Ecological Engineering xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Shorebird abundance and species diversity in natural intertidal and non-tidal anthropogenic wetlands of the Colorado River Delta, Mexico

Martha M. Gomez-Sapiens[a,*], Eduardo Soto-Montoya[b], Osvel Hinojosa-Huerta[c]

[a] Department of Soil, Water and Environmental Science, University of Arizona Campus, Room 502 Shantz Building #38, Tucson, AZ, United States
[b] Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado, Jalisco 903. Col. Sonora, San Luis Rio Colorado, Son., Mexico
[c] Pronatura Noroeste A.C., Ave Primera e/Todos Santos y Colosio Fracc., Bella Vista No. 1114, La Paz, Baja California Sur, Mexico

ARTICLE INFO

Article history:
Received 6 July 2012
Received in revised form 28 February 2013
Accepted 15 March 2013
Available online xxx

Keywords:
Shorebirds
Colorado River Delta
Habitat use
Anthropogenic wetlands
Intertidal wetlands

ABSTRACT

Shorebirds constitute the highest abundance group of birds that use the Upper Gulf of California and Colorado River Delta (CRD) wetlands for nesting, spring stopover and overwintering sites. From August 2005 to December 2008 ground surveys were conducted on three natural intertidal wetlands (Golfo de Santa Clara, Isla Montague and Bahia Adair) and three brackish anthropogenic wetlands (Cienega de Santa Clara, Cerro Prieto and Mesa de Andrade) in the Upper Gulf and CRD. The goal was to determine the overall importance of the CRD in supporting shorebirds, and in particular the role of the anthropogenic wetlands, which face uncertain futures. Species richness varied from 15 to 26 species among sites and 29 species were detected across sites. The most abundant species was *Calidris mauri*, which was most abundant in Isla Montague and Golfo de Santa Clara in winter and spring, while it was most abundant in the Cienega de Santa Clara and Mesa de Andrade wetland in spring and fall. Cienega de Santa Clara and Golfo de Santa Clara had the highest bird density with 168 and 105 individuals/ha in the peak migration month. Birds tended to use the intertidal wetlands during the winter and spring migration period while the inland wetlands were most used during spring and fall. The Cerro Prieto geothermal power plant wetlands were most used by Phalaropes species during fall migration. Bahia Adair, an extensive intertidal wetland system south of the CRD, had a low density of shorebirds (10 individuals/ha) compared to CRD sites, but it had higher species diversity and the highest proportion of large size shorebirds. This study shows the importance of both intertidal and anthropogenic wetlands in supporting shorebirds along the Pacific Flyway. Management decisions that might impact these wetlands should consider their habitat value for migratory shorebirds as documented here.

1. Introduction

The Colorado River Delta (CRD) and the Upper Gulf of California support 37,890 ha of intertidal and non-tidal brackish wetlands (Glenn et al., 1996). Much of this area is protected by Mexican Law as a Biosphere Reserve and is designated as a Ramsar Site, an Important Bird Conservation Area (AICA), and a component of the Western Hemispheric Shorebird Reserve Network (WHSRN). Even though biotic and abiotic characteristics of this delta region have been modified by the reduction in water flow due to upstream water diversion (Glenn et al., 1996, 2006) the CRD and Upper Gulf area still have high productivity wetlands that support resident and migratory waterbird communities (Hinojosa-Huerta et al., 2004a).

Documented waterbird habitat uses for Upper Gulf and CRD region include reproduction sites for several species, and stopover and wintering sites for migratory species along the Pacific Flyway (Hinojosa-Huerta et al., 2004b; Mellink et al., 1997; Morrison, 1992). Shorebirds (families: *Charadriidae*, *Recurvirostridae*, *Haematopodidae* and *Scolopacidae*) are the group with the highest abundance (Mellink et al., 1997; Hinojosa-Huerta et al., 2004b). An earlier aerial survey estimated 163,744 wintering shorebirds in the CRD (Morrison, 1992), whereas subsequent ground survey estimates ranged from 88,000 (Román-Rodríguez, 2004) to 148,285 (Mellink et al., 1997). These studies indicated that the CRD region is equal to the Salton Sea and other high-density shorebird sites on the Pacific Flyway (Shuford et al., 2002). Shorebirds use the CRD wetlands mostly as a wintering site, with the mudflats and saltflats located near the mouth of the river being the most used areas (Mellink et al., 1997). According to Mellink et al. (1997) there is a possibility that individuals that use the Salton Sea could be the same individuals that use CRD wetlands since both

* Corresponding author. Tel.: +1 5203708385.
E-mail address: sneipas@gmail.com (M.M. Gomez-Sapiens).

0925-8574/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2013.03.004

sites are reported to be on the flyway for birds moving southward to the Pacific coastal areas during their migrations (Shuford et al., 2002).

The intertidal wetlands are extensive due to the shallow slope of the seabed and the high amplitude (up to 5 m) of the mixed diurnal tides (two tide cycles per day) in the CRD. However, the Colorado River no longer carries seasonal fresh water flows due to upstream dams and water diversions, and as a consequence the salinity regime of the estuary has been altered from seasonally miohaline to consistently euryhaline, which has induced changes in the flora and fauna (e.g., Avila-Serrano et al., 2006). On the other hand, a series of non-tidal, anthropogenic brackish wetlands have been created in the delta from the disposal of agricultural drainage water and other management activities. Our research question was, what is the relative contribution of the now-euryhaline intertidal wetlands and the brackish anthropogenic wetlands in supporting shorebird abundance and diversity? The answer to this question has management implications, because these anthropogenic wetlands were all inadvertently created by water management decisions in the U.S. and Mexico, and as a result they could be altered or eliminated by future management activities.

2. Methods

2.1. Study sites

Studies sites are shown in Fig. 1 and their size and main features are described in Table 1. The intertidal zone (Fig. 1) includes the coastline located at El Golfo de Santa Clara village, Isla Montague, San Felipe and Bahia Adair. The first three localities are part of the CRD estuary, which is dissected by three channels bordering the Montague-Gore and Pelicano Islands inside the core zone of the Biosphere Reserve. The coastline consists of extensive mudflats that decrease in silt and clay with increasing distance from the river mouth. The vegetation includes patches of the endemic saltgrass *Distichlis palmerii* on the Isla Montague and adjacent coastline areas and other halophytic species at other locations in the intertidal zone (Yensen et al., 1983; Felger, 2000).

The shoreline sites selected for sampling in the CRD consists of silty-clay (limo-arcilloso) sediments, with high benthic species richness (46), high density of benthic organisms (98.6 individuals/m^2) and high values for biomass (58.07 mg/m^2) (Villarreal and Carmona, 1999). Sampling was also conducted in Bahia Adair, an extensive estuary of tidal channels, mudflats and saltflats southeast of the CRD on the Sonoran shoreline (Felger, 2000). Sediments in that estuary sit on cemented seashell formations called coquinas, interrupted by tidal ponds and sandy areas. Halophytic species from Bahia Adair include *Allenrolfea occidentalis*, *Batis maritima*, *Salicornia bigelovii*, *S. subterminalis*, *S. virginica*, *Suaeda esteroa*, *S. puertopenascoa*, *Atriplex linearis*, *Atriplex barclayana*, *Cressa truxillensis*, *Frankenia salina*, *Distichlis palmeri*, *Monanthochloë littoralis* (Felger, 2000).

The first anthropogenic wetland complex selected for sampling was Cienega de Santa Clara (Fig. 1), a 4200 ha brackish wetland maintained by mildly saline (2–3 ppt) water releases from the Wellton-Mohawk Irrigation District in the U.S. (Glenn et al., 1992, 2001). It is an emergent marsh dominated by cattail (*Typha domingensis*), with about 15% open water areas, and patches of *Phragmites australis*, *Juncus*, *Distichlis spicata*, *D. palmeri*, *Scirpus* spp., *Tamarix chinensis* and *Allenrolfea occidentals* within the marsh or along the sides of the marsh (Abarca et al., 1993). The Cienega also supports large quantities of submerged aquatics such as *Najas marina* and *Ruppia maritima* (Glenn et al., 1992), important food sources for some waterfowl. South of the Cienega is an extensive evaporation basin that receives effluent from the Cienega and occasional tidal flooding. The Cienega is within the core and buffer zone of the Biosphere Reserve.

The second anthropogenic wetland complex is the Cerro Prieto geothermal field (Fig. 1). It consists of approximately 4000 ha of evaporation ponds, mud volcanos (0.05–2 m high), hot springs, vents, salt pans and fault scarps (Mercado and Fernández, 1998). Water sources include ground water fed by the Cucapa Mountain Range alluvial fans and the Colorado River (Mercado and Fernández, 1998). The wetlands are salty and shallow with an important microcrustacean community and other benthic species (Varela-Romero et al., 1998). *A. occidentalis* is the dominant plant species. The main shorebird habitats are in a series of evaporation ponds where effluent water from the geothermal electric generating facility is discharged. These shallow ponds contain islands of dredged material, which provide protection from predators for nesting birds. The ponds also provide food in the form of submerged aquatic vegetation, fish and invertebrates growing in the brackish ponds. According to Hinojosa-Huerta et al. (2004a) the Cerro Prieto wetlands are a nesting site link for shorebirds, between the Lower Colorado River (Isla Montague) and Salton Sea nesting sites.

The third set of anthropogenic wetlands are the Mesa de Andrade wetlands (Fig. 1), extending over an area of 6200 ha. These wetlands are formed by water seeping from the formerly unlined All American Canal in the United States. Seepage flows under the dune field comprising the San Andrade Mesa and surfaces along the foot of the dune field at its southern extent in Mexico, forming small, isolated wetlands separated by dunes. The wetlands consist of emergent marshes, playas and vegetated dunes, where the water table is within the reach of phreatophytic vegetation. Representative plant species in the marshes are *Distichlis spicata* and *T. domingensis*, while the dunes support *Larreta tridentata*, *Prosopis glandulosa*, *P. pubescens* and *Atriplex* spp. and other halophytes (Hinojosa-Huerta et al., 2002). With the lining of the All American Canal in 2008, seepage is not expected to continue and the future of these wetlands is in doubt.

2.2. Survey methods

The methods were based on the protocol of the Western Shorebird Survey (Bart et al., 2005). Surveys at each site were conducted at times of year previously identified as critical migration, wintering or nesting periods. Counts started at around 0800 h and continued throughout the day. At each site transects were set along the coastline or edge of the wetland and consisted of five or more point counts 400 m apart unless noted otherwise below. Each survey point had a radius of 250 m and an area of 12.5 ha. Surveyors used 10× binoculars and a 20× spotting scope to observe birds. In cases in which species identification was not possible, only the genus of the bird was recorded. In cases when larger concentrations than could be counted were encountered, numbers of shorebirds were determined by flock estimation following Kasprzyk and Harrington (1989) recommendations. Relative abundance (% composition) was calculated for each species.

At the intertidal zone habitats, the sampling dates corresponded to the lowest neap tide day for each month. At the non-tidal sites sampling dates were selected by chance keeping a similar time frame among surveys on each site. Surveys started in August 2005 in all the sites and in November for Bahia Adair and Isla Montague.

For the period from August 2005 to December 2006 six sampling zones were selected in Golfo de Santa Clara, Isla Montague and Bahia Adair for the intertidal zone and Cienega de Santa Clara, Cerro Prieto and Mesa de Andrade for the anthropogenic sites. At El Golfo de Santa Clara five points each were set along the shoreline from northwest to southeast.

Please cite this article in press as: Gomez-Sapiens, M.M., et al., Shorebird abundance and species diversity in natural intertidal and non-tidal anthropogenic wetlands of the Colorado River Delta, Mexico. Ecol. Eng. (2013), http://dx.doi.org/10.1016/j.ecoleng.2013.03.004

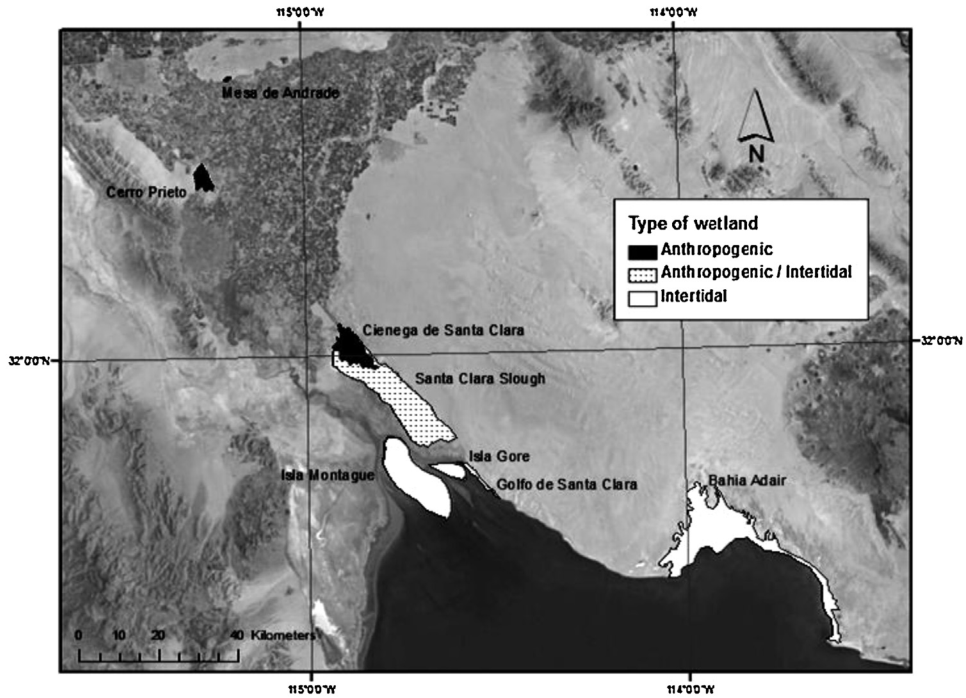

Fig. 1. Survey sites at the Colorado River Delta.

Around Isla Montague 15 points were set along the intertidal mudflat and surveys were done from a small boat using binoculars at a variable distance to the land (5–20 m) according to the topography of the shoreline, weather and tidal conditions. At Bahia Adair two localities were established with a five point transect on each one with a separation of 500 m among points in the sandy shoreline and coquinas, and along the estuary. At the Cienega de Santa Clara surveys were conducted since April 2007 in the three points in the southwest part of the wetland which has open areas in the southern limit of the cattail distribution. These habitats are composed of mudflats and saltflats that extend toward the mouth of the river and points were separated by 500 m.

For the Mesa de Andrade wetlands three points were established, one for each of the lagoons. Visits to Mesa de Andrade Wetlands were discontinued in January 2007 due the lowest abundance of shorebirds recorded for the site. In the case of the Cerro Prieto Geothermal Field the surveys were done along the evaporation ponds by car to include individuals feeding in the shorelines of the ponds and using the spotting scope and binoculars to observe the flocks in distant areas. In Cerro Prieto the visits were restricted to the summer months (fall migration) since it was determined to be a more important season for shorebird use.

2.3. Data analysis

In order to compare density among the sites, annual mean density was estimated using the peak migration month for each site and the sampled area. In the case of Isla Montague two points were eliminated since they do not contain mudflat area and shorebirds visits were very infrequent (see Table 1). To detect differences in mean abundance per site among years one-way analysis of variance (ANOVA) and *t*-tests were conducted on log transformed data, using SPSS version 13.0.

Shannon diversity index was estimated for each community's sampled year, and similarity indices (Jaccard, Sorenson, Morisita–Horn and Bray–Curtis) on the total of individuals detected per site during the period of survey. Correspondence Canonical Analysis (CCA) was used to determine the differences on community's structure and conducted on CANOCO version 4.5.

3. Results

3.1. Overall abundance and diversity

The sites with the highest shorebird density during peak migration months were the Cienega de Santa Clara and Golfo de Santa Clara with 168 and 105 individuals per ha, respectively (Table 1). Species richness ranged from 15 to 26 species among individual sites and 29 shorebird species were recorded among all the sites (Tables 2 and 3).

The site with the highest diversity of habitats (Bahia Adair) showed highest Shannon Diversity Index values from 1.90 to 2.62 and the lowest abundances (below 6000 shorebirds per sampled year), playa habitat sampled in the Cienega had the highest

Table 1
Shorebird survey sites.

Site	Area (Ha)	Type of wetland	Habitats
Bahia Adair (BA)	28,709	Intertidal	Sandy/rocky shore/estuaries
Golfo de Santa Clara (GSC)	969	Intertidal	Mudflat
Isla Montague (IM)	16,050	Intertidal	Mudflat
Cienega de Santa Clara (CSC)	22,104	Anthropogenic	Playa areas/saltflats
Cerro Prieto (CP)	1739	Anthropogenic	Lagoons/saltflats
Mesa de Andrade (MA)	42	Anthropogenic	Lagoons

Please cite this article in press as: Gomez-Sapiens, M.M., et al., Shorebird abundance and species diversity in natural intertidal and non-tidal anthropogenic wetlands of the Colorado River Delta, Mexico. Ecol. Eng. (2013), http://dx.doi.org/10.1016/j.ecoleng.2013.03.004

Table 2
Shorebird mean density during the peak migration month of each site.

Site	Month	Mean abundance	95% CI	N	Sampled area (ha)	Density (individuals/ha, CI)
BA	November	1021 (SD ± 250)	674–1377	2	98.1	10 (7–14)
GSC	February	7518 (SD ± 7363)	814–15,850	3	49.0	153 (17–323)
IM	February	4846 (SD ± 4353)	80–9772	3	127.6	38 (1–76)
CSC	August	4960 (SD ± 4202)	863–10,783	2	29.4	168 (29–367)
CP	August	7245 (SD ± 3751)	3569–10,921	4	300	24 (12–36)
MA	August	520 (SD ± 300)	104–936	2	29.4	18 (3–32)

abundance along with mudflats habitats in some of the sampled years (over 19,000 shorebirds) with diversity value in the middle of the spectrum found for this region (about 1.5), the lagoon habitats sampled in the Cerro Prieto Site showed diversity values below 1.3 and abundances in the range of 13,000–18,000 shorebirds per year. Mudflats sampled in the Delta (Golfo and Isla Montague) showed the highest variation in terms of diversity and number of shorebirds (Fig. 2).

Shorebird community assemblage differs mainly by type of wetland and diversity of habitats. According to the ordination model from a CCA (Fig. 3), 53% of the variation in the shorebird community structure was explained by the sites Adair, Cienega and Cerro Prieto (p-value < 0.001), even though the axis that defines the Cienega site had a higher p-value (0.08). The axis defined by the shorebird community assemblage of El Golfo de Santa Clara and Isla Montague had higher p-values (>0.3). Differences between the axis can be attributed in the case of Bahia Adair to the highest abundance of *Arenaria* species, Surfbird and American Oystercatcher. In the Cienega de Santa Clara the axis was defined by species detected in higher abundances (American Avocet and Black-necked Stilt) or exclusively at that site (Stilt Sandpiper and Killdeer). In the Cerro Prieto site the axis was defined by higher abundance of Phalarope species, Least Sandpiper and Spotted Sandpiper (Fig. 3).

3.2. *Shorebird composition and abundance in the intertidal zone*

El Golfo de Santa Clara and Isla Montague had a similar distribution of shorebirds species. At both sites the most abundant shorebirds were small *Calidris* species, with *C. mauri* individuals accounting for about 60% of relative abundance (Table 3). Other

Table 3
Total and relative abundance on intertidal zone sites from August 2005 to December 2008, see Appendix 1 for species code.

Species	Bahia Adair		Golfo de Santa Clara		Isla Montague	
	Total	Relative abundance	Total	Relative abundance	Total	Relative abundance
AMAV	184	1.30	251	0.46	778	2.29
AMGP	4	0.03	4	0.01	0	0
AMOY	685	4.84	53	0.10	84	0.25
AREN	3	0.02	0	0	0	0
BBPL	606	4.28	871	1.61	489	1.44
BLTU	56	0.40	25	0.05	1	0
BNST	16	0.11	0	0	0	0
CALI	2489	17.58	23,357	43.17	18,282	53.89
CHAR	84	0.59	17	0.03	13	0.04
DUNL	177	1.25	11	0.02	117	0.34
GRYE	3	0.02	1	0	0	0
KILL	1	0.01	6	0.01	1	0
LBCU	1551	10.95	1124	2.08	2541	7.49
LBDO	0	0	0	0	3	0.01
LESA	1	0.01	0	0	6	0.02
LEYE	11	0.08	6	0.01	0	0
MAGO	1564	11.04	1872	3.46	660	1.95
NUME	1641	11.59	1099	2.03	863	2.54
PAGP	0	0	1	0	0	0
PHAL	0	0	0	0	0	0
PLUV	313	2.21	161	0.30	134	0.39
REKN	186	1.31	3470	6.41	1853	5.46
RNPH	0	0	0	0	0	0
RUTU	227	1.60	18	0.03	0	0
SAND	97	0.68	371	0.69	188	0.55
SBDO	11	0.08	116	0.21	4	0.01
SEPL	52	0.37	10	0.02	8	0.02
SESA	0	0	0	0	0	0
SNPL	121	0.85	76	0.14	2	0.01
STSA	0	0	0	0	0	0
SPSA	0	0	0	0	1	0
SURF	6	0.04	0	0	0	0
TRIN	78	0.55	54	0.10	11	0.03
UNDO	525	3.71	6891	12.74	3582	10.56
WESA	734	5.18	11,701	21.63	1003	2.96
WHIM	258	1.82	287	0.53	482	1.42
WILL	2393	16.90	2198	4.06	2803	8.26
WIPH	0	0	0	0	0	0
WIPL	84	0.59	57	0.11	16	0.05
Total	14,161		54,108		33,925	

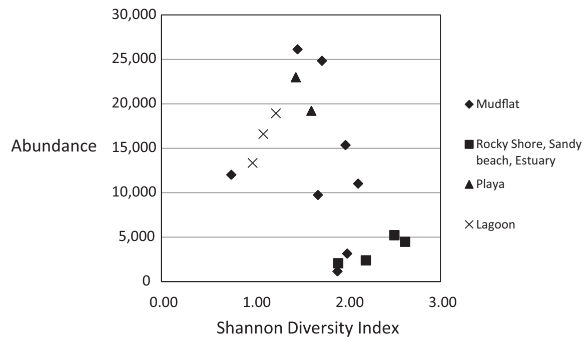

Fig. 2. Relationship between the Shannon diversity index and abundance per year in the wetlands, mudflat corresponds to Golfo de Santa Clara and Isla Montague, Rocky shore, Sandy beach and Estuary to Bahia Adair, Playa to the Cienega de Santa Clara and Lagoon to Cerro Prieto site.

dominant species included Dowitchers (*Limnodromus* spp.) with 12.7% and 10.5% of relative abundance respectively. After *C. mauri* the most common *Calidris* species was Red Knot (*Calidris canutus*) in the case of El Golfo site, and Willet (*Tringa semipalmata*) in Isla Montague. *Numenius* species were abundant at the Isla Montague accounting for 11.4% of relative abundance, and most were individuals of Long-billed Curlews (*Numenius americanus*). At the El Golfo site the percentage of the large size shorebirds like Willet, Long-billed Curlew and Marbled Godwit was approximately 12%. Plovers represented 2.2% of relative abundance at El Golfo and nearly 1.9% at Isla Montague. In Bahia Adair the most abundant shorebirds were *Calidris* and *Numenius* species which accounted for 24% of relative abundance with *N. americanus* being the most common species from that genus. Willets (*Tringa semipalmata*) accounted for 17% of relative abundance while Marbled Godwits (*Limosa fedoa*) were slightly less dominant accounting for 11% of the total abundance. In this site a large flock (350 individuals) of American Oystercatchers (*Haematopus palliatus*) was detected in the "Coquina" areas during the winter months. From the three intertidal zone sites, Bahia

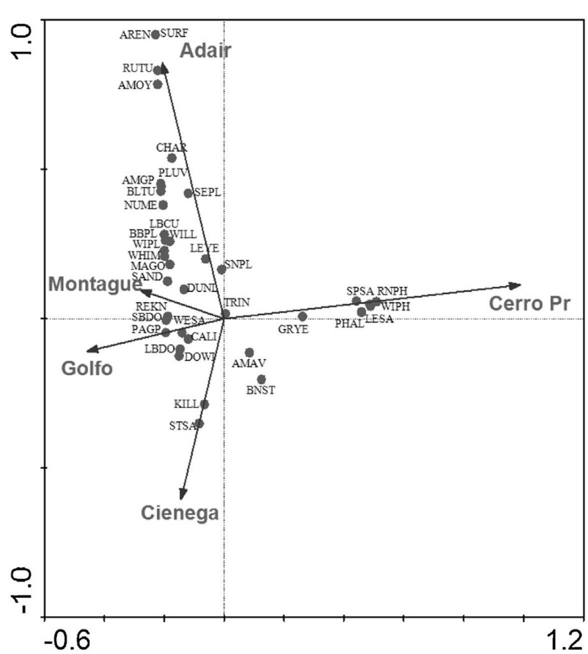

Fig. 3. Ordination diagram of species/taxa presence and abundance on the sites from Canonical Correspondence Analysis. The letters refer to species/taxa code showed in Appendix 1.

Adair showed the highest relative abundance of plovers with 8.9% (Table 3).

3.3. Shorebird composition and abundance in the anthropogenic wetlands

In the southern portion of the Cienega, *Calidris* and *Limnodromus* species were the most abundant species, with relative abundances of approximately 56.9% and 19.3% respectively, followed by Black-necked Stilt and American Avocet (7.1%), and phalaropes (5.9%) (Table 4). 1110 records of Marbled Godwit (*Limosa fedoa*) were recorded in this location and the Snowy Plover (*Charadrius nivosus*) was the most abundant plover with 89 records.

The most common shorebirds at the Andrade Mesa Wetlands were *Calidris*, or small sandpipers, representing 33% of the shorebird community. Dowitchers (*Limnodromus* sp.) and Black-necked Stilts (*Himantopus mexicanus*) were the second and third most abundant species with 24.3% and 23.8% respectively, with occurrence of phalaropes and American Avocets (*Recurvirostra americana*) being around 5% (Table 4). The most common plover was Killdeer (*Charadrius vociferus*) with 35 records.

The Cerro Prieto ponds were used mostly by phalaropes during the summer months or fall migration (relative abundance of 80%), with more than 20,000 individuals in three summers of surveys and a range of 3000–8000 individuals recorded during each visit. *Calidris* species were the second most abundant (11.7%) shorebird in these ponds. American Avocet (4.0%) and Black-necked Stilt (3.3%) were abundant all year round, and among the plovers the most recorded species were Snowy Plovers and Black-bellied Plovers with 121 and 66 individuals (Table 4).

3.4. Communities comparison based on similarity indices

Qualitative indices Jaccard and Sorenson suggest high similarity in terms of the number of shared species between Bahia Adair and El Golfo site, between the rest of the intertidal sites and also between Bahia Adair and Cerro Prieto with values higher than 0.6 for both indices (Table 5). Quantitative indices Morisita-Horn and Bray–Curtis suggest high similarity among the three communities close in distance to the delta (Cienega, Golfo and Isla Montague) and lower similarity between Bahia Adair and Cerro Prieto and El Golfo and Mesa de Andrade (Table 5).

3.5. Differences in seasonal abundance among sites

Seasonal abundance at El Golfo and Isla Montague intertidal sites showed the same pattern with highest abundance during winter months and over spring migration, which corresponds with *C. mauri* wintering and migration (Fig. 4.). In contrast, summer months showed a low abundance of *C. mauri* and an increase in the abundance of Red Knots (*C. canutus*).

In Bahia Adair seasonal abundance of shorebirds was high from November to January with another peak during spring migration (Fig. 4), due mainly to visitations by *C. mauri* and *Numenius* spp.

In the Cienega de Santa Clara peak abundances were recorded in April and August as a result of the presence of both *Calidris* and *Limnodromus* species in April, and of *C. mauri* in August (Fig. 5). Important numbers of other species (American Avocet and Phalaropes) contributed to seasonal abundance in the summer months.

For the last three years of sampling at Cerro Prieto the months of highest abundances were August and September (Fig. 5) as a result of Phalarope migration. For the Mesa de Andrade wetlands abundance peaks were recorded in winter due the presence of

Table 4
Total and relative abundance on inland wetlands from August 2005 to December 2008 in the Cienega and Cerro Prieto sites and from August 2005 to December 2006 in the Mesa de Andrade site (see Appendix 1 for species code).

Species	Cienega		Cerro Prieto		Mesa de Andrade	
	Total	Relative abundance	Total	Relative abundance	Total	Relative abundance
AMAV	3002	7.11	2146	4.08	189	4.61
AMGP	0	0	0	0	0	0
AMOY	0	0	0	0	0	0
AREN	0	0	0	0	0	0
BBPL	0	0	66	0.13	0	0
BLTU	0	0	0	0	0	0
BNST	2998	7.10	1738	3.30	977	23.83
CALI	20,940	49.61	4579	8.70	1000	24.39
CHAR	2	0	7	0.01	0	0
DUNL	319	0.76	12	0.02	2	0.05
GRYE	8	0.02	23	0.04	10	0.24
KILL	54	0.13	4	0.01	35	0.85
LBCU	3	0.01	20	0.04	1	0.02
LBDO	0	0	0	0	4	0.10
LESA	9	0.02	599	1.14	117	2.85
LEYE	0	0	5	0.01	16	0.39
MAGO	1110	2.63	3	0.01	0	0
NUME	4	0.01	21	0.04	0	0
PAGP	0	0	0	0	0	0
PHAL	2355	5.58	24,365	46.28	200	4.88
PLUV	0	0	0	0	0	0
REKN	0	0	12	0.02	0	0
RNPH	71	0.17	15,431	29.31	105	2.56
RUTU	0	0	1	0	0	0
SAND	0	0	8	0.02	28	0.68
SBDO	0	0	0	0	6	0.15
SEPL	9	0.02	12	0.02	4	0.10
SESA	0	0	0	0	0	0
SNPL	89	0.21	121	0.23	0	0
STSA	3	0.01	0	0	0	0
SPSA	0	0	9	0.02	0	0
SURF	0	0	0	0	0	0
TRIN	177	0.42	100	0.19	19	0.46
UNDO	8176	19.37	4	0.01	1156	28.20
WESA	2773	6.57	988	1.88	227	5.54
WHIM	10	0.02	1	0	0	0
WILL	26	0.06	72	0.14	4	0.10
WIPH	74	0.18	2299	4.37	0	0
WIPL	0	0	2	0	0	0
Total	42,212		52,648		4100	

Limnodromus spp. In August, bird abundance increased due to visitations by *Calidris* sp. (Fig. 5).

Differences in abundance among years (from 2006 to 2008) were non-significant ($p > 0.05$) for Bahia Adair, ($F = 0.671$, p-value = 0.522). La Flor in Cienega de Santa Clara ($F = 0.817$, p-value = 0.425 for years 2007 and 2008), Isla Montague, ($F = 0.537$, $p = 0.611$ for years 2006 and 2007). There was moderate evidence of a difference among years in the Golfo de Santa Clara ($F = 3.39$, $p = 0.046$).

Table 5
Shorebird similarity indices.

1st Sample	2nd Sample	Shared species	Jaccard	Sorenson	Morisita–Horn	Bray–Curtis
BA	CP	19	0.68	0.81	0.08	0.11
BA	CSC	13	0.46	0.63	0.50	0.19
BA	IM	18	0.67	0.80	0.61	0.45
BA	GSC	21	0.84	0.91	0.60	0.34
BA	MA	13	0.50	0.67	0.37	0.22
CP	CSC	15	0.60	0.75	0.25	0.26
CP	GSC	17	0.61	0.76	0.15	0.12
CP	IM	16	0.57	0.73	0.15	0.15
CP	MA	13	0.52	0.68	0.24	0.10
CSC	GSC	12	0.44	0.62	0.91	0.69
CSC	IM	13	0.52	0.68	0.94	0.64
CSC	MA	12	0.60	0.75	0.80	0.17
GSC	IM	17	0.65	0.79	0.91	0.71
GSC	MA	11	0.42	0.59	0.66	0.09
IM	MA	11	0.44	0.61	0.63	0.14

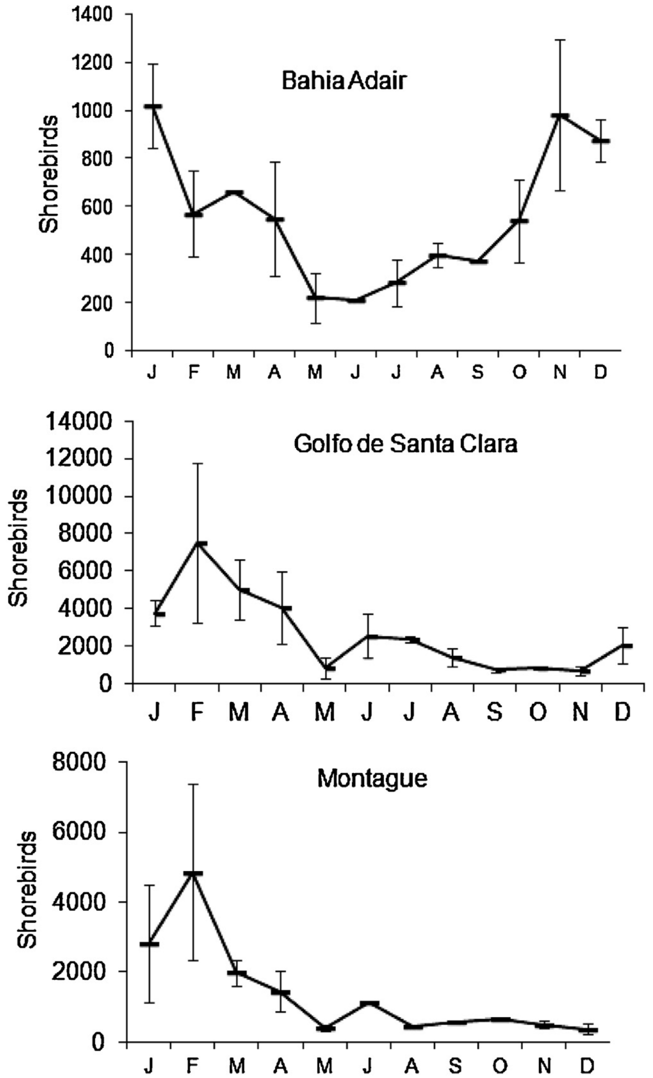

Fig. 4. Shorebirds mean seasonal abundance and standard error at the intertidal wetlands, from August 2005 to December 2008.

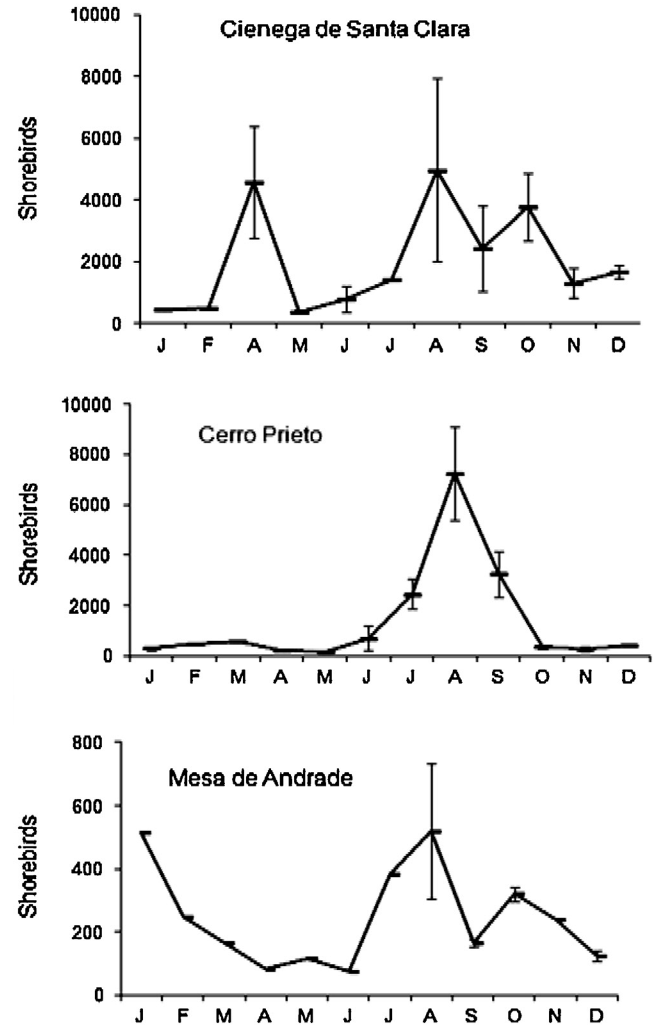

Fig. 5. Shorebirds mean seasonal abundance and standard error at the inland wetlands, from August 2005 to December 2008.

4. Discussion

4.1. Overall abundance and species diversity of CRD and upper Gulf wetlands

During the four years of the monitoring program we recorded 54,108 shorebirds at all localities. Mellink et al. (1997) recorded 170,700 shorebirds in 1993–1994 for the same localities. However, the area surveyed by Mellink et al. (1997) at each location was much larger than in our surveys, since they used wide-area estimates for their census versus our use of point counts which result in a smaller area being surveyed Nonetheless, both surveys show the CRD is a major stopover spot for migratory shorebirds on the Pacific Flyway. We did not detect decreases in habitat use over the years of our study. However, total abundance from specific sampling points should not be considered as the only indicator of population trends since other variables such as turnover rates and the use of other areas not sampled could be taking place (Morrison et al., 2001; Skagen et al., 2008; Warnock et al., 1998).

4.2. Seasonal patterns of abundance in intertidal versus non-tidal wetlands

The seasonal patterns of abundance indicate that the intertidal zone had the highest use by shorebirds during winter and spring migration periods, whereas the anthropogenic wetlands had highest abundance during the spring and fall migration. Bahia Adair appears to be more important in the early winter months of November and December than at other times of year. Peak abundances of seasonal shorebird variation in winter and spring months at nearby staging sites in the Central Valley of California and Baja California (Palacios et al., 1991; Shuford et al., 1998) matched the seasonal patterns observed in our intertidal sites. On the other hand, sites such as the Salton Sea and Humboldt Bay show same pattern (peak abundance in spring and fall months) as our anthropogenic (non-tidal) wetlands (Colwell, 1994; Shuford et al., 2002 and Carmona et al., 2004). Thus, shorebird visitation in intertidal and anthropogenic wetlands were complimentary to each other, extending the regional habitat value of the CRD and Upper Gulf beyond what could be provided by the intertidal sites alone. They also appeared to be complimentary to seasonal visitation to other major shorebird visitation sites on the flyway. The CRD non-tidal wetlands and the Salton Sea provide inland stopover sites along the Pacific Flyway and studies suggest connectivity between both areas (Shuford et al., 2002).

4.3. Abundance of Western Sandpipers

The peak shorebird abundances in April and August at the Salton Sea and in February in the CRD are mainly the result of the high abundance of Western Sandpipers (Shuford et al., 2002). Our data suggest that part of the population of Western Sandpiper is wintering in the intertidal zone in the CRD and other studies indicate that the species also winters in the Central Valley of California and at southern stopover sites such as Ensenada Pabellones and Bahía Santa María in Sinaloa, Guerrero Negro and Ensenada de La Paz in Baja California Sur, México, where high relative abundance (60–80%) of this species has been reported (Carmona and Danemann, 1998; Engilis et al., 1998; Fernández et al., 1998).

Western Sandpipers might also overwinter in the Salton Sea since highest abundances are reported in fall surveys (Shuford et al., 2002). These birds then move south to the intertidal zone at the CRD. Mellink et al. (1997) suggested that the same individuals might be using both areas. In spring, Western Sandpipers use the CRD coastal wetlands (Golfo de Santa Clara and Isla Montague) but they also use the Cienega during both spring and fall as well as the Salton Sea (Shuford et al., 1998). The migration of Western Sandpiper is reported to be more compressed in time and space in spring compared to fall (Butler et al., 1996). Clearly, Western Sandpipers use both intertidal and anthropogenic wetlands in the CRD, and display different seasonal preferences for these wetlands.

4.4. Abundance of Phalaropes

In the case of highly abundant phalarope species in summer, 1999 data for Salton Sea were lower than numbers observed in the present study (Shuford et al., 2002). They found fewer than half as many Red-necked and Wilson's Phalaropes as we found in the Cerro Prieto geothermal ponds. However, similar to our study, a high concentration of Wilson's Phalarope were reported to be using evaporation ponds during late July in the Central Valley of California, along with Red-necked Phalarope, American Avocets, small sandpipers and Black-necked Stilts (Shuford et al., 1998). Although Great Salt Lake, Utah, along with Mono Lake, California and Lake Albert, Oregon are reported to be the main staging areas for Wilson's Phalarope, anthropogenic wetlands such as Cerro Prieto also appear to be important during fall migration, being the inland wetland with the highest abundance of *Phalaropus* (mostly *lobatus*) species in Northwest Mexico. The Cerro Prieto ponds represent protected feeding areas, similar to the saltworks at Guerrero Negro on the Baja California peninsula (Carmona and Danemann, 1998). The species use saltworks to recover during migration on their route to the South America wintering areas. However, our data suggest Phalaropes might use an alternate route during their northward migration, since they were not recorded in the CRD during the spring migration months.

4.5. Shorebird usage of specific habitat features in each wetland system

According to Mellink et al. (1997) the most frequently used parts of the intertidal zone in the CRD were the mudflats between Pelicano and Isla Montague and the mudflats between Pelicano Island and the coastline of El Golfo de Santa Clara. In our surveys, however, the areas with the highest numbers of shorebirds per sampling unit were Cienega de Santa Clara and Golfo de Santa Clara mudflats. Water enters the Cienega from the U.S. at about 2–3 ppt, and it exits at about 6 ppt at the southern end, where the shorebirds tend to concentrate. The reduced salinity associated with this effluent may support higher abundance or a more diverse invertebrate community on which shorebirds feed.

For the Cienega de Santa Clara there appear to have been changes in the dominant shorebird species assemblage, since previous studies reported highest abundance for the species *Limnodromus* sp., *C. mauri*, *R. Americana* and *H. mexicanus* (Abarca et al., 1993; Román-Rodríguez, 2004, unpublished data), whereas the most abundant group of species in our surveys were small sandpipers (*Calidris* sp. and mostly Western Sandpiper). The change in the community composition may be linked to dynamic vegetation changes. The sites that were monitored by this study are open shallow areas with less proportion of emergent vegetation, a habitat that may be preferred by small sandpipers due to a higher density of invertebrates and a lower risk of depredation (Fernández and Lank, 2006). The proportion of area covered by vegetation has changed over time at this site, and the sites that were previously monitored were covered by vegetation with availability of open lagoons which are more often used by medium and large size shorebirds.

The data suggest that the Cienega de Santa Clara habitats might be an important site in terms of food sources for Western Sandpipers and/or an alternative site when the coastal mudflats are unavailable during high tides as well as for species that showed preference for brackish water habitats. Although further studies are needed to determine the biological and physical characteristics that determine shorebird habitat use in the Cienega, it has been documented that drops in the average water inflow (4.5 m^3/s) have effects on the availability of playa areas for shorebirds (Gomez-Sapiens et al., 2013, this issue). This highlights the need of including the prevalence of this wetland feature as one of many conservation goals in the water management schemes for the Cienega.

Bahía Adair represents a different system with the least influence from the Colorado River. Even though this site showed a low density of shorebirds there was a high diversity and a high proportion of large size shorebirds using Bahia Adair. The different composition in the shorebird assemblage for this area is the result of the diversity of habitats at the bay i.e. saltflats, mudflats, estuaries, rocky intertidal areas "coquinas" and sandy shores. Some of the concerns for this recently monitored area include the construction of a new highway that will facilitate increased human access to nesting habitats for at least two shorebird species (Snowy Plover and Wilson Plover) and the endangered Least Tern. Additionally, the highway will likely enable human development along the coastline area close to the shorebird's feeding and resting areas between Puerto Peñasco and El Golfo de Santa Clara, including Bahia Adair, which combined represents about 90% of the northern Gulf of California wetlands that currently have no major human impact (Glenn et al., 2006). It is remarkable that during one survey event 100% of the American Oystercatcher population reported by Wetlands International (2006) for the Gulf of California and Western Mexico (350 individuals) was detected in this area. This highlights the importance of documenting the shorebird use of these habitats in undisturbed conditions in order to keep track of any changes in shorebirds habitat use as a result of human impacts.

Cerro Prieto geothermal ponds offer protection to birds nesting on mounds of dredge spoils which formed islands within the brackish ponds. They also provide food in the form of small fish and aquatic plants such as *R. maritima*. They support a high density and diversity of shorebirds. On the other hand, the Andrade Mesa Wetlands appear to be less important areas for shorebirds, perhaps due to their intermittent inundation patterns, smaller lagoons for phalarope species and less availability of playa areas for small and medium size shorebird species.

5. Conclusions

Our study confirms the relevance of the CRD natural and artificial wetlands for shorebirds along the Pacific Flyway. Some species appear to be specialists regarding habitat selection, having been detected only in the inland artificial wetlands (Cerro Prieto geothermal power plant, Cienega de Santa Clara and Mesa de Andrade Wetlands). Moreover non-intertidal wetlands represent alternative feeding sites for nearly all the species of shorebirds observed. They provide important brackish habitats and food chains that were formerly associated with the intertidal zone wetlands when seasonal fresh water flows still reached the intertidal zone. Hence, maintaining the habitat value of the CRD for shorebirds will require active management steps to preserve the size and habitat quality of the anthropogenic wetlands in the CRD.

Acknowledgments

This work was possible – thanks to the funding provided by Comision Nacional de Areas Naturales Protegidas (CONANP), Global Environmental Funds (GEF), toward the Upper Gulf of California and Colorado River Delta Biosphere Reserve Shorebird Monitoring Program. The authors thank the personnel of the Direccion of Evaluacion and Seguimiento in Oficinas Centrales CONANP, especially to Biol. Ivonne Bustamante. The authors also thank the Cerro Prieto Geothermal Powerplant (CFE) personnel for allowing us to conduct the surveys and the assistance they provided during the field work. The first author thank CONACyT for the doctoral grant provided to complete this work.

Appendix 1.

List of species

Code	Common name	Scientific name
AMAV	American avocet	*Recurvirostra americana*
AMGP	American golden plover	*Pluvialis dominica*
AMOY	American oystercatcher	*Haematopus palliatus*
AREN	Turnstones	*Arenaria* sp.
BBPL	Black bellied plover	*Pluvialis squatarola*
BLTU	Black turnstone	*Arenaria melanocefala*
BNST	Black necked stilt	*Himantopus mexicanus*
CALI	Sandpipers	*Calidris mauri, minutilla, alba, alpina* and others sandpipers shorebirds size
CHAR	Plovers	*Charadrius semipalmatus, C. melodus, C. nivosus* and plovers of similar size.
DUNL	Dunlin	*Calidris Alpina*
GRYE	Greater yellowlegs	*Tringa melanoleuca* and *T. flavipes*
KILL	Killdeer	*Charadrius vociferus*
LBCU	Long-billed curlew	*Numenius americanus*
LBDO	Long-billed dowitcher	
LESA	Least sandpiper	*Calidris minutilla*
LEYE	Leaser yellowlegs	*Tringa flavipes*
MAGO	Marbled godwit	*Limosa Fedra*
NUME	Long-billed curlew and Whimbrel	*Numenius americanus* or *N. phaeopus*
PAGP	Pacific golden plover	*Pluvialis fulva*
PHAL	Pharalopes	*Phalaropus tricolor, P. lobatus* and *P. fulicaria*
PLUV	Plovers	*Pluvialis* sp.
REKN	Red knot	*Calidris canutus*
RNPH	Red-necked phalarope	*Phalaropus lobatus*
RUTU	Ruddy turnstone	*Arenaria interpres*
SAND	Sanderling	*Calidris alba*
SBDO	Short-bill dowitcher	*Llimnodromus griseus*
SEPL	Semipalmated plover	*Charadrius semipalmatus*
SESA	Semipalmated sandpiper	*Calidris pusilla*
SNPL	Snowy plover	*Charadrius alexandrinus*
STSA	Stilt sandpiper	*Calidris himantopus*
SPSA	Spotted sandpiper	*Actitis macularia*
SURF	Surfbird	*Aphriza virgata*
TRIN	Yellowlegs	*Tringa flavipes* or *melanoleuca*
UNDO	Unknown dowitcher (long-billed or short-billed)	*Limnodromus scolopaceus*, and *L. griseus*
WESA	Western sandpiper	*Calidris mauri*
WHIM	Whimbrel	*Numenius phaeopus*
WILL	Willet	*Tringa semipalmata*
WIPH	Wilson phalarope	*Phalaropus tricolor*
WIPL	Willson's plover	*Charadrius wilsonia*

References

Abarca, F.J., Ingraldi, M.F., Varela-Romero, A., 1993. Observaciones del cachorrito del desierto (Cyprinodon macularius). Palmoteador de Yuma (*Rallus longirostris* yumanensis), y comunidades de aves playeras de la Ciénega de Santa Clara, México. Nongame and Endangered Wildlife Program Tech. Report. Arizona Game and Fish Department, Phoenix, AZ.
Avila-Serrano, G.E., Flessa, K.W., Tellez-Duarte, M.A., Cintra-Buenrostro, C.E., 2006. Distribution of the intertidal macrofauna of the Colorado River Delta northern Gulf of California, Mexico. Cienc. Mar. 32, 649–661.
Bart, J., Manning, A., Thomas, S., Wightman, C., 2005. Preparation of regional shorebird monitoring plans. In: Ralph, C.J., Rich, T.R. (Eds.), Proceedings of the Third International Partners in Flight International Symposium. US Forest Service, General Technical Report. Arcata, California, USA.
Butler, R.B., Delgado, F.S., De La Cueva, H., Pulido, V., Sandercock, B.K., 1996. Migration routes of the western sandpiper. Wilson Bull. 108, 662–672.
Carmona, R., Danemann, G., 1998. Distribución espaciotemporal de aves en la salina de Guerrero Negro, B.C.S., México. Cienc. Mar. 24, 389–408.
Carmona, R., Ruíz-Campos, G., Brabata, G., 2004. Seasonal abundance of migrant shorebirds in Baja Califórnia Península, México and California, USA. Wader Study Group Bull. 105, 65–70.
Colwell, M.A., 1994. Shorebirds of Humboldt Bay California: abundance estimates and conservation implications. Western Birds 25, 137–145.
Engilis, A., Oring, L.W., Carrera, E., Nelson, J.W., Martinez-Lopez, A., 1998. Shorebird surveys in Ensenada Pabellones and Bahía Santa María, Sinaloa, México Critical winter habitats for Pacific flyway shorebirds. Wilson Bull. 110, 332–341.
Fernández, G., Lank, D., 2006. Sex age and body size distribution of western sandpipers during the nonbreeding season with respect to local habitat. The Condor 108, 547–557.
Fernández, G., Carmona, R., De la Cueva, H., 1998. Abundance and seasonal variation of Western Sandpipers (*Calidris mauri*) in Baja California Sur México. Southwest Nat. 43, 57–61.
Felger, R.S., 2000. Flora of the Gran Desierto and Rio Colorado of Northwestern Mexico. The University of Arizona Press, Tucson, AZ.
Glenn, E.P., Felger, R.S., Burquez, A., Turner, D.S., 1992. Ciénega de Santa Clara: endangered wetland in the Colorado River Delta Sonora, México. Nat. Resour. J. 32, 817–824.
Glenn, E.P., Lee, C.R., Felger, R., Zengel, S., 2006. Effects of water management on the wetlands of the Colorado River Delta, Mexico. Conserv. Biol. 10, 1175–1186.
Glenn, E.P., Zamora-Arroyo, F., Nagler, P.L., Briggs, M., Shaw, W., Flessa, K., 2001. Ecology and conservation biology of the Colorado River delta, Mexico. J. Arid Environ. 49, 5–15.
Glenn, E.P., Nagler, P., Brusca, R., Hinojosa-Huerta, O., 2006. Coastal wetlands of the Northern Gulf of California: inventory and conservation status. Aquatic Conserv: Mar. Freshw. Ecosyst 16, 5–28.
Hinojosa-Huerta, O., Nagler, P.L., Carrillo-Guerrero, Y., Zamora-Hernández, E., García-Hernández, J., Zamora-Arroyo, F., Gillon, K., Glenn, E.P., 2002. Andrade Mesa wetlands of the all-American canal. Nat. Resour. J. 42, 899–914.
Hinojosa-Huerta, O., Iturribarría-Rojas, H., Carrillo-Guerrero, Y., De La Garza Treviño, M., Zamora-Hernández, E., 2004. Bird Conservation Plan for the Colorado River Delta. Pronatura Noroeste, Dirección de Conservación Sonora. San Luis Río Colorado, Sonora, México.
Hinojosa-Huerta, O., Destefano, S., Carrillo-Guerrero, Y., Shaw, W., Valdes-Casillas, C., 2004b. Waterbird communities and associated wetland of the Colorado River Delta, México. Stud. Avian Biol., 52–60.
Kasprzyk, M.J., Harrington, B.A., 1989. Manual de campo para el estudio de aves playeras. CICESE, MBO, Ensenada, Mexico134.
Mellink, E., Palacios, E., González, S., 1997. Non-breeding waterbirds of the Delta of the Río Colorado, México. J. Field Ornithol. 68, 113–123.
Mercado, S., Fernández, H., 1998. Developments in geothermal-energy in Mexico. 18. History of the exploration of the Cerro-Prieto geothermal-field. Heat Recov. Syst. CHP 8, 315–321.
Morrison, R.I., Ross, R.K., Torres, M.M., 1992. Aerial surveys of Neartic shorebirds wintering in Mexico: some preliminary results. Progress note. Canadian Wildlife Service, Canadian Ministry of the Environment.

Morrison, R.I.G., Gill, R.E., Harrington, B.A., Skagen, S., Page, W.G., Gratto-Trevor, C.L., Haig, S.M., 2001. Estimates of shorebird population in North America, Occasional Paper No. 114. Canadian Wildlife Service, Ottawa, Ontario.

Palacios, E., Escofet, A., Loya-Salinas, D.H., El Estero Punta Banda, B.C., 1991. México como eslabón del Corredor del Pacífico: abundancia de aves playeras. Cienc. Mar. 17, 109–130.

Román-Rodríguez, M. J. 2004. Plan de Monitoreo y Difusión de los humedales prioritarios de la Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado y su zona de influencia. Reporte parcial. Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora.

Skagen, S.K., Granfors, D.A., Melcher, C.P., 2008. On determining the significance of ephemeral continental wetlands to North American migratory shorebirds. The Auk 125, 20–29.

Shuford, D., Page, G.W., Kjelmyr, J.E., 1998. Patterns and dynamics of shorebird use of California's Central Valley. The Condor 100, 227–244.

Shuford, W.D., Warnock, N., Molina, K.C., Sturm, K.K., 2002. The Salton Sea as critical habitat to migratory and resident waterbirds. Hydrobiologia 473, 255–274.

Varela-Romero, A., Ruíz-Campos, G., Yépiz-V.L.M., Alaníz-G, J., 1998. Evaluación de la situación actual de las poblaciones del pez perrito del desierto (*Cyprinodon macularius macularius*) en la cuenca del Bajo Río Colorado, Sonora y Baja California, México. Informe Final CONABIO H126.

Villarreal-Chávez, G., Carmona-Zedillo, C., 1999. Estructura de la comunidad béntonica (infaunal) en el delta del Río Colorado, México. Rev. Biol. Trop. 47, No. 4.

Warnock, N., Heig, S., Oring, L., 1998. Monitoring species richness and abundance of shorebirds in the Western Great Basin. The Condor 100, 589–600.

Wetlands International, 2006. Waterbird Population Estimates, Fourth edition. Wetlands International, Wageningen, The Netherlands.

Yensen, P., Glenn, E.P., Fontes, M.R., 1983. Biogeographical distribution of salt marsh halophytes on the coasts of the Sonoran Desert. Desert Plants 5, 76–81.