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Markov Chain and Cluster Model of Green Algae Phytoplankton (Chlorophyceae) Diversity and Spatial Distribution Pattern along Stream, Water Quality, and Land Use Gradients in Krukut River, Jakarta City

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Abstract

Green algae phytoplankton (Chlorophyceae) have a wide aquatic distribution, including saltwater and freshwater environments. Compared to the ones living in saltwater, green algae diversity in freshwater ecosystems in rivers is influenced by stream gradients, water quality, and land uses. Meanwhile, in Jakarta, 17 rivers have the potential to provide a habitat for green algae communities. Due to anthropogenic activities, river streams have been affected by influences that may affect the water quality and green algae community along stream gradients. One of the critical rivers in Jakarta is the Krukut river, which has the most extended stream spanning over 40 km and downstream in Jakarta bay. This study aims to model the diversity and distribution pattern of green algae in the Krukut river from its upstream segment in Jakarta city, surrounded by settlements, to the downstream segments in Jakarta bay. The distribution model uses the Cluster Analysis and Markov Chain Model to elaborate the probabilities of green algae phytoplankton distribution in downstream, midstream, and upstream segments of the Krukut river. The results show that 7 species of Chlorophyceae have been recorded in the Krukut river. All species had a high likelihood of being found downstream, particularly Cosmarium sp., Eudorina sp., Spyrogyra sp., and Volvox sp. Regarding distribution, all phytoplankton species have a high probability (4%–31%) and tendency to be distributed from upstream and midstream to downstream rather than from downstream to midstream and upstream, with probability ranges of 2%–27%. The probability and tendency of phytoplankton distribution towards downstream directions avoiding upstream were related to the deteriorating water quality in the upstream, characterized by high turbidity, low dissolved oxygen, and more acidic water.

Keywords: *distribution, Chlorophyceae, cluster, Markov chain, river*

1. Introduction

Phytoplankton is known as the earth's vascular organ's least primary producer. Phytoplankton is predominantly planktonic algae that, together with benthic algae and macrophytes, constitute the autochthonous primary producers in aquatic ecosystems, including freshwater ecosystems that range from lakes, rivers, and streams. Phytoplankton form part of the basis of the food web in terms of energy and material input in riverine ecosystems, including rivers in urban ecosystems and cities [1]. Chlorophyceae or green phytoplankton are primarily aquatic organisms that live in fresh or salt water. Freshwater forms in ponds, lakes, streams, rivers, and reservoirs. Chlorophyceae has a vital role in the aquatic

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environment since it has chlorophyll a that allows this phytoplankton to be a producer. Chlorophyceae can be found in various habitats on earth, including the sea, rivers, and lakes; on soil and walls; in animals and plants; and pretty much anywhere there is light to perform photosynthesis. With more Chlorophyceae forms being identified for commercialization, microorganisms play an increasingly important role, particularly in aquatic habitats. There must be hundreds of natural forms with different characteristics for every identified and proven species. A city like Jakarta should be recognized for the presence of a diverse range of aquatic forms, such as Chlorophyceae, considering the presence of urban water bodies that include lakes and rivers.

River in a city can provide a suitable habitat and ecosystem that can support the biodiversity of phytoplankton. In the West Banjir Kanal River passing through Semarang City, Khaqiqoh et al. [2] have recorded 4 phytoplankton families and up to 19 genera. The Shannon-Wiener diversity index (H') in the West Banjir Kanal River ranged from the lowest 0.20 to the highest 1.96. In the West Banjir Kanal River, the phytoplankton genera Nitszchia and Melosira were observed as the most abundant and common phytoplankton genera. The abundance of Nitszchia was 780 individuals/l and 2522 individuals/l for Melosira. The phytoplankton genera with the lowest abundance were observed in Ceratium, with an abundance as low as 6 individuals per liter. While in the Cisadane river in Tangerang city, Rosarina and Rosanti [3] have recorded 19 phytoplankton species. In the Cisadane river, those phytoplankton species have a Shannon-Wiener diversity index (H') ranging from 2.21 to 2.41, indicating high diversity. The highest phytoplankton abundance was observed in Synedra ulna species, with an abundance of 8.13 individuals/liter. In contrast, the lowest phytoplankton abundance was observed in Oscillatoria limosa, Anabaena spiroides, and Trachelomonas oblonga with an abundance of 0.63 individuals/liter.

Jakarta is one of Indonesia's cities with numerous aquatic ecosystems in the form of rivers. In total, 17 rivers pass through Jakarta, consisting of natural and artificial rivers, including Cengkareng and Cakung drains [4]. Based on its location, the river in Jakarta is distributed in the west, central, and east parts of Jakarta. In the west, the rivers include Mookevart, Angke, Pesanggrahan, Grogol, Krukur, Krukut Baru, and Cengkareng drain. The rivers in the central parts include Ciliwung, Banjir Kanal Barat, and Kalibaru Timur. Cakung drain, Banjir Kanal Timur, Cakung, Jati Kramat, Buaran, Sunter, and Cipinang Rivers are located in the eastern parts of Jakarta. In the western parts, the Krukut river is the longest river spanning over 40 km. According to recent studies, rivers in Jakarta city are suitable marine ecosystems as plankton habitats since the water quality in rivers in Jakarta is tolerable for plankton. Research carried out by Pambudi et al. [5] in the Ciliwung river has found about 53 genera of plankton representing Bacillariophyta, Chlorophyta, Chrysophyta, Cyanophyta, and Rhodophyta. The plankton abundance ranged from 1495 individuals per liter to 2511 individuals per liter. At the same time, the Shannon-Wiener diversity index (H') ranged from 1.21 to 2.6 in Ciliwung [6].

Considering the areas of the Krukut river that can potentially be the phytoplankton habitat in urbanized areas of Jakarta City, this study first aims to map the spatial distributions of Chlorophyceae along with the water quality in the Krukut river. Second, the spatial distribution patterns of Chlorophyceae in the Krukut river's downstream, midstream, and upstream segments were modeled using the Markov chain. The results of this study will contribute to the conservation of Chlorophyceae within urban aquatic ecosystems.

2. Methodology

2.1. Study Area

The study area was a segment of the Krukut river with its surrounding land uses (Figure 1). The studied segment of the Krukut river has a total length of 40 km and a width of 10 m, with a longitude of 106.75320^0-106.77500^0 East and a latitude of 6.13570^0-6.22050^0 South. For sampling purposes, the river was divided into three segments: downstream, midstream, and upstream. The downstream of the Krukut river in the north was directly bordered by Jakarta bay. The land uses that surrounded the river were dominated by built land uses, followed by combinations of vegetation and bare land uses. The debit of the Krukut river was 135 $m^{3,}$ and it received a daily rainfall of 129 mm/day. According to Hambali [4], water debit in the Krukut river can reach 869.299 m^3 during the rainy season and occur for at least 75 hours, or approximately 3 days.

Sampling activities were conducted for one day in each location (downstream, midstream, and upstream) in August 2021. Sampling activities were replicated 3 times in one month, for a total of 9 sampling times covering 3 locations and 3 replications.

2.2. Water quality samplings

The water quality survey includes in situ water dissolved oxygen (DO), turbidity, and pH measurements. Those water quality variables were measured in each sampling location with 3 replications for each location (Table 1). DO was measured using a multi-parameter (Lutron DO 5510), pH with a pH meter (Lutron PH 208), and turbidity with a turbidity meter (Ezdo TUB-430). The geographical locations of samplings were recorded using an Etrex Garmin GPS handheld.

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Table 1. Phytoplankton and water quality variables

Variables	Unit	Measurement methods
Phytoplankton	Cells/ml	Norpac plankton net, counting chambers
Dissolved oxygen (DO)	mg/L	Lutron DO 5510 multi-parameter
pH	na	Lutron PH 208
Turbidity	NTU	Ezdo TUB-430
Geocoordinate	Decimal degree	Garmin Etrex GPS handheld

2.3. Phytoplankton and Chlorophyceae samplings

The phytoplankton and Chlorophyceae were collected from water in each site using a modified plankton net with a mesh size of 150 microns, as described by Sidabutar et al. [7]. Collected samples were stored in bottles and preserved in 37% formaldehyde [8]. The filtered water volume was calculated using the equation v = r^2 multiplied by d, with v: filtered water volume; r: radiant of net opening; and d: plankton net depth lowered into the water. Phytoplankton and Chlorophyceae were identified using a light microscope with 400x and 1000x magnifications. The classification was carried out based on published literature on the algal taxonomy using the Book of Illustrations of the Marine Plankton of Japan by Yamaji [9] and the Book of Marine Phytoplankton of the Western Pacific by Omura et al. [10]. Phytoplankton and Chlorophyceae abundance counting was performed using Sedgwick Rafter counting chambers and the obtained abundance results were expressed in cells/ml.

2.4. Mapping and spatial analysis

Mapping and spatial distribution analysis of Chlorophyceae, water quality, and land use types consisted of developing the presence map of those variables and then the interpolation to estimate those variables' patterns. First, the recorded geo coordinate of Chlorophyceae, water quality, and land use variables in each river segment were tabulated into the table. Then, the recorded data in the table were mapped using Geographical Information System (GIS) with ArcView version 3.2 to pinpoint the geo-locations of Chlorophyceae, water quality, and land use variables in 3 segments of the Krukut river. The tabulated GIS tables containing Chlorophyceae, water quality, and land use variables were interpolated [11, 12, 13] to create a pattern map.

2.5. Chlorophyceae diversity

Chlorophyceae diversity was calculated and presented using the Lorenz graph. This graph indicated diversity based on the evenness. Within the Lorenz graph, the diversity was measured based on the curve shapes under the diagonal line representing the evenness. The farther the curve off the line of evenness lines, then the more diverse the certain species become and the more uneven the abundance of each species becomes [14, 15, 16].

2.6. Chlorophyceae cluster model

Cluster methods aim to determine the concentrations and hotspots of the Chlorophyceae community in 3 studied river segments follow current methods [17]. The input data were the abundances of Chlorophyceae species in each river species and were presented as points in the GIS interface. Cluster analysis was conducted using an extension of GIS, and the cluster calculation was based on the K-means method. This method uses an algorithm that assigns each point to the cluster whose center, or known centroid, is nearest [18]. The center is the average of all the points in the cluster, and the coordinates of the points are the arithmetic mean for each dimension separately over all the points in the cluster. The determination of the centroid, or cluster point, was as follows:

$$\mathrm{z1} = \frac{x1 + y1}{2}, z2 = \frac{x2 + y2}{2}, z3 = \frac{x3 + y3}{2}$$

with: z = centroid, x = coordinate in axis x, y = coordinate in axis y

2.7. Chlorophyceae Markov chain model

A Markov chain [19, 20] is a model consisting of and representing the probabilities of a certain state and the probabilities of transition between states. A Markov chain uses transition probabilities to describe the transitions between a given set of states. The set of possible states is called state space. In this study, the state is the 3 river segments, including downstream, midstream, and upstream. Transition

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probabilities describe the transition of Chlorophyceae between river segments in the chain as a conditional probability.

To run the Markov chain model [21], our study follows standard textbook treatments of Markov chains. Let $Z_t \in S$ denote the state a discrete-time Markov chain is in at t = 0,1,2,…, for some finite state space S consisting of m states. The transitions between states are governed by transition probabilities $\Pr(Z_{t+1} = s_j | Z_t = s_i) = p_{ij}$ with $s_i, s_j \in S$, which capture the probability of Chlorophyceae moving from state s_i at time t to state s_j at time t + 1. Transition probabilities only depend on the current state the Markov chain is in at time t, and not on any previous states at t−1,t−2, …..

3. Results and Discussion

3.1. Water quality spatial distribution

The result of comprehensive water quality spatial distributions in the Krukut river is presented in Figure 2. The measured water quality variables consisted of turbidity, dissolved oxygen, and pH with value ranges of 20.5-64.0 NTU, 6.0-11.0 mg/l, and 4.5-7.5. along streams of Krukut river, Jakarta city. The turbidity values were observed lower downstream and higher upstream. The water downstream near Jakarta bay was clearer than other river segments.

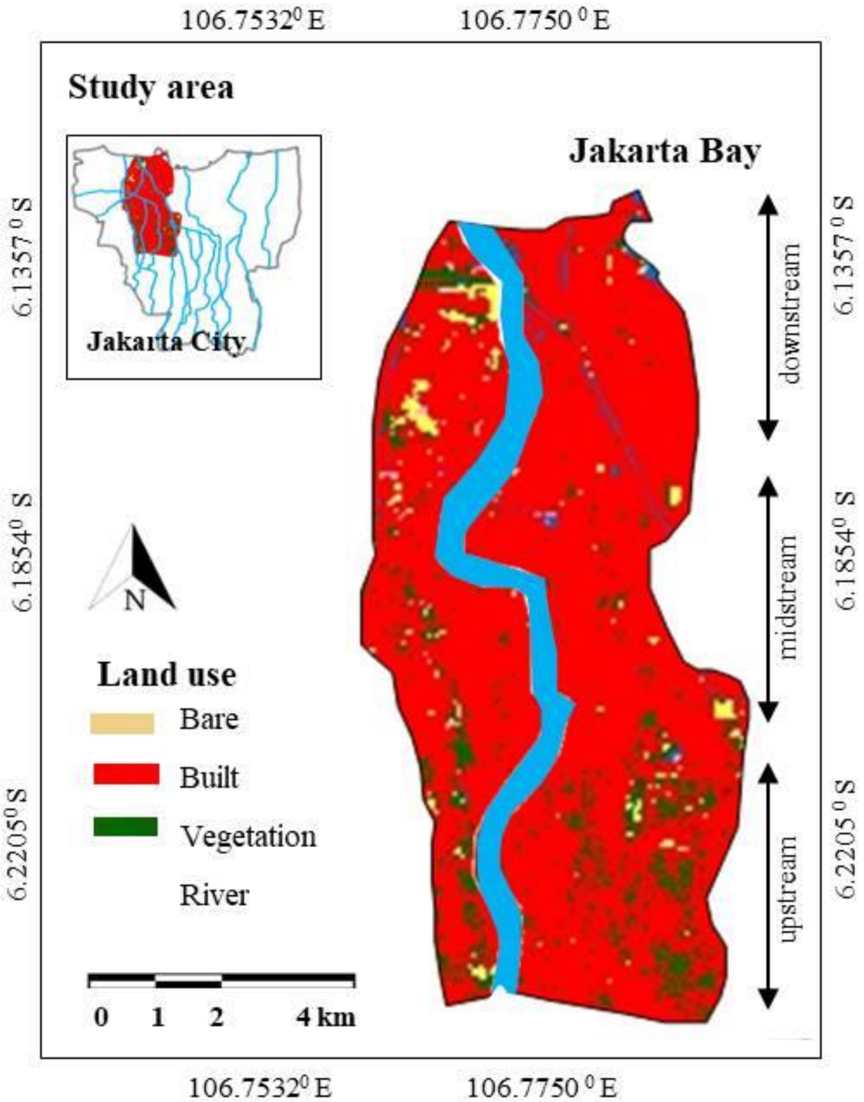

Figure 1. Study area and sampling locations in upstream, midstream, and downstream segments of Krukut river, Jakarta city.

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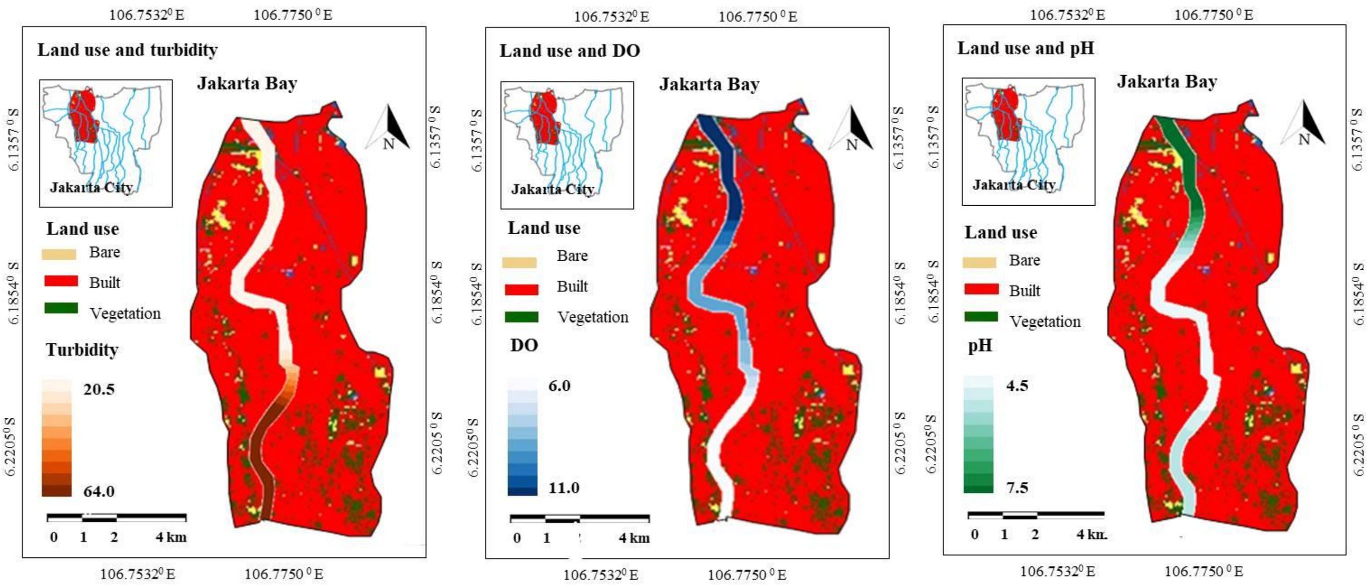

Figure 2. Spatial patterns of water quality variables, including turbidity (20.5-64.0 NTU), dissolved oxygen (6.0-11.0 mg/l), and pH (4.5-7.5) overlaid with land use types in upstream, midstream, and downstream of Krukut river, Jakarta city.

In contrast, the segments in upstream segments were murkier than those downstream. Similar patterns were also observed for DO and pH variables. The downstream has a higher DO than other segments of the Krukut river. In contrast, the DO increased towards upstream segments. It indicates that the downstream of Krukut river near Jakarta bay has high contents of oxygen dissolved in water. The upstream segments of Krukut river, characterized by murky and low DO contents in water, had low pH values indicating acidic water. In contrast, downstream of the Krukut river, characterized by clear water and enriched by oxygen, had high pH values. This value indicates the water downstream is base.

Regarding land use, there was also an observed discrepancy in land use between downstream and upstream segments. The upstream segments represent more acidic and murky water with low DO dominate by settlement land use type. In contrast, vegetation land use types dominated the downstream segments of the Krukut river that had clear, alkaline water with high DO values.

The results of water quality recorded in the Krukut river compared to previous research about water quality in rivers in Jakarta City [22, 23, 24]. A study by Anggeraeni et al. [25] observed that Jakarta's river turbidity was decreasing towards the upstream level. The turbid water in the upstream segment of rivers in Jakarta was related to the presence of settlement along the river streams.

The influences of land use in the forms of settlements observed in the Krukut river were corroborated by findings from other river streams. In India, deteriorating freshwater quality was correlated with using the Rawalakot water bodies for domestic, industrial, and agricultural purposes, introducing an influx of pollution and nutrients [26, 27].

3.2. Chlorophyceae diversity, spatial distribution, cluster model, and water quality

The result of comprehensive Chlorophyceae abundances in the Krukut is presented in Figure 3. There were in total 7 species of Chlorophyceae were observed along streams of Krukut River. Those species were *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spyrogyra* sp., and *Volvox* sp. Chlorophyceae in Krukut River has different abundances, with *Volvox* sp., *Scenedesmus* sp., and *Pediastrum* sp. among the most abundant species. Regarding diversity measured using the Lorenz graph (Figure 4), the Chlorophyceae diversity was high downstream. According to the Lorenz graph, the Lorenz curve downstream is farther than the curve in midstream and upstream. The curve is further away from the line of perfect evenness, indicating the more diverse the Chlorophyceae downstream of the Krukut river.

The Chlorophyceae species that had high abundances in the Krukut river were in order of *Volvox* sp., followed *by Scenedesmus* sp., and *Pediastru*m sp. with the maximum abundance values of 36.24 cells/ml, 31.6 cells/ml, and 30.5 cells/ml. While *Cosmarium* sp., *Eudorina* sp., and *Spyrogyra* sp. were observed as Chlorophyceae with low abundances, with maximum abundance values of 1.29 cells/ml, 4.15 cells/ml, and 4.31 cells/ml. In general, all Chlorophyceae species have higher abundances towards the downstream river segment, with the upstream mostly having lower abundances. Despite these general patterns, *Oocystis* sp. *Scenedesmus* sp. and *Pediastrum* sp. were observed to still have higher abundances up to the midstream and upstream segments (Figure 5).

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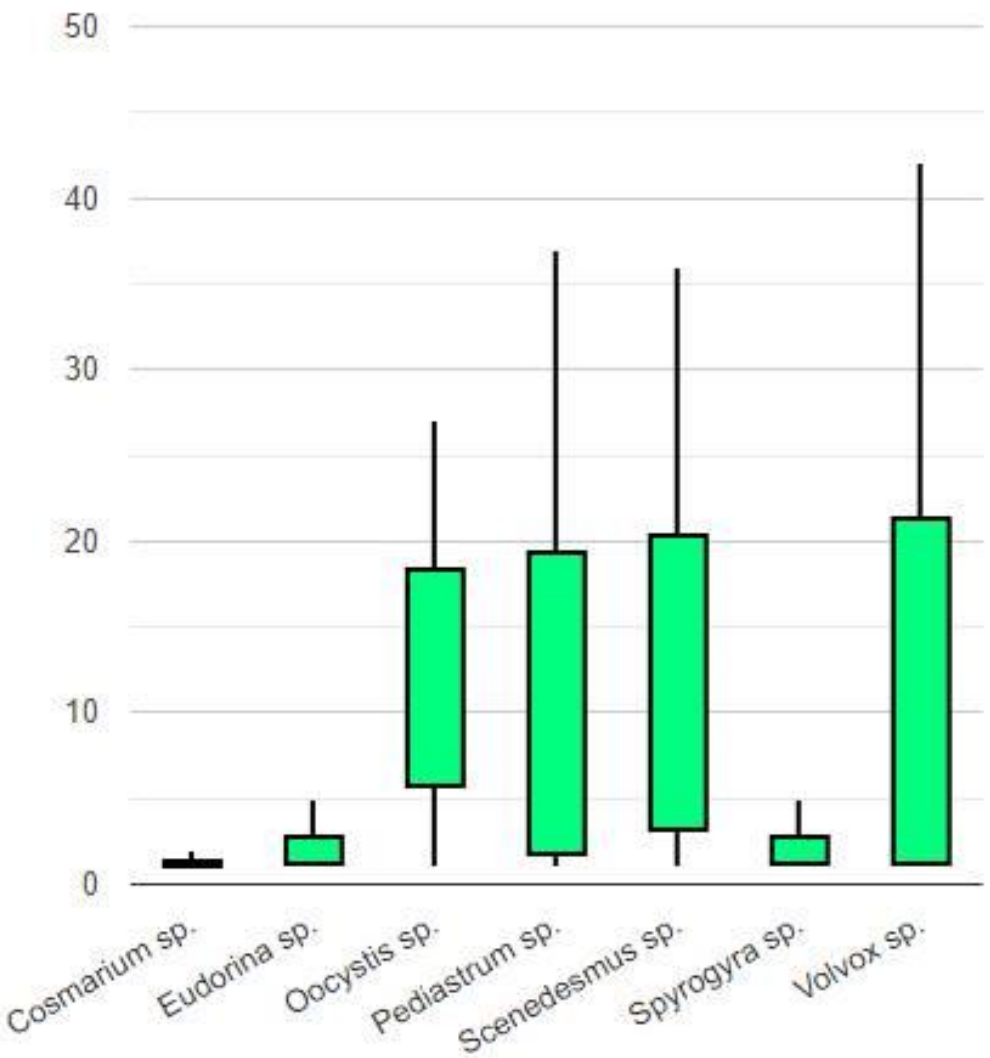

Figure 3. Abundances (cells/ml) of Chlorophyceae species in Krukut river, Jakarta city.

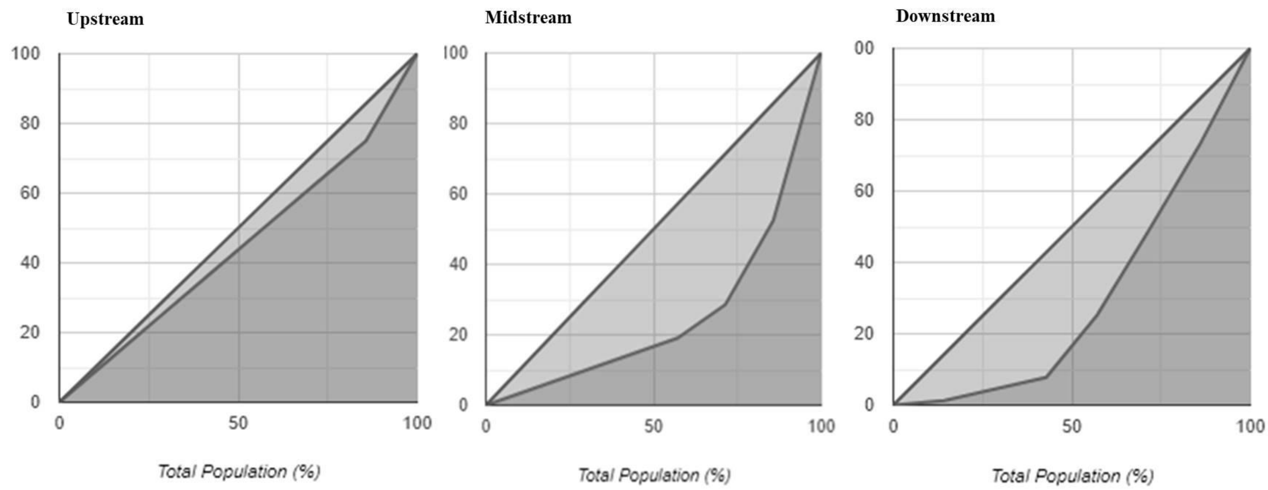

Figure 4. Lorenz curve for the cumulative proportion of Chlorophyceae population and diversity in upstream, midstream, and downstream of Krukut river, Jakarta city.

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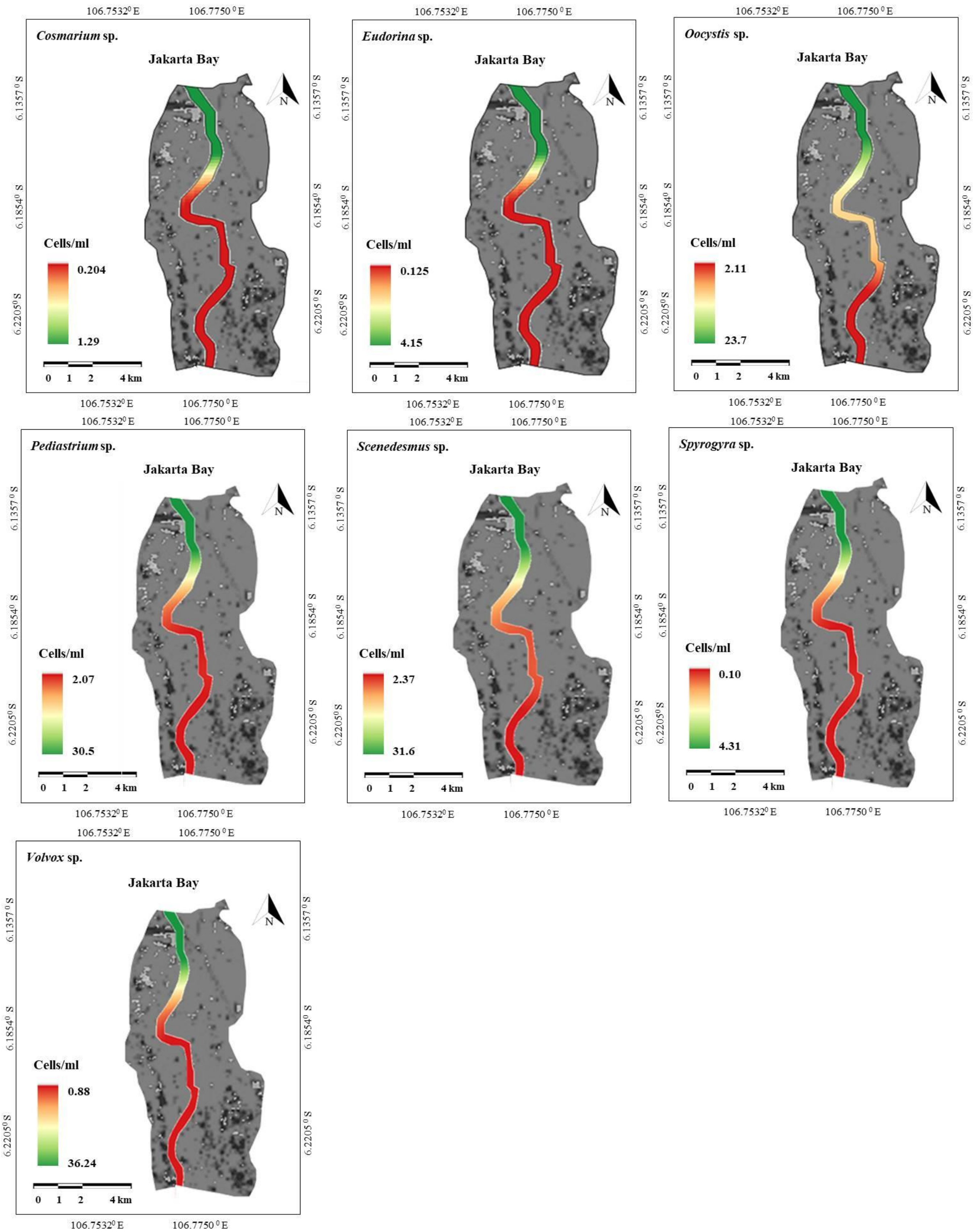

Figure 5. Abundance spatial patterns of *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spirogyra* sp., and *Volvox* sp. in upstream, midstream, and downstream of Krukut river, Jakarta city.

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In contrast, Chlorophyceae species, including *Cosmarium* sp., *Eudorina* sp., *Spyrogyra* sp., and *Volvox* sp., showed abundant declines in midstream river segments. Chlorophyceae species have higher abundances in the downstream segments than in other river segments (Figure 6). The cluster analysis (Figure 7) shows there are 3 clusters of Chlorophyceae abundances. The first group indicated high abundance in the downstream, the second group indicated moderate abundance in the midstream, and the third group indicated low abundance in the upstream. In contrast to the majority of the Chlorophyceae abundance cluster, a high and moderate abundance of *Oocystis* sp. were also observed in the midstream segments of the Krukut river.

The correlation of Chlorophyceae with water quality variables in the Krukut river is presented in Figure 8. There were in total of 7 species of Chlorophyceae observed along the Krukut river's streams. Those species were *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spyrogyra* sp., and *Volvox* sp. The river segments characterized by low DO, low pH value, and high turbidity were dominated by *Scenedesmus* sp. According to Guedes et al. [28], *Scenedesmus* sp. is a Chlorophyceae species that can tolerate and prefer acidic water characterized by low pH. This condition was related to the findings that the highest Scenedesmus sp. biomass specific growth rate was associated with relatively low pH. River segments with moderate levels of DO and pH were inhabited by *Oocystis* sp., *Pediastrum* sp., and *Scenedesmus* sp. Some Chlorophyceae species were found to be limited to the river segments with clear water and high DO. Those Chlorophyceae species include *Cosmarium* sp., *Eudorina* sp., *Spyrogyra* sp., and *Volvox* sp. Those species cannot tolerate the water quality upstream, characterized by low DO and murky water. This finding is in agreement with the result from the previous study. In contrast to *Scenedesmus* sp., *Cosmarium* sp. avoids polluted water with anthropogenic influences. High concentrations of highly polluted water inhibit the growth and physiological activities of *Cosmarium* sp. [29].

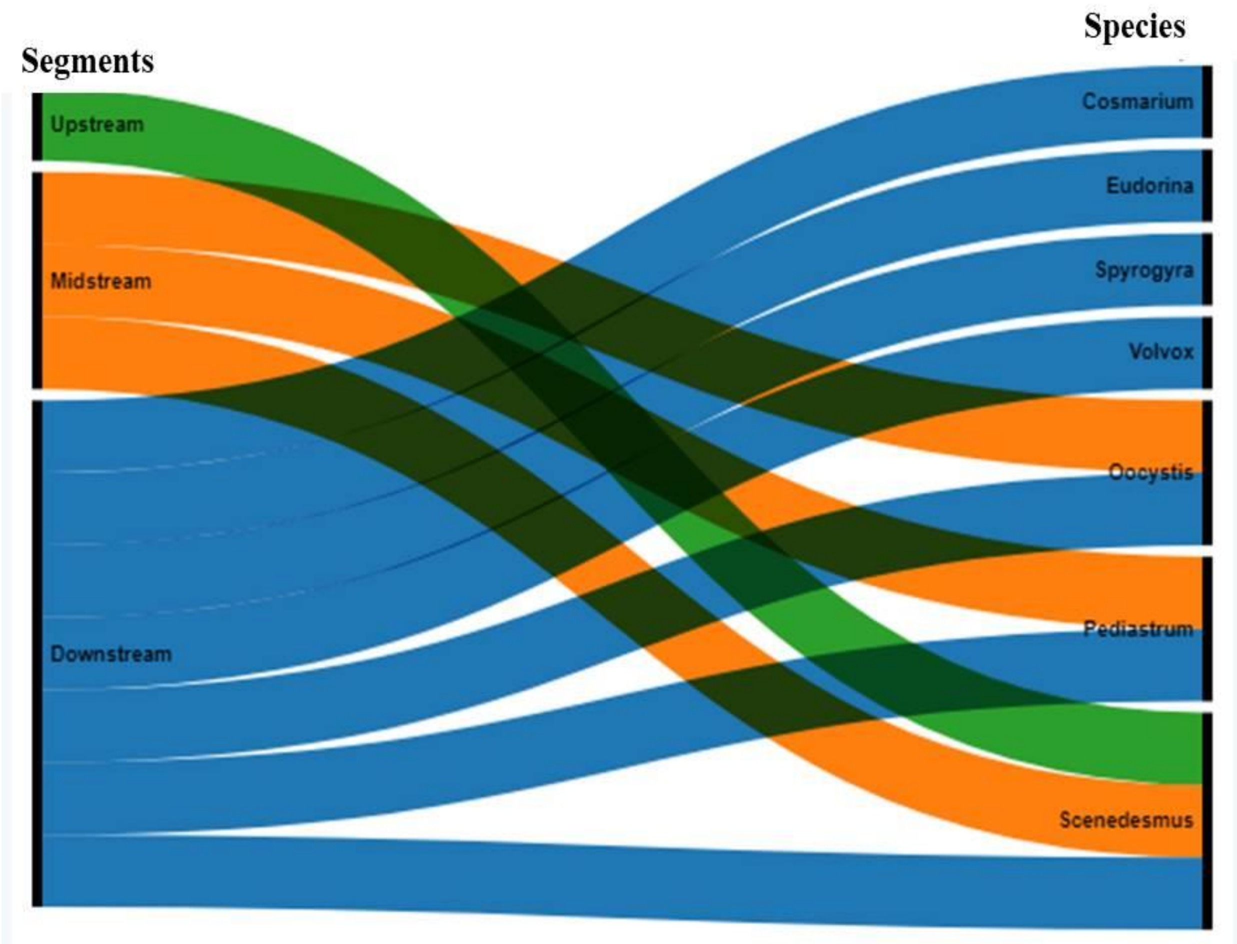

Figure 6. Sankey correlation diagrams of Chlorophyceae species abundances in upstream, midstream, and downstream of Krukut river, Jakarta city.

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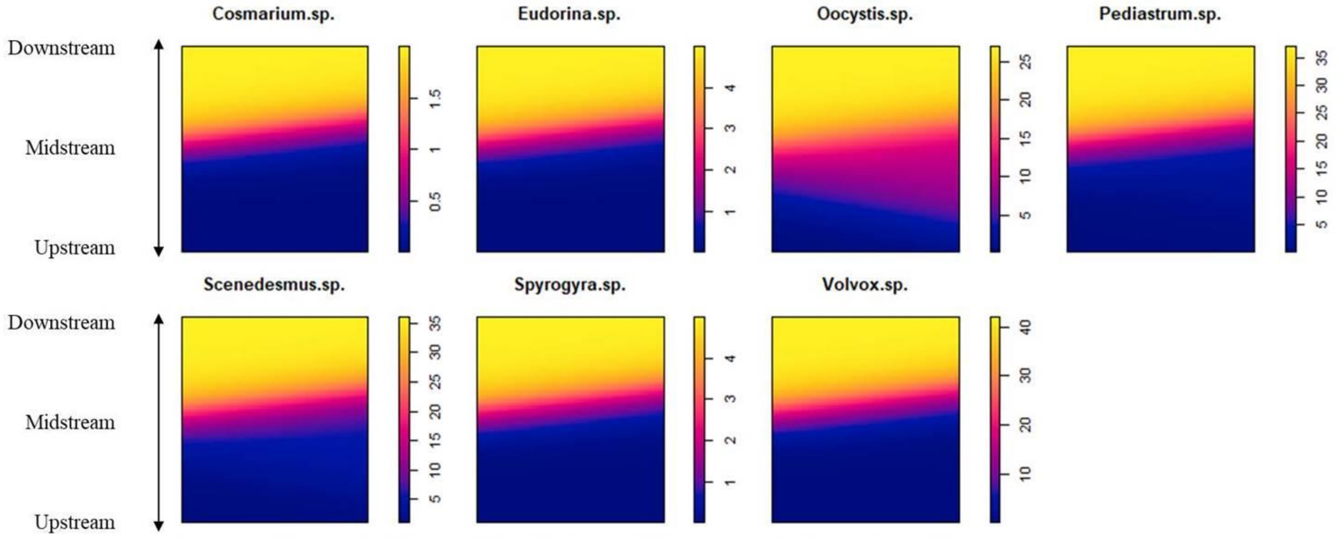

Figure 7. Cluster model of *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spirogyra* sp., and *Volvox* sp. in upstream, midstream, and downstream of Krukut river, Jakarta city

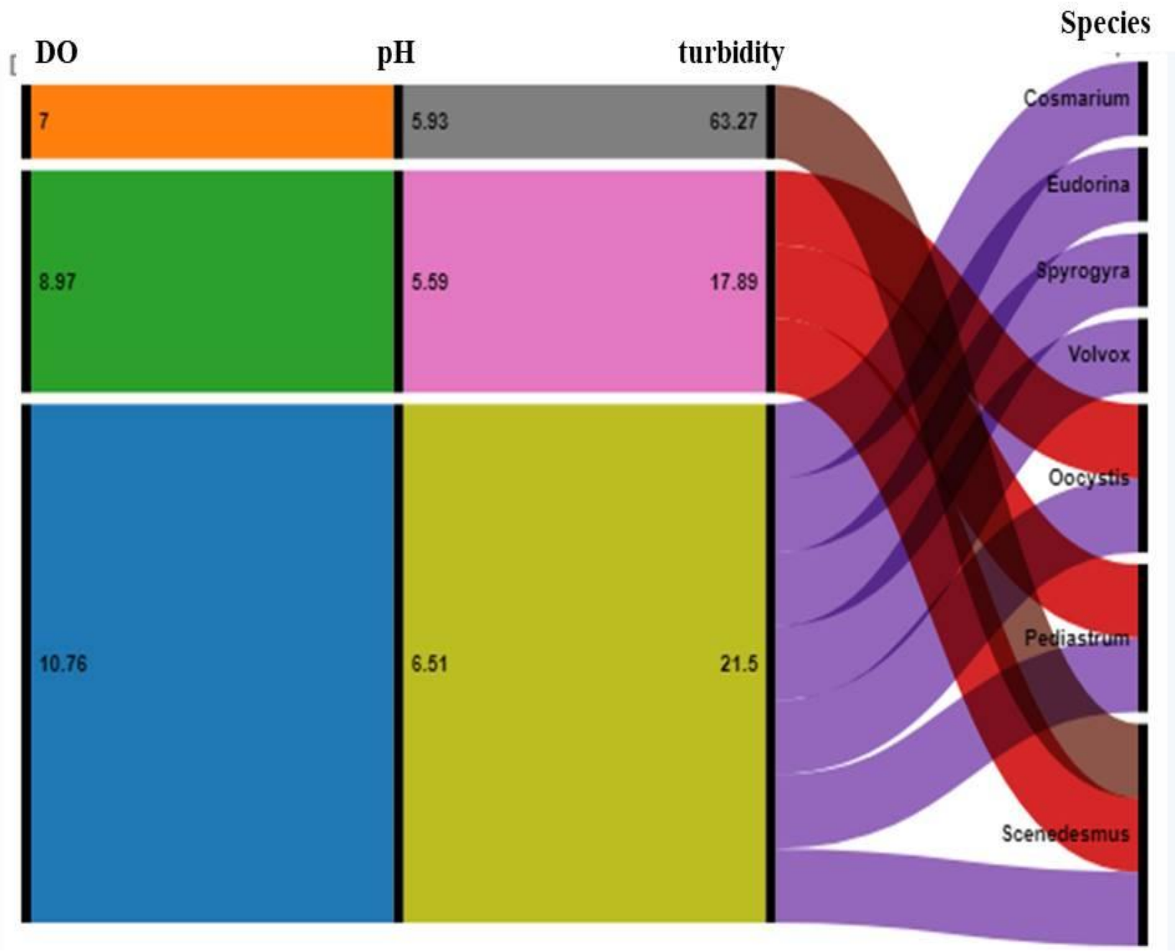

Figure 8. Sankey correlation diagrams of Chlorophyceae species abundances with water quality variables (DO, pH, turbidity) of Krukut river, Jakarta city

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3.3. Markov chain model of Chlorophyceae distributions

Figure 9 depicts the probabilities of Chlorophyceae in every state (downstream, midstream, and upstream) and the probabilities of transitions between states modeled using the Markov chain. There are two distribution patterns. First, some Chlorophyceae species are more likely to be distributed from midstream to downstream than from downstream to midstream and upstream. Those species were *Cosmarium* sp., *Eudorina* sp., *Spirogyra* sp., and *Volvox* sp., with probabilities of 25%, 31%, 31%, and 31%, respectively. This indicates that those species preferred the downstream segments more than the midstream and upstream segments. Low DO and murky water were limiting those species to occupying the midstream and upstream of the Krukut river. *Volvox* sp. has been observed growing in freshwater ecosystems with low turbidity and nutrient-rich water and in alkaline water with pH ranges of 7.3-7.5 [30]. The pH in midstream and upstream was acidic, with pH values of less than 7.

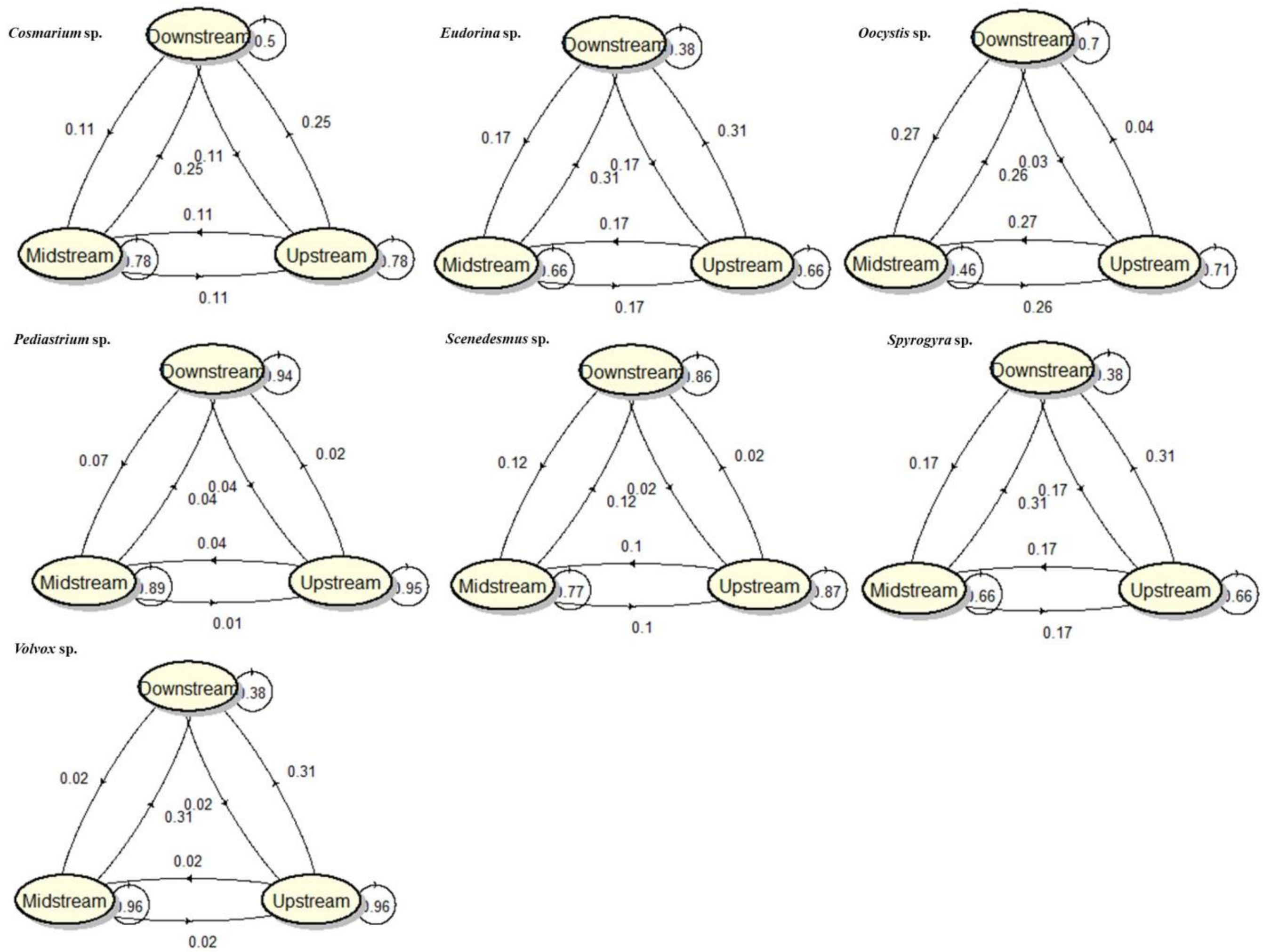

Figure 9. Markov chain model of Chlorophyceae distributions along streams of Krukut river. The numbers indicate the probabilities of Chlorophyceae in every state (downstream, midstream, upstream) and the probabilities of transitions between states

In contrast, there were species with high probabilities of inhabiting the midstream and downstream, whereas other Chlorophyceae species avoided this river segment. Those species with wide environmental tolerances are *Oocystis* sp., *Pediastrum* sp., and *Scenedesmus* sp. According to the Markov chain model, the probabilities of *Oocystis* sp., *Pediastrum* sp., and *Scenedesmus* sp. moving to polluted water are 27%, 7%, and 12%. It indicates that *Oocystis* sp. is the most tolerant species since this species has the highest probability of being found in polluted aquatic environments upstream. *Oocystis* is a common dominant species in subtropical aquatic environments and has a strong adaptability

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to environmental stress conditions [31, 32, 33]. In polluted water due to nutrient enrichment, *Oocystis* performs urea-based nitrogen removal in water. The presence and redistribution of *Oocystis* sp. in the polluted water upstream is due to nitrogen-rich water correlated with acidic water [34, 35]. This is considering that *Oocystis* sp. can consume and remove nitrogen [36, 37] from water that usually was available in the polluted water upstream surrounded by settlements.

4. Conclusions

In this study, we found a distinct segment characterizing the Krukut river. The downstream segment was characterized by clear, alkaline water and high DO. In contrast, the midstream and upstream have different environmental conditions than the downstream. This condition was also related to the presence of settlements nearby the Krukut river. There are 7 Chlorophyceae species observed in the Krukut river, with downstream segments being more diverse than midstream and upstream. *Cosmarium* sp., *Eudorina* sp., *Spirogyra* sp., and *Volvox* sp. are Chlorophyceae species with the limited spatial distribution. In contrast, *Oocystis* sp. is more tolerant toward polluted water in the Krukut river since this species is highly likely to be distributed from downstream to the midstream and upstream.

To the best of our knowledge, this study contributes to the conservation of aquatic ecosystems along with the plankton community. The progress of aquatic ecosystem conservation, particularly urban ecosystems, is dependent on information about still intact areas with fewer anthropogenic impacts. To conclude, this study has elaborated on the importance and potential of downstream river segments to be protected and conserved since these segments have high plankton diversity and better water quality than midstream and upstream segments.

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