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RESEARCH ARTICLE

Acoustic telemetry data on lake-migratory brown trout, *Salmo trutta lacustris* L., behavior in Lake Hańcza, northeastern Poland, within one year of release

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Abstract. The poor results of lake-migratory brown trout, *Salmo trutta lacustris* L., restoration in Lake Hańcza Nature Reserve prompted undertaking the current study that sought to verify if hatchery-reared fish age 2+ can survive the critical period of acclimation and remain in the lake. Thirty-one individuals were tagged with coded acoustic transmitters and observed for 317 days. This method helped to analyze: 1) the spatial behavior of tagged fish for one year following their release; 2) the possible differences in the behavior of fish released in various places habitually used for stocking. By the end of study, 6.5–12.9% of the tagged fish remained in the lake. The most interesting phenomenon the data indicated was the trout behavior in late spring and early summer, when the fish moved vigorously along the longitudinal axis of the lake continuously for several weeks. The reasons for the fish movements observed in Lake Hańcza were not clear. For this unique species/population it is important to determine whether such behavior is typical of this fish also in other water bodies and if it is only seen in hatchery-reared fish aged 2+ and 3+.

Keywords: hatchery-reared fish, species restoration, fish telemetry, fish migration

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Introduction

Autochthonous lake-migratory brown trout, *Salmo trutta lacustris* L., in Poland is a relict form created by the isolation of the Baltic Sea during the last glaciation. This species occurs most abundantly in ten Polish lakes. The largest population is in Lake Wdzydze and three smaller interconnected lakes (Sakowicz 1961, Bartel 1988, 2000, Radtke and

Dębowski, 1996, Radtke 2008). The population increased until the mid 1960s most likely thanks to protection and stocking. Unfortunately, it declined substantially in subsequent decades. Commercial catches decreased from 606 kg in 1960 to about 100 kg at the beginning of the 1990s and to 6 kg on average in 2001–2007. Despite constant stocking, by the 1990s lake brown trout in Lake Wdzydze faced extinction (Radtke and Dębowski 1996, Obolewski 2008). Other autochthonous populations were clearly declining or had become extinct, like those from the lakes of the Suwałki Region (Chybowski et al. 1994) and the eastern part of Poland within the area of the Würm glaciation (Fig. 1), and common causes included overfishing and poaching and pollution, accelerated eutrophication, and siltation (Radtke and Dębowski 1996, Acornley and Sear 1999, Bartel 2000). Substrate and oxygen requirements for salmonid redds exclude muddy-bottomed areas for spawning. Hydropower constructions, dams, and other barriers in streams preventing fish access to spawning grounds also threaten wild populations of adfluvial fishes, which was observed in Lake Constance (Ruhlé 1996, Schulz 1999) and is commonly noted in anadromous fish species. At the end of the twentieth century, attempts to restore lake brown trout were made in selected water bodies in the Suwałki Region. The first success was noted in Lake Wigry. In 1991, stocking Lake Hańcza (Fig. 1) with lake brown trout from Lake Wdzydze began. In subsequent years, the fish were introduced into several more lakes in the Suwałki Region (Hus and Krzywosz 1993, Chybowski et al. 1994, Chybowski and Stabiński 1996). Thanks to introduction, lake brown trout is also observed in several dam reservoirs in Poland (Wajdowicz 1976, Bartel et al. 1996, Bartel 2000).

Despite systematic fish stocking conducted by the Fish Stocking Centre in Gawrych Ruda (Fisheries Enterprise, Polish Angling Association in Suwałki), no natural trout spawning has been noted yet in Lake Hańcza, even if individual spawning redds have been found in the Czarna Hańcza (Figs. 2a-c) inflow just above the lake (Chybowski, personal communication). However, no electrofishing was carried out to confirm the presence of a new generation of fish. More than twenty years of restoration measures in Lake Hańcza have not produced the expected results. Several thousand hatchery-reared larvae (2,724 in 1991 and 6,900 in 2001) or fish aged 1+ / 2+ (approximately 1,100 specimens, on average) have been released into the lake almost every year since 1991. Despite this, no more than a few new specimens are caught annually to supplement the spawning stock, although Lake Hańcza still offers favorable environmental conditions (Pyka et al. 2007, Łopata et al. 2014) that meet the requirements of lake brown trout (optimal temperature for good growth and survival 12-19°C, optimal oxygen levels 9-12 mg O_2 l^{-1}) (Raleigh et al. 1986). The reasons why the restoration of the species failed and delivered no stable effects re-

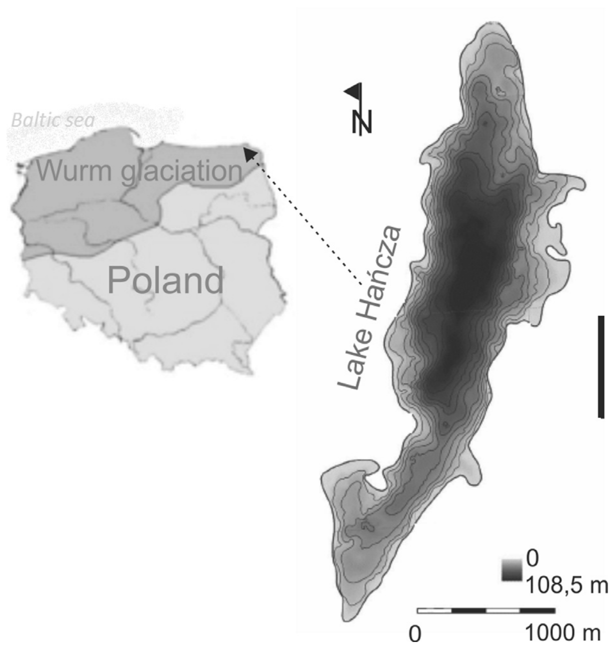
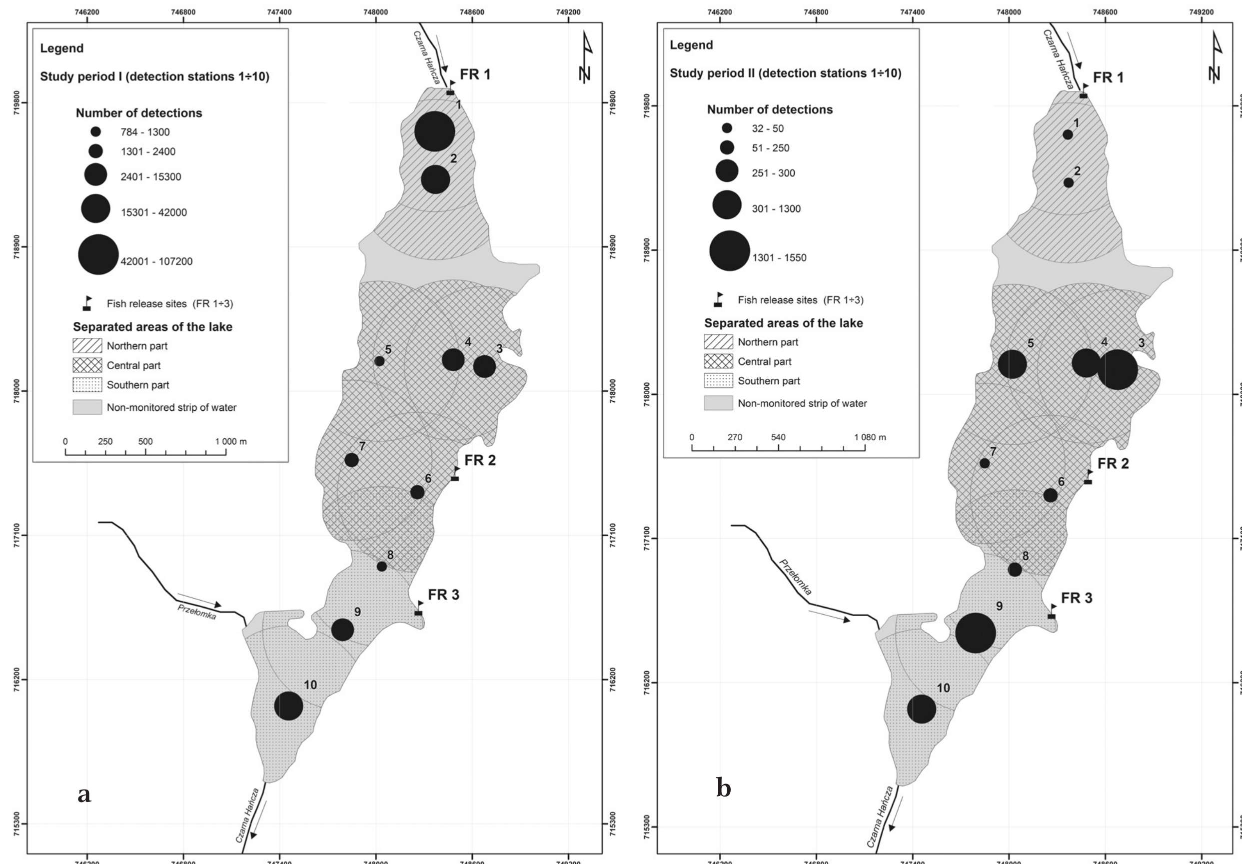


Figure 1. Map of Poland with the position of Lake Hańcza and the extent of the Würm glaciation shown.

main unknown. It is commonly believed that the success of reintroduction programs are strongly linked to fish survival after release. Maladaptive behavior that is observed widely in animals is one of the main reasons for low survival rates after release into nature. This has led to the concept of enriched rearing, which is recommended and is currently under development (Hyvärinen and Rodewald 2013, Karvonen



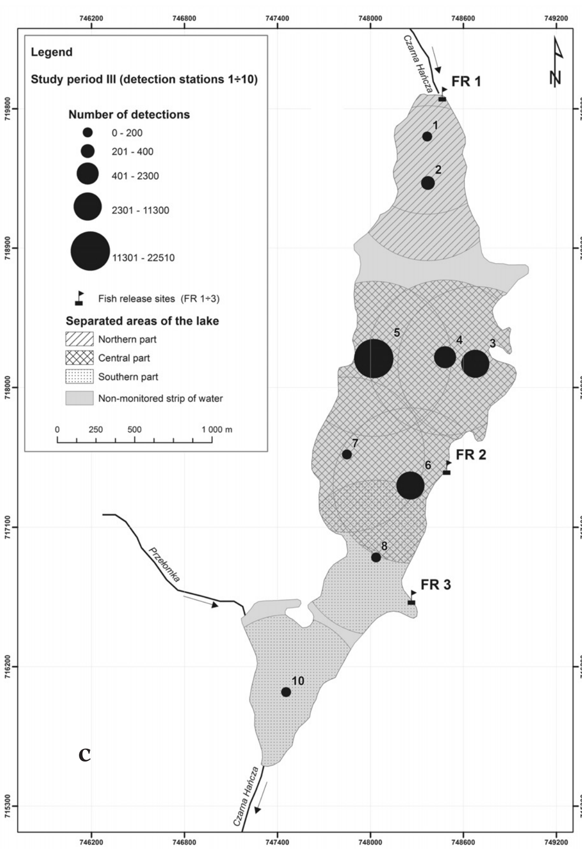


Figure 2. Distribution and range of hydrophones (stations 1–10) in Lake Hańcza and fish release sites (FR 1–3) and detections recorded in the northern, central, and southern part of the lake in subsequent periods of the study: a) period I (winter) from 2012-01-19 to 2012-04-25; b) period II (spring/summer) from 2012-04-26 to 2012-07-03; and c) period III (summer/fall) from 2012-07-04 to 2012-11-29.

et al. 2016, Rosengren et al. 2016). One of the crucial issues in trout reintroduction in Lake Hańcza is to verify if hatchery-reared fish can survive the critical period of acclimation and remain in the lake. For this purpose, telemetry observations of individuals released into the lake were conducted for nearly a year. This study also investigated 1) fish spatial behavior in different seasons and 2) possible differences in the behavior of fish released at three sites commonly used for stocking.

Material and methods

Study area

Lake Hańcza, a typical post-glacial lake, is the deepest lake in the entire North European Lowland (maximum depth 108.5 m; average depth 38.7 m; area 304 ha; length 4.5 km; width approximately 1.2 km) (Pochocka-Szwarc et al. 2013) (Figs. 1 and 2a-c). It is a mesotrophic water body with a high concentration of oxygen and a generally low content of nutrients and ammonium compounds (Pyka et al. 2007). Since 1963, Lake Hańcza is strictly protected and is a nature reserve in its entirety. However, recent studies conducted at 79 sampling points throughout the lake demonstrated the existence of zones (the southern part, especially near the inflow from the village of Przełomka) (Figs. 2a-c) where nutrient content reaches typically eutrophic or even higher levels (Łopata et al. 2014). Near the bottom, the concentration of oxygen is still high (with a minimum in the range of 4.0–7.7 mg O_2 l^{-1}). However, it was also found (Pyka et al. 2007) that, because of a more intense rate of oxygen deficiency in the hypolimnion during the summer stagnation (on average, 0.100 mg O_2 cm^{-2} d^{-1}), Lake Hańcza might be more susceptible to eutrophication than previously assumed. The Czarna Hańcza River enters Lake Hańcza from the north and flows out from the southern shore (Figs. 2a-c) and carries water down to Lake Wigry. Other temporary streams in the catchment area of the lake are not important migration routes for salmonids.

Fish studied

The lake brown trout individuals intended for tagging were bred at the Fish Stocking Centre in Gawrych Ruda, which belongs to the Fish Farm of the Polish Angling Association in Suwałki, and were reared to age 2+, length 27.5–38.5 cm, on average 33.52 ± 2.50, weight 226.5–695.5 g, mean 405.37 ± 106.14 (Table 1). The hatchery is located approximately 40 km from Lake Hańcza in the vicinity of Lake Wigry. The small neighboring Lake Staw supplies water to the fish farm. A broodstock of approximately 400–500 fish aged from 2+ to 6+ weighing between approximately 0.7 and 5.0 kg is maintained at the fish farm. Annual efforts to obtain a few wild spawners from Lake Hańcza are undertaken, but, unfortunately, these are sometimes unsuccessful when no trout are caught.

Telemetry

Fish (31 individuals) were tagged (Table 1) with V6-180 kHz (Vemco Ltd., Canada) coded acoustic tags, with dimensions of 16.5 mm x 6.5 mm and a weight of 1 g in the air; the minimum weight of fish suitable for tagging was 50 g (Jepsen et al. 2002). To extend transmitter operation time to approximately 1 year, ping intervals from 15 to 210 s were programmed with the shortest ones at the beginning and the end of project and during anticipated data collection periods. The estimated tag life was 317 days, i.e., from January 17 to November 29, 2012. Simultaneously, at fixed GPS positions (GPSmap 60CSx Garmin Ltd., USA) covering the entire area of the lake, ten omni-directional receivers (VR2W, Vemco Ltd., Canada with a detection range of 500 m were installed (station numbers 1–10) (Figs. 2a-c). The detection range was determined experimentally using a range test transmitter at a constant interval of 10s. A rowboat with the submerged test tag stopped for 5 min at every subsequent 50 m distance away from the receiver. The exact time of subsequent stops was recorded to check if the tester was detected at particular hours. The test was performed in lake waters during windy weather and light rain. The test tag was recorded when the boat with the tester was up to 500 m from the receiver, but when the test boat was at a distance of 550 m, the receiver failed to detect it. The fish in the northern (N), central (C), and southern (S) parts of the lake were registered by hydrophones at stations 1–2; 3–7, and 9–10, respectively (Figs. 2a-c). The hydrophone at station 8 monitored the area in the south-central part of the lake. The Czarna Hańcza tributary and its outflow are the only routes permitting tagged fish to leave the monitored area

Table 1

First and last detections of transmitters (date and time) with identification numbers (ID), initial total length (TL), and body weight (BW) of tagged lake brown trout, total number of stations visited during study from release into Lake Hańcza on 2012-01-19 at three different fish release sites (FR 1-3)

No.	ID	TL (cm)	BW (g)	Fish release sites	First detection (at station no.)	Last detection (at station no.)	No. of days	Detections per day (mean ÷ SD)	No. of detec-tions	No. of sta-tions visited
1	262	28.5	295.0	3	2012-01-19 (8)	2012-03-31(10)	72	106.1 ± 102.5	7,003	3
2	263	36.0	470.0	3	2012-01-19 (8)	2012-04-18(1)	90	56.6 ± 69.7	4,191	8
3	264	34.0	380.5	3	not detected					
4	265	38.5	674.2	3	2012-01-19 (9)	2012-06-16(6)	149	62.9 ± 88.3	8,619	6
5	266	34.0	428.0	3	not detected					
6	267	31.0	226.5	3	2012-01-19 (8)	2012-12-04(5)*	320	179.3 ± 58.8	46,259	10
7	268	34.5	479.0	3	2012-01-19 (9)	2012-10-02(2)	257	132.0± 157.4	20,852	10
8	269	33.5	440.0	3	2012-01-20 (9)	2012-10-31(10)*	285	51.6 ± 81.9	12,237	10
9	270	28.5	254.5	3	2012-01-19 (8)	2012-05-22(8)	124	96.2 ± 99.4	10,963	10
10	271	34.0	410.4	3	2012-01-19 (8)	2012-04-15(1)	87	53.5 ± 65.3	1,337	9
11	272	36.5	695.5	2	2012-01-19 (3)	2012-04-15(1)	87	166.8 ± 148.1	14514	4
12	273	32.5	355.7	2	2012-01-19 (3)	2012-01-21(1)	2	204.0 ± 192.6	612	5
13	274	35,5	465.0	2	2012-01-19 (3)	2012-04-13(1)	85	61.4 ± 51.0	1474	10
14	275	34.0	385.0	2	2012-01-19 (6)	2012-04-15(10)	87	154.8 ± 136.3	11763	10
15	276	33.0	396.5	2	2012-01-19 (3)	2012-12-05(6)*	321	55.1 ± 76.0	14004	10
16	277	35.0	391.8	2	2012-01-19 (3)	2012-06-12(9)	145	117.9 ± 132.0	12375	10
17	278	32.0	349.5	2	not detected					
18	279	35.5	464.9	2	2012-01-20 (6)	2012-10-20(10)*	274	48.8 ± 56.5	7510	10
19	280	34.0	386.4	2	2012-01-19 (1)	2012-03-28(10)	69	140.6 ± 105.0	9562	6
20	281	34.0	460.8	2	2012-01-19 (4)	2012-04-15(1)	87	114.6 ± 154.6	9397	7
21	282	34.5	394.9	1	2012-01-19 (1)	2012-04-16(10)	88	45.2 ± 52.1	1266	10
22	283	34.5	405.5	1	2012-01-19 (1)	2012-04-24(1)	96	311.7 ± 279.5	29926	6
23	284	33.0	352.7	1	not detected					
24	285	30.5	297.2	1	not detected					
25	286	33.5	353.0	1	not detected					
26	287	27.5	244.5	1	not detected					
27	288	32.5	397.6	1	2012-01-19 (1)	2013-02-02(1)	380	148.5 ± 185.6	30445	5
28	289	31.5	277.1	1	not detected					
29	290	34.0	389.7	1	not detected					
30	291	38.0	592.0	1	2012-01-19 (1)	2012-03-28(1)	69	268.1 ± 170.9	18770	10
31	292	35.0	453.1	1	2012-01-19 (1)	2012-04-18(1)	90	57.7 ± 60.6	4613	7

* live fish detected until the end of study (or until station 10 ceased monitoring).

since the other streams are temporary and impassable for salmonids. Unfortunately, when setting up the experiment, it was impossible to install receivers in the Czarna Hańcza River either upstream or downstream from the lake. Because of the difficulties and risk of mounting receivers near the bottom, especially in the deepest places (approximately 100 m), the hydrophones were attached to anchored ropes approximately 2–4 m below the water surface, with the receiver facing vertically downward. They were identified with visible floats attached at a depth of approximately 1 m below the water surface beneath the maximum ice cover thickness.

Tagging

On January 17, 2012, 31 individuals were tagged surgically by implanting transmitters into the body cavities (Jepsen et al. 2002) of fish anesthetized with 2-phenoxyethanol at a dose of 0.6 ml dm^{-3} determined experimentally (according to Gomułka, unpublished data). After measuring and weighing the fish, an incision approximately 15 mm long was made in the skin along the *linea alba* approximately 1 cm in front of the anus). The transmitters were implanted intraperitoneally parallel to the longitudinal axis of the fish, then the incision was closed with a single interrupted stitch using PremiCron polyester, braided, coated, non-absorbable threads, 3/0 met. 2, needle HR 30 1/2 c. Betadine (povidone-iodine 100 mg/ml^{-1}) was used to disinfect the skin. The tagging procedures were approved by the Local Ethics Committee for Animal Experimentation, University of Warmia and Mazury in Olsztyn, Resolution No. 24/2011/N). The tagged fish (with individual ID numbers) intended for release at three fish release sites (FR 1, FR 2, FR 3) (Figs. 2a-c) were quarantined in three different tanks (10–11 individuals per tank).

Fish release

After a two-day quarantine (45–48 h), no fish losses were noted. The fish tagged with transmitters were then transported for approximately 45–60 min in aerated polyethylene sleeves placed in styrofoam cases (Berka 1986) and were then released into Lake Hańcza on January 19, 2012 (between 08:00 and 09:00) at three locations (according to National Geodetic Coordinate System 1992, a flat rectangular coordinate system based on the mapping of Gauss-Kruger for GRS80 ellipsoid in a ten-point area): FR 1 (E748606 N719555) in the northern part of the lake; FR 2 (E749034 N716980) in the central part; and FR 3 (E748555 N716590) in the southern part. All of the fish release sites were previously used for fish stocking and were located on the eastern shore (Figs. 2a-c) where the nearshore zone is the widest (Rühle 1932) and forms gentle shallow patches with convenient access to the reservoir.

Data processing

Data were recovered on April 25, 2012, June 12, 2012, July 3, 2012, and October 31, 2012. After changing the batteries in October, no hydrophone was installed at station 10 for technical reasons; and the last signals were recorded there on October 31, 2012 at 12:12; which, according to the guarantee, was 29 days prior to the end of the transmitters' operation time. Nine hydrophones were left in the lake for the following winter. Seven of them were uninstalled in July 2013. The eighth receiver was recovered from fishing nets in the vicinity of station 3 (where it had been installed) (Figs. 2a-c) in October 2013; the last record was recorded on December 2, 2012. The hydrophone located at station 9 was lost (the last record was on June 12, 2012). A single fish that was continuously recorded by one receiver or the common coverage area of two or more receivers for more than seven consecutive days with no movement detected and no records on other receivers, and, thus, in different lake areas, was assumed to be dead. Detections after the fish death dates were omitted from further analysis. The fish death date was designated as the first day of a seven-day sequence of consecutive transmitter detection by one receiver or adjacent ones. The period of seven days is rational because with the continual mobility and active foraging of this

Figure 3. Time of transmitter detections (identification numbers 262–292) in Lake Hańcza from fish release on 2012-01-19 at three different fish release sites (FR 1–3) divided by the three subsequent periods of study.

species, it is unlikely that trout would be recorded continuously (i.e., every 15–210 s) for seven days at the same site.

For the results presentation, three separate periods of study were analysed. These periods were divided according to the decrease in transmitter numbers at the monitored area, visible on the detection plot overview (Fig. 3).

Period I (22 tags detected) – winter with ice cover – from the fish released on January 19, 2012 to April 25, 2012 (ice cover melting) (Fig. 2a).

Period II (9 tags detected) – spring and early summer – from April 26, 2012 to July 3, 2012 (including the summer stagnation from mid-June) (Fig. 2b).

Period III (6 tags observed) – summer and fall – from July 4, 2012 to the end of transmitter operation on November 29, 2012 (including the summer stagnation to mid-September) (Fig. 2c).

Data analysis and plotting: VUE Software Version 1.8.1. Mapping: MapSource ver. 6.16.3, Excel 2007, ArcMap 9.3.1 (Esri inc.) software. To eliminate possible signal interferences and noises, detection records were sent to the receiver manufacturer (Vemco) and verified. The fine data were then analyzed.

Results

The first data recovery on April 25, 2012, confirmed the detection of 22 of the 31 transmitters implanted in lake brown trout released on January 19, 2012 (Table 1) into Lake Hańcza. Each of the ten receivers deployed throughout the lake recorded from 784 to 111,752 records. Most fish were detected for the first time on the day of release, only two fish were detected one day later (Table 1). In period I, the total number of detections recorded was 200,268 with the majority at stations 1 and 2 (the northern part of the lake) and 18 fish identified (Fig. 2a). In period II, a total of 32,691 detections were recorded with the majority at stations 3 and 5 (central part) from eight different tags and at station 9 (southern part) from the same eight tags (Fig. 2b). In period III, 44,733 detections were recorded, and the majority of them were in the central part of the lake at stations 3 and 5 (two fish identified) and at station 6 (another two fish identified) (Fig. 2c). Nine fish were not detected during this experiment (Table 1). One fish (ID 273) was not detected until January 21, 2012 (last signal at station 1). Another ten individuals were recorded for the last time immediately after the ice cover melted (in late March / early April 2012); e.g. trout ID 291 (Fig. 4a). One of these ten fish (ID 270) was caught in nets on May 23, 2012, the remaining eight fish

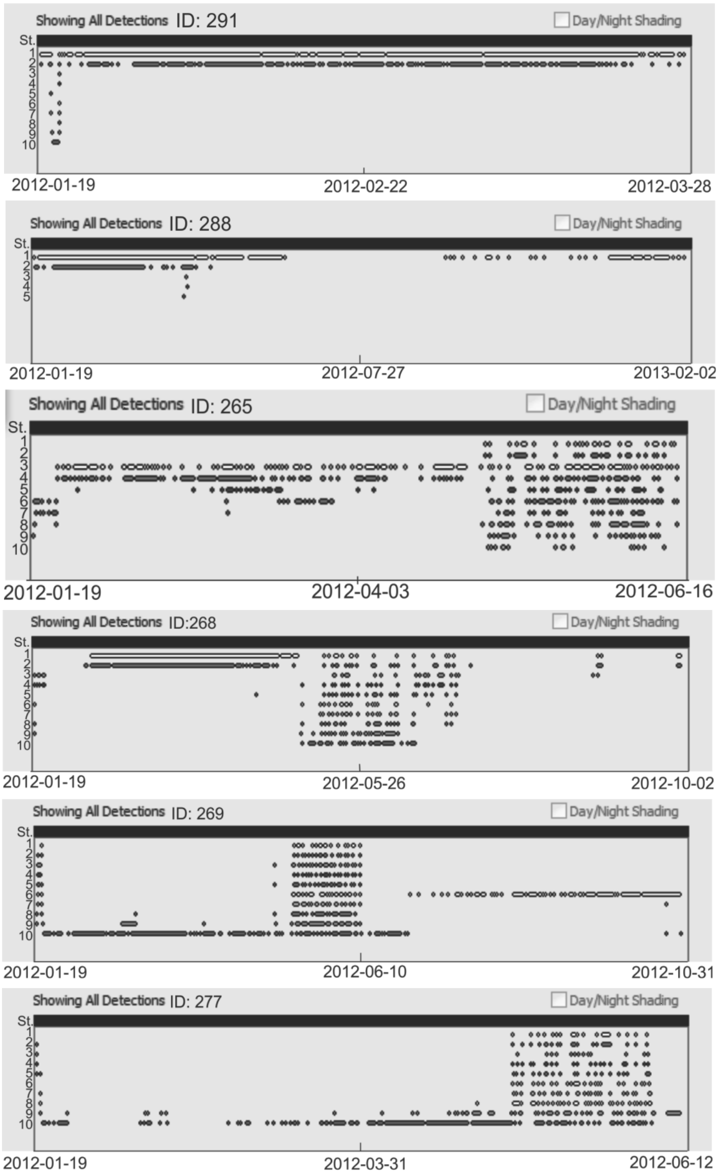


Figure 4. Detections of lake brown trout tagged with acoustic transmitter ID numbers: a) 291; b) 288; c) 265; d) 268; e) 269; f) 276; g) 277 at stations 1–10 in Lake Hańcza.

disappeared from the monitored area at station 1 (vicinity of the Czarna Hańcza inflow) (Table 1, Fig. 3).

Most of the tagged fish (18 individuals) exhibited shorter or longer periods of continuous activity, during which they moved from the north to the south of the lake and back, covering the distance from station 1 to 10 (approximately 2.5–4.5 km) (Figs. 4c-g) or the shorter distance from station 1 to 9 or 6 in approximately 4 h. This movement generally started in March (or, exceptionally, at the end of February or in April). Eight fish had left the monitored area by the end of April. A further three individuals were detected by the end of May or mid-June (Table 1, Fig. 3), and signals were lost during fish migration (e.g., fish ID 265) (Fig. 4c), or shortly thereafter (e.g., fish ID 277) (Fig. 4g). Five fish continued this activity until the beginning of June (ID 267) or July (IDs 268, 269, 276, 279) and then remained in the lake until October 2012 or longer (Table 1, Figs. 2a-c). The last signals from fish ID 268 were recorded in the northern part of the lake at station 2 (Fig. 4d). The last records from fish IDs 269 (Fig. 4e) and 279 were recorded at station 10 near the Czarna Hańcza outflow. It should be noted here that from October 31 the area of station 10 was not monitored since no hydrophone was installed at this station following the battery change, and the last signals recorded by the lost hydrophone (station 9) were on June 12, 2012. Until October 31, the area surrounding station 9 was, for the most part, monitored by the hydrophones at stations 8 and 10 (Fig. 2c). After this date, there was a lack of information about fish moving through the range area of station 10; i.e., IDs 269 (Fig. 4e) and 279 (Table 1). On November 29, 2012 (the end of transmitter operation), signals from three tags were still being received (Figs. 3 and 5). One of them (ID 288) belonged to a fish which, following a short two-day period of activity, remained in the vicinity of station 1 until February 2, 2013 (Table 1, Figs. 3 and 4b).

Discussion

The most interesting phenomenon observed during this study was the intense movement of tagged fish that began in spring and continued for several weeks. At that time, lake brown trout moved quickly along the longitudinal axis of the lake, which was the

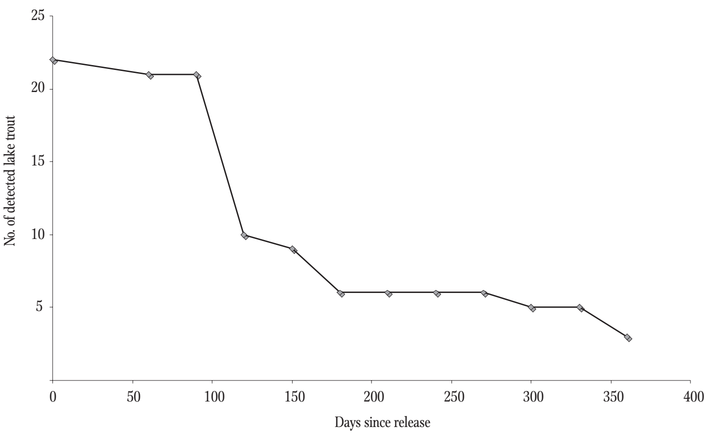


Figure 5. Number of lake brown trout detected on consecutive days of telemetry observations in Lake Hańcza.

distance from the most northerly station (station 1) to the most southerly station (station 10) (Figs. 4a and 4c-g) that the fish covered in just a few hours (minimum 4 h). At this time, the fish were most likely dispersed; data analysis and plotting with VUE Software did not provided convincing evidence that fish tended to gather in migratory groups. Taking into account fish length (TL) ranging from 27.5 to 38.5 cm, and the straight line distance between stations 1 and 10 from 2,500 to 4,500 m (receivers with 500 m omnidirectional range), the fish swimming speed was from approximately 0.9 to 2.3 body lengths s^{-1}. These values are considered the optimal swimming speed for salmonids (Webb 1971) observed during routine migrations. The critical swimming speed (range 35.8 to 145.6 cm s^{-1}) reported for brown trout 5 or 35 cm in length at temperatures between 5°C and 15°C (Peake et al. 1997) were never exceeded by the fish in the current study. However, being in the range 34.7–62.5 cm s^{-1} clearly exceeded the value of 25.9 ± 4.5 cm s^{-1} that was determined experimentally to be optimal for brook charr, *Salvelinus fontinalis* (Mitchill) (Tudorache et al. 2011).

In two fish, the period of heightened activity lasted for a short time (1–2 days). Fish ID 291 (Fig. 4a) migrated from stations 1 to 10 shortly after being released (on January, 20–21, 2012) and signals from its transmitter were then constantly recorded by two hydrophones (at stations 1 and 2) until the end of March 2012. The second fish, ID 288, migrated from April 16–18, after which signals from its transmitter were recorded at station 1 for a long time following the end of guaranteed transmitter operation, i.e., until February 2013 (tag operation 380 days, 62 days more than the expected) (Table 1, Figs. 3 and 5). The atypical behavior of these two fish, the abrupt interruption of activity, and the detection of their transmitters at the same stations for a long time permitted concluding that both fish were dead; probably captured by predatory fish inhabiting the lake, presumably a burbot, *Lota lota* (L.), pike, *Esox lucius* L., or Wels catfish, *Silurus glanis* L. (Wziątek et al. 2008). A dead fish or a transmitter expelled by a predator propagated signals from the bottom of the lake. During the summer stagnation (June 14– September 16, 2012), no hydrophone received a signal from transmitter ID 288 (Fig. 4b). This might have been caused by the reflection and refraction of the acoustic wave within the thermocline. The loss of signals during the summer stagnation or a decreased number of detections in this time (periods II, III) (Figs. 2b-c) might have been because the fish migrated to the deeper water layers of the thermocline or hypolimnion that formed in Lake Hańcza at a depths of approximately 5.5–8.0 m (Skowron 2007).

While searching for causes of either the lack or the rapid loss of transmitter signals, it should be noted that at the time the fish were released predation pressure was limited primarily because of the low temperature (approximately 0°C in the surface water layer), which can partially limit burbot and pike predation and completely prevent that of Wels catfish, which are the natural predators of young trout in the lake (Wziątek et al. 2008). Strong wind and snowfall prevented piscivorous birds from foraging, and the rapidly progressing ice cover precluded fishing and angling.

The endemic population of lake brown trout in Lake Wdzydze, introduced into Lake Hańcza, is clearly adfluvial, and its life-cycle is associated with both the lake environment and the river in which it spawns and spends the juvenile stages of its life

(Sakowicz 1961, Radtke and Dębowski 1996, Radtke 2005). The increased activity of the fish immediately after being released into Lake Hańcza (Figs. 4a, c-e, g) and in the spring following the disappearance of the ice (Figs. 4c-g) might suggest that fish movements were induced by changes in temperature and mineral or odorant concentrations in the water, as has been observed in homing movements (Stuart 1957, McCormick et al. 1998). Regular trout movement in Lake Hańcza in the spring might be associated with intense searches for memorized natal sites and could be related to difficulties the fish have acclimating to lake waters (the fish were reared in Lake Staw waters). Prolonged movement along the longitudinal axis of the lake is probably not connected with feeding behaviors or migrations, because the prey fish available for trout such as European smelt, *Osmerus eperlanus* (L.) and bleak, *Alburnus alburnus* (L.) (Kozłowski et al. 2008) move horizontally in the spring to reach spawning grounds quickly where they stay for 1-3 weeks. It also should be noted that foraging for prey fish or following planktivorous fish that move vertically daily (like vendace, *Coregonus albula* (L.) and smelt) requires additional energy expenditures that pose the risk of fish depletion during such movements in the short term.

Since the transmitter signals most often cut off in the vicinity of the Czarna Hańcza river inflow (station 1) or outflow (station 10) (Table 1), this suggests that the fish could have entered the upstream or downstream segments of the river. The Czarna Hańcza inflow (Figs. 2a-c) with a width of approximately 3-4 m, a depth of 20-40 cm, and a muddy bottom of organic sediments with low water flows (which prevailed in the study period) did not allow the fish, at least of the size under study, to swim upstream. Moreover, approximately 150 m above the river inflow to the lake, beaver dams completely prevented further fish migration.

In previous years, sporadically in the spring (May, June) lake brown trout were found in the Czarna Hańcza outflow. In fall, presumably due to the lower water flow, trout were not detected by electrofishing. The Czarna Hańcza outflow (Figs. 2a-c) with a width of approximately 1 m, and a depth range of 50–20 cm or less is not conducive to fish migration. Frequent fluctuations in water flow, numerous rapids, and large rocks scattered on the bottom prevent fish, especially larger specimens, from swimming. However, it cannot be excluded that the fish escaped this way.

It is also possible that the fish were caught by anglers, who are most often fish near stations 1 and 10. Assuming the goodwill of the anglers, who were informed of the experiment, they could have easily missed the small tags used in this study while gutting the fish they had caught. Consequently, tag recovery and the evaluation of the impact of angling on the fish released were limited. Losses to poaching cannot be ruled out even in protected areas monitored systematically by guards.

An analysis of records in subsequent periods of the study indicated that from January 19 to April 25, 2012, in the winter season with complete ice cover (locally more than 50 cm thick), the lake brown trout preferred places near the Czarna Hańcza inflow, which was evidenced by the greatest number of detections at stations 1 and 2 (Fig. 2a), i.e., 68% of all signals transmitted by 17 fish (omitting detections of transmitter ID 288 from a fish that had died or been caught). This might have been associated with the search for increased water flow, which usually ensures better oxygenation than that under ice cover.

During the spring circulation until thermocline formation in summer (period II), the fish were very active and moved rapidly back and forth from the north to the south of the lake (Figs. 4c-g). Most detections were received by the hydrophones in the central part of the lake (stations 3, 4, 5) and at station 9 in the southern part of the lake (Fig. 2b). Given the movements of the fish it is difficult to say which areas of the lake were preferred during this period. The data showed that migrating fish were recorded in the central part more frequently than in the southern and the northern ends of the lake during this period.

From July 4 to the end of study on November 29, 2012 (period III), i.e., during the summer stagnation and then fall, by far most of the detections were recorded at stations in the deepest central part of the lake (Figs. 1 and 2c), and this was probably an effect of the fish moving toward the cool waters above the deepest part of the lake bed. In Lake Wdzydze in the summer trout preferred the deeper, southern part of the lake (Radtke 1999), where younger individuals also stayed in the fall, unlike spawners that migrated to spawning grounds in the shallower, northern part. Earlier studies concerning the diet of the trout in Lake Wdzydze confirmed seasonal migrations; this fish preyed on roach spawners near the littoral zone in the spring and choose deeper water in summer where they preyed on perch and bleak (Wojno 1961).

To summarize, telemetry observations indicated that two (or maximally four) of 31 tagged lake brown trout (6.5–12.9%) stayed in Lake Hańcza for the entire duration of the study (317 days). The other individuals left the lake before the end of the guaranteed transmitter operation period, were caught, or fell victim to predators. The fish release site could have had an effect on losses of lake brown trout just after stocking, which was evidenced by the number of transmitters never detected and which was higher at the station nearest the Czarna Hańcza inflow (FR 1) (Table 1). Recently, it was assumed that even subtle currents might be a stimulus during the open water phase of salmon migration to natal streams (Binder et al. 2011). Therefore, it cannot be excluded that the increased water flow in the area of the tributary could have prompted the fish to gather there immediately after being released. Thus, the preferred fish release site of those currently used could be the small secluded bay on the eastern shore in the central part of the lake (FR 2) (Figs. 2a-c) far from surface water inflows and outflows and underground water supply points located mainly on the western shore. To provide better monitoring of fish adaptation, we recommend measuring water flow at fish release sites.

However, the most beneficial area for the trout release seems to be the Czarna Hańcza River above Lake Hańcza. According to data from 1996 (Białokoz and Chybowski 1997), a few kilometres above the mouth Czarna Hańcza is a fast-flow stream with a bottom of sand, gravel, and large stones. Lake brown trout larvae and fry would find suitable conditions there and could avoid most predators, adapt to water characteristics, and, as adults, return to spawn there. Unfortunately, beaver dams have altered the tributary unfavorably. A decrease in water flow from bottom slope reduction (from 1.8 to 0.1 and 0.9‰) was accompanied by increased siltation locally (Chybowski and Białokoz 2013). This brook has probably been unavailable to fish since as early as 2002. The lack of suitable bottom substrate from an excess of sludge prevents the trout from building redds. Additionally, barriers do not permit fish to search for suitable spawning grounds upstream from this site. The removal of this obstacle could be crucial for establishing a sustained population of lake brown trout with permanent spawning grounds and natural recruitment, provided that the removal of the beaver dam would facilitate decreased siltation followed by the appearance of appropriate gravel size on the river bed. However, it should be noted that the European beaver is still protected in Poland (since 1994, with exceptions), and this site is in a nature reserve and a Special Area of Conservation (SAC) for the Natura 2000 network. If the Czarna Hańcza inflow becomes available for lake brown trout, regular stocking should be undertaken in this location. Lake trout fry were released several times previously into the river above the lake, but the effects of stocking were largely undetectable and were not investigated.

The typical behavior of the lake brown trout in the first year following introduction to Lake Hańcza (at least those age 2+ and 3+) was intense spring movement along the longitudinal axis of the water body. This activity started after ice cover disappeared, and, for certain fish, lasted as late as into the summer months. Exploration of this issue requires further research and determining whether this type of behavior is typical of lake brown trout 1) in other reservoirs, or 2) if it applies only to hatchery-reared fish age 2+ and 3+ or 3) younger and older individuals, and also 4) to wild fish. To optimize measures to restore lake brown trout in Lake Hańcza, breeding stocking material in the waters of this lake might also be considered. This might support fish adapting to the new habitat; however, there are a number of serious impediments in this protected area. Since angling pressure on this population must be better assessed, the fish should be visibly tagged at post-larval stages prior to release (e.g., by adipose fin amputation or attaching an externally visible artificial tag). All the work aimed at restoring lake brown trout in Lake Hańcza could produce stable effects provided measures inhibiting the progression of unfavorable processes occurring in the lake were undertaken. These processes include local increases in nutrient contents to eutrophic, or even higher, levels (Łopata et al. 2014). The increased input of organic loads could lead to deteriorating oxygen conditions in the meta- and hypolimnion, contributing to intensified internal loading with nutrients from the bottom sediments and, consequently, to the limitation of salmonid populations (Pyka et al. 2007).

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