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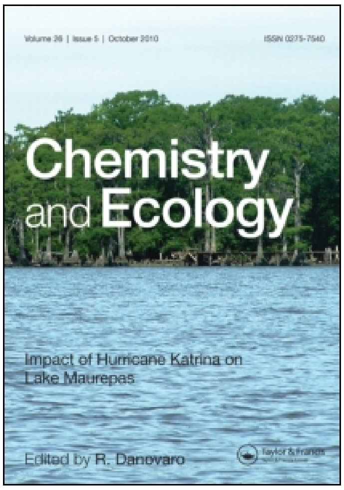

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Impact of a trout farm on the water quality of an Apennine creek from daily budgets of nutrients

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A detailed 24-h investigation in August 2005 evaluated net dissolved and particulate nutrient budgets in a small trout farm located in the Parma Apennines. During the monitoring period, due to water shortage, the Cedra Creek was almost entirely diverted into the farm; the water flow was $190\,\mathrm{l\,s^{-1}}$, and the fish standing stock about 20 t. Inflow and outflow waters were characterized for dissolved gases (O_2 and CO_2) and dissolved and particulate inorganic nutrients (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, PN, and PP). Solute concentrations in outflowing waters were found to fluctuate considerably during the day, due to fish metabolic activity and farm-management practices. Despite the small amount of feed supplied to the fish ($75\,\mathrm{kg\,d^{-1}}$) due to high water temperatures (~20 °C) and the high feed conversion factor (~1.2), the farm released net amounts of 2.20 and $0.76\,\mathrm{kg\,d^{-1}}$ of nitrogen and phosphorus, respectively, to the Cedra Creek. Of the nutrients produced, 68% of the nitrogen was as NH_4^+, while 67% of the phosphorus was particulate. Significantly different NH_4^+, NO_2^-, and PP concentrations were measured 500 m downstream of the fish farm compared with inflowing water. This study supports the hypothesis that the ecological quality of creeks or streams receiving fish farm effluents can be seriously affected due to fine particle sedimentation, interstice clogging, simplification of benthic macrofauna communities, and stimulation of microfitobenthos growth.

Keywords: Trout; Fish farming; Nutrient; Budgets; Apennine; Creeks; Pollution

1. Introduction

Recent literature reporting on mass balances in fish farms has evidenced a great degree of dispersion of particulate and dissolved nutrients in the natural environment. Of the total amount of C, N, and P supplied as fish feed during the cultivation cycle, only a small part (generally 20–30%) is recovered as harvested fish biomass [1–4]. Most studies are based on very accurate C, N, and P mass balances where initial and final fish biomass, fish mortality, benthic processes of sedimentation, burial, regeneration, total supplied fish feed, and its elemental composition are known or measured precisely. In the open sea and in large lakes, around floating cages, the direct determination of dissolved or particulate nutrients dispersed in the water column is difficult [5–8]. Therefore it is very difficult to detect differences between farmed areas and

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uncontaminated sites [6]. In the pelagic area, water monitoring requires a frequent, accurate, and expensive sampling, and results can be sometimes insufficient to evaluate the waste produced and fish-farm environmental impacts [7, 8]. Better indicators are the presence/absence of macrophyte meadows, oxygen, nitrogen, and sulfur dynamics at the sediment level, micro- and macrofauna community characterization, or micro- or macroalgal growth rates [9–14].

Where fish farming is land-based, waste production and deterioration of aquatic ecosystems receiving effluents can be readily quantified through water monitoring. In artificial ponds or raceways, water flow is known accurately, and solute concentrations can be easily turned into loads; nutrient mass balances can be calculated through repeated monitoring of incoming and outflowing water. Dispersion of pollutants in the water, which for fish cages is generally calculated by difference, is thus readily measured in enclosed ponds with a known water flow [15].

In Italy, aquaculture is mainly driven by mollusc farming, which covers about 72% of the total production and is carried out in marine and brackish waters; the remainder is mainly due to flow-through trout farming in freshwater environments (21%) for a production estimated in 49 000 $\mathrm{t\,y^{-1}}$ [16]. There are actually 562 trout farms operating in Italy; most of these are located in northern mountain regions (Piemonte, Lombardia, Veneto, and Friuli) and utilize creek, river, or lake water; the predominant farmed species is the rainbow trout, *Oncorhynchus mykiss*. Many of these fish farms are small, with limited and local production (10–20 $\mathrm{t\,yr^{-1}}$); trout densities and feed conversion ratio are in the range of 15–35 $\mathrm{kg\,m^{-3}}$ and 1.1–2 respectively. Managers sometimes collaborate with local authorities and natural parks in repopulation programmes aimed at improving the genetics of natural stocks, reintroducing autochthonous species (*i.e. Salmo trutta marmoratus*) or increasing fish densities in the natural environment. The bibliography related to nutrient and organic matter release in these fish farms is poor, even if freshwater fish farming represents a relevant activity for Italian aquaculture (€150 million $\mathrm{yr^{-1}}$) and can greatly impact final receptors that are generally oligotrophic systems [17].

In mountain aquatic environments, primary production is severely limited, and nutrient dynamics and food chains are generally based on external inputs of refractory organic material as dead leaves or woody fragments [18–21]. Negative effects of nutrient inputs are enhanced by water shortage and thus by minor dilution of pollutants; this happens during summer months, in particular in the last years characterized by scarce precipitation events.

In this paper, results related to net daily balances of dissolved and particulate nutrients calculated in an Apennine flow-through a trout farm are presented and discussed with respect to the potential impact on the creek receiving effluents. The investigated farm rears trout (15–25 $\mathrm{t\,yr^{-1}}$) in artificial ponds receiving and returning back water from an Apennine creek, the Cedra Creek (Parma Province, northern Italy). This study was performed during summer 2005 when, due to water shortages, most of the creek water was diverted into the fish farm. The present work has a two aims: (1) to accurately quantify exported dissolved and particulate N and P through repeated water sampling and (2) to evaluate the sustainability of aquaculture in Apennine environments with strong seasonal fluctuations of water availability.

2. Study area

The Val Cedra fish farm is located in the Apennine portion of the Parma Province, northern Italy, 650 m above sea level and has been in operation for at least 10 yr. It consists of an artificial, roughly triangular basin (length 180 m, maximum width 70 m, average depth 1.5 m) with the longest side parallel to the Cedra creek (figure 1). The water body is divided into

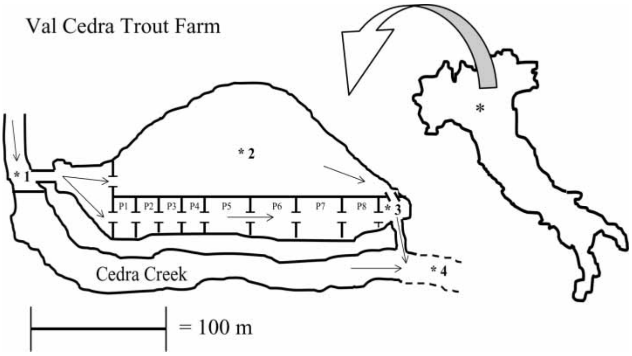

Figure 1. Schematic representation of the Val Cedra Trout Farm with the sampling stations (1 = inlet, 2 = main basin, 3 = trout farming whole outflow, 4 = downstream station). When this study was performed, the Cedra Creek was diverted to feed only fish ponds P1–P8 due to water shortage, and the main basin was isolated; water flow was 190 l s^{-1} (see text for major details).

two portions: a large pond (~4000 m^3) with a relatively low trout density (0.2–2.5 kg m^{-3}) in which angling is allowed, and a series of eight ponds (~1800 m^3) arranged in a cascade where trout is allowed to grow. Water from the Cedra Creek is diverted and driven into the fish farm where the flow is split into two areas and feeds the main basin and the series of ponds. The water is then returned to the Cedra Creek. When water flow in the Cedra Creek is consistent (1–2 $m^3 s^{-1}$), the amount diverted into the fish farm is ~0.40 $m^3 s^{-1}$, and the renewal time for the ponds and main basin is ~2.7 and ~5.6 h, respectively. In the summer months, due to water shortages, most of the Cedra Creek water flow (0.15–0.20 $m^3 s^{-1}$) is diverted into the fish farm and feeds only the pond series, while the main basin remains isolated. This was the case in August 2005, when the work was carried out.

The farmed species are the lake trout *Salvelinus namaycush*, the brown trout *Salmo trutta trutta*, the brook trout *Salvelinus fontinalis*, and the rainbow trout *Oncorhynchus mykiss*; the fish biomass stock in the period of this investigation is reported in table 1. In the Val Cedra fish farm, feeding is manual and accurately calibrated for fish size, season, and water renewal so that the feed conversion ratio is optimal and in the range of 1.1–1.3. In the period of this study, due to a combination of warm water temperatures (~20 °C) and water shortages from the Cedra Creek, feeding was kept at a minimum, and a series of aerators were running intermittently day and night.

Table 1. Salmonids standing stocks in the ponds P1–P8 during the period of this investigation.

Pond	Species	Stock (kg)
P1	Salvelinus namaycush	600
P2	–	–
P3	*Salmo trutta trutta*	500
P4	*Salvelinus fontinalis*	600
P5	*Oncorhynchus mykiss*	6000
P6	*Oncorhynchus mykiss*	12 000
P7	*Oncorhynchus mykiss*	300
P8	*Salvelinus fontinalis*	800

3. Materials and methods

Water was withdrawn from stations 1–4 (figure 1) starting at 10.00 a.m. on 19 August 2005, at 3-h intervals for 24 h; a total of eight samplings were performed. Station 1 was situated where the Cedra Creek is diverted and driven into the fish farm; station 2 was located approximately in the centre of the main basin, where fish are not fed; station 3 was the outflow of the whole fish farm; and station 4 was situated in the Cedra creek, 500 m downstream of station 3. At each site, water was characterized *in situ* with a multiple probe (YSI Instruments, mod. 556) for temperature, conductivity, pH, and dissolved oxygen (O_2). Approximately 1 l was collected in glass bottles, flushing the sample to avoid gas bubble formation and minimize water stirring. In a few minutes, unfiltered subsamples were transferred in glass probes (12-ml Exetainers, Labco, UK) for total dissolved inorganic carbon (DIC, six end-point titrations with 0.1 N HCl [22]) and dissolved oxygen (iodometric titration [23]) determination. The CO_2 concentration and saturation values were calculated from pH, DIC, temperature, and conductivity data [24].

Known amounts of water from each sample were filtered on GFF Whatman filters and transferred into glass probes for soluble reactive phosphorus (SRP) determination (spectrophotometry, reaction with ammonium molybdate and potassium antimonyl tartrate and reduction by ascorbic acid [25]) and into plastic probes for dissolved inorganic nitrogen determination ($\mathrm{DIN{=}NH_4^+ + NO_2^- + NO_3^-}$). Ammonium was determined spectrophotometrically using salicylate and hypochlorite in the presence of sodium nitroprussiate [26], nitrite was determined spectrophotometrically using sulfanilamide and N-(1-naphtyl) ethylendiamine [27], and nitrate was determined after reduction to NO_2^- in the presence of cadmium. Total particulate phosphorus and nitrogen (PP and PN) were determined as SRP and NO_3^-, respectively, after persulfate oxidation in autoclave at 120 °C [25].

During each sampling, water flow was measured at stations 3 and 4 by means of an FP101 Flow Probe (Global Water instrumentation), and photosynthetically available radiation (PAR) was measured via a portable quantum photo radiometer (Delta OHM, mod. HD 9021). Qualitative samples for planktonic and macrobentic communities characterization were collected from station 2.

Net daily balances of O_2, DIC, SRP, DIN, PP, and PN were calculated for the fish farm as differences between incoming and outflowing loads. The concentrations of the above-mentioned solutes measured at stations 1 and 3 were multiplied by water flow and time intervals (3 h) and transformed into partial loads. Incoming and outflowing partial loads were then integrated over 24 h and net daily balances calculated.

Differences between the four sampling stations were tested with ANOVA for repeated measurements, followed by a post hoc HSD Tukey test (SPSS software, version 13.0).

4. Results

Incoming water flow was constant during the period of this study and quantified in $190 \pm 12\,\mathrm{l\,s^{-1}}$; the residual flow in the Cedra creek between stations 1 and 3 was about $20\,\mathrm{l\,s^{-1}}$, meaning that about 90% of the creek course was diverted into the fish farm.

Minimum and maximum values of the main physico-chemical parameters measured at the four sampling stations are shown in table 2. Most of the parameters were not or only weakly correlated with light intensity, meaning that in both creek and fish farm systems, primary-producer activity was not a strong driving factor for water chemistry. Indeed, at station 3 some chemical parameters (*i.e.* NH_4^+ and SRP) displayed a certain fluctuation during the day, probably due to fish feeding, which occurred at 9.00 a.m., and fish metabolic activity (figure 2).

Table 2. Minimum and maximum values of the main physico-chemical parameters measured at the sampling sites during a 24-h investigation cycle.

	Station 1	Station 2	Station 3	Station 4
Temperature (°C)	17.1–22.7	19.4–22.3	18.4–22.4	18.2–21.9
Conductivity (μS cm^{-1})	299–339	316–327	314–341	317–355
pH	8.00–8.52	7.97–8.34	7.89–8.31	7.88–8.31
O_2 saturation (%)	70.6–91.8	67.6–86.3	49.0–62.3	66.0–84.2
DIC (mM)	2.44–3.04	2.68–2.91	2.63–3.04	2.67–2.93
CO_2 saturation (%)	125.9–444.9	211.4–349.9	417.8–593.7	227.8–569.8
SRP (μM)	0.00–0.41	0.04–0.82	0.40–1.57	0.08–2.12
NH_4^+ (μM)	0.10–8.05	0.09–5.29	5.91–14.57	4.42–12.00
NO_2^- (μM)	0.07–0.16	0.08–0.26	0.08–0.21	0.20–0.46
NO_3^- (μM)	9.20–19.08	10.10–16.00	4.11–16.47	10.02–16.92
PP (μM)	0.06–0.16	0.15–0.21	0.21–0.54	0.15–0.34
PN (μM)	3.55–6.34	3.68–7.07	4.80–11.45	3.45–7.64

Note: Samples ($n = 8$) were collected at 3-h intervals starting at 10.00 a.m. on 19 August 2005.

At station 1, the Cedra Creek water was characterized by a relatively high-temperature (~20 °C), conductivity (~0.32 mS cm^{-1}) and dissolved inorganic nitrogen and phosphorus ($NH_4^+ \sim 3\,\mu$M, $NO_3^- \sim 13\,\mu$M, SRP $\sim 0.2\,\mu$M); on average, dissolved oxygen was below saturation (78 ± 8%), while the opposite was found for CO_2 (266 ± 105%).

At station 2, most of the parameters were overlapping those measured at station 1, with the only exception of water temperature that was slightly but significantly higher, probably due to water stagnation; water from this site had a generally lower dissolved nutrient concentration and higher particulate concentrations (table 3). The main basin of the fish farm contained about 1 t of rainbow trouts; surface sediments were soft, organic, and reduced with chironomid larvae as the most abundant representative of benthic macrofauna. Phytoplankton community was represented by a considerable number of species ($n = 38$), mostly large diatoms as *Cymbella* sp., *Pinnularia* spp., and *Fragilaria* sp. but also cyanobacteria, both unicellular and colonial as *Oscillatoria* spp., *Mersimopedia* sp., and *Chroococcales* sp. The zooplankton community had a very low number of species with low abundances and was mostly represented by littoral and benthic species as *Lecane* sp. and *Lepadella* sp., among rotifers, and *Alona* sp. and *Pleuroxus* sp., as cladocerans.

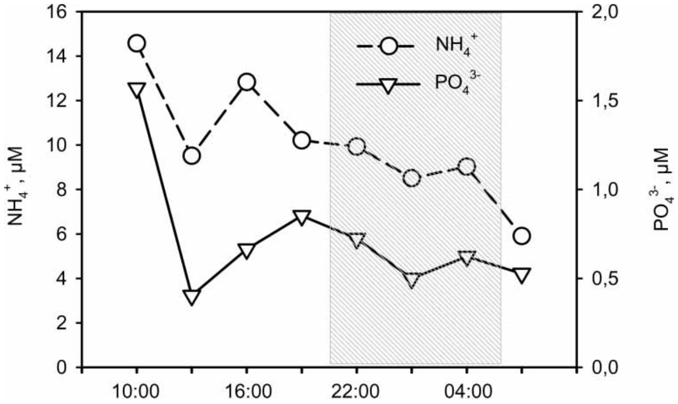

Figure 2. Daily evolution of ammonium and soluble reactive phosphorus concentrations at station 3; sampling was started at 10.00 a.m. on 19 August 2005.

Table 3. Results of the ANOVA carried out to test for differences between stations.

Stations		2	3	4		2	3	4
	Temperature				Conductivity			
1		*	n.s.	n.s.		n.s.	n.s.	n.s.
3		–	–	n.s.		–	–	n.s.
	pH				O_2 saturation			
1		n.s.	**	n.s.		n.s.	***	n.s.
3		–	–	n.s.		–	–	***
	DIC				CO_2 saturation			
1		n.s.	n.s.	n.s.		n.s.	***	n.s.
3		–	–	n.s.		–	–	***
	SRP				NH_4^+			
1		n.s.	*	n.s.		n.s.	***	**
3		–	–	n.s.		–	–	*
	NO_2^-				NO_3^-			
1		n.s.	***	***		n.s.	n.s.	n.s.
3		–	–	***		–	–	n.s.
	PP				PN			
1		n.s.	***	***		n.s.	***	n.s.
3		–	–	n.s.		–	–	n.s.

Two stations are different ($p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

At station 3, water outflowing from the fish farm had markedly lower oxygen concentrations (56.1 ± 4.9%) and was supersaturated with CO_2 (491.9 ± 69.1%), even if aerators were running in ponds P3, P5, P6, P7, and P8 intermittently day and night. At station 3, the SRP, PP, and NH_4^+ average concentrations were about threefold higher than those measured at station 1, while PN almost doubled. At station 4, the values were generally between those measured at station 1 and 3 due to progressive dilution of produced nutrient loads. Overall, inorganic nutrients as NH_4^+ and SRP exhibited the greatest differences among sites and sampling time, while NO_3^- content was rather constant; NO_2^- concentrations were also varying, but values were close to analytical detection limits.

Table 3 reports all the results of the statistical analyses carried out to test concentration differences between investigated sites. The ANOVA indicates that major differences characterize station 1 and 3, with the latter richer in dissolved and particulate nutrients; on the contrary, stations 1 and 2 were rather similar. Downstream (station 4), the concentrations of some parameters (NH_4^+, NO_2^-, and PP) were significantly higher than those measured upstream from the fish farm (station 1), while others (dissolved gases, SRP, PN) were not.

The net daily oxygen balance for the trout farm was negative ($-1108.5\,\mathrm{mol\,d^{-1}}$, table 4), while that for DIC was largely positive ($1759.8\,\mathrm{mol\,d^{-1}}$); regarding inorganic nutrients, the trout farm was revealed to be a source of nitrogen and phosphorus (table 4). Net daily NH_4^+ and SRP balances were positive (109.4 and $8.1\,\mathrm{mol\,d^{-1}}$, respectively) while that for

Table 4. Net daily balances of a number of chemical parameters calculated for the whole trout farm.

	O_2 ($\mathrm{mol\,d^{-1}}$)	DIC ($\mathrm{mol\,d^{-1}}$)	SRP ($\mathrm{mol\,d^{-1}}$)	NH_4^+ ($\mathrm{mol\,d^{-1}}$)	NO_x^- ($\mathrm{mol\,d^{-1}}$)	PP ($\mathrm{mol\,d^{-1}}$)	PN ($\mathrm{mol\,d^{-1}}$)
Station 1	3842.2	45 136.3	3.9	54.9	211.4	1.9	55.8
Station 3	2733.6	46 896.1	12.0	164.3	201.7	18.2	104.6
Net daily balance	−1108.6	1759.8	8.1	109.4	−9.7	16.4	48.8

Note: Incoming and outflowing loads at stations 1 and 3 were calculated by multiplying concentrations, water flow, and time intervals; eight repeated samplings were performed in 24 h (see the text for more detail).

NO_x^- (NO_2^-+NO_3^-) was negative ($-9.7\,\mathrm{mol\,d^{-1}}$); on a molar basis, the N:P ratio of dissolved nutrients released to the creek was ~30, while upstream of the fish farm, this ratio was ~80. The trout farm was also a net source of particulate matter: the PP and PN net daily balances were 16.4 and $48.8\,\mathrm{mol\,d^{-1}}$, respectively.

5. Discussion

5.1 *Feeding practises*

Food composition for salmonids has been studied in detail to meet fish metabolic requirements so that feed waste, loss of phosphorus, and excretion of excess ammonia via the gills are minimized. Proper diets allow for good feed conversion factors close to the unit (on a dry-feed-to-wet-flesh-weight basis) with a considerable reduction in costs for farmers and benefits for the natural environment receiving effluents [28–32].

In the Val Cedra fish farm, managers have optimized fish feeding by the manual supply of floating pellets; they carefully avoid food and thus nutrient waste in the surrounding environment. They also maintain a low biomass in ponds (maximum ~$20\,\mathrm{kg\,m^{-3}}$, P6) avoiding excessive oxygen consumption and accumulation of waste metabolic products. During the summer months, due to high temperature and low water flow, trout are fed for their subsistence; during the period of this investigation, for example, only $75\,\mathrm{kg\,d^{-1}}$ was distributed in fish ponds P1–P8 to feed ~20 t of trouts; in colder periods of the year, when water flow in the farm is higher, this amount can be eightfold higher. In our opinion, feeding practices in this plant are already optimized and there are limited possibilities for further significant improvements.

5.2 *Waste produced by the farm*

The primary sources of aquaculture wastes are from fish excretion and uneaten feed. When fish farms have been running for a while and are not properly managed, surficial, organic-rich sediments can be an important source of dissolved nutrients and CO_2 and a sink for oxygen [3, 12].

Only about 30% of feed N and P is retained by salmonids fed with most commercial feeds even if they consume all of the pellets supplied, as is probably the case for the farm studied. Feed N and P not retained by the fish are excreted as dissolved forms (up to 60% of the supplied N and 6–30% of the supplied P) or particulate matter (7% of the supplied N and up to 60% of the supplied P) resulting in eutrophication of water bodies receiving wastewater [2, 29, 33].

To avoid fish stress and not to waste uningested food when growing conditions are sub-optimal, farmers feed the fish stock with a minimum amount of pellets. This was the case in the period of our experiment. When the Cedra Creek flow was very low, water temperatures were close to 20 °C, and standing fish biomass (~20 t) were fed with only ~75 kg of pellets per day. The composition of the pellets used in the fish farm studied was 12.0% water, 36.0% C, 6.5% N, and 1.3% P, meaning that ~$4.29\,\mathrm{kg\,N\,d^{-1}}$ and ~$0.9\,\mathrm{kg\,P\,d^{-1}}$ were added to the fish farm through the pellets during this investigation. We measured a net daily load exported from the fish farm of $2.20\,\mathrm{kg\,N\,d^{-1}}$ (1.50 kg as NH_4^+ and 0.70 kg as PN) and of $0.76\,\mathrm{kg\,P\,d^{-1}}$ (0.25 kg as SRP and 0.51 kg as PP) (table 4). This means that about 51% and 84% of N and P supplied with fish feed were released to the Cedra Creek. Our results confirm the general finding that even if the small amount of supplied food is completely eaten by fish, excreted and faecal materials are dispersed in the natural environment. In addition, in the case of nitrogen, most (~68%) is in the dissolved form, while in the case of phosphorus, most (~67%) is in the particulate form. When higher amounts of fish feed are used the proportion of waste products probably remains about the same.

Proposed calculations are a simplification of nutrient dynamics as NH_4^+ and SRP leaving the farm can be produced by fish metabolic activity or regenerated by surface sediments, while PN and PP pools include non-ingested food, fish faeces, and resuspended material within ponds.

Considering that, for salmonids, gill NH_3 excretion is generally 100–200 mg N kg fish^{-1} d^{-1} [34], the total amount of dissolved N generated by the fish stock in the Val Cedra fish farm should be 2–4 kg N d^{-1}. Our results (1.50 kg N as NH_4^+ d^{-1}) are close to the lower extreme of this range; it is likely that the missing fraction is exported to the atmosphere as NH_3 due to the aerators.

5.3 *Oxygen and inorganic carbon daily balances*

Calculated net daily O_2 and DIC balances (−1108.5 and 1759.8 mol d^{-1}, respectively; table 4) are both underestimates of true oxygen uptake and inorganic carbon production due to the O_2 and CO_2 quota respectively diffusing to the water from the atmosphere and released from the water to the atmosphere, in particular when aerators were operating. Considering a total surface of 1500 m^2 for the entire pond series, oxygen and inorganic carbon balances can be converted in fluxes on an area basis (−30.7 mmol O_2 m^{-2} h^{-1} and 49.2 mmol CO_2 m^{-2} h^{-1}). These fluxes are also underestimates but still are very high rates of oxygen demand and carbon regeneration for any aquatic environment [12]. Assuming a similar error in both estimates, it is possible to calculate the $|DIC/O_2|$ respiratory quotient, which is ~1.58 and indicates the occurrence of anaerobic mineralization in the trout farm sediments. Scarce colonization of the sediments collected at station 2 by macrofauna supports this finding; chironomids are known as tolerant organisms able to survive in organic-rich substratum. Limited oxygen penetration and organic carbon availability in surface sediments inhibit nitrification but favour denitrification or dissimilative nitrate reduction processes which are probably responsible for negative NO_x^- daily balances (table 4) [12]. On an area basis, NO_x^- loss is significant (~270 μmol m^{-2} h^{-1}) despite the relatively low nitrate concentration in the water column (10–16 μM).

5.4 *Potential impact of fish farm effluents on the Cedra Creek*

At station 3, the outflow of the fish farm, most of the parameters analysed were significantly different from those measured at station 1; the farming activity was affecting the creek water chemistry increasing its nutrient content and N and P stoichiometry. Upstream and downstream from the fish farm the N:P ratio of dissolved nutrients was significantly different (from ~80 to ~30), meaning that fish-farm effluents were attenuating phosphorus limitation in the Cedra Creek water. Nutrients released by the fish farm were measurable in the Cedra Creek 500 m downstream at station 3 in terms of higher NH_4^+, NO_2^-, and PP concentrations, while other parameters recovered their original concentrations (*i.e.* O_2 and CO_2) and were not statistically different from those measured upstream from the fish farm (table 3). Water shortage in the Cedra Creek results in less dilution of pollutants released by the farm and reduces the natural self-depuration capacity of the aquatic environment.

In running waters, the effects of nutrient enrichment on primary producers is an open debate; it is in fact not clear whether it increases or decreases benthic microalgal diversity [35]. An input of dissolved nutrients in the water can fuel the growth of attached algae with a positive feedback on the accumulation of organic matter in the creek bed and definitely alter the stream food chain. Labile particles exported from the fish farm are likely to sediment in the creek bottom and change the porosity of the creek; fine sediment accumulation may clog the interstices and affect macroinvertebrate colonization and distribution reducing the size of the interstitial space available, interstitial water exchange, macrofauna mobility, and oxygen penetration [36–38].

The paradox is that where hatcheries and fish farms are run with the aim of improving natural salmonid populations, the same activity can alter and simplify the natural environment in which the fish are released through water eutrophication. It seems contradictory to release salmonids in environments with poor macrofauna communities which are an important food source for fish.

In our study, benthic macrofauna in the Cedra Creek upstream and along from the fish farm were not monitored, but future studies should be addressed to this issue.

5.5 *Water recirculation in the main basin: a solution for nutrient abatement?*

Plankton characterization in the main basin of the fish farm revealed the absence of pelagic forms of zooplankton, represented by low numbers of species associated with the surface sediments. The algal community was represented by large diatoms probably stimulated by the relatively high nutrient content in the water column; furthermore, small trout probably feed on filter-feeding zooplankton and indirectly favour phytoplankton development. In the Val Cedra trout farm the water of small fish ponds could be recycled into the larger pond before returning it to the Creek. A relatively longer renewal time in the basin could favour suspended particle settlement reducing suspended solid input to the Cedra Creek. Emergent or floating leaved macrophytes could be introduced and managed in the basin in order to convert dissolved nutrients in recalcitrant biomass and control microalgal growth through shading. The gas-transport mechanism associated with macrophytes' parenchyma could favour both microbial and chemical processes as coupled nitrification–denitrification and phosphorus precipitation with ferric iron oxides [39]. The nutrient load produced is relatively small, and it is likely that the conversion of the main basin into a phytotreatment pond could significantly improve effluent water quality.

6. Conclusion

In this study, repeated water sampling and flow measurements at inflow and outflow sites were carried out only over one day, but they allowed an accurate estimate of net daily dissolved and particulate nutrient balances. A sampling effort over 24 h, as shown in this investigation, is unavoidable to obtain reliable balances due to wide fluctuations of solutes concentrations in effluents. Obtained results, even if limited to one sampling period, yield realistic proportions of large amounts of N and P in fish feed lost in natural environments, similar to those found in other studies [2, 29, 33]. Due to the relevance of trout farming in Italy, potential impacts on the natural environments receiving released nutrient and organic matter are remarkable. Since there is a vast literature and generally a good agreement between studies related to nutrient balances in different fish farms, future studies should address the effects of nutrients and labile organic matter like that produced in fish farms on macroinvertebrates, primary producers, and food webs in running waters.

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