ORNITOLOGIA NEOTROPICAL 24: 67–83, 2013

WATERBIRD POPULATION DYNAMICS AT ESTUARINE WETLANDS OF CENTRAL CHILE

Cristián F. Estades & M. Angélica Vukasovic

Wildlife Ecology Laboratory, School of Forest Science and Nature Conservation, Universidad de Chile. Av. Santa Rosa 11315, La Pintana, Santiago, Chile. *E-mail:* cestades@uchile.cl

Resumen. – Dinámica poblacional de aves acuáticas en humedales estuarinos de Chile central. – En junio de 2006 se inició un estudio de largo plazo de las poblaciones de aves acuáticas en el estuario del río Itata (Chile central) como parte del programa de monitoreo ambiental de una de las plantas de celulosa más grandes del país. La evaluación de las poblaciones se ha basado en 10 campañas al año e incluye el monitoreo de tres sitios adicionales que actúan como controles (Mataquito, Reloca, Topocalma). Durante los primeros 5 años de estudio, las trayectorias poblacionales de la mayoría de las especies han mostrado una notable regularidad en sus ciclos estacionales. Entre éstos, los más evidentes son debidos a la llegada y partida de especies migratorias. Mientras las especies que se reproducen en el sur de Chile se agregan en el área durante el invierno, los migrantes de larga distancia se concentran en los estuarios estudiados durante el verano austral. Adicionalmente, muchas especies residentes se concentran en estos estuarios durante el período post-reproductivo, aparentemente, provenientes de humedales del interior. Las similitudes entre las trayectorias poblacionales de algunas especies en los diferentes sitios estudiados sugieren que estas dinámicas están dominadas principalmente por factores regionales, más que por causas locales. Además, existieron evidencias de redistribuciones interanuales de aves entre sitios. A pesar de que los estuarios estudiados tienen baja importancia como sitios de reproducción, sí juegan un rol muy importante como lugar de descanso y baño para muchas aves marinas, y representan un área de invernada de gran importancia para algunas especies migratorias de larga distancia como la gaviota de Franklin (*Leucophaeus pipixcan*), el gaviotín elegante (*Thalasseus elegans*) y el rayador (*Rynchops niger*).

Abstract. – In June 2006, we began a long-term study of the waterbird populations of the estuary of the Itata river (Central Chile) as part of an environmental monitoring program of one of the largest pulp mills in the country. The population assessment has been based on 10 field campaigns per year and comprises the monitoring of three more estuaries as control sites (Mataquito, Reloca, Topocalma). During the first 5 years of study, population trajectories of most bird species have shown a remarkable level of regularity in their seasonal cycles; the most evident ones are due to the arrival and departure of migratory species. While species that breed in southern Chile aggregate in the area during the winter, long-distance migrants concentrate in the studied estuaries during the Austral summer. Additionally, many resident species had the tendency to concentrate in the estuaries during the post-breeding season, presumably moving from interior wetlands. The similarities of population trajectories of some species in the different sites suggests that most dynamics are driven by regional rather than local factors. There was also evidence for inter-annual redistribution of birds among sites. Although the studied estuaries have a small importance as breeding sites, they have a significant role as a roosting and bathing place for many seabirds, and it is a very important wintering area for long-distance migrants, such as Franklin's Gull (*Leucophaeus pipixcan*), Elegant Tern (*Thalasseus elegans*), and Black Skimmer (*Rynchops niger*).
Accepted 23 May 2013.

Key words: Waterbirds, estuaries, population dynamics, long-term monitoring, Chile.

INTRODUCTION

Estuaries are among the most productive ecosystems in the world (Costanza *et al.* 1993, Harding *et al.* 2002), and due to this and their unique geographic position, these coastal wetlands are highly valuable ecosystems for many bird species (Davidson *et al.* 1991), including those depending mostly on fresh water, as well as seabirds. The shallow and calm waters of estuaries and their high nutrient concentrations attract several fish species to spawn in them (Haedrich 1983), generating an important source of food for piscivorous birds. Additionally, because estuaries act as an interface between freshwater and salt-water environments, they are characterized by a salinity gradient that favors the presence of species with very different ecological requirements (Ysebaert *et al.* 2000).

Coastal wetlands and, particularly, estuaries constitute important staging and wintering sites for birds that migrate along coasts (Page *et al.* 1997, Skagen 1997), and many of these sites host significant proportions of the world population of some species (Myers *et al.* 1987). Chile has one of the longest coastlines in the world, which is reflected by a large proportion of the country's avifauna being associated to coastal environments (Estades *et al.* 2012). Additionally, the Chilean coast is part of an important migration route in the Americas (Morrison & Myers 1987).

Although estuaries are recognized as very important for the conservation of waterbirds in Chile (Victoriano *et al.* 2006), there is very little information published on the ecology of birds in the country's coastal wetlands (Quezada *et al.* 1986, Estades *et al.* 2012). Particularly there is an important lack of information on population dynamics (Victoriano *et al.* 2006), and this is a clear limitation for the implementation of effective conservation and management plans. Thus, the purpose of this paper is to describe the dynamics of the waterbird populations that used four estuaries in central Chile, between 2006 and 2011, as a way to understand the main functional relationships that exist between these coastal wetlands and the bird species that use them.

METHODS

Study sites. As part of an environmental monitoring program of a pulp mill in the Itata river (Fig. 1), a long term study of the waterbird populations inhabiting the river's estuary was initiated. Additionally, two other estuaries were selected as controls (Mataquito and Reloca, Fig. 1), with a third one being added during 2008 (Topocalma, Fig. 1). The study region has a Mediterranean climate with rainfall concentrated during the winter months (Fuenzalida 1971). Because the four estuaries differed significantly in their physical attributes (see Fig. 1 and descriptions below), the comparison of the Itata estuary with the three control sites did not focus on the absolute abundances of the different bird species between estuaries, but mostly on the temporal trends.

The estuary of the Itata river (36º23'S, 72º51'W) is the largest of the four sites, with approximately 300 ha of water (considering up to 2 km from the river's mouth) and 30 ha of sandbars and islets (Fig. 1). There is a marginal cover of marshes and other type of aquatic vegetation. The area is surrounded by dunes, meadows, and some agricultural fields. Human presence in the area is restricted to some artisanal fishers and low-level recreational use (camping, fishing, etc.) during the summer months.

The Mataquito river (35º07'S, 72º10'W) is the second largest site, with an estuarine area of approximately 220 ha of water and 45 ha of sandbars (Fig. 1), with very little marsh cover. As in the previous case, the estuary is surrounded by dunes, the beach and some fields

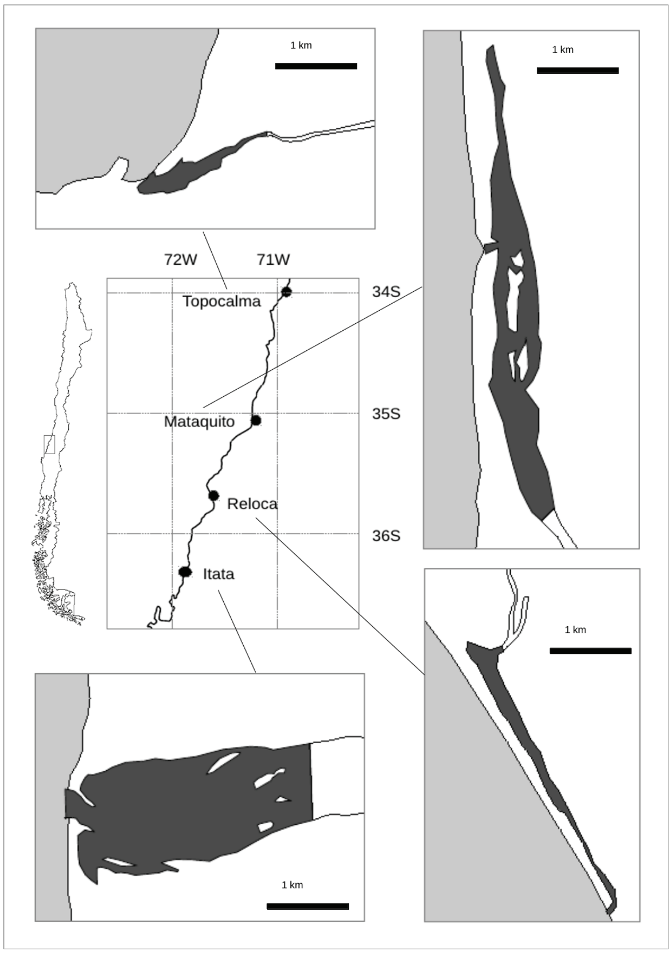

FIG. 1. Location and general shape of the studied estuaries. Censuses were limited to the area with a dark gray shading, including the immediate shore and sandy islets.

of extensive agriculture. Human use is similar to the one in the previous site.

The Reloca river (35º43'S, 72º35'W) has a much smaller estuarine area, with 46 ha of water and approximately 9 ha of marshes. Sandy islets cover less than 1 ha, although this estuary is bordered by a long sandy beach (Fig. 1). Most of the surrounding vegetation is typical dune vegetation and pine plantations. Human presence is very limited.

Topocalma estuary (34º07'S, 71º53'W) has 30 ha of water and 2 ha of sandbars (Fig. 1). There are approximately 2 ha of marshes and the site is surrounded by native scrub and some pine plantations. Access to the area is very restricted and human use is limited to some recreational activities in the neighboring beach.

Bird censusing. At Itata, the study included 10 field campaigns per year, including three campaigns during the summer (December–February), two during the fall migration (April–May), three during the winter (July–August) and two during the spring migration (October–November). Each campaign involved three days of censuses, with two censuses per day (08:00–12:00 h, 14:00–16:00 h). In the remaining sites, eight field campaigns per year with just one census in the morning (08:00–12:00 h) each were conducted.

On every occasion, a complete census of all the birds using the estuary was conducted, including islets, sandbars, and the immediate shore (Bibby *et al.* 1992). Flying birds were only included when they were clearly moving within one of the study estuaries.

At each site, birds were recorded using a spotting scope from fixed vantage points. The area of each estuary was divided into sectors in order to minimize double counting of birds, particularly when moving from one observation point to another. No observations were made during periods of heavy rain. Observations obtained on days with dense fog were discarded. All censuses were conducted by MAV and an assistant.

In order to describe the population trajectory of the recorded species, we analyzed the data using a simple auto-regressive model (Brockwell & Davis 1991). For that purpose we pooled the data for all sites and we used four regularly distributed data points per year (i.e., seasons). We included as predictors the date of the observation and the population size with time lags of one and two seasons. A significant effect of date is an indication of a long-term trend, and a negative effect of the population size with a two-seasons lag indicates the presence of an annual cycle. All analyses were performed using the R system (R Development Core Team 2008).

Finally, based on the authors' experience and the literature, we classified the different species in relation to their residence status, their typical foraging habitat and their degree of dependence on estuaries (i.e., abundance in estuarine ecosystems compared to other wetland types in central Chile).

RESULTS

Between June 2006 and June 2011 we recorded 74 species of waterbirds, 59% of all waterbirds species (including seabirds) ever reported from coastal wetlands in Chile (125 species; Estades *et al.* 2012). Sixty-six percent of the species are resident of central Chile, whereas 23% are long-distance migrants, either Neartic or Neotropical.

The dynamics of the waterbird populations in the studied estuaries are visualized in Figs 2–5. For this purpose, the population trajectories of species that are good examples of qualitatively different behaviors are presented. Some of the species for which no population trends are presented do conform to some of the shown patterns, but others, mostly the scarcest ones, may not show any pattern at all. Table 1 summarizes some quantitative traits of each population, including minimum and maximum records, and the statistical evidence for annual cycles an trend. The following graphs show the recorded population for a species in a given campaign. For Itata, the latter number corresponds to the average of the six censuses, assigned to the second day of the three-day campaign. For all species, the population trajectory for each estuary is presented, alongside the aggregate of the populations at the four sites.

Figure 2 shows two species that breed in southern Chile and winter in the central part of the country (Scolaro *et al.* 1996, Guicking *et al.* 2001, Kusch & Marín 2004). Although in low and variable numbers, both Rufous-chested Plover (*Charadrius modestus*) and South American Tern (*Sterna hirundinacea*) are regular winter visitors to the studied estuaries, leaving the area by the beginning of spring.

Several long-distance (northern) migrants use the studied estuaries as feeding and resting sites during the Austral summer (Fig. 3). Elegant Tern numbers show a great level inter-annual regularity at the aggregated level,

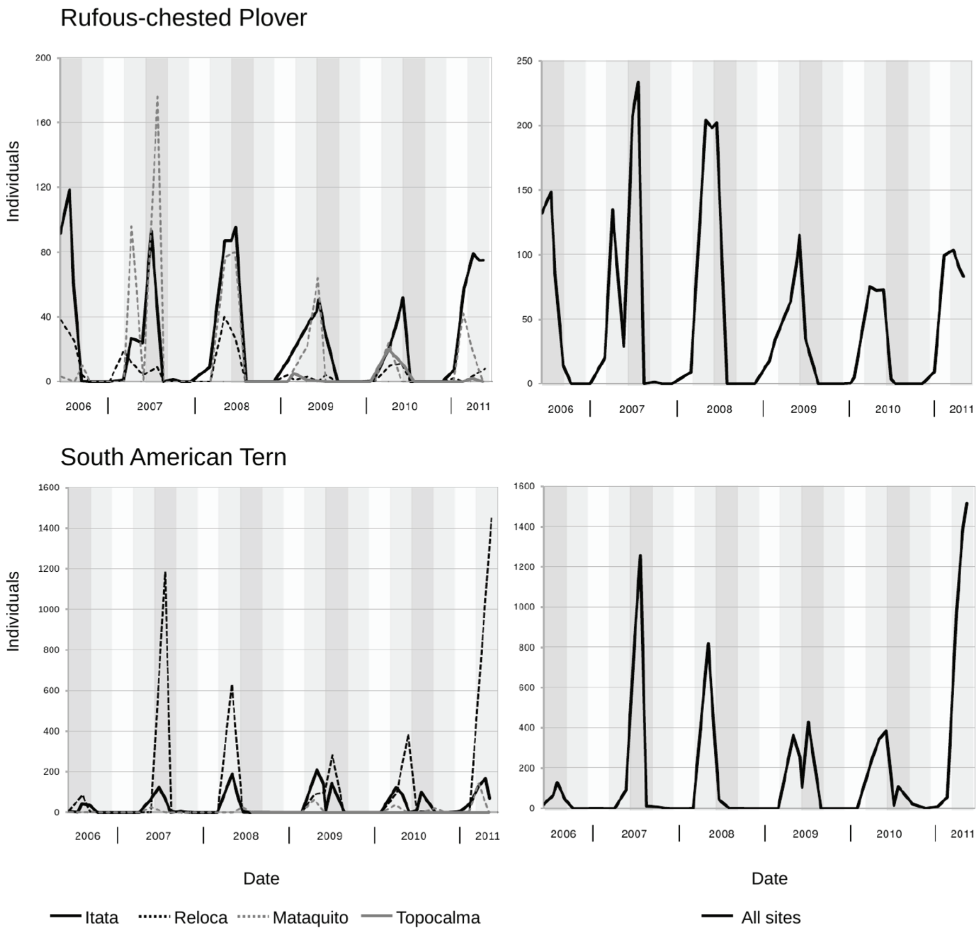

FIG. 2. Population trajectories of Rufous-chested Plover (*Charadrius modestus*) and the South American Tern (*Sterna hirundinacea*) in four estuaries of central Chile (2006–2011). Left graph: individual sites; right graph: aggregate numbers. Background shading represents season (Austral): dark gray = winter, white = summer, light gray = spring or fall.

contrasting with a much higher variation at the site level. On the contrary, Franklin's Gulls have a large yearly variation at the regional scale, but this pattern is replicated at each estuary. While the previous two species showed one population peak by the middle of the summer, the Baird's Sandpiper (*Calidris bairdii*) had two clear peaks in a year (Fig. 3).

Figure 4 shows three examples of resident waterbird species: Snowy Egret (*Egretta thula*), Cinnamon Teal (*Anas cyanoptera*), and Great Grebe (*Podiceps major*). All the latter species had very low abundances during the breeding season (spring), significantly increasing their numbers during the summer and reaching a peak during the fall. Coincidentally, the three species showed a significant signal of an annual cycle ($P < 0.05$, Table 1).

Finally, among the birds recorded during the censuses, a large number of them corre-

Table 1. Water bird populations in four estuaries in central Chile (2006–2011). [1]Site with the highest count. I: Itata, M: Mataquito, R: Reloca, T: Topocalma. [2]Numbers shown only in cases where the criterion is met (Wetlands International 2013). [3]Itata, Reloca and Mataquito meet the 1% criterion for the species. [4]Itata, and Mataquito meet the 1% criterion for the species. Threshold for subspecies *cinerascens* estimated as the sum of the values for the other subspecies. [5]Statistical support for the existence of an annual cycle. * : $P < 0.05$, ** : $P < 0.01$, *** $P < 0.001$. [6]Statistical support for the existence of a long term trend. * : $P < 0.05$, ** : $P < 0.01$. Trend sign in parenthesis. [7]Residence Status. Bor M: Boreal Migrant, N Ch: from Northern Chile, S Ch: from Southern Chile, Neo M: Neotropical Migrant, Res: Resident in Central Chile. [8]Foraging habitat. FW: Fresh water. [9]Reliance on estuaries. L: Low, M: Medium, H: High.

Family/species	Total count/ campaign		Maximum count in one site		1% criterion[2]	Annual cycles[5]	Trend[6]	Residence status[7]	Foraging habitat[8]	Reliance on estuaries[9]
	Min	Max								
PODICIPEDIDAE										
Rollandia rolland	0	135	108	R[1]		*		Res	FW	M
Podilymbus podiceps	0	10	8	R				Res	FW	L
Podiceps major	1	87	55	R		*	*(+)	Res	FW	M
Podiceps occipitalis	0	617	605	I		*		Res	FW	L
SULIDAE										
Sula variegata	0	8	8	IR				Res	Sea	L
PELECANIDAE										
Pelecanus thagus	61	17725	11668	R	10000	*	*(-)	Res	Sea	M
PHALACROCORACIDAE										
Phalacrocorax brasilianus	195	1884	1295	R				Res	Sea/FW	M
ARDEIDAE										
Ardea cocoi	0	8	3	RM				Res	FW	L
Ardea alba	0	75	73	R		*		Res	FW	L
Egretta thula	0	169	121	I		*		Res	FW	L
Bubulcus ibis		5	5	R				Res	FW	L
Nycticorax nycticorax	0	13	13	I				Res	FW	L
THRESKIORNITHIDAE										
Plegadis chihi	0	15	15	R				Res	FW	L
PHOENICOPTERIDAE										
Phoenicopterus chilensis	0	362	357	M		*		N Ch	Salty/FW	H

TABLE 1. Continuation.

Family/species	Total count/ campaign		Maximum count in one site	1% criterion[2]	Annual cycles[5]	Trend[6]	Residence status[7]	Foraging habitat[8]	Reliance on estuaries[9]
	Min	Max							
ANATIDAE									
Coscoroba coscoroba	0	86	56	R			Res	FW	L
Cygnus melancoryphus	0	308	258	T			Res	FW	L
Anas platalea	0	20	20	R			Res	FW	L
Anas cyanoptera	0	51	40	R	*		Res	FW	L
Anas versicolor	0	4	4	R			Res	FW	L
Anas sibilatrix	1	298	179	R			Res	FW	L
Anas flavirostris	0	228	179	I			Res	FW	L
Anas bahamensis	0	4	4	R			Res	FW	L
Anas georgica	26	1592	1451	I			Res	FW	L
Anas platyrhynchos	0	1	1	I			Exotic	FW	L
Netta peposaca	0	2	2	R			Res	FW	L
Heteronetta atricapilla	0	4	4	R			Res	FW	L
Oxyura spp.	0	166	166	R			Res	FW	L
ACCIPITRIDAE									
Circus cinereus	0	1	1	R			Res	FW	L
PANDIONIDAE									
Pandion haliaetus	0	1	1	IM			Bor M	Coast/FW	M
RALLIDAE									
Pardirallus sanguinolentus	0	3	3	M			Res	FW	L
Gallinula melanops	0	37	35	R			Res	FW	L
Fulica armillata	0	753	693	R	**		Res	FW	L
Fulica leucoptera	0	244	171	I	*		Res	FW	L
Fulica rufifrons	0	18	18	R			Res	FW	L
HAEMATOPODIDAE									
Haematopus palliatus	87	1167	761	M	***		Res	Coast	M
Haematopus ater	0	4	4	T			Res	Coast	M

TABLE 1. Continuation.

Family/species	Total count/ campaign Min	Max	Maximum count in one site		1% criterion[2]	Annual cycles[5]	Trend[6]	Residence status[7]	Foraging habitat[8]	Reliance on estuaries[9]
RECURVIROSTRIDAE										
Himantopus melanurus	49	344	215	M				Res	FW	M
CHARADRIIDAE										
Vanellus chilensis	21	922	540	M		*		Res	FW	L
Pluvialis dominica	0	1	1	I				Bor M	Coast	M
Pluvialis squatarola	0	21	21	M				Bor M	Coast	M
Charadrius alexandrinus	0	5	5	M				Res	Coast/FW	L
Charadrius falklandicus	0	12	12	M				S Ch	Coast/FW	L
Charadrius collaris	0	71	52	M				Res	Coast/FW	L
Charadrius vociferus	0	1	1	I				N Ch	Coast/FW	L
Charadrius modestus	0	234	176	M				S Ch	Coast/FW	M
SCOLOPACIDAE										
Tringa melanoleuca	0	9	8	I				Bor M	Coast/FW	L
Tringa flavipes	0	26	21	R				Bor M	Coast/FW	L
Tringa semipalmata	0	1	1	I				Bor M	Coast	L
Numenius phaeopus	1	319	308	M			*(+)	Bor M	Coast	L
Limosa haemastica	0	42	41	R				Bor M	Coast	M
Arenaria interpres	0	2	2	R				Bor M	Coast	L
Calidris canutus	0	20	20	M				Bor M	Coast	L
Calidris alba	0	514	513	M				Bor M	Coast	L
Calidris bairdii	0	329	229	M		*	**(+)	Bor M	Coast/FW	L
Gallinago paraguaiae	0	5	5	I				Res	FW	L
Phalaropus tricolor	0	14	14	R				Bor M	Sea/FW	L
LARIDAE										
Stercorarius chilensis	0	1	1	IR				Res	Sea	L
Chroicocephalus maculipennis	26	4287	3613	R				Res	FW/Coast	L
Larus dominicanus	280	6208	5586	I				Res	Sea/Coast	L

TABLE 1. Continuation.

Family/species	Total count/ campaign Min	Total count/ campaign Max	Maximum count in one site		1% criterion[2]	Annual cycles[5]	Trend[6]	Residence status[7]	Foraging habitat[8]	Reliance on estuaries[9]
LARIDAE										
Leucophaeus pipixcan	0	62754	21099	R	12200[3]	*		Bor M	Sea/Coast	M
Leucophaeus modestus	1	4622	3746	M	250[3]		*(-)	N Ch	Sea/Coast	M
Sterna hirundinacea	0	1519	1446	R				S Ch	Sea/FW	H
Sterna trudeaui	0	149	120	R				Res	Sea/FW	M
Thalasseus elegans	0	14812	10012	M	2700[3]			Bor M	Sea/FW	M
Larosterna inca	0	19	19	I				N Ch	Sea	M
Rynchops niger	0	5476	3888	I	2000[4]	***		Neo M	FW/Sea	H
FURNARIIDAE										
Cinclodes patagonicus	0	6	6	R				Res	FW	L
Cinclodes oustaleti	0	1	1	I				Res	FW	L
Cinclodes fuscus	0	16	15	I				Res	FW	L
Phleocryptes melanops	0	2	2	R				Res	FW	L
TYRANNIDAE										
Tachuris rubrigastra	0	4	4	R				Res	FW	L
Lessonia rufa	0	17	14	R				Res	FW	L
Hymenops perspicillata	0	4	4	R				Neo M	FW	L
ICTERIDAE										
Agelaius thilius	0	4	4	R				Res	FW	L

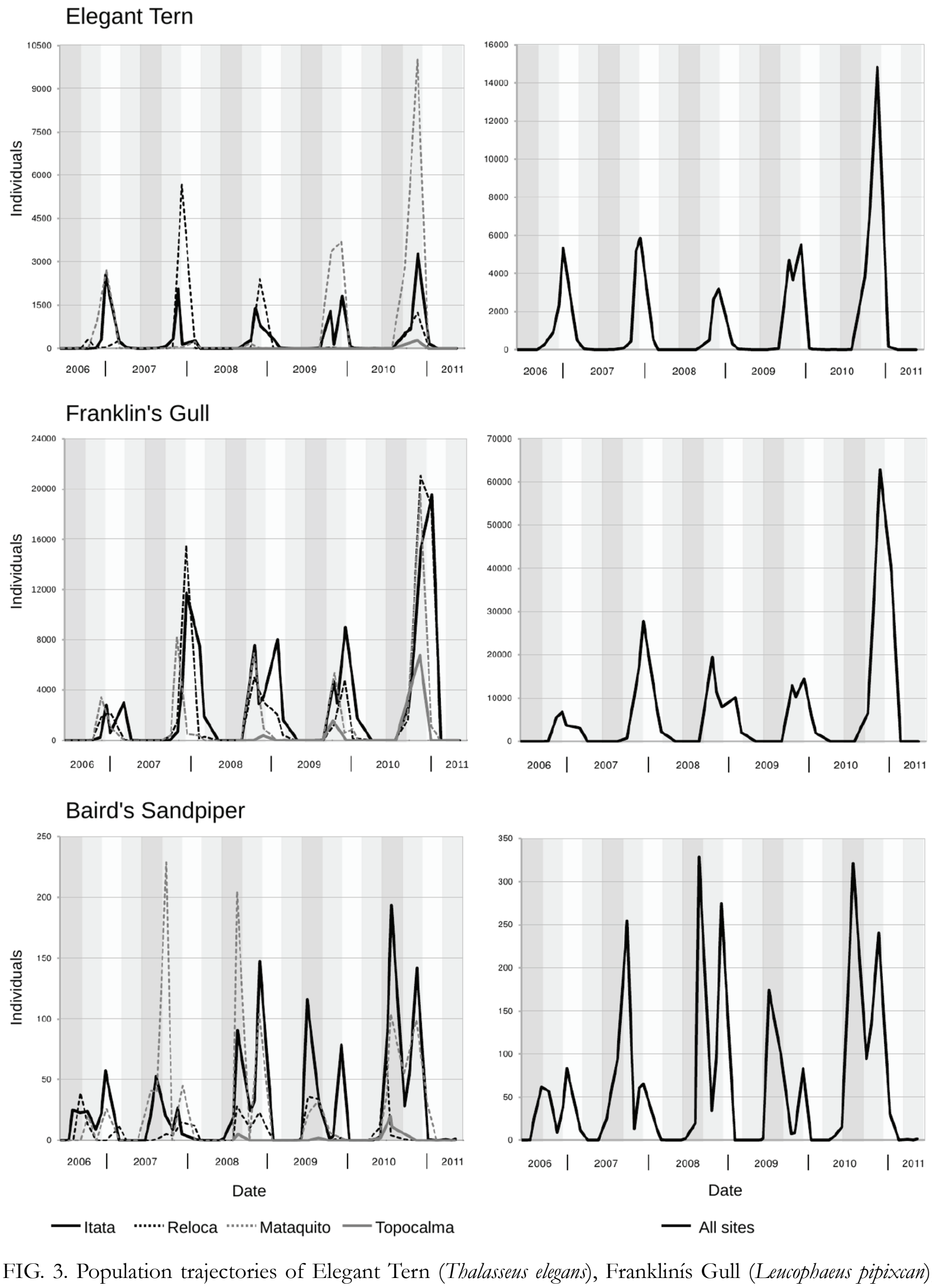

FIG. 3. Population trajectories of Elegant Tern (*Thalasseus elegans*), Franklinís Gull (*Leucophaeus pipixcan*), and Bairdís Sandpiper (*Calidris bairdii*) in four estuaries of central Chile (2006–2011). Left graph: individual sites; right graph: aggregate numbers. Background shading represents season (Austral): dark gray = winter, white = summer, light gray = spring or fall.

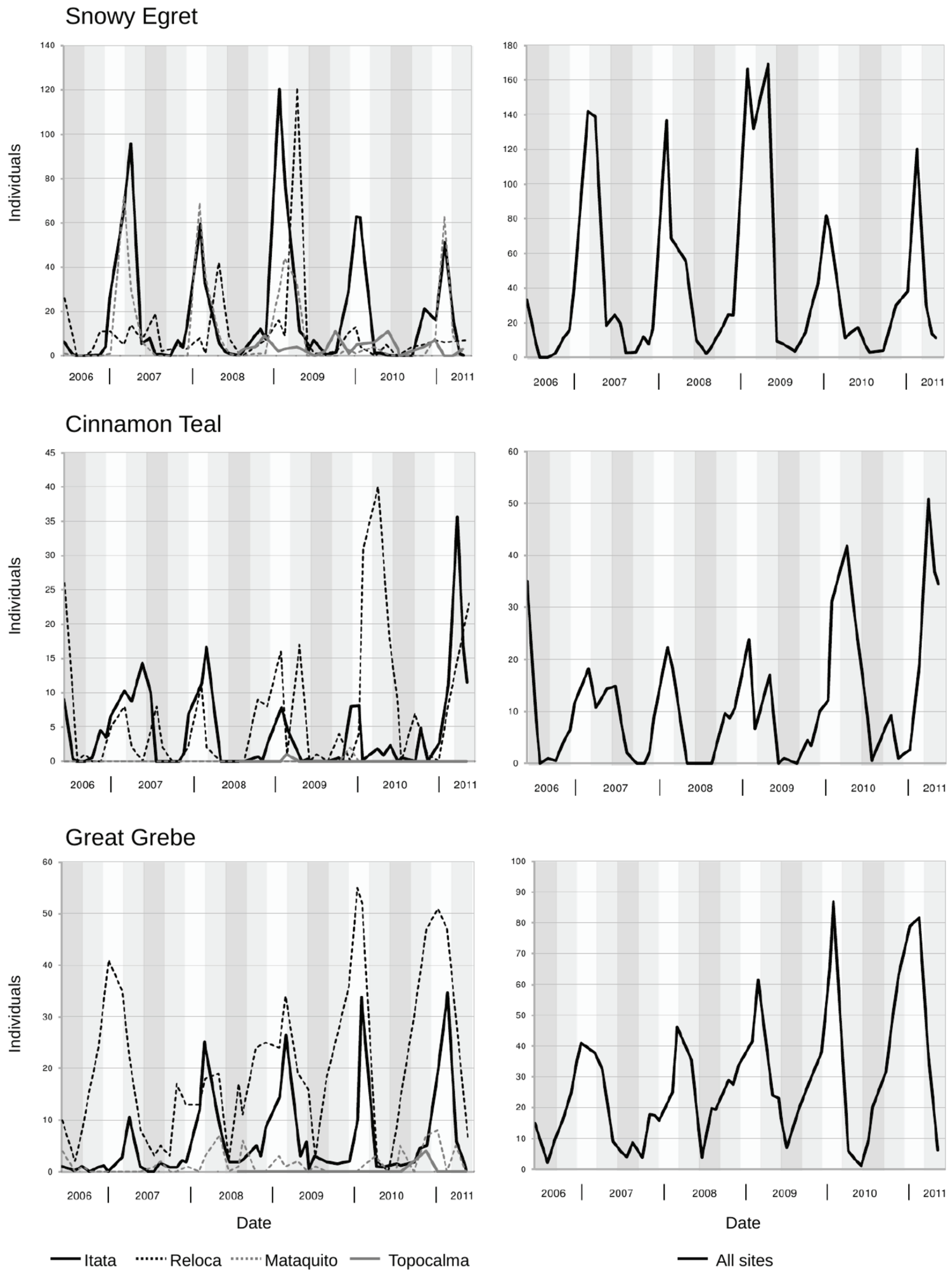

FIG. 4. Population trajectories of Snowy Egret (*Egretta thula*), Cinnamon Teal (*Anas cyanoptera*), and Great Grebe (*Podiceps major*) in four estuaries of central Chile (2006ñ2011). Left graph: individual sites; right graph: aggregate numbers. Background shading represents season (Austral): dark gray = winter, white = summer, light gray = spring or fall.

spond to resident seabirds that use the estuaries for resting and bathing. Figure 5 shows the population trajectories of Peruvian Pelican (*Pelecanus thagus*) and Neotropic Cormorant (*Phalacrocorax brasilianus*). Although with differences, both species also show lowest abundances during the spring and peaks during the fall.

DISCUSSION

The data presented show that bird communities in estuaries of central Chile are highly dynamic but exhibit relatively clear and predictable patterns. The most evident seasonal cycles are due to the arrival and departure of migratory species. While species that breed in southern Chile aggregate in the area during the winter (Fig. 2), long-distance migrants concentrate in the studied estuaries during the Austral summer (Fig. 3).

Our data allow for the distinction between different behaviors among long-distance migrants. For example, some species, such as Franklin's Gull or Elegant Tern, showed just one peak in a season (Fig. 3), suggesting that they used the estuaries as their final destination during that year. On the other hand, Baird's Sandpipers showed two clear peaks (Fig. 3), which is an indication that the estuaries in central Chile are being used mostly as staging sites during their movements to and from areas further south. This pattern differs from Aparicio's (2006) observation that Baird's Sandpipers were present in her study site (Valdivia, approximately 400 km to the south) only during the southwards migration, suggesting that this species might use different stopover sites during its migrations.

A rather unexpected pattern was that observed on most resident species, which showed significant seasonal variation (Table 1, Fig. 4). In most cases these species had very low abundances during the breeding season (spring), increasing during the summer and peaking during summer–fall. The steep subsequent decrease and the lack of evidence of significant reproduction in the area, indicate that these changes are not governed by recruitment and mortality but, most likely, by the movement of individuals. There is some indirect evidence of seasonal movements of birds between estuaries and non-coastal wetlands, and between wetlands and the surrounding agricultural landscapes, that could account for the observed pattern (Estades *et al.* 2012).

The high level of coincidence between population trends of most species (including residents) at the different studied estuaries suggests that local dynamics are mostly driven by regional factors rather than by local mechanisms. Aggregate population trajectories were more consistent than the dynamics at individual estuaries, suggesting that the studied sites are part of a larger system and that the behavior of the populations at different estuaries are not independent from each other. The example of the Elegant Tern is evident (Fig. 3). While the aggregate numbers were fairly stable between 2006 and 2009, in Mataquito the population went from approximately 3000 birds in 2006 to almost nothing in the 2007–2008 seasons, and then, again, to more than 3000 in 2009. Coincidentally, in Reloca the trend was the opposite (Fig. 3), suggesting a redistribution of birds among sites.

Estades *et al.* (2008) observed that populations of the Chilean Flamingo (*Phoenicopterus chilensis*), a species that winters in coastal wetlands of south-central Chile, also showed evidences of inter-annual redistribution of birds among estuaries, and hypothesized that these changes might be associated to rainfall, as in rainy years the water level in large rivers reduced the amount of habitat available for the species, forcing individuals to use smaller estuaries.

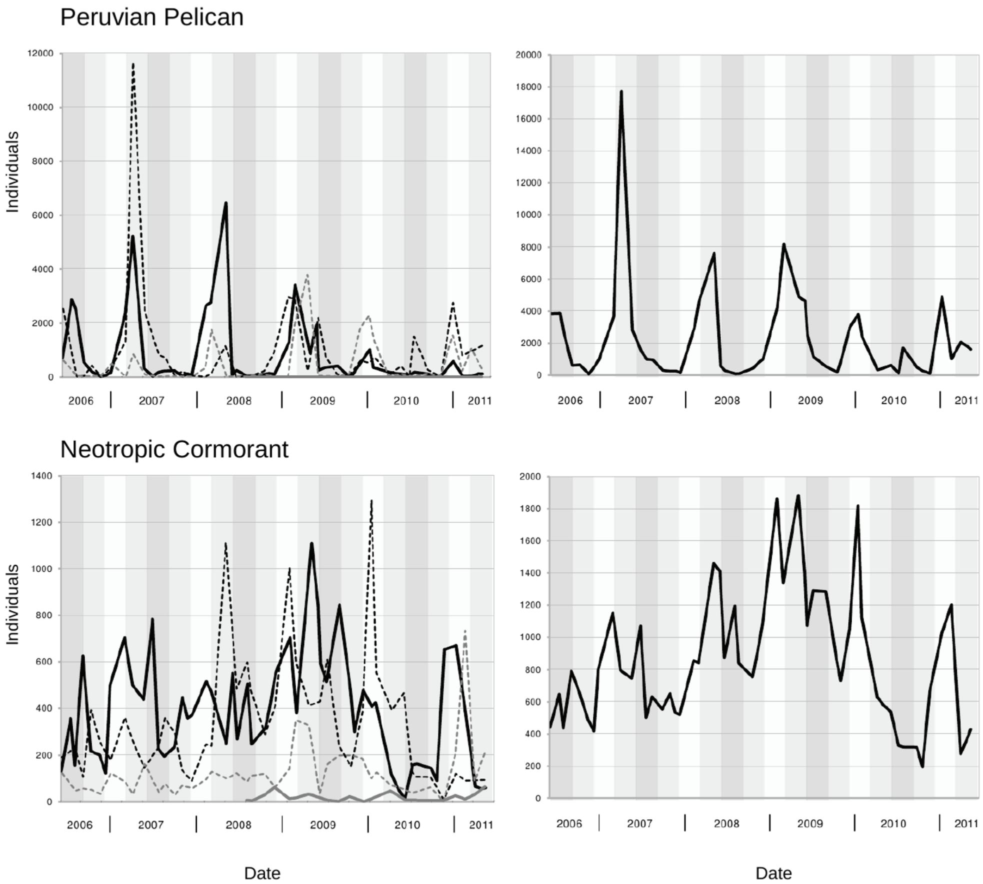

FIG. 5. Population trajectories of Peruvian Pelican (*Pelecanus thagus*) and Neotropic Cormorant (*Phalacrocorax brasilianus*) in four estuaries of central Chile (2006–2011). Left graph: individual sites; right graph: aggregate numbers. Background shading represents season (Austral): dark gray = winter, white =summer, light gray = spring or fall.

The previous case is not the only example of climatic variables modulating population dynamics of waterbirds in wetlands of south-central Chile. For example, the number of Black-necked Swans (*Cygnus melancoryphus*) is increased in central Chile during El Niño (wet) years (Vilina *et al.* 2002), whereas during La Niña (dry) years they tend to concentrate in southern wetlands (Schlatter *et al.* 2002). Vilina & Cofré (2000) also reported a positive association between rainfall and the abundance of Silvery Grebes (*Podiceps occipitalis*) and White-tufted Grebes (R*ollandia rolland*) during the following year in coastal wetlands of central Chile.

In addition to rainfall and other climatic variables, food availability may affect the abundance of some species at a regional or even continental scale. For instance, large inter-annual population differences such as those observed with the Franklin's Gull (Fig. 3) might be due to continental redistribution of migrant birds that may track regional changes in food availability (Estades *et al.* in prep.). Additionally, food availability may be influenced by human activities, like in the case of Elegant Terns, where numbers are negatively affected by the anchovy fisheries along the west coast of the United States (Schaffner 1986). Thus, changes in harvest rates could indirectly impact the numbers of birds migrating through the Chilean coasts.

Another factor that may alter the population dynamics of waterbirds in Chilean estuaries are physical changes in the configuration of these coastal wetlands due to seismic activity. For example, the earthquake that struck the Valdivia region in 1960 caused an extensive subsidence that created some important coastal wetlands (Reinhardt *et al.* 2010). Likewise, on 27 February 2010, the coast of central Chile experienced a strong earthquake and a tsunami that affected all study sites. Among the most evident effects was the loss of most of the sand bars in Mataquito, which apparently forced some birds such as the Black Skimmers to leave the area before the normal migration date (Estades & Vukasovic in prep.).

Although reproduction was not formally assessed in the present study, observations indicate that the estuaries in central Chile have a very limited role in waterbird breeding. This conclusion agrees with Victoriano *et al.* (2006) who stated that the most important coastal wetlands in relation to breeding activity are not estuaries. Several factors might be involved in the latter, but likely the effect of tides and the scarcity of aquatic vegetation strongly limit the capacity of many birds to nest in these estuarine wetlands. Among the studied sites, Reloca is the only one with some marsh habitat and, consequently, hosts species showing breeding activity. An example of the latter is the Great Grebe (*Podiceps major*), of which juveniles were observed regularly in the area. Accordingly, this species showed an increase during the spring in Reloca (Fig. 4).

The most important activity of birds in estuaries in central Chile is roosting (Estades *et al.* 2012). Many seabirds that forage in the ocean, such as gulls, pelicans, and cormorants, roost in the sandbars and islets that exist in these wetlands. Apparently these structures provide a safer place to rest than beaches, because of their low accessibility to non-volant predators, such as feral dogs (Estades *et al.* 2012). Most seabirds also used the studied estuaries for bathing (Estades *et al.* 2012), likely to remove the salt from the plumage (e.g. Mahoney & Jehl 1985). Although freshwater bathing by seabirds is a not a rare event (e.g., Cramp & Simmons 1983, Burger *et al.* 2010, pers. observ.), to our knowledge there is not a formal assessment on the adaptive value of this behavior for seabirds, an important information to further understand the role of coastal wetlands for bird populations.

Foraging is not an important activity for most birds in the studied sites (Estades *et al.* 2012), with the exception of species such as the Chilean Flamingo or the Black Skimmer, which rely strongly on the calm and shallow brackish waters of the estuaries to obtain their food. Accordingly, the latter species were classified as highly dependent on estuaries (Table 1).

The disparity between the size of the breeding and the wintering grounds for many shorebirds usually causes great concentrations of birds in small sites (Myers *et al.* 1989). The latter is the case in most of the studied estuaries, which hosted large numbers of some migratory species. The Ramsar Convention considers a that a wetland is "internationally important" if it contains at least 1% of the total population of a bird species. That criterion was met by three of the analyzed estuaries: Itata, Reloca, and Mataquito (Table 1), at least once during the studied period. Of particular importance are the cases of Elegant

Tern in Itata and Mataquito, and Black Skimmer in Itata, which surpassed the 1% threshold during all the five studied seasons, highlighting the importance of these sites in the conservation of the latter species.

Coastal wetlands are subject to high anthropogenic pressure throughout the world, and the estuaries of central Chile are not an exception to the latter. Although the studied sites have a relatively low level of human presence, they show evident signs of disturbance, such as the destruction of the already scarce marsh habitat by cattle, the harassment of birds by feral dogs, and the destruction of dune habitat by "off road" vehicles.

Although this study has had a much broader scope, its original motivation was to detect any potential effects of the pulp mill that started its operations upstream of the Itata estuary in 2006. The process of formally analyzing the trends of different species in relation to other environmental variables obtained during the same period is still ongoing, but a simple visual inspection of the data seems to rule out any significant impacts so far. In the case of some species that have shown clear declines in Itata, such as the Peruvian Pelican ($P < 0.05$, Table 1; Fig. 5), a similar trend in the control sites suggests that the observed decline is due to a regional phenomenon rather than to a local effect. The same is true for some species that have shown an increase over the years, such as the Great Grebe ($P < 0.05$, Table 1; Fig. 4).

Because of the complexity of the factors involved, understanding the drivers of the composition and functioning of waterbird communities in the estuaries of central Chile requires a long-term research approach. Fortunately, the monitoring program described here has such a scope. However, the fact that, at a given site, the populations of most of the studied birds are apparently dependent on the ecological conditions elsewhere (i.e., other wetlands, the surrounding landscape, migration route, etc.) indicates that these systems cannot be considered as isolated entities. Therefore, in order to understand the dynamics of waterbirds in Chilean estuarine wetlands in a way that is useful for its management and conservation, a more integrated approach to monitoring is also needed.

ACKNOWLEDGMENTS

The long-term monitoring program upon which this study was based is funded by Arauco. We also want to thank the important contribution of several field assistants, including A. Cánepa, R. P. Thomson, V. López, A. M. Venegas, N. Fuentes, and R. Chiappe. This manuscript significantly benefited from the comments of the Editor, A. Weller, M. Fasola, and two anonymous reviewers.

REFERENCES

Aparicio, A. 2006. Abundance, distribution and migration chronology of shorebirds on exposed sandy beaches of south central Chile. P. 188 *in* Boere, G. C., C. A. Galbraith, & D. A. Stroud (eds). Waterbirds around the world. The Stationary Office, Edinburgh, UK.

Bibby, C. J., N. D. Burguess, & D. A. Hill. 1992. Bird census techniques. Academic Press, London, UK.

Brockwell, P. J., & R. A. Davis. 1991. Time Sseries and forecasting methods. 2nd ed. Springer, New York, USA.

Burger, J., M. Gochfeld, & R. Ridgely. 2010. Migratory behavior of Franklin's Gulls (*Larus pipixcan*) in Peru. Energ. Pow. Eng. 2: 143–147.

Costanza, R., W. M. Kemp, & W. R. Boynton. 1993. Predictability, scale, and biodiversity in coastal and estuarine ecosystems: implications for management. Ambio 22: 88–96.

Cramp, S., & K. E. Simmons. 1983. The birds of the western Palearctic, Volume 3. Oxford Univ. Press, Oxford, UK.

Davidson, N. C.,D. d'A Laffoley, J. P. Doody, L. S. Way, J. Gordon, R. Key, C. M. Drake, M.W.

Pienkowski, R. Mitchell, & K.L. Duff. 1991. Nature conservation and estuaries of Great Britain. Nature Conservancy Council, Peterborough, UK.

Estades, C. F., J. Aguirre, & A. Camaño. 2008. Chilean Flamingos (*Phoenicopterus chilensis*) in estuaries of central Chile. Flamingo 16: 50–54.

Estades, C. F., M. A. Vukasovic, & J. Aguirre. 2012. Aves en los humedales costeros de Chile. Pp. 67–99 *in* Fariña, J. M., & A. Camaño (eds). Humedales costeros de Chile. Aportes científicos a su gestión sustentable. Ediciones Univ. Católica de Chile, Santiago, Chile.

Fuenzalida, H. 1971. Climatología de Chile. Dpto. Geofísica y Geodesia, Univ. de Chile, Santiago, Chile.

Guicking, D., S. Mickstein, P. H. Becker, & R. Schlatter. 2001. Nest site selection by Brown-hooded Gull (*Larus maculipennis*), Trudeau's Tern (*Sterna trudeaui*) and White-faced Ibis (*Plegadis chihi*) in South Chilean tule marsh. Ornitol. Neotrop. 12: 285–296.

Harding, L. W, Jr., M. E. Mallonee, & E. S. Perry. 2002. Toward a predictive understanding of primary productivity in a temperate, partially stratified estuary. Estuar. Coast. Shelf S. 55: 437–463.

Kusch, A., & M. Marín. 2004. Distribución del Chorlo Chileno, *Charadrius modestus*, (Lichtenstein) (Charadriidae) en Chile. Ans. Inst. Pat. (Chile) 32: 69–78.

Mahoney, S. A, & J. R. Jehl, Jr. 1985 Adaptations of migratory shorebirds to highly saline and alkaline lakes: Wilson's Phalarope and American Avocet. Condor 87: 520–527.

Morrison, R. I. G., & J. P. Myers. 1987. Wader migration systems in the New World. Wader Stud. Group Bull. 49S: 57–69.

Myers, J. P., R. I. G. Morrison, P. Z. Antas, B. A. Harrington, T. E. Lovejoy, M. Sallaberry, E. Senner, & A. Tarak. 1987. Conservation strategy for migratory species. Am. Sci. 75: 18–26.

Myers, J. P., R. I. G. Morrison, P. A. Antas, B. A. Harrington, T. E. Lovejoy, M. Sallaberry, S. E. Senner, & A. Tarak. 1989. Estrategia de conservación para especies migratorias. Taller de campo sobre ambientes acuáticos y técnicas de estudio, captura marcado y manejo de chorlos migratorios. Red Hemisférica de Reservas de aves playeras. La Serena, Chile.

Page, G. W., E. Palacios, L. Alfaro, S. González, L. E. Stenzel, & M. Jungers. 1997. Numbers of wintering shorebirds in coastal wetlands of Baja California, Mexico. J. Field Ornithol. 68: 562–574.

Quezada, A. E., H. Oyarzo, & V. H. Ruiz. 1986. Distribución de avifauna en los distintos "hábitats" del Estuario Andalién, Bahía de Concepción, Chile. Stud. Neotrop. Fauna Environ. 21: 197–206.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at http://www.R-project.org.

Reinhardt, E. G., R. B. Nairn, & G. Lopez. 2010. Recovery estimates for the Río Cruces after the May 1960 Chilean earthquake. Mar. Geol. 269: 18–33.

Schaffner, F. C. 1986. Trends in Elegant Tern and northern anchovy populations in California. Condor 88: 347–354.

Schlatter, R. P., R. A. Navarro, & P. Corti. 2002. Effects of El Niño southern oscillation numbers of Black-necked Swans at Rio Cruces Sanctuary, Chile. Waterbirds 25: 114–122.

Scolaro, J. A., S. Laurenti, & H. Gallelli. 1996. The nesting and breeding biology of the South-American Tern in northern Patagonia. J. Field Ornithol. 67: 17–24.

Skagen, S. K. 1997. Stopover ecology of transitory populations: the case of migrant shorebirds. Ecol. Stud. 125: 244–269.

Victoriano, P. F., A. L. González, & R. Schlatter. 2006. Estado de conocimiento de las aves de aguas continentales de Chile. Gayana 70: 140–162.

Vilina, Y. A., & H. Cofré. 2000. El Niño effects on the abundance and habitat association patterns of four grebe species in Chilean wetlands. Waterbirds 32: 95–101.

Vilina, Y. A., H. L. Cofré, C. Silva-García, M. D. García, & C. Perez-Friedenthal. 2002. Effects of El Niño on abundance and breeding of Black-necked Swans on El Yali Wetland in Chile. Waterbirds 25: 123–127.

Wetlands International. 2013. Waterbird Population Estimates. Available at http://wpe.wetlands.org [Assessed on 29 April 2013].

Ysebaert, T., P. L. Meininger, P. Meire, K. Devos, C. M. Berrevoets, R. C. W. Strucker, & E. Kuijken. 2000. Waterbird communities along the estuarine salinity gradient of the Schelde estuary, NW-Europe. Biodivers. Conserv. 9: 1275–1296.