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Priority sites for wildfowl conservation in Mexico

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Abstract

A set of priority sites for wildfowl conservation in Mexico was determined using contemporary count data (1991–2000) from the U.S. Fish & Wildlife Service mid-winter surveys. We used a complementarity approach implemented through linear integer programming that addresses particular conservation concerns for every species included in the analysis and large fluctuations in numbers through time. A set of 31 priority sites was identified, which held more than 69% of the mid-winter count total in Mexico during all surveyed years. Six sites were in the northern highlands, 12 in the central highlands, six on the Gulf of Mexico coast and seven on the upper Pacific coast. Twenty-two sites from the priority set have previously been identified as qualifying for designation as wetlands of international importance under the Ramsar Convention and 20 sites are classified as Important Areas for Bird Conservation in Mexico. The information presented here provides an accountable, spatially-explicit, numerical basis for ongoing conservation planning efforts in Mexico, which can be used to improve existing wildfowl conservation networks in the country and can also be useful for conservation planning exercises elsewhere.

INTRODUCTION

Mexican wetlands are biologically diverse, including extensive coastal zones and inland waters and they act as important stopover and wintering grounds for North America's wildfowl and for other migratory birds (Wilson & Ryan, 1997). They also satisfy the essential requirements of resident waterbirds and, thus, from a variety of perspectives can be extremely important in an international context (Scott & Carbonell, 1986; Pérez-Arteaga, Gaston & Kershaw, 2002*a*). Recognising these circumstances, Mexican authorities joined the North American Waterfowl Management Plan (NAWMP) in 1994 (USDI, 1994). This is the largest government-driven wildfowl conservation initiative in the Americas (and perhaps worldwide), drawing efforts from Canada, the USA and Mexico. The vision of the NAWMP is to conserve landscapes that sustain North American wildfowl populations throughout their annual cycles (NAWMP, 2002). It is essentially a compromise between signatories, to establish conservation criteria for wildfowl under general guidelines set by the NAWMP but individual to each country's needs and performed within national wildfowl conservation frameworks.

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The primary funding source for NAWMP projects is the North American Wetlands Conservation Act (NAWCA) (Williams, Koneff & Smith, 1999). This is a U.S. Congress fund to conserve North American wetlands, wildfowl and other water-related wildlife (Wilson & Ryan, 1997). The majority of NAWCA-sponsored projects in Mexico have centred around 32 priority wetlands selected in 1993 by the Director of the Mexican national wildlife authority (Wilson & Ryan, 1997). The selection criteria are not available; sites were chosen mainly upon information generated by earlier NAWCA projects in Mexico (Wilson & Ryan, 1997) and thus reflect conservation interest at that time, but are not representative of the biological diversity of Mexican wetlands. Moreover, the set was not selected to function as a network, but rather by the features of individual sites. As these priorities have clearly become obsolete, NAWCA-sponsored projects have recently been conducted elsewhere.

Other efforts to identify priority sites for bird conservation in Mexico include: Western Hemisphere Shorebird Reserve Network (WHSRN: Manomet Centre for Conservation Science, 2001), CONABIO's (Comisión Nacional para el Uso y la Conservación de la Biodiversidad) Important Bird Conservation Areas (AICAS) (Arizmendi & Vazquez-Valdelamar, 2000) and Ducks Unlimited de Mexico (DUMAC) key wetlands for waterfowl (Ducks Unlimited, 2001).

Recent changes in Mexico's political structure have brought about a rearrangement of the national wildlife conservation scheme that, combined with lobbying by non-governmental organisations (NGOs), has triggered within wildlife authorities a better awareness of the conservation needs and the biological importance of wildfowl. For the first time, a wildfowl conservation framework is being developed (the National Strategy for the Conservation, Management and Rational Use of Waterfowl and their Habitats in Mexico), which responds to NAWMP and national conservation requirements. Such an initiative will establish general conservation needs in the country, to guide conservation efforts on wildfowl and their habitats. It will propose harvest rates and seek funding for conservation and monitoring programmes, as well as introducing planning and management regions.

Such a strategy would greatly benefit from an updated network of priority sites for wildfowl conservation, identified using explicit and transparent methodologies. Due to the scarcity of conservation resources in Mexico, it is important to distinguish higher from lower priority areas for conservation. By selecting a set of sites that function as a network, limited funds could be more efficiently applied where they could be more effective. A network of priority sites can also be helpful for planning conservation-related research, results from which can be used to devise species-specific conservation actions that can potentially impact important proportions of the wildfowl populations in the country.

Acknowledging the above, we identify a set of priority sites for wildfowl conservation in Mexico which can be used as a spatially explicit base for current conservation planning efforts, with the objective of optimising the limited available funds for wildfowl research and conservation in Mexico. We use biologically significant criteria in the selection process, employing linear integer programming methods that are highly efficient, transparent and accountable. They also permit an examination of the network as a whole, rather than evaluating each site on its own.

METHODS

Data

The U.S. Fish and Wildlife Service and Mexican authorities have monitored wintering waterfowl in Mexico since the late 1940s through the mid-winter waterfowl survey (e.g. USDI, 1997). Waterfowl are counted during January (although not in every year), through aerial counts of discrete wetlands. The survey is conducted separately in four regions: interior highlands (northern and central highlands), lower Pacific coast, Gulf of Mexico coast and upper Pacific coast. Using data from this survey, wildfowl counts covering the period 1991–2000 ($n = 4$) were used in this analysis, to ensure that the assessment was reasonably up-to-date, since wildfowl numbers in Mexico experience large fluctuations (Pérez-Arteaga & Gaston, 2004). 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, due to permanently changed conditions. This is the case for many wetlands in Mexico, which are subject to constant degradation (CONABIO, 1997). It also secures the selection of those sites that have become important, even if long-term averages are not particularly large (Pérez-Arteaga, Gaston & Kershaw, 2002*b*).

Selection of priority sites

We searched for the minimum set of sites that could be considered as a priority for wildfowl conservation in Mexico, using a complementarity approach that addresses large fluctuations in numbers of wildfowl recorded in the mid-winter surveys. This priority set was subject to numerical restrictions that function as requirements for the inclusion of sites within the set, unique for every species and year in which the survey was conducted. These restrictions operate as conditions to be fulfilled not by individual sites but by the set as a whole, within the smallest possible number of sites.

To numerically define restrictions, we first derived indices for every species and restrictions were then calculated from the indices (see below). Indices were set according to demographic features, using a method similar to that developed by the Nature Conservation Council (NCC) in Great Britain (Stroud, Mudge & Pienkowski, 1990). The NCC method uses data such as population trends and population sizes to derive indices for each species, which can then be transformed into numbers of birds to include in a network of priority sites. The advantage of this method is that it uses readily available information but can be updated when more data are generated, is easy to use and able to provide information quickly for officials without biological training (Stroud *et al*., 1990). The key point is to allow priorities and provisional targets to be set now, whilst further research is undertaken (Stroud *et al*., 1990).

To derive indices for every species, we used the following criteria: (A) proportion of the biogeographical population in Mexico (wintering for migratory species, breeding for resident species), (B) biogeographical population size, (C) long-term continental trend and (D) long-term national trend (Table 1). (A), (B) and (C) were determined from Wetlands International's Waterbird Population Estimates (Delany & Scott, 2002), and (D) was determined from Pérez-Arteaga & Gaston (2004). Each criterion was given a numeric value ranging from 0 to 6 (Table 1), and the index was then calculated by summing these scores (Table 2).

Restrictions for the priority set (Table 2) were then calculated from the indices as a proportion of the maximum index value (restriction = (index value/maximum index value)*100). To avoid narrowly defined targets, restrictions were grouped in 10% bands, 70% being the highest (Table 2; see Stroud *et al*., 1990). These restrictions are the proportion of the total count (in Mexico) of a particular species that had to be included in the minimum set. These targets had to be met during every year considered, regardless of the variation in numbers of birds counted amongst years.

Table 1. Derivation of values (A)–(D) used to calculate species' indices for setting restrictions for the priority set (see Methods)

Criterion[a]	Value
(A) Proportion of the species' population in Mexico	
< 1.0%	0
1.0–4.9%	1
5.0–9.9%	2
10.0–19.9%	3
20.0–29.9%	4
30.0–59.9%	5
≥ 60.0%	6
(B) Species' population size	
≥ 5 000 000	0
2 000 000 to 4 999 999	1
1 000 000 to 1 999 999	2
500 000 to 999 999	3
200 000 to 499 999	4
100 00 to 199 999	5
< 100 000	6
(C) Long-term continental trend	
Increasing	1
Stable	3
Decreasing	6
(D) Long-term national trend	
Increasing	1
Stable	3
Decreasing	6

[a] (A), (B) and (C) were calculated from Delany & Scott (2002); (D) was calculated from Pérez-Arteaga & Gaston (2004).

Table 2. Indices and restrictions for wildfowl species within the set of priority sites

Species	A	B	C	D	Index	Restriction
Black brant *Branta bernicla nigricans*	6	5	3	6	20	≥ 70%
Mexican duck *Anas diazi*	6	6	3	3	18	≥ 70%
Northern pintail *Anas acuta*	2	1	3	6	12	≥ 60%
Mottled duck *Anas fulvigula*	0	5	3	3	11	≥ 50%
Lesser scaup *Aythya affinis*	1	1	6	3	11	≥ 50%
Redhead *Aythya americana*	5	3	1	1	10	≥ 50%
Ring-necked duck *Aythya collaris*	1	3	3	3	10	≥ 50%
Gadwall *Anas strepera*	1	1	1	6	9	≥ 40%
Bufflehead *Bucephala albeola*	0	3	3	3	9	≥ 40%
American green-winged teal *Anas crecca carolinensis*	2	1	1	3	7	≥ 30%
Mallard *Anas platyrhynchos*	0	0	1	6	7	≥ 30%
Northern shoveler *Anas clypeata*	2	1	1	3	7	≥ 30%
Greater white-fronted goose *Anser albifrons*	1	2	1	3	7	≥ 30%
American widgeon *Anas americana*	1	1	1	3	6	≥ 30%
Canvasback *Aythya valisineria*	1	3	1	1	6	≥ 30%
Blue-winged teal *Anas discors*	2	0	1	1	4	≥ 20%
Lesser snow goose *Anser caerulescens caerulescens*	1	0	1	1	3	≥ 20%

Criteria (A)–(D) are explained in Table 1.
Index column corresponds to the summed values of each criterion. Restriction column represents the proportion of the total count (in Mexico) of a particular species which had to be included in the set of priority sites (see Methods).

The index accentuates those species with small population sizes, a large proportion of their populations in Mexico and decreasing trends. Those with large, thriving populations that are largely distributed elsewhere are given a lower value. As restrictions are derived from this index, this method ensures that higher priority is given to species that are important from both a national and continental perspective. For example, the restriction for black brant (*Branta bernicla nigricans*) required 70% of the counted birds in Mexico to be represented in the minimum set, due to the large proportion of the species' population wintering in Mexico, the small population size and its declining trend (Table 2). Mexican duck (*Anas diazi*) and northern pintail (*Anas acuta*) also had demanding restrictions (70% and 60%, respectively: Table 2); the former because of its distribution range, practically confined to Mexico, and the latter due to decrease of the continental population (albeit mainly distributed in the USA and Canada).

The priority (minimum) set of sites was determined through linear integer programming using C-Plex (ILOG, 1999), based on complementarity procedures described by Rodrigues, Cerdeira & Gaston (2000) and Pérez-Arteaga *et al*. (2002*b*). The minimum set, subject to meeting the restrictions, was determined by solving the integer problem:

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

subject to

$$\sum_{i=1}^{I} C_{ijk} x_i \geq t_{jk} \quad j = 1, 2, \ldots, J \quad k = 1, 2, \ldots, K \qquad \text{(II)}$$

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

where I is the number of sites, J is the number of count years, K is the number of wildfowl species included in the analysis, c_{ijk} is the count for site i in year j for species k, and variable x_i is 1 if, and only if, site i is selected. Restriction t_{jk} is the required proportion in the set of the count in year j of species k (according to Table 2). The objective function (I) is to minimise the number of sites selected. Inequality (II) ensures, for all the years considered, the selection of a set representing the required proportion of the count of every species. The restriction of integrality (III), states that the variable x_i is either 0 or 1, thereby treating each site as an indivisible unit.

Irreplaceability of priority sites

As an indicator of the overall importance of a site, we calculated a measure of irreplaceability (Ferrier, Pressey & Barrett, 2000). We take irreplaceability as the likelihood that the site will be required as part of a conservation system that achieves the set of targets (Pressey, Johnson & Wilson, 1994). A site, which is 100% irreplaceable, must be included in the set of priority sites if all targets are to be achieved (Ferrier *et al*.,

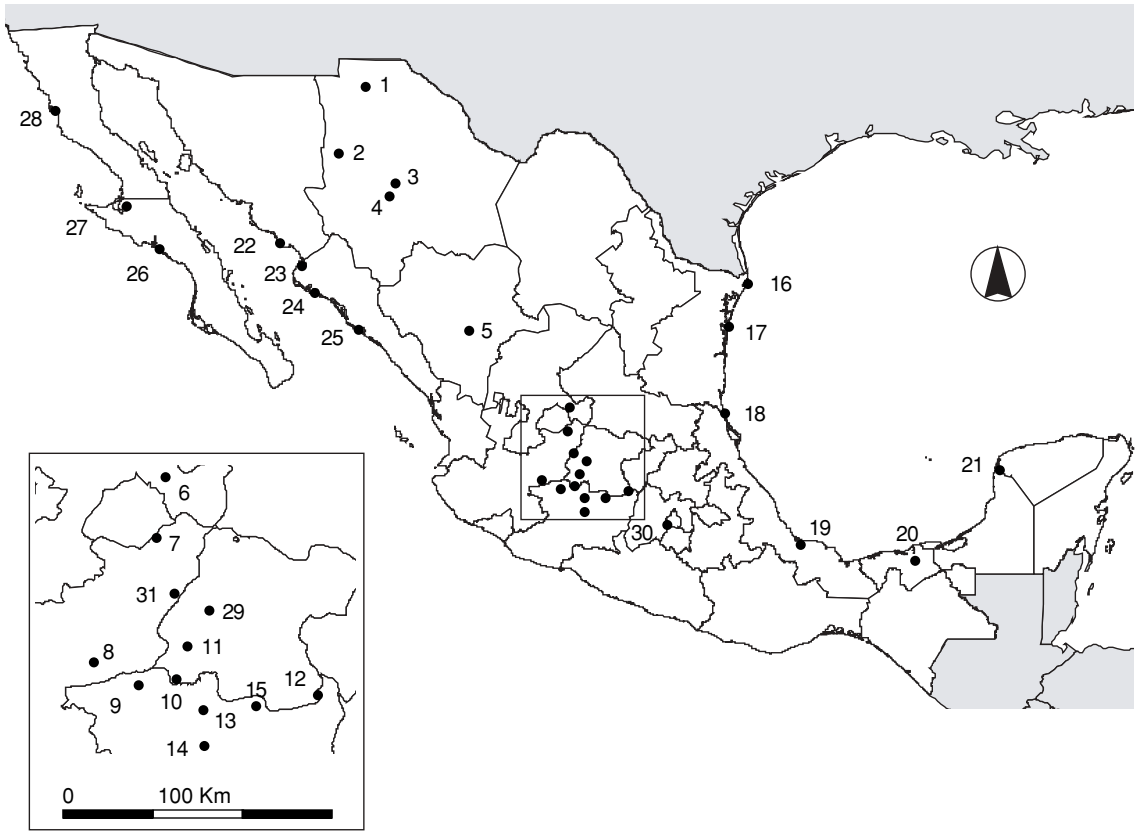

Fig. 1. Priority sites for wildfowl conservation in Mexico. Site names are given in Table 3. Site locations are given in Appendix 1.

2000). If such a site is not selected, one or more targets will not be attained unless a larger number of sites are selected, thus compromising the efficiency of the resulting set.

The irreplaceability of a site was measured as the proportion of all representative combinations of sites in which that site occured (see Pressey *et al*., 1994). We obtained all possible minimum sets of sites that met the restrictions and counted the frequency of each site in the possible combinations, in a similar fashion to that described by Csuti *et al*. (1997).

To select a final set among all possible solutions, management or conservation criteria such as location, known threats, or importance to other wildlife can be used (Ferrier *et al*., 2000). However, due to the lack of information for the majority of wetland systems in Mexico, we propose that the final minimum set be based on the presence of sites with the highest irreplaceability values. Nevertheless, we also present all other possible minimum sets that met the selection criteria.

RESULTS

Indices and restrictions

Restrictions were set for 14 duck species and three goose species (Table 2). Targets were not derived for those lacking population estimates (black-bellied whistling duck, *Dendrocygna autumnalis*, fulvous whistling duck, *Dendrocygna bicolor*) or trends (ruddy duck, *Oxyura jamaicensis*), or for which counts were comprised of several species combined (blue-winged teal, *Anas discors*, and cinnamon teal, *Anas cyanoptera*, in the central highlands, generic merganser, *Mergus* sp., and generic scoters, *Melanitta* sp.). Seven species required 50% or more of their mid-winter counts to be represented within the priority set (Table 2).

Priority sites

The proposed set of priority sites includes 31 sites (Table 3, Fig. 1). Eighteen are located in the interior highlands (6 in the northern highlands, 12 in the central highlands), six on the Gulf of Mexico coast and seven on the upper Pacific coast. Twenty-eight sites in the priority set are 100% irreplaceable, while three can be substituted (Table 3).

Many of the sites in the priority set have previously been recognised as being of importance for bird conservation, forming part of other conservation networks (Table 3). DUMAC's network of sites was selected specifically for wildfowl conservation (Ducks Unlimited, 2001) and had the most sites in common with the priority set. The NAWCA network shared fewer sites with the priority set ($< 50\%$), reflecting the broader conservation focus of that network. Twenty sites within the priority set are classified as AICAS (Arizmendi & Vazquez-Valdelamar, 2000), reflecting the importance of the priority set not only for wildfowl but for other waterbirds as well. The majority of the sites in the priority set also formally qualify as wetlands

Table 3. Priority sites for wildfowl conservation in Mexico and their relationship to established or proposed networks of key sites

ID	Region[a]	Name	Irreplaceability (%)	DU[b]	NAWCA[c]	Potential Ramsar[d]	AICA[e]
1	NH	Ascension	100			✓	
2	NH	Laguna Babicora	100	✓	✓	✓	✓
3	NH	Laguna Bustillos	100	✓	✓	✓	✓
4	NH	Laguna Mexicanos	100	✓	✓	✓	✓
5	NH	Laguna Santiaguillo	100	✓	✓	✓	✓
6	NH	Saladillo	100				
7	CH	Languillo	100			✓	
8	CH	East Atotonilco	100			✓	
9	CH	East Chapala	100				
10	CH	Cabadas	100			✓	
11	CH	Irapuato	100			✓	
12	CH	Presa Solis	100			✓	
13	CH	Zacapu	100			✓	
14	CH	Lago Patzcuaro	100				✓
15	CH	Lago Cuitzeo	100	✓	✓	✓	✓
16	GC	Rio Grande Delta	100	✓			✓
17	GC	Laguna Madre & Tamaulipas lagoons	100	✓	✓	✓	✓
18	GC	Tamesi & Panuco river deltas	100	✓		✓	✓
19	GC	Alvarado lagoons	100	✓	✓	✓	✓
20	GC	Tabasco Lagoons	100	✓	✓		✓
21	GC	Campeche-Yucatan lagoons	100	✓	✓		✓
22	PC	Isla Tobari	100	✓		✓	✓
23	PC	Agiabampo	100	✓		✓	✓
24	PC	Topolobampo	100	✓	✓	✓	✓
25	PC	Ensenada Pabellon	100	✓	✓	✓	✓
26	PC	Bahia San Ignacio	100	✓	✓	✓	✓
27	PC	Laguna Ojo de Liebre	100	✓	✓	✓	✓
28	PC	San Quintin	100	✓	✓	✓	✓
29	CH	Leon	80				
30	CH	Lerma	80				✓
31	CH	Lagos de Moreno	60				

Irreplaceability indicates the percentage occurrence of each site in all possible solutions (see Methods).
[a] NH, northern highlands; CH, central highlands; GC, Gulf of Mexico coast; PC, upper Pacific coast.
[b] Ducks Unlimited de Mexico's 28 key wetlands for waterfowl.
[c] North American Wetlands Conservation Act 32 priority wetlands.
[d] Undesignated sites meeting Ramsar Convention's criteria of wetlands of international importance.
[e] Important areas for bird conservation in Mexico.

of international importance (although not designated) by either hosting large numbers of birds (> 20 000) or by holding internationally important proportions of waterbird populations (>1%; for the application of the Ramsar Convention criteria to waterbird count data in Mexico see Pérez-Arteaga *et al*., 2002*a*). One site in the priority set (Tabasco lagoons) is already designated as a Ramsar site (Ramsar Bureau, 2002) and four sites are included within Biosphere Reserves (Tabasco lagoons, Bahía San Ignacio, Laguna Ojo de Liebre and Campeche-Yucatán lagoons).

The priority set has held more than 70% of the total mid-winter wildfowl count in the country during the analysed years, regardless of the large fluctuations in bird numbers (Table 4). The priority set also surpassed all targets for individual species. This was particularly true for redhead (*Aythya americana)*, ring-necked duck (*Aythya collaris*), American green-winged teal (*Anas crecca carolinensis*), northern shoveler (*Anas clypeata*), greater white-fronted goose (*Anser albifrons*), American widgeon (*Anas americana*), canvasback (*Aythya valisineria*) and blue-winged teal (*Anas discors*), for which targets were greatly exceeded (Table 4). Four alternative sets also met the selection criteria and are presented in Table 5.

DISCUSSION

Indices and restrictions

Black brant and Mexican duck required the most demanding restrictions (Table 2), due to the large proportions of their populations in Mexico and their small population sizes. Three-quarters of the black

Table 4. Wildfowl counted in the set of priority sites (see Table 1). Numbers in brackets indicate the proportion of the total wildfowl count in Mexico that is represented in the set (see Methods)

	1991	1994	1997	2000	Restriction
Species with restrictions					
Black brant	85 025 (78%)	78 700 (78%)	99 233 (76%)	92 825 (86%)	70%
Mexican duck	7390 (71%)	14 875 (73%)	10 875 (72%)	8160 (72%)	70%
Northern pintail	313 170 (81%)	190 760 (65%)	146 020 (65%)	142 874 (79%)	60%
Mottled duck	1240 (100%)	1435 (100%)	105 (100%)	830 (100%)	50%
Lesser scaup	133 515 (71%)	87 175 (75%)	35 742 (59%)	34 839 (53%)	50%
Redhead	290 885 (98%)	233 480 (97%)	164 078 (90%)	227 976 (95%)	50%
Ring-necked duck	1915 (70%)	28 150 (85%)	6941 (86%)	15 263 (87%)	50%
Gadwall	32 075 (81%)	21 290 (49%)	14 475 (58%)	14 174 (55%)	40%
Bufflehead	4515 (95%)	905 (71%)	1100 (76%)	421 (74%)	40%
American green-winged teal	200 370 (75%)	145 190 (65%)	114 580 (59%)	54 018 (69%)	30%
Mallard	875 (34%)	1770 (60%)	672 (57%)	136 (46%)	30%
Northern shoveler	308 595 (71%)	308 460 (62%)	232 830 (74%)	171 336 (68%)	30%
Greater white-fronted goose	33 720 (90%)	20 640 (86%)	13 944 (55%)	35 013 (93%)	30%
American widgeon	103 995 (79%)	107 735 (81%)	72 421 (81%)	40 701 (65%)	30%
Canvasback	11 335 (98%)	4955 (97%)	17 904 (99%)	7475 (96%)	30%
Blue-winged teal	308 405 (87%)	296 755 (83%)	71 825 (80%)	397 456 (94%)	20%
Snow goose	68 784 (55%)	111 490 (58%)	52 740 (47%)	70 915 (52%)	20%
Species without restrictions					
Black-bellied whistling duck	7315 (62%)	5455 (29%)	360 (7%)	65 934 (90%)	
Blue-winged & cinnamon teal	4625 (30%)	21 065 (44%)	9465 (29%)	4943 (16%)	
Fulvous whistling duck	21 970 (96%)	2110 (87%)	170 (30%)	17 857 (100%)	
Generic mergansers	4600 (78%)	2000 (52%)	9975 (79%)	2821 (62%)	
Ruddy duck	7570 (73%)	18 290 (46%)	13 187 (73%)	15 688 (76%)	
Generic scoters	7855 (92%)	0	18 865 (100%)	770 (96%)	
Total count	1 959 744 (78%)	1 702 685 (70%)	1 107 507 (69%)	1 422 425 (80%)	

Numbers in brackets indicate the proportion of the total wildfowl count in Mexico that is represented in the set (see Methods).

Table 5. Alternative minimum sets (see Methods and proposed set totals in Table 4)

Alternative solutions	1991	1994	1997	2000
Leon (CH), Presa Tepuxtepec (CH), Lerma (CH)	1 960 924 (78%)	1 694 740 (70%)	1 106 942 (69%)	1 423 670 (80%)
Lagos de Moreno (CH), Leon (CH), el Dorado to Dimas (PC)	1 975 719 (79%)	1 721 470 (71%)	1 123 692 (70%)	1 417 294 (79%)
Lagos de Moreno (CH), Lerma (CH), Apan (CH)	1 962 704 (79%)	1 702 590 (70%)	1 114 497 (70%)	1 422 425 (80%)
Durango (NH), Leon (CH), Lerma (CH)	1 959 089 (78%)	1 690 165 (70%)	1 103 037 (69%)	1 420 225 (79%)

The first column indicates sites that can substitute for the three non-irreplaceable sites (those with irreplaceability values $< 100\%$ in Table 3) in each alternative set. Wildfowl counts in the corresponding set (31 sites) are presented under year columns; brackets indicate the proportion of the total wildfowl count in Mexico represented in a set.
NH, northern highlands; CH, central highlands; PC, upper Pacific coast.

brant population winter in Mexico (Bellrose, 1980; Reed, Stehn & Ward, 1989). Furthermore, numbers in Mexico have been declining since 1961 (Pérez-Arteaga & Gaston, 2004). Development, pollution and commercial and recreational activities are now threatening critical wintering areas therein (Ward *et al*., 1997). Black brant have highly specialised feeding habits during the wintering season, relying almost exclusively on sea grasses and algae (Ward, 1983; Wilson & Atkinson, 1995), making survival during this period dependent upon the availability and abundance of these resources (Ward *et al*., 1997). Mexican duck is almost exclusively distributed in Mexico, with up to 98% of the global population occurring there (Williams, 1980). Even though its population is considered stable (Delany & Scott, 2002) and mid-winter count data have not shown any overall decreases (Pérez-Arteaga *et al*., 2002*b*), it has recently been classified as 'threatened' under Mexican legislation (SEMARNAT, 2002), owing to acute wetland degradation in the interior highlands. The high index values and restrictions of these two species indicate the importance that they should be given by national conservation policies.

Other species with demanding restrictions, such as the northern pintail and lesser scaup (*Aythya affinis*) are also considered to be of particular continental conservation value. Northern pintail is regarded as of priority concern under the NAWMP (2002), due to the sustained decline

of its continental population (Ducks Unlimited, 1990; Banks & Springer, 1994; Beauchamp *et al*., 1996; Fling, Grand & Rockwell, 1998; Miller & Duncan, 1999; USFWS, 2001; Wilkins, Otto & Garrettson, 2001). This is reflected in the numbers wintering in Mexico, where counts have declined since 1978 (Pérez-Arteaga & Gaston, 2004). Scaup in North America have also shown dramatic declines since 1955 (Allen, Caithamer & Otto, 1999; Austin *et al*., 2000). Scaup wintering in Mexico have been declining at a rate of 8% per year since the early 1980s (Pérez-Arteaga & Gaston, 2004). Redhead, albeit not showing decreasing continental or national long-term trends, is also of great importance from a national perspective. Around 80% of the world population of redhead winters in Laguna Madre in southern Texas and Mexico (Custer, Custer & Zwank, 1997). Mid-winter counts in Mexico alone represent 35% of the estimated continental population (Pérez-Arteaga & Gaston, 2004).

Species with the lowest index values (Table 2) have high population sizes, long-term increases and are largely distributed outside Mexico; therefore species-specific conservation actions are not as urgent as for those species with small, decreasing populations. Lesser snow goose (*Anser caerulescens caerulescens*) populations, for example, have increased dramatically, up to 300% since the 1950s (Ankney, 1996; Abraham & Jefferies, 1997), to the point where they are causing serious damage to Arctic ecosystems (Cooke *et al*., 2000).

Priority sites

Some of the sites selected in the priority set have very important concentrations of wildfowl or constitute particularly important wintering sites for certain species. Ensenada Pabellon may well be the most important site for wildfowl in Mexico (Pérez-Arteaga *et al*., 2002*a*), holding almost 10% of all wildfowl wintering in the region (Ducks Unlimited, 2001). It is one of the most important wintering sites for northern pintail in North America (Migoya & Baldasarre, 1993, 1994), holding up to 1.5 million individuals of this species alone (Migoya & Baldasarre, 1995). It meets the Ramsar Convention's criteria to be designated as a wetland of international importance, holding globally important concentrations of northern pintail, northern shoveler and American green-winged teal (Pérez-Arteaga *et al*., 2002*a*) and nearly 10% of the world population of American avocet (*Recurvirostra americana*) (Engilis *et al*., 1998).

Laguna Madre winters more than 30% of the world population of redhead and internationally important concentrations of ruddy duck (*Oxyura jamaicensis*) (Pérez-Arteaga *et al*., 2002*a*). This site has more than 33 000 ha of monotypic beds of shoalgrass (*Halodule wrighti*), which are particularly important for redheads (Carrera & de la Fuente, 1994; Ducks Unlimited, 2001). On the adjacent mainland, there are more than 36 000 ha of freshwater wetlands (Carrera & de la Fuente, 1994). It also holds around 50% of the reddish egrets (*Egretta rufescens*) migrating to Mexico and about 30% of the North American population of the threatened piping plover (*Charadrius melodius*) Ducks Unlimited, 2001). It is an internationally important reserve for shorebirds under the Western Hemisphere Shorebird Reserve Network (WHSRN: Manomet Centre for Conservation Science, 2001). Dredging and construction of permanent channels along barrier islands have lowered salinity levels (Ducks Unlimited, 2001) and shoalgrass abundance has decreased by 60% (Mitchell, Custer & Zwank, 1994). Rising macroalgae biomass may increase vulnerability to mass shoalgrass mortalities (Onuf, 1996).

Topolobampo is also internationally important for northern shoveler, northern pintail and American green-winged teal (Pérez-Arteaga *et al*., 2002*a*). It holds approximately 7% of all wildfowl wintering in the country (Ducks Unlimited, 2001). The Tamesi and Panuco river deltas support around 3.6% of all wintering wildfowl in Mexico (Ducks Unlimited, 2001).

Lago Cuitzeo holds internationally important populations of the American white pelican (*Pelecanus erythrorhynchus*), Mexican duck and canvasback (Pérez-Arteaga *et al*., 2002*a*). The globally-endangered, endemic black-polled yellowthroat warbler (*Geothlypis speciosa*), which is known from only four localities, is also present on this site (BirdLife International, 2000). Five native species of fish have been eliminated from the Cuitzeo basin, of which two endemics have recently become extinct (Soto-Galera *et al*., 1999). These changes in the fish fauna can be attributed to drying and hyper-eutrophication of the lake owing to substantial reductions in the amount and quality of tributary inputs (Soto-Galera *et al*., 1999; see Lyons *et al*., 1994, 1998).

Lago Babicora holds internationally important populations of lesser snow goose, Mexican duck and sandhill crane (*Grus canadensis*) (Pérez-Arteaga *et al*., 2002*a*). It is the most important wintering area in Mexico for white-fronted goose, sandhill crane and lesser snow goose (Drewien, Brown & Benning, 1996; Ely & Takekawa, 1996; Ducks Unlimited, 2001).

Laguna Ojo de Liebre, Bahia San Ignacio and San Quintin hold more than 38%, 18% and 16%, respectively, of the Eastern Pacific population of black brant (Pérez-Arteaga *et al*., 2002*a*). Laguna Ojo de Liebre also holds the largest number of wintering waders in Baja California (Page *et al*., 1997), and provides habitat for the endangered clapper rail (*Rallus longirostris*) (BirdLife International, 2000). Laguna Ojo de Liebre is located within the largest Biosphere Reserve in Mexico (Ortega-Rubio, Castellanos-Vera & Lluch-Cota, 1998) and Bahia San Ignacio is considered to be a World Human Patrimony (Ducks Unlimited, 2001). Both sites are important breeding grounds for snowy plovers (*Charadrius alexandrinus*) (Palacios, Alfaro & Page, 1994) and are also calving grounds for the grey whale (*Eschrichtius robustus*).

Apart from Lago Cuitzeo, sites in the central highlands that are included in the priority set have not been included in existing conservation networks (Table 3), since they do not support numbers of birds as high as those of other sites and wildfowl conservation interests in Mexico have been biased towards sites with the largest concentrations. Priority sites in the central highlands (except for Presa

Solis, Lago Patzcuaro and Lago Cuitzeo) are wetland complexes that can be highly seasonal. These wetlands are especially significant for Mexican duck populations, a nationally threatened species (SEMARNAT, 2002) with very low densities (Williams, 1980). Eight out of the 11 priority sites within the central highlands have been recognised as priority sites for Mexican duck conservation in a previous study (Pérez-Arteaga *et al*., 2002*b*). Sites in this region are essential for meeting the targets required in this analysis, due to the high level of representation that the Mexican duck requires, as an endemic species with a small population size (Table 2). The distribution range of the Mexican duck is restricted to the interior highlands, 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 (Williams, 1980), thus making imperative the selection of sites within this region. For a review of conservation issues for the Mexican duck, see Pérez-Arteaga *et al*. (2002*b*).

CONCLUSION

Ongoing initiatives in Mexico aim to produce a national strategy for wildfowl conservation. Such a scheme will guide the conservation efforts of government institutions and will greatly influence how funding is allocated to research, conservation and management projects in the country. To be sound, such a strategy must be based upon objective, numerical bases. Methods should also be accountable and easily understood. The set of priority sites proposed here provides a spatial basis on which to focus research and conservation efforts, with the aim of optimising the application of limited available funds. Such an approach emphasises species with large proportions of their populations distributed in Mexico, since they largely depend on the resources available therein and on the state of conservation of Mexican wetlands, but it also accounts for other species with less pressing conservation needs. The results of this study find support for the conservation value of sites already recognised as important for wildfowl, but also identify sites that are particularly significant for certain species that have not previously been recognised as being of conservation interest. Linear integer programming methods allow the representation of the maximum diversity of relevant features (in this case, multiple restrictions for every year) at the minimum cost (minimum number of sites). Solutions are obtained in a transparent, accountable way, allowing others to understand why and how the result was arrived at (Rodrigues *et al*., 2000). In addition, the selection targets can be changed if special concern for a species arises and the methods can be used to obtain an optimum solution for the revised thresholds. They also permit examination of the network as a whole, rather than evaluating each site on its own.

This analysis used mid-winter count data, which is the only available source of wildfowl population data in the country. Only those species accounted for in the survey could be included in this study. Basic population studies for other species not included should be carried out to more accurately define conservation priorities in Mexico.

Although applied, in particular, to wildfowl in Mexico, the methods employed here can also be used to obtain networks of priority sites for research or conservation for other taxa in different regions. The procedures can be easily modified to accommodate different levels of data to help systemise the prioritisation processes to become as transparent as possible. This is of particular relevance in developing countries, where often only poor levels of data exist and pressing conservation needs require the implementation of an easily deployable, accountable prioritisation procedure.

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APPENDIX 1. Location of priority sites for wildfowl conservation in Mexico

ID	Region[a]	Name	Location	Location notes
1	NH	Ascension	31°05′N 107°55′W	Includes Laguna Seca and wetland complex within 23 km SSW of Guzman
2	NH	Laguna Babicora	29°23′N 108°25′W	Includes wetlands within 20 km W and 10 km NE
3	NH	Laguna Bustillos	28°48′N 106°74′W	Includes wetlands within 16 km S
4	NH	Laguna Mexicanos	28°10′N 106°90′W	Includes wetlands within 2 km N
5	NH	Laguna Santiaguillo	24°48′N 104°78′W	Includes Bordo de San Bartolo and wetlands within 10 km W
6	NH	Saladillo	22°38′N 102°02′W	Soldadito, including Lagunas el Salado and el Tule and other wetlands 25 km N and 20 km S of San Jose Saladillo
7	CH	Languillo	21°74′N 102°10′W	Wetland complex centred 32 km SE of Aguascalientes within a 25 km radius
8	CH	East Atotonilco	20°43′N 102°77′W	Wetland complex extending 19 km N of Ocotlan and 29 km W and NW and 30 km NE, including Lagunas el Jihuite and la Rod
9	CH	East Chapala	20°20′N 102°30′W	Wetland complex extending 45 km E of Lago de Chapala, including Rios de Lerma and Duero
10	CH	Cabadas	20°25′N 101°92′W	Wetland complex centred 12 km SE of 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
11	CH	Irapuato	20°60′N 101°78′W	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
12	CH	Presa Solis	20°08′N 100°46′W	20 km E of Acambaro
13	CH	Zacapu	19°92′N 101°63′W	Wetland complex extending 23 km NE of village, including Presas aristeo, Mercado, Copandaro and San Rafael
14	CH	Lago Patzcuaro	19°55′N 101°61′W	
15	CH	Lago Cuitzeo	19°95′N 101°07′W	
16	GC	Rio Grande Delta	25°75′N 97°20′W	
17	GC	Laguna Madre & Tamaulipas lagoons	24°63′N 97°80′W	
18	GC	Tamesi & Panuco river deltas	22°25′N 97°87′W	
19	GC	Alvarado lagoons	18°62′N 95°76′W	
20	GC	Tabasco Lagoons	18°25′N 92°67′W	
21	GC	Campeche-Yucatan lagoons	20°70′N 90°45′W	
22	PC	Isla Tobari	26°88′N 109°88′W	
23	PC	Agiabampo	26°25′N 109°30′W	
24	PC	Topolobampo	25°50′N 108°93′W	
25	PC	Ensenada Pabellon	24°50′N 107°71′W	
26	PC	Bahia San Ignacio	26°62′N 113°13′W	
27	PC	Laguna Ojo de Liebre	27°88′N 114°00′W	
28	PC	San Quintin	30°44′N 115°96′W	
29	CH	Leon	20°96′N 101°57′W	Wetland complex extending 20 km SW of Leon, 40 km S and 45 km SE, including Laguna San Antonio and Cinco de Mayo
30	CH	Lerma	19°20′N 99°40′W	Wetland complex extending 35 km NNW, 19 km NE, 23 km SE and bordering Toluca, including Presas Tlachaloya, Texcalyoacac, Janacio Ramirez, Inf. Azate and the large marsh S of Lerma
31	CH	Moreno	21°15′N 101°93′W	Wetland complex extending 24 km SW, S and SE of Lagos de Moreno

[a] NH, northern highlands; CH, central highlands; GC, Gulf of Mexico coast; PC, upper Pacific coast.