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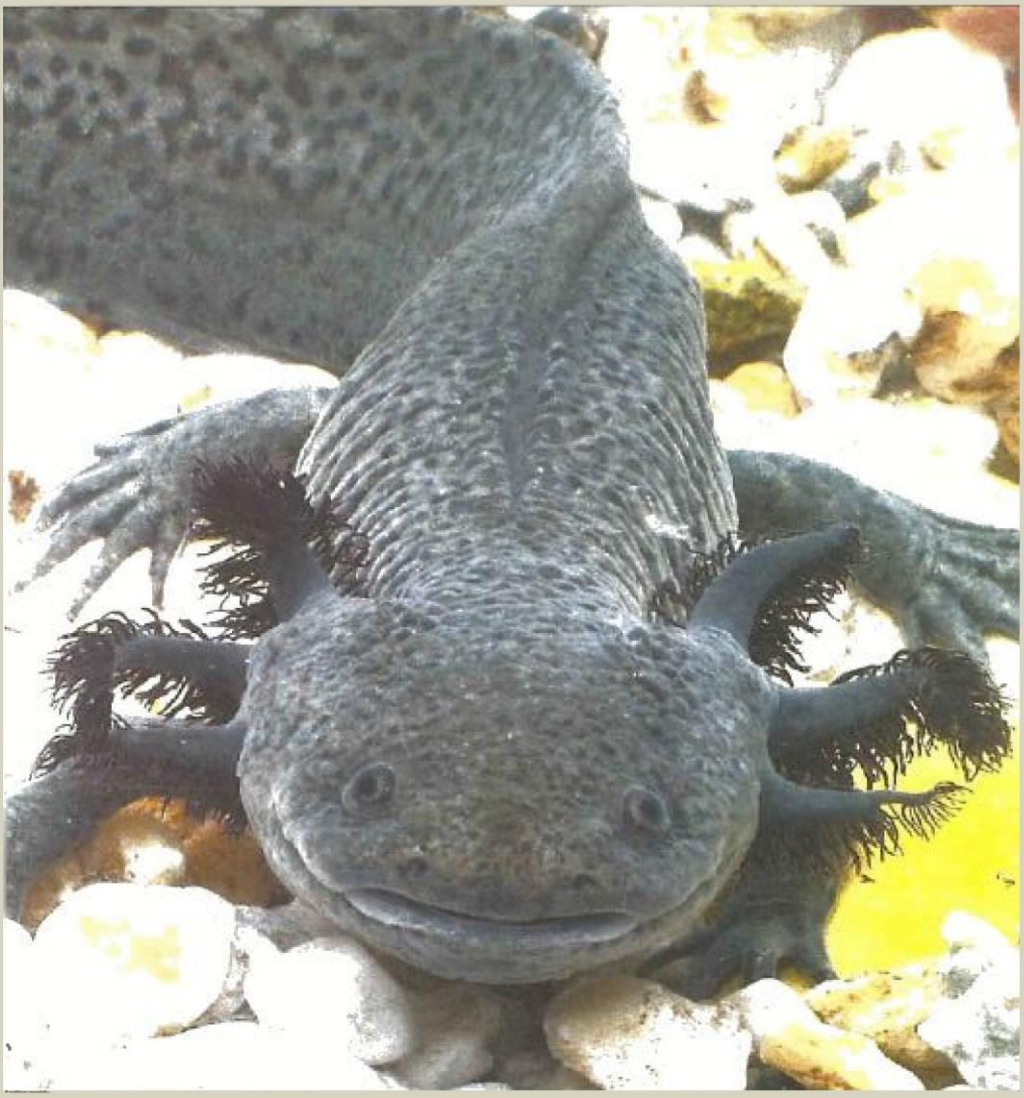

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Conservation of the axolotl (*Ambystoma mexicanum*) at Lake Xochimilco, Mexico

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ABSTRACT — Although the Mexican axolotl (*Ambystoma mexicanum*) is well known as a popular laboratory and aquarium animal, in the wild it is almost extinct and confined to the remnant canals of Lake Xochimilco on the edge of Mexico City. Loss of habitat, introduced fish, pollution and illegal collection for food and medicines have all played a role in its decline. Capitalizing on its high profile within local culture, a multidisciplinary conservation programme is being developed using the axolotl as a flagship species for the wider Xochimilco system. The programme is focusing on raising the profile of the axolotl and other species by promoting nature tourism and conservation education within the local community. Complementing these socio-economic initiatives is biological research on population ecology, survey methods and threat mitigation. The axolotl has been bred in captivity very successfully both in Mexico and elsewhere. However, reintroduction to Lake Xochimilco will not be a realistic option until the threats facing the species have been addressed. Equally, the disease and genetic risks posed by the release of captive bred stock need to be evaluated prior to any reintroduction.

IN 1989 the relationship between the axolotl (*Ambystoma mexicanum*) and those who studied it was aptly described as 'schizophrenic' by Shaffer (1989). At that time, researchers fell into two distinct camps – a large group of developmental biologists, geneticists and endocrinologists on the one hand, and a smaller group of evolutionary biologists on the other. In recent years, however, a third research front has opened up, albeit driven by a mere handful of dedicated field workers in Mexico. Work in this new area has been stimulated by heightened concern for the status of the axolotl in its last remaining natural habitat on earth – the remnant canals of Lake Xochimilco on the edge of Mexico City. Even 15 years ago the future of the axolotl was known to be precarious (e.g. Griffiths & Thomas, 1988; Shaffer, 1989; Brandon 1989; Smith, 1989a,b), but it has taken a renewed global interest in the plight of amphibian populations to precipitate action. The ground that needs to be made up is best illustrated by Smith's (1989a) comment that out of some 4656 works on the axolotl published up to that time, not a single one dealt with field studies. The axolotl (Fig. 1), then, is something of a paradox – immortalized in murals in the National Palace by the celebrated Mexican master, Diego Riviera, and in the writings of Julio Cortazar; widely known and widely used throughout the world as a popular laboratory and aquarium animal; yet almost extinct in the wild.

Figure 1. The Mexican axolotl, *Ambystoma mexicanum*. Photograph © Stuart Harrop.

THREATS TO AXOLOTLS

Lake Xochimilco is the last remnant of a once extensive wetland system that covered much of the volcanic basin in which Mexico City now sits. This closed aquatic system was maintained by a network of natural springs, rainwater and meltwater from surrounding volcanoes. Development of the wetland for agriculture stems from pre-Aztec times, possibly as early as 1000 BC (Rabiela, 1991), but intensified following the foundation of the Aztec capital city of Tenochtitlán on an island in the lake. Farmers reclaimed land by piling up mud and vegetation inside corrals of the water-loving willow (*Salix bonplandiana*) thereby forming raised fields known as 'chinampas' and developing an extensive lacustrine economy. The significance of this economy is neatly summed up by Deevey (1955): 'Four centuries of scholarship have not sufficed to bring limnological knowledge of the Valley of Mexico up to the stage attained by the Aztecs, many of whom spent most of their lives in canoes and depended on knowledge of the lacustrine flora and fauna for their livelihood'. The axolotl was a significant component of this economy, as alluded to by the Franciscan Friar Bernardino de Sahagún in his *Historia General de las Cosas de Nueva España*, when he commented 'it is good to eat, it is the food of lords'.

The chinampas are still very evident today, but are now used mainly for the production of vegetables, flowers and plants. Surrounded by remnant canals that were once part of the extensive lake, the chinampas have become known as the 'floating gardens', even though they are not floating at all. Present-day water bodies cover a mere 2.3 square kilometres, and this reduction is largely the result of the diversion of natural springs over 100 years ago to meet the water demands of a burgeoning human population. In order to try and restore water levels, discharge of tertiary-treated sewage back into the system was initiated in 1957, and in 1990 the government signed the 'Accord of Democratic Co-operation for the Ecological Rescue of Xochimilco' which included plans to restrict development, construct lagoons to control water levels, and improve the treatment of the water put back into the system (Wirth, 1997). Although these actions have probably stopped Lake Xochimilco disappearing completely, water quality and eutrophication are still major issues, alongside continued illegal settlement. Exacerbating the water quality problem is additional pollution from the wide variety of pesticides that have been used on the chinampas. For example, heavy metals have been detected in both axolotls and fishes sampled from the lake (Gonzalez et al., 1997). Moreover, recent surveys have found a strong female bias in the sex ratio of the axolotls captured (Vergara, 1990; Graue, 1998). Hormonal disruption resulting in 'feminization' has been linked to pollution in other amphibians (e.g. Hayes et al., 2002), and presents a worrying spectre for the axolotl.

In addition to water quality and pollution problems, the axolotl is also threatened by introduced fish and possibly by collection for food and medicines (Fig. 2). It is likely that the axolotl was once the top predator in the Xochimilco system. Indeed, most of the other native fish

species – including endemic cyprinids and goodeids – are relatively small-bodied, and co-evolved with the axolotl. In the second half of the 20th century large carp (*Cyprinus carpio*) were introduced to the lake as a food source, as were African *Tilapia* in the 1980's. Through direct predation – and possibly competition – these fish have accelerated the decline of the amphibian population. The axolotl has been widely regarded as a delicacy endowed with medicinal properties since prehispanic times. In fact, 'axolotl syrup' is still produced from a closely related neotenic species, *Ambystoma dumerilii*, and has been used to treat chest problems for centuries. Although the axolotl is listed on CITES Appendix II – which theoretically means that trade is controlled in a way that does not threaten the survival of the species – axolotls are still illegally collected. Enforcement of the legislation is difficult, but the government authorities have recognised the danger to human health posed by the consumption of fish and axolotls contaminated by heavy metals. Paradoxically, this has created something of an incentive to remove the introduced fish and discourage the consumption of fish and axolotls that have been fished from the lake.

POPULATION STATUS OF THE AXOLOTL AT LAKE XOCHIMILCO

The starting point of any conservation programme for a threatened species should be the establishment of the exact status of the wild population. Once this is known, those factors that have led to its decline should be identified – and hopefully neutralised – before a recovery programme begins. Unfortunately, carrying out population censuses of axolotls is difficult. The only established methodology for finding the animals is that developed and used by local fishermen. This involves casting a 6 m wide throw-net (or 'atarraya') from a stationary canoe, and drawing in the net along the bottom of the canal (Fig. 3). This is a very skilled procedure, and not one that is suitable for all parts of the system or that can be learnt quickly by researchers or students. A census carried out at 12 sampling sites using the services of a reliable local fisherman between 1995–1996 captured 76 animals. This translates into a population density of about 60 individuals per hectare. Although direct comparisons with other amphibians are difficult due to differences in sampling protocols, this is an order of magnitude lower than the densities of ambystomatid salamanders reported elsewhere, which can run to several thousand per hectare (e.g. Husting, 1965; Pechmann *et al.*, 1991). A more recent survey of axolotls carried out in January-February 2002 – again using the traditional fishing method – yielded more worrying findings, as no axolotls were captured at all (Jones, 2002). It may well turn out that surveys need to be conducted later in the year when axolotls are more active, as the earlier surveys indicated that May seems to be a peak month. Despite these disappointing survey results, some unscrupulous fishermen certainly know where axolotls occur and how to catch them, as a recent investigation found axolotls continue to be illegally sold in local markets (McKay, 2003). Future work will refine the design and timing of the field surveys and attempt to gain the confidence of local fishermen who remain suspicious of researchers asking questions about their activities. Tests are also currently being carried out using a variety of funnel trap designs with a view to establishing a standardized method for determining the status of the population.

DEVELOPMENT OF A CONSERVATION STRATEGY

With multiple threats stacked against it, and census methods in an embryonic stage of development, the axolotl could be perceived as having not much going for it. However, as a result of its long history within Aztec mythology and its prominent position within the ancient lacustrine economy of the region, it has become something of a cultural icon. Moreover, Lake Xochimilco is an extremely popular recreational area for the people of Mexico City, and as well as being on the tourist trail for overseas visitors, was inscribed on the UNESCO list of World Heritage Sites in December 1987 and designated under the Ramsar Convention on 2nd February 2004. Highly decorated barges (or 'trajineras') cruise the lake at weekends, while their passengers are serenaded by Mariachi bands and plied with food and drink

from sellers on accompanying canoes (Fig. 4). For many visitors, Xochimilco provides a brief respite from the pressures and bustle of the third largest city in the world. Although the demands of a growing Mexico City might be the ultimate source of the axolotl's problems, local people could also be an integral part of the solution.

With generous pump-priming funding from the British Council and the Declining Amphibian Population Task Force (DAPTF), a series of meetings were held between DICE (University of Kent) and the UAM (Unidad Xochimilco) in 2000 and 2001 to devise a strategic framework for the conservation of the axolotl. During these meetings we talked to local fisherman, boatmen (remeros), farmers and artisans; tour operators, schoolteachers, researchers, and representatives from zoos and conservation organisations. It became obvious that these people valued Lake Xochimilco in different ways; and although the vast majority knew of the axolotl and appreciated its cultural importance, few of the local stakeholders were aware of its precarious status. To our minds, then, there seemed great potential for raising the whole profile of the cultural and ecological importance of the Xochimilco system by using the axolotl as a 'flagship' species for a conservation education and nature tourism programme. This view was reinforced by the fact that the Mexico City authorities had recently granted UAM extra land for the expansion of CIBAC (Centro de Investigaciones Biologicas y Acuicolas de Cuemanco), its research and education field station on the shore of Lake Xochimilco (Fig. 5). With an axolotl breeding and research facility already in place at CIBAC, this opportunity was particularly timely, as we could seek to develop our plans for a conservation education and tourism programme around this existing facility, using the axolotl as a flagship. However, this would all cost money. Strengthening our proposal by enlisting the support of a range of national and international organisations, notably the Mexican conservation authorities (CONABIO and SEMARNAT); Chapultepec, Toronto and Chester Zoos (who all have breeding colonies of axolotls); DAPTF and the British Herpetological Society; a bid was submitted to the British Government's Darwin Initiative programme to fund a three-year project entitled 'Aztecs and Axolotls: Integrating Conservation and Tourism at Xochimilco, Mexico'. Singling out the project in a statement to the British media, the British Government's Environment Minister announced that the bid had been successful in April 2002.

THE DARWIN INITIATIVE PROJECT

The Darwin Initiative project is taking a multidisciplinary approach to the conservation of the Xochimilco system, and is using the axolotl as the centrepiece of this strategy. The project aims to develop CIBAC as an information and education centre with a view to enhancing understanding of the ecology and conservation of Xochimilco among local people and visitors. This is being undertaken in parallel with an educational outreach programme; ongoing research into the threats facing the axolotl and other endemic fauna; population assessment; and breeding and reintroduction protocols. To achieve these goals, a series of training workshops for staff and students of UAM – as well as local stakeholders – have been held at CIBAC (Fig. 6). These have covered conservation education, nature guiding for local boatmen, souvenir production for unemployed artisans, amphibian biology and conservation, and captive breeding and reintroduction methodologies. These workshops have been informed by social survey work carried out by a team of Mexican undergraduate 'investigators', and have drawn upon the expertise of our project partners both in Mexico and elsewhere. In addition, Alejandro Melendez – a UAM staff member – completed the MSc in Tourism and Conservation at DICE in 2003. Alejandro is continuing to oversee the development of the project in Mexico. Despite the pressures on Lake Xochimilco, there is still much for the naturalist to see, particularly in terms of its birdlife (over 160 species have been recorded at the site). However, as it is unlikely that visitors will have the opportunity to see live axolotls in the lake itself, future nature tours will conclude with a visit to

CIBAC, where visitors will be able view axolotls being used for the captive breeding and conservation research programme, and learn more about the natural history and conservation of the Xochimilco system. Posters, information leaflets, T-shirts, school work-packs, a website and souvenirs produced by local craftsmen are providing material support for the project, and will hopefully continue to do so when the project is over. It is anticipated that these products will help the axolotl become marketed as a flagship for wildlife conservation throughout Mexico City, as well as nationally and internationally. We anticipate that educational displays focusing on the axolotl will be running in parallel at the partner institutions of Chapultepec Zoo (Mexico), Toronto Zoo (Canada), the Indiana Axolotl Colony (USA) and Chester Zoo (UK). To conclude the Darwin Initiative project, in December 2004 we are organising an international workshop at CIBAC, entitled 'Conservation of the Axolotl and Xochimilco' which will allow all the contributing parties to report their successes (and failures!), and launch an action plan for the future.

A ROLE FOR CAPTIVE BREEDING AND REINTRODUCTION?

Amphibians are potentially excellent subjects for captive breeding and reintroduction programmes. Unlike many mammals and birds, the high fecundity of many amphibians can be utilized to produce large numbers of offspring quickly. Equally, the feeding and general maintenance of amphibians in captivity is often straightforward and relatively inexpensive, and animals for reintroduction do not need long periods of pre-release training so that they know what food to eat and what predators to avoid when released into the wild (e.g. Bloxam & Tonge, 1995). Axolotls have the added advantage of having a long history of captive propagation. Many of the animals currently in laboratories and aquaria around the world are descended from 34 animals sent to the Museum of Natural History in Paris in 1863, and aquaculture techniques for breeding and rearing this species are probably the most sophisticated for any amphibian. However, there are a number of important issues that need to be addressed before a reintroduction programme can be seriously instigated.

Trade-offs exist between different methods of rearing axolotls in captivity. A recent study by one of us (McKay, 2003) compared the performance of axolotls raised in enclosures in a semi-natural canal (i.e. 'low maintenance' regime) with those in aquaria (i.e. 'high maintenance' regime). Axolotls raised in the enclosures grew much faster than those raised in aquaria, but survival was much lower. A 'high maintenance' regime may therefore result in more animals produced at a smaller size, but at a significantly higher cost.

The genetic management of any animals earmarked for reintroduction needs careful evaluation. Inbreeding depression in captive bloodlines initiated by a small number of founders can be a problem, and could lead to animals that are maladapted for life in the wild. Preliminary work using starch-gel electrophoresis indicated that a captive colony contained a lower degree of genetic variation than the wild population (Graue, 1998). This was, perhaps, to be expected given the relatively small number of founders of the captive colony. However, both the captive and the wild stock analysed displayed less genetic variation than that observed in other ambystomatids and in other amphibians in general (Nevo, 1978). If the wild population has itself now been reduced to a small remnant population, breeding from a sample of these animals may also accelerate inbreeding depression. One possibility might be to augment inbred 'wild type' with alleles from carefully selected captive bloodlines, but this remains work for the future.

A second important issue concerning the reintroduction of animals to the wild is that related to disease. Animals bred under captive conditions may be exposed to a variety of novel pathogens that they may not necessarily experience in the wild. Even if such pathogens appear to have benign effects on captive stock, it is crucially important that they do not find their way into natural systems. If wild animals are already

Figure 2. Axolotls are still used to produce general purpose health tonics, bottles of which can be purchased locally. Photograph © Richard Griffiths.

Figure 3. A local fisherman using the traditional netting method ('atarraya') for catching axolotls. Photograph © Richard Griffiths.

Figure 4. Highly decorated 'trajineras' take visitors on leisurely cruises along the canals of Lake Xochimilco. Photograph © Richard Griffiths.

Figure 5. Richard Griffiths presents Virginia Graue with a set of BHS journals at CIBAC – the field station on the banks of Lake Xochimilco. Photograph © Ian Bride.

Figure 6. Participants and facilitators of a training workshop on board the project's own appropriately named trajinera. Photograph © Ian Bride.

suffering from, for example, immunosupression as a result of pollution, attack by a novel pathogen inadvertently introduced by releasing captive-bred stock could prove detrimental to the existing wild populations. Emerging infectious diseases, such as chytridiomycosis and ranaviral disease, have already been shown to have catastrophic effects on amphibian populations in different parts of the world (Daszak et al., 2003). Indeed, ranaviruses have been associated with mortalities observed in wild populations of the closely related tiger salamander (*Ambystoma tigrinum*) in North America (Jancovich et al., 1997; Bollinger et al., 1999). To minimise the risks that captive-bred stock may pose for wild stock, a sound reintroduction policy should focus on targeting and restoring habitats where there are no extant wild populations, coupled with a rigorous health screening of animals earmarked for release. However, this process might be compromised by the uncontrolled release of captive bred specimens by well-meaning local people – a practice that project members have been told has already occurred. This in turn raises the biggest issue of all in reintroduction programmes. Can it be certain that the factors that led to the decline – and perhaps extinction – of the original populations have been removed? If not, there is no point in releasing more animals that may go the same way as their predecessors. Some of these problems are already being addressed at CIBAC. The effectiveness of using plants as natural water treatment systems (bioremediation) is being tested as a method for cleaning up axolotl habitats. Other work is investigating the impact of various land-use regimes on the water quality and fauna and flora, as well as the overall landscape, whilst plans are afoot for the creation of an experimental in-situ restoration study site from which exotic species will be removed. Radio-tracking studies of axolotls may shed some light on how much movement and gene flow there is between subpopulations within the lake system, and the survival of eggs, larvae and adults are being compared under semi-natural conditions with a view to determining the most efficient stage for any future reintroduction programme.

CONCLUSIONS

Flagship species for conservation projects are invariably highly charismatic species that can engage the interest and imagination of people. This creates a sense of purpose in trying to save them, while the measures taken to protect the species – be it removing alien predators or saving the habitat – will also help protect other, less charismatic species in their wake. Amphibians, including the axolotl, seem to be unlikely candidates for flagship species. Although the threats that it faces seem almost overwhelming, the axolotl has three things going for it that other amphibians unfortunately lack: (1) a long history of importance as an icon of Aztec heritage and culture; (2) widespread familiarity throughout the world as a result of its longstanding use as a laboratory model and aquarium exhibit; and (3) an association with an area that local people and tourists alike value as a place to enjoy both themselves and the wildlife that surrounds them. Only time will tell whether these three factors will provide the foundations for bringing the last remaining wild population back from the brink of extinction, but ultimately, all will depend upon the understanding and support of the people of Xochimilco.

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POSTSCRIPT

Dr Virginia Graue, who instigated this project and co-authored this paper, sadly passed away in January 2004 after a long battle against serious illness. Her enthusiasm, knowledge and sense of humour will long be remembered, and the Darwin Initiative project will be dedicated to her memory.

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