Study on the Population and Effect of Fish Passing Through the Fishway in Cao'e River Gate

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Abstract: Fishway is one of the important ways to solve that gate dam obstructs fish migration. Through the monitoring and sampling of the right bank fishway of the Cao'e River Gate during May to November 2019, a total of 27 species of nektonic organisms were captured, totaling 2,926, belonging to 10 orders and 15 families, including mostly coilia ectenes, secondly minnow and others (crucian carp, bighead carp, silver carp, carp, and lateolabrax maculatus, etc.); the average species diversity index of nektonic organisms is 2.278, the average species richness index is 1.704, the average uniformity is 1.12, and the average dominance is 0.728. The data show that the effect of fish passing through fishways in different seasons, hydrological conditions, and weather conditions is very different. In general, the number of fish passing in spring and summer is much higher than that in autumn and winter. Of which, the number (individuals accounted for 91.41% of all) monitored in May, June, and July far exceeded that in other months. From May, the species and number of fish passing gradually increased, and by July, they reached their peak. Comparing the historical monitoring data in this region and the effects of fish passing through other typical fishways at home and abroad, the Cao'e River fishway provides a channel for the exchange of upstream and downstream fish of the gate, becoming an important channel to resolve the migration of blocked fish. It is recommended to strengthen the long-term monitoring and study of fishway, providing scientific basis for the collection of fish fry by opening the sluice gate, and also laying the foundation for further evaluation of the fish-passing effect of the sluice dam project in the Yangtze River Delta.

1. Introduction
The construction of dams and other water-tight buildings on the river course inevitably changes the natural connectivity of the river course, destroys the original landscape and ecological integrity of the river course and affects the migration behavior of fish. This not only causes the reduction of fish populations in numbers and even leads to the extinction of some populations. As an ecological protection project, the fishway has become an important compensation project for the adverse impact of the water conservancy project on the regional ecological environment due to its role in connecting upstream and downstream.

The fishway has been researched for hundreds of years in foreign countries, and foreign scholars have carried out some researches in this area about how its fish passing effect is and how to evaluate its function[1]. In Brazil, the Engenheiro Sergio Motta fishway was monitored from December 2004 to March 2005 and a total of 37 fish species were monitored[2]. Australia monitored the Burnett River
barrage fishway from 1984 to 1987, and monitored a total of 34 species, 187 fishes [3]; from 2002 to 2003, the fish passing effect of the Deelder fishway in Murrumbidgee River was monitored, which found that 11 fish species and various shrimps passed through the fishway, and a maximum of 854 fishes passed through the fishway in a single day [4]. The United States monitored daily fish-passing effects at all fish-passing facilities in all dams in the Columbia River Basin, and established a long-term serial monitoring database [5]. Japan investigated the number of juvenile sweetfish passing through the sluice on the left bank of the Nagara River estuary weir through video, which showed that the average number of fish passing was approximately 428,000 from 1995 to 2007, and reached 2.7 million in 2008 and 2.174 million in 2009 respectively [6]. In addition, Austria, the Czech Republic, and Denmark carried out a large number of monitoring and evaluation work on the restoration of fish migration channels in their territory [7].

The fishway research in China started late and developed slowly. At present, there are no formed design specifications and concepts [8], and there are relatively few research reports on the monitoring and operation effects of fishway in China. Early reports include Yuxi Fishway [9] in Anhui Province and Yangtang Fishway [10] in Hunan Province. In recent years, Chinese scholars have also carried out related researches: Tan Xichang et al. [11] used the interception method to monitor and sample the trial run Changzhou Hydraulic Complex, and analyzed the fish population structure passing through the fishway and the factors affecting the running effect of fishway. Wang Ke et al. [12] investigated the population and biological characteristics of fishway fishes in the Hanjiang Cuijiaying Navigation and Hydropower Project using a combination of net replenishment and hydroacoustic monitoring; Li Jie et al. [13] used the method of netting and blocking method was used to monitor the fish-passing effect of the Xiniu Fishway in Lianjiang, Guangdong, and analyze the time and seasonal characteristics of fish passing through the fishway; Zhang Yanyan et al. [14] analyzed statistically the monitored data of Liuxi River Water Plant Dam Fishway in Guangzhou from August 2015 to July 2016, evaluated the fish passing effect of the fishway by comparison with similar fishways, and analyzed the fish population passing through the fishway and the factors affecting the fish passing effect.

In this thesis, the fishway on the right bank of the Cao'e River was monitored for more than half a year through the netting method. By studying the structure and quantitative characteristics of the fish populations passing through the fishway, comparing the historical monitoring data in this region and the effects of other typical fishways at home and abroad, the thesis analyzed the operation effect and influencing factors of fishway and grasped the fish migrating in the fishway in different seasons and months, providing real-time basis for the collection of fish fry by opening the sluice gate, and also laying a foundation for further evaluating the fish passing effect of the sluice dam project in the Yangtze River Delta.

2. Project Overview
The Cao'e River Gate is located in Shaoxing City, Zhejiang Province. The main tributary of the right bank of the lower bank of the Qiantang River is the Cao'e River estuary, the left side of the estuary is the Xiaoshao Plain and the right is the Yaojiang Plain. The Cao'e River gate project is composed of two parts: the main hub project (consisting of the tide-blocking and flood-discharging sluice, dam blocking, diversion embankment, and management area) and ancillary projects (the gate-slope protection project of the river on the gate). The total gate length is 1,482m (excluding the length of the blocking dam on the left side). There are a total of 28 holes in the middle tide-blocking and flood-discharging sluice with a net hole width of 20.0m, the length of 697m (total net width of 560m). The length of blocking dam is 785m. The project had a total flood discharge of 11,030m³/s and was invested with RMB 1.25 billion in total, which is known as "China's first estuary gate". Due to the existence of migratory aquatic organisms such as coilia ectenes, eels, and eriocheir sisensis on the Caojiang River, in order to minimize the impact of the project on aquatic organisms during the construction of the Cao'e River Gate, combined with the overall layout of the gate, one fishway was set on the left bank dike and the right diversion dike of the sluice gate, respectively. The fishway on the left bank is 514m long and that on the right is 429m long. The fishway is divided into an upstream section, a middle section and a downstream section. The
3. Sampling and Methods

3.1. Fish sampling in fishways
From May 2019 to November 2019, the fish population passing through the fishway on the right bank of Cao'e River Gate was monitored monthly through netting method. That is, the net was set in the outlet of the fishway on the right bank and the fish inlet was weld with the steel framwork, of which, the dimension of the steel framwork (L*W*H) was 3m*2m*2m and that of the fishing net (L*W*H) was 12m*2m*2m. Fishing net was divided into 2 parts, the middle of the front part was set with a closing hole, the net size was gradually reduced from the net into the fish inlet of the fishing net. The fishing net and its installation way are shown as Figure 1. The tail of the fishing net was held by 2 ropes and fixed at the upstream exit of the fishway, so that the fishing net is in an open state. Each time the fishing net was collected, the steel frame that holds the fishing net was first lifted out of the fishway, then the 2 ropes were loosened, and the fish was removed from the fishing net at the end. Finally, fishes were collected, the size was measured, weighed, and their pictures were taken.

3.2. Biodiversity analysis
The water temperature, air temperature and upstream and downstream water level data of the right bank fishway were collected, and the regional fish population diversity was analyzed based on the biodiversity index.

- Shannon diversity index:
  \[ H' = -\sum P_i \ln P_i \]

- Margalef species richness index:
  \[ D = (S-1)/\ln N \]

- Pielou uniformity index:
  \[ J = H/\ln S \]

In the formula: N refers to the number of fish individuals collected in each batch; S refers to the number of fish species in each batch; P_i refers to the ratio of the number of individuals of the ith species in each batch to the total number of individuals.

Simpson dominance index (D') was used to compare the concentration of dominance types in different sampling batches. \[ D' = 1 - \sum P_i^2 \]; where P_i is the ratio of a certain number of individuals to the total number of individuals.
3.3. Species cumulative curve
In this study, statistical software EstimateS was used to statistically analyze the cumulative curve of fish species passing through Cao'e River.

4. Results and Analysis

4.1. Type composition and specifications
From May to November 2019, fishes were caught by the net and sampled at the fishway exit twice each month during the big and small tide flood seasons, respectively. Fishes were caught by the net 14 times in total, and 27 species of nektonic organisms were caught, totaling 2,926, belonging to 10 orders and 15 families. Of which, there are 23 species of fishes, belonging to 9 orders and 13 families; 1 species of shrimps and 2 species of crabs.

The individual body length of the caught fish ranged from 2.5cm (Lateolabrax maculatus) to 80cm (grass carp), and the weight ranged from 2g (baby croaker) to 3,000g (carp). The fish with largest number was coilia ectenes, totally 1,465, accounting for 50.07% in total; that with second number was minnow, totally 892, accounting for 30.49%; besides, crucian carp, bighead carp, silver carp, carp, lateolabrax maculatus also had large number, as shown in Table 1 in detail. Most of the fishes caught were migratory fish species, including saltwater and freshwater fishes such as baby croaker and hyporhamphus intermedius, and migrating fishes in the estuary included eel, Liza haematocheila, coilia ectenes, silverfish, Lateolabrax maculatus, Takifugu obscurus, Synechogobius hast. White prawns were mainly Macrobrachium superbum, and the individuals found were also small. In the surveys of previous years, the numbers of exopalaemon modestus heller and Palaemon serrifer had been very small and almost cannot be seen; the fishing net was set near the exit on the right bank fishway of Cao'e River, so the fishes surveyed were basically some of the fishes that had completed upstream migration through the right bank fishway.

Table 1 Species Composition and Specifications of Fishes Passing through the Right Bank Fishway from May to November 2019

| Order          | Family     | Species                  | Statistical period (month) | Quantity | Proportion /% | Body length Range/cm | Weight Range/g |
|----------------|------------|--------------------------|----------------------------|----------|---------------|----------------------|----------------|
| I. Decapoda    | Palaemonidae | Macrobrachium superbum   | + + + + + + + + +          | 48       | 1.64          | 4-9                  | 1.6 - 9         |
| (II) Grapsidae |            | Eriocheir sinensis       | + + + + + + + +           | 7        | 0.24          | 5-6                  | 4              |
|                |            | Ilyoplax tanssuensis     | +                          | 14       | 0.48          | 2 - 15               | 5 - 20          |
| II. Clupeiformes | Engraulidae | Coilia ectenes           | + + + + + + +             | 1,465    | 50.07         | 10 - 27              | 8 - 90          |
|                |            | Grass carp               | +                          | 1        | 0.03          | 80                   | 3500           |
|                |            | Black carp               | +                          | 2        | 0.07          | 22 - 32              | 100 - 250       |
|                |            | Megalobrama amblycepha    | + + + + + + +             | 6        | 0.21          | 23 - 28              | 140 - 400       |
| III. Cypriniformes | Cyprinidae | Erythroculter dabryi     | + + + + + + +             | 1        | 0.03          | 40                   | 400            |
|                |            | Erythroculter ilishaeformis | + + + + + + +           | 41       | 1.40          | 13 - 38              | 12 - 650        |
|                |            | Culter mongolicus        | + + + + + + +             | 38       | 1.30          | 14 - 30              | 50 - 150        |
|                |            | Minnow                   | + + + + + + +             | 892      | 30.49         | 8 - 19               | 7 - 90          |
|                |            | Xenocypris davidi        | + + + + + + +             | 42       | 1.44          | 10 - 30              | 30 - 210        |
|                |            | Silver carp              | + + + + + + +             | 52       | 1.78          | 15 - 55              | 50 - 2,000      |
4.2. Species richness

Species richness is often regarded as one of the most important criteria for determining conservation value, and obtaining reliable estimates of species richness is an important goal for diversity conservation. The species richness of fish passing through the fishway was estimated through the common estimation methods ACE (Abundance-base Coverage) and ICE (Incidence-based Coverage Estimator) provided by EstimateS software, and the final species richness was estimated to be 30 species (Table 2). From the effect of sampling, the actual number of species collected (27 species) was about 90% of all species in the fishway (estimated species richness). Most swimming species in the fishway on the right bank of Cao’er River were collected and the effect was good.

### Table 2 Summary of EstimateS Calculation Results

| Samples | Individuals (computed) | S(est) | ACE Mean | ICE Mean |
|---------|------------------------|--------|----------|----------|
| 1       | 209.93                 | 8.33   | 9.49     | 8.59     |
| 2       | 419.86                 | 12.43  | 13.49    | 13.52    |
| 3       | 629.79                 | 15.11  | 16.24    | 15.32    |
| 4       | 839.71                 | 17.03  | 18.43    | 17.53    |
| 5       | 1049.64                | 18.52  | 20.14    | 19.24    |
| 6       | 1259.57                | 19.73  | 21.66    | 20.74    |
| 7       | 1469.5                 | 20.74  | 22.61    | 21.74    |
| 8       | 1679.43                | 21.6   | 23.39    | 22.52    |
| 9       | 1889.36                | 22.34  | 24.1     | 23.2     |
| 10      | 2099.29                | 23     | 25.57    | 24.68    |
| 11      | 2309.21                | 23.58  | 26.55    | 25.7     |
| 12      | 2519.14                | 24.1   | 27.98    | 26.1     |
| 13      | 2729.07                | 24.57  | 28.96    | 27.58    |
| 14      | 2939                   | 25     | 29.49    | 28.62    |

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| 13      | 2729.07                | 24.57  | 28.96    | 27.58    |
| 14      | 2939                   | 25     | 29.49    | 28.62    |
4.3. Biodiversity indicators
Comparing the 14 sampling results from May to November 2019, it was found that the biodiversity indicators of different batches changed significantly. The average value of diversity was 2.278 and the range of change is 1.449 to 3.11; the average value of species richness index was 1.704 and the range of change is 1.048 to 2.646; the average of uniformity was 1.12 and the range of change was 0.628 to 1.393; the average of dominance was 0.728 and the change range was 0.556 - 0.869 (Table 3).

| Month  | Batch | Diversity index H | Species richness index D | Uniformity J | Dominance D’ |
|--------|-------|-------------------|--------------------------|--------------|--------------|
| May    | 1     | 1.449             | 1.084                    | 0.697        | 0.566        |
|        | 2     | 1.662             | 1.376                    | 0.722        | 0.595        |
| June   | 3     | 1.484             | 1.232                    | 0.714        | 0.556        |
|        | 4     | 2.090             | 1.395                    | 1.167        | 0.721        |
| July   | 5     | 1.611             | 1.753                    | 0.628        | 0.521        |
|        | 6     | 2.738             | 2.469                    | 1.102        | 0.750        |
| August | 7     | 2.957             | 2.154                    | 1.346        | 0.855        |
|        | 8     | 2.712             | 1.662                    | 1.393        | 0.839        |
| September | 9     | 2.190             | 1.200                    | 1.361        | 0.763        |
|        | 10    | 2.812             | 1.850                    | 1.352        | 0.845        |
| October | 11    | 2.879             | 1.924                    | 1.385        | 0.853        |
|        | 12    | 3.110             | 2.646                    | 1.351        | 0.869        |
| November | 13    | 2.214             | 1.595                    | 1.236        | 0.752        |
|        | 14    | 1.985             | 1.516                    | 1.233        | 0.704        |

According to the monitored biodiversity index of nektonic organisms in the fishway on the right bank of the Cao'e River, they were generally at the upper and middle levels, and they were evenly distributed. Numerically, it was slightly lower than the average value of the overall biodiversity index of Cao'e River basin in 2014 (2.47) [16].

4.4. Seasonal differences
According to the monitored results of the fishway on the right bank of Cao'e River from May to November, it was found that there was a certain month difference in the fish population and quantity entering the fishway in different months. From the number of species, the average number of species monitored each month was 16 species, of which the largest number was in July in which a total of 25 species were monitored, accounting for 92.59% of the total number of species monitored; numerically, the average number monitored monthly reached 106, of which the largest number was in May in which a total of 1,356 were monitored. Of which, the numbers monitored in May, June, and July far exceeded other months, and the numbers monitored in those three months accounted for 91.41% of the total number, and the number of species and the number of individuals also showed a certain positive correlation. It can be seen from Figure 2 that, overall, the difference in the number of fish individuals monitored in each month was far greater than the difference in population numbers, and the number of fish passing in spring and summer was much higher than in autumn and winter.
4.5. Temperature difference

The changes of the ecological environment factors are the main factors that induce the fish migration behavior. Through literature research, the main ecological environment factors that influence the fish passing effect are water temperature and runoff. For the fishway on the right bank of Cao'e River, because it belongs to the tidal estuary gate fishway, the upstream and downstream water levels and runoff change in real time, each monitoring in this study goes through a complete tide cycle. The effect of temperature on the fish passing effect is temporarily considered here.

The analysis results are shown in Figure 3, which shows that the temperature has a significant effect on the fish passing effect of the fishway. During the year, the temperature varied greatly with the season. From the monitoring months, there were many types and numbers of fish passing through the fishway in May, June, and July. They showed a positive correlation, and with the increase of temperature, the species and quantity of passing fish further increased. Since then, the species of fish declined significantly, and was around lows in the autumn and winter seasons. However, the number of individual fish reached a peak and then fell back to a certain extent, and a certain amount of increase occurred in September (autumn). Thereafter, as the temperature further decreased, the number of individuals gradually decreased.

The correlation between the population and quantity of fishes in the fishway and temperature was further quantitatively analyzed. As shown in Figure 4, the species and quantity of fishes passing through the fishway on the right bank of Cao'e River showed a certain correlation with temperature. As the temperature increased, both the number of fish species and the species of fish species increased to a certain extent. When the temperature reached about 30 °C, the species and number of fishes were increased. After that, as the temperature increased, they decreased to a certain extent.
4.6. Fish effect

According to 14 times of monitoring of the fishway on the right bank of Cao’e River from May to November 2019, a total of 27 species of nektonic organisms were monitored, of which 23 species were fish, 1 was shrimps, and 2 were crabs. Among them, the quantities of coilia ectenes, minnows, bighead carps, carps and crucian carps were relatively abundant; white prawns were mainly Macrobrachium superbum, and the individuals found were also small. In the surveys of previous years, the numbers of exopalaemon modestus heller and Palaemon serrifer had been very small and almost cannot be seen; the fishing net was set near the exit on the right bank fishway of Cao’e River, so the fishes surveyed were basically some of the fishes that had completed upstream migration through the right bank fishway.

According to the estuarine migratory fishes surveyed in the Cao’e River estuary from 2014 to 2015 [16], Coilia ectenes, Coilia mystus, Takifugu obscures, Lateolabrax maculatus, and eel as the main estuarine migratory fishes. However, in the monitoring of the right bank fishway, no Coilia mystus was found, and less Takifugu obscures and eels were detected. This may not coincide with the time period of this monitoring and the migration time of individual migratory fishes and related to the fact like that eel belongs to the migratory species of lower sea.

According to the results of field investigations of swimming organisms in Cao’e River waters from May 2014 to May 2015 by the Second Institute Of Oceanography, MNR [16], 57 species of nektonic organisms were captured, including 51 species of fishes, 4 species of shrimps, and 3 species of crabs; more than 40 nektonic organisms were captured in the fishway on the two sides of the Cao’e River Gate and the waters near the Xinsanjiang Gate. A total of 27 fish species were monitored in the fishway on the right bank of Cao’e River this time, accounting for 47.37% of the total species in this water area. In addition to the Coilia mystus, the other major Cao’e river migratory fishes, as well as the "four major Chinese carps", crucian carp, carp, and Lateolabrax maculatus, etc., all appeared in the fishway, and some of them had a larger number distribution; from 2.5cm Lateolabrax maculatus to 80cm grass carp; from baby croaker weighing 2g to carp weighing 3,000g, all kinds of fish species in different development periods can pass through the fishway smoothly, indicating that the design and operating conditions of the Cao’e River fishway can meet most fishes to overcome the factors such as flow velocity and flow field of the fishway, and successfully migrate. Therefore, the Cao'e River fishway has a good fish passing effect.

In Table 4, we can see the comparison of the operating effects of domestic and foreign fishway. In terms of fish species passing through fishway, they were in the middle of several listed fishways at home and abroad, but the number of individuals passing through the fishway is the largest among these fishways. The reason for this phenomenon is that on the one hand, there are a large number of coilia ectenes and minnow migrating in the fishway during the spring and summer seasons, which causes a large number of fish individuals to be monitored; on the other hand, due to the monitoring period of only 7 months, some periodic fish failed to appear in the monitoring period. In addition, the downstream of the Cao’e River fishway belongs to the tidal estuary of the Qiantang River. The water level in the downstream changes in real time. During some low tide periods, the water level has not passed through the fishway entrance, which prevents fish from entering the fishway. In addition, compared with the
wide surface of Cao'e River estuary, the entrance to the fishway on the right bank is relatively small, and there are no other fish trapping equipment and devices, which has a great impact on the fishway passing effect. According to the analysis, these three aspects are the main factors limiting the current fish species passing through the fishway.

Table 4 Comparison of Fish Passing Effect of Passway at Home and Abroad with Fish Passing Effect of Cao'e River Gate Fishway

| Fishway name                        | Fishway type          | Monitoring time          | Fish species passing | Number of fishes | References                                      |
|-------------------------------------|-----------------------|--------------------------|----------------------|------------------|------------------------------------------------|
| Yangtang                            | Vertical groove       | From April to July 1981  | 36 species           | 385 fishes       | Xu Weizhong and Li Shengwu, 1982                |
| Yu Xi Gate                          | Partition vertical seam | March-May 1973         | 15 species           | 75 fishes        | Anhui Aquatic Resources Investigation Team, 1975 |
| Engelheiro Sergio Motta (Brazil)    | Partition vertical seam | December 2004-March 2005 | 37 species           | /                | Sergio M et al, 2007                            |
| Burnett River barrage (Australia)   | Partition vertical seam | 1984-1987              | 34 species           | 187 fishes       | Stuart I G & Berghuis A P, 2002                 |
| Xiniu Fishway                       | Vertical groove       | March-August 2012       | 38 species           | 41 fishes        | Li Jie et al., 2013                            |
| Water Plant Dam Fishway             | Daniel                | August 2015-July 2016   | 39 species           | 35 fishes        | Zhang Yanyan, et al., 2017                     |
| Changzhou Fishway                   | Partition vertical seam | April-May 2012         | 23 species           | 2,206 fishes     | Tan Xichang et al., 2013                       |
| Fishway of Cuijiaying Navigation and Hydropower Project | Partition vertical seam | September 2012 | 11 species           | 37 fishes        | Ke Wang et al., 2013                            |
| Cao'e River Fishway                 | Partition vertical seam | May-November 2017      | 27 species           | 2,926 fishes     | This study, 2019                                |

5. Conclusions and Recommendations

(1) Through 14 fishing samples from the right fishway on the right side of the Caojiang River flood gate during May and November of 2019, a total of 27 species of nektonic organisms were collected, totaling 2,926, belonging to 10 orders and 15 families. The individual range of the caught fish is 2.5cm (Lateolabrax maculatus) to 80cm (grass carp), and the weight range is 2g (baby croaker) to 3,000g (carp). Coilia ectenes is the most, minnow is the second and there are other fishes (crucian carp, bighead carp, silver carp, carp, and lateolabrax maculatus, etc.) The Cao'e River fishway provides a channel for the exchange of fish upstream and downstream of the dam, becoming an important channel for resolving the migration of blocked fish, and has played a positive role in protecting fish resources in the basin.

(2) During the experiment, the average value of the biodiversity index of nektonic organisms in the fishway on the right bank of Cao'e River was 2.278, the average value of species richness index was 1.704, the average value of uniformity was 1.12, and the average value of dominance was 0.728. The data show that the effect of fish passing through fishways in different seasons, hydrological conditions, and weather conditions is very different. In general, the number of fish passing in spring and summer is much higher than that in autumn and winter. Of which, the number monitored in May, June, and July far exceeded that in other months and the number of those three months accounted for 91.41% of the total number. From May, the species and number of fish passing gradually increased, and by July, they reached their peak.

(3) There is a certain relationship between the fish passing effect of the Cao'e River fishway and the upstream water level. In the migratory season, if conditions permit, the high water level in the upstream
can be appropriately maintained, and the over-current flow can be increased to improve the effect of over-fishing. During the fishing flood season, when the water (tide) level downstream of the sluice is slightly higher than the upstream, the gate holes on both sides of the Cao'e River gate are opened for the collection of juvenile fishes. And in different seasons and months, the migration time and population of fish are different, and the fish passing situation in the fishway can provide real-time basis for the collection of fish fry by opening the sluice gate. Therefore, it is recommended to strengthen the monitoring of the number of fish populations passing through the fishway and further improve the plan of collection of fish fry by opening the sluice gate based on the observation results.

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