Research on Leaf Decomposition Rate in Tamagawa River Basin

D Kong*
Global Environmental Studies, Sophia University, 102-0094 Chiyoda 7-1 Kioicho, Japan

*E-mail: rossoneri.kong@gmail.com

Abstract. The decomposition of litter is an important function in the regulating service of the river ecosystem. The decomposition of litter can not only provide energy and material for the ecosystem, but also evaluate the health of the ecosystem. Fallen leaves are the most common litter in the riparian zone. There are three main stages in the decomposition of leaves in rivers. In these three stages, there are many factors that affect the rate of decomposition of leaves. These factors are divided into three categories: the difference in the physical and chemical properties of the litter itself, the difference between the biological and non-biological characteristics in the river, and the feeding activity of the shredder. However, the previous scholars' studies on leaf decomposition mostly focused on soil ecosystems, and there were few studies on leaf decomposition in aquatic ecosystems. And no one has studied the relationship between blade surface hardness and thickness and blade decomposition rate. In addition, previous studies were conducted at fixed locations in the river, and very few studies have been conducted on different areas of the same river. In this study, three sites in the upper, middle and lower reaches of the tamagawa river were selected for leaf decomposition experiments. And use the newly designed penetrometer and micrometer to measure the surface hardness and thickness of the leaves. After 25 days of decomposition experiments, the final results showed that the lower the hardness and thickness of the leaves, the higher the decomposition rate. But when the blade hardness and thickness are similar, the characteristics of the blade surface will also affect the decomposition speed of the blade. And human activities will affect the function of leaf decomposition in the river ecosystem.

1. Introduction
For rivers surrounded by forests, in addition to photosynthesis of vegetation in the water, litter produced by plants or animals in the riparian zone is also the main energy source for the river ecosystem [1]. However, for most water bodies, at the source stream, because of the dense canopy, the producers in the river can receive limited light [2], so photosynthesis of aquatic plants does not provide enough energy to support the operation of the whole water ecosystem, the energy from riparian litter plays an important role in maintaining the health and balance of the ecosystem [3].

Riparian zone is the transition zone between aquatic habitat and terrestrial habitat [4]. It is composed of unique flora and fauna, not found in the adjacent highland habitats, only exists due to the increase in water content and the change in stream hydrology. Some definitions of the riparian zone take into account the spatial extent of herbaceous plants, the production of aquatic biological nutrient resources, and the area where sediments are generated [5]. An important function of riparian vegetation is to control energy in streams and rivers [6]. The organic matter transported by the riparian zone like a river species...
includes leaves, bark, cones, nuts and animals. Among them, leaf books are the most popular and extensive riparian input [7].

Fallen leaves not only provide energy and organic matter for the aquatic ecosystem, but it also participates in the process of material transportation and energy transfer in the aquatic ecosystem [8]. Leaf decomposition is an important ecological process [9]. Therefore, the decomposition rate of leaves will directly affect the operation and development of aquatic ecosystems.

According to the study of Shragge (2013) [10], the decomposition of leaves was divided into three main stages: (1) The fallen leaves falling into the river water, under the leaching action of water, the leaching of soluble organic matter and inorganic matter leads to the initial loss of biomass; (2) Next, microorganisms and fungi attach to the leaves to decompose the leaves. (3) Finally, it is the shredder that mechanizes the shredding of animals. It is not difficult to see that leaf decomposition is a complex ecological process [11]. In this process, leaf chemistry, leaf structure, stream type, temperature and invertebrate community structure were found to be the factors affecting leaf explication rate [12]. The discovery of these factors is important for monitoring the health of river ecosystems by analyzing leaf decomposition rates because different decomposition rates reflect the nutrient supply of pests and other aquatic organisms over a period [13].

In the previous studies, scholars often focus on the effects of detritivores activities in the river and the chemical properties of leaves on the decomposition rate of leaves. There are few studies on the relationship between leaf surface hardness and leaf decomposition rate. The main reason is that it is difficult to measure the hardness of the leaves. On the one hand, there is a lack of accurate equipment and methods for measuring the surface hardness of blades. On the other hand, the hardness of leaves of the same species may be different.

In addition, previous studies have selected specific locations in natural rivers for leaf decomposition experiments. However, leaf decomposition is a dynamic process and does not occur at a fixed location in the river. Moreover, the water quality and environment of different sections of the river are different, and these factors will also affect the decomposition of leaves. Therefore, there is a lack of comparisons in current research, especially for comparisons between different sections of the same river.

In this study, the physical properties of the leaves were taken as the main research object, and the thickness and hardness of the leaves were the main physical indicators of the leaves measured in this experiment. In order to obtain accurate data on the surface hardness of the blade, the researchers designed and produced a brand-new penetrometer to measure the surface hardness of the blade on the basis of traditional measurement methods and principles. The use of this penetrometer greatly improves the convenience and accuracy of leaf hardness measurement. In addition, the leaf decomposition experiment will be carried out in three different river sections of Tamagawa River. Count the water quality and surrounding environmental conditions of each river section and compare the leaf decomposition rate.

The goal of this study is to prove through experiments that the rate of leaf decomposition will be affected by the hardness and thickness of the leaves. The higher the hardness and thickness of the leaves, the lower the rate of decomposition of the leaves. In addition, this experiment will also verify that human activity is a factor that affects the rate of decomposition of leaves. The purpose of verifying the above two points of view is, for the first time, to supplement the previous research on the decomposition of leaves with Tamagawa's experiments. Second, it calls on people to reduce or avoid the negative impact of human activities on ecosystem services.

According to the research results of previous experiments, the following assumptions are made for the results of this research:

(1) There is a positive correlation between the hardness and thickness of the leaves. The higher the thickness, the higher the surface hardness of the leaves.

(2) In the same experimental site, the higher the surface hardness and thickness of the leaves, the lower the decomposition rate.

(3) River sections with better environmental conditions and water quality have a higher rate of leaf decomposition.
2. Methodology

2.1. Research site

The target river for this experiment is the Tamagawa River. The Tamagawa River began at Kasatori Mountain in Yamanashi Prefecture and eventually flowed into Tokyo Bay. The total length is 138km, and the drainage area is 1,240 square kilometers. It is an important first-class river in the Tokyo area (1986) [14, 15]. This study will conduct leaf decomposition experiments in three river sections of the Tamagawa River with different ecological environments. In addition, the Tamagawa River was chosen because its upper reaches, the middle reaches and the lower reaches are in different environments. The upper reaches are in the deep mountains with better ecological environment, the middle reaches are in the countryside and suburbs around Tokyo, and the lower reaches of the Tamagawa River flows through the Tokyo metropolitan area. Inside, it finally merges into the sea.

2.1.1. Hikawa Gorge. Hikawa Gorge is located in the upper reaches of the Tamagawa River, where the Tamagawa River and the Hihara River meet. The water flow here is swift, and the direction of the river is complicated. The riparian zone has lush vegetation. And there are very few residents by the river. Although many people used to come here to hike or camp by the river. However, due to the spread of the new coronavirus, there are very few tourists here this year.

2.1.2. Hamura Water Intake Weir. The Hamura Water Intake Weir is located in the middle reaches of the Tama River. The Hamura Water Intake Weir was built in 1654 to provide water for the old Edo Castle and today's Tokyo. In addition, due to its unique design, the weir also has flood control and flood discharge functions [16]. In addition, because it is often used for flood discharge, the water ecosystem tends to change due to floods. The riparian zone is artificially constructed, but there is a buffer zone between the shore and the artificial walkway, and the buffer zone is still rich in vegetation. There are dense reeds, grasses and shrubs on the banks of the river. There are many trees, but few types. Some living facilities have been built on the shore of the test site. For example, Hamura City Water Purification Plant, parking lots, sports fields, parks and other facilities provide services to local residents. However, this is a rural area, and the natural environment is better than that of the city. And there are few people, so there are few human activities. Finally, in order to ensure the safety of water in Tokyo, the water quality here is required to meet the tap water quality standards. In addition, compared with site1, the river flow at this test site is smoother, the river width is wider, the vegetation on the river bank shields the river water less, and the river water can receive more sunlight.

2.1.3. Futako Tamagawa Park. Futako Tamagawa Park is located in the lower reaches of the Tamagawa River. As an urban river, although the vegetation coverage and ecological environment of the riparian zone are not as good as the first two test sites, the environment here is well restored and protected compared with other urban rivers. There are many residential areas near Futako Tamagawa Park, so many people come to Futako Tamagawa Park at ordinary times, and there are also frequent activities on the riverbank and grassland of the park. There are obvious traces of human activities on the river bank, such as garbage left on the river bank and shallow water, coke left after barbecue, and stones moved by children. These actions have potential impacts on local water quality. In addition to residents, there are roads and railway bridges near the test site. Exhaust gas and dust from vehicles will also be thrown into the water. There is a construction site next to the experimental site, which will also have an impact on water quality and the environment. In this test site, the width of the river is constantly increasing, and the vegetation on the river bank cannot cover the river. The main river here is turbulent and the water depth is very deep. There are tributaries beside the main rivers. The tributaries have shallow water and gentle flow rates, which are closer to the river bank vegetation. The specific locations of the three experimental sites are shown in Figure 1. These three locations represent the river courses in three different environments of the Tamagawa River.
Figure 1. Location map of the three experimental sites in this experiment (Quoted from Google Maps)

2.2. Detection of water quality
Water quality is an index that judges the health of river ecosystems, and it is also a quantifiable index. In this experiment, dissolved oxygen (DO), acidity and alkalinity (pH), electrical conductivity (COND), nitrate content (NO3⁻), and temperature are used as the main water quality indicators for testing. To ensure the accuracy and universality of the data, each site. The water quality will be tested 5 times, and the final data will be the average of these five times.

The reasons for choosing these four chemical indicators are, on the one hand, the limitations of equipment and funding; on the other hand, these four indicators are important standards for measuring water quality, and they all have important research significance.

2.3. Collection and processing of leaf samples
Choose the leaves of 2-3 species of trees at the riverside of each experimental site. When collecting leaves, choose newly fallen leaves and make sure that these fallen leaves have not been soaked by rain. Put the leaves into a fresh-keeping bag to record the type, time, and location information of the leaves. After returning to the laboratory, wipe off the dust and impurities on the surface of the leaves, use plastic window screens and a large cardboard box with many holes (about 3 cm in diameter) to make a leaf drying device. Put the leaves into the drying device and place the device in a dry place. Turn the box over every day and gently move the leaves to promote drying. Continue for 3-5 days to wait for the leaves to basically dry out.

After the leaves are air-dried, the hardness and thickness will be measured. To ensure the accuracy of the data, ten pieces of each type of leaf are selected for measurement, and the average value is calculated as the hardness and thickness data of the type of leaves. After measuring the thickness with a micrometer, use a penetrometer to measure the surface hardness of the leaves. When using a micrometer to measure the thickness of leaves, it is necessary to avoid the veins of the leaves, because the veins of the leaves are thicker than the part of the leaf. If the veins are not avoided, the final thickness measured will be inaccurate. In addition, for thicker leaves, it is necessary to prevent the thickness of the micrometer from being pressed too tightly to cause indentation on the leaf surface, which will affect the final measurement result.
To accurately measure the hardness of leaves, the researchers improved the traditional measurement method and designed and produced a pressure-sensitive penetrometer.

In theory, the surface hardness of a leaf refers to the force required to penetrate the leaf [17]. Therefore, to measure the force that penetrates the leaves is to measure the surface hardness of the leaves. The traditional method is to press the beaker on the needle, and the needle tip is fixed on the fixed leaf surface. Increase the pressure on the beaker by adding water to the beaker, and the tip penetrates the surface of the blade. Finally, the weight of the water in the beaker when it penetrates the surface of the blade represents the surface toughness of the blade [18, 19, 20]. The disadvantage of this method is that the error is large, especially for low-hardness leaves that cannot be accurately measured. Secondly, adding water to the beaker is not a continuous force application process, so the accuracy of the result cannot be guaranteed.

Aiming at these two shortcomings, the new pressure-sensitive penetrometer (Figure 2) will use the handle to pull the needle tip to move to the leaves and use the pressure sensor to accurately measure. When the needle tip touches the leaf, the pressure sensor starts to measure, and the display shows real-time data. As the needle tip presses the page, the value starts to increase, and the peak value is reached at the moment of penetration of the leaf surface, and immediately becomes 0 after penetration. The peak value is the hardness of the leaf surface.

![Figure 2. The structure and components of pressure-sensing penetrometer](image)

A1=pressure sensor, A2=monitor (can show pressure values to be accurate to 0.01), A3=needle (used for piercing leaves), A4=power line (control the monitor), A5= connecting line (combine the pressure sensor and monitor), B1=the base of the penetrometer, B2=T groove screw (link the platen and the base), B3=turnbuckle (control looseness), B4=splint (press the leaves tightly and flat), B5=platen (fix the splint on the base), B6=stroke scale (show the distance the needle moves down), B7=handle (let the needle move vertically downward), B8=column.

The specific procedures of measuring leaf surface hardness with a pressure-sensitive penetration meter are as follows:

1. Cut the air-dried leaves into 20-50 square millimeters, avoiding the stem of the leaves as much as possible.
2. Use the splints to make a leaf disc flat and tight, through tightening turnbuckles let the platens fix the splints on the base.
3. Pull-down the handle causes the needle to move vertically downward with the suitable speed.
4. When the needle reached the leaf disc, it began to read the values on the display and records the peak value when the needle pierces the leaf.
5. The leaf surface toughness could be expressed as the peak value multiplied by 10 (gravitational acceleration) of the pressure.

After measuring the hardness and thickness, the leaves need to be weighed and placed in a nylon mesh bag to make experimental samples. When choosing a nylon net, pay attention to the size of the net's aperture. It can ensure that the water flow and the decomposer enter the net bag to decompose the
leaves, but also ensure that the leaf fragments will not fall out of the bag. Each leaf requires 25 samples, and the dry weight of each sample is 0.3g. The 25 samples are divided into 5 groups, 5 samples in each group, and 5 samples in each group are tied together with rope. The nylon rope should be as long as possible to ensure that there is enough length to fix the sample on the shore.

2.4. Decomposition experiment
After the sample is made and tied to the rope, the sample is thrown into the river water, and the coordinate information of the entering water position is recorded. When the leaves are completely immersed in the river water, the other end of the rope is fixed to the shore. In order to ensure that the rope can be firmly tied to the shore, the researcher wrapped the rope around a large rock and tied a long iron nail to the end of the rope, nailed the nail to the shore, and pressed the nail with a stone. After the sample is fixed and confirmed that it will not be washed away by the water, the experiment officially starts. From that day on, take a set of samples of each type of leaf every five days. After returning to the laboratory, take extra care when removing the leaves from the net bag, because some leaves are broken under the impact of water flow during the process of decomposition in the water. Therefore, it is necessary to remove the broken pieces in the net bag, otherwise it will affect the final experimental results. In addition, some leaves become very fragile after being soaked for many days, so be careful when removing them from the net bag to prevent the loss of debris from breaking the leaves. Next, wipe off the impurities on the surface of the leaves with a paper towel. When wiping the impurities on the surface of the leaves, be careful to wipe the leaves. The leaves will become easy to break if they are soaked in water. If the leaves are damaged by wiping, it may affect the result. And continue to air-dry for 3-5 days according to the above-mentioned method. When it is air-dried naturally, you must pay attention to protect the fragments of some leaves from being blown away by the wind and causing loss. When the leaves are completely dry, measure the dry weight of the leaves.

2.5. Data calculate and analysis.
Scientist Olson began to use exponential functions to simulate the decomposition process of litter in 1963 [21]. Afterwards, scientists modified the Olson equation and finally got the formula for calculating the decomposition rate of leaves [22]:

\[ M_t = M_0 e^{-kt} \]  (1)

Where \( M_t \) is the leaf litter dry mass at the time of \( t \) (day); \( M_0 \) is the initial dry mass of leaf litter; \( k \) is the leaf litter decomposition rate coefficient; \( t \) is the decomposition time (day).

Use this equation in Excel to fit the process of leaf dry weight loss to show the decomposition rate of different types of leaves in different locations. The simulation index of the exponential equation is usually used as the decomposition constant of litter, and the unit is \( 1d^{-1} \).

All data are statistically performed with Excel, compared, and analyzed to reach the conclusion.

3. Results and analysis

3.1. Water quality test results
From the beginning of the sample injection to the end of the experiment, the water quality of the three test points was tested 5 times. The average value of the five times represents the water quality of each site. The specific results are as follows (table 1):

| Site | pH   | NO₃ (ppm) | COND (μs/cm) | DO (mg/L) | Temperature (℃) |
|------|------|-----------|--------------|-----------|-----------------|
| 1    | 9.36 | 12.8      | 111.4        | 11.268    | 14.58           |
| 2    | 8.82 | 8.6       | 92           | 10.84     | 16.66           |
| 3    | 9.5  | 26.6      | 262          | 17        | 24.52           |
Based on various indicators, site 2 has the best water quality, followed by site 1, and site 3 has the worst water quality compared to the other two sites.

3.2. Feature measurement results of leaf samples

The leaves collected in this experiment are the most common leaves on the riverside of the three experimental sites. There are three types of site1: Deutzia crenata Siebold & Zucc (Deutzia crenata), Cyclobalanopsis myrsinifolia (Cyclobalanopsis) and Zelkova schneideriana (Zelkova). There are two types of site2: Juglans mandshurica (Juglans) and Acer paxii (Acer). The third site also has two types: Salix integra (Salix) and Aphananthe aspera (Aphanathe).

In this experiment, the thickness and hardness of these leaves are mainly measured as their main characteristics. Each leaf is measured ten times, and the final average value represents its hardness and thickness. The measurement results are shown in the table 2 below:

| Site  | Species       | Hardness (N) | Thickness (mm) |
|-------|---------------|--------------|----------------|
| Site 1| Deutzia crenata| 0.4          | 0.091          |
|       | Cyclobalanopsis| 2.1          | 0.463          |
|       | Zelkova       | 1.6          | 0.377          |
| Site 2| Juglans       | 0.2          | 0.103          |
|       | Acer          | 0.3          | 0.081          |
| Site 3| Salix         | 0.3          | 0.071          |
|       | Aphanathe     | 0.6          | 0.169          |

Based on the above data, it can be seen that in addition to site2, the difference in hardness and thickness between different types of leaves of the other two sites is more obvious, and the thicker leaves have higher hardness. But in site2, the hardness of the two leaves is very similar, but the thickness of the Juglans with lower surface hardness is a bit thicker.

3.3. Leaf litter decomposition rate

Use Excel to bring in the initial dry weight of each group of leaves, the average dry weight after decomposition, and the number of decomposition days to make a line chart. Combine the leaf decomposition equation to fit the leaf decomposition rate. The approximate function obtained by fitting the dry mass loss and time of each blade based on the function is summarized in the following table 3. The value of the constant k in the function represents the rate of leaf decomposition. The larger the k value, the higher the decomposition rate of the leaves.

| Species          | Regression model         | R²    | k value |
|------------------|--------------------------|-------|---------|
| Deutzia crenata  | y = 0.2565e^{-0.005x}    | 0.9335| 0.065   |
| Cyclobalanopsis  | y = 0.2958e^{-0.024x}    | 0.9975| 0.024   |
| Zelkova          | y = 0.2922e^{-0.028x}    | 0.9592| 0.028   |
| Juglans          | y = 0.2215e^{-0.054x}    | 0.835 | 0.054   |
| Acer             | y = 0.2587e^{-0.039x}    | 0.9174| 0.039   |
| Salix            | y = 0.2552e^{-0.03x}     | 0.8572| 0.03    |
| Aphanathe        | y = 0.2846e^{-0.018x}    | 0.9426| 0.018   |

According to the above table, it is not difficult to find that the decomposition rate of these 7 kinds of leaves is different. There are many reasons for the differences in their decomposition rates. Next, this study will compare the decomposition rates of these leaves from the perspectives of leaf hardness, thickness, water quality of the experimental site, and the surrounding environment to find out the reasons for the differences.
4. Conclusion
This study was generally successful, and the results were basically consistent with the assumptions. That is, the surface hardness and thickness of the leaves will affect the rate of decomposition of the leaves. Basically, the higher the surface hardness and thickness of the leaves, the lower the rate of decomposition. In addition, water quality and the surrounding environment will also affect the decomposition of leaves. In waters with better water quality and less human activities, the rate of decomposition of leaves will be higher. However, some problems were still found during the experiment and when summing up the data. Through thinking and exploring these problems, the following conclusions were reached:

(1) One of the reasons why leaves with low hardness decompose faster than leaves with high hardness is that leaves with low hardness are more susceptible to breaking and folds under the impact of water, and the broken leaves will increase the contact area with decomposers in the water. And folds will facilitate the attachment of the decomposers, thereby speeding up the decomposition of the decomposers, so that the leaves with low hardness have a higher decomposition rate.

(2) The surface characteristics of the leaves also affect the decomposition rate. The fluff on the surface of the leaves easily sticks to impurities and organisms in the water, which facilitates the decomposers to attach to the surface of the leaves to decompose the leaves, resulting in a higher decomposition rate of Juglans leaves.

(3) Only when the leaf hardness and thickness are similar, the surface characteristics of the leaves have a more significant effect on the decomposition rate of the leaves. Once the difference in hardness and thickness between the leaves becomes larger, the effect of the leaf surface characteristics on the decomposition rate will be weakened. Take the two leaves of site3 as an example. Aphananthe leaves have many folds on the surface to facilitate the attachment of decomposers, but the decomposition rate is still slow compared with Salix leaves, which are less than half of their hardness and thickness and have a smooth surface.

(4) From the perspective of the overall decomposition of leaves, site1 with the least human activities has the best overall decomposition of leaves. Site3, where human activities are the most frequent, has the worst overall leaf decomposition. Therefore, human activities will affect the function of leaf decomposition in the river ecosystem.

To sum up, the hardness and thickness of leaves are two factors that cannot be ignored that affect the decomposition of leaves. The study of leaf decomposition needs to take these two factors into consideration. Secondly, human activities will have an impact on the function of leaf decomposition in aquatic ecosystems. Therefore, people need to find ways to avoid and reduce the impact of leaf human activities on ecosystem service functions as much as possible.

References
[1] Allan JD, Castillo MM and Capps KA Stream ecology: structure and function of running waters. Netherlands: Springer; 2020.
[2] Pozo J, González E, Díez J, Molinero J and Elósegui A 1997 J. North Am. Benthol. Soc. 16 602-11
[3] Wallace JB, Eggert SL, Meyer JL and Webster JR 1997 Science 277 102-4
[4] Naiman RJ and Decamps H 1997 Annu. Rev. Ecol. Syst. 28 621-58
[5] Fry J, Steiner FR and Green DM 1994 Landsc. Urban Plan. 28 179-99
[6] Lindeman RL 1942 Ecology 23 399-417
[7] Bray JR and Gorham E Litter production in forests of the world. In: Advances in ecological research. Volume 2, edn.: Elsevier; 1964: 101-57.
[8] Vannote RL, Minshall GW, Cummins KW, Sedell JR and Cushing CE 1980 Can. J. Fish Aquat. Sci. 37 130-7
[9] Alvim EACC, de Oliveira Medeiros A, Rezende RS and Goncalves Jr JF 2015 Limnologica 51 131-8
[10] Shragge BB: The Decomposition of Mistletoe Leaf Litter in a Stream Ecosystem. 2013.
[11] Hauer FR and Lamberti G 2011 *J. North Am. Benthol. Soc.* **27** 223
[12] Webster J, Benfield E, Ehrman T, Schaeffer M, Tank J, Hutchens J and D’angelo D 1999 *Freshw. Bio.* **41** 687-705
[13] Walpola H, Leichtfried M, Amarasinghe M and Füreder L 2011 *Int. Rev. Hydrobiol.* **96** 90-104
[14] Webster J and Benfield E 1986 *Annu. Rev. Ecol. Syst.* **17** 567-94
[15] Ministry of Construction Kanto Regional Construction Bureau Keihin Construction Office Tamagawa Magazine Editorial Committee Planning / Editing 1986 Tamagawa magazine, River Environmental Management Finance Group, JP number 87013797.
[16] Chino Y and Okuma T 1994 *Hist. Stu. Civil Eng.* **14** 93-108
[18] Arsuffi TL and Suberkropp K 1984 *Oikos* **14** 43-54
[19] Williams L 1954 *Ecol. Entomol.* **105** 423-54
[20] Tanton M 1962 *Entomol. Exp. Appl.* **5** 74-8
[21] Olson JS 1963 *Ecology* **44** 322-31
[22] Petersen RC and Cummins KW 1974 *Freshwater Biology*, **4** 343-68