The effect of hydrochemical and other environmental variables on zooplankton communities in artificially connected ponds Highgate, London

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Abstract. Hydrochemical and other environmental variables can have impacts on zooplankton communities in artificially connected ponds. We examined five ponds environmental parameters by using lab equipment to identify and quality the zooplankton subsamples. From Shannon diversity figure and RDA analysis, indeed, environmental variables can affect the zooplankton communities in the ponds, and zooplankton communities varied in the different range in each pond.

1. Introduction

1.1. Natural and artificial aquatic bodies
Ponds, either natural or man-made, are often looked as a significant aquatic eco-system for farmland irrigation, flood protection, water supply, and fish production [1]. In the global scale, natural and artificial ponds still represent major percentage of the surface area of the standing freshwater resource, not all of them are in uniform distribution. Ponds and lakes, as small water reservoirs, are not expected to be rich in terms of biodiversity, because they tend to be physically and biologically unstable [2]. Mutual effects between physical and chemical profiles to water bio species are strongly connected with each other and bidirectional. Ecologically, many aquatic species and zooplanktons are important in defending surface water quality in many agricultural landscapes. Trophic state has been reported as a dynamic in biological abundance in aquatic area, such as nitrogen and phosphorus. However, exceeding nutrients will cause a serious environment issue, such as eutrophication; lack of fundamental nutrients may destroy the food chain in freshwater bodies [3].

1.2. Zooplankton

1.2.1. Basis information of zooplankton
Zooplankton is the common name given to many small species of animals found in fresh and marine waters throughout the world. The word zooplankton, derived from Greek, means "wandering animals." [4]. Planktons are organisms drifting in oceans, and bodies of fresh water. Zooplankton is an important ecological parameter in water monitoring and management schemes. Zooplankton species monitoring has been used widely in developed area research.

1.2.2. General factors which can influence the freshwater zooplankton community
Zooplankton community structure can be affected by biotic and abiotic factors within the freshwater zones. An abundance of zooplankton is related to many factors, such as water hydrochemistry, season, lake morphology, presence of macrophytes, predators etc., and related to the productivity of a lake, for example, lake trophic condition [5]. Global warming can influence the zooplankton directly. Most species of phytoplankton and
zooplankton can endure temperatures more than those now being forecast. Relatively subtle shifts in species dominance are brought form changes in the frequency and intensity of wind-induced mixing [6]. A study suggested that environment indexes, such as altitude, agricultural development, and geological morphology, in both local and regional can produce bio-patterns of zooplankton species composition and diversity in reservoirs [7]. Both natural profiles and anthropogenic changes in lake and watersheds can potentially influence zooplankton community structure [8]-[10]. Hydro-chemical materials in pond and lakes can literally affect freshwater zooplankton community in uncertain extents, such as total phosphorus, dissolved oxygen, soluble reaction phosphorus, and Nitrite Nitrogen. Some zooplankton studies focused on the impacts of ecosystem connectivity [11]. Examined zooplankton communities in ponds with and without artificial connections, and found that unconnected ponds were significantly correlated to environmental and distance factors.

1.3. Aims
This project aimed to access the zooplankton communities in five artificially connected ponds. The objectives were: (1) to provide the description of zooplankton communities, (2) to explore to discuss the relationships between the environment variables of the ponds and zooplankton communities. The main hypothesis: (1) total phosphorus can significantly influence the zooplankton communities; (2) Dissolved Oxygen is the subordinate factor of the zooplankton communities.

2. Method
2.1. Study sites
Highgate ponds chain was initially dug in the 17th and 18th centuries and currently is located in the eastern of Hampstead Heath Park, London. Five freshwater ponds constitute the Highgate chain; they are Stork pond, Bird Sanctuary pond, Model Boating pond, Highgate Men’s Bathing Pond, and Highgate No.1 pond. The elevation gradient of Highgate Chain is from 87.97m to 65.5m, and all of the ponds are artificially connected by one or two water channels (which called spillway in Highgate Chain). Thus, the aquatic chain has high intra-communication in water chemistry and biology.

Stock pond (area, 4,401 m²; elevation, 87.97 m) is located in the north part of Highgate Chain and completely surrounded by deciduous vegetation. Bird Sanctuary pond (area, 7,694 m²; elevation, 78.20 m) is surrounded by overhung deciduous. The pond littoral zone was dominated by emergent macrophytes with no record of submerged vegetation. Model Boating pond (area, 16,280m²; elevation, 76.01 m) is an open and public accessible pond. Little bankside vegetation could be found in the area because of the surrounding reinforced concrete. Men’s Bathing Pond (area, 18,250 m²; elevation, 70.8m) is the deepest and largest pond in this pond chain. The majority of the pond is surrounded by bankside trees in east and west sides. Highgate NO.1 pond (area, 13,660 m²; elevation, 65.5m) is located in the south of the Highgate Chain. Dog is only allowed in this pond and can cause physical disturbance to an uncertain extent.

2.2. Sampling Methodology
2.2.1. Water sampling
All sampling bottles should be washed by 2% hydrochloric acid, distilled water and deionized water in order. In each pond, two 250 ml un-filtered water samples (open water and littoral zone) were collected for Total Phosphorus (TP) analysis using bottle samples. And for Nitrate Nitrogen and Soluble Reactive Phosphorus analysis, two 250ml filtered water samples were collected for each site.

2.2.2. Zooplankton sampling
Vertical core tube and a 53-μm mesh Wisconsin bucket zooplankton net have been used to collect zooplankton. Zooplankton samples were taken from open water and littoral zone parts of each pond.

2.3. Laboratory works
2.3.1. Water chemistry and chlorophyll a analysis
Chlorophyll a concentration can be calculated as the following equation:
\[
\text{chlorophyll a} = \frac{11.0(A663)}{V(d)}
\]
Where: \(A_{663}=\) absorbance at 663
\(v=\) volume (ml) of 90\% acetone used for extraction (in this case 10ml) 
\(V=\) volume of water filtered (in liters) 
\(d=\) path length (cm) of the spectrophotometer cell (in this case 1cm) 

2.3.2. Zooplankton identification and count 
Using counting cell (1ml with 20×50 micro squares) and Leico microscope is the way to identify and quantify the zooplankton subsamples. Open water and littoral zone zooplankton communities were counted and recorded separately.

2.4. Cluster analysis 
Diversity in each pond was used to compare the species diversities between connected ponds. To reveal the relationships between zooplankton communities and environmental parameters, canonical ordination was used in analysis. Fish predation level, dissolved oxygen, Chlorophyll \(\alpha\), total phosphorus, and nitrogen were picked as environmental variables in RDA analysis systematically.

3. Result 

3.1. Limnological characteristics 

3.1.1. Conductivity in the ponds 
According to the data taken (Tab.1), the conductivity in Bird Sanctuary Pond was the highest among Highgate Ponds Chain (460.5). The conductivity of Men’s Bathing Pond (385.71) was the lowest.

3.1.2. Chlorophyll \(\alpha\) in the ponds 
Based on the presented data (Tab.1), Highgate NO.1 Pond which is located in the south of the Highgate Chain had the highest Chlo \(\alpha\) (172.85μg/L). The top pond named Stock Pond had lowest Chlo \(\alpha\) in the result.

| Table 1. The basic information of the highgate ponds |
|-----------------------------------|
| Pond code | Stock | Bird | Boating | Men’s | No.1 |
| Elevation (m) | 87.97 | 78.2 | 76.01 | 70.8 | 65.5 |
| Area (m\(^2\)) | 4401 | 7694 | 16780 | 18250 | 13600 |
| Volume(m\(^3\)) | 3400 | 7500 | 32900 | 42900 | 22300 |
| Conductivity | 447.33 | 460.5 | 421.62 | 385.71 | 393.57 |
| Chlo \(\alpha\) (μg L\(^{-1}\)) | 9.48 | 17.26 | 19.9 | 65.86 | 172.85 |

3.2. Zooplankton in each pond 

3.2.1. Zooplankton species 
Highgate Ponds Chain was the habitat for fifteen kinds of zooplankton species in the sampling period; they were Cyclopoid copepoda, Daphnia, Bosmina, Capepoda nauplus, Diaptmus, Kellicottia, Keratella cochlearis, Brachionus, Keratella quadrata, Asplanchna, Filinia, Polyarthra, Notcholca, Sida crystallina, and Scapholeberis. Total number of zooplankton in Bird Sanctuary Pond (6630 Ind L\(^{-1}\)) was the highest. Especially for Keratella cochlearis, it represented 5014 Ind L\(^{-1}\) in Bird Sanctuary Pond. The second pond which had higher total number of zooplankton species was Men’s Bathing Pond (3534 Ind L\(^{-1}\)); Kellicottia dominated the total number of zooplankton in this pond was 2560 Ind L\(^{-1}\). The next two ponds were Model Boating Pond (184 Ind L\(^{-1}\)) and Highgate NO.1 Pond (1734 Ind L\(^{-1}\)). Model Boating Pond had a high number of Bosmina (875 Ind L\(^{-1}\)).

3.2.2. Zooplankton species richness 
Three main species groups in each pond were Rotifer, Cladocera, and Copepod (Figure.1). The percentage of Rotifer group in Bird Sanctuary Pond was up to 90.00\%, the next was 80.00\% in Men ‘s Bathing Pond and Rotifer group in the whole Ponds Chain was around 75.00\%. Cladocera occupied the half of species group in Model Boating Pond, and more than 40.00\% in the NO.1 Pond. Copepod dwelled much in Stock Pond but less in other four ponds.
The Shannon Diversity was a typical index to represent the species diversity in freshwater biology. Figure 2 listed the Shannon Diversity for the target five ponds. No.1 Pond had highest Shannon Diversity value of 7.77. However, the lowest reservoir was Bird Sanctuary with value of 1.15.

3.3. Chemical substances in each pond

Highgate No.1 Pond had 13.27 mg∙L\(^{-1}\) oxygen and the oxygen content was the highest among five ponds. Men’s Bathing Pond (9.11 mg∙L\(^{-1}\)) ranked second, and then was Model Boating Pond (6.35 mg∙L\(^{-1}\)). The forth one and fifth one were Bird Sanctuary and Stock Pond.

Table 2. The composition of zooplankton species in each pond

| Species          | Stock | Bird | Boating | Men’s | No.1 |
|------------------|-------|------|---------|-------|------|
| Cyclopid copepoda | 105   | 216  | 3       | 97    | 81   |
| Daphnia          | 112   | 4    | 22      | 401   | 266  |
| Bosmina          | 15    | 92   | 875     | 11    | 402  |
| Copepoda Nauplius | 16    | 215  | 61      | 116   | 9    |
| Diaptomus        | 94    |      |         |       | 5    |
| Kellicottia      | 35    | 209  | 2560    | 358   |      |
| Keratella cochlearis | 28 | 5014 | 223     | 165   | 189  |
| Brachionus       |       |      |         | 19    | 18   |
| Keratella Quadrata | 12 | 314  | 5       | 20    | 21   |
| Asplanchna       | 393   | 68   |         |       |      |
| Filinia          |       | 168  |         | 82    |      |
| Polyarthra       | 244   | 115  |         | 5     |      |
| Notholca         | 1     | 48   | 77      | 66    |      |
| Sida crystallina | 15    | 31   | 6       | 64    | 117  |
| Scapholeb eris   | 71    | 19   | 18      | 22    |      |
| Total Number(in d∙L\(^{-1}\)) | 399 | 6630 | 1841 | 3534 | 1734 |

Figure 1. The percentage of three zooplankton groups in each pond

The highest SRP (soluble reactive phosphorus) was in No.1 Pond, the next one was in Bird Sanctuary Pond. The other pond which had SRP more than 100 mg∙L\(^{-1}\) was Stock Pond. Then, the rest ponds had less than 100 mg∙L\(^{-1}\) SRP.
Highgate No.1 Pond had the highest total Phosphorus which was 610.09 (μg/L), Bird Sanctuary and Stock Pond had 262.68 (μg∙L⁻¹) and 203.72 (μg∙L⁻¹) TP respectively. The next two ponds were Boating Pond and Men’s Bathing Pond.

Men’s Bathing Pond had the lowest content of NN (Nitrate Nitrogen), 0.155 (mg∙L⁻¹). Boating Pond, and Stock Pond had more NN. The higher one was in Bird Pond. No.1 pond had the highest content of NN.

Figure 2. Shannon Diversity for each pond.

| Pond code | Stock | Bird | Boating | Men’s | No.1 |
|-----------|-------|------|---------|-------|------|
| Oxygen (mg∙L⁻¹) | 3.16  | 5.44 | 6.35   | 9.11  | 13.27 |
| SRP (μg∙L⁻¹) | 152.41 | 237.38 | 42.64 | 14.06 | 416.33 |
| TP (μg∙L⁻¹) | 203.72 | 262.68 | 76.68 | 52.12 | 610.09 |
| NN (mg∙L⁻¹) | 0.82  | 1.008 | 0.249  | 0.155 | 2.256 |

3.4. Environmental variables
Conductivity caused decrease of *Daphnia* and *Kellicot*. And for *Bosmina*, the number increased initially and then it nearly reached to zero. And *Keratella cochlearis* increased rapidly.

Figure 3. Generalized Linear Models shows the relationship between conductivity and zooplankton.

Total phosphorus had a mainly influence on *Kellicottia*, and made it increase. *Keratella cochlearis* initially increased and then decreased as the total phosphorus increased.

Figure 4. Generalized Linear Models shows the relationship between total phosphorus and zooplankton.
When the number of predation reached around one, *Keratella cochlearis*, *Daphnia* and *Bosmina* fell to zero but *Bosmina* started to rise then. And the curve of *Daphnia* was symmetrical from negative x-axis to positive x-axis. *Kellicottia* increased and then decreased.

![Figure 5](image-url) Generalized Linear Models shows the relationship between fish predators and zooplankton

When Chlo α increased, *Bosmina* fell first and then increased. But for *Daphnia*, it rose at first and fell finally.

![Figure 6](image-url) Generalized Linear Models shows the relationship between chlorophyll α and zooplankton.

*Keratella cochlearis* and *Kellicot* rose firstly and then fell in different time but they all became zero when the number of dissolved oxygen was two. The slope of *Bosmina* and *Daphnia* was upward originally and then downward.

![Figure 7](image-url) Generalized Linear Models shows the relationship between dissolved oxygen and zooplankton.

![Figure 8](image-url) Redundancy analysis (RDA) bi-plot of zooplankton species and environmental variables.
From Fig. 8, conductivity had the positive correlation with *Kerat q* mainly, and had negative correlation with *Notholca*. It was the main factor which could cause a change in zooplankton communities. Predation was proportional to the communities of *Filinia, Kellicot and Brachion* and inversely proportional to *Cyclopid*. Total phosphorus had relatively less impact on zooplankton communities but also could cause a decrease of *Kellicot* as it fell. The increase of dissolved oxygen might result an increase on *Notholca* or a decrease on *Keratella quadrata* and *Cyclopid*. While chlorophyll α increased, *Notholca* increased extremely. In addition, it almost had no influence on *Scaphohoe*.

4. Discussion

4.1. Zooplankton species richness and diversity

Generally, two process categories, local processes (e.g., environmental heterogeneity and species interactions) and regional processes (e.g., dispersal, connectivity), are the main factors which can influence the community composition and species diversity [12]-[14]. Besides the general impacts, local factors have effects on zooplankton species richness which have been determined: lake area and primary productivity [15], [16], [10], water quality [17], [18], lake depth [19], latitude [20], nutrients [17], [21], predation and competition [22].

From the result, the data showed that zooplankton communities in each pond were highly fluctuated. Reference [23] indicated that within the finite range in habitat sizes of the ponds studied, the number of species had no statistic relationship with the ponds area. In Highgate Pond Chain, the relationship between the ponds area and zooplankton communities was not distinct. The largest area in the target chain was Men’s Bath-18250 m² and the smallest one was 4401 m². The number of zooplankton in Men’s Bathing Pond was relatively high, and that in Stock Pond, the smallest zone, was dramatically tiny refer to the study. Based on the field observation, Bird Pond, the pond with a plenty of vegetation coverage on and around it, had richest species. However, Bird Pond held an extreme difference in aspect of area to Men’s Bath Pond. Therefore, zooplankton communities were not correlated with area obviously.

Refer to the local geography, Stock Pond was in the highest elevation of 87.97m, and No.1 Highgate Pond sited in 65.6m. However, the total number of zooplankton communities in Stock Pond was the least, and remarkably less than No.1 Highgate Pond. Thus, the elevation in Highgate Pond Chain is not the factor which can negatively influence the zooplankton in local. In addition, the elevation difference between each pond in this study is not remarkable, so that the elevation of each pond technically has no marked influence on the zooplankton communities. The tiny difference in elevation typically could be ignored during the biological study. Water body depth was regarded as a fundamental index in biological studies as well. According to the basic information of Highgate Pond Chain, Highgate Men’s Bathing Pond was the deepest one (>2.5m), and Stock Pond was the shallowest one among the five ponds. However, the depth of these ponds was not related to the zooplankton species richness, the species richness in these two ponds were both relatively high from the result, and statistical correlation was not obvious.

The Highgate pond field work records showed that the Stock Pond had many branches and leaves covered on water, and the de-composition activity was relatively vibrant. This was the primary factor causing the great consumption of dissolved oxygen. Therefore, this reason shall be placed as major account of zooplankton community deficiency. Only a few bankside vegetations could be found around Model Boating Pond and the banks were entirely re-enforced. Therefore, the solar accessibility in Model Boating Pond was considerable. In contrast, Men’s Bathing and Stock Ponds had enormous crown coverage above the water body. Hence, the sunlight was not available to some extent in these two ponds. Correspondingly, *Bosmina* was richest in Boating Pond and scarce in Men’s Bathing and Stock Ponds. As a result, the surrounding of each pond and the solar accessibility could positively impact on the species richness, in this study area.

Diversity has been regarded as a significant indicator in biological survey, usually focused on species richness and distribution. Three possible explanations were considered to illustrate the low diversity: low richness and uniform distribution, high richness but with dominate species and low richness with dominated species. Mathematically, nearly all 13 zooplankton species were uniformly distributed in No.1 Highgate Pond. Therefore, the Shannon Diversity for this pond was dramatically larger than others. The Shannon Diversity was the lowest in Bird Sanctuary Pond; however the total number of zooplankton species was the highest. One remarkable factor that could determine the low Diversity parameter was the extreme dominance species- *Keratella cochlearis*.

4.2. The relationship between environmental variables and the zooplankton communities in Highgate Pond.

RDA analyses showed that conductivity, dissolved oxygen, chlorophyll α were the most significant environmental variables in Highgate ponds. Reference [24] performed a research and found that 41 percent of the variance in species richness could be contributed to conductivity. Conductivity was positively correlative with
eight zooplankton species and negatively related to seven species, and especially it had the largest influence on species. Literally, conductivity was regarding to the number of removable and accessible ions in the ponds. Some zooplankton species were able to adapt the aquatic environment easily but some were not. On the basis of the result (Figure 3), when the value of conductivity rose, the number of *Kellicot* and *Keratella cochlearis* was altered. Since *Kellicot* decreased extremely, this species was vulnerable against the conductivity, and also *Kerat c* increased exceedingly, the tolerance was smaller than *Kellicot*. In addition, *Daphnia* fell as *Bosmina* increased in a certain interval that the conductivity maintained in low numeric values. These two zooplankton species had a typically competitive relationship to each other.

Dissolved oxygen ranked second in influencing the communities of zooplanktons, and this index was able to drive eight species in positive direction, as well as seven species in negative correlation. This parameter stood opposite to the conductivity in RDA analysis. Species *Keratella cochlearis* increased initially and decreased with the richness of dissolved oxygen. Dramatically, species *Kellicot* increased rapidly when the community of *Keratella cochlearis* was decreased. Therefore, the most reasonable explanation was the competitive relationship between these two species within this certain ecological environment. Even *Bosmina* and *Daphnia* had a less amount; the tolerance of them was nearly same as that of *Keratella cochlearis*. The peak of *Kellicot* was overly high in species; however its environment tolerance was comparatively lower than others. The dissolved content for oxygen in Bird Sanctuary Pond was the most suitable for *Keratella cochlearis* to survive, since DO in this pond was not extremely high or low.

Predation also was a factor which can impact zooplankton species, whereas the influence was not significant, because of the intensive competition between species. For example, the competition between *Daphnia* and *Bosmina* also existed. Past studies suggested that fish predation could impact the density of zooplankton; however, most studies had not clearly presented the influence in details. Same scenario could be found in Highgate Pond chain.

In Highgate pond chain, the chlorophyll *α* distribution was disordered without any linear relationships. Chemically, Dissolved Oxygen content was dramatically important to the trend of Chlo *α*. Highgate No.1 pond was characterized by high density of algae and plankton (high chlo *α*), *Kerat c* was extremely increased as the content of Chlo *α* had been raised; therefore the tolerance community change of the species against Chlo *α* was not obvious. From figure 3, the comparative relationship between *Daphnia* and *Bosmina* could be extracted as well, and the tolerance of them was identity and relatively in a high level. In Boating Pond, the content of Chlo *α* was ranked in the middle. However, *Bosmina* in the pond was the highest among these five ponds, and *Bosmina* was the dominated species in this target pond. This result was different to the relationship with chlo *α*, and the reason could be explained by other factors, such as the competition, nutrients and physical phases. Therefore, low dissolved oxygen and primary productivity restricted the zooplankton composition, richness and diversity. Whereas, the data maintained that these two factors could not determine the composition of zooplankton. As a result, the matrix of environment in Highgate Pond chain was complex and disordered.

Nutrient, for an outstanding example: total phosphorus, was unable to affect species intensively. The content level distribution within these five ponds was obviously. Boating and Men’s had dramatically low TP content, in contrast, the TP content in other three reservoirs were visually high. For stock pond, the deposition of TP was regarded as main activities of the biological nutrient activities. For bird and no.1, the biological activities were obviously extreme, and the nutrients physical input was relatively higher than others. According to the local survey, Boating and Men’s Bathing Ponds were maintained by anthropogenic activities. Park volunteers cleaned up these two ponds, by algae salvage. TP was inversely related with these two species and positively related to s even species, and especially it had the largest influe nce on the richness of dissolved oxygen. Dramatically, species *Keratella cochlearis* was extremely increased as the content of Chlo *α* had been raised; therefore the tolerance community change of the species against Chlo *α* was not obvious. From figure 3, the comparative relationship between *Daphnia* and *Bosmina* could be extracted as well, and the tolerance of them was identity and relatively in a high level. In Boating Pond, the content of Chlo *α* was ranked in the middle. However, *Bosmina* in the pond was the highest among these five ponds, and *Bosmina* was the dominated species in this target pond. This result was different to the relationship with chlo *α*, and the reason could be explained by other factors, such as the competition, nutrients and physical phases. Therefore, low dissolved oxygen and primary productivity restricted the zooplankton composition, richness and diversity. Whereas, the data maintained that these two factors could not determine the composition of zooplankton. As a result, the matrix of environment in Highgate Pond chain was complex and disordered.

5. Conclusion
This study clearly indicated that conductivity, chlorophyll *α*, dissolved oxygen and predation can be important factors to influence zooplankton communities, including species richness, diversity and distribution, in Highgate Chain, London. Conductivity could be regarded as the most significant indicator to alter the ecological structure
of zooplankton. As each pond has different physical and chemical environmental variables, the zooplankton communities were generally in high diversity. Some variables showed highly influence on zooplankton distribution in other papers were not important here.

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