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**Feature Article**

# Effects of experimental flooding on brown trout (*Salmo trutta fario* L.): The River Spöl, Swiss National Park

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**Abstract.** Following the construction of two large reservoirs in the late 1960s on the River Spöl, Swiss National Park, flow was greatly reduced and regulated at a relatively constant discharge. The regulated flow regime resulted in the elimination of river changing floods, causing altered and degraded habitat conditions for the brown trout (*Salmo trutta fario* L.). Although food resources (i.e., zoobenthos abundance) increased after flow regulation, trout spawning areas were greatly reduced by the clogging of coarse sediments. Consequently, the National Park in agreement with power authorities initiated an experimental flood program in 2000 to improve the fisheries potential of the River Spöl. Fish abundance was not reduced by the floods and relatively few fish (<2%) were killed or stranded by the floods. In fact, the quality of fish habitat, spawning grounds in particular, was noticeable improved, even though food resources were altered to some degree by the floods. The results showed that the condition of trout in the Spöl remained relatively constant, but the number of redds has increased three-fold since initiation of the flood program.

**Key words.** River management; regulated river; mountain river; fish stock; spawning conditions; flushing flows; Switzerland.

## Introduction

Flushing flows are increasingly being used for the rehabilitation of regulated rivers (Acreman, 2000), especially in respect to fisheries (Kondolf et al., 1987; Valdez et al., 2001; Welcomme, 2001; Rood et al., 2003). The use of flushing flows is not novel but how they are being used has changed with the information gained from past research (Welcomme, 2001). In this respect, Reiser et al. (1987) summarized different issues to consider regarding the use of flushing flows, whereas Kondolf and Wilcock (1996) provide a more recent view. Following the installation of two reservoirs for hydro-electric power production on the River Spöl (Engadin, Switzerland) in 1970, changes in the flow regime affected river morphology, sediment structure and food resources (Scheurer and Molinari, 2003). The regulated flow regime, having a nearly constant discharge of about 1 $m^3/s$, resulted in the elimination of river changing floods, a general feature of many regulated rivers (Ward and Stanford, 1989).

The loss of floods altered the habitat conditions for fishes, specifically the brown trout (*Salmo trutta fario* L.). For example, a dense coverage of mosses (*Fontinalis* spec., *Drepanocladius* spec.) developed in the Spöl that favoured the population of *Gammarus fossarum,* thereby enhancing the food supply for fish. The intensive red color (carotinids) of eggs from trout in areas with high densities of Gammaridae, in contrast to the pale color of eggs from trout in areas with few gammarids (P. Pitsch, pers. comm.), indicates the importance of the carotinid-rich gammarids in the diet. Although food resources (i.e., zoobenthos abundance) increased following flow regulation in the Spöl, trout spawning areas were greatly reduced by the clogging of coarse sediments (Mürle, 2000;

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Mürle et al., 2003), as frequently observed in other regulated trout streams (Wu, 2000). Based on the results of an earlier flood release in 1995 (Ackermann et al., 1996), an experimental flood program was initiated in 2000 to enhance the ecological integrity of the Spöl (Scheurer and Molinari, 2003).

The only fish species that lives and reproduces in the Spöl is the brown trout (*Salmo trutta fario*). This trout population predominantly belongs to the genetic group of Danubian (Bernatchez, 2001) trouts (F. Baumann, pers. comm.). The trout population in the River Spöl between the Livigno and Ova Spin reservoirs is isolated by reservoir dams and discharge gauging stations (Fig. 1). Exchange among Spöl trout populations with those of the River Inn is possible only below Ova Spin reservoir. Recreational fishing is restricted to one short section along the Spöl between Ova da Cluozza and the Ova Spin reservoir. Since 1993, stocking of the river with trout occurred only in 1993 and 1994 in the section below Livigno reservoir and in 1996 below Ova Spin reservoir before and after two ‘flushings’ of the reservoirs. The status of the trout population has been evaluated several times since 1990 by electro-fishing (Rey and Gerster, 1991), although some additional information on the fish stock since 1980 is available through annual counts of spawners (P. Pitsch, pers. comm.). Here we report changes in trout habitat and the status of the brown trout populations during the 3 years (2000–2002) of artificial floods along two major segments of the River Spöl.

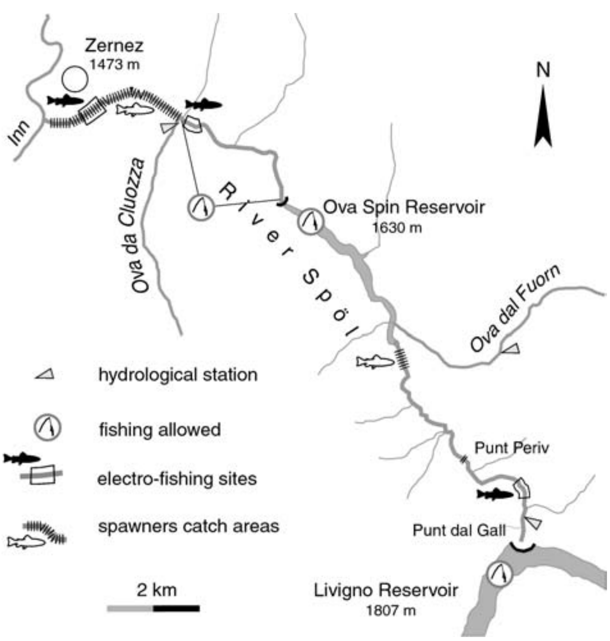


**Figure 1.** Map of the River Spöl in eastern Switzerland near the Swiss-Italian border showing locations of different sites for examining brown trout populations during the flood program.

## Material and methods

### Riverbed structure: changes in fish habitat

During each flood, the volume of suspended sediments was measured (Imhoff funnels, 30 min. settling time) at different places along the river (Mürle et al., 2003). During summer 1999, one year before the flood program, habitat structure relevant to trout was mapped in each study area (Fig. 1). Specifically, the heterogeneity of habitat structure was characterized before and after floods using changes in depth profiles from a number of permanent cross-sectional transects. Sediment composition of the upper layer (8–12 cm depth) of the streambed also was determined for 190 μm and 63 μm size classes using sieves. Once sorted, each size class was dried and weighed. In addition, the habitat usage by trout was investigated in a 200-m reach ca. 600 m downstream of Livigno reservoir by electro-fishing (Mürle, 2000); electro-fishing of this same reach was repeated after the floods of summer 2000.

### Fish stocks

In April 1999, the fish stocks in two reaches of the Spöl (Fig. 1) were examined in cooperation with the Canton Fisheries Department using electro-fishing. Electro-fishing of these reaches was performed at various times during and after the 3-year experimental flood period. In each case, each reach was electro-fished twice and the total fish stock was calculated by the method of DeLury (1947). The length and weight of each captured fish was measured and its condition factor (Fulton index) computed as $K = 100 * w/TL3$; where K = condition factor, w = weight in g, and TL = total length in cm.

Additional information on the fishery during the study period was available from annual catches recorded each autumn of pre-spawning fish in a 2.5-km segment just upstream of the mouth of the Spöl. Furthermore, the spawning redds of trout from Livigno reservoir to Punt Periv (2.6 km downstream, Fig. 1) were mapped annually at the end of November by Park officials. Redds were counted and mapped with a GPS-system while walking down the study reach. Redds could be easily recognised as bright (denuded) areas among the periphyton-covered gravel. Completed redds and (smaller) test-excavations were counted separately. The loss of fishes was estimated after each flood by searching the banks for dead fish and from those stranded in residual waterbodies. Fish also were examined for visual damage, e. g., gill or body abrasions.

## Results

### Direct effects of the floods on fishes

Suspended sediments usually remained <10 ml/l and only rarely achieved higher values (maximum of 17.5 ml/l) and these for only a short time (see Mürle et al., 2003 for additional information on changes in river structure).

In the segment downstream of Livigno reservoir, a maximum of 50 fish (>5 cm) was found dead or stranded in small isolated waterbodies after the floods (Fig. 2). This amount is ca 2% of the number of total fish (>5 cm) estimated by electro-fishing in April 1999 (i.e., 96 fish/100 m). In the study segment downstream of Ova Spin reservoir (2.9 km), losses amounted to <1% of the estimated standing stock (110 fish/100 m) with 10–15% of the fish stranded on the river bank found dead. The dead fish were almost exclusively in dry areas and generally showed no visual damage. After the June flood in the 2nd flood year, more than 100 live fingerlings (some with a vestige of the yolksac) were stranded in isolated waterbodies. Following each flood, none of ca. 200 examined fish was found to have visual damage, such as abrasion of the gills or skin mucous layer.

### Riverbed and sediment structure

The Spöl between the Livigno and Ova Spin reservoirs showed an increase in the variability of water depth from the floods, although pre-existing structures remained or were slightly shifted (Mürle et al., 2003). At most gravel bars before the floods, the content of fines (63–190 µm size class) in the upper 10 cm of the sediment layer was about 5% of sediment dry weight and many bars were highly colmated (clogged). Only a small reduction of fines was caused by the floods, although the degree of colmation was considerably lower (Mürle et al., 2003).

Between the mouth of the Spöl and the confluence with the Cluozza River, the morphology of the riverbed changed substantially via the input of gravel and coarse sediments from Cluozza. For example, considerable quantities of gravel were transported into the Spöl from the Cluozza after a major flood in summer 2000 (authors, pers. observ.). This material was redistributed then by the floods, accumulating on the riverbed in areas with a low gradient. The accumulated gravel was continually mobilized by changes in discharge, causing the riverbed to be relatively unstable. However, later floods (post–2000) eroded these gravel deposits, thereby again restructuring the riverbed (Fig. 3).

### Fish stocks

Over the study period, the condition factor of trout in the Spöl remained nearly constant (Fig. 4). In river sections where the riverbed structure hardly changed, trout abundance remained fairly constant after the floods. For ex-

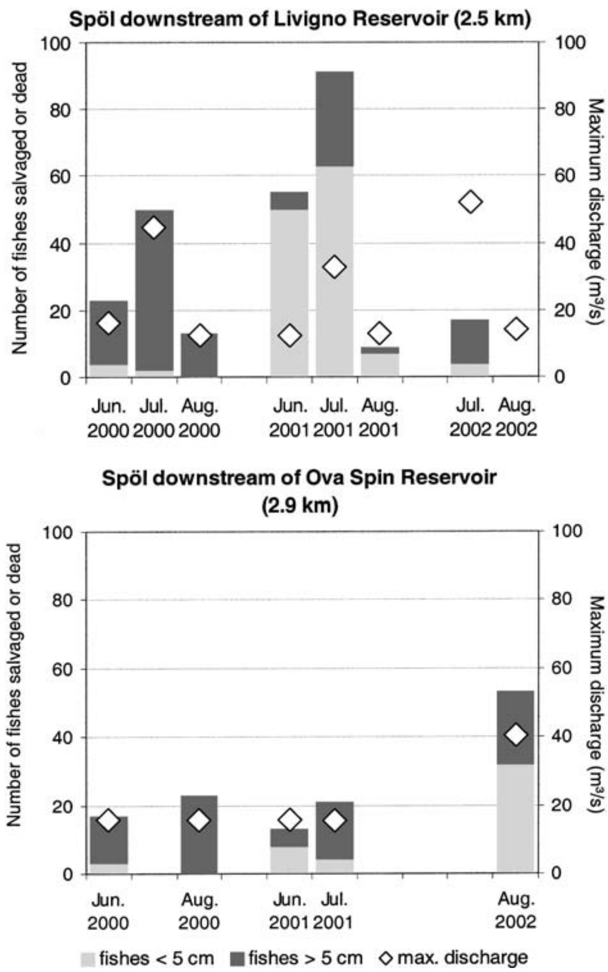


**Figure 2.** The number of fish stranded in side-pools or found dead immediately after each flood from the two study sections on the Spöl. Diamonds represent the maximum discharge of each flood.

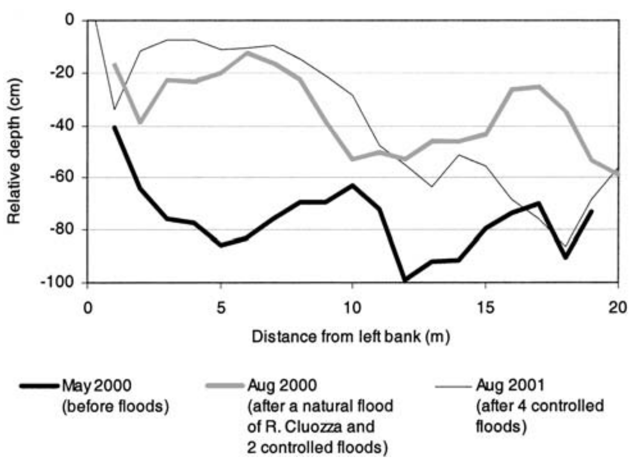


**Figure 3.** Cross-sectional depth profile recorded on the Spöl near the town of Zernez at periodic times before and during the flood program.

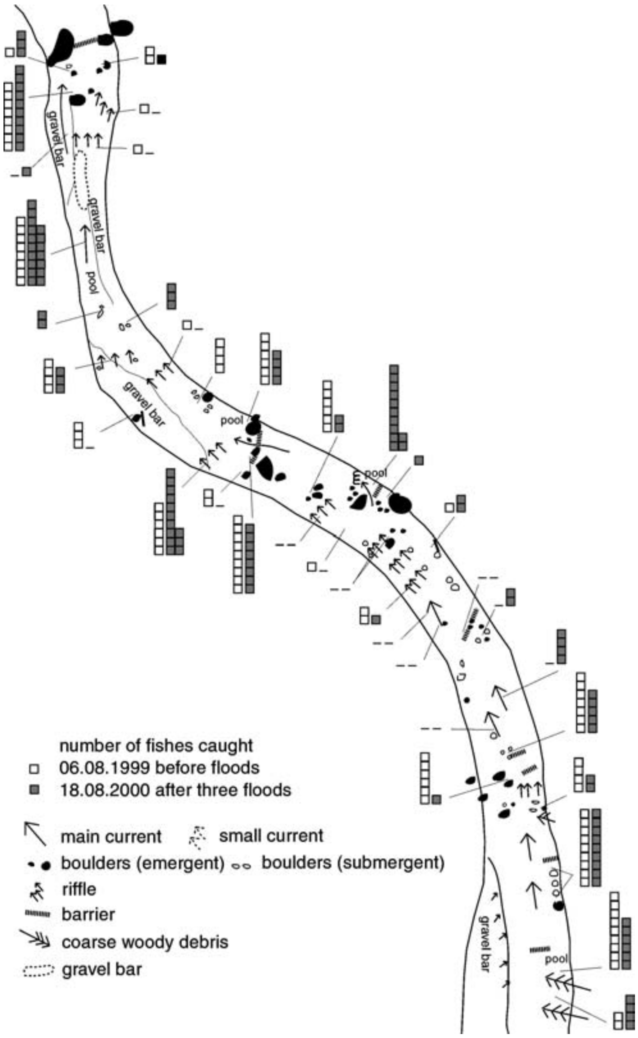


**Figure 4.** Habitat structures and number of fishes caught before and after the first three floods in a reach 1.5 km downstream of Punt dal Gall.

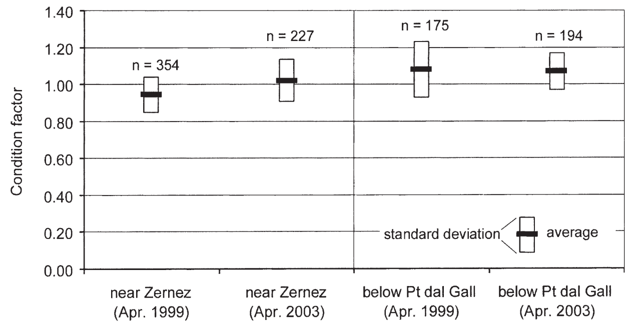


**Figure 5.** Average condition factor of brown trout before (1999) and after the floods (2003) at the two study reaches on the River Spöl. Symbols represent the minimum and maximum condition factor measured. The number of fish recorded is labelled on each bar.

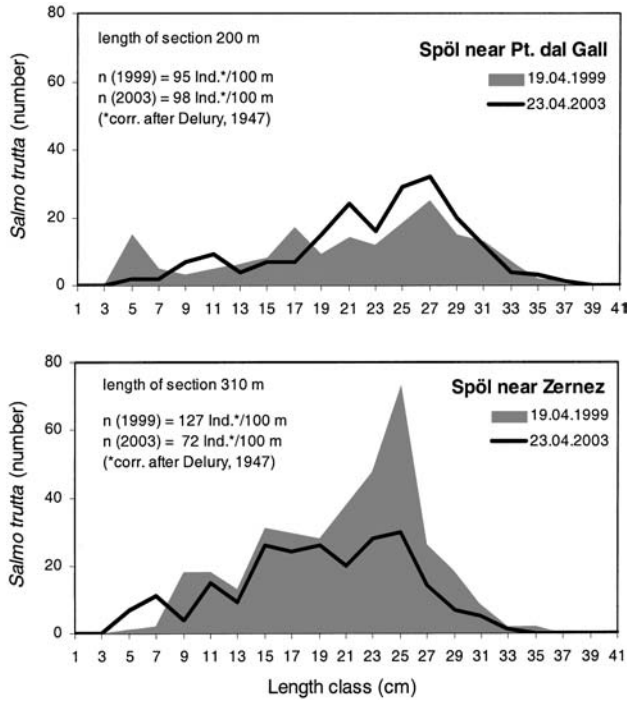


**Figure 6.** The number of fish captured by electro-fishing in the two study segments on the Spöl before (1999) and after (2003) the 3-year flood program.

ample, in the study section ca. 1.5 km downstream of Livigno dam (Fig. 1), the total number of fish (98 vs 104 fish/200 m) and the number of fish habitat structures remained similar after 3 examined floods (Fig. 5). Further, the electro-fishing in April 2003 (98 fish/100 m) resulted in the same fish density as before the floods (April 1999; 95 fish/100 m) (Fig. 6). In the lower Spöl, following the major gravel input from the River Cluozza in summer 2000, considerably fewer fish were counted in autumn 2000 than in 1999 (Fig. 7). The number of fish increased again in subsequent years, although the total number of trout was still less in 2003 than before the sediment input, larger fish in particular (Fig. 6).

## Fish recruitment

Before the flood program, most gravel areas with potential for spawning were heavily clogged by fines or went dry during low flows in winter. In 1999 before the floods, 58 spawning redds were counted in the 2.6 km long study section downstream of Livigno reservoir. In the following flood years, the number of redds increased nearly three-fold by 2002 (166 redds) in this same study reach (Fig. 8).

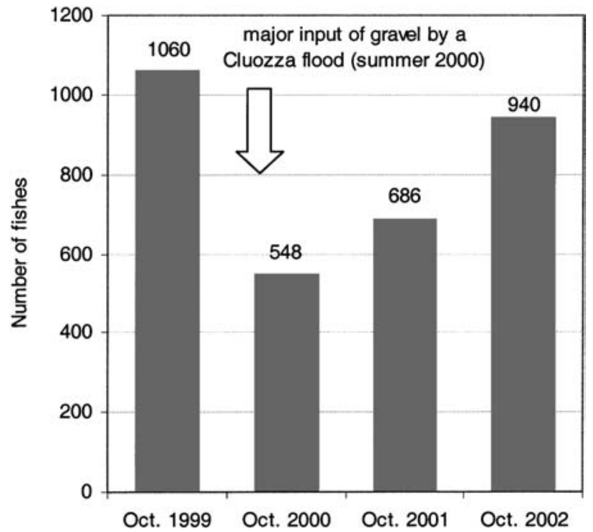


**Figure 7.** Number of fish caught by electro-fishing between the mouth of the River Spöl and its confluence with the River Cluozza from 1999 to 2002. Electro-fishing was conducted at the end of October when the spawning season began. A major sediment input from Cluozza occurred in summer 2000.

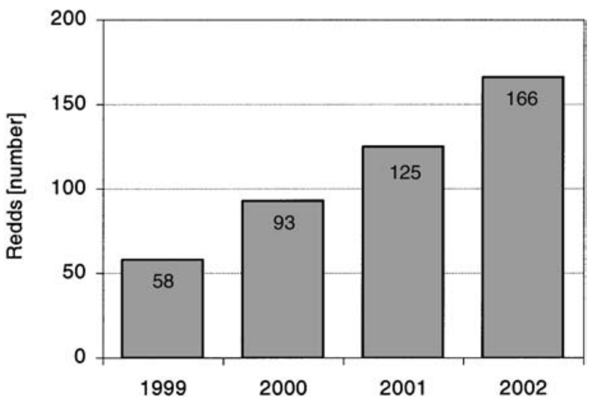


**Figure 8.** The number of spawning redds counted each November from 1999 to 2002 in the Spöl River between Punt dal Gall dam at Livigno reservoir and Punt Periv (distance = 2.6 km).

## Discussion

### Effects of the floods on fish

The experimental floods eroded debris fans and mobilized fine sediments from the river bed, leading to a significant increase in the volume of suspended sediments (Mürle et al., 2003). The volume of suspended sediments rarely exceeded 10 ml/l, the suggested limit of sediment concentrations harmless to fish (Gerster and Rey, 1994), although a maximum sediment load of 17.5 ml/l was measured for 15 min downstream of a debris fan at the confluence of the Spöl with the Cluozza River. Gerster and Rey (1994) observed damages to the gills and skin mucous layer of fish at high suspended sediment concentrations (ca. 30 ml/l) during high discharge. However, no such damages to fish were observed during the floods in the Spöl River. Fish that drifted downstream during the floods could not be observed directly, but many trout were seen to swim upriver near the bank during the lower discharge following each flood, perhaps as compensation for downstream drift. Valdez et al. (2001) found many fish to be displaced downriver after the test flood on the Colorado River. The main danger to fish during the flood process became evident with the decrease in post-flood discharge, as some fish became stranded in side-channel waterbodies that later went dry. However, these losses were a low percentage (<2%) of the total standing stock of fish in the examined segments. In general, observations during the flood, and the results of electro-fishing before and after the floods, revealed few losses of fish due to the floods. Further, the number of stranded fish was not correlated with maximum flood discharge. The observation of numerous fingerlings along the study reaches after the large June floods in year 2 and 3 suggests that even the juvenile stages can survive these larger floods. Some of the fingerlings still had remnants of their yolksac, indicating relatively late egg development in the Spöl (Friedl, 1996) and has implications regarding the timing of floods in the future (Welcomme, 2001).

### Riverbed habitat structure

As an alpine river, the Spöl has an inherent riverbed structure well-suited for the trout population. Brown trout use different habitat structures for each developmental stage and for different functional needs such as resting, feeding, hiding, and spawning. Poddubny and Galat (1995) relate the importance of different habitat types for fishes in the Volga River as influenced by reservoirs. For instance, habitats with low flow velocities are used for resting and are common in Spöl because of the regulated flow, although low water depths restrict the number of sites for larger fish. Consequently, the increase in water depth variability resulting from the floods (Mürle et al., 2003) probably improved habitat conditions for larger trout. Bischoff and Wolter (2001) found that reophilic fish, such as brown trout, capitalized on newly formed mesohabitats resulting from a flood.

The draining of Ova Spin reservoir in 1995, with a discharge peak of 70 $m^3/s$, also increased the habitat heterogeneity of the river downstream of the reservoir by forming numerous rough blocks, pools, and riffles (Ackermann et al., 1996). However, these habitats were homogenized by the large input of gravel from the Cluozza River during the summer 2000 flood. The initial floods in the Spöl transported some of the gravel downstream but without increasing the habitat structure in the river. Elwood and Waters (1969) found a reduction in trout production in a river when flood waters filled pools and clogged riffle habitats with fine sediment. The later floods in the Spöl, however, eroded the gravel and partly restored the habitat structure of the river. This restructuring of the riverbed was reflected in the increase in spawning trout that initially decreased after the input of the gravel.

**Food resources and the condition of trout**

Before flow regulation, food resources for trout were low in the River Spöl, and the trout were known for their poor condition (Ambühl, 1966). Following flow regulation, mosses (e.g., *Fontinalis* spec.) increased substantially in the stabilized river, along with the abundance of particular benthic macroinvertebrates, especially Gammaridae (e.g., max. 38,000 gammarids/m$^2$ in 1999). Presently, trout in the Spöl, which use this food source intensively, are in good condition, averaging >1.0 (Fulton Condition Index). Moss coverage in the river was strongly reduced by the floods (Uehlinger et al., 2003), and the abundance of Gammaridae also decreased (Robinson et al., 2003a; b). Nevertheless, the condition of trout remained the same during the study period. Valdez et al. (2001) also found fish condition to be little affected after the Glen Canyon test flood. Further investigations are needed to examine the present food resources and their usage by trout; e.g., is the current abundance of gammarids adequate to sustain the trout population in the Spöl?

**Fish standing stocks**

In the Spöl between Livigno reservoir and Punt Periv (Fig. 1), the floods did not reduce the number of fish in the river. Several investigations of the fish abundance before, during, and after the experimental floods showed almost identical densities of trout (Fig. 5). In the Spöl between the confluence of the Cluozza and the Spöl mouth, considerably fewer fish were caught in 2000 than in 1999. The likely reason for this decrease in fish density (especially large fish) is the loss of shelter habitats following the input of gravel from the Cluozza in summer 2000; this gravel homogenized the riverbed (also see Elwood and Waters (1969). By 2002, however, the density of trout had increased as more habitat structure resulted with the continuation of the flood program.

The reproductive potential of trout was substantially reduced with the regulation of flow in the Spöl. The loose substrate of gravel bars, typical for alpine streams and rivers, that allow fish to excavate redds for spawning and provide good aeration of eggs was clogged and covered by fines (Mürle, 2000). Spawning trout were observed to frequently terminate the excavation of redds upon reaching a clogged layer of sediments. The floods had a positive effect of increasing the porosity of the riverbed and covering other areas with a layer of loose gravel suitable for spawning (Mürle et al., 2003). Indeed, the number of spawning redds increased nearly three-fold over the three year study period.

One objective of the floods was to reduce the amount of fines in the upper layer of the river bed, thereby decreasing the degree of colmation. An increase of the content of fines is typically correlated with a decrease in the survival of trout eggs (Wu, 2000). A content of fines (< 1 mm) around 12% is thought to reduce fry emergence by 50% (Kondolf, 2000). Even before the floods the upper layer of gravel bars contained few fines (about 5% of total dry weight), thus the improvement of spawning habitat was mainly due to the formation of new gravel bars and a reduction in colmation (Mürle et al., 2003). It is not certain whether this habitat improvement also resulted in better egg development. For example, the thick layer of algae in early winter (Uehlinger et al., 2003) may result in a loss of eggs due to poor aeration. Further investigations must test whether a sequence of low magnitude floods during embryonic development should be considered to reduce egg mortality (Wu, 2000). However, the large number of fingerlings observed in summer 2001 and 2002 in different reaches of the Spöl suggests that recruitment has improved. In conclusion, our results show that an artificial flood regime can be used to rejuvenate habitat conditions for fish in a regulated river downstream of a large reservoir.

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