcher				4																	
Long-billed Dowitcher					14			6		2	8	4								16	92
Common Snipe												1									
Wilson's Phalarope		5		280	1000	49						5	80							70	120
TOTALS	353	289	61	505	1369	220	484	55		137	528	765	172	46	0	0	0		718	1101	669

APPENDIX A. Peak numbers of birds by waterbody.

CONSTRUCTED WETLAND -- Peak number of individuals by census period.											
	1997							1998			
Common Name	**Apr**	**May**	**Jun**	**Aug**	**Sep**	**Oct**		**Mar**	**Apr**	**May**	**Jun**
				[DRY]		[DRY]					
Eared Grebe	7										
Western Grebe		1									
Great Blue Heron								1			
Snowy Egret										2	
Cattle Egret											
Green Heron											
Black-crowned Night Heron											
White-faced Ibis									6	78	5
Fulvous Whistling-duck											
Black-bellied Whistling-duck									1		
Ross's Goose									1		
Snow Goose								1		2	
Green-winged Teal										9	
Mallard	8		3						18	2	
Northern Pintail											
Blue-winged Teal		2						100	52	9	
Cinnamon Teal								30	5		
Northern Shoveler	29							49	109	10	
Gadwall		2						2		2	
American Wigeon	1							17	17		
Canvasback											
Redhead									2		
Ring-necked Duck											
Lesser Scaup								4			
Common Merganser											
Bufflehead											
Ruddy Duck									13		
American Coot								6			
Black-bellied Plover											
Snowy Plover		3	5					2	1	6	7
Semipalmated Plover									1		
Killdeer	2	4	6		14			20	25	6	5
Black-necked Stilt	18	2							30	22	25
American Avocet	2	1	2						2	38	15
Greater Yellowlegs	5							4			
Lesser Yellowlegs											
Solitary Sandpiper	6								1		
Willet											
Spotted Sandpiper											
Whimbrel											
Long-billed Curlew								1			5
Marbled Godwit											
Western Sandpiper	34								29	41	
Least Sandpiper									38		
White-rumped Sandpiper											
Baird's Sandpiper								1			
Stilt Sandpiper											
Short-billed Dowitcher											
Long-billed Dowitcher	2										
Common Snipe											
Wilson's Phalarope	13									2	
TOTALS	127	15	16	0	14	0		238	351	229	62

APPENDIX B . Common names, scientific names and alpha codes for HAFB wetland birds.

Common Name	Scientific Name	Code
Eared Grebe	*Podiceps nigricollis*	EAGR
Western Grebe	*Aechmophorus occidentalis*	WEGR
Great Blue Heron	*Ardea herodias*	GBHE
Snowy Egret	*Egretta thula*	SNEG
Cattle Egret	*Bubulcus ibis*	CAEG
Green Heron	*Butorides virescens*	GRHE
Black-crowned Night Heron	*Nycticorax nycticorax*	BCNH
White-faced Ibis	*Plegadis chihi*	WFIB
Black-bellied Whistling-duck	*Dendrocygna autumnalis*	BBWD
Fulvous Whistling-duck	*Dendrocygna bicolor*	FUWD
Snow Goose	*Chen caerulescens*	SNGO
Ross' Goose	*Chen rossii*	ROGO
Green-winged Teal	*Anas crecca*	AGWT
Mallard	*Anas platyrhynchos*	MALL
Northern Pintail	*Anas acuta*	NOPI
Blue-winged Teal	*Anas discors*	BWTE
Cinnamon Teal	*Anas cyanoptera*	CITE
Northern Shoveler	*Anas clypeata*	NSHO
Gadwall	*Anas strepera*	GADW
American Wigeon	*Anas americana*	AMWI
Canvasback	*Aythya valisineria*	CANV
Redhead	*Aythya americana*	REDH
Ring-necked Duck	*Aythya collaris*	RNDU
Lesser Scaup	*Aythya affinis*	LESC
Bufflehead	*Bucephala albeola*	BUFF
Common Merganser	*Mergus merganser*	COME
Ruddy Duck	*Oxyura jamaicensis*	RUDU
American Coot	*Fulica americana*	AMCO
Black-bellied Plover	*Pluvialis squatarola*	BBPL
Snowy Plover	*Charadrius alexandrinus*	SNPL
Semipalmated Plover	*Charadrius semipalmatus*	SEPL
Killdeer	*Charadrius vociferus*	KILL
Black-necked Stilt	*Himantopus mexicanus*	BNST
American Avocet	*Recurvirostra americana*	AMAV
Greater Yellowlegs	*Tringa melanoleuca*	GRYE
Lesser Yellowlegs	*Tringa flavipes*	LEYE
Solitary Sandpiper	*Tringa solitaria*	SOSA
Willet	*Catoptrophorus semipalmatus*	WILL
Spotted Sandpiper	*Actitis macularia*	SPSA
Whimbrel	*Numenius phaeopus*	WHIM
Long-billed Curlew	*Numenius americanus*	LBCU
Marbled Godwit	*Limosa fedoa*	MAGO
Western Sandpiper	*Calidris mauri*	WESA
Least Sandpiper	*Calidris minutilla*	LESA
White-rumped Sandpiper	*Calidris fuscicollis*	WRSA
Baird's Sandpiper	*Calidris bairdii*	BASA
Stilt Sandpiper	*Calidris himantopus*	STSA
Short-billed Dowitcher	*Limnodromus griseus*	SBDO
Long-billed Dowitcher	*Limnodromus scolopaceus*	LBDO
Common Snipe	*Gallinago gallinago*	COSN
Wilson's Phalarope	*Phalaropus tricolor*	WIPH

APPENDIX C

SNOWY PLOVER DIET AT A DESERT PLAYA: IMPORTANCE OF BLEDIUS BEETLES

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Abstract.---We analyzed Snowy Plover (Charadrius alexandrinus) fecal pellets collected during fall, 1997, migration at a Chihuahuan Desert playa on Holloman Air Force Base, New Mexico, USA. Our objectives were to evaluate the usefulness of fecal examination as a method for analyzing Snowy Plover diets and to determine the importance of soil-inhabiting, burrowing beetles (Bledius spp.) in the diet of Snowy Plovers at this wetland site. Bledius spp. are a major component of the invertebrate fauna at the mudflat and saltflat habitats at Holloman. The most abundant items in the fecal samples were mandibles of Bledius mandibularis (Staphylinidae). Less abundant, but common, prey items included other beetles (Carabidae, Cicindelidae), aquatic hemipterans (Corixidae), ants (Formicidae), and shore flies (Ephydridae). Examination of fecal droppings is a productive method for acquiring data on Snowy Plover diets, and might be useful for other shorebird species that consume hard-bodied prey. We conclude that Bledius spp. are a major food resource for stopover migrants and suggest that these beetles may be important prey items for nesting adults and their chicks. In arid-zone wetlands, management for Snowy Plovers and other shorebirds with similar diets should consider habitat needs and management for playa invertebrates such as Bledius spp.

Inland shorebird habitats for both migration stopover and nesting in the desert Southwest are scarce and limited to playas, artificial impoundments, and wildlife refuges. Stopover areas must provide shorebirds with sufficient food to increase their fat reserves during a relatively short stay (Castro and Myers 1989). Chicks require an abundant supply of appropriate invertebrate food for their development.

Lake Holloman and Stinky Playa are remnants of a Pleistocene lake bed that was divided by construction of an earthworks dam in the late 1960's. They are one of several broad drainage basins that terminate on Holloman Air Force Base (HAFB). Lake Holloman contains water throughout the year (surface area, 60-70 ha.). Stinky Playa (surface area, 12 ha between dam and highway) floods periodically after heavy rainfall. Its northern margin adjacent to the dam contains small, shallow pools fed by seepage from Lake Holloman. These water bodies have also been altered by the construction of U.S. Highway 70 and the use of Lake Holloman as a reservoir for treated sewage effluent (U S Army Corps of Engineers 1996).

In 1996, HAFB contracted to US Fish and Wildlife Service for the design and building of a constructed wetland complex. These wetlands began receiving effluent from the base's waste water treatment plant in the fall of 1997. These new wetlands, along with Lake Holloman and Stinky Playa, provide shorebird habitat and hold the increased flow from the new sewage treatment plant. When the constructed wetland is filled, approximately 48 ha of alkali flats and pickleweed shrubland will be transformed into wetland bird habitat. The Holloman wetland complex will be one of the largest permanent water sources in the Tularosa Basin, providing important stopover habitat for migrating shorebirds and waterfowl, as well as increased breeding habitat for resident species. The wetland is designed to add large areas of shallow water and mudflat habitat to the existing mudflat, playa, and deep-water habitats.

One shorebird species that frequents the Holloman wetlands is the Snowy Plover (Charadrius alexandrinus), a cosmopolitan inhabitant of beaches and inland salt flats.. Historically, Holloman Lakes is known as a Snowy Plover breeding area (Page et al. 1991), and our surveys document at least one successful nest on the playa every year since 1994 (New Mexico Natural Heritage Program, unpublished data). Our recent field observations also document groups of migrating Snowy Plovers foraging at Stinky Playa.

Since the late 1800s, substantial declines have occurred in Snowy Plover populations on the US Pacific and Gulf coasts due to habitat alteration and increased recreational use, while inland populations have declined since the 1980s due to decreased river flows (Page et al. 1995). The Snowy Plover is a former federal Category 2 species. The breeding population on the Pacific coast is currently listed as threatened by the US Fish and Wildlife Service, and the species has some category of state listing status in Washington, Oregon, California, Alabama, and Florida (Page et al. 1995).

Major prey items of Snowy Plovers are terrestrial and aquatic invertebrates (Page et al. 1995). On inland salt flats, the main food items identified from observations of plover foraging are burrowing staphylinid beetles (Bledius spp.), shore flies (Ephydra spp.), and other insects blown onto the salt flats from surrounding vegetation (Purdue 1976). In Oklahoma, Snowy Plovers were frequently observed running from one Bledius burrow to another, probing at each one (Grover and Knopf 1982, Purdue 1976).

Beetles of the genus Bledius live in riparian and intertidal habitats and on the margins of salt marshes and salt flats, inhabiting galleries constructed in sand or mud. They are often abundant at saline flats and playas in the western U. S (Herman 1986). Both adults and larvae feed on algae and diatoms and construct burrows, leaving a characteristic cast of soil on the surface above the burrow entrance. Although these beetles remain underground much of the time, they are active on the surface during mate-finding, dispersal, and escape from flooded burrows. They will swarm after or during midday rainfall and have been collected in large numbers at lights in the early evening (Herman 1986). They live in dense aggregations, usually composed of a single species, with adults and larvae often using the same or adjacent galleries. Ortenburger and Bird (1933) reported 285 galleries per ft^2 (approximately 3000 galleries per m^2) for a Bledius sp. inhabiting a salt flat in Oklahoma.

Bledius is an important component of the invertebrate community at Stinky Playa. Herman (1972, 1976) collected four Bledius spp. at this site in May 1968 in habitats described as "shore of salt lake," "near salt lake," and "salt lake". Our invertebrate surveys and collections at Stinky Playa and Lake Holloman have found Bledius spp. in similar habitats. Burrows at Stinky Playa can be found in densities of several hundred per m^2 in active beetle areas around the margin of the playa. At this site we have excavated burrow systems to the depth of the water table (8-12 cm), counting as many as 50 adult beetles and 3 to 22 burrow entrances per 0.1-m^2 quadrat.

We report the results of an analysis of Snowy Plover fecal pellets collected at Stinky Playa during the fall migration, 1997. Our purposes were to evaluate fecal examination as a method of analyzing Snowy Plover diets and to assess the importance of Bledius as a food item for migrating Snowy Plovers at HAFB.

METHODS

An opportunity to assess the diet of Snowy Plovers at HAFB occurred on 26 Aug. 1997. During a shorebird census of the Holloman wetlands complex, we observed a flock of 25 Snowy Plovers foraging at Stinky Playa at 0800 h. The birds were concentrated around and within the only vegetated area on the playa interior, a patch of Cressa truxillensis (a prostrate perennial halophyte that attains a maximum height of 10 cm). They were actively foraging, probing the soil surface and running in directed movements, but were too far away for us to identify the prey items, and remained at the site for at least 1 h. The plovers were gone at the end of the census (1200 h). We conducted fieldwork near Stinky Playa for the remainder of the day and saw no other birds in this area.

The next morning we collected all fecal droppings in the vicinity of plover activity (a 16 x 28 m area). The droppings were conspicuous against the light-colored salt crust of the playa and had become cemented to the soil surface. Active Bledius burrows were observed in the plot and a survey of burrows on 28 August revealed the presence of burrows throughout the western margin of the playa.

A total of 106 fecal pellets was collected. A preliminary screening of all the pellets, using a dissecting microscope, indicated that at least 30% contained Bledius remains. The presence of these beetles is indicated by their distinctive bidentate, or sometimes tridentate, mandibles (Herman 1972, 1976). A random sample of 50 droppings was selected for a detailed examination of recognizable insect parts. The fecal samples were processed and analyzed using techniques similar to those developed by Ralph et al. (1985) for Hawaiian forest frugivores and insectivores. Individual droppings were not weighed, as they could not be easily separated from the salt crust in which they were embedded. We found that steaming was not necessary to disperse the droppings, but that mixing and allowing them to stand in water was sufficient. After soaking samples in individual vials of water for at least 30 min and mixing thoroughly, we filtered each sample through Whatman no. 1 white filter paper (5.5 cm diameter) in a Buchner funnel. The filter paper samples were dried at 27 C for 24 hr.

Under a binocular dissecting microscope at 15 power, each filter paper was scanned for mandibles of Bledius and other taxa. For each sample, mandibles were counted and stored in a numbered transparent gelatin capsule. The sample was then loosened from the paper and poured into a rectangular (97 mm length, 16 mm width, 10 mm depth) white porcelain combustion boat (see Ralph et al. 1985) for scanning and retrieval of arthropod remains. These were stored in small vials in 70% ethyl alcohol. The remainder of the sample was stored dry in an upright shell vial without a stopper.

Borror et al. (1981) and Merritt and Cummins (1996) were used for identification of insect taxa in the fecal samples. For identification of Bledius spp., their mandibles and other hard parts we consulted Herman (1972, 1976, and pers. comm.). Mandibles and hard parts of other taxa were compared to our reference collection of insects from HAFB

RESULTS

We identified six major categories of insects in the 50 fecal pellets, with 44 samples containing representatives of at least one major prey type (Table 1). We define "major" groups as ones that could be classified to family or genus and occur in at least five (10%) of the samples. Bledius occurred in the highest frequency (56% of the samples), followed by ants (Formicidae), water boatmen (Corixidae), tiger beetles (Cicindelidae), shore flies (Ephydridae), and ground beetles (Carabidae) [Table 1]. Bledius mandibles were clearly recognizable (Fig. 2, 3). Softer-bodied prey such as ephydrids and corixids could be identified using leg and wing fragments.

We collected three Bledius spp. at Stinky Playa. B. mandibularis is the most abundant; B. eximius and B. ferratus are less common. Adults of these species are 4 to 10 mm long. Only mandibles of B. mandibularis and a few head capsules of B. eximius were present in the droppings. We found 159 Bledius mandibles, representing 70% of the total mandibles recovered (Table 1).

DISCUSSION

Contrary to some published opinions (Schneider and Harrington 1981, Wilson 1994) for other species of small shorebirds, examination of fecal droppings proves to be a productive method of acquiring information on Snowy Plover diets. Durell and Kelly (1990) and Piersma et al. (1994) have successfully used fecal analyses in identifying and quantifying invertebrate prey of shorebirds at intertidal flats in Europe. A close correspondence between fecal and stomach samples has been noted for other avian taxa with insects or other invertebrates in their diets (Rosenberg and Cooper 1990). This method most efficiently detects evidence of hard-bodied arthropods such as beetles and ants, but also softer-bodied taxa such as corixids and shore flies. Fecal examination is particularly effective in quantifying prey items that have morphologically unique, indigestible parts such as the mandibles of Bledius spp. In the samples of prey items examined by Ralph et al. (1985) there was no apparent bias against small or soft-bodied arthropods. An objection to fecal analysis is that retention of indigestible material in the gizzard will bias diet studies. However, Pienkowski et al. (1988:38) contend that, for shorebirds, turnover of food items in the digestive tract is so rapid that retention of prey fragments is not a serious bias in field studies where a high proportion of prey contains hard parts.

We assume that the Bledius and other insect parts recovered from the feces were eaten at or near Stinky Playa and that the retention time in the gut of Snowy Plovers is relatively short. We are not aware of studies specifically addressing gut retention times for Snowy Plovers. Using Karasov's (1990) analysis of mean retention time as a function of bird mass, and a mean body mass of 40 g for Snowy Plovers in the western U. S. (Page et al. 1995), we estimate a mean gut retention time for these birds to be approximately one hour. However, retention time is probably less than this estimate, given the higher than expected metabolic rates of shorebirds compared to other bird taxa of similar mass (Kersten and Piersma 1987). Our estimate seems reasonable, given that passage time of crustacean eggs in captive Killdeer (Charadrius vociferus) [with a body mass twice that of a Snowy Plover] peaked at 1.5 h and declined sharply after 2 h (Proctor et al. 1967). We know that the Snowy Plover flock in question was foraging at the site for at least one hour. The common prey items in their feces are characteristic of aquatic (corixids), mudflat (ephydrids, Bledius), and saltflat (Bledius, cicindelids) habitats at Lake Holloman and Stinky Playa.

Given the abundance of Bledius in mudflat habitat at the Holloman wetlands, the beetle may be an important food source for other shorebird species. For example, Western

Sandpipers (Calidris mauri) and Killdeer forage in habitats that are wetter than Stinky Playa, but that also harbor large numbers of Bledius. Methods similar to the ones used here may be applicable to dietary analysis in those species as well.

The large numbers of Bledius at Stinky Playa, as well as their suitability as a food source for Snowy Plovers, suggest that these beetles constitute a significant food source for stopover migrants. Peak numbers of shorebirds are present at the Holloman wetlands during spring and fall migration, with smaller numbers of Snowy Plovers, Killdeer, American Avocets (Recurvirostra americana), and Black-Necked Stilts (Himantopus mexicanus) present during the breeding season. The HAFB populations of Bledius appear to offer a high potential as a food source for migrant shorebirds.

At the Holloman wetlands, suitable Snowy Plover nesting habitat is small in area and patchy, and chicks stay in the same area where they were hatched for several weeks, until they are able to fly. Bledius burrows are abundant within these habitats and should be easy for chicks to find; thus, the beetles may provide a significant food source for nesting plovers and their chicks. We have observed chicks foraging in areas where Bledius burrows occur on Stinky Playa.

Our sampling at the Holloman wetlands indicates that Bledius beetles are the most abundant food source in mudflat habitat that is not inundated. Management of water levels and moist soil habitat in the constructed wetland for Snowy Plovers (and other shorebirds) should include consideration of the habitat needs of Bledius beetles. Substantial areas of moist to drier mudflat habitat will be required. Flooding must be restricted, because the beetles can tolerate only brief periods of inundation, perhaps 12 hours. For example, 10 hours after a heavy rainfall in Sep. 1996, the surface of Stinky Playa was littered with carcasses of adult B. mandibularis in an area of high burrow density (Freehling, personal observation). They did not revive, indicating that this species does not enter torpor when its habitat is inundated [as do some intertidal Bledius (Herman 1986)]. These beetles drowned when the playa became saturated with rainwater.

In conclusion, fecal examination is a productive method of acquiring data on Snowy Plover diets and might be useful for other shorebird species with similar diets. Although other insects were evident in the fecal analysis, Bledius was represented in the highest proportion of samples. Snowy Plovers and other shorebirds may depend on beetles of the genus Bledius as a food source during migration stops at inland playas in the arid Southwest. Bledius also may be an important food item for nesting adults and their chicks.

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APPENDIX C

TABLE 1. Arthropod taxa and number of mandibles in Snowy Plover fecal samples.

Sample	Bledius	Cicindelidae	Carabidae	Corixidae	Formicidae	Ephydridae	Other
1		+[a]					
2		2[b]					
3				+	+		
4	1					+	
5	5						
6			38		+	+	Pyralidae(+)
7		4					
8						+	Anthicidae (+)
9	2						
10							
11	1						Coleoptera (1)
12	3	+					Coleoptera (2)
13							
14							
15	3			+		+	
16	2		2				
17							
18							Chironomidae (+)
19	3						
20	12						
21			3				
22							
23							Coleoptera (2)
24	13						Coleoptera (1)
25		+			+		Coleoptera (2)
26				+			
27	1			+		+	
28				+			
29				+			
30				+			

31	+						
32							
33	3						
34	10		2				Diptera: larva
35	8			+	+	+	Coleoptera (1)
36	55				5		
37							
38							
	11						Chrysomelidae (1)
40	8						Coleoptera (2)
41	3						
42							
43	4						
44				+	+		
	4						
46					+		
47					+		
48							
49							Coleoptera (1)
50							Coleoptera (1)
Total mandibles	159	8	47	--	8	--	14
Total samples	28 (56)[c]	7 (14)	6 (12)	11 (22)	14 (28)	7 (14)	

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[a] +, presence indicated by hard parts other than mandibles.
[b] Number of mandibles.
[c] Percent of samples (N = 50).

APPENDIX D. Statistical analyses for invertebrate and shorebird numbers.

Table D1. One-way ANOVAs comparing CW invertebrate numbers in April versus May, at all sampling sites combined, for two habitats.

SATURATED SOIL				**SHALLOW WATER**			
treatment	F-value	P-value	df	treatment	F-value	P-value	df
month	5.3	**0.031**	1	month	14.09	**0.0011**	1
may > april				may > april			

Table D2. One-way ANOVAs and Duncan's multiple comparisons of invertebrate numbers among CW sites in April and May, arranged by habitat type.

	treatment	F-value	P-value	df	Duncan's
APRIL SATURATED SOIL	SITE	3.47	0.071	3	t1=t2=t3=t4
MAY SATURATED SOIL	SITE	12.09	**0.0024**		**(T1=T2)<(T3=T4)**
APRIL SHALLOW WATER	SITE	26.92	**0.0002**		**(T1=T2)<(T3=T4)**
MAY SHALLOW WATER	SITE	28.63	**0.0001**	3	**(T1=T2)<(T3=T4)**

Table D3. One-way ANOVAs comparing number of birds of three foraging guilds at the CW in April versus May, 1997.

Guild	April Mean	May Mean	F-value	P-value	df, corr.
AVOCETS/STILTS	0.225	1.54	41.84	0.0001	1,107
SANDPIPERS	1.81	0.64	12.16	0.0007	
PLOVERS	0.79	0.55	1.78	0.185	,109

Table D4. One-way ANOVAs and Duncan's multiple comparisons of numbers of birds at four CW sites, arranged by guild, month, and habitat type.

	treatment	F-value	P-value	df	DUNCANS
Avocets/Stilts, April	SITE				
DEEP		2.28	0.1031	3,29	
SHALLOW		2.61	0.0729	3,29	
SATURATED		0.76	0.5276	3,29	
DRY		0	0	3,29	
Avocets/Stilts, May					
DEEP		4.72	0.0119	3,23	**(T3)>(T1=T2=T4)**
SHALLOW		14.95	0.0001	3,23	**(T3=T4)>(T1=T2)**
SATURATED		1.46	0.2565	3,23	
DRY		0	0	3,23	
Sandpipers, April					
DEEP		0	0	3,30	
SHALLOW		5.91	0.0031	3,30	**T4>(T1=T2=T3)**
SATURATED		0.2	0.8986	3,30	
DRY		0	0	3,30	
Sandpipers, May					
DEEP		0	0	3,23	
SHALLOW		4.48	0.0146	3,23	**T4>(T1=T2=T3)**
SATURATED		0.79	0.5111	3,23	
DRY		0	0	3,23	
Plovers, April					
DEEP		0	0	3,30	
SHALLOW		3.99	0.0179	3,30	**T4>(T1=T2=T3)**
SATURATED		5.15	0.0061	3,30	**(T4=T1)AND[(T4>(T2=T3)]**
DRY		0.7	0.5603	3,30	
Plovers, May					
DEEP		0	0	3,23	
SHALLOW		6.39	0.0033	3,23	**T4>(T1=T2=T3)**
SATURATED		7.68	0.0013	3,23	**T4>(T2=T3)**
DRY		0	0	3,23	

APPENDIX D. Statistical analyses for invertebrate and shorebird numbers.

Table D5. One-way ANOVAs and Duncan's multiple comparisons of number of birds in four CW habitat types, arranged by month within guild.

Avocets/Stilts								
APRIL	**ALL HABITATS**				**SAT VS. SHALLOW**			
	F-value	P-value	df	DUNCANS	F-value	P-value	df	DUNCANS
T1	0	0						
T2	0	0						
T3	3.86	0.0183	3,35	shallow>(sat=dry=deep)	4.15	0.0585	1,17	
T4	1.5	0.2463	3,35	shallow=saturated	2.09	0.1784	1,11	
MAY								
T1	26.2	0.0001	3,23	shallow>(sat=dry=deep)	17.16	0.002	1,11	shallow>sat
T2	26.94	0.0001	3,23	shallow>(sat=dry=deep)	19.57	0.0013	1,11	shallow>sat
T3	42.04	0.0001	3,23	(shallow>sat,dry,deep)and (sat	40.41	0.0001	1,11	shallow>sat
T4	73.46	0.0001	3,23	shallow>sat,dry,deep	65.81	0.0001	1,11	shallow>sat
Sandpipers								
APRIL								
T1	6.85	0.0017	3,27	sat>(shallow=dry=deep)	3.18	0.0998	1,13	
T2	7.42	0.0008	3,31	sat>(shallow=dry=deep)	7.42	0.0165	1,15	sat>shallow
T3	9.75	0.0001	3,35	sat>(shallow=dry=deep)	3.2	0.0924	1,17	
T4	9.03	0.0004	3,27	(shallow=sat)>(dry=deep)	1.09	0.3171	1,13	
MAY								
T1	1.72	0.1959	3,23		1.72	0.2195	1,11	
T2	0.77	0.5261	3,23		0.3	0.5958	1,11	
T3	1	0.4133	3,23		1	0.3409	1,11	
T4	2.7	0.0734	3,23		0.69	0.4255	1,11	
Plovers								
APRIL								
T1	5.78	0.004	3,27	sat>(shallow=dry=deep)	7.49	0.0181	1,13	sat>shallow
T2	3.06	0.0445	3,31	sat>(shallow,deep)	4.2	0.0596	1,15	
T3	7.77	0.0005	3,35	sat>(shallow=dry=deep)	7.35	0.0154	1,17	sat>shallow
T4	15.14	0.0001	3,27	sat>[(shallow>(dry=deep)]	5.06	0.044	1,13	sat>shallow
MAY								
T1	15.57	0.0001	3,23	sat>(shallow=dry=deep)	15.57	0.0027	1,11	sat>shallow
T2	2.86	0.0628	3,23		1.43	0.2596	1,11	
T3	0	0	3,23		0	0	1,11	
T4	11.21	0.0002	3,23	(shallow=sat)>(dry=deep)	2.09	0.1791	1,11	

APPENDIX D. Statistical analyses for invertebrate and shorebird numbers.

Table D6. Relationship between number of birds of each guild and number of invertebrates, months and habitats combined, by month, and by habitat. Bird data are square root transformed to eliminate negative logs for zero data; invertebrate data are log transformed. Sites are Holloman (April), Stinky (May), and CW 1-4 (April and May).

	AVOCETS/ STILTS	**SANDPIPERS**	**PLOVERS**	**GUILDS COMBINED**	
COMBINED MONTHS AND HABITAT (Sites = constructed wetland T1-T4)					
ADJ r squared	0.278	-0.071	-0.062	0.021	1,15
f	6.79	0.003	0.119	1.319	1,15
p	0.0207	0.9578	0.7348	0.27	1,15
SLOPE	POS	NEG	NEG	POS	
APRIL					
ADJ r squared	0.188	0.045	-0.115	0.048	1,7
f	2.623	1.332	0.28	1.356	1,7
p	0.1564	0.2923	0.6155	0.2884	1,7
SLOPE	POS	POS	POS	POS	
MAY					
ADJ r squared	-0.033	-0.13	-0.142	-0.11	1,7
f	0.778	0.193	0.128	0.92	1,7
p	0.4118	0.6759	0.7328	0.3746	1,7
SLOPE	POS	POS	NEG	POS	
SATURATED					
COMBINED MONTHS					
ADJ r squared	0.439	-0.053	-0.029	-0.084	1,7
f	7.819	0.646	0.805	0.456	1,7
p	0.0313	0.4521	0.4042	0.5248	1,7
SLOPE	POS	NEG	NEG	NEG	
SHALLOW					
COMBINED MONTHS					
ADJ r squared	0.913	-0.066	-0.047	0.703	1,7
f	74.137	0.566	0.683	17.609	1,7
p	0.0001	0.4803	0.4402	0.0057	1,7
SLOPE	POS	**POS**	**POS**	**POS**	