*Journal of Environmental Science and Management 21-1:110-119 (June 2018) ISSN 0119-1144*

# Lead Biomagnification in a Food Web of the Open Waters along Sta. Rosa Subwatershed, Philippines


## ABSTRACT

*Contamination of lead in fishes from Laguna de Bay was previously recorded to have the highest concentrations that may pose a hazard to human health. However, no previous study was conducted on its biomagnification. This research is the first exploratory study that examined lead biomagnification in a food web of the lake. Water quality, aquatic communities, trophic levels and lead concentrations were analyzed during the dry and wet seasons. Lead concentrations were analyzed using Atomic Absorption Spectrometry. Levels of lead in the water were 0.05 mg $L^{-1}$ and 0.03 mg $L^{-1}$ for dry and wet seasons, respectively. Lead concentrations increased in phytoplankton with 3.87 and 9.66 mg $kg^{-1}$ lead during wet and dry season, respectively. Furthermore, lead levels increased in zooplankton with 2.92 and 14.31 mg $kg^{-1}$ during wet and dry seasons, respectively. In fishes, the highest lead concentration in dry season was detected in Hypophthalmichthys nobilis with 0.38 mg $kg^{-1}$ while the highest during wet season was observed in Oreochromis niloticus with 0.67 mg $kg^{-1}$. Lead biomagnification was observed in this study in the following order: water < phytoplankton < zooplankton. However, this increasing trend did not continue up to fishes.*


**Key words**: *: Lead Biomagnification, Laguna de Bay, Contamination*


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## INTRODUCTION

Contamination of heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg) and zinc (Zn) are increasing in freshwater ecosystems. Heavy metals are substances that exhibit metallic properties. Some are hazardous due to its toxicity especially in Cd, Hg and Pb (*Manahan 2003*). When heavy metals enter into aquatic ecosystems, they can either adsorb on sediments or accumulate in aquatic species (*Mohamed 2008; Chojnacka 2010; David et al. 2012*). This poses an environmental hazard to invertebrates, fishes and humans.

Laguna de Bay is contaminated with heavy metals (*Lasco and Espaldon 2005; Molina et al. 2011*). The lake is the largest inland body of water in the Philippines with total surface area of 900 $km^2$ and has 2920 $km^2$ watershed. It has 22 major river tributaries and only one outlet. The economy is based on urban/industrial activities. Industrial estates, economic zones and residential areas are established (*Sta. Rosa 2011*). The lake is an important freshwater inland system that provides wide array of resources including food source, flood water reservoir,power generation, irrigation, industrial cooling water, source of potable water, navigation, recreational and cultural activities as well as waste sink (*LLDA 2009*).

Commercially-important fish species *Oreochromis niloticus* (tilapia), *Chanos chanos* (milkfish) and A*rius manillensis* (Manila catfish) from the Laguna de Bay were found to have high levels of As, Cd, Cr, Pb and Hg. Among the heavy metals, Pb had the highest concentration in fishes (*Molina et al. 2011*). Pb is one of the most significant toxicants that are extensively studied. It is a toxic metal even in very low exposure levels. Pb in the environment is particle-bound and has low mobility. It is also bioavailable and can accumulate in organisms. In human adults, the main pathway for lead is through dietary uptake. The contaminated fishes from the lake were not recommended for human consumption because of potential health risks (*Molina et al. 2011; Tamayo-Zafaralla and Vidal 2011*). Hence, it is important to track down Pb since it is one of the three major heavy metal poisons that causes impaired neurobehavioral development in children and neurological, cardiovascular, renal, gastrointestinal, haematological and reproductive effects in adults (*WHO 2007*).

Lead concentration may magnify in aquatic biota. Biomagnification is increase of chemical concentration of the contaminant in the organism through dietary absorption. Biomagnification through trophic transfer is evident when there is a higher concentration in the predator than that of its prey. Trophic transfer in food webs is important in studying biomagnification since information provided by it can explain the dietary toxicity (secondary poisoning). In food web biomagnification studies, trophic level establishment is a requirement (*McGeer et al. 2004; Jorgensen, 2010*). Previous studies on lead concluded that it can biomagnify in at least one top predator (*Rubio-Franchini and Rico-Martínez 2011*).

To the extent of our knowledge, no biomagnification study in Laguna de Bay has been published. This research is the first exploratory study on Pb biomagnification in the lake. The main goal of the study was to assess Pb biomagnification in a food web in the open waters along Sta. Rosa subwatershed.

## MATERIALS AND METHODS

### Sampling Area and Zones

The study area was conducted in the open waters of Laguna de Bay along Sta. Rosa City shoreline. Laguna de Bay is the largest inland body of water in the Philippines. It has 22 major river tributaries and one of it is Sta. Rosa River. Sta. Rosa City lies in Sta. Rosa subwatershed and is located at the western side of Laguna de Bay (*LLDA 2009; Sta. Rosa 2011*). The research focused on the lakeshore barangays namely Sinalhan, Aplaya and Caingin. In each barangay, three lake zones (nearshore, farshore and offshore) were established in the open waters along Sta. Rosa Subwatershed. Each zone represented a sampling site. The nearshore was 0.5 km from the shoreline, farshore with 1 km away and offshore with 2 km (**Figure 1**).

### Sampling Frequency

Sampling were done on November 2012 and May 2013 to represent the wet and dry seasons, respectively.

### Sample Collection

The following water quality parameters were measured: pH and water temperature (YSI EcoSense pH100 Instrument), dissolved oxygen (YSI 5700 Series oxygen meter), total hardness (Hach test kit), total alkalinity (Hach test kit) and chlorophyll a (chl a determination via ethanol extraction). For plankton samples, plankton nets were used to collect phytoplankton (25 μm) and zooplankton (56 μm). The depth of the water column for vertical haul was one meter since the average depth of the lake was only 2.5 m. The samples were put to 500 ml polyethylene (PE) bottles. Planktonsamples for identification and counting were fixed in 10%

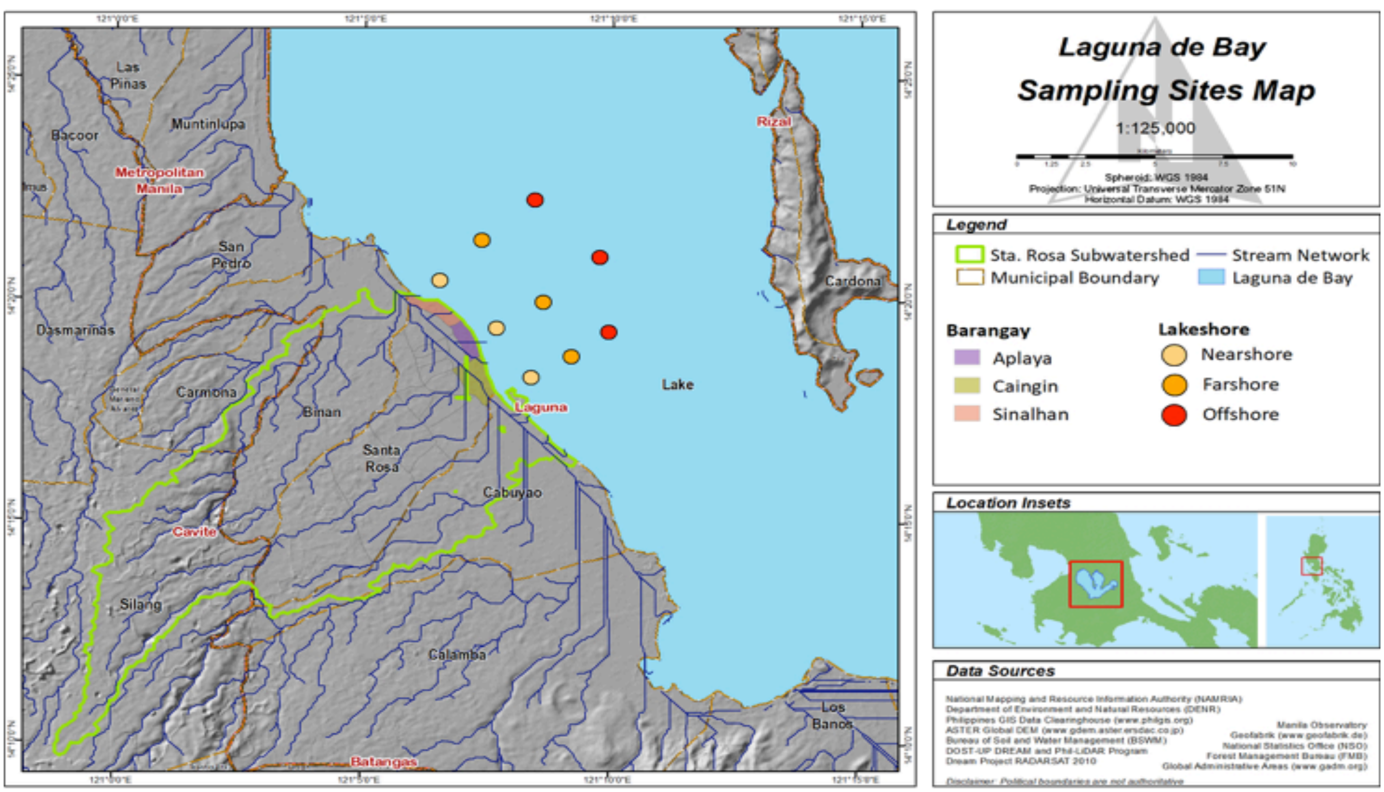


Figure 1. Map of sampling points in the open waters along Sta. Rosa subwatershed.

formalin. Identification and counting of phytoplankton and zooplankton were done to evaluate the community structure in terms of species composition and species abundance. For plankton identification, several field manuals, picture keys and dichotomous keys were used (*Shiel 1995; Bellinger and Sigee 2010*). For counting, Hemacytometer counting chamber was used for phytoplankton while Sedgewick-Rafter counting chamber for zooplankton. An electric compound microscope was used for plankton observation. For fish samples, freshly caught fishes were purchased from the fishermen who were encountered in the lake.

## Trophic level establishment

Simplified interactions among the aquatic communities in the open waters along Sta. Rosa subwatershed were illustrated using the identified organisms from the lake. Trophic levels were enumerated using diet analysis from secondary literature (**Table 1** and **2**). Color-coded arrows were assigned to show the diet of a specific predator.

## Determination of lead concentrations

To measure lead in water and plankton, 3 replicates of 1 L for each sample were collected in the lake zones (nearshore, farshore and offshore). Water samples was acidified with nitric acid to < pH 2 for lead preservation. Lead in phytoplankton were measured by using 0.47 µm microfiber filter while 1 mm microfiber filter were used for zooplankton samples (*Kuo et al. 2010*). To measure lead in fishes, muscles were removed and wrapped with aluminum foil and placed in ziplock bags. Samples were put in an ice chest with ice while in transport. The number of fish samples depended on fishermen's daily catch. All the samples were sent immediately to UPLB Institute of Chemistry Analytical Service Laboratory for lead analysis using Atomic Absorption Spectrometry (AAS) following *APHA AWWA* (*2005*) standard methods.

## Statistical Analysis

Non-parametric Kruskal-Wallis Test was done to determine the significant differences of lead concentrations among water, phytoplankton,

Table 1. Food items of zooplankton species.

| Taxon | Diet | Reference |
|---|---|---|
| **Rotifera** | | |
| *Anuraeopsis fissa* | Bacteria and detritus | *Pourriot 1977* |
| *Brachionus calyciflorus* | Microalgae like Cyclotella and *Chlamydomonas sphaericus* | *Rothhaupt 1990* |
| *Conochilus sp.* | Microalgae (Chlorella), detritus, bacteria | *Pourriot 1965* |
| *Euchlanis sp.* | Algae, cyanobacteria (*Oscillatoria, Aphanizomenon, Microcystis*), diatom (Cyclotella), detritus, bacteria | *Carlin 1943* |
| *Filinia longiseta* | Microalgae (*Chlorella*), detritus, bacteria, decompose plankton | *Glime 2013* |
| *Filinia opoliensis* | Bacteria that are chemosynthetic or decompose plankton | *Glime 2013* |
| *Keratella cochlearis* | Algae (Chlamydomonas) bacteria and detritus | *Marce et al. 2005* |
| *Keratella tropica* | Algae (Chlamydomonas) bacteria and detritus | *Marce et al. 2005* |
| *Polyarthra vulgaris* | Algae (Chlamydomonas) bacteria and detritus | *Bogdan and Gilbert 1982; Glime 2013* |
| *Testudinella patina* | Green alga *Chlorella* and diatoms | *Bogdan and Gilbert 1982; Glime 2013* |
| Order Bdelloidea | Unicellular algae, bacteria, microflagellates, yeasts or particulate organic matter | *Bogdan and Gilbert 1982; Glime 2013* |
| **Copepoda** | | |
| Calanoida | Algae (diatom, dinoflagellate), rotifers, microzooplankton, protozoans, detritus | *Burke 1977; DeMott 1989* |
| Copepodite Nauplius | Pico and nanophytoplankton, bacteria, protozoan, diatoms, ciliates and dinoflagellates with <20um | *Burke 1977; DeMott 1989* |
| Cyclopoida | Algae, rotifers, algivorous ciliates, bacteria, nauplii, juvenile copepods, cladocera, protozoa | *Burke 1977; Kleppel 1993* |
| Harpacticoida | Microalgae, nauplius, diatom, bacteria, detritus, protozoans | *Turner et al. 2001* |
| **Cladocera** | | |
| *Bosmina longirostris* | Algae (*Chlamydomonas*), protozoans, detritus and bacteria | *DeMott and Kerfoot 1982* |
| *Ceriodaphnia sp.* | Algae (*Selenastrum*), bacteria, detritus, yeast | *Burke 1977; DeMott & Kerfoot 1982* |
| *Daphnia sp.* | Algae (*Chlorella, Scenedesmus, Nitzschia*), *Paramecium*, bacteria, dissolved organic matter | *Burke 1977; DeMott & Kerfoot 1982* |
| *Diaphanosoma sp.* | Microalgae like *Scenedesmus acuminatus*, bacteria | *Pagano 2008* |

Table 2. Food items of fishes.

| Taxon | Diet | Reference |
|---|---|---|
| *Arius manillensis* | Plankton, chironomid larvae, snails, shrimp | *Delmendo 1966; Fishbase 2018a* |
| *Oreochromis niloticus* | Phytoplankton (like *Navicula, Nitzschia, Stauroneis, Synedra, Melosira, Oscillatoria, Scenedesmus*), zooplankton, aquatic invertebrates, larval fish, detritus, and decomposing organic matter, some aquatic macrophytes | *Jihulya 2014* |
| *Clarias batrachus* | Insect larvae, earthworms, shells, shrimps, small fish, aquatic plants and debris | *Fishbase 2018a* |
| *Hypophthalmichthys nobilis* | Phytoplankton (diatoms, green alage, blue-green algae), zooplankton (cladocerans, copepods, rotifers), detritus, aquatic insects | *Sampson et al. 2008* |

zooplankton, and fishes since data was not normally distributed. IBM SPSS Statistics 20 was used for the analyses.

## RESULTS AND DISCUSSION

### Water Quality

Water temperature, dissolved oxygen and pH in the open waters along Sta. Rosa City met the Class C standards according to the Department of Environment and Natural Resources Administrative Order (DAO) 2016-08. Average surface water temperature in dry season was 31.6ºC and 28.6ºC in wet season. Measurements of pH were 9.0 and 8.08 for dry and wet seasons respectively and the average surface dissolved oxygen during dry season was relatively higher (9.66 mg $L^{-1}$) than during wet season (7.77 mg $L^{-1}$) (**Table 3**). These imply that the lake can be used in fisheries, recreational activities (e.g. boating) and industrial purposes (DAO 2016-08).

Moreover, Secchi disc transparency (SDT) readings classified as hypertrophic waters in the study area during dry season while eutrophic during wet season. However, chlorophyll a readings classified the open waters as mesotrophic for both season. Lead concentrations in water measured 0.05 mg $L^{-1}$ during dry season and 0.03 mg $L^{-1}$ during wet season. These values have met theClass C standards based on DAO 2016-08 which is 0.05 mg $L^{-1}$ (**Table 3**).

The speciation and solubility of lead in freshwater is controlled by parameters such as pH, hardness and alkalinity. The solubility of Pb increases in acidic waters (pH<6.5) and low alkalinity (15 mg $L^{-1}$). At pH >5.4, the total solubility of lead was around 30 and 500 µg $L^{-1}$ in hard water and soft water, respectively. Moreover, Pb toxicity was increased in both soft water (i.e. 20 mg$L^{-1}$ $CaCO_3$) and hard water (i.e. 330 mg $L^{-1}$ $CaCO_3$). Conversely, there was low solubility of lead (<1 µg $L^{-1}$) in alkaline waters (pH>8.5) with carbon dioxide and sulfur (*ATSDR 2005*).

Lead concentrations in dry and wet seasons followed the aforementioned relationships in water chemistry. Higher lead concentration (0.05 mg $L^{-1}$) was observed during summer because of increased solubility in hard water (228 mg $L^{-1}$). During wet season, lead concentration (0.03 mg $L^{-1}$), pH (8.08) and total hardness (133 mg $L^{-1}$) decreased while alkalinity (89 mg $L^{-1}$) increased. In general, the levels of Pb in the open waters were considerably low since there were alkaline waters (pH 9.0 and pH 8.08) during spot samplings for both seasons (**Table 3**).

### Plankton Identification and Densities

A total of 32 phytoplankton taxa belonging to six classes were recorded: Chlorophyceae (13), Cyanophyceae (8), Bacillariophyceae (7), Dinophyceae (2), Chrysophyceae (1), Euglenophyceae (1) (**Table 4**). Taxa identified under Bacillariophyceae (diatoms) were *Aulacoseira sp., Cyclotella sp., Melosira sp., Navicula sp., Nitzschia sp., Stauroneis sp. and Surirella sp.* Chlorophyceae (green algae) taxa were *Cladophora sp., Closterium sp., Eudorina sp., Pandorina sp., Pediastrum simplex, Pediastrum duplex, Scenedesmus acuminatus, Scenedesmus quadricauda, Scenedesmus sp., Selenastrum sp., Staurastrum sp., Volvox aureus and Zygnema sp.* There was only one genus under Chrysophyceae (golden brown algae) which was Uroglena sp. Cyanophyceae (blue-green algae) had 8 taxa namely *Anabaena sp., Aphanizomenon sp., Aphanocapsa sp., Arthrospira sp., Chroococcus sp., Lyngbya sp., Microcystis sp. and Oscillatoria sp. Euglena sp.* was the only genus identified under Euglenophyceae (euglenoids) and listed under Dinophyceae (dinoflagellates) were *Ceratium sp. and Peridinium sp.*

Table 3. Average values of water quality parameters in the open waters of Sta. Rosa subwatershed during wet season (2012) and dry season (2013).

| Parameter | Wet season | Dry season | Standard values |
|---|---|---|---|
| Surface Water Temperature (°C) | 28.6 | 31.6 | 3[a] |
| Surface Dissolved Oxygen (mg $L^{-1}$) | 7.77 | 9.66 | 5[a]<br>5 – 9.5[b] |
| pH | 8.08 | 9.0 | 6.5 - 9.0[a]<br>6.0 – 9.0[c] |
| Chlorophyll a (µg $L^{-1}$) | 6.06 | 9.54 | 0 - 4: Oligotrophic[d]<br>5 - 9: Mesotrophic<br>10 - 100: Eutrophic<br>>100: Hypertrophic |
| Secchi Disc Transparency (m) | 1.47 | 0.63 | 3.0: Oligotrophic[e]<br>3.0 - 1.5: Mesotrophic<br><1.5 - 0.7: Eutrophic<br><0.7: Hypertrophic |
| Total Hardness (mg $L^{-1}$) | 133 | 228 | 100 – 300[c]<br>soft: 0-75<br>moderately hard: 75-150<br>hard: 150-300<br>very hard: >300 |
| Total Alkalinity (mg $L^{-1}$) | 89 | 17.10 | ≥ 20 c |
| Lead (mg $L^{-1}$) | 0.03 | 0.05 | 0.1 a |

[a] Department of Environment and Natural Resources Administrative Order (DAO) 2016-08
[b] *WHO and UNEP* (*1997*)
[c] *ANZECC* (*2000*)
[d] *APHA-AWWA* (*2005*)
[e] *Hakanson 1980*; *Hakanson and Jansson 1983*; *Meybeck et al. 1989*

Moreover, a diverse zooplankton community existed in the study sites in Laguna de Bay. A total of 50 zooplankton taxa belonging to three zooplankton orders were recorded: Rotifera (35), Cladocera (10) and Copepoda (5) (**Table 5**).

Mean densities of plankton during dry and wet seasons were calculated. Higher average densities and abundance of phytoplankton and zooplankton were observed during dry season than the wet season (**Table 6**).

**Proposed Food Web in Laguna de Bay**

As illustrated in the proposed food webs, the basal species were the phytoplankton groups (**Figure 2**). These primary producers were grazed by small-bodied zooplankton such as *Bosmina longirostris* (cladoceran) and *Euchlanis* (rotifer). Larger zooplankton such as cyclopoids and copepods had a wide variety of diet that includes bacteria, protozoa, detritus, dissolved organic matter and even other zooplankton species (*Burke 1977; Kleppel 1993*) (**Table 1** and **Figure 2**). These plankton *species are eaten by fishes. Fishes prefer cladocerans (i.e. Moina, Daphnia and Diaphanosoma*). Other food items for the fishes are aquatic insects, snails, shrimps, larval fish, detritus and aquatic macrophytes (**Table 2; Figure 2**).

**Biomagnification of Lead**

The lead concentration in the water were within the DAO 2016-08 standards (0.05 mg $L^{-1}$ and 0.03 mg $L^{-1}$ for dry and wet seasons, respectively). Lead concentrations increased in phytoplankton (Plankton A) with 3.87 and 9.66 mg $kg^{-1}$ lead during wet and dry season, respectively (**Figure 3**). Furthermore, lead levels increased in zooplankton (Plankton B) with 2.92 and 14.31 mg $kg^{-1}$ during wet and dry seasons, respectively. Based on the computed mean densities of the phytoplankton and zooplankton samples, plankton A was used as the representative sample for phytoplankton as it consisted of 70% phytoplankton and 30% zooplankton. Moreover, plankton B was used as the representative sample for zooplankton as it consisted of 80% zooplankton and only 20% phytoplankton. Lead concentrations in fish muscles were variable for both seasons. The highest lead in dry season was detected in *Hypophthalmichthys nobilis* with 0.38 mg $kg^{-1}$ while the highest during wet season was observed in *Oreochromis niloticus* =with 0.67 mg $kg^{-1}$. Levels of Pb in Tilapia (*Oreochromis niloticus*) were measured at 0.35 and 0.67 mg $kg^{-1}$ for dry and wet seasons, respectively. In bighead carp (*Hypophthalmichthys nobilis*), levels did not vary much with 0.33 and 0.38 mg $kg^{-1}$ during wet and dry

Table 4. Phytoplankton species in the open waters of Laguna de Bay along Sta. Rosa Subwatershed.

| A. Phytoplankton Class | Taxa |
|---|---|
| Bacillariophyceae (diatoms) | *Aulacoseira sp.* |
| | *Cyclotella sp.* |
| | *Melosira sp.* |
| | *Navicula sp.* |
| | *Nitzschia sp.* |
| | *Stauroneis sp.* |
| | *Surirella sp* |
| Chlorophyceae (green algae) | *Cladophora sp.* |
| | *Closterium sp.* |
| | *Eudorina sp.* |
| | *Pandorina sp.* |
| | *Pediastrum simplex* |
| | *Pediastrum duplex* |
| | *Scenedesmus acuminatus* |
| | *Scenedesmus quadricauda* |
| | *Scenedesmus sp.* |
| | *Selenastrum sp.* |
| | *Staurastrum sp.* |
| | *Volvox aureus* |
| | *Zygnema sp.* |
| Chrysophyceae (golden brown algae) | *Uroglena sp.* |
| Cyanophyceae (blue-green algae) | *Anabaena sp.* |
| | *Aphanizomenon sp.* |
| | *Aphanocapsa sp.* |
| | *Arthrospira sp.* |
| | *Chroococcus sp.* |
| | *Lyngbya sp.* |
| | *Microcystis sp.* |
| | *Oscillatoria sp.* |
| Dinophyceae (dinoflagellates) | *Ceratium sp.* |
| | *Peridinium sp.* |
| Euglenophyceae (euglenoids) | *Euglena sp.* |

Table 5. Zooplankton in the open waters of Laguna de Bay along Sta. Rosa Subwatershed.

| B. Zooplankton Order | Taxa |
|---|---|
| Rotifera (rotifers) | *Anuraeopsis fissa* |
| | *Aneuropsis sp.* |
| | *Ascomorpha ovalis* |
| | *Bdelloidea* |
| | *Brachionus angularis* |
| | *Brachionus budapestinensis* |
| | *Brachionuscalyciflorus* |
| | *Brachionus caudatus* |
| | *Brachionus sp.* |
| | *Collotheca sp.* |
| | *Collotheca cf. pelagica* |
| | *Conochilus unicornis* |
| | *Conochilus sp.* |
| | *Euchlanis sp.* |
| | *Filinia opoliensis* |
| | *Filinia longiseta* |
| | *Hexarthra intermedia* |
| | *Keratella cochlearis* |
| | *Keratella tropica* |
| | *Lecane bulla* |
| | *Lecane luna* |
| | *Lecane sp.* |
| | *Lepadella sp.* |
| | *Monostyla sp.* |
| | *Mytilina sp.* |
| | *Platyias leloupi* |
| | *Platyias quadricornis* |
| | *Polyarthra vulgaris* |
| | *Rotaria sp.* |
| | *Testudinella patina* |
| | *Trichocerca sp.* |
| | *Trichocerca capucina* |
| | *Trichocerca inermis* |
| | *Trichocerca pusilla* |
| | *Trichocerca sp.* |
| Cladocera (cladocerans) | *Bosmina longirostris* |
| | *Ceriodaphnia cornuta* |
| | *Ceriodaphnia sp.* |
| | *Daphnia sp.* |
| | *Diaphanosoma sp.* |
| | *Moina micrura* |
| | *Moina sp.* |
| | *Daphniidae* |
| | *Monidae* |
| | *Sididae* |
| Copepoda (copepods) | *Cyclopoida* |
| | *Calanoida* |
| | *Harpacticoida* |
| | *Copepodite nauplius* |
| | *Juvenile copepoda* |

seasons, respectively. There is no significant difference in lead concentration in Tilapia muscles (p=0.121) and bighead carp muscles (p=0.121). The other two fish samples were only caught during wet season, hence comparison between seasons cannot be done.

Average lead concentrations from water, bulk plankton up to fishes had the same observable trend for both seasons wherein levels of lead significantly increased in the following order: water < plankton A or mostly phytoplankton < plankton B or mostly zooplankton. However, lower concentrations were measured in fishes compared to plankton.

During dry season, the mean concentration of lead significantly increased from water to Plankton A (p = 0.000), Plankton A to Plankton B (p =0.003), but decreased from Plankton B to fishes (p=0.007). The observed trend in lead concentrations during summer increased from water to Plankton A, then increased from Plankton A to Plankton B but significantly decreased from

Table 6. Plankton Mean Density in the open waters along Sta. Rosa subwatershed.

| | Mean Density (individual $m^{-3}$) | |
|---|---|---|
| Plankton | Wet Season (November 2012) | Dry Season (May 2013) |
| Phytoplankton | $1.81 \times 10^{12}$ | $8.36 \times 10^{12}$ |
| Zooplankton | $6.39 \times 10^{4}$ | $3.26 \times 10^{5}$ |

Plankton B to fishes. During wet season, the mean lead concentration significantly increased from water to Plankton A ($p = 0.000$), insignificantly decreased from Plankton A to Plankton B ($p = 0.094$), then significantly decreased from Plankton B to fishes ($p = 0.000$).

The extent of lead biomagnification is only restricted to invertebrate predators (zooplankton groups represented as Plankton B). According to *Leeves* (*2011*), primary producers and organisms at lower trophic level (zooplankton) tend to have higher lead concentrations from water because of large surface to volume ratio and less developed methods for excretion. This may also be due to the ability of vertebrates to excrete heavy metals, in which many aquatic invertebrates do not (*Rubio-Franchini and Rico-Martínez 2011; Rubio-Franchini et al. 2008*).

In phytoplankton, metals are absorbed or adsorbed in the cell possibly by cation exchange. It is then diffused across the cell membrane and binds within the cell (*Hudson 1998*). There is a rapid equilibrium that only takes minutes or hours. There is a passive uptake. and once metal is in the cell, there are several transport mechanisms such as carrier proteins, passive diffusion of lipid-soluble metals (*Phinney and Bruland 1994*).

One manner in which zooplankton could acquire

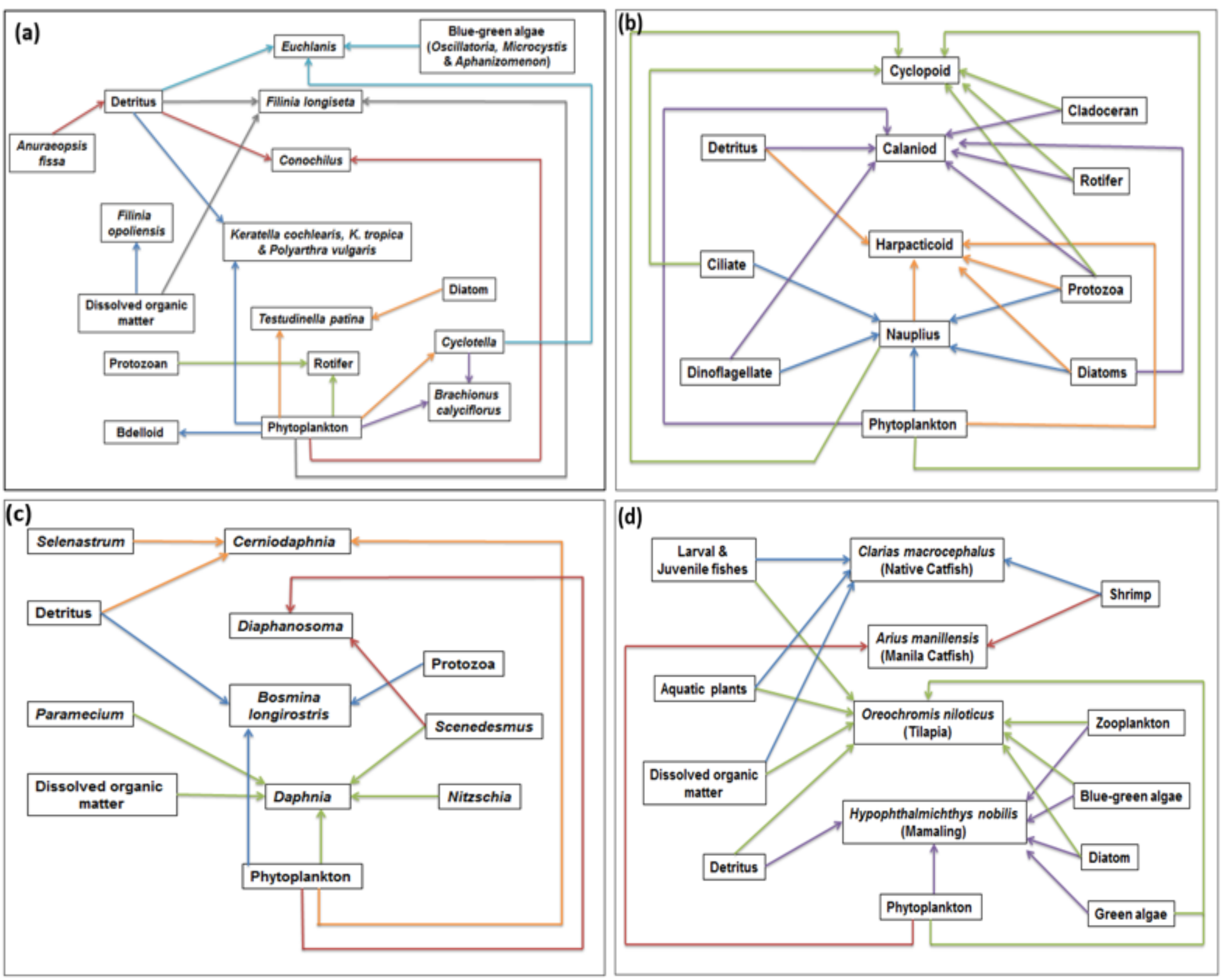


Figure 2. Proposed food webs in the open waters along Sta. Rosa subwatershed: (a) rotifers (b) copepods (c) cladocerans (d) fishes.

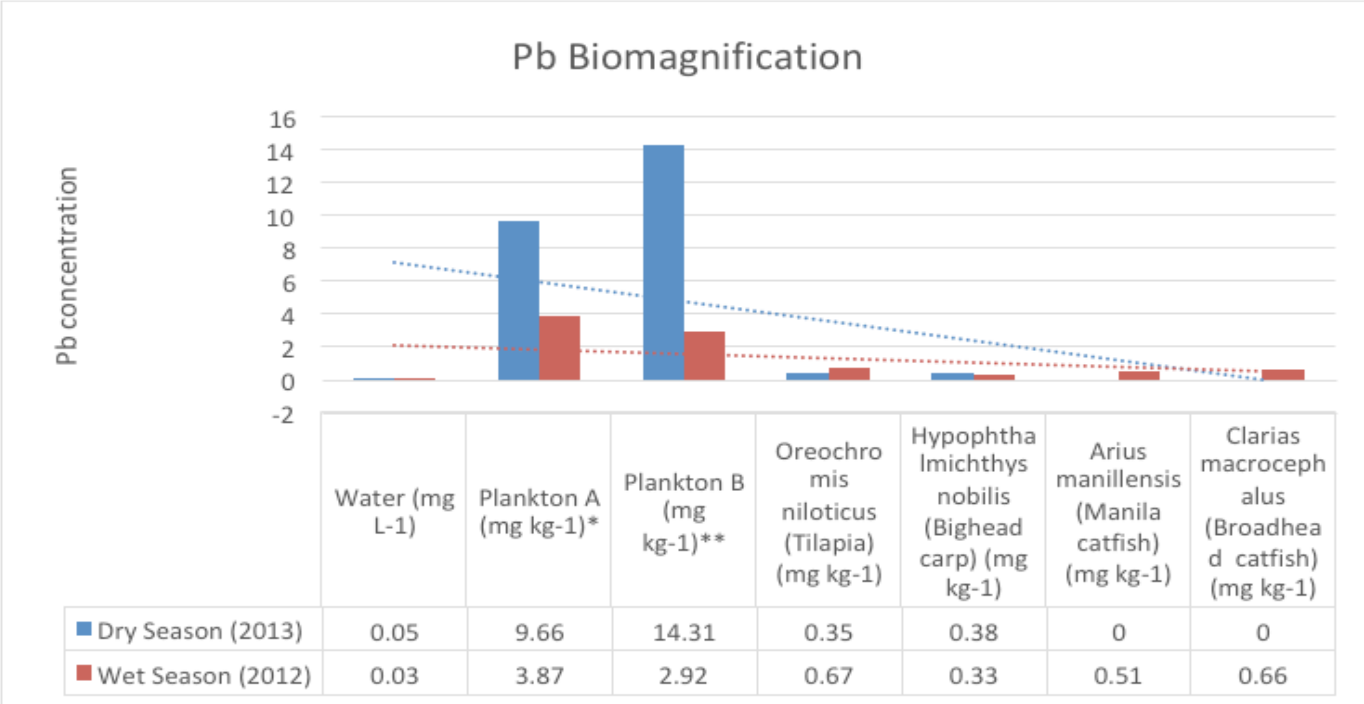


Figure 3. Average lead concentrations in samples from open waters of Sta. Rosa subwatershed during dry season (2013) and wet season (2012).

Assumptions based on plankton mean densities and filters used: *Plankton A: 70% Phytoplankton, 30% Zooplankton

metals is through ingesting phytoplankton. However, metal concentration that will be assimilated in their tissues will depend on the location of metal in the phytoplankton. When the metal is permeated in the algal cell, it will be absorbed in the tissues of zooplankton. When the metal is bound to the cell membrane, it will be bundled into fecal pellets that will be eliminated by the zooplankton. There is a rapid elimination in zooplankton because of simple gastrointestinal tract (*Reinfelder et al. 1998*).

Metal accumulation in fishes may be caused by dietary exposure to phytoplankton and zooplankton (*Arantes et al. 2016; Rubio-Franchini et al. 2015*). When there is elevated metal concentrations, aquatic organisms have the ability to detoxify and control toxicity. One way is through binding to metallothioneins (*Wepener 1997*). The formed complex could be excreted, recycled or stored in tissues. The absorption of Pb in fish muscles depend on the binding on a specific ligand (*Wepener 1997*). Therefore, aquatic organisms can regulate metal toxicity to maintain physiological functions.

## CONCLUSION AND RECOMMENDATIONS

Lead biomagnification was significantly increased from water to smaller plankton (mostly phytoplankton), then to larger plankton (mostly zooplankton) However, levels of lead in fishes did not follow biomagnification trend. For future studies, lead concentrations could be analyzed in different organs of fish such as muscle, gills, liver stomach and kidney to measure the total level of lead in fish. Total lead concentration in fishes, water, sediment, plankton and invertebrates (i.e. edible snails and shrimps) could be checked for biomagnification trends. Moreover, stable isotopes could be used to determine sources of lead and trophic status of biological samples. This is one method of determining biomagnification of lead in aquatic systems.

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## ACKNOWLEDGMENT

I would like to thank Department of Science and Technology Accelerated Science and Technology Human Resource Development Program (DOST-ASTHRDP) and Research Institute for Humanity and Nature (RIHN), Kyoto, Japan for the financial assistance of this research.