What's the effectiveness of stocking actions in small creeks? the role of water discharge behind hatchery trout downstream movement

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Fish stocking to enhance freshwater fisheries or to improve the conservation status of endangered fish species is a common practice in many countries. Little is known, however, of the effectiveness of these practices in spite of the high efforts and investments required. The movement of subadult/adult hatchery-released brown trout *Salmo trutta* L. was studied by passive telemetry in a small tributary of Lake Lugano (i.e., Laveggio Creek, Canton Ticino, Switzerland). Hatchery fish, together with some resident wild individuals sampled during electrofishing surveys, were tagged with Passive Integrated Transponders (PIT) tags. Hatchery fish were released upstream and downstream a submersible monitoring antenna, which was anchored to the streambed in a pass-over orientation. The number of hatchery fish detected daily by the antenna (divided between fish released upstream and downstream the antenna) was analyzed in relation to the daily water discharge, to search for similar patterns in their fluctuation over time. Only the movement of fish released upstream the antenna displayed a significant relationship with water discharge, with the highest number of fish detected during periods of high-water flow, occurring after heavy rains. High-water discharge events had a significant role in hatchery trout downstream movement in our study site, likely acting as a driver for the downstream migration to Lake Lugano. Such events contributed to the poor effectiveness of stocking actions in this small tributary, providing further evidence against stocking strategies based on subadult/adult fish.

1 **What's the effectiveness of stocking actions in small**
2 **creeks? the role of water discharge behind hatchery trout**
3 **downstream movement**

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16 **ABSTRACT**
17
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19 conservation status of endangered fish species is a common practice
20 in many countries. Little is known, however, of the effectiveness
21 of these practices in spite of the high efforts and investments
22 required. The movement of subadult/adult hatchery-released brown
23 trout *Salmo trutta* L. was studied by passive telemetry in a small
24 tributary of Lake Lugano (i.e., Laveggio Creek, Canton Ticino,
25 Switzerland). Hatchery fish, together with some resident wild
26 individuals sampled during electrofishing surveys, were tagged
27 with Passive Integrated Transponders (PIT) tags. Hatchery fish
28 were released upstream and downstream a submersible monitoring
29 antenna, which was anchored to the streambed in a pass-over
30 orientation. The number of hatchery fish detected daily by the
31 antenna (divided between fish released upstream and downstream the
32 antenna) was analyzed in relation to the daily water discharge, to
33 search for similar patterns in their fluctuation over time. Only
34 the movement of fish released upstream the antenna displayed a
35 significant relationship with water discharge, with the highest
36 number of fish detected during periods of high-water flow,
37 occurring after heavy rains. High-water discharge events had a
38 significant role in hatchery trout downstream movement in our study

39 site, likely acting as a driver for the downstream migration to
40 Lake Lugano. Such events contributed to the poor effectiveness of
41 stocking actions in this small tributary, providing further
42 evidence against stocking strategies based on subadult/adult fish.

INTRODUCTION

Brown trout *Salmo trutta* L. is one of the fish species with the highest economic value, both for professional and recreational fisheries (ICES, 2016; Schwinn et al., 2017). Hatchery-reared brown trout have been used for a long time to enhance and/or maintain artificial populations in fresh waters (Einum & Fleming, 2001, Aprahamian et al., 2003; Flowers et al., 2019). However, hatchery fish face several problems compared with wild conspecifics, such as reduced fitness and feeding efficiency, and high mortality (Waples, 1999; Brannon et al., 2004; Araki, Cooper & Blouin, 2007). This is usually due to rearing conditions presenting high densities, unnatural food sources and absence of external stimuli, like predation and variations in water flow (Fernö & Järvi, 1998; Aarestrup et al., 2005; Pedersen, Koed & Malte, 2008).

Millions of hatchery-reared trout are still released into creeks/streams every year (Waples, 1999; Aprahamian et al., 2003; Brockmark & Johnsson, 2010; Polgar et al., 2022) despite their fate and survival being largely unknown after the release into the wild. Furthermore, a few studies have investigated the environmental variables behind the movements of hatchery-reared brown trout following their release into water courses, especially in creeks and little streams (Helfrich & Kendall, 1982; Pedersen, Dieperink & Geertz-Hansen, 2003; Aarestrup et al., 2005).

Fish movement is influenced by a variety of factors. One of the main driving forces for large-scale fish migrations is the search for suitable spawning habitats (Northcote, 1992; Larinier, 2000; Young et al., 2010; Alò et al., 2021). However, fish can move along streams and rivers for several other reasons, such as to seek better feeding grounds or better water conditions, including more suitable thermal conditions (Hughes, 1998; Gowan & Fausch, 2002; Hughes et al., 2003).
Movement is not always a volunteer action, as fish can be displaced downstream because of high-water discharge, and this is especially true for juveniles, less capable to withstand high-water flows compared to adults (Jowett & Richardson, 1989; Hayes, 1995; Nislow et al., 2002).

84 Contrastingly, periods of high-water flow may also favor upstream
85 movements allowing fish to take advantage of temporary passages
86 created during high-flow conditions and, in general, to overcome
87 in-river barriers more easily (Jonsson, 1991; Jowett & Richardson,
88 1994; Dedual & Jowett, 1999; Schwartz & Herricks, 2005).
89 In many salmonid species water discharge variation, combined with
90 other environmental factors such as water temperature and
91 photoperiod, regulates the downstream migration from nursery
92 grounds (Elliott, 1994; Klemetsen et al., 2003; Byrne et al.,
93 2004). Fish move to better feeding areas or to areas with better
94 environmental conditions, such as lakes or seas/oceans (Klemetsen
95 et al., 2003), to maximize fitness (Olsson & Greenberg, 2004).
96 This migration is part of the smoltification process, which is
97 preceded by a series of morphological, physiological and
98 behavioral changes in juveniles, and starts as they reach a minimum
99 size, depending on the salmonid species (Thorstad et al., 2011).
100 Brown trout smolts, for instance, initiate their downstream
101 migration a few years after hatching, usually as 2- and 3-year-
102 old individuals. However, hatching can also take place in 1- to 8-
103 year-old fish/individuals (Elliott, 1994; Jonsson et al., 1999;
104 Klemetsen et al., 2003).
105
106 Despite the migratory potential of the species, stocking subadult
107 and adult fish is still considered as a useful method to increase
108 biomass of catchable fish both in the short and long term. To test
109 the effectiveness (i.e., the short-term availability of catchable
110 fish) of brown trout stocking with subadult and adult fish in a
111 small creek, we analyzed the movement of hatchery-reared brown
112 trout released in Laveggio Creek (Lake Lugano catchment, Canton
113 Ticino, Southern Switzerland), assessing the role exerted by water
114 discharge in altering their post-release residence time and
115 abundance.
116 We hypothesize that water discharge plays an important role in
117 fish movement, either as a physical stimulus behind hatchery trout
118 migration towards lake habitats (active movement), or as a physical
119 factor forcing hatchery fish to move downstream, due to their
120 scarce attitude to sustained swimming during high water discharge
121 events (passive movement).

122 **MATERIALS & METHODS**

123 **Study area**

124

125 Laveggio is a small creek located in the southern side of the Alps
126 (45°54'N 8°58'E), at the Swiss-Italian border within the Lake
127 Lugano basin. Lake Lugano is a eutrophic lake with a surface area
128 of 49 km^2 (Fig. 1). Laveggio Creek has a spring origin, flowing
129 for 11 km; the streambed width ranges from 4 to 8 meters, with
130 many human-altered and channelized sections, except for some of
131 its uppermost portions (https://map.geo.admin.ch). Located in an
132 area with high rainfall (mean daily precipitation: 4.0 ± 10.7 mm,
133 max daily precipitation: 82.5 ± 11.2 mm, last 5 years data), this
134 creek can undergo dramatic changes in its discharge rate, reaching
135 more than 10 m^3 s^{-1} (mean daily discharge: 1.1 ± 1.2 m^3 s^{-1}).
136 Water temperature varies significantly during the year, peaking in
137 the summer (~ 27 °C) and reaching its coldest point in the winter
138 (~ 6 °C).
139 Precipitation and water temperature data were taken from the
140 Environmental Observatory of Switzerland
141 (https://www.oasi.ti.ch/web/dati/idrologia.html).
142 The fish community is made of brown trout *S. trutta*, European river
143 lamprey *Lampetra fluviatilis* (L.), European perch *Perca*
144 *fluviatilis* L., roach *Rutilus rutilus* (L.), Italian chub *Squalius*
145 *squalus* (Bonaparte, 1837) and the Italian dace *Telestes muticellus*
146 (Bonaparte, 1837).

147

148 On the streambed of Laveggio, around 1.2 km upstream from the
149 confluence with Lake Lugano (Fig. 1), we positioned two high-
150 density polyethylene (HDPE) antennas (3 meters each; Biomark,
151 Boise, Idaho, USA), which were lined up to cover the entire width
152 of the streambed, forming a singular flat-bed PIT monitoring
153 system. The antennas were anchored to the streambed of Laveggio,
154 at the end of a large pool in approx. 30 cm of water, to make sure
155 to detect fish during high-water events.

156

157 This system usually registers the passage of PIT tagged fish moving
158 up to 10 m s^{-1} and within a range up to 0.9 meters, although the
159 latter can vary according to the physico-chemical properties of
160 waters and to the background noise (e.g., electromagnetic
161 interference from a nearby-electrified railway). Once fish enter

162 the electromagnetic field generated by the antennas, the implanted
163 PIT tag is charged and can transmit its unique identification code.
164
165 The PIT tag antenna system together with its recording station
166 (Biomark Master Controller), was installed and anchored to the
167 streambed at the end of August 2020.
168

169 **Fish sampling**
170
171 Fish used in this study came from the fish hatchery managed by the
172 Office of hunting and fishing of Canton Ticino, Bellinzona
173 (Switzerland). After eggs hatched, trout were reared under natural
174 light conditions and fed with commercial pellet.
175
176 Stocking with subadult and adult fish in Laveggio Creek is
177 forbidden by law and, thus, the stocking is usually carried out
178 using eggs and fry. However, to study the movement of trout in
179 Laveggio, we were allowed to mark and release 998 subadult/adult
180 hatchery-reared trout during autumn 2020, and 520 during autumn
181 2021.
182
183 PIT tags (Biomark APT12, Advanced Performance Tag, 12 x 2 mm, ISO
184 Standard, 134.2 kHz) were implanted in the intraperitoneal cavity
185 through a Biomark MK25 implanter and pre-loaded single-use needles
186 to minimize fish stress and possible disease transmission and to
187 reduce the healing time. Fish underwent a light eugenol anesthesia
188 during handling and tagging operations, while feeding was stopped
189 2 days prior to the marking day. All trout remained in the
190 hatchery, in a dedicated tank for at least 10 days after tagging
191 and before release to monitor the healing of the implant incision
192 and to allow a full recovery. Feeding resumed 24 hours after the
193 tagging day. No mortality was observed during the 10 days of
194 recovery time.
195
196 Fish released in 2020 were equally divided between fish of age 1^+
197 (total length range: 15-20 cm) and 2^+ (total length range: 20-30
198 cm), whereas all fish released in 2021 were of age 1^+. Hatchery
199 trout were marked and released at the end of October 2020 and 2021
200 at four different sectors of the creek, one sector close to the
201 confluence with Lake Lugano, downstream of the antenna, and three
202 sectors upstream of the antenna (Fig. 1).

203 After a few days of data monitoring, some of the fish seemed to
204 pause in the proximity of the antenna; this location was probably
205 used as temporary feeding area and refuge. A delay of 15 seconds
206 between each recording was necessary to avoid memory overload.
207
208 During the study period, in order to search for marked trout, we
209 conducted six electrofishing surveys using a Hans-Grassl EL64GII
210 electrofisher, with settings of 7000 W, 300 V. Because of the study
211 area extension, we had to focus on different portions of the creek
212 in each electrofishing survey: between sector 3 and 4 during the
213 first survey (January 2021), near sector 1 and 3 during the second
214 (February 2021), near sector 2 and 3 during the third (first half
215 of April 2021), near the antenna and between the sector 3 and 4
216 during the fourth (second half of April 2021), between sector 3
217 and 4 during the fifth (June 2021), and near the antenna during
218 the sixth survey (December 2021). During three surveys (first and
219 second half of April and December 2021), 226 wild fish were
220 captured, measured (total length and total weight) and marked with
221 PIT tags before being released back to their site of capture.
222 Wild trout movement data was used to look for possible differences
223 between hatchery and wild trout response to high water discharge
224 events, although the number of wild trout marked was not comparable
225 with hatchery conspecifics.
226
227 The experiment was conducted with permission of the 'Dipartimento
228 della sanità e della socialità-Esperimenti su animali',
229 authorization N° TI-27-2020 (Supplementary materials).

Data collection

Fish passages started to be recorded by the antenna from October 29th, 2020, and terminated on April 30th, 2022, the last date in which hatchery trout were detected by the antenna. The main variable measured was the Number of Fish Detected Daily (hereinafter referred as NFDD) by the antenna, which is the total amount of individuals registered by the antenna during one day. Hatchery fish were divided into two groups based on whether they were released upstream (NFDD upstream) or downstream (NFDD downstream) the antenna, in order to discriminate the role of high-water events.

To assess the relation between NFDD (upstream and downstream) and daily water discharge, hydrological data were retrieved from the Environmental Observatory of Switzerland (https://www.oasi.ti.ch/web/dati/idrologia.html). Hydrological data were recorded by a monitoring station positioned close to the PIT tag antenna (Riva San Vitale).

Statistical analysis

NFDD released upstream and downstream and water discharge fluctuated over time, so they were analyzed implementing a time series analysis approach.

The ARIMA (Autoregressive Integrated Moving Average) model was applied to analyze the structure of each variable. The optimal model was determined by automatic model selection based on the Akaike information criterion (AIC) function, included in the package "*forecast*" (Hyndman et al., 2020). The residuals of each resulting model were examined to check possible structures within each time series. In case a trend in the residual distribution of the time series is present, an adjustment for the estimated coefficients and standard errors is required to fit the generalized estimating equation (GEE) of generalized linear model, performed using the "*geepack*" package included in R software (Højsgaard et al., 2016).

Cross-correlation (CC) analysis was used to measure the similarity between time series and, in particular, to look for shifted patterns between water discharge time series and NFDD time series;

272 this was done using the R package "*tseries*" (Trapletti et al.,
273 2015).

274 **RESULTS**
275
276 In total, 1518 hatchery trout were PIT-tagged and released in
277 Laveggio Creek. Among these trout, 222 fish were registered by the
278 antenna at least once, which corresponded to only the 14.6 % of
279 the total amount of trout released in the creek. The highest number
280 of fish registered by the antenna in a day was 38, one day after
281 the release date in 2021.
282 From November 29th to December 7th, 2020, the antenna stopped
283 recording data because of memory overload, whereas from June 7th
284 to July 9th, 2021, it stopped working for an electrical malfunction
285 (Fig. 2,3).
286 During the five electrofishing surveys conducted in the first half
287 of 2021, only nine marked trout were recaptured: six in January,
288 one in February, two in the first half of April and zero during
289 the last two surveys in the second half of April and in June.
290 During the survey of June 2021 23 marked wild trout were
291 recaptured. During the electrofishing survey of December 2021, one
292 month after the second release of hatchery trout in Laveggio Creek,
293 only 4 hatchery trout were recaptured, together with one marked
294 wild trout.
295 Electrofishing efficiency was supposed to be high, since together
296 with the few hatchery trout found during these surveys, we were
297 able to sample several wild trout along Laveggio Creek, most of
298 them under-size for PIT tag marking and therefore not considered
299 further.
300
301 During three electrofishing surveys, 226 wild trout were marked
302 with PIT tags (75 and 139 fish in the first and second part of
303 April 2021, respectively, and 12 in December 2021), with an average
304 length of 18.7 ± 4.7 cm. The number of wild fish detected daily by
305 the antenna is shown in Figure 4.
306 Six of the wild fish detected by the antenna stationed in the
307 proximity of the antenna for a very long time (two individuals for
308 almost one year), suggesting that these trout particularly
309 appreciated the antenna area which was potentially used as
310 refuge/feeding ground.
311
312 Water discharge was on average 1.0 ± 1.0 m^3 s^{-1} and exceeded 3.5 m^3
313 s^{-1} for 13 non-consecutive days, usually after short periods of

314 heavy rains, and water levels remained high for several days after
315 these events (Fig. 2,3).
316
317 For each analyzed time series, ARIMA model outputs revealed that
318 residuals were randomly distributed (Supplementary materials). ACF
319 and PACF did not show any relevant peak for the time series of
320 NFDD released downstream (Fig. S2), whereas the ACF and PACF of
321 NFDD released upstream and water discharge time series showed one
322 or two peaks far from the zero, respectively (Fig. S1 and S3 for
323 NFDD released upstream and water discharge series, respectively).
324 Since residuals of the ARIMA model were randomly distributed, with
325 no evident structure, there was no need to adjust the estimated
326 coefficient and standard error, and the generalized estimating
327 equation (GEE) could be fitted.
328 In the generalized linear regression model obtained through the
329 GEE, only NFDD released upstream displayed a significant
330 relationship with water discharge (Table 1). No significant
331 relationship was found between NFDD released downstream and water
332 discharge (Table 2).
333
334 Between NFDD released upstream and water discharge, Cross-
335 correlation (CC) found a correlation at lag 1, suggesting a 1-day
336 shift between the two time series (Fig. 5).
337 CC analysis highlighted a shifted pattern between NFDD released
338 downstream and water discharge at lag 2, suggesting a 2-days shift
339 between the two time series (Fig. 6). However, since there was no
340 clear relation between these time series, this result could be
341 misleading.

342 **DISCUSSION**

343

344 Trout stocking into fresh waters has been a common practice for
345 decades (Brockmark & Johnsson, 2010), but its effectiveness and
346 utility to support local populations and/or local fishing is
347 debated (Halverson, 2008; Araki & Schmid, 2010; Hunt & Jones, 2018;
348 Pinter et al., 2018).

349

350 The life stage of fish used for stocking may vary depending on the
351 final aims of the stocking activities (conservation and/or
352 supplementation for recreational fishing), as well as on the
353 hatchery dimensions and production capacity (Cowx, 1994; Letcher
354 & Terrick, 2001). Stocking with eggs (Vibert boxes, cocooning) and
355 with yolk-sac fry is one of the most used procedures for stocking
356 (Kirkland, 2012). However, the use of juveniles and subadult fish
357 is still implemented in many freshwater fisheries and considered
358 a suitable system to artificially increase the productivity of
359 water courses (Baer, Blasel & Diekmann, 2007). Nevertheless, the
360 adverse effects of domestication on fish physiology and behavior
361 are not often considered and fish mortality is usually
362 underestimated (Araki & Schmid, 2010).

363

364 In this study we used PIT tag telemetry to monitor the movement of
365 post-release subadult/adult hatchery trout in a small creek, a
366 typical environment subject to stoking practices for fishery
367 enhancement. The number of fish detected by the PIT tag antenna
368 steadily decreased monthly and, only six months after both release
369 dates, no more hatchery trout were detected by the antenna. The
370 steep reduction in hatchery trout abundance after the release in
371 wild ecosystems has been also observed in several other studies
372 (Näslund, 1992; Wiley et al., 1993; Pedersen, Dieperink & Geertz-
373 Hansen, 2003; Pinter et al. 2018), including also water courses of
374 Canton Ticino (Molina, 2019) and Switzerland (Gmünder & Friedl,
375 2002).

376

377 Water discharge significantly influenced the movement of hatchery
378 trout across the antenna in this study. The effects of water
379 discharge strongly depended on the release site: peaks in water
380 discharge were mirrored by peaks in fish passages only for fish
381 released upstream the antenna, with one-day lag after high-water
382 events.

383
384 The relationship between fish movement and water discharge has
385 been observed by many authors, in several fish species and
386 environments. For example, Tytler, Thorpe & Shearer (1978) and
387 Thorpe et al. (1981) observed a strong passive displacement in
388 *Salmo salar* L. smolts, which were mainly transported to the ocean
389 after high spring runoffs, which is one of the factors controlling
390 their anadromous behavior (Jonsson & Jonsson, 2009). The
391 downstream movement of smolts can also be a survival strategy, as
392 highlighted by Hansen & Jonsson (1985), where moving into the main
393 current of the river allows smolts to avoid water sloughs and
394 remnant pools. In contrast, Brown, Power & Beltaoa (2001) observed
395 an opposite behavior: many fish take advantage of shelters in the
396 creek margins, to minimize energy expenditure, avoid strong
397 currents, and mitigate the risk of uncontrolled downstream
398 dispersal. It has been observed that brown trout, in particular,
399 move to side channels searching for refuges from peak flows (Bunt
400 et al., 1999). These strategies enable fish to avoid physical
401 injuries and getting trapped in shallow waters, where they would
402 inevitably die as water dries up or because of anoxia (Ortlepp &
403 Mürle, 2003). An alternative tactic used by some fish, described
404 by Brown, Power & Beltaoa (2001), is to take refuge in very large
405 and deep pools during floods: these pools usually have a very low
406 water velocity close to the bottom, which provides a suitable place
407 where fish can endure flood events.
408
409 Water discharge variation is a well-known stimulus initiating
410 brown trout smolt descend to lentic habitats, such as alpine lakes
411 (Klemetsen et al., 2003); such habitats provide higher food
412 availability and more favorable environmental conditions compared
413 to nursery grounds (Økland et al., 1993; Olsson et al., 2006). The
414 observed peaks in water discharge followed by peaks in fish moving
415 downstream after a one-day lag suggest that these steep variations
416 in water flow triggered the downstream movement of post-release
417 hatchery trout.
418 Hatchery trout released in Laveggio Creek were brown trout of age
419 1+ and 2+, in which the smoltification process, although not
420 assessed in this study, might have played a fundamental role in
421 their downstream movement towards Lake Lugano, even after a few
422 days/weeks from the release (Flowers et al., 2019).

423 Space and food competition with wild trout could also play an
424 important role in the downstream migration of hatchery trout, since
425 wild fish could induce hatchery trout to search for areas with
426 lower intraspecific competition (low population density, higher
427 food availability), e.g., lake habitats (Olsson et al., 2006).
428
429 Another hypothesis behind the hatchery trout downstream movement,
430 may be attributed to a passive transportation due to the high-
431 water events occurred in Laveggio Creek. Laveggio is for a good
432 portion of its lower course a channelized creek, with most of its
433 banks being completely human altered; furthermore, it exhibits few
434 slow and deep pools where fish can take refuge. Therefore, trout
435 may struggle to find any suitable cover on creek margins or in
436 deep pools during high-water events. As stated before, spatial
437 competition with established wild trout could also limit the number
438 of available covers for post-release hatchery trout, through a
439 prior-resident effect (Deverill, Adams & Bean, 1999; Sánchez-
440 González & Nicieza, 2021).
441 Hatchery trout are more vulnerable to high-current conditions
442 compared to wild trout (Pedersen, Koed & Malte, 2008): hatchery
443 trout usually have reduced fin quality due to abrasion with tank
444 sides and over-density conditions (Drucker & Lauder, 2003;
445 Ojanguren & Brana, 2003). Lack of genetic diversity is also common
446 in hatchery-reared fish, which, coupled with artificial selection,
447 can favor the maintenance of stocks made by sedentary individuals
448 that invest energy intake in growth rather than in movement
449 (Duthie, 1987; Molina, 2019). Hatchery fish are usually bred under
450 low flow rates, which may also reduce their activity levels,
451 reducing activity of fatty acid oxidation enzymes in slow and fast
452 muscle (Johnston & Moon, 1980).
453
454 Nevertheless, a good portion of the hatchery fish released upstream
455 the antenna where registered again after the first passage across
456 the antenna following a high-water event, so this passive
457 transportation, if any, was limited to a little percentage of the
458 released fish. Therefore, the results of the present study point
459 mainly to the first hypothesis, for which water discharge acted
460 mainly as a driver for the active downstream migration of the
461 released hatchery trout.
462

463 These assumptions on the fate of hatchery trout along Laveggio
464 Creek should take into account the antenna detection range and
465 efficiency, which is a potential source of bias, quite difficult
466 to estimate. In general, the detection efficiency of PIT tag
467 antennas is not constant over time, and can rarely reach 100%
468 (Horton, Dubreuil & Letcher, 2007; Connolly et al., 2008). Several
469 factors can alter PIT tag antenna detection efficiency, such as
470 tag orientation, water properties (e.g., water salinity), tag
471 collision and external electromagnetic interferences such as high-
472 voltage power line (Zydlewski et al., 2001; Aymes & Rives, 2009;
473 Zentner et al., 2021). However, Laveggio is a shallow creek, and
474 the noise sources are limited (according to the noise levels
475 measured by the recording station Biomark Master Controller), thus
476 the detection efficiency during normal flows should be potentially
477 very high. Nevertheless, high-water discharge events (such as the
478 ones occurred during the study period) may have decreased the
479 detection range and efficiency of the PIT tag antenna (Zydlewski
480 et al., 2006; Horton, Dubreuil & Letcher, 2007). Hence, we could
481 not exclude that there may have been other fish that moved over
482 the antenna position, but which were not detected because of the
483 reduced antenna detection range during periods of high-water flow.
484 Yet, the low number of hatchery trout remained in the study area
485 after a few months from the release was also pointed out by the
486 results of five electrofishing surveys performed during the same
487 period, in which only a few marked trout (13 trout, 0.9% of the
488 total amount released into the creek) were detected. This low
489 number could also be related to the low percentage of creek sampled
490 during the electrofishing surveys, compared to the extension of
491 the study area.
492
493 Despite our data suggest the importance of high-water discharge
494 events behind the downstream movement of hatchery-reared brown
495 trout (only fish released upstream the antenna were significantly
496 related to water discharge), we cannot exclude the contribution of
497 other factors in the apparent steep decrease of hatchery trout
498 abundance. For instance, harvest by anglers can be very impactful
499 on trout populations, especially in little creeks like Laveggio
500 (Almodóvar & Nicola, 2004; Wallace, 2010; Flowers et al., 2019).
501 Since anglers do not have the ability to detect or report
502 interactions with PIT tagged fish, we were limited in our ability
503 to assess angler exploitation and impact on movement and survival.

504 However, the minimum size limit for trout harvest is set at 24 cm
505 and at least 70% of the hatchery-reared fish were under this limit,
506 so the role of fishing harvest on our results, if any, was limited.
507

508 Another important factor behind the drop in hatchery trout
509 abundance from Laveggio could be linked to avian predation. This
510 predation can be very effective and cause huge drops in trout
511 abundance, and this is particularly relevant for hatchery fish
512 (Matkowski, 1989; Dieperink, Pedersen & Pedersen, 2001). As stated
513 before, hatchery fish are not used to sustained swimming and/or to
514 predator avoidance, which, coupled with their more surface-
515 oriented behaviors, makes them more vulnerable to bird predation
516 than wild conspecifics (Maynard, Flagg & Mahnken, 1995; Dieperink,
517 Pedersen & Pedersen, 2001). The collection of a PIT tag inside the
518 stomach of a dead grey heron Ardea cinerea (L.) along the Laveggio
519 Creek banks (Molina pers. comm.) could suggest a hidden effect of
520 waterbirds on hatchery trout.
521 These factors, coupled with the downstream movement following
522 high-water events, may help to explain the low percentage of
523 recaptured trout during the electrofishing surveys, as well as the
524 low percentage of fish detected by the antenna (0.9 % and 14.6 %
525 of the marked hatchery trout, respectively), suggesting that most
526 of the released trout died or moved downstream undetected by the
527 antenna. Unfortunately, it was not possible to discriminate
528 between these two hypotheses, and this aspect should be considered
529 in future studies.
530

531 Wild trout movements seemed to be less influenced by high water
532 events than hatchery trout. Some of the wild fish marked were
533 detected by the antenna for the entire duration of the study
534 period, despite the repeated high-water events particularly
535 occurring in summer and early autumn 2021. However, comparisons
536 between wild and hatchery trout should be taken with caution since
537 data on wild fish were scarce, both for the low number of wild
538 fish marked and for the low number of wild fish detected by the
539 antenna; besides, wild trout were marked in different time period
540 than hatchery trout. For these reasons any further assumptions on
541 the resilience of wild trout and their differences with hatchery
542 trout behavior in Laveggio Creek are limited.
543

544 In conclusion, our results suggest that stocking for fishery
545 enhancement in creeks like Laveggio should probably be adjusted
546 and moved toward different methods, since the traditional stocking
547 activities with subadult/adult trout is not effective. We
548 highlighted how fragile the stability of artificial populations
549 made of hatchery trout is in this type of environment, and how
550 easily different biotic and abiotic factors can disrupt this
551 stability.
552
553 We cannot exclude the usefulness of these stocking actions on the
554 long-term period, since hatchery trout moved downstream may
555 potentially return back in Laveggio Creek as spawners, enhancing
556 the natural stock of this freshwater system. The PIT tag antenna
557 monitoring system used in this study will be maintained for the
558 next years and it will contribute to shed new light on this
559 possible hidden aspect.

560 **CONCLUSIONS**

561

562 This study showed how the effectiveness of stocking practices using
563 subadult and adult hatchery brown trout is limited by downstream
564 movements toward lentic connected systems, eased by high-water
565 discharge events. Peaks in water discharge mirrored peaks in PIT-
566 tagged hatchery trout detections registered by a PIT tag antenna
567 system. The number of fish detected by the antenna decreased
568 monthly until, after only six months from the two release dates,
569 the number of hatchery trout detected was close to zero. The
570 absence of hatchery trout was also confirmed by different
571 electrofishing surveys carried out in the study site. High-water
572 flow events, coupled with other factors, could be the main causes
573 behind the poor effectiveness of stocking actions using
574 subadult/adult fish.

575

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Figure 1

Study area

Figure 1: Study area. Black triangles are the four stations where marked hatchery trout were released.
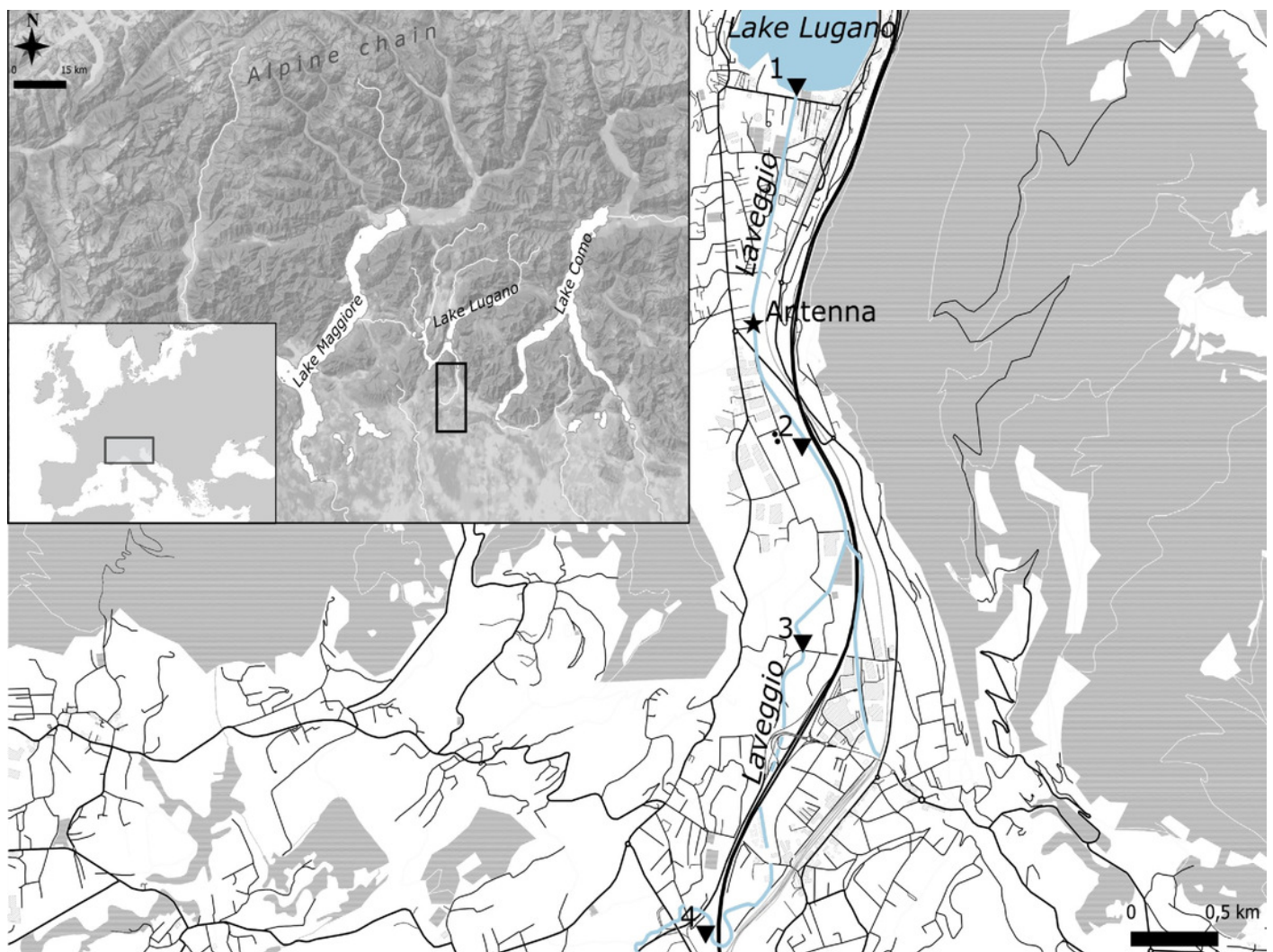
Figure 2

NFDD upstream & Water discharge

Figure 2. Trend comparison between Number of fish detected daily (NFDD) released upstream the antenna and daily water discharge measured in Laveggio creek between October 2020 and April 2022. Dashed areas are the periods in which the antenna did not work.
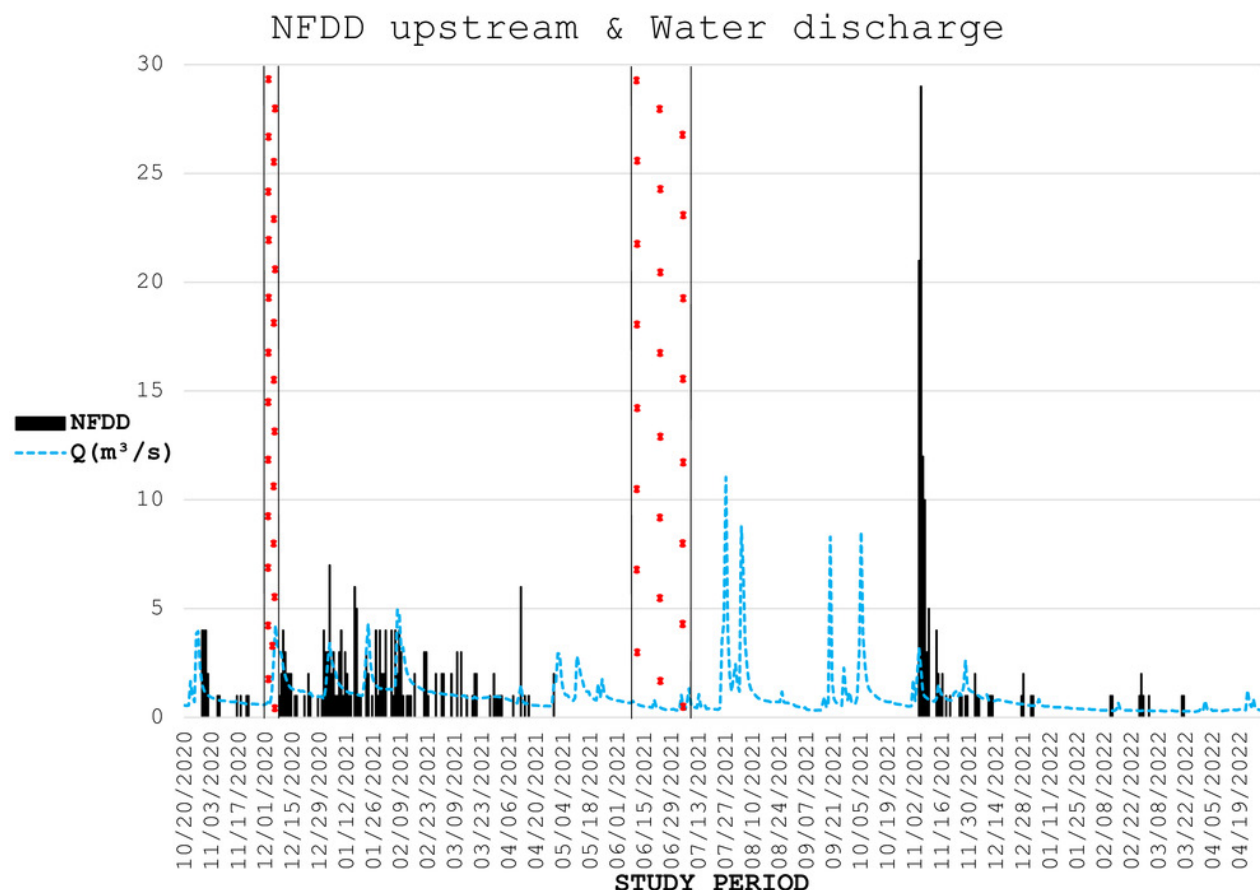
Figure 3

NFDD downstream & Water discharge

Figure 3. Trend comparison between Number of fish detected daily (NFDD) released downstream the antenna and daily water discharge measured in Laveggio creek between October 2020 and April 2022. Dashed areas are the periods in which the antenna did not work.
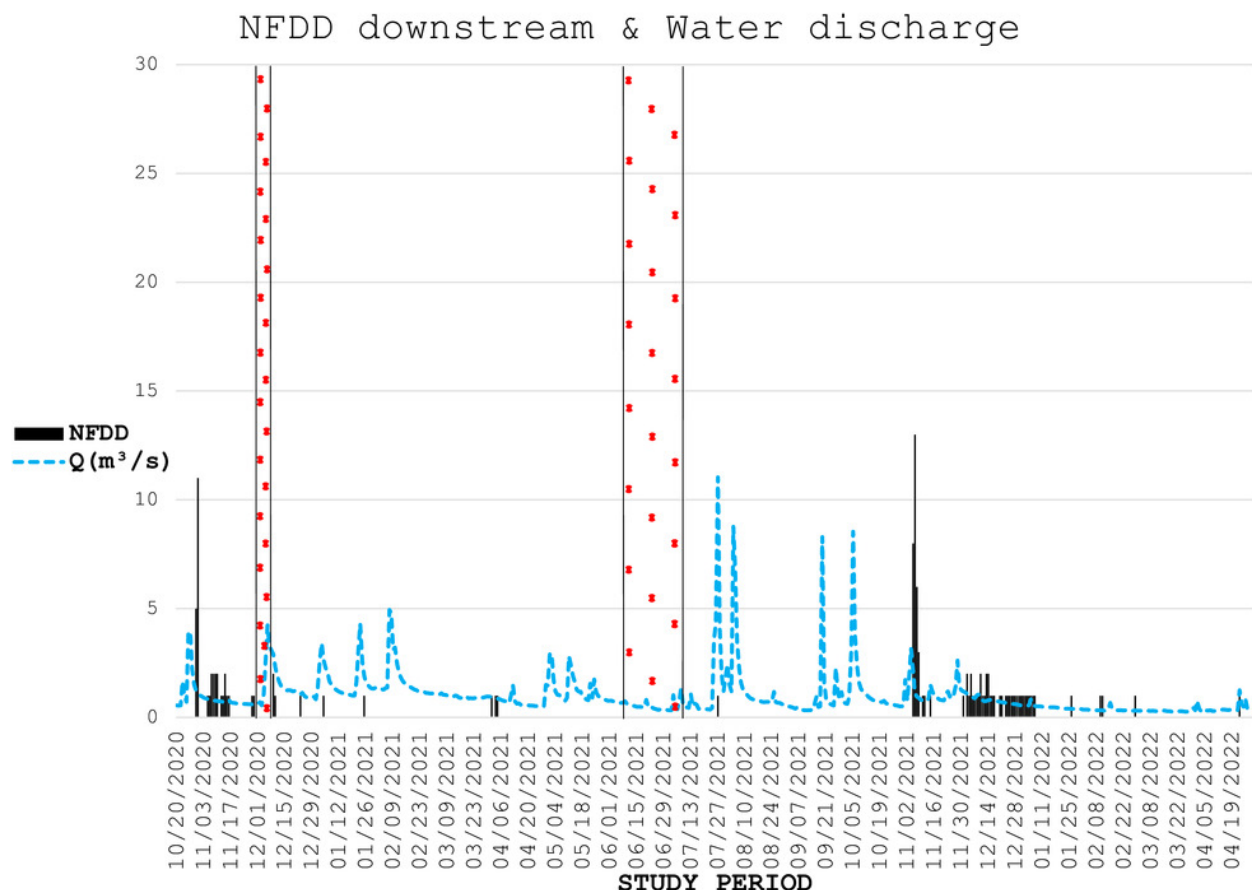
Figure 4

NFDD Wild & Water discharge

Figure 4. Trend comparison between Number of wild fish detected daily (NFDD) and daily water discharge measured in Laveggio creek between April 2021 and April 2022. Dashed areas are the periods in which the antenna did not work.
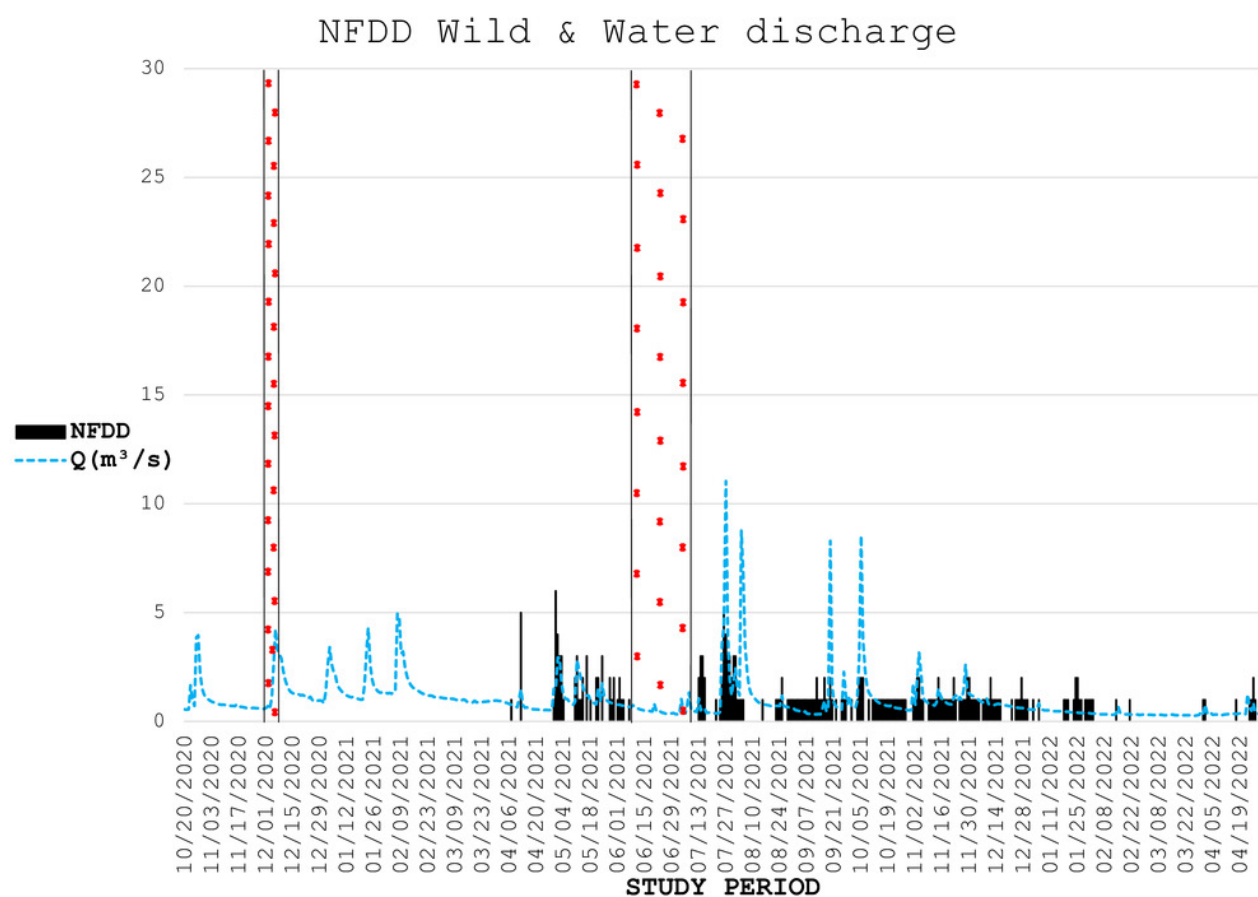
Figure 5

NFDD upstream vs Water discharge

Figure 5: Cross-Correlation (CC) analysis between NFDD released upstream and water discharge.
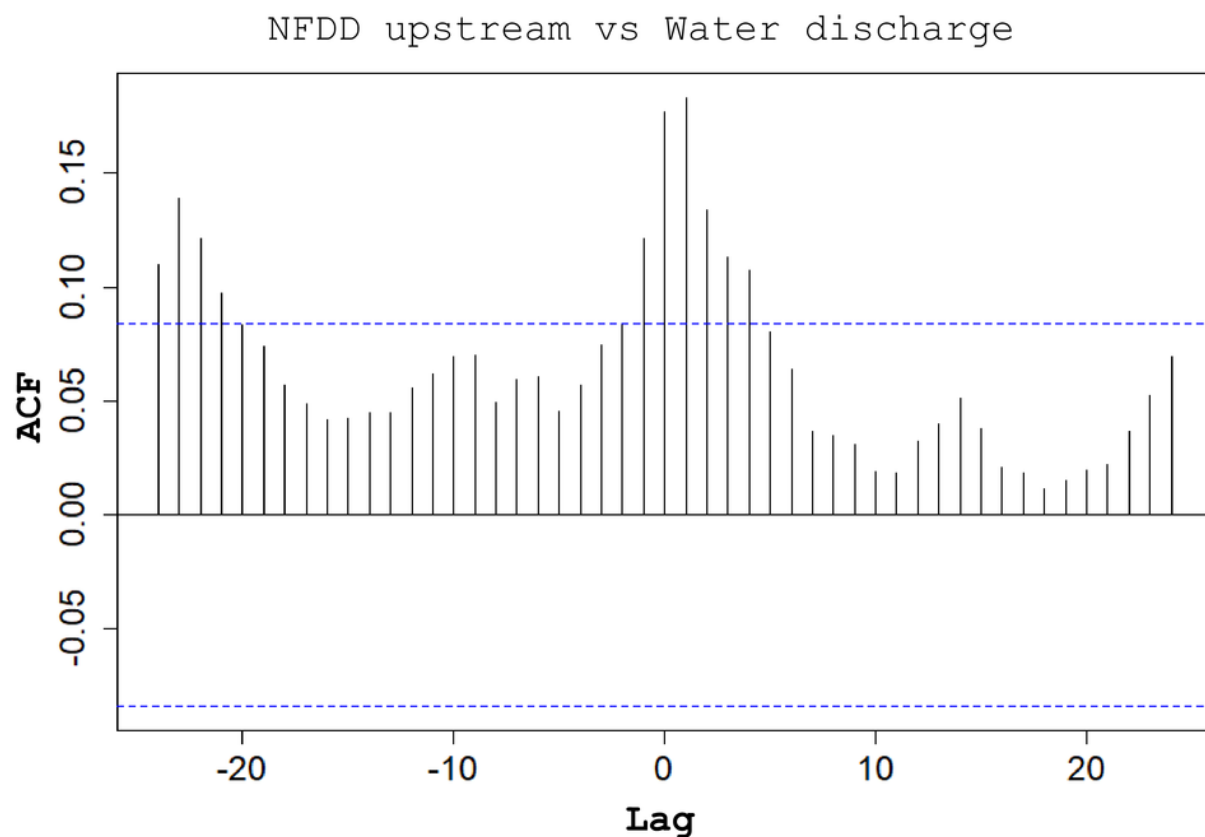
Figure 6

NFDD downstream vs Water discharge

Figure 6: Cross-Correlation (CC) analysis between NFDD released downstream and water discharge.
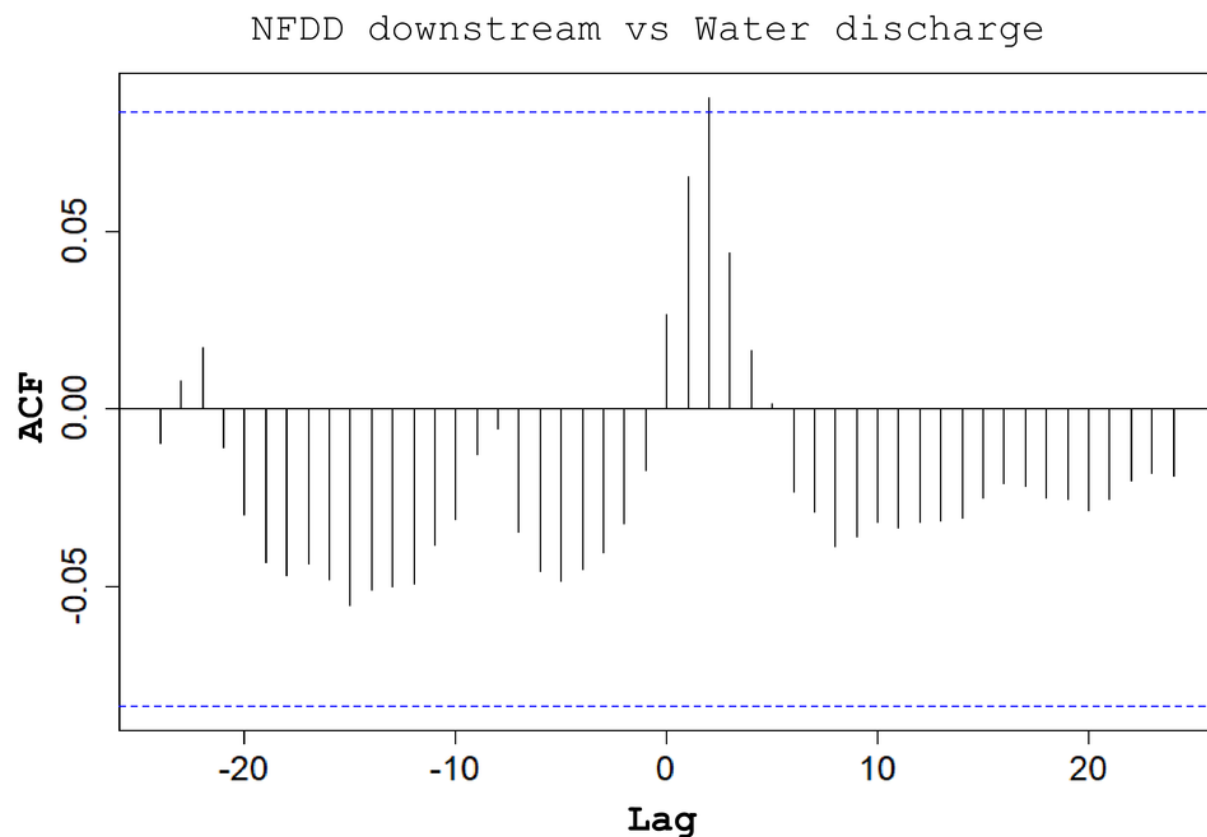
Table 1: Results of the generalized linear model analysis using the generalized estimating equation (GEE), performed between NFDD released upstream and water discharge.

Analysis of GEE parameter estimates			
	Estimate	Std. Error	*P*-value
(Intercept)	0.227	0.105	0.031*
Water discharge	0.33	0.141	0.02*

Table 2: Results of the generalized linear model analysis using the generalized estimating equation (GEE), performed between NFDD released downstream and water discharge.

Analysis of GEE parameter estimates			
	Estimate	Std. Error	*P*-value
(Intercept)	0.1961	0.0389	0.00000046*
Water discharge	0.0245	0.0232	0.29