TRACKING 48 AND 150 MHZ RADIO-TAGGED MALE LAKE-TROUT DURING THEIR SPAWNING MIGRATION IN A MOUNTAIN REGULATED RIVER

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Abstract - Since 1991, the natural migration of trout (*Salmo trutta* L.) from Lake Geneva to the Lower-Dranse river has been jeopardized by a weir that trout apparently cannot pass. To estimate whether adding a fishway to this weir is useful, five male trout were surgically tagged with radio transmitters operating at radio frequencies of either 48 to 50 MHz and or at 150 MHz to localise eventual spawning grounds. Healing after surgery was very good despite the low water temperature (5.5°C). The 150 MHz system was easy to use and localised fish precisely. The trout migration area was located downstream from a hydraulic power station inducing peaking flows in this very turbulent upland river. Despite these difficult conditions, tracking the trout migration made it possible to localise probable spawning areas.

Key-words: Trout, radio-tracking, *Salmo trutta* L., spawning, migration, Lake Geneva

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1. Introduction

It seems increasingly difficult to properly manage upland rivers because they represent such a major economic stake. These rivers can be inhabited by various native species, in particular river-, lake- or sea-trout (*Salmo trutta* L.). These rivers are used to produce hydraulic power (dams, installations) as well as for rapidly expanding leisure activities, such as angling and white water sports. Sometimes, effluents are poured into them. This means that these rivers suffer significant anthropic damage. Spawning areas are sometimes located in places where white water sports take place, which can lead to their destruction. There are also artificial and natural obstacles that trout running upstream cannot pass. It can thus be necessary to create specific installations to maintain spawning grounds. This involves improving current knowledge of the environment and eventually performing preliminary studies to estimate the carrying capacity of the rivers, that is to determine whether they present areas suitable for spawning where eggs can survive.

Such studies are usually done by walking along and visually observing the river. A traditional spawning ground in a lowland river presents specific characteristics: it is usually a riffle, *i.e.* a shallow area covered with pebbles or gravel, which are moved by trout. Moss does not accumulate on the stones making the river-bed appear white. Upland rivers, however, are not only more difficult to reach but present problems because they are turbulent (and thus the whole river-bed appear white). For these reasons, discovering spawning grounds in upland rivers requires tracking and direct observation of tagged fish.

Mass marking techniques, such as external tagging with labels or fin removal (Champigneulle & Escomel, 1984) and chemical marking (Nielson, 1990; Rojas-Beltran *et al.*, 1995) do not make it possible to track the fish daily in all their migration and activity phases. Only radio-tagging and ultrasonic tagging allow such an approach. Radio-tagging has been used for about 20 years (Stasko & Pincock, 1977; Winter, 1983). Salmon (*Salmo salar* L.) is the main species studied with this technique (Baglinière *et al.*, 1991; Baril & Gueneau, 1986; Hawkins & Smith, 1986; Hawkins & Webb, 1989). The migratory behaviour of the barbel (*Barbus barbus* L.) (Baras, 1992) as well as that of the sea-trout (*Salmo trutta* L.) (Heggenes, 1988;

Fig. 1 - Weir at Vongy ("Le Messager")

Ottaway *et al.*, 1981) have also been studied.
The weir at Vongy (Fig. 1), built in 1991, is located near the mouth of the Lower-Dranse, which is one of the main tributaries of Lake Geneva. According to anglers, this obstacle prevents apparently lake-trout from migrating upstream. Large lake-trout can effectively often be observed failing to jump the obstacle. Moreover, there is some decrease in the number of large trout caught by anglers.
In 1994, the anglers association had 6,300 annual members and issued 2,200 tourist licences. Anglers represent a major economic stake and have a certain influence on local councillors. They asked for a fishway to be installed at the weir at Vongy. Since 1992, anglers have caught trout arriving at the weir at Vongy at the time of spawning and released them upstream from the weir, without knowing whether spawning takes place upstream. Each year around 50 trouts are caught by electro-fishing for this purpose.
The study presented here was carried out during the spawning period to observe the migratory behaviour of trout in order to:
i) determine whether fish caught downstream and released upstream reproduce
ii) provide information, such as the carrying capacity of the river in terms of areas suitable for spawning, to help assess whether it is useful to construct a fish-way in the weir at Vongy.
The use of transmitters with different frequency ranges, *i.e.* 48 MHz and 150 MHz, respectively, made it possible to compare these two systems.

2. Study area and species

The Lower-Dranse is a tributary of Lake Geneva, which is a French and Swiss lake of 582.3 km^2. The Lower-Dranse is an upland river and originates from Bioge at the confluence of three rivers originating from the Pre-Alps range at an altitude of 2478 m. It is 13.5 km long and loses a total altitude of 168 m (Fig. 1).
This river is a spawning river for migratory

lake-trout (Champigneulle *et al.*, 1991). It presents peaking flows due to the hydraulic power station of Bioge (Fig. 2). This river is subjected twice daily to major changes in the water flow rate ranging from a mean flow rate of 19.9 $m^3 s^{-1}$ to a low flow rate of 4.44 $m^3 s^{-1}$ (CIPEL, 1995).

The data measured were: water temperature, flow rate, water conductivity and atmospheric pressure. Water temperature and conductivity were measured each time a fish was localised using a portable WFW LF96 conductimeter. The depth of the water was measured continuously in Bioge station using a limnimeter. These data enabled us to calculate the flow rate using the rating curve provided by EDF (Electricité de France). The atmospheric pressure was provided by the INRA meteorological station located on Lake Geneva.

The brown trout (*Salmo trutta*), sometimes called "common trout", is a salmonid species ecologically very diverse. Behnke (1986) described more than fifty sorts of brown trout according to morphologic and ecologic variations. However, three ecological subspecies are commonly admitted: the sea-trout (*Salmo trutta trutta*), the lake-trout (*Salmo trutta lacustris*), and the river-trout (*Salmo trutta fario*). These subspecies live in different environments and present specific physical and behavioural characteristics resulting from the influence of their environment. *S. t. fario* is a resident subspecies. Resident trout spend their entire life in a river or a small stream, isolated by obstacles. *S. t. lacustris* and *S. t. trutta* are migratory forms. Sea-trout migrate from the rivers or streams in which they are born to the sea. They return to their native rivers to spawn. The lake-dwelling trout migrate from their native rivers to lakes, and also return to the rivers to spawn.

The form studied in this paper is the lake-trout (*S.t. lacustris*). Spawning takes place in rivers from November to January and three stages are observed in the migratory behaviour, *i.e.* upstream movement, stabilisation and voluntary downstream movement to the lake.

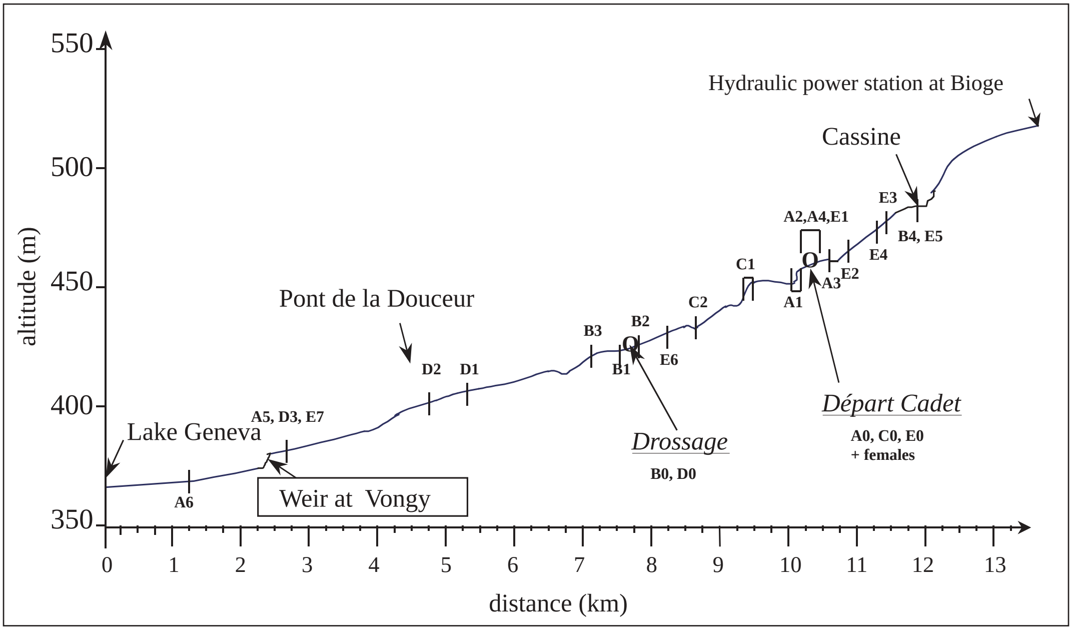

Fig. 2 - Profile of the Lower-Dranse river

When the fish reaches sexual maturity (*see* § 3.6) it goes back to its native river, it is "homing" (Champigneulle, 1991). The upstream migration is usually triggered by an increase in the flow rate (Banks, 1969). Under normal hydrological conditions, temperature seems to have a major effect on migration (Fragnoud, 1987; Baglinière *et al.*, 1991; Meyers *et al.*, 1992). Females create a redd and go back to the lake as soon as spawning is finished. On the contrary, males move upstream from one redd to the next and can spawn until exhaustion. They stay for a few days on the site before returning to the lake.

3. Material and methods

3.1. Transmitters and radio frequencies

The battery-operated radio transmitter emits a pulsed signal. Its life and weight depends on the battery. The transmitter should not weight more than 2% of the fish body weight. Signal propagation is omnidirectional in water and air thanks to the transmitting antenna. The signal is picked up by a receiving antenna and amplified by a receiver in the form of a series of beeps.

During propagation, the signal is subject to various disturbances which often lead to the signal being lost: scattering loss in the air, refraction at the air/water interface, attenuation due to plants, reflection and diffraction due to high rocky cliffs. The signal is further attenuated by high water conductivity and radio frequency. Attenuation at a depth of 5 m in water with a conductivity of 80 μScm^{-1} is 12 dB at 48 MHz and 18 dB at 150 MHz (Winter *et al.*, 1978; *in* Baras, 1992). The 48 MHz frequency range is consequently often used in rivers (Baglinière *et al.*, 1991; Baras, 1992). The 150 MHz range is more commonly used for terrestrial animals radio-tracking (Cerdelund *et al.*, 1979; Lee *et al.*, 1985).

3.2. Transmitting and receiving antennae

A compromise has to be made when choosing the transmitting antenna. The aerial gain which governs the transmitting power depends on the ratio antenna length/wave length. This ratio must belong to geometric series 1/2, 1/4, 1/8, etc. (harmonics) and the bigger it is, the better the gain is: 1/4-wave antenna, for example, has a better yield than 1/8-wave antenna. But an 1/8-wave antenna measures 75 cm at a frequency of 48 MHz (λ=6m) and 25 cm at a frequency of 150 MHz (λ=2m) and an 1/4-wave antenna would be twice as long (150 and 50 cm at 48 and 150 MHz respectively). A coil antenna could be used but this increases the size of the transmitter and decreases the gain, which is why the transmitter antenna is usually external and flanks the fish.

The lake-trout migrating upstream to spawn measured around 75 cm. We consequently had to use 1/32-wave antennae (length: 20 cm) at 48 MHz and 1/8-wave antennae (length: 25 cm) at 150 MHz.

The size of receiving antennae is subject to similar rules. The dipole of Yagi type directional antennae should measure a half-wave length, *i.e.* around 1 m at 150 MHz and around 3 m at 48 MHz. But it is impossible to use these 48 MHz antennae on upland rivers banks because they are too cumbersome. A loop antenna with a diameter of about 70 cm was therefore used although it was less directional. Moreover, this type of antenna has a lower reception gain whereas Yagi antennae have a high reception gain.

Listening takes place at the peak with the Yagi antenna while it occurs at the null level with a loop antenna.

3.3. Radio-tracking instruments

For the 48 MHz frequency range, we used ATS (Advanced Telemetry Systems) equipment: a transmitter with an external antenna of about 20 cm, model 5, 21 g, 250 days of theoretical working life; a transmitter with a coil antenna of about 20 cm BE110-18, 14 g, 35 days of theoretical working life; two ATS R2100 receivers with either a whip antenna used from a vehicle or an ATS loop antenna used at the river side.

For the 150 MHz frequency range, we used three LOTEK transmitters with external antennae of 25 cm (FSM-3 21, 3 g, 34 days of theoretical working life) as well as a receiving 6-element Yagi antenna and an AVM receiver.

3.4. Capture, marking and tracking protocol

A total of five male and 31 female trout were caught by electro-fishing downstream from the weir at Vongy on 28 November 1994 (male A and 6 females) and on 5 December (males B, C, D, E and 25 females). Since trouts cannot easily pass the weir, they were numerous during the migration period and catching them was easy.

3.5. Transmitter installation

Solomon and Storeton-West (1983) indicated that the transmitter should be introduced into the peritoneal cavity of the *Salmo trutta fario* trout, since transmitters are rejected when they are introduced into the stomach. In the peritoneal cavity the transmitter is rapidly covered with a fibre capsule which limits the movements of the transmitter and reduces pathogenic risks (Lucas, 1989). Lucas showed that, in 45% of the 34 trout tagged with this method, the transmitter was covered with the fibre capsule one month after introduction. After seven months, all transmitters were covered with fibres with a thickness varying from 0.5 to 2.5 mm. We decided therefore to introduce the transmitters into the peritoneal cavity. After anaesthesia with phenoxy-ethanol, the disinfected transmitter was introduced via a 3 cm incision near the median ventral line below the pelvic belt. The antenna was made to protrude through a cut in the skin by inserting it into a hollow needle and pushing this needle from the inside out. The wound was then stitched with 3 or 4 separate stitches. A fungicide was applied to the wound. The operation lasted about 5 min. Only males were tagged since they tend to stay longer in the spawning grounds and can even visit several of them. The surgical operation of male fish required an incision which was closed with four stitches for fish A, B and C, three stitches for E and five stitches for fish D, which had to carry the heaviest transmitter (21 g, *i.e.* 0.4% of its weight). A nerve of fish C was touched during the operation. Fish B, C, D and E recovered consciousness easily (within 1 minute). Fish A had a small haemorrhage and needed more time than the other fish to recovered consciousness (around 4 min). Fish B was electro-fished on 53th day (Tab. 2) before returning to the lake. The wound had healed well and no fungi were observed on its body. It had a nice colour and seemed to be in good health. We preferred not to operate females so as not to disturb egg laying since eggs pass through the peritoneal cavity.

3.6. Characteristics of the tagged fish

The tagged males measured from 690 to 800 mm and weighed between 3 and 5 kg (Tab. 1).

Tab. 1 - Characteristics of the tagged male trouts

FISH	WEIGHT (g)	SIZE (mm)	FREQUENCY (MHz)
A	3,335	690	150
B	3,000	700	150
C	4,300	770	150
D	5,140	800	48
E	4,490	770	48
Mean	4,053	746	

During the spawning period, the male has a more pronounced orangey colour and its lower jaw has a hooked protuberance. The main characteristic is the presence of sperm which can be observed by slightly pressing the belly of the fish.

3.7. Release and tracking

Fish were kept for 5 hours between their capture and release. This was the time required to operate on and transport them. The tagged males were released at two sites, Drossage and Départ Cadet (Fig. 2), located far upstream from the weir at Vongy so that they could not go back to the lake following a post-surgery downstream movement (Baril & Gueneau, 1986). The release site Départ Cadet is suitable for spawning. It is composed of several riffles in a calm area. This is where the trout caught downstream from the weir are released every year. In our study, all the females were released in this site. Since this site is located far upstream from the weir, we chose a second release site, Drossage, located closer to the weir but far enough to avoid a precipitated downstream movement towards the lake. This site was easy to reach and contained numerous riffles.

Tracking lasted 53 days (day 1 to day 53). Each fish was tracked for 16 to 45 days depending on the release date (A was released on 28 November 1994, day 1; B, C, D and E were released on 5 December 1994, day 8) and the date when the fish returned to the lake. Fish were first localised by driving along a road never more than 300 m away from the river. More accurate localisations took place by walking along the riverside. Each fish was located twice daily. For each localisation, we noted the fish identity, the exact time, the site, the type of area where the fish was located, such as riffles, rapids, shelters and pits, climatic and hydrological conditions, such as spate and low water, as well as the distance travelled by the fish since its previous localisation. Water temperature and conductivity were measured twice daily during localisations.

4. Results

4.1. Hydrology

The water temperature slightly increased for the first 14 days (Fig. 3). The mean temperature was 6.1°C. Temperature then decreased to 1.7°C on day 51, *i.e.* on 19 January 1995. The mean temperature for this second period was 4.5°C. The most noteworthy hydrological phenomenon during the tracking period was a high spate resulting from violent storms on days 12 and 13 which led to a peak flow of 90 m^3s^{-1}. The water level decreased for three days and the flow rate fell to 16 m^3s^{-1}.

The atmospheric pressure regularly decreased over the first 12 days from 742 mbar to 730 mbar and then rapidly increased to 743 mbar during the two-day spate. The conductivity of the Dranse river varied from 308 to 754 μScm^{-1} over the study period. These large variations are due to flowing peaks from the hydraulic power station. In the case of very low water levels, the high conductivity of the Dranse river is due to its tributary, the Brevon river, which presents a high mineral salt content.

4.2. Technical results

Localisation was always possible with varying degrees of ease depending on the site and the frequency. The 150 MHz system had a transmitting range of 300 to 400 m so that the fish were rapidly localised from a vehicle driven along the river (2 or 3 minutes after the car was in the transmitting range). The 48 MHz transmitter with external antenna was detected within about 100 m at best, but the localisation was rapid in most cases although it took a little longer (about 5 minutes) than with the 150 MHz transmitters. In contrast, the transmitter with the coil antenna (E, 48 MHz) was very difficult to localise from the vehicle. This sometimes took 45 minutes, which meant driving up and down the river at least three times. Localisation was also more difficult on the sites with high rocky cliffs due to the reflection of waves provoked by echoes

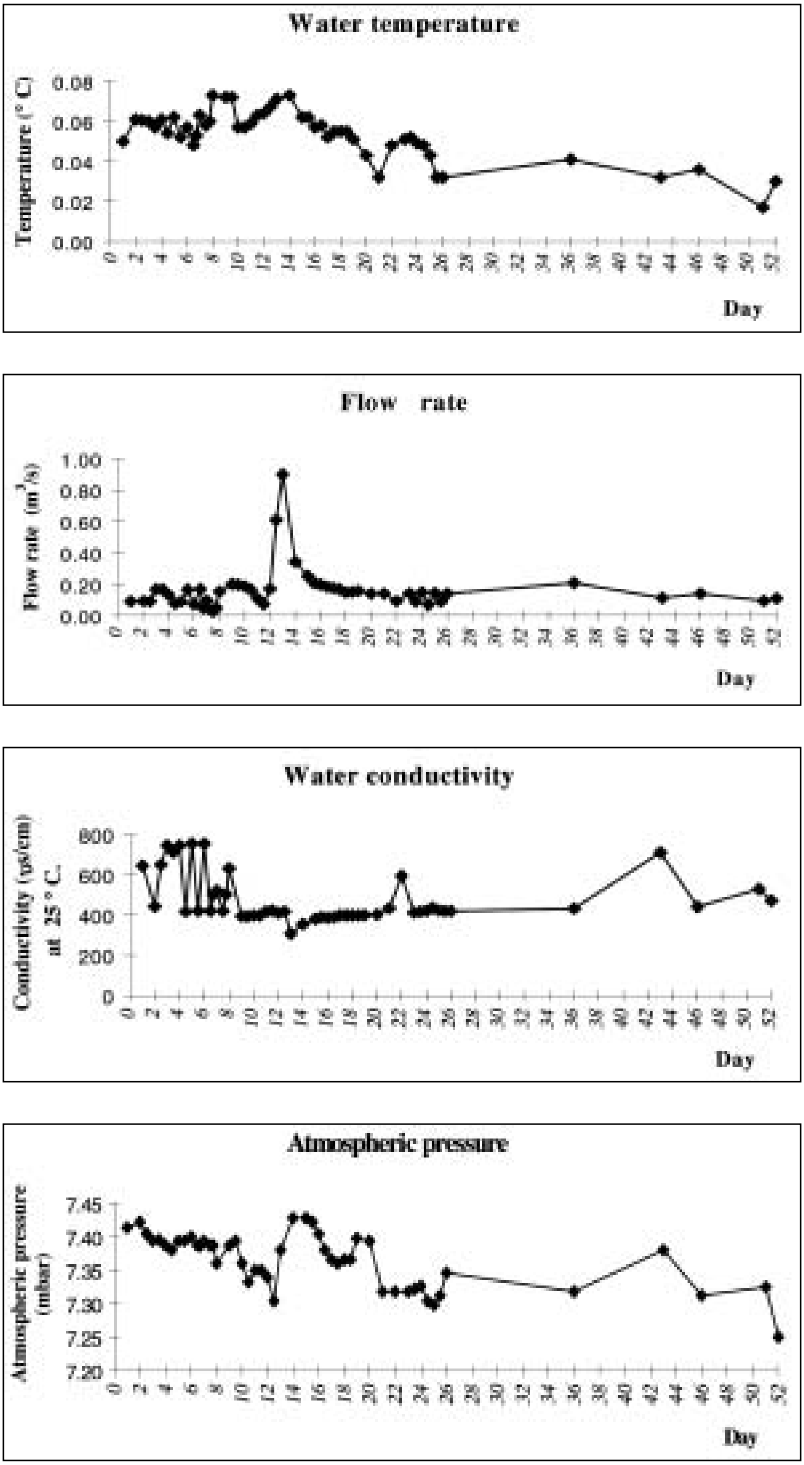

Fig. 3 - Abiotic factors

Tab. 2 - Migratory behaviour of radio-tagged male trouts

Fish	Day(s)*	DIRECTION OF MOVEMENT**	Eventual designation and description of departure or rest site / *Events (distance)*
A	*D1*	⋯	**A0**: *Departure Cadet - Capture and release / Post-surgery downstream movement(- 300 m after realease)*
	D2 – D14	——	**A1** : Plunge pool / *Rest*
	D15	╱	*Upstream migration (+ 300 m)*
	D16 – D17	——	**A2** = A4 = E1: Calm area near riffles /
			Rest during upstream migration
	D18	╱	*Upstream migration (+ 300 m)*
	D19 – D21	——	**A3**: Plunge pool / *Stabilisation*
	Night D21-D22	╲	*Downstream movement during the night (- 100 m)*
	D22 - D35	——	**A4** = A2 = E1: Calm area near riffles / *Stabilisation - Presence of a trout on day 24*
	D36	╲	**A5** = E3 = E6: Calm and deep area / *Downstream movement (-7300 m since previous localisation in A4)*
	D37	╲	Located near **A6**: Inaccessible area / *Downstream movement - Return to the lake*
B	D8	⋯	**B0**: Drossage - Capture and release / *Post-surgery downstream movement (- 100 m after release)*
	D8 evening	——	**B1**: Plunge pool/ *Rest*
	D9	╱	*Upstream migration (+ 300 m)*
	D10 - D12	——	**B2**: Plunge pool/ *Rest or stabilisation*
	D13 – D15	╲	*Downstream movement following the spate on days 12 and 13 (- 800 m)*
	D15 evening	——	**B3**: Calm and shallow area / *Rest*
	D16 - D17	╱	*Upstream migration (+ 4200 m)*
	D18 - D52	——	**B4** = E5: plunge pool / *Stabilisation - Spawning behaviour*
	D53	╲	*Downstream movement-Capture of fish B before its return to the lake (-100m)*
C	D8 – D9	⋯	**C0**: Departure Cadet - Capture and release / *Post-surgery downstream movement (- 1000 m after release)*
	D10	——	**C1** : Area with riffles / *Rest or beginning of stabilisation*
	D11 – D13	╲	*Downstream movement following the spate (- 1700 m)*

	D14 – D26		**C2**: Shallow area with a slight current./ *Movement of the fish over ± 150m on several occasions – Stabilisation on this large area*
D	D8		**D0** : Drossage - Capture and release / *Post-surgery downstream movement(- 2000 m after release)*
	D9 – D20		**D1**: Calm and shallow area / *Stabilisation*
	D21		*Downstream movement (- 700 m)*
	D22 - D23		**D2**: Calm and shallow area / *Rest*
	D23 evening		**D3** = A5 = E6 Plunge pool / *Downstream movement (- 2000 m since previous localisation) - Return to the lake*
E	D8		**E0**: Departure Cadet - Capture and release / *Post-surgery downstream movement (- 80 m after release)*
	D8 evening		**E1**: Slight currents / *Rest*
	D9 – D10		*Upstream movement (+ 500 m)*
	D11		**E2**: Slight current, shallow/ *Rest during the upstream movement*
	Night D11/D12		*Upstream movement (+ 450 m)*
	D12		E3: Slight currents / *Rest or beginning of stabilisation*
	D13		*Downstream movement following the spate on day 12 and day 13 (- 200 m)*
	D14		E4 : Plunge pool/ *Rest*
	D15		*Upstream movement (+ 150 m)*
	D16 – D24		**E5**: Cassine, plunge pool (ª5 m) / *Stabilisation – Spawning behaviour*
	D25 – D26		*Downstream movement (- 2800 m)*
	D27 – D35		**E6**: = A5 = D3: Calm and deep area / *Stabilisation*
	D36		**E7** =A5 = *D3 /Downstream movement (-5000 m since previous localisation) – Return to the lake*

* A2, B3, C2, D1, E4 : Location when the water level decreased

A4, B4, C2, D1, E5, E6 : Likely location during spawning

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Post-surgery downstream movement

Upstream movement

Stabilisation or rest

Downstream movement – Return to the lake

D12: Beginning of the spate / Flow rate = 60 m^3s^{-1}

D13: Spate / Flow rate = 90 m^3s^{-1}

D14: The water level starts decreasing / Flow rate = 34 m^3s^{-1}

D15 : The water level decreased / Flow rate = 25 m^3s^{-1}

both by the 150 MHz and 48 MHz transmitters. Once the fish was localised, its exact location was determined within 1 m for both types of transmitter, but the precise localisation took 2-3 times longer with the 48 MHz transmitter because of more difficult "null"-level listening.

4.3. Migratory behaviour (Tab. 2, Fig. 2)

During the night following their release, the migration rate of the male trouts ranged from 80 m (male E) to 2000 m (male D) downstream (Tab. 2 - and fig. 1).

Male C continued moving downstream for a few days before stabilising (day 14) whereas male D stabilised on the following day. Males A, B and E also stopped moving downstream on the day following their release.

Throughout the study, C and D never moved upstream but stabilised for about 10 days (C2, D1). Males A, B and E showed a traditional migratory behaviour (Tab. 2), involving moving upstream to look for spawning areas, stabilising and moving downstream at the end of the spawning period.

Short rest periods (1 to 2 days) were observed during migration. The main stabilisation periods lasted for about 10 days, however fish B stayed 34 days in the same site (B4).

The downstream movements were very rapid. Once started, they lasted from 2 to 10 days depending on the fish. Trouts moved night and day. Fish A and E travelled 10 km in 10 days (A4 to A6; E5 to E7). The parameters which triggered the downstream movement are not known but we observed that fish A and E started going back to the lake on the day following the new moon, *i.e.* on 1st January 1995.

4.4. Spawning behaviour

Spawning behaviour was detected (but not visually observed) at Cassine, at the level of a deep pool. It was characterised by a rivalry between fish B and E as shown by the activity of fish B. Fish E first reached the spawning site four days after its release (day 16). Fish B reached this site two days later (day 18). Both remained in this site, but fish B moved back and forth, going about 10 m away and coming back to the spawning area. Fish E, which was probably dominant, never went more than 2 m away. After 9 days (Tab. 2: day 25) fish E left this site, probably to look for another site. This behaviour is be characteristic of spawning behaviour.

Male A remained at the site A4 for about 13 days. During this stabilisation phase, we observed it near a trout of about 50 cm on day 24 during both localisations. They were swimming side by side at a distance of about 10 cm. Their behaviour at this site which is located near riffles suggests that spawning might have occurred.

4.5. Stabilisation areas

The areas where fish stabilised were either calm shallow areas (C2, D1) sometimes located near riffles (A4) or deep pools (B4, E5, E6). This type of pools are located upstream from obstacles, such as rocks. They are designated as plunge pools. They originate from the convergence of currents and result from increased digging of the river-bed. They are characterised by large surface areas (about 10 to 15 m^2) and are deep (about 5 m). These pools are suitable for large lake-trout, especially during low water levels because there is always enough water.

5. Discussion

5.1.Technical concern

Males C and D never tried to move upstream. This might be explained by the fact that fish D carried the heaviest transmitter and a nerve of fish C was injured during surgery. However, neither C nor D entirely moved downstream after surgery. Although they were located downstream from the area studied, both had a long stabilisation period before definitively returning to the lake. The spate on day 13 did not induce any hurried return to the lake, which means that fish were in good health. The fact that the wound in fish B healed well despite the coldness of the water showed that fish reacted well to the operation.

The two frequency ranges used were satisfactory since the tagged fish were always located. The 150 MHz transmitters were quicker and easier to use than the 48 MHz transmitters because the detection of an absence of signal ("null" level) requires more concentration than the detection of a noise peak, especially when there is noise around, such as cars passing by. In France, the 48 MHz range is more widely used since written authorisation from the Ministry of telecommunications is necessary to use the 150 MHz range. Although the 150 MHz range is mainly used for tracking terrestrial animals, it is increasingly used in water environments in Canada and some northern European countries (Lotek, 1994).

5.2. Migratory behaviour

After their release, trout moved downstream over distances ranging from a few meters to several hundreds of meters. Baril and Gueneau (1986) consider that any downstream movement after release is due to surgical stress. Capture and transportation are also stress factors. The effect of transportation from the fish farm to the migratory river was studied in salmon by Schreck *et al.* (1989) who observed an increase in the plasma cortisol level.

Upstream migration depends on the spates which systematically occur during spawning, *i.e.* from November to January. In the absence of spates, Baglinière *et al.* (1987) observed a minimum temperature threshold of 6°C in a lowland river. Banks (1969) verified that the flow rate had more influence than temperature and light. He considers that an increase in the flow rate triggers an upstream movement in salmonids. However, Hawkins and Smith (1986) showed that fish might have moved downstream from their location to shelter from strong currents resulting from the spate. In our study, we could not show the role of temperature since the spate on day 13 (10 Dec) masked all the other phenomena. As suggested by Hawkins and Smith (1986), the spate influenced the migration of the tagged males, most of which (males B, C and E) moved downstream over various distances (from 200 m to 1700 m). Fish A and D, which had been in the stabilisation phase for a few days, did not move during the spate. When the water level decreased (days 15 and 16) fish B and E started moving upstream again and fish A started moving upstream for the first time.

The Lower-Dranse river undergoes peaking and low flows every 6 hours, which leads to a variation in the flow rate of 5 m^3 to 20 m^3 in the absence of natural spates. The tagged fish seemed to be well adapted to these conditions since they often sheltered in pools. Heggenes (1988) noticed that sudden flow peaks did not have an heavy incidence on trout habitat, as they were capable of avoiding strong currents by sheltering. Arnekleiv *et al.* (1996) even recommends repeated releases of water to enhance trout migration and spawning success in regulated water rivers.

The rivalry behaviour detected between fish B and E was observed at the end of the afternoon, before the dusk. Spawning is usually observed at dusk (Champigneulle *et al.*, 1991), and without visually observation, it is difficult to affirm that spawning occurred. However, the presence of a trout near fish A indicates that spawning probably occurred since the stabilisation period of each fish lasted for about 12 days. Hawkins and Webb (1989) assume that a long stabilisation period in a small area indicates that spawning was successful whereas wide movements without any stabilisation, indicate that mating failed.

Redds are usually located in shallow areas, such as riffles and glides, at the end of pools or at a break of slope (Melhaoui, 1985). Pools are usually not considered as spawning sites, however, we observed long stabilisation and spawning behaviour in pools. Ottaway *et al.* (1981) indicate that spawning can occur in any area where the substrate can easily be moved, such as in the Dranse river (Soares, 1985).

It would seem to be useful to install a fishway to enable trout stopped by the weir to continue upstream where sites suitable for spawning are located. In February 1996, the Direction Départemental de l'Agriculture et de la Forêt (DDAF) requested a technical study on the installation of a fishway, which had to meet several objectives. It had to allow lake-trout to pass the weir and enable trout to be caught both to collect eggs and carry on the study of this species. The cost was estimated at 2.2 million French francs before tax. The pressure exerted by anglers enabled this project to be passed and work started in August 1997. The fishway includes nine successive pools (length: 3.5 m, width: 2 m, depth: 1.8 m). The descent between pools is 0.4 m.

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