Liver histological changes and lipid peroxidation in the amphibian *Ambystoma mexicanum* induced by sediment elutriates from the Lake Xochimilco

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**Abstract**

Lacustrine sediments accumulate pollutants that input from the lake watershed and can be released to the water column by sediment resuspension; thus, pollutants can change their bioavailability and exert adverse effects to aquatic biota. Shallow-urban lakes are particularly susceptible to receive pollutants from urban discharges and sediment resuspension. Lake Xochimilco, in Mexico City, an urban-shallow lake, faces multiple problems: urban sprawl, overexploitation of aquifers, drying of springs, discharge of wastewater from treatment plants, and sediment resuspension. The aquatic biota living in this ecosystem is continuously exposed to the release of pollutants from the sediments. We assessed the risk that pollutants released from sediments from Lake Xochimilco, Touristic (TZ) and Agriculture zone (AZ), can exert on a native amphibian species of the lake (*Ambystoma mexicanum*) through exposure bioassays to sediment elutriates. We evaluate alterations in the amphibian by three approaches: biochemical (level of lipid peroxidation, LPO), cellular (ultrastructure) and the liver histology of *A. mexicanum* and we compare them with a batch control. Additionally, we assessed heavy metals (Pb, Cd and Hg) in elutriates. Elutriates from TZ showed the highest concentrations of the metals assessed. Organisms exposed to sediment elutriates from either study sites showed higher LPO values than control organisms (p < 0.05). Organisms exposed to elutriates from the TZ showed the most conspicuous damages: hepatic vasodilation of sinusoids, capillaries with erythrocytes,
Introduction

Urban lakes are vulnerable ecosystems that receive the inputs of various sources, atmospheric deposition, runoffs from urban areas and rainfall containing a wide range of pollutants (Baek and An, 2010). Lake sediments are normally the final breakdown product of both organic and inorganic pollutants discharged in aquatic ecosystems; hence, sediments of urban lakes are pools of complex mixtures of pollutants. In consequence, concentrations of contaminants in sediments are often several orders of magnitude higher than those in the overlying water. Among these pollutants, the hydrophobic organic compounds (HOCs) cannot be considered in the bioavailable fraction owing to their strong interaction with the soil matrix, hydrophobic nature and low-water solubility. These HOCs can be incorporated to the particulate matter of the sediments due to the binding or sequestrate to particles in sediments (Koh et al., 2004). On the other hand, in the group of inorganic compounds, heavy metals in aquatic ecosystems have increased considerably due to the inputs of industrial waste, sewage runoff and agriculture discharges (Kazanci et al., 2010). Heavy metals in aquatic ecosystems are of major concern because they have several attributes that contribute to its importance as toxic agents: they are persistent in the environment; cause acute or chronic toxicity in their own right; and they can be bio-accumulative (Daughton, 2004).

Some of these contaminants can be released to the overlying water by sediment resuspension via natural or anthropogenic processes and, consequently, can exert adverse health effects on aquatic organisms (McCready et al., 2006). Sediment resuspension can be provoked by wind-induced wave disturbances, currents, turbulent fluctuations, bioturbation, and even human activities, all of which can favor the release of contaminants from sediments to the water column (Eggeton and Thomas, 2004). However, some pollutants exhibit very slow release rates from sediment due to the binding or sequestration to particles in sediments, as is the case of HOCs, thus they can have a lower contribution to the toxicity of waters affected by resuspension (Luthy et al., 1997). Shallow lakes are one of the ecosystems more susceptible to resuspension of sediments and the consequent release of contaminants (Zheng et al., 2013). Sediment elutriates have been used for evaluating the risk that sediment contamination can exert on aquatic biota and the potential contributions from this matrix to the water column (Abrantes et al., 2009). Although numerous methods have been developed for assessing the potential toxicity of sediments in aquatic ecosystems, elutriate tests have provided to be one of the most practical alternatives for toxicity assessments (Haring et al., 2010). Elutriates have been used to evaluate potential water column effects during the removal and disposal of sediments or other natural or anthropogenic short-term resuspension events (Apitz et al., 2005).

Lake Xochimilco, located on the south side of Mexico City, is an historical and cultural area, and is an important recreational zone for the city. The lake has contrasting environments, the touristic zone (TZ) that is an area with intensive human activities, and the agricultural zone (AZ), where various vegetables and ornamental flowers are cultivated. The biodiversity of Xochimilco is valuable, particularly since some of its native species are microendemic and have significant biological and commercial importance (Alcocer-Durand and Escobar-Briones, 1992; Stephan-Otto, 2005). However, due to several modifications in the habitat, Lake Xochimilco faces a rapid ecological imbalance (Audefroy and Aceves, 2006). Lake Xochimilco currently exists as an urban water body, consisting of a series of shallow lakes interconnected by small channels, but it is facing multiple problems, including, urban sprawl, overexploitation of aquifers, drying of springs, and discharge of wastewater from two treatment plants, which replaced the original springs that naturally supplied the lake. Furthermore, Bojórquez and Amaro (2003) showed in an historical review that among the metals detected in Lake Xochimilco those of major concern by their higher concentration are cadmium, mercury and lead. Due to the human activities around the lake, there are inputs from untreated wastewater, wastes from livestock barns, and pesticide residues. Moreover, the main touristic activity provokes resuspension of sediments by boat transit (Audefroy and Aceves, 2006), making this disturbance a frequent event in the lake. Thus, there is a potential risk for the aquatic biota to be exposed to the contaminants stored in the sediments of Lake Xochimilco when resuspension of sediments occurs.

Among the native species exposed is the case of the amphibian “axolotl” Ambystoma mexicanum, a microendemic species, which is facing a notable depletion in their populations in the last decade (Robles-Mendoza et al., 2009).

The deleterious pollution effects on aquatic biota cannot be simply determined through the quantification of contaminant levels in aquatic systems (Van der Oost et al., 2003). It is a recognized fact that the chemical sampling and analyses only yield information on the chemical status of the sample site at the time of sampling. Even though quantification of individual contaminants is an important tool to investigate the fate and distribution of known pollutants in the environment, the analysis of individual, known contaminants does not account for possible interactions among chemicals or for those compounds that are not identified or not quantified (Daughton, 2004). The possible biological effects of complex mixtures are difficult to predict solely from chemical analysis, whereas biotic responses in organisms reflect the impact of all these pollutants in the biological status of a site from the recent past until the time of sampling. Thus, bioassays have been applied to assess injuries in aquatic biota that reflect the impact of the exposure to bioactive substances in various environmental compartments, such as surface water and sediments (Rodríguez et al., 2010).
A large suit of biomarkers has been recommended to assess exposure to or effects of environmental pollutants on aquatic ecosystems, among them oxidative stress biomarkers and histological parameters have been widely used (Van der Oost et al., 2003). Some pollutants can be soluble and bioavailable by the elutriation process (the water extractable phase), while other remain insoluble and consequently could not be bioavailable (HOCs) (Pereira et al., 2011). In the bioavailable fraction, various pollutants promote oxidative stress in organisms by the oxidation-reduction transformation into reactive oxygen species (ROS). These ROS can cause deleterious effects at different levels of biological organization (e.g., molecular, biochemical, histological, and physiological). These effects can be detected by early warning biomarkers that identify changes at either biochemical or cellular levels (Valavanidis et al., 2006). One of the main effects of ROS is lipid peroxidation (LPO), which can occur from the toxic action of environmental pollutants, leading to stress-induced loss of cellular function (Al-Gubory, 2014). The most widely used assay to assess LPO levels is the malondialdehyde (MDA) formation (Valavanidis et al., 2006).

There are numerous studies on cell and tissue damage in aquatic organisms induced by pollution; however, unlike marine and estuarine organisms, little is known on the biomarkers, histology, and ultrastructure of the freshwater biota (Greenfield et al., 2008; Tidou et al., 2012). Here, we assessed the risk that pollutants in sediments elutriated of Lake Xochimilco can exert on aquatic biota by sediment resuspension through the evaluation of the biochemical, cellular, and tissue responses in a native species exposed to sediment elutriates. The aim of this study was to determine the LPO levels, as well as the ultrastructure and histology of the liver of the native amphibian *A. mexicanum* (which is facing a decline in their populations), after exposure to sediments elutriates from Lake Xochimilco, and make comparisons with control organisms.

1. Methods

1.1. Study area

Several environmental factors were recorded at the water column from each study site: Temperature (°C), dissolved oxygen (mg/L), pH, conductivity (mS/cm), transparency (m), turbidity (NTU), and depth (m) using a multiparameter sonde (Quanta G Hydrolab, USA). Surface sediment samples were collected from the Lake Xochimilco in two zones (Fig. 1): (1) Agricultural zone (AZ, 19°16′28.22″N, 99°5′45.37″W) at a depth of 1.5 m and (2) touristic zone (TZ, 19°16′44.12″N, 99°6′9.21″O) at a depth of 2.2 m. The main land use around the AZ is agriculture and farming; while, the TZ is surrounded mainly of urban settlements and the aquatic system is influenced by boat transit for tourist activities.

1.2. Acclimatization of organisms

Juvenile organisms of *A. mexicanum* (7 ± 1 cm length and weight of 4.0 ± 0.5 g) were used for the bioassays, organisms were donated by the aquarium of the Faculty of Sciences of the National Autonomous University of Mexico (UNAM). For acclimatization, organisms were maintained in aquaria for 30 days with hard reconstituted water (100 mg/L CaCO₃) (APHA et al., 2005). The oxygen saturation levels in the aquaria were maintained by aeration, the temperature was 17 ± 1°C and the photoperiod was 12 hr light:12 hr dark. Organisms were fed with *Tubifex* in a daily ration equal to 10% of the wet weight of the amphibians.

1.3. Sediment elutriation

Sediments were prepared following the procedure of the USEPA (1998). Water (hard reconstituted water with 100 mg/L CaCO₃) was added to sediments in a volume ratio of 1:4 at room temperature (20 ± 2°C). After the correct ratio was achieved, the mixture was stirred vigorously (100 r/min) for 30 min using a shaker (Max Q 3000 Thermo Scientific, USA) and then was allowed to settle for 1 hr. The supernatant was siphoned off without disturbing the settled material, and centrifuged (Hettich Universal 32r, England), to remove particulates prior to chemical analysis (2000 r/min, 30 min). The elutriated sediments from each study site (TZ and AZ) were used for bioassays. Additionally, elutriated sediments from each study site were maintained in three aerated aquaria of 20 L without organisms, this elutriates were used to refill the water levels of the bioassays England throughout the study.

1.4. Heavy metal determinations

The concentration of cadmium (Cd), mercury (Hg), and lead (Pb) in elutriated sediments was estimated by acid digestion (HCl, HNO₃) and spectrophotometer flame atomic absorption (SpectrAA-100 Varian, USA), using the Mexican standard NMX-AA-051-SCFI-2001 for water.
1.5. Exposure bioassays

Once the organisms were acclimatized, they were organized in groups for static-renewal assays: the control group consisted of 4 20 L aquaria, each containing 3 healthy amphibians. The two study groups, one for the AZ site and one for the TZ site, each consisted of 4 aquaria containing elutriated sediment (20 L) from the appropriate study site. Each aquarium contained 3 amphibians (a total of 12 organisms per study site) that were exposed to the sediment elutriates. Organisms were fed Tubifex daily, as in the acclimatization period. The oxygen saturation, temperature, and photoperiod were maintained as in the acclimatization period. The water levels in the aquaria used for bioassays were maintained by refilling with elutriated sediments from the appropriate study site that were prepared and stored in aerated aquaria without organisms.

1.6. Histological analysis

Every 30 days during five months, two organisms per study site and two control organisms were analyzed. Organisms were anesthetized in a solution NaHCO3 (1 g/L) and then were sacrificed by decapitation. Immediately, organisms were dissected to remove the liver, which was divided in three fractions. One fraction was fixed in 2.5% glutaraldehyde in sodium cacodylate and processed for electron microscopy (JEOL-100SX, USA). We obtained thin sections of 70 nm (ultramicrotome EMUC7 Leica, Germany) and microphotographs with the transmission microscope (JEOL-100SX, USA). The second fraction was preserved in liquid nitrogen. The tissue was embedded on paraplast and cut in 7 μm thick sections (microtom HM315 Microm USA). The slides were stained with hematoxylin–eosin (H&E) and with Masson’s Trichrome stain. The slides were examined by using a Photo Microscope (Eclipse Di-U Nikon, Japan).

1.7. Biochemical tests

All biochemical assays were assessed in duplicate. The LPO was evaluated in aliquots of the homogenates at 10%, by quantification of malondialdehyde (MDA) with the method of Buege and Aust (1978). At 300 μL of homogenate were added 700 μL of 150 mM Tris–HCl, pH 7.4, that was incubated at 37°C for 30 min. After incubation, was added 2 mL of thiobarbituric acid at 0.375% dissolved in 15% trichloroacetic acid and was heated to boiling for 45 min. The mixture was cooled and centrifuged at 3000 r/min for 10 min, the absorbance of each aliquot was measured at 532 nm (DR 5000 UV-vis spectrophotometer Hach, USA). The level of LPO was expressed as nmol MDA/mg protein, using a molar extinction coefficient of 1.56 × 105/M cm. Protein content measurements were estimated in the sample of homogenates by the method of Bradford (1976) using bovine serum albumin as a standard. Values are reported as mean ± SE, differences in biomarker responses were assessed by ANOVA and with Tukey’s multiple comparison.

2. Results

2.1. Environmental conditions and heavy metals in elutriates

The water column of the study sites showed Lake Xochimilco has temperate conditions, alkaline waters, high turbidity, and it is mineralized, well oxygenated and shallow (Table 1). The elutriated sediments of the TZ had the highest concentrations of the three metals assessed (Table 2). Lead showed the highest concentration of the metals while Cd and Hg were present at lower concentrations.

2.2. Biological responses by exposure to elutriated sediments

2.2.1. Lipid peroxidation

Organisms exposed to the elutriated sediments of the AZ had a mean LPO value of 1.21 (±0.03) nmol MDA/mg protein, which was 3.7-fold greater than the levels of LPO in control organisms (p < 0.05). Organisms exposed to the elutriated sediments of the TZ had a mean LPO value of 1.903 (±0.0075) nmol MDA/mg protein, which was 5.8-fold higher than the controls (p < 0.05) (Fig. 2). The LPO for organisms exposed to elutriated sediments from the TZ was significantly greater than the LPO for organisms exposed to sediment from the AZ (p < 0.05) (Fig. 2).

2.2.2. Ultrastructure

In the hepatic cells of the control organisms, a spherical nucleus, rough endoplasmic reticulum, and mitochondria with different sizes and shapes were observed in the cytoplasm (Fig. 3a). In organisms exposed to the sediment elutriates of the TZ changes were detected since the first month of exposure. There were many vacuoles in the cytoplasm of hepatocytes (Fig. 3b, c). There were no changes in the nucleus, rough endoplasmic reticulum, or mitochondria in the hepatic cells of the AZ.

2.2.3. Histological structure

In the control organisms, the liver was surrounded by a layer of hematopoietic tissue, hepatic cord cells were shown with a central spherical nuclei and granular cytoplasm. On this kind of cord, there were sinusoid capillaries and vessels containing erythrocytes (Fig. 4a). In the organisms exposed to the TZ elutriated sediment, after the first month, a gradual increase was observed in the cytoplasm vacuolation of hepatic cells (Fig. 4b), sinusoidal vasodilatation, and the number of capillaries with erythrocytes (Fig. 4c). Other alterations in these organisms included hemorrhagic areas and infiltration of hematopoietic tissue (leukocyte infiltration) (Fig. 4c). It is noteworthy that these changes were more pronounced in organisms exposed to elutriated sediment from the TZ than the AZ.

3. Discussion

The sediments of urban lakes contain a wide range of pollutants; in particular, the metal concentrations in sediments are several orders of magnitude higher than aqueous...
concentrations (Mahler et al., 2006). Our data showed that the metal concentrations analyzed in sediment elutriates of the two study sites of Lake Xochimilco were higher than those recorded by Bojórquez and Amaro (2003) in the water column of the lake with the exception of Pb. These authors compared the metal concentrations from several years and found increasing values among the most conspicuous metals: Pb from 0.50 to 2.9 mg/L (in a period of two year), Cd from 0.0030 to 0.05 mg/L (in a period of five years); and Hg from 0.00016 to 0.00040 mg/L (in a period of two years). There are several sources of these metals in urban lakes, including vehicle emissions, atmospheric sources, and industrial effluents (Sezgin et al., 2004). Storm water runoff and atmospheric deposition into the lake could contribute to deterioration of the quality of water and sediment. Additionally, Lake Xochimilco receives water from two wastewater treatment facilities; since 1971 to 1993 the facilities had a secondary treatment, nowadays the facilities have tertiary treatment (Bojórquez and Amaro, 2003). The slight decreases in Pb concentrations of the elutriates can be explained by the change in the formulation of gasoline with Pb by unleaded gasoline since 1990. Cortez-Lugo et al. (2003) stated that the elimination of lead from gasoline produced a cumulative decrease of 23% of Pb in air of the Mexico City. In our study, we use surface sediments, which include the recent pollution sources in the Lake Xochimilco. Values found in the sediment elutriates from Lake Xochimilco are higher in several orders of magnitude when compared to values detected in sediment elutriates of Gironde Estuary, France (Cd 0.485 μg/L) (Geffard et al., 2002a); and also when compared to the Atlantic coast of France (Cd 0.020 to 0.10 μg/L and Pb 0.3 to 8.3 μg/L) (Geffard et al., 2002b). The higher concentration values in Lake Xochimilco can be attributed to the endorheic nature of this lake (Alcocer-Durand and Bernal-Brooks, 2010); thus, pollutants entering this waterbody can be deposited in sediments because the lake has not outlet and sediments continuously accumulates. Furthermore, Lake Xochimilco is an urban lake which receives wastewaters and thus, is more prone to receive a higher load of pollutants (Baek and An, 2010).

Lead, Cd, and Hg are metals with unknown biochemical functions (Pinto et al., 2003); these metals are generally found in lake sediments as trace elements, but at high concentrations are toxic. In the bioassays of this study, the amphibian A. mexicanum was exposed to a complex mixture of pollutants from elutriated sediments (the water-extractable phase) from two sites of Lake Xochimilco that contained metals such as Pb, Cd, and Hg. Several authors have found that metals are strong inducers of oxidative stress in aquatic organisms promoting the formation of ROS through several mechanisms. Redox active metals generate reactive oxygen species through redox cycling, while metals without redox potential, as is the case of Pb, Cd and Hg, impair antioxidant defenses, particularly that of thiol-containing antioxidant enzymes (Ercal et al., 2001; Sevcikova et al., 2011).

The metal Pb was detected with values of 0.48 and 1.0 mg/L for the AZ and TZ, respectively. According to the Mexican guidelines NOM-001-ECOL-1996, the maximum permissible threshold for Pb is 0.2 mg/L for natural wetlands. Lead is found in nature and is one of the most abundant metals in the environment. This metal has been used in paints, gasoline, and pesticides in large amounts. Lead can induce oxidative damage by several mechanisms: the Pb (II) ion can accelerate oxidation of oxyhaemoglobin to methaemoglobin (with increased formation of ROS). In addition, Pb combines with thiol groups on proteins and, at high concentrations, causes glutathione (GSH) depletion and also the formation of complexes with selenium, which decrease the activity of the Glutathione peroxidase enzyme (Ercal et al., 2001; Sevcikova et al., 2011). Lead may directly be attached to a cell membrane, thus increasing the sensitivity of the membrane to the process of lipid peroxidation. All of these interactions can cause depletion of cellular antioxidant pool and cell susceptibility to oxidative damage. Due to the fact that Pb was present in elutriates of the bioassay, these processes could contribute to the higher LPO.

![Fig. 2 - Level of lipid peroxidation in the liver of A. mexicanum controls and organisms exposed to sediment elutriates of the AZ and TZ. * Significant difference compared with control (p < 0.05). Bars represents Error Standard. AZ: agriculture zone; TZ: touristic zone.](image-url)
values detected in the livers of *A. mexicanum* exposed to the elutriated sediments from both study sites compared with control organisms.

Cadmium is highly toxic to aquatic species and wildlife associated with aquatic habitats (Dovzhenko et al., 2005). Cadmium is a non-redox-active metal, hence it cannot induce ROS production directly, however, it has been shown that Cd increases the free Fe-concentrations possibly by its replacement in various proteins and hence increases the cellular amount of free redox-active metals and also inactivating several enzymes as SOD and CAT (Ercal et al., 2001). Furthermore, Cd shows a high affinity for thiols, in consequence GSH that is the major thiol antioxidant is a primary target for free Cd-ions. Therefore, Cd-induced depletion of the GSH pool (Lopez et al., 2006) leading to oxidative stress. Cadmium enters the electron transport chain in mitochondria, leading to accumulation of unstable semiubiquinones, which donate electrons and create superoxide radicals. In consequence Cd is able to induce oxidative stress by several mechanisms.

The highest concentration of Hg was 0.00892 mg/L in the TZ; while, it was 0.00478 mg/L in the AZ. According to the Mexican guidelines NOM-001-ECOL-1996, the threshold for wastewater discharges into soil and natural wetlands is $5 \mu$g/L. Mercury is one of the most toxic metals to aquatic life and its concentration in the aquatic environment has risen significantly because of human activities (Selin, 2009). This metal can enter the lake system of Xochimilco through natural processes in the atmosphere and as a result of industrial pollution (Colacevich et al., 2011). One mechanism of mercury-induced oxidative damage is sulfhydryl reactivity. Mercury is characterized by its high volatility and its dissolved elemental nature (Hg0). Once inside the cell, the Hg0 is oxidized by the enzyme catalase and is converted to highly reactive Hg2+ (Ercal et al., 2001). Inside the cell, both Hg0 and methyl mercury (MeHg) form covalent bonds with the glutathione and cysteine residues of the proteins. Thus, this metal may also provoke the high levels of LPO in organisms exposed to the elutriated sediments of Lake Xochimilco.

The present study highlights the oxidative damages exerted by sediment elutriates in the amphibian *A. mexicanum*, even when all the components of the mixture of pollutants in the elutriates were not identified. Among the pollutants that have been recorded world-wide in sediments, those known as HOCs, due to the hydrophobic nature, have slow release rates and may be less leachable by water during the elutriation process;

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**Fig. 3** – (a) Hepatocyte in the liver of *A. mexicanum* control organisms, ×1200; (b) and (c) liver of an amphibian exposed to elutriated sediments from the touristic zone, ×1000, ×1400. Hepatocytes contained vacuoles in the cytoplasm (arrow).

**Fig. 4** – (a) Liver of *A. mexicanum* control organisms showing hematopoietic tissue and cords of hepatocytes; H&E stain, Bar = 100 μm, (b) Cytoplasmic vacuolation of hepatocytes (arrow), H&E stain, Bar = 20 μm, (c) infiltration of hematopoietic tissue (leukocyte infiltration) between the hepatic cords and vasodilation with increased vascular congestion (arrow), Masson’s Trichrome technique, Bar = 100 μm.
Therefore, many HOCs are not incorporated in the water after the elutriation. In our bioassay we exposed the amphibian to elutriates (the water-extractable phase), but not to the whole sediments (bulk sediments) where HOCs can be stored. Nevertheless, metals such as Cd, Pb and Hg were present in the elutriates and are able to exert several damages. In ecotoxicological studies those pollutants that are bioavailable are of major concern, the bioavailability was defined as the fraction of the bulk amount of the chemical present in sediment and (interstitial) water that can potentially be taken up during the organism’s lifetime into the organism’s tissues, these pollutants can trigger toxic effects (de Paiva et al., 2015).

The results showed that the combined action of the metals detected and the additional mixture of other organic and inorganic xenobiotics in the urban sediments exert a synergistic effect on the LPO responses of A. mexicanum. The LPO reaction mechanisms can damage the lipids found in the cell membrane, altering their cohesion, flowability, permeability, metabolic function, and lead to membrane instability and cell death (Van der Oost et al., 2003). Various studies reported that LPO was an indicator of the toxic action of contaminants, which leads to loss of cell function by oxidative stress. The LPO results in this study showed it is a suitable biomarker that provides important qualitative and quantitative information about the effects of toxic exposure from elutriated sediments from Lake Xochimilco.

The assessment of histological structures and ultrastructure alterations is very useful for determining the environmental risk (Damek-Poprawa and Sawicka-Kapusta, 2004; Pereira et al., 2006). Several studies have used the liver as the main target organ for the assessment of histopathological changes caused by heavy metal contaminants, this organ contains considerable amounts of polyunsaturated fatty acids which are susceptible to be damaged by free radicals (Pereira et al., 2006). Chronic exposure to pollutants such as heavy metals can cause chronic stress that can induce damage to histological structures and ultrastructures (Nelson, 2000). In the present study, liver damage in A. mexicanum was represented by cytoplasmatic vacuolization and leukocyte invasion, as the result of chronic exposure to elutriated sediments. The most pronounced damages were observed in the TZ, which was also the site with more external runoffs due to the urban and touristic activities in the lake and its adjacent area. The damages found in our study are consistent with those reported in the fish Cyprinus carpio (Jiang et al., 2011) and the mammal Clethrionomys glareolus (Damek-Poprawa and Sawicka-Kapusta, 2004), where authors found infiltration of inflammatory cells, cytoplasmatic vacuolation in liver cells, and some cells in apoptosis. One mechanism of inducing toxicity lipidosis is the disruption of lipid oxidation and protein synthesis, resulting in triglyceride accumulation in hepatocytes (Greenfield et al., 2008). Elevated levels of ROS lead to oxidative damage including lipid damages; as a result, the increase of cytoplasmatic vacuolization could be a consequence of the high levels of lipid peroxidation detected in the liver of the amphibian exposed. In addition, the immune system of the organisms is responsible for the removal of particles (among them heavy metals) by phagocytosis (Sheir et al., 2013); thus, the leukocyte infiltration is an important indicator of the presence of strange particles in the tissue.

Amphibians are facing massive declines in their populations worldwide (Allentoft and O’Brien, 2010). This decline may be due to infectious diseases, chemical pollution, increased ultraviolet radiation, climate changes, and the loss and modification of habitats and invasive species. The exposure of amphibians to pollutants increases the production of ROS, causing subsequent alterations in the antioxidant defenses (Zocche et al., 2014). Amphibians have distinctive characteristics, such as their aquatic-terrestrial life and the semi-permeability of their skin, that make these species useful as bioindicators, however, there are few studies evaluating amphibian ecotoxicology from urban ecosystems (Venturino et al., 2003). A. mexicanum is a neotenic species that spends its whole life cycle in water and is susceptible to be exposed to pollutants that can change their bioavailability when sediments are resuspended and can induce oxidative stress and chronic stress that can induce damage to histological structures and ultrastructures.

4. Conclusions

The results of this study showed that the elutriated sediments from the two study sites of Lake Xochimilco were able to induce damages by LPO, including structural and ultrastructural changes that can compromise several physiological functions and ultimately the life cycle of the amphibian. Since the runoff of pollutants is a common event in urban lakes and sediment resuspension is a frequent process in Lake Xochimilco, due to its shallowness and human activities, the biological responses observed in A. mexicanum after exposure to sediment elutriates reflect the risks that this amphibian faces in Lake Xochimilco, due to the toxicological potential of this sediments.

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