Birds and fish as bioindicators of tourist disturbance in springs in semi–arid regions in Mexico: a basis for management


Abstract

Birds and fish as bioindicators of tourist disturbance in springs in semi–arid regions in Mexico: a basis for management.— Tourist disturbance in semi–arid springs was analysed; birds and fish were selected as bioindicators. Media Luna spring is the biggest and most spatially complex system in the region, with the highest biodiversity levels and tourist use. Areas with the highest bird species richness and abundances showed highest structural heterogeneity and least direct human impact. No differences in species richness of fish were observed between sectors and the most abundant species were found in the sectors least perturbed by human activity. Factors that explained the bird distribution were the species’ tolerance to the effects of direct tourism (noise and direct presence of people) and habitat quality, mainly riparian vegetation. Aquatic vegetation condition was very important for fish. Six bird species and two fish species were relevant as indicators of the habitat quality related to human impact. Anthropic disturbance such as tree plantation favoured some bird species, whereas aquatic vegetation removal was favourable for some fish species, such as the endemic Cichlasoma bartoni; however, both types of disturbance were unfavourable for other species; riparian vegetation removal was negative for both groups. Controlled tourism promotes good conditions for C. bartoni establishment. Efficient conservation measures such as limiting touristic distribution are necessary for all species, especially for the fish community, in order to conserve biodiversity in general.

Key words: Wetlands, Species distribution, Threatened species, Endemism, Habitat loss, Spatial heterogeneity, Bioindicators.

Resumen

Aves y peces como bioindicadores de las alteraciones debidas al turismo en manantiales de zonas semiáridas en México: bases para la gestión.— Para analizar las alteraciones por el turismo en manantiales de zonas semiáridas se utilizaron aves y peces como bioindicadores. Se seleccionó el manantial de la Media Luna por ser el más grande y complejo, y por incluir la más alta biodiversidad y el mayor impacto turístico en la zona. Los sectores con alta diversidad y abundancias de aves fueron los que tienen la mayor heterogeneidad estructural y menor impacto humano directo. Las mayores abundancias de peces se encontraron en los sectores menos perturbados sin diferencias para la riqueza de especies. Los factores que explicaron la distribución de las aves fueron la tolerancia de las especies a los efectos directos del turismo (ruído y presencia directa de gente) y la calidad del hábitat, principalmente la vegetación ribereña. La condición de la vegetación acuática fue muy importante para los peces. Seis especies de aves y dos de peces fueron relevantes como indicadores de la calidad del hábitat en función del impacto humano. Las alteraciones antrópicas tales como la plantación de árboles favoreció a algunas especies de aves mientras que la eliminación de la vegetación acuática fue favorable para algunos peces como el endémico Cichlasoma bartoni, pero estas alteraciones fueron negativas para otras especies; la eliminación de la vegetación ribereña tuvo efectos negativos para ambos grupos. El turismo controlado crea condiciones favorables para C. bartoni. Para la conservación de la biodiversidad en general, se requieren medidas eficientes de conservación tales como la restricción geográfica del turismo especialmente importante para la comunidad de peces.
Palabras clave: Humedales, Distribución de las especies, Especies amenazadas, Endemismos, Pérdida de hábitat, Heterogeneidad espacial, Bioindicadores.

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Introduction

Arid and semi-arid zones have limited water resources. The few existing springs are usually isolated, relict in nature, and in poor condition. They may contain endemic fish species with restricted distribution, sometimes limited to a single spring (Contreras–Balderas, 1969). Freshwater environments are especially susceptible to modifications such as overexploitation, pollution and allochthonous species introduction, the main factors affecting biodiversity (Cooperrider & Noss, 1994; Curtis et al., 1998). The increasing transformation that such environments are subjected to has negative consequences for ictiofauna and riparian biodiversity in general (Mensing et al., 1998; Fu et al., 2003), as well as for local biodiversity (Angermeyer & Schlosser, 1995). An important source of disturbance is tourism. Tourism is an important means of income in Mexico but it is causing increasing environmental degradation in many places due to the lack of planning and preventive measures.

Ecotourism strategies related to natural resources, participation of local people and visitor education (e.g. Boo, 1992; Ross & Wall, 1999; Burger, 2000) must be established and adapted to the particular conditions such as the Media Luna system. Media Luna has been used increasingly by tourists since the 1950s (Michelet, 1996), leading to continuous disturbances and transcendental changes during the 1960s and 1970s with the introduction of exotic fish and trees species (Palacio–Núñez, 1997).

The state of an area's conservation can be well evaluated on the basis of bioindicators selected from previous data (Randall, 1992), but this is not usually possible for most protected ecosystems (Heino et al., 2005). Consequently, threatened or endemic species, or other sensitive species are frequently used as indicators (Rubinoff & Powell, 2004). Different indicators cannot lead to the same responses (Duelli & Obrist, 2003) and different combinations of biological and ecological groups have been used (Van Rensburg et al., 2000; Heino et al., 2005; Pineda et al., 2005). Birds (Pyrovetsi & Papastergiadou, 1992; Browder et al., 2002) and fish (Heino et al., 2005; Fu et al., 2003) are important groups as indicators as both have at least the following points in common: 1) individual species are associated with singular habitats, 2) most are short-lived species so any change in their composition may manifest shortly after a disturbance, and 3) some species groups can be used to develop habitat associations which are predictors of relative human disturbance levels, and both groups may be affected by some tourist activities (e.g. Tershy et al., 1997; Higginbottom et al., 2003; Newsome et al., 2004).

Bioindicators most commonly used to estimate effects of habitat transformation on biodiversity are arthropods (Micó et al., 1998; Verdú et al., 2000; Bestelmeyer & Wiens, 2001) or vertebrates (e.g. Flather et al., 1997) such as birds (e.g. Fleishman et al., 2001), mammals (e.g. Lomolino et al., 1989) or fish (e.g. Heino et al., 2005). The location we chose was the Media Luna spring because it is the biggest and the most representative spring in the Rioverde valley, with high tourist influence and biodiversity (Miller, 1984; Palacio–Núñez, 1997). It includes several bird species and some endemic fish species, mainly the monospecific Cualac and Ataeniobius genus (Miller, 1984; Contreras–Balderas, 1969). Media Luna was declared a State Park in 2003 due to its biological importance and state of conservation (SEGAM, 2003), but more basic management and ecological research are required. This paper aims to determine the impact of tourism and management on springs in semi-arid areas, using birds and fish as bioindicators, and to propose suggestions for management strategies which should be followed in order to preserve biodiversity in such locations.

Methods

Study area

The Media Luna system is located in the Rioverde Valley, San Luis Potosí, Mexico (between X UTM: 393723 & 395317 and Y UTM: 2417647 & 2418070 coordinates, zone 14 N), at an average altitude of 1,000 m a.s.l. It is a complex of spring–lakes (Media Luna and Los Anteojitos) and channels or rivers with permanent water, two seasonal lakes, and flooding zones with lateral infiltrations which maintain a wet environment at variable distances from the source. This effect contrasts with the aridity of the plain. Media Luna is the largest spring lake (with 15 springs) in the valley and consists of six spring craters that provide a constant flow of about 5,000 l s⁻¹ crystalline thermal water (Miller, 1984; Labarthe et al., 1989) that flows through three main channels (fig. 1). These wetlands are an important refuge for many aquatic and riparian bird species (IIZD, 1994). A total of 13 sectors were established for the lake and channels, according to their vegetation and environmental variability, and they are subject to variable anthropic pressure (Palacio–Núñez, 1997).

Riversides contain zones with dense and scarce allochthonous woodland and other zones with native vegetation dominated by Panicum bulbosum Kunth and Andropogon glomeratus (Walt) BSP grasses (table 1). Riparian vegetation has previously been classified in a range between 0 (bare ground) to 5 for excellent conditions. Aquatic vegetation has been classified between 0 to 3. This vegetation is highly dominated by Nymphaea sp. and has two structural forms: 1) big size plants with isolated bases and floating leaves, and 2) small size plants with high population density, creating a close dense layer at leaf level (Palacio–Núñez et al., 1999).

Sampling design

Increasing relevance is being given to the use of spatial scales as bioindicators and the effect of habitat structure on the dynamics of animal and vegeta-
tion populations, but bioindicators can only show some environmental peculiarities (Duelli & Obrist, 2003). As bird and fish species in Media Luna have different origins, habitat requirements and risks of extinction (table 2) they were used to seek the widest possible environmental representation.

Bird sampling was carried out on monthly field visits between November 1996 and May 1997. Under seasonal variability and two conditions of tourist presence, a single transect was repeated 39 times across the entire 2,498 m distance covering all the Media Luna System sectors. Transect repetitions were made in an inflatable boat and we counted the total number of birds observed through binoculars in each transect. The two cited conditions were based on visitor presence: without people (WP, when there was nobody in the area), with n = 24 transects, and with people (P, when there were people present), with n = 15 transects.

Fish sampling considered three factors: 1) the population of some fish species was very low so it was not appropriate to carry out captures; 2) fish were not distributed among different levels of the water column, but always near the bottom or the banks between *Nymphaea* sp. stems, or over the vegetation cover (fish do not go under leaves of small plants); and 3) the great clarity of the water and the few visual obstacles allowed species sighting and count, even in the case of juveniles (Palacio–Núñez, 1997). Faced with this situation and to avoid altering populations, we carried out the sampling in 54 subaquatic transects; these transects were repeated five times on seasonal visits in spring and summer 1998, winter 1998–99, and summer and autumn 1999. We adapted the Finland transect of Järvinen & Väisänen (Tellería, 1986) for subaquatic use in free diving, determining each transect as 10 m long and 2 m fixed width (20 m²). We traced each transect with orange cord in a perpendicular position to the riparian line. We made three repetitions per riverside, per sector.

### Biodiversity analysis

We constructed species–accumulation curves to assess the adequacy of our sampling. Species–accumulation curves relate sampling effort to the cumulative number of species to evaluate sampling effectiveness (e.g. Longino & Colwell, 1997; Gering et al., 2003). Species accumulation curves and richness estimators (Chao 2, Jack 1 and ACE) were calculated using EstimateS 7.0 (Colwell, 2000).

The rarefaction technique corrects unbalanced sample sizes, the main problem in diversity comparisons (Gart et al., 1982). For different sample sizes for birds, we calculated species richness expected for each situation WP or P through rarefaction curves for 1,000 randomizations, using EcoSim 7.0 software (Gotelli & Entsminger, 2001). For fish, sampling size was identical (see above), so rarefaction was not used.

### Statistical analysis

To evaluate population distribution of the bioindicator groups in the sectors, we used the
Kruskal–Wallis non–parametric test (KW) with the STATISTICA package (StatSoft, 2001), and multiple comparisons of average range pairs using the Dunn test (Gardiner, 1997). We analysed bird and fish abundance and richness; in both WP and P conditions for birds. Interrelationships among birds and fish in each sector (for both WP and P conditions) were analysed by a Factorial Correspondence Analysis (FCA), using the STATISTICA software. For each sampling site we used the relative abundance of each species. FCA is an ordination–multivariate technique which simultaneously arranges species and habitats. As there was no discontinuity between habitats, they were grouped in ecological series, thus reducing complex patterns into simple and interpretable forms (Braak, 1985; Moreno, 2000).

Results

Species richness

Accumulation curves showed 20 bird species for both conditions WP and P. Eleven fish species were present in the 13 sectors of the Media Luna. There are two particular species of the Cichlasoma genus that could not be differentiated and were therefore analysed together (C. labridens + Cichlasoma sp.). Our inventories showed 100% completeness for both bioindicator groups according to the Chao 2, Jack 1 and ACE estimators. Bird species richness was statistically different between both WP and P conditions (fig. 2).

Species distribution among sectors

Species richness and abundance of bird species distribution were statistically different among sectors. Differences in fish abundance were also significant but species richness was statistically indistinguishable among sectors (see table 3 for KW probabilities).

The largest differences in the Dunn and KW test in bird species richness and abundance were between sectors 9 and 4 (highest figures), and sectors 13, 11 and 12 (the poorest; fig. 3). In these five sectors there is woodland presence but, in sectors 9 and 4 there is little human impact and riparian grassland. Sectors 13, 11 and 12 have no grassland and human impact is very high (see table 1, fig. 1).

Species richness between sectors 8 and 3 (without woodland and low human impact) was statistically non–significant compared with the high richness sectors, whereas sectors 1 and 10 (with woodland and very high human impact) were similar to the poorest sectors.

For fish abundance the greatest differences were observed between sector 4, with dense aquatic vegetation coverage and highest abundance values, and the poorest 12, 13 and 1 sectors (fig. 4) with scarce Nymphaea sp. coverage.

Species distribution among sectors was confirmed by species grouping in the FCA analysis. Bird species ordination showed three main groups for both WP and P conditions related to axis 1 (fig. 5). In the WP plot the first two axes accounted for 64.6% of the variance in the data (fig. 5A). According to the distribution of sectors and species, axis 1 could be explained as the level of disturbance originated by tourists. In this sense, the first species group was determined by low human impact (sectors 6, 7 and 8, see table 1) with the more intolerant species such as Bubulcus ibis and Anas diazi. The second species group (Ardea herodias and Casmerodius albus) corresponded to intolerant species and was related to the well–conserved sector 5, whereas the third group contained generalist species such as Phalacrocorax olivaceus and Podylimbus podiceps in the most disturbed sectors (1, 11, 12 and 13) and well conserved (2, 3, 4, 9 and 10) sectors. In the P plot, the first two axes

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Table 2. List of the 20 bird and 11 fish species and taxonomic family found in the Media Luna system. Abbreviations (Abbr) used in this study, origin information (O) and extinction risk (ER) according to the Mexican Red List NOM 059 (INE, 2002) and IUCN Red List (2004). Bird list based on Peterson & Chalif (1989), and fish list based on List for Mexican Fish of Espinosa Pérez et al. (1993). For birds habitat requirements (HR): SW. Superficial water; DP. Open water for dive with close rocks or trunks for perching; OW. Open water; P. Branches or rocks close to the water; FV. Floating vegetation; BT. Big trees near the water. For population status (PS): T. Threatened; E. Endangered; CR. Critically endangered; V. Vulnerable. 1These two species of fish are reported together

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accounted for 55.35% of variance (see fig. 5B). Sectors 5 and 6 were the least susceptible to people presence and some intolerant species such as *Fulica americana* and *Pandion haliaetus* from the first group (in WP condition), and *Dendrocygna autumnalis* from the third group were redistributed in the second group in condition P.

The first two axis from FCA accounted for 66.7% of the variance in the fish data (fig. 6). The fish community showed three main groups. The first group was represented by *Cichlasoma bartoni* and *Oreochromis* sp. and was related to the most disturbed sectors (1, 11, 12 and 13). A second group corresponded to the most generalist species such as *Astryxanx mexicanus*, *Cichlasoma labridens* and *C. cyanoguttatum*, and is related to sectors 2 and 10; these species did not show special requirements. *Dionda dichroma* was only observed in sector 10. The third group contained the best conserved sectors; *Ataeniobius toweri* only appeared related to sectors with well established sub–aquatic vegetation (sector 3, 4, 5, 6, 7, 8 and 9).

**Discussion**

Sector characteristics were reflected by species distribution and abundance of bioindicator groups. Vegetation and other structural habitat variables are important to determine bird abundance (Read...
et al., 2000). Although birds can move openly into Media Luna sectors, some sectors do not have the appropriate conditions for all species observed. Our results showed statistical differences in the spatial distribution of birds among sectors, with lowest abundance and richness values when there was visitor presence (fig. 3). We suggest that this presence creates environmental stress that accounts for the different responses to tolerance among birds throughout the Media Luna system.

FCA confirmed the observations that bird distribution changes between conditions of human presence. Some bird species benefit from anthropic modifications which tend to disguise some impact (Read et al., 2000). Species such as *P. olivaceus, A. anhinga*, most Ardeidae species, all Alcedinidae species, *P. haliaethus* and *M. americana* benefit from riparian woodlands. *C. albus, A. herodias* and *N. nycticorax* benefit from trees but are affected by border changes and *P. podiceps* which do not benefit are affected by riparian grassland destruction.

Bird groups or particular species which are affected by any kind of change are usually considered the indicator species for this particular change (Read et al., 2000; Paillison et al., 2002; Veraart et al., 2004). The best example of a close relation with habitat structure and high quality of aquatic vegetation was *J. spinosa*. This species lives on floating vegetation and is very territorial (Peterson & Chalif,

![Fig. 3. Results of Dunn test for bird species in Media Luna sectors, in both WP and P conditions for: A. Species richness; B. Mean individual abundance. The letters over the bars indicates the statistical group for each condition; similar letters indicate statistical similarity between sectors. There were strong statistical differences between sectors 9, 4 and 8 in contrast with 10 to 13 for bird richness and abundance.](image-url)
Conservation policies may underestimate the value of small fragments. Each small fragment of unique and isolated native habitat can be important not only to maintain, but also to generate endemic biodiversity, and it must be carefully evaluated (Rubinoff & Powell, 2004). We emphasize the importance of small wetlands in semi-arid regions with fish endemism and the need for good management planning in order to avoid a critical situation.

The use of bioindicators helps us to analyse the impact of direct and indirect effects of tourism on biodiversity (e.g. Mancini et al., 2005). We observed altered conditions in Media Luna, such as abrupt riverside and areas > 1 m deep (non anthropized sectors have gentle slopes and gradual deep increases) which are now completely unusable for some riparian bird species, such as Ardeidae. Among fish groups, we observed that cichlids have parental care and their young are sure to be found anywhere, but the other young fish species need shallow waters (< 0.5 m) and dense vegetation coverage for survival. Only cichlids were observed breeding successfully in the most disturbed sectors; for C. bartoni and Oreochromis sp. these sectors were the best places.

For fish, species richness and spatial distribution show a complex relation with the geographic location, size of the river or creek and the habitat characteristics in these system parts (Heino et al., 2005). Media Luna sectors have enough habitat conditions for most fish species and there are no significant differences in species richness between sectors (fig. 4). These results were confirmed by few relations between most fish species and habitat particularities as shown in the FCA results (fig. 6). This ordination method emphasizes opposite habitat structure preferences between two endemic species: C. bartoni related to bare ground and A. toweri related only to dense subaquatic vegetation. We considered these species as fish indicators for tourist impact and habitat changes in Media Luna.

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Fig. 5. FCA plot for birds in Media Luna system showing relationships between sectors and bird species for axis 1 and 2: A. For WP condition; B. For P condition. In the principal axis, species group according to direct anthropic tolerance. Some species change sector if the condition varies from WP to P, but most tolerant species do not move.

Fig. 5. Resultados de FCA para las aves del sistema de la Media Luna mostrando la relación entre los sectores y las especies de aves para los ejes 1 y 2: A. Para la condición sin gente (WP); B. Para la condición con gente (P). Algunas especies cambian de sector si la condición varía de WP a P, sin embargo las especies más tolerantes no cambian.
Both indicator groups are important elements in this ecosystem, but management and conservation actions should focus mainly on the fish group, considering the arrival of visitors and their implication in habitat structure and quality (e.g. Root, 1998; Currie, 2003). We observed that the best riparian grassland conservation, with and without trees, was related to the maximum bird diversity and abundance, and the best subaquatic quality and abundance was related to the best fish density. Grassland and aquatic vegetation constitute barriers as few visitors cross them. As long as these barriers remain this system can be maintained. These habitat structures are the basis of conservation of the entire system. Restriction of sector 10 is especially important for conservation of *D. dichroma*, and tourist use should be kept moderate in altered channels in view of the conservation implications with *C. bartoni*. Finally, subaquatic coverage is especially important for *A. toweri*.

Media Luna spring shares species, environmental variables and problems with several other semiarid springs (Palacio–Núñez, 1997) and our present findings may provide helpful information for their management.

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