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Preliminary study on the application of radio-telemetry techniques to evaluate movements of fish in the Lateral canal at Itaipu Dam, Brazil

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A preliminary study on the application of radio-telemetry techniques to describe the movements of fish in a bypass channel at Itaipu Dam (Paraná River), known as "Canal da Piracema," was carried out between January and February of 2004. Fourteen individuals of six species (*Prochilodus lineatus, Leporinus friderici, Schizodon borellii, Pseudoplatystoma fasciatum, Pterodoras granulosus* and *Cichla kelberi*) were intragastrically and surgically radiotagged and monitored by three experimental fixed radio-telemetry stations installed in the upper portion of the Canal. The surgical implantation of transmitters and the anesthesia using clove oil proved to be more efficient and allowed easier handling in comparison to intragastric implantation and electronarcosis immobilization. The use of fixed stations to obtain data was found to be very suitable for tracking movements of several different fish species in the Itaipu lateral channel. Three species (*P. granulosus, S. borellii* and *C. kelberi*) moved downstream after release. Two individuals of *P. fasciatum* and two of *P. lineatus* migrated upstream, leaving the channel 7 and 10 days and 2 and 24 days after release, respectively. *Leporinus friderici* was the only species that did not leave the release site until the end of the study period.

Um estudo preliminar sobre a aplicação de técnicas de radiotelemetria para descrever os movimentos de peixes no canal de transposição da UHE Itaipu (Rio Paraná), conhecido como "Canal da Piracema", foi realizado entre janeiro e fevereiro de 2004. Seis espécies (*Prochilodus lineatus, Leporinus friderici, Schizodon borellii, Pseudoplatystoma fasciatum, Pterodoras granulosus* e *Cichla kelberi*) totalizando 14 indivíduos foram marcadas com radiotransmissores via cirúrgica e esofágica e rastreados através de três estações fixas experimentais de radiotelemetria instaladas na porção superior do Canal. A implantação de transmissores através de cirurgia e a anestesia por óleo de cravo mostraram-se mais eficientes e de fácil manejo do que a imobilização por eletronarcose e a implantação intragástrica. A utilização de estações fixas para obtenção dos dados mostrou-se apropriada para rastrear os movimentos de diferentes espécies no canal de transposição de Itaipu. Três espécies (*P. granulosus, S. borellii* e *C. kelberi*) movimentaram-se para jusante após a soltura. Dois indivíduos de *P. fasciatum* e dois de *P. lineatus* migraram para montante, deixando o canal 7 e 10 dias e 2 e 24 dias após a soltura, respectivamente. *Leporinus friderici* foi a única espécie que não deixou o local de soltura até o final do estudo.

Key words: Itaipu Dam, Fish channel, Migratory fish, Radio-telemetry.

Introduction

Since the construction of the first fish ladder in a tributary of the Upper Paraná River in 1911, changes in the Brazilian regulation on the mandatory construction of fish passages in dams have been discussed. Central to these discussions is the role of the passages for the conservation of the fish fauna (Agostinho *et al*., 2002), and particularly of migratory species which are generally the most affected by dams. In the Paraná River basin there are around 130 dams higher than 10 m, and 26 possess areas greater than 100 km^2.

Agostinho *et al*. (2007) report that the construction of

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successive dams in the Paraná River was largely responsible for the disappearance of the large migrators in the upper stretches of the basin. To provide continuity to the migration of fishes in the Paraná River, from downstream of Itaipu Dam to the upper stretches of the basin, the Itaipu Binacional constructed the "Canal da Piracema," a 10-km bypass channel that started operation in December, 2002.

The Canal could be a viable option for enhancing fish movement upstream of the dam, especially because of the presence of an unimpounded stretch (230 km) between Itaipu Reservoir and Porto Primavera Dam, but the effectiveness of this lateral channel as a migratory route has not been demonstrated. Makrakis *et al*. (2007) describe the ichthyofauna present in the channel and discuss some general aspects that may be limiting the ascent of fish. Other fish passages, particularly ladders, have been evaluated in the Neotropical region over the past two decades (Quirós, 1988; Godinho *et al*., 1991; Borghetti *et al.*, 1994; Agostinho *et al*., 2002; Fernandez *et al*., 2004).

However, most of these studies were carried out sampling fish with gillnets or cast nets, and some tagging was done. Radio-telemetry, which may be the best approach to study fish passages, was first applied in Brazil only after 2002. This technique can be used to precisely evaluate the movements of fish by the Itaipu lateral channel, especially due to its features such as dimension and diversity of environments, which make the application of other techniques difficult.

Therefore, the purpose of this preliminary study was to test different tagging procedures, with regard to where to insert the tags, type of tags, tracking equipment and radio frequencies, in order to determine protocols to be applied in other studies to be conducted in Itaipu Dam lateral channel (Canal da Piracema) and in the upper Paraná River basin. Due to the absence of information for the Paraná River, several species were tagged, which also furnished initial informative data about their movements in the channel. We used this to determine the species to be tagged in future studies.

Materials and Methods

Study Area

The Itaipu reservoir, formed in November 1982, has a total area of 1350 km^2 and 170 km long. Itaipu Dam is 120 m high in average and the Canal da Piracema was constructed to link the Paraná River to the Itaipu reservoir. This is the world's largest bypass channel, with a total length of about 10 km. The Canal is positioned at a lateral point of the dam (Fig. 1), part of which contains a stretch (6 km) of a natural creek (the Bela Vista Creek). The Canal has many different environments, each with different challenges to fish movements, such as ladders, lakes and the Bela Vista Creek.

For this study, only the upper part of the Canal (4 km) was considered, which includes the "Lago Principal" (resting pool), "Canal de Alimentação em Aterro" (ladder), "Lago das Grevilhas" (small resting pool) and "Canal de Alimentação em Trincheira" (a ladder). These stations were selected because of the better logistic conditions for the stations, fish lab and fish transportation in this area, leading to less stress. In addition, the selected section included both low and moderate gradient reaches and contained a small pond near its middle part which gave the tagged fish the proper conditions to acclimate to the characteristics of the channel after being released.

The "Lago Principal" (downstream station 1) has an area of 14 ha with a depth ranging from 3 to 9 m. This lake has two lateral escapes for safety reasons, with triangular floodgates for flow control. The "Canal de Alimentação em Aterro" (between station 2 and 1) is 1620 m long in the initial portion with a mean slope of 3.1%, 2% in the intermediate stretch and 0.7% in the final stretch. The small resting lake at the end of the "Canal de Alimentação em Trincheira" is named "Lago das Grevilhas" (station 2) and is 2 ha in size with a maximum depth of 0.80 m. The "Canal de Alimentação em Trincheira" is the first part of the Canal, between station 3 and 2 (Fig. 1). It is 8 m wide, 720 m long with a slope of 0.759%. This Canal has many sections of depth controls, with concrete baffles and rock blocks. For a detailed description of the entire lateral channel, see Makrakis *et al*. (2007).

Fish Sampling and Transportation

Fish were captured in the Bela Vista Creek (except one captured in a resting pool), with cast nests (mesh size of 6.0 and 14.0 mm stretched knots), operated during January 14-20, 2004. Five species with different migratory capacities (*Prochilodus lineatus, Leporinus friderici, Schizodon borellii, Pseudoplatystoma fasciatum,* and *Pterodoras granulosus*), and one sedentary species (*Cichla kelberi*) were tagged.

Collected fish were transported to the laboratory located

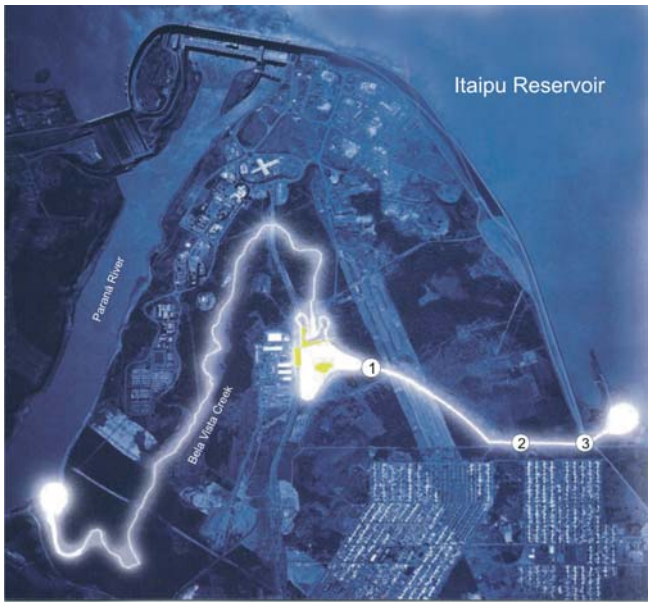

Fig. 1. Locations of the fixed-station receivers (numbers inside the white circles) during the pilot study conducted in the lateral channel located near Itaipu Dam.

in the lower portion of the Canal in a circular fish transport tank (1000 l), supplied with oxygen. In the lab, fish were held in tanks, with pumps providing freshwater from the channel for each tank. The water levels in each tank were maintained at 1-1.5 m during the holding periods and were reduced to 0.3 m when fish were removed for tagging or release. All fish were held in these tanks for at least one night prior to tagging, and for 1-3 days between tagging and release. The same apparatus was used to transport tagged fish to the release site. All fish were released during January 18 - 21, 2004 in site 2, to identify whether tagged fish moved out of the study area, either upstream or downstream.

Tagging

Two types of radiotransmitters were used in this study: MCFT-3BM (Lotek, 16x43 mm, 5 g in water) were implanted in smaller fish (30-50 cm) and MCFT-3A (Lotek, 16x46 mm, 6.7 g in water) in fish larger than 50 cm. Transmitters were implanted both surgically and esophagically. For the surgical procedures fish were anesthetized with clove oil or immobilized through electronarcosis, according to protocols described by Henyey *et al.* (2002). We used these procedures to select the most appropriate method to be applied for the different species captured in the Itaipu lateral channel.

For the surgeries, we placed fish in a bath of clove oil (1 ml eugenol/40 l water) for approximately 2 to 4 min. During surgeries, we kept the fish immobile on a padded V-shaped tray, and the gills were constantly bathed with anesthetic - 1 ml of eugenol per 80 l of water (Fig. 2). The surgical procedures followed Jepsen *et al*., 2002.

Electrical immobilization was carried out in a larger container with the fish in a cloth sling. Electric current (AC) was applied through sheet metal plate electrodes at either end of the bath, and the amperage was slowly increased until the fish became immobilized and unresponsive to touch. The surgical procedures were similar for both anesthesia and immobilization.

We removed scales before making a 2-cm incision in the abdomen body wall. A catheter was inserted in the incision and further pulled out through the body wall. The antenna was inserted through the catheter and extended posteriorly through the body wall so that it exited the body about 3 cm below the lateral line. The catheter was removed before the insertion of the transmitter in the body cavity. The incision was sealed using Vetbond (a tissue adhesive manufactured by 3M). Once the radio-tag was successfully implanted, an external hydrostatic tag was applied and each fish was measured for fork length and total length and weighed.

Tracking

Post-release tracking was conducted using a fixed-station set up at the following three proposed stations: between "Lago Principal" and "Canal de Alimentação em Aterro" (Station 1); adjacent to the pond where all the fish would be released in the upper channel (Station 2); and at the upstream exit of the channel (Station 3; Fig.1). Each fixed-station included a Lotek SRX400 receiver, two 3-element Yagi antennas (one pointed upstream and the other pointing downstream); one antenna switcher; a 12-volt battery to power the receiver; and a coax cable to connect the antennas to the switcher and switcher to the receiver (Fig. 3). At two of the stations, the receivers, switchers and batteries were secured inside a metal box with a lock and both antennas were mounted on a single 3-m wooden pole adjacent to the box. At the site near the upstream exit of the canal, the receiver, switcher and battery were stored inside a small building adjacent to a flow control structure and the antennas were mounted on the railings at each end of the flow control structure. The heights of the antennas above the water were 4 m at Station 1, 15 m at Station 2 and 4 m at Station 3.

Data Analysis

The data stored by the automatic Lotek stations were downloaded a minimum of two times per week, and more of-

Fig. 2. Surgical implantation of a radiotransmitter in *Pseudoplatystoma fasciatum*, captured in the lateral channel located near Itaipu Dam.

Fig. 3. Radio-telemetry fixed station at "Lago das Grevilhas", in the lateral channel near Itaipu Dam.

ten if receiver memory began to fill up prior to the scheduled downloads. All fixed-stations were monitored daily for the first week to check the receiver memory status, accuracy of the internal clock and battery voltage.

Once received, all fixed-station data were organized into structured databases and analyzed using *Telemetry Manager* Version 2.8, developed by LGL Limited. The *Telemetry Manager* software facilitates the importing of the raw data files downloaded from the LOTEK SRX receivers and organizes these data into a database containing records for each logged data transmission from the tagged fish. The software then processes the data to remove records that did not meet the criteria specified for valid data records. Examples of invalid data included background noise, records with a signal strength that was below a set threshold and records that fell outside the time period identified as the official release time and date.

Table 1. Length, weight and tagging method for each radio-tagged fish.

Fish nº	Fish species	Weight (g)	Total length (cm)	Standard length (cm)	Tagging method	Anesthetic
1	*P. lineatus*	3400	55.0	47.0	esophagic	none
2	*L. friderici*	550	35.0	28.0	esophagic	none
3	*L. friderici*	550	36.0	29.2	surgery	clove oil
4	*P. lineatus*	3350	58.0	49.2	surgery	clove oil
5	*S. borellii*	850	42.5	37.0	surgery	clove oil
6	*S. borellii*	550	39.0	34.0	surgery	electric
7	*P. granulosus*	2050	54.0	48.0	surgery	clove oil
8	*P. granulosus*	1800	56.0	40.0	surgery	electric
9	*P. fasciatum*	2950	77.0	66.5	surgery	clove oil
10	*P. fasciatum*	2850	76.0	68.0	surgery	clove oil
11	*C. kelberi*		49.0	42.0	surgery	clove oil
12	*C. kelberi*		41.0	35.5	surgery	clove oil
13	*P. fasciatum*		86.0	77.0	surgery	clove oil
14	*P. granulosus*		50.0	42.0	surgery	clove oil

Results

Sampling and Transportation

We used cast nets to sample fish, since this active fishing gear is less stressing, because fish spend little time in the net and because it is also appropriate for use in the channel.

However, this method could lead to mucus loss of the scales during captures, which may facilitate infestation by fungus, virus and bacteria.

Keeping fish in the tanks of the laboratory, before and after surgery, was important to evaluate fish behavior. This allowed us to choose the most active fish and to monitor tagged fish after surgery, information still not available for several neotropical species.

Tagging

A total of 14 fish of 6 different species (*Prochilodus lineatus, Leporinus friderici, Schizodon borellii*, *Pseudoplatystoma fasciatum, Pterodoras granulosus* and *Cichla kelberi*) were radio-tagged and released. For all tagged fish, the time from the induction of anesthesia (clove oil), when fish were placed in the bath, to the total recovery of opercular movements was 1 to 4 min. The clove oil was used in 10 of the 12 individuals that were surgically tagged. Only one individual died after tagging, apparently due to the high concentration of clove oil.

Immobilization with electronarcosis was applied to an individual of *S. borellii* and another of *P. granulosus*. For both species, time for immobilization and recovery was short (less than 1 min). However, a restriction of the method is the risk of intense stress resulting from the application of inadequate voltage levels. All tagged fish were released in the upper "Lago das Grevilhas" adjacent to Station 2 (Table 1).

Tracking

Data collections using fixed station were satisfactory. The three stations worked properly during almost all the period considered, except for a problem with the internal battery of the receiver of Station 2, which resulted in no data from February 13 to the end of the study period (February 18, 2004).

Although preliminary, radio-telemetry was shown to be adequate for determining the movements of fish in the Itaipu lateral channel. Among the species tagged, two (*P. fasciatum* and *P. lineatus*) moved upstream through the upper portions of the canal (Table 2). Two *P. fasciatum* (fish 9 released on January 18 and fish 13 released January 21) passed the upstream station (Site 3) and exited the channel on January 28 at 6:52 and 6:57a.m., respectively, after residing in the mid-channel pool for 10 and 7 days. The other *P. fasciatum* (fish 10) migrated downstream 10 h after being released and was last tracked by the downstream antenna of Station 1 just prior to its demobilization on February 18 (Fig. 2). This fish was detected in different parts of the lake as well as by the upstream antenna of Station 1 on several occasions during the one-month study period.

The two *P. lineatus* were detected as they exited the upper end of the canal. The first *P. lineatus* that exited the canal was esophagically tagged, whereas the second *P. lineatus* was tagged surgically. The travel time from Station 2 to 3 was similar for both fish, so the entire difference in exit date was due to the longer residence time at the release site (24 days) for the second fish (Fig. 4).

Of the other four species tagged, three (*P. granulosus, S. borellii* and *C. kelberi*) demonstrated clear downstream movements. The three tagged *P. granulosus* migrated downstream at different rates. One *P. granulosus* was detected at Station 1 within 10 h of the release time but was not detected again during the study. The other two fish were detected at Station 1 for time periods ranging from 8.6 days to 29 days. The *S. borellii* moved faster downstream than any other fish, taking only 1 h to move from Station 2 to Station 1. Both *C. kelberi* tagged moved downstream but at different rates after different residence periods at the release site. Neither of these fish was detected during the last three weeks of the monitoring period.

Leporinus friderici was the only species tagged that did not leave the release site, but the two individuals showed small-scale movements and were continuously detected at

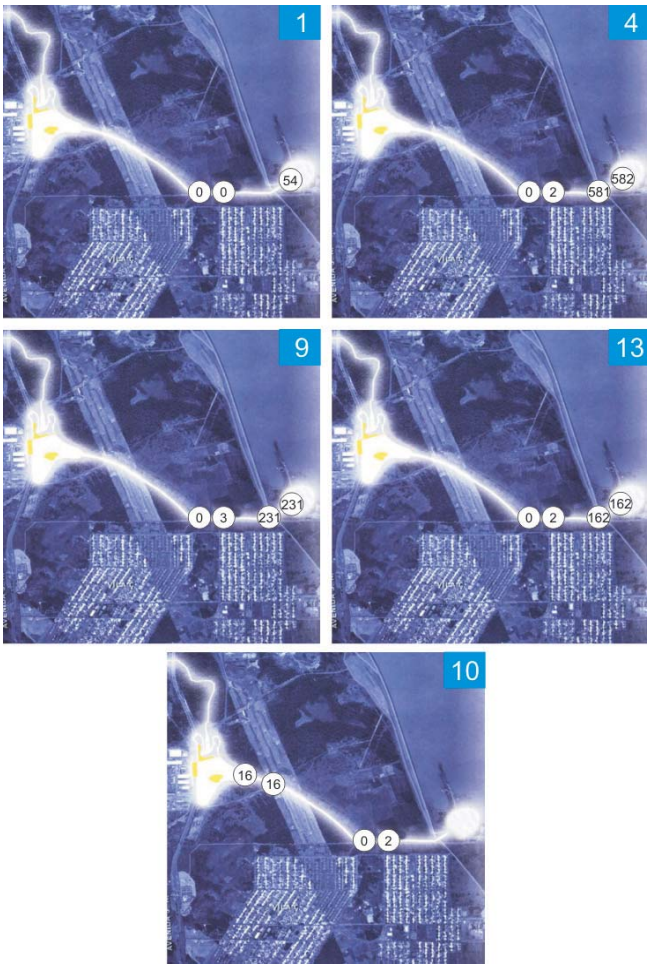

Fig. 4. Movements of *Prochilodus lineatus* (fish nº 1 and 4) and *Pseudoplatystoma fasciatum* (fish nº 9, 10 and 13) in the lateral channel located near Itaipu Dam (detections in the fixed stations, in number of hours post-release, are shown in the white circles).

the release site for the entire period that Station 2 was operational. These individuals were the smallest of the tagged fish (35-36 cm in total length and only 550 g).

Discussion

The 14 fish reacted very well to the surgery procedures, and none of them died and continued to show movements at different scales and intensities until the end of the study. The use of clove oil as anesthetic proved to be efficient, in part because of the high temperatures during the study period. This efficiency was due to the fast immobility and recovery provided, and apparently, the clove oil did no show toxic effects on tagged fish (Taylor & Roberts, 1999). According to Jepsen *et al.* (2002), the induction and recovery time is temperature dependent, and in general, pikes (*Esox lucius*) needed several hours to fully recover from anesthesia in cooler temperatures (water temperature < 2ºC). On the other hand, perch (*Perca fluviatilis*) was rapidly anesthetized on warm days (> 20ºC).

The induction time for anesthesia in this study could be considered normal. Average time to induction is approximately 2-4 min and the time for recovery is 4-6 min (Jepsen *et al.*, 2002). Near the end of the surgery, the mix of clove oil and water that irrigates the gills was diluted (more water and less anesthetic), which enabled the fish to recover faster. The interval between the end of the surgeries and the re-started movements of the opercula were reduced (less than two minutes for all tagged fish).

Electronarcosis was efficient for the two tagged fish. However, the low number of individuals and species tagged using this approach prevented further analysis. Nonetheless, results from studies carried out in São Francisco River Basin indicate that this technique is also adequate for neotropical fish (Godinho & Kynard, 2006).

Intragastric implantation of transmitters in two species (*P. lineatus* and *L. friderici*) was successfully carried out and both fish survived. However, the effects of this approach are still unknown, and are especially important in species that show high feeding activity, since the transmitters are likely to interfere with feeding, while in some species, they may be regurgitated (Armstrong *et al*., 1992; Armstrong & Rawlings, 1993; Lucas & Baras, 2000).

The fixed stations documented the movements of tagged fish during the study period. The data obtained were filtered

Table 2. Release dates and tracking results for each radio-tagged fish. Resident (d) = residence time in each fixed station expressed in number of days.

Fish nº	Species	Release date	First record		Resident (d)		
			Station 1	Station 3	Station 1	Station 2	Station 3
1	*P. lineatus*	18-January		20-January		2.258	0.013
2	*L. friderici*	18-January				25.85	
3	*L. friderici*	18-January				25.84	
4	*P. lineatus*	18-January		11-February		24.23	0.014
5	*S. borellii*	18-January				25.85	
6	*S. borellii*	18-January	19-January		0.355	0.838	
7	*P. granulosus*	18-January	21-January		6.548	2.657	
8	*P. granulosus*	18-January	19-January		29.49	0.580	
9	*P. fasciatum*	18-January		28-January		9.653	0.019
10	*P. fasciatum*	18-January	19-January		30.03	0.686	
11	*C. kelberi*	20-January	22-January		0.004	1.974	
12	*C. kelberi*	21-January	24-January		5.846	3.316	
13	*P. fasciatum*	21-January		28-January		6.737	0.035
14	*P. granulosus*	22-January	23-January		0.002	0.406	

to eliminate error codes. However, installation of the stations depended on security (to avoid robbery), availability of material in local market (compatible cables along with connectors) and noise caused by interferences. The last was the main problem due to the close urban area and the amount of radio frequencies used by the Itaipu personnel.

Two tagged species were long-distance migratory (*P. lineatus and P. fasciatum*), and both moved upstream and reached the reservoir. Two of the three tagged *P. fasciatum* reached the reservoir during the study period. The difference in the displacement speed detected between the two individuals of *P. lineatus* (22 days) could be related to the method employed to implant the tag. The fish tagged intragastrically left the channel earlier than the one surgically tagged which might have needed more time to recover. The three individuals of *P. granulosus* and one *S. borellii* tagged in this study showed clear downstream movements which could have been related to post-surgical stress or post-spawning migration. The two *L. friderici* did not leave the release site after tagging, but they moved within the channel. This is an indication that these individuals found good conditions in the channel (feeding). *Cichla kelberi* was recorded in the Canal since the beginning of the study, suggesting a likely colonization of this new environment. The two tagged individuals did not leave the Canal until the end of the study.

The use of different protocols to tag and anesthetize the six species captured in the lateral channel (despite the limited number of individuals) indicated the most suitable approach for future studies. The surgical implantation of transmitters and the anesthesia by clove oil proved to be more efficient and allowed easier handling in comparison to the intragastric implantation and electronarcosis immobilization.

This preliminary study also demonstrated that radio-telemetry techniques could be very suitable for tracking both upstream and downstream movements of several different fish species in the Itaipu lateral channel. Some features of this channel, such as high water velocity, sometimes high turbidity and dimensions, make it difficult to collect data on fish behavior using traditional methods. The data and experiences obtained in this study will be useful to new projects in the upper Paraná River with the purpose of evaluating the use of fish bypasses by migratory fish species, and also to identify possible problems for the migration of fish in these structures.

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