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Perez-Arteaga, A., Gaston, K.J. and Kershaw, M. (2002) Population trends and priority conservation sites for Mexican Duck Anas diazi. Bird Conservation International, 12 (1). pp. 35-52. ISSN 0959-2709

https://doi.org/10.1017/S0959270902002034

Bird Conservation International (2002) 12:35–52. © BirdLife International 2002
DOI: 10.1017/S0959270902002034 Printed in the United Kingdom

Population trends and priority conservation sites for Mexican Duck *Anas diazi*

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Summary

Little is known about Mexican Duck *Anas diazi* biology and populations. We analyse long-term (1960–2000) trends of Mexican Duck numbers in Mexico and employ contemporary count data (1991–2000) from the U.S. Fish and Wildlife Service midwinter surveys to identify key sites for conservation using a complementarity approach. The overall Mexican Duck population showed a significant long-term increase of 2.5% per year, with large fluctuations throughout the study period. The Northern highlands population increased at an annual rate of 7.7%, while the Central highlands population showed no significant long-term trend. During the last decade, counts in both the Northern and Central highlands exhibited no significant change. At the site level, significant long-term increases occurred in four localities in the Northern highlands (Laguna BabPcora +13.9% annually, Laguna Bustillos +25.9%, Laguna Mexicanos +20.4% and Laguna Santiaguillo +16.9%) and in three localities in the Central highlands (Languillo +15.3% annually, Presa Solís +8.9%, Zacapu +13.4%). Two sites in the Central highlands showed significant declines, in the long term (Lago de Chapala, –5.2% per year) and during the last decade (Lerma, –11.8% per year). The Northern highlands held 16% and the Central highlands 84% of the Mexican Duck population in the period 1960–2000; during the last decade, these figures were 31% and 69%, respectively. A set of priority sites for conservation of the Mexican Duck was identified, consisting of 15 sites holding more than 70% of the midwinter Mexican Duck counts in Mexico. Ten sites from the priority set also qualify for designation as wetlands of international importance under the Ramsar Convention on Wetlands, by holding $\geq$ 1% of the estimated population. Four of the priority sites are in the Northern highlands and 11 in the Central highlands, of which eight are distributed along the Rio Lerma drainage. The most urgent actions that need to be undertaken are to estimate the current minimum population size in Mexico; to establish a programme for monitoring populations in the priority sites, especially those located within the highly degraded Rio Lerma drainage; and to determine the most feasible management actions for the species, concentrating efforts around the priority sites.

Introduction

Mexican Duck *Anas diazi* is perhaps the least known of all North American waterfowl (Williams 1980). Literature on the species is markedly biased towards taxonomic issues (see Delacour and Mayr 1945, Pitelka 1948, Huey 1961, Johnsgard 1961, Aldrich and Baer 1970, Hubbard 1977), and basic conservation information is extremely scarce. Some ecological and demographic information exists, but has been obtained from highly hybridized, isolated populations from the southern United States (Swarbrick 1975, Nymeyer 1977). Despite the fact that Mexican Duck is the only member of its genus to have successfully adapted as a year-round resident to the highlands of Mexico, with an estimated 98% of the global population occurring there (Williams 1980), the natural history described by Williams (1980) is perhaps the only reliable source of general information for the species in Mexico. This paucity of knowledge has generated confusion and has resulted in intermittent legal protection in the United States (see AOU 1957, Aldrich and Baer 1970, Hubbard 1977, USFWS 1977, 1978), with a subsequent reluctance to fund research and conservation projects for the species.

From the information that is available for Mexican Duck, there is no evidence for migratory movements, with breeding and wintering records occurring throughout its range (Friedmann *et al*. 1950, Goldman 1951, Aldrich and Baer 1970, Ohlendorf and Patton 1971, Tomlinson *et al*. 1973, Hubbard 1977, Williams 1980). Mexican Ducks seem to be well adapted to the agricultural environment that prevails in the highlands (Scott and Reynolds 1984), apparently using crop fields and irrigation structures in substitution for natural habitat, feeding largely on waste grain (Leopold 1959). Their life cycle is closely related to pluvial regimes and water availability, occupying large permanent wetlands during the dry season and dispersing to breed in small seasonal ponds after the onset of rains (Williams 1980). Climate over most of the Mexican highlands is characterized by a summer rainy season beginning abruptly in June and continuing into October, followed by a dry winter season. The rainy season begins earlier (around May) in the south-east and later (around July) in the north-west. The use of wetlands by Mexican Duck is likely to be limited by excessive human disturbance, availability of nesting cover, and escape cover for the broods; water quality does not seem to be a limiting factor, regardless of the season (Bevill 1969, Williams 1980, Mellink 1994). Some management for the species, in the form of excluding grazing livestock from small wetlands and their periphery to promote nesting cover and improve water quality has been conducted in the Northern highlands (Ducks Unlimited 2001).

Williams (1980) estimated the minimum (pre-breeding) population of Mexican Duck in Mexico at around 55,500 individuals, with between 85% and 90% of the total population concentrated in a small area in the western Central highlands, where the states of Guanajuato, Jalisco and Michoacán meet. This is the figure currently in use by Wetlands International (Rose and Scott 1997).

There is growing concern for waterfowl conservation in Mexico, with a particular interest in resident species (E. Carrera *in litt*. 2001). The scarcity of resources for such action makes it important to distinguish higher from lower priority areas for conservation. Competition with incompatible land uses also limits the area that is available for conservation (Kirkpatrick 1983, Pressey 1994, Pressey and Tully 1994). Here, we analyse long-term count data for Mexican Duck in Mexico to identify population trends and recent count data to identify key sites for conservation.

Methods

Data

The U.S. Fish and Wildlife Service and Mexican authorities have been monitoring wintering waterfowl in Mexico since the late 1940s through the midwinter waterfowl counts (e.g. USDI 1997). Waterfowl are counted during the highlands' dry season in January (though not in every year), through aerial surveys of discrete wetlands. Using data from this survey, Mexican Duck counts from the interior highlands of Mexico which cover the period 1960–2000 ($n = 21$) were used in this analysis. For this period, the coverage of count sites was well established and encompassed most of the distributional range of the species. The survey was conducted every year from 1960 up to 1966, and then on an irregular basis until 1975. After 1977 it was again conducted every year until 1982, and has been conducted every three years since.

Population trends

Trends in numbers of Mexican Ducks were analysed for sites (localities), for the Northern and Central highlands (following the regional divisions in Saunders and Saunders 1981), and for Mexico overall.

Trends were assessed using TRIM v3.04, a program developed for the analysis of count data derived from wildlife monitoring schemes (Pannekoek and van Strien 2000). The program uses loglinear models to produce annual population indices and population trends from time series of count data (Pannekoek and van Strien 2001). Large-scale wildlife monitoring schemes are often characterized by the presence of many missing values from individual sites within the scheme. In order to combine the counts from individual sites to derive a national or regional population index or trend it is necessary to account for the missing counts. TRIM provides a framework for so doing by producing a model based on the existing counts and then using this to predict those that are missing. National or regional population indices and trends can then be calculated using a complete dataset where the missing counts are replaced by predicted counts from the model.

For the Mexican duck dataset, TRIM was used to fit a loglinear model to the observed counts, where each count was expressed as a function of a site factor and a separate year factor for each survey year (Linear (switching) trend model, selecting each year in which there was a survey as a changepoint (see Pannekoek and van Strien 2001for a full explanation of the model)). The model was then used to predict missing site counts within the survey years and annual population indices were obtained for each survey year using the predicted counts to replace any missing values.

A population index is simply the ratio between the total count for a given year and the total count in the base year, representing the increase (or decrease) with respect to the base year (Pannekoek and van Strien 2001). In the present analysis, the base year was 2000, in which indices were set to 100. Simple measures of overall trend were also obtained from the completed dataset by linear regressions of the log-transformed year totals on years.

Only those sites with count data for 50% or more of the number of years in which the survey took place were used for the assessment of trends to reduce the number of missing values that had to be imputed by the model (see Underhill and Prys-Jones 1994). Of 109 sites with Mexican Duck data, 50 sites met this requirement. These sites were considered representative of the entire set, as they included 94.9% of the total number of Mexican Ducks counted during the study period.

Identification of priority sites

Priority sites for the Mexican Duck were identified using data from the period 1991–2000 ($n = 4$) to ensure that the assessment was reasonably up to date, as waterfowl numbers in Mexico experience large fluctuations (Ducks Unlimited 2001). The use of relatively recent count data avoids the selection of sites that, although having high long-term average numbers, are no longer of great significance for the species. It also secures the selection of those sites that have become important, even if long-term averages are not particularly large.

We searched for the minimum set of sites, which could be considered as a priority for conservation of Mexican Duck. Here, we used a complementarity approach for the selection of a set of sites that addresses large fluctuations in numbers of Mexican Ducks recorded in the midwinter surveys. This minimum (priority) set was subject to certain restrictions that function as requirements for the inclusion of sites within the set, and are unique values for every year in which the survey was conducted. These restrictions operate as conditions that have to be fulfilled not by individual sites but by the set as a whole, within the smallest possible number of sites. The restrictions were such that the minimum set represented at least 70% of the Mexican Duck midwinter count, for every surveyed year from the time series employed (1991, 1994, 1997 and 2000).

The rather high target of representing 70% of the midwinter count within the priority set of sites was chosen due to the endemicity of Mexican Duck, and the lack of information about its population status and conservation requirements. Apart from identifying areas for efficient application of conservation resources, a priority set of sites covering such a large proportion of the counted individuals is also useful in designing population surveys. Alternative solutions for less demanding targets are also presented.

The priority (minimum) set of sites was determined through linear integer programming using LINDO (LINDO Systems 1996), based on complementarity procedures by Rodrigues *et al*. (2000). The minimum set, subject to the restrictions described above, was determined by solving the integer problem:

minimize

$$\sum_{i=1}^{I} x_i \qquad \text{(I)}$$

subject to

$$\sum_{i=1}^{I} c_{ij} x_i \geqslant t_j \qquad j = 1, 2, \ldots, J \qquad \text{(II)}$$

$$x_i \; \varepsilon \; \{0,1\} \qquad i = 1, 2, \ldots, I \qquad \text{(III)}$$

where I is the number of sites, J is the number of count years, c_{ij} is the count of Site I in year j, and variable χ_i is 1 if and only if site i is selected. Target t_j is 70% of the Mexican Duck mid-winter count of year j. The objective function (I) is to minimize the number of sites selected. Inequality (II) ensures, for all the years considered, the selection of a set representing at least 70% of the Mexican Duck

Table 1. Trends in Mexican Duck counts. Only those sites with significant changes ($P < 0.05$) and average counts larger than 300, or those showing significant declines are included in the table

	1960–2000 ($n = 21$)			1991–2000 ($n = 4$)		
	Average count	Annual rate of change (%)	Sig.	Average count	Annual rate of change (%)	Sig.
Overall	16,455	+ 2.5	*	14,249	+ 1.7	NS
Northern highlands	2,694	+ 7.7	***	4,676	+ 2.7	NS
Central highlands	13,762	+ 1.6	NS	9,572	+ 1.4	NS
Local trends: Northern highlands						
Laguna de Babícora	496	+ 13.9	*			
Laguna Bustillos	536	+ 25.9	***			
Laguna Mexicanos	321	+ 20.4	***			
Laguna de Santiaguillo	398	+ 16.9	***			
Local trends: Central highlands						
Languillo	657	+ 15.3	**			
Lago de Chapala	1,194	− 5.2	*			
Presa Solís	577	+ 8.9	**			
Zacapu	315	+ 13.4	*			
Lerma				131	− 11.8	**

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

count. The restriction of integrality (III), states that the variable χ_i is either 0 or 1, thereby treating each site as an indivisible unit.

Results

Trends in numbers of Mexican Ducks

The overall Mexican Duck population showed a small significant long-term increase of around 2% per year (Table 1, Figure 1). Most of this increment was a result of population increases in the Northern highlands where the population augmented at an average rate of 7.7% per annum since numbers in the Central highlands remained stable (Table 1, Figure 2). During the last decade, Mexican Duck numbers remained reasonably stable, both nationally and in the two regions, although it should be noted that these trends are based on only four surveys. The overall long-term increase in population is not constant throughout the whole period however, as large fluctuations in the counts exist. Mexican Duck counts during 1982 and 1988 were particularly high, while 1962, 1963 and 1977 had the lowest counts.

On average, for the period 1960–2000, 84% of the Mexican Ducks counted in the midwinter surveys were in the Central highlands and 16% in the Northern highlands. However, due to the sustained increase in Mexican Duck numbers in the Northern highlands, the proportion of the population that this region contributes to the total has increased spectacularly, contributing more than 38% of the count in 2000, as opposed to 8% in 1960. This proportion reached 44% of the total in 1994. During the last decade, the Northern and Central highlands had, on average, 33% and 67% of the counts, respectively (Table 2).

Figure 1. Overall Mexican Duck population indices (log-scale), 1960 to 2000, using mid-winter survey data (see Methods). Solid lines connect surveys in consecutive years, dashed lines connect non-consecutive surveys.

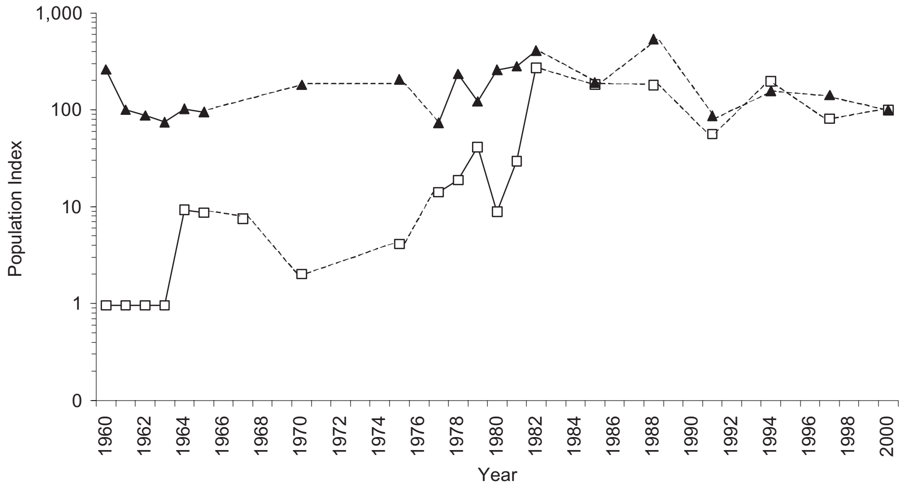

Figure 2. Regional Mexican Duck population indices (log-scale), 1960 to 2000. Northern highlands (squares), Central highlands (triangles). Solid lines connect surveys in consecutive years, dashed lines connect non-consecutive surveys.

Of sites with average counts in excess of 300 birds between 1960 and 2000, four localities in the Northern highlands and three in the Central highlands showed significant long-term increases in Mexican Duck numbers (Table 1). One site in the Central highlands (Lago de Chapala) exhibited a significant long-term decrease, while another site in the same region (Lerma) was the only site that showed a significant decrease during the last decade (Table 1).

Table 2. Annual population indices and numbers of Mexican Ducks counted in Mexico. Indices express the relationship to the base year 2000

	Annual indices			Total counts		
	Overall	Northern highlands	Central highlands	Overall	Northern highlands	Central highlands
1960	153.18	35.79	215.22	18,913	1,529	17,384
1961	56.76	7.80	82.64	7,007	334	6,673
1962	49.63	6.79	72.27	6,127	291	5,836
1963	42.05	8.60	59.73	5,188	366	4,823
1964	60.46	8.27	88.04	7,463	351	7,112
1965	53.82	20.94	71.19	6,646	895	5,750
1967	106.21	31.06	145.93	13,112	1,326	11,786
1970	98.56	3.47	148.82	12,166	147	12,019
1975	120.81	5.65	181.68	14,915	241	14,674
1977	50.16	14.43	69.05	6,194	616	5,578
1978	154.84	19.47	226.38	19,116	831	18,285
1979	91.81	41.93	118.18	11,335	1,790	9,545
1980	165.76	9.02	248.61	20,465	385	20,080
1981	187.7	30.92	270.57	23,175	1,320	21,855
1982	359.91	274.98	404.79	44,433	11,739	32,694
1985	184.72	185.66	184.23	22,806	7,926	14,880
1988	401.02	182.24	516.65	49,510	7,780	41,730
1991	74.68	57.27	83.88	9,220	2,445	6,775
1994	169.15	198.76	153.50	20,883	8,485	12,398
1997	117.81	82.10	136.68	14,545	3,505	11,040
2000	100	100	100	12,346	4,269	8,077

Priority sites

Fifteen sites were identified as priorities for Mexican Duck conservation (Figure 3). In sum, they have held between 70% and 75% of the midwinter Mexican Duck count during the analysed years, averaging around 18% of the population estimate of 55,500 individuals (see Rose and Scott 1997). None of the sites are protected areas or managed for conservation.

Laguna Bustillos, Cabadas, Languillo, Presa Solís, Laguna de Babícora, Lago de Cuitzeo, Laguna Mexicanos, Presa Tepuxtepec, Irapuato and West Yuriria qualify for designation as wetlands of international importance for the Ramsar Convention on Wetlands, under criterion 6 of holding, on average, 1% or more of the individuals in the population (Ramsar Bureau 1999), using the estimated population size of 55,500 (Table 3; see Rose and Scott 1997).

Four priority sites are located in the Northern highlands, and 12 in the Central highlands (Figure 3). Eight of the selected sites (East Atotonilco, Cabadas, West Yuriria, Lago de Cuitzeo, Irapuato, Presa Solís and Presa Tepuxtepec), are located within a relatively small area in the western Central highlands along the Rio Lerma drainage (Figure 3). Laguna de Santiaguillo lies approximately in the middle of the distribution range of Mexican Duck, while three sites (Laguna de Babícora, Laguna Mexicanos and Laguna Bustillos) are located on the northern fringe of the range, and one site (Apan) lies in the eastern tip of the range (Figure 3). The state of Guanajuato has six priority sites, Michoacán has three sites, Chihuahua has three sites, Jalisco has two sites, and Durango and Tlaxcala one site.

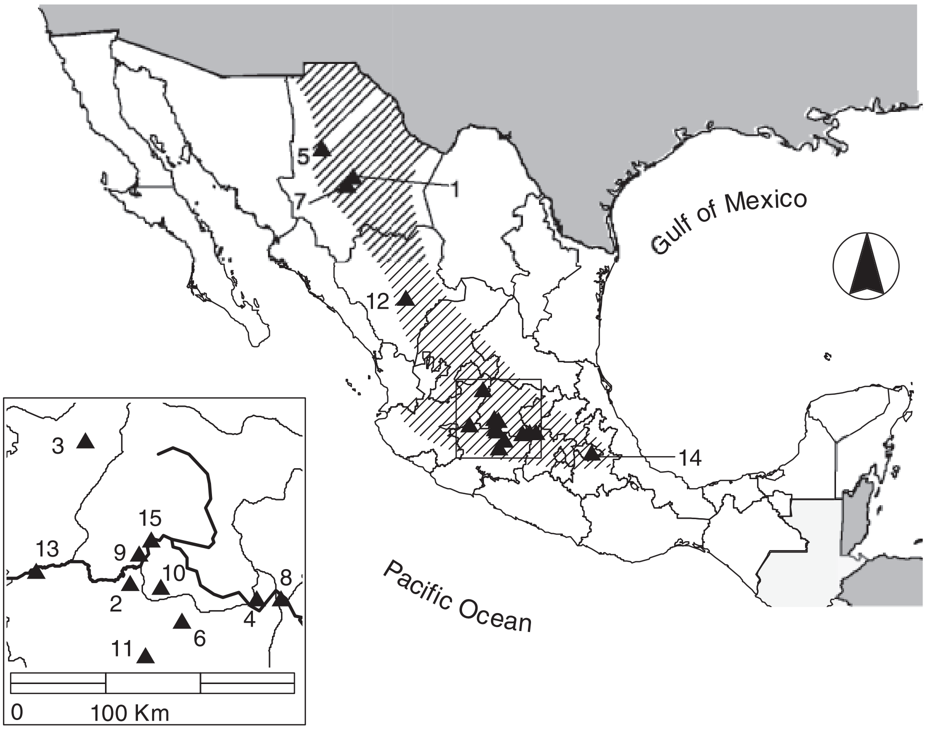

Figure 3. Priority sites for conservation of the Mexican Duck, determined using 1991–2000 count data (see text for details). 1, Laguna Bustillos; 2, Cabadas; 3, Languillo; 4, Presa Solís; 5, Laguna de Babícora; 6, Lago de Cuitzeo; 7, Laguna Mexicanos; 8, Presa Tepuxtepec; 9, Irapuato; 10, West Yuriria; 11, Zacapu; 12, Laguna de Santiaguillo; 13, East Atotonilco; 14, Apan; 15, León. The shaded area denotes the geographical distribution of the species proposed by Williams (1980). The Rio Lerma is represented in bold in the insert. Geographical locations of the sites are given in the Appendix.

The sites required to meet other, less strict targets for the priority set of sites, are presented in Table 4. Bullets indicate sites which are required to reach the population targets on the first column. However, as little is known about the conservation requirements of Mexican Duck, it is advisable to employ rather high targets, which could be changed if required when more detailed conservation information is generated.

Discussion

Population trends

The sustained upward trend of Mexican Duck counts in the Northern highlands (Figure 2) seems to reflect a true population increase in the area. Some of the sites within this region held, during recent years, larger numbers than sites in the Central highlands, the region that historically has been home to the largest concentrations (Leopold 1959, Hubbard 1977, Williams 1980, Scott and Reynolds

Table 3. Numbers of Mexican Ducks counted in 15 priority sites in Mexico during midwinter surveys. The percentage these represent of midwinter count totals and the estimated population size of 55,500 birds are shown. See text for details on prioritization procedure.

	Region[a]	1991	1994	1997	2000	Average 1991–2000	Percentage of STA[b]	Percentage of PE[c]
Laguna Bustillos	NH	565	3,310	890	1,551	1,579	11.1	2.9
Cabadas	CH	940	2,405	935	665	1,236	8.7	2.2
Languillo	CH	950	1,095	1,550	800	1,099	7.7	2.0
Presa Solís	CH	905	675	1,335	557	868	6.1	1.6
Laguna de Babícora	NH	150	980	725	1,064	730	5.1	1.3
Lago de Cuitzeo	CH	190	440	1,065	569	566	4.0	1.0
Laguna Mexicanos	NH	295	1,130	530	307	566	4.0	1.0
Presa Tepuxtepec	CH	90	1,600	355	210	564	4.0	1.0
Irapuato	CH	570	560	610	500	560	3.9	1.0
West Yuriria	CH	5	275	545	1,385	553	3.9	1.0
Zacapu	CH	55	250	1,465	409	545	3.8	0.9
Laguna de Santiaguillo	NH	385	1,055	180	353	493	3.5	0.9
East Atotonilco	CH	440	665	610	105	455	3.2	0.8
Apan	CH	435	250	105	150	235	1.7	0.4
León	CH	550	55	40	101	187	1.3	0.4
Total count in priority sites		6,525	14,745	10,940	8,726	10,234		
Proportion of midwinter count		70.2%	70.6%	75.1%	71.0%	71.8%		
Proportion of PE		11.8%	26.3%	19.7%	15.7%	18.4%		

[a] NH, Northern highlands; CH, Central highlands.
[b] Short-term average total (1991–2000, $n = 4$) in all 50 sites used in the analysis (see Methods).
[c] Population estimate of 55,500 individuals (Rose and Scott 1997).

Table 4. Alternative sets of priority sites required to comply with different targets (proportions of midwinter counts of Mexican Duck in Mexico, 1991–2000). Bullets denote the selection of the site in the priority set for the corresponding target. Locations are given in the Appendix.

Target (proportion of average count)	Laguna Bustillos	Cabadas	Languillo	Presa Solís	Laguna de	Babícora Lago de Cuitzeo	Laguna	Mexicanos Presa tepuxtepec	Irapuato	West Yuriria	Zacapu	Lagnun	Santiaguillo East Atotonilco	Apan	León
10%	•			•											
20%	•	•		•											
30%	•	•	•						•		•				
40%	•	•	•	•						•			•		
50%	•	•	•	•	•	•	•		•			•			
60%	•	•	•	•	•			•	•	•	•	•	•	•	•
70%	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

1984). Large irrigation projects have been developed in the Northern highlands since the 1970s, that have created habitat for a Mexican Duck population that is probably many times larger than that previously maintained (Scott and Reynolds 1984). Mexican Duck populations in the region seem to be increasing with agricultural habitat availability, as this provides readily available resources of food and water (Scott and Reynolds 1984). Agricultural practices have displaced natural vegetation with crops, and the natural ponds have been modified either by draining and ploughing or deepened for water retention. This in turn has apparently been beneficial for Mexican Duck populations, which use the modified wetlands for renesting efforts, effectively extending the breeding season (Williams 1980). Irrigation channels and drains may also function as corridors for the expansion to new areas, as Mexican Ducks have been seen in the coastal agricultural areas of Sonora using these artificial structures (E. Carrera *in litt*. 2001). Scott and Reynolds (1984) attributed the increase of the Mexican Duck population near Laguna Bustillos to the expansion of irrigation agriculture, facilitating movement of ducks through the irrigation structures along the Conchos River.

The adaptability of Mexican Duck to agriculture has been reported by a number of authors (Leopold 1959, Hubbard 1977, Scott and Reynolds 1984, Williams 1984). This is apparently not a sudden modification of behaviour to newly created conditions, but a gradual process of adaptation according to progressive habitat modifications. Intense human occupation and the introduction of agriculture in the Mexican highlands date back at least 4,000 years (Bradbury 2000). The landscape in the highlands has suffered a progressive modification since the introduction of agriculture and throughout the prehispanic and conquest periods (Endfield and O'Hara 1999, McAuliffe *et al*. 2001, see also Borah and Cooke 1963, Licate 1981, Hassig 1994), apparently allowing Mexican Duck to adapt gradually to the agricultural conditions of the region and successfully exploit the landscape features and food made available by intensive agricultural practices. However, there is no information with which to determine if the carrying capacity of the region has been reached.

The absence of population growth in the Central highlands (Figure 2, Table 2) may be influenced by factors such as vegetation cover, contaminants or human disturbance. Lack of suitable vegetation cover for nesting and escape for the broods has been suggested as a possible limiting factor for Mexican Duck populations (Bevill 1969, Williams 1980), but they have been found to have flexible nesting cover requirements, using any type of available vegetation ranging from crop fields to dry forests, even a considerable distance away from water (Williams 1980). Pollutants from agricultural runoff could also directly affect the success of local Mexican Duck populations. In the Lerma Valley, Montes de Oca *et al*. (1996) found cadmium at toxic concentrations in Mexican Duck livers, being 10 times higher than in migratory duck species in the same area. Cadmium is used in fertilizers (Montes de Oca *et al*. 1996), and the higher concentrations in Mexican Ducks could reflect the longer exposure, as they stay year-round in possibly contaminated waters, or may be a consequence of field feeding. Large quantities of domestic and industrial sewage from the entire Lerma-Chapala basin also flow largely untreated into lakes and reservoirs, with increasing phosphorus loads transported by the Lerma River (de Anda *et al*. 2000). The disturbances of the system are so severe that the entire regional ecosystem could be irreversibly affected (de Anda *et al*. 1998). The effects on the icthyofauna are already evident; of 44 endemic fish species of the Lerma-Chapala basin, three are extinct and 23 greatly reduced in range and population due to environmental degradation (Lyons *et al*. 1998). The marshes and lakes along the Rio Lerma drainage are also important to disjunct populations of wetland birds. Endemics to marshes in the region include Black-polled Yellowthroat Warbler *Geothlypis speciosa* (Curson *et al*. 1995), Yellow Rail *Coturnicops noveboracensis goldmani*, Mexican Clapper Rail *Rallus eleganstenuirostris* (Taylor and van Perlo 1998) and Northern Boat-billed Heron *Cochlearius cochlearius zeledoni* (MartPnez-Villalta and Motis 1992). The extinct Slender-billed Grackle *Quiscalus palustris* was a resident endemic in marshes at the headwaters of the Lerma River (Stattersfield *et al*. 1998).

Some sites show disproportionately large counts during certain years. For example, in Laguna de Santiaguillo, more than 3,000 Mexican Ducks were counted in 1988, and in Laguna Mexicanos a similar number was recorded during the same year, both figures much higher than the average counts of 398 and 321 individuals, respectively. In Lago de Chapala more than 10,000 Mexican Ducks were counted in 1982, a considerably higher number than the mean of 1,194 individuals. The largest count of Mexican Ducks in Mexico was recorded in Cabadas in 1988, when more than 32,000 individuals were counted, an extraordinarily high number considering the average of 3,454 individuals for this site. Large concentrations are apparently common during the dry season, when Mexican Ducks are highly gregarious, forming flocks containing up to 5,000 individuals and possibly more during very dry years (Williams 1980). Large midwinter counts may be a product of unusually large concentrations during years with locally dry conditions, as they tend to move towards wetlands with available water when the small seasonal ponds, which were occupied during the breeding season, disappear (Williams 1980). Smith *et al*. (1959) and Williams (1980) noted that counts of Mexican Ducks tend to vary inversely with the amount of available aquatic habitat; when water is abundant, fewer are counted, while exceptionally dry winters yield larger numbers (birds concentrate in permanent wetlands in which the survey is conducted).

Priority sites

Although the selected priority sites account for more than 70% of the midwinter Mexican Duck counts, they only represent 18% of the estimated population size. The estimate of a minimum population size of 55,500 Mexican Ducks was calculated using data from aerial counts in 1978, by predicting numbers of ducks for unsurveyed areas from a count of around 39,000 individuals (Williams 1980). The survey used for the calculation of the population size covered an extensive area of the distribution range of the species, and special efforts were made to cover small seasonal ponds in agricultural areas, as well as large permanent wetlands (Williams 1980). However, the data from the midwinter surveys used in the analysis presented here is not extrapolated for uncovered areas, and as these surveys are not designed specifically for Mexican Duck, coverage of small seasonal wetlands is not as extensive (Williams 1980). This explains the rather small proportion of the population estimate that the counted individuals in the priority sites represent. This proportion most likely fluctuates throughout the year, increasing as the birds concentrate when the dry season progresses, and decreasing as they disperse to breed after the start of the wet season.

Calculating an up-to-date estimate of the minimum population size of Mexican Duck is probably the most urgent research task that needs to be undertaken. This estimate can be derived from aerial counts prior to dispersal of the dry season flocks to the breeding areas, at the end of the dry season. During this time of year, counting conditions are optimal as Mexican Ducks are in large concentrations, most wintering waterfowl of other species have gone, and the lack of vegetative cover and the barren shorelines of the wetlands facilitate the detection of ducks from the air (Williams 1980). These counts should ideally cover the largest possible area of the highlands, also surveying wetlands that are not covered by the midwinter counts. If funding annual aerial counts to calculate and regularly update a minimum population size estimate proves difficult, volunteer teams could be trained to conduct ground surveys, which should ideally be concentrated on the priority sites identified here, where the highest densities are known to occur.

The priority sites identified may also incorporate the main breeding areas, as Mexican Ducks apparently move to the closest available wetland with suitable cover for nesting after the beginning of rains, when vegetation cover has grown to an acceptable height and the seasonal wetlands have gathered sufficient water (Williams 1980). Due to the low breeding densities of Mexican Duck (about 1 pair/250–300 ha) (Williams 1980), intensive habitat management to supply nesting cover seems impractical, but schemes aimed at promoting escape cover for the broods seem a more feasible option. Conservation of Mexican Duck is expected to be costly, because its large distributional area and low densities during the breeding season prevent the efficient application of programmes to promote vegetative cover. Barbed-wire exclusions in small sections of seasonal wetlands to prevent livestock from grazing and to promote escape cover during the brood-rearing season are probably the most viable management option. A similar programme, with the aim of improving nesting cover and water quality in small wetlands has been carried out in Mexico (Ducks Unlimited 2001). The improvement of wetland conditions not only benefits Mexican Duck and other wetland-related wildlife, but also improves watering conditions for cattle and provides a readily available seed bank for rapid reestablishment of annual herbs. An analogous programme could be promoted among state governments and farmers in the priority sites, and around sites showing population declines.

To date, Mexican Ducks have not yet been marked in Mexico. Banding efforts should also be concentrated in the priority sites, as the large dry season flocks make morning and evening feeding flights on a regular basis to surrounding crop fields (Williams 1980), where they could be captured more easily. Banding recovery data would provide information about dispersal, survival, and movements between areas, also generating valuable data about site fidelity and movements in response to local environmental change.

Hybridization

Hybridization has contributed to the extinction of many species through direct and indirect means (Allendorf *et al.* 2001). Mallard *Anas platyrhynchos* genic introgression has been reported in Black Duck *A. rubripes* (e.g. Deon *et al.* 1995, Shutlet *et al.* 1996), Hawaiian Duck *A. wyvilliana* (e.g. Browne *et al.* 1993) and Grey Duck *A. superciliosa* (e.g. Gillespie 1985, Haddon 1998). The level of introgressive hybridization between Hawaiian and Grey Duck with Mallard is so large that few pure populations remain (Rhymer *et al.* 1994, BirdLife International 2000).

Concern has been expressed that Mexican Duck is being swamped by Mallard phenotype, especially in U.S.A. populations (Johnsgard 1961, Aldrich and Baer 1970, Hubbard 1977). In Mexico, Hubbard (1977) found that Mexican Duck had fewer *platyrhynchos* characteristics in phenotypes of southern populations and more Mallard influence to the north. Scott and Reynolds (1984) found a clinal change from north to south in plumage characteristics, with more evident Mallard influence as latitude increased. They identified a ''fulcral'' population (i.e. where the phenotypes are possibly in a state of flux) in southeastern Chihuahua, and pointed out the original source of the birds inhabiting this area to Trans-Pecos Texas and northern Chihuahua, with birds moving southwards along the Río Conchos drainage through irrigation systems.

Before 1920, Mallard were a conspicuous component of wintering waterfowl as far south as the Valley of Mexico, but they are now scarce, even in northern Chihuahua (Scott and Reynolds 1984). Populations have apparently declined due to increasing grain production in the U.S.A., as migrating birds are effectively short-stopped by easily available food resources before reaching Mexico (Leopold 1959, Saunders and Saunders 1981). Even though no significant simple downward trend can be detected in Mallard numbers in the country, its population has declined at an average rate of around 1.6% per year since 1960 (Pérez-Arteaga *et al.* unpubl. data). The decline in Mallard numbers and its scarcity in the Central highlands, the region with ''pure'' *diazi* populations (Scott and Reynolds 1984), may limit the risk of Mallard genetic introgression there. Scott and Reynolds (1984) found no evidence in Mexico for genetic swamping of Mexican Duck by Mallard phenotype, even though significant phenotypic variation was found. However, morphological characters do not allow the precise determination of hybridization levels (Allendorf *et al.* 2001). Determining whether individuals are first generation hybrids, backcross, or later generation hybrids is crucial, because populations still containing reasonable numbers of parental individuals could be potentially recovered by removal of hybrids or captive breeding (Allendorf *et al.* 2001). This information is not available for Mexican Duck populations. Molecular techniques, which simplify identification and description of hybridized populations (Allendorf *et al.* 2001) could be used to determine Mallard introgression in Mexican Duck, and whether populations in the Central highlands are under any threat from contamination. If this information is made available, it could be integrated in the selection of priority sites, assigning values to sites according to degrees of hybridization as a further restriction in the prioritization process.

Conclusion

Mexican Duck seems well adapted to the agricultural landscape of the highlands, and there is not sufficient evidence to consider it under serious threat. As the development of agriculture has provided newly created wetland habitat and a constant food surplus, it is unlikely that populations have ever been much larger than at present, and even when local declines exist in some areas and large fluctuations occur between years, the overall population seems to be compensating with increases in other areas. There exists no information about movements of Mexican Ducks between areas or survival between seasons or years, so no inferences can be made about the response of populations to local conditions. Due to the endemicity of the species and naturally occurring low numbers, such responses to changes in local conditions need to be investigated, especially in the highly degraded areas within the Rio Lerma drainage. Continuous monitoring through population surveys and banding efforts can be designed and implemented around the priority sites determined here, where a high proportion of the Mexican Ducks recorded in Mexico are present. Yet another priority action is to estimate the current minimum population size, and to regularly update this figure. Determining the degree of hybridization in northern populations is also recommended to assess if ''pure'' populations are at risk from genetic introgression and if so, to integrate it as a restriction for the selection of priority sites. The unique plasticity of the species and its adaptability to the agricultural environments of the highlands have prevented a severe impact by large-scale environmental changes on the populations. This unique situation also provides the rare opportunity to bring together sectors that have been traditionally incompatible, such as farming and conservation. Coordinated management efforts can be beneficial for Mexican Duck and other wildlife and also improve wetlands for livestock and irrigation use.

Acknowledgements

A.P.A. is funded by a Mexican National Council for Science and Technology (CONACYT) Scholarship (136790), and K.J.G. is a Royal Society University Research Fellow. We are grateful to Mark C. Otto for supplying the count data, to Ana Rodrigues for assistance with the selection algorithms, and to Eric Mellink, Ana Rodrigues and Tom Webb for commenting on the manuscript.

Appendix. Location of count sites mentioned in the text.

	Coordinates	Region[a]	Location notes
Apan	19°35′N 98°17′W	CH	Wetland complex extending 5 km NW of Apan, 8 km S, and 40 km SE, including Lagunas Atlangatepec, San Fernando and Tecocomulco
Cabadas	20°17′N 101°57′W	CH	Wetland complex centred 12 km SE La Piedad extending 32 km E and W and 16 km N and S, including Lagunas El Triunfo, Palo Alto and La Loma and Presa Tres Mezquites
East Atotonilco	20°28′N 102°47′W	CH	Wetland complex extending 19 km N of Ocotlán and and 29 km W and NW and 30 km NE, including Lagunas el Jihuite and la Rod
Irapuato	20°43′N 101°48′W	CH	Wetland complex centred 45 km W of Irapuato extending 30 km NW and 35 km SE including Bordo La Tacita, El Coyote and Guadalupe Corralejo
Lago de Chapala	20°15′N 103°00′W	CH	Only lake and its shoreline
Lago de Cuitzeo	19°58′N 101°07′W	CH	Includes wetlands extending 20 km NE and Lagunas Santa Clara and Chambacua
Laguna Bustillos	28°33′N 106°45′W	NH	Includes wetlands within 16 km SE
Laguna de Babícora	29°02′N 107°48′W	NH	Includes wetlands within 20 km W and 10 km NE
Laguna de Yuriria	20°15′N 101°07′W	CH	Lagoon only
Laguna Mexicanos	28°01′N 106°58′W	NH	Includes wetlands within 10 km N
Laguna Santiaguillo	24°48′N 104°05′W	NH	Includes Bordo de San Bartolo and wetlands within 10 km W
Languillo	21°44′N 102°00′W	CH	Wetland complex centered 32 km SE of Aguascalientes within a 25 km radius
León	20°56′N 101°37′W	CH	Wetland complex extending 20 km SW of León, 40 km S and 45 km SE, including Laguna San Antonio and Cinco de Mayo
Lerma	19°20′N 94°40′W	CH	Wetland complex extending 31 km NNW of Toluca 19 km NE and 22 km SE
Presa Solís	20°03′N 100°36′W	CH	20 km E of Acámbaro
Presa Tepuxtepec	20°03′N 100°13′W	CH	Includes wetlands 5 km N and 8 km E, also called San Isidro
West Yuriria	20°13′N 101°28′W	CH	Wetland complex extending 20 km W of Laguna de Yuriria and within a 20 km radius
Zacapu	19°52′N 101°43′W	CH	Wetland complex extending 23 km NE of village, including Presas Aristeo, Mercado, Copándaro and San Rafael

[a] NH (Northern highlands), CH (Central highlands).

References

Aldrich, J.W. and Baer, K.P. (1970) Status and speciation in the Mexican Duck (*Anas diazi*). *Wilson Bull.* 82:63–73.

Allendorf, F.W., Leary, R.F., Spruell, P. and Wenburg, J.K. (2001) The problems with hybrids: setting conservation guidelines. *Trends Ecol. Evol.* 16:613–622.

AOU (1957) *Check-list of North American Birds. Fifth edition*. Baltimore, MA: American Ornithologists' Union.
Bellrose, F.C. (1980) *Ducks, geese and swans of North America*. Harrisburg: Stackpole Books.
Bevill, W.V., Jr. (1969) Effects of supplemental stocking and habitat development on abundance of the Mexican Duck. MSc thesis, New Mexico State University, Las Cruces.
BirdLife International (2000) *Threatened birds of the world*. Barcelona and Cambridge, U.K.: Lynx Edicions and BirdLife International.
Borah, W. and Cooke, S.F. (1963) *The aboriginal population of Central Mexico on the eve of the Spanish conquest*. Berkeley, CA: University of California Press.
Bradbury, J.P. (2000) Limnologic history of Lago de Patzcuaro, Michoacán, Mexico for the past 48,000 years: impacts of climate and man. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 163: 69–95.
Browne, R.A., Griffin, C.R., Chang, P.R., Hubley, M. and Martin, A.E. (1993) Genetic divergence among populations of the Hawaiian Duck, Laysan Duck, and Mallard. *Auk* 110: 49–56.
Curson, J., Quinn, D. and Beadle, D. (1995) *New world warblers*. London: Christopher Helm.
Delacour, J. and Mayr, E. (1945) The family Anatidae. *Wilson Bull.* 57: 3–55.
de Anda, J., Quiñones-Cisneros, S.E., French, R.H. and Guzman, M. (1998) Hydrologic balance of Lake Chapala (Mexico). *J. Amer. Water Resources Assoc.* 34: 1319–1331.
de Anda, J., Shear, H., Maniak, U. and Riedel, G. (2000) Phosphorus balance in Lake Chapala (Mexico). *J. Great Lakes Res.* 26: 129–140.
Deon, R.G., Seymour, N.R., Newsome, G.E.B. and Boer, A.H. (1995) A Mallard, *Anas platyrhynchos*, increase in the maritimes: implications for Black Ducks, *A. rubripes. Can. Field Nat.* 109: 459–462.
Ducks Unlimited (2001) *Ducks Unlimited's Conservation Plan*. Long Grove, Ill: Ducks Unlimited.
Endfield, G.H. and O'Hara, S.L. (1999) Degradation, drought, and dissent: an environmental history of colonial Michoacán, west Central Mexico. *Ann. Assoc. Amer. Geogr.* 89: 402–419.
Friedmann, H., Grixcom, L. and Moore, R.T. (1950) Distributional check-list of the birds of Mexico. Part 1. *Pacif. Coast Avifauna* 29: 1–202.
Gillespie, G.D. (1985) Hybridization, introgression, and morphometric differentiation between Mallard (*Anas platyrhynchos*) and Grey Duck (*Anas superciliosa*) in Otago, New Zealand. *Auk* 102: 459–469.
Goldman, E.A. (1951) Biological Investigations in Mexico. *Smithsonian Miscell. Collab.* 115: 1–476.
Haddon, M.W. (1998) Introgressive hybridisation, ducks, and ecological character displacement. *N. Z. J. Zool.* 25: 245–248.
Hassig, R. (1994) *Mexico and the Spanish Conquest*. London and New York: Longman.
Hubbard, J.P. (1977) *The biological and taxonomic status of the Mexican Duck*. Santa Fe: New Mexico Department of Game and Fish (bulletin 16).
Huey, W.S. (1961) Comparison of female Mallard with female New Mexican Duck. *Auk* 78: 428–431.
Hunter, M.L. and Witham, J.W. (1984) Effects of a carbaryl-induced depression in invertebrate abundance on the growth and behavior of American Black Duck and Mallard. *Can. J. Zool.* 62: 452–456.
Johnsgard, P.A. (1961) Evolutionary relationships among the North American mallards. *Auk* 78: 3–43.
Kirkpatrick, J.B. (1983) An iterative method for establishing priorities for the selection of nature reserves: an example from Tasmania. *Biol. Conserv.* 25: 127–134.
Leopold, A.S. (1959) *Wildlife of Mexico*. Berkeley, CA: University of California Press.
Licate, J.A. (1981) *Creation of a Mexican landscape: territorial organisation and settlement in*

the eastern Puebla basin, 1520–1605. Chicago, IL: University of Chicago, Department of Geography (research paper 201).
LINDO Systems (1996) *Student/PC Release 6.00*. Chicago, IL: LINDO Systems.
Lyons, J., Gonzalez-Hernandez, G., Soto-Galea, E. and Guzman-Arroyo, M. (1998) Decline of freshwater fishes and fisheries in selected drainages of west-Central Mexico. *Fisheries* 23: 10–18.
Martínez-Villalta, A. and Motis, A. (1992) Famili Ardeidae (Herons). Pp.376–429 in J. del Hoyo, A. Elliott and J. Sargatal, eds. *Handbook of the birds of the world*, 1. *Ostrich to ducks*. Barcelona: Lynx Edicions.
McAuliffe, J.R., Sundt, P.C., Valiente-Banuet, A., Casas, A. and Viveros, J.L. (2001) Pre-columbian soil erosion, persistent ecological changes, and collapse of a subsistence agricultural economy in the semi-arid Tehuacán Valley, Mexico's 'cradle of maize'. *J. Arid Environ.* 47: 47–75.
Mellink, E. (1994) Grazing and Mexican Ducks in Central Mexico. *Euphonia* 3: 5–7.
Montes de Oca, J.R., Velázquez-Ortega, V., Rosiles-Martínez, R. and López-López, R. (1996) Niveles de varios metales en hígado de aves acuÆticas capturadas en la Laguna del Valle de Lerma, Estado de México. *Veterin. México* 27: 249–251.
Nymeyer, L.A. (1977) Waterfowl ecology in the Rio Grande and Uvas valleys of southern New Mexico, with emphasis on the Mexican Duck. MSc thesis, New Mexico State University, Las Cruces.
Ohlendorf, H.M. and Patton, R.F. (1971) Nesting record of Mexican Duck (*Anas diazi*) in Texas. *Wilson Bull.* 83: 97.
Pannekoek, J. and van Strien, A. (2000) *TRIM v3.04*. Voorburg: Statistics Netherlands.
Pannekoek, J. and van Strien, A. (2001) *TRIM 3 Manual: Trends and indices for monitoring data*. Voorburg: Statistics Netherlands (research paper 102).
Pitelka, F.A. (1948) Notes on the distribution and taxonomy of Mexican game birds. *Condor* 50: 113–123.
Pressey, R.L. and Tully, S.L. (1994) The cost of ad hoc reservation: a case study in eastern New South Wales. *Aust. J. Ecol.* 19: 357–384.
Ramsar Bureau (1999) *People and wetlands: the vital link*. 7th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971), San Jose, Costa Rica, 10–18 May, 1999.
Rhymer, J.M., Williams, M.J. and Braun, M.J. (1994) Mitochondrial analysis of gene flow between New Zealand Mallards (*Anas platyrhynchos*) and Grey Ducks (*A. superciliosa*). *Auk* 111: 970–978.
Rodrigues, A.S., Cerdeira, J.O. and Gaston, K.J. (2000) Flexibility, efficiency, and accountability: adapting reserve selection algorithms to more complex conservation problems. *Ecography* 23: 565–574.
Rose, P.M. and Scott, D.A. (1997) *Waterfowl population estimates. Second Edition*. Wageningen: Wetlands International (publication 44).
SAGAR (2000) *Anuario estadístico de la producción agrícola de los Estados Unidos Mexicanos, 1999*. México: Secretaría de Agricultura, Ganaderia y Desarrollo Rural.
Saunders, G.B. and Saunders, D.C. (1981) *Waterfowl and their wintering grounds in Mexico, 1937–64*. Washington, D.C.: U.S. Fish and Wildlife Service (resource publication 138).
Scott, N.J., Jr. and Reynolds, R.P. (1984) Phenotypic variation of the Mexican Duck (*Anas platyrhynchos diazi*) in Mexico. *Condor* 86: 266–274.
Shutler, D., Ankney, C.D. and Dennis, D.G. (1996) Could the blood parasite *Leucocytozoon* deter Mallard range expansion? *J. Wildl. Manage.* 60: 569–580.
Smith, R.H., Jensen, J.H. and McKeen, J.W. (1959) *Winter waterfowl survey, west coast and interior areas of Mexico, January 1959*. Washington, D.C.: U.S. Department of the Interior.
Stattersfield, A.J., Crosby, M.J., Long, A.J. and Wege, D.C. (1998) *Endemic bird areas of the world: priorities for biodiversity conservation*. Cambridge, U.K.: BirdLife International.

Swarbrick, B. M. (1975) Ecology of the Mexican Duck in the Sulphur Spring valleys of Arizona. MSc thesis, University of Arizona, Tucson, AZ.

Taylor, B. and van Perlo, B. (1998) *Rails: a guide to the rails, crakes, gallinules and coots of the world*. Sussex: Pica Press.

Tomlinson, R.E., Levy, S.H. and Levy, J.J. (1973) New distributional records of breeding Mexican ducks. *Condor* 75: 120–121.

Underhill, L.G. and Prys-Jones, R.P. (1994) Index numbers for waterbird populations. I. Review and methodology. *J. Appl. Ecol.* 31: 463–480.

USDI (1997) *Mexico winter waterfowl counts*. Portland, OR: U.S. Department of the Interior.

U.S. Fish and Wildlife Service (1977) Republication of the list of species. *Fed. Register* 42: 36420–36431.

U.S. Fish and Wildlife Service (1978) Deregulation of the Mexican Duck. *Fed. Register* 43: 32258–32261.

Williams, S.O. III. (1980) *The Mexican Duck in Mexico: natural history, distribution, and population status*. PhD thesis. Colorado State University, Fort Collins, CO.

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Received 18 September 2001; revision accepted 12 November 2001