Research Article

Evaluation of small-scale trout farming impact on water quality in Santa Catarina State, Brazil

Everton Skoronski, André Fernando Nascimento Gonçalves, Erick William Hessa Melim
Arthur Rodrigues de Aguiar, Karoliny Libardo, Wikeff Fritzke & Thiago El Hadi Perez Fabregat
Universidade do Estado de Santa Catarina, Lages, Brazil
Corresponding author: Everton Skoronski (everton.skoronski@udesc.br)

ABSTRACT. This study evaluated the environmental impact on water quality in a small-scale trout farming facility. The parameters measured were pH, dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), color, turbidity, biochemical oxygen demand (BDO_5), ammonia nitrogen ($N-NH_4$), nitrate ($N-NO_3$), nitrite ($N-NO_2$), and thermotolerant coliforms. The quality of the water after being used by the farming facility did not exceed the values measured upstream. The physical, chemical and microbiological analyses of the water showed that trout activities do not significantly affect the water quality when compared with the upstream and downstream sampling points of the fish farm. Results showed that the water load used on the trout farm was 148 $m^3 kg^{-1}$, similar to values observed worldwide. The flow rate used by the trout farm, along with a conventional decantation system, were responsible for maintaining the water quality. In general, the results indicate that small trout farming facilities can be attractive from an economic point of view, with low environmental impact.

Keywords: trout farming, stream flow rate, water quality, sustainability, environmental impact.

INTRODUCTION

In Brazil, the tropical climate restricts trout production to mountainous regions. In particular, Santa Catarina State is located in the south of the country and has a suitable climate and mountains that enable rainbow trout (*Oncorhynchus mykiss*) production. Trout farming in Brazil is often carried out by small family producers, which account for a total harvest of more than 100 t per year (Amaral, 2007).

The potential environmental impacts from fish farming are of increasing concern. The more problematic impacts are observed in the effluent, which increases suspended solids and dissolved nutrients, and reduces dissolved oxygen concentrations in receiving water bodies (Dalsgaard & Pedersen, 2011). Enrichment from phosphorus and nitrogen are also of concern due to the stimulated growth of phytoplankton (Wong & Piedrahita, 2003). In addition to the effluents from natural processes such as feces, unconsumed feed, and nutrient enrichment, fish farming also applies chemicals for disinfection, pest control, and treatment of diseases (Buenaventura *et al*., 1997; Good *et al*., 2009; Azevedo *et al*., 2011).

The concept of sustainable aquaculture has recently been introduced in light of environmental impacts from fish farming. Sustainable aquaculture is considered as the profitable production of aquatic organisms while maintaining an enduring harmonious interaction with local ecosystems and communities (Valenti, 2000; Valenti *et al*., 2011). Sustainability in trout farming has been the subject of several research projects at the international level (Roque *et al*., 2009; Azevedo *et al*., 2011; Davidson *et al*., 2013; Chen *et al*., 2015; Colson *et al*., 2015).

Trout farming has been suggested to have a negative impact on water quality (Buenaventura *et al*., 1997; Stewart *et al*., 2006; Good *et al*., 2009; Azevedo *et al*., 2011; Dalsgaard & Pedersen, 2011; Chen *et al*., 2015). However, small-scale trout farming still needs further evaluation to elaborate a feasible management plan that also favors the sustainable production from the environmental perspective. Therefore, the present study evaluated the impact of a small-scale trout facility in Santa Catarina State (Brazil) on the water quality.

MATERIALS AND METHODS

Characteristics of the studied hatchery

The water quality was monitored at a farm capable of producing 36 t of trout per cycle, located in Santa Catarina, Brazil. The productivity of the hatchery was 38.05 kg m^{-3} obtained from cycles of 10 months. The facility is allocated in a total area of 2 ha and holds 22 grow-out tanks for trout production (21 rectangular tanks and a larger tank divided into smaller subsections) (Fig. 1). The supply channel is 170 m long. The total culture area is 946 m². In addition to the tanks, there is a sedimentation pond of 200 m² to treat wastewater. The culture water is wholly renovated each hour (average hydraulic retention time in the system). The tanks are arranged in three arrays in which the water is reused three times among the tanks of each array.

Fingerlings were stocked at a density of 95.1 ind m^{-3}. The fish received a commercial feed for carnivorous fish (Nicoluzzi Rações, Brazil) with 45% crude protein and 14% fat. During the first month, the juveniles were fed six times daily at 10% of the body weight. In the next phase, the fish received feed twice daily at 3% of the body weight. The pellet size increased according to the fish growth, in which the feed was milled for the fingerlings and pelleted at 1 cm in diameter for larger fish. The average feed conversion was 1.54 kg of feed kg^{-1} of fish produced. The mortality rate was approximately 10%. The fish were classified and re-stocked among the tanks monthly. Fish were harvested with a weight of 400 g and sent to a processing plant.

Evaluation of water quality

The experimental design consisted of five sampling points to assess the water quality: raw water upstream from the farm (P0); output from the trout rearing tanks (P1); output from the sedimentation pond (wastewater) (P2); river (mixing zone), 15 m downstream from the release (P3) and, 30 m downstream from the release (P4). Water quality was evaluated based on pH, dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), color, turbidity, biochemical oxygen demand (BOD$_5$), ammonia nitrogen (NH$_4$), nitrate (NO$_3$), nitrites (NO$_2$), total dissolved phosphorus (P), and thermotolerant coliforms (TC).

Water samples were taken seven times over an experimental period of twelve months. The analyses were carried out as described in Standard Methods for the Examination of Water and Wastewater (Eaton, 2005). The dissolved oxygen analyses, total dissolved solids, and pH were carried out using a multi-parameter probe (YSI, United States of America). The samples of nitrogen compounds, ammonia, nitrite, and nitrate,

were analyzed using colorimetric methods, after filtration through a membrane of 0.45 µm. The detection limits of these methods were 0.02, 0.005 and, 0.01 mg L^{-1}, respectively. The analyses of color, turbidity and suspended solids were determined by spectrophotometry using a photometer Spectroquant Pharo 300 (Merck Germany). The biochemical oxygen demand was determined by respirometry in an OxiTop system (WTW, Germany). The thermotolerant coliforms were identified and measured using membrane filtration and subsequent incubation at 44.5°C in water mFC medium, and rosolic acid as an indicator.

Measuring the stream flow rate

For the hydrometric analyses, the stream flow rate upstream from the diversion point and the flow rate of the water diverted to supply the facility was measured. The measurements were carried out using the Ford method by applying a propeller flow meter (OTT/ Hydromet C31). This method considered the data from the velocity profile obtained in the measurement channel, which determined the stream flow rate. The average velocity was measured (60% beneath the water surface) following the guidelines described by the manufacturer.

Statistical analyses

The analyses were performed with the software SAS 9.0. The normality and homoscedasticity were verified before all of the statistical analyses. The analysis of variance (ANOVA) was then carried out ($P < 0.05$).

RESULTS

The means of the different water quality parameters did not differ between the different sampling points (Tables 1-3). The results show that the temperature mean was 12°C for all of the sampling periods (Table 1). This condition plays an important role on the dissolved oxygen, which was above 8.66 mg L^{-1} in all samples (Table 2). The low biochemical oxygen demand of less than 1.25 mg L^{-1} also influenced the dissolved oxygen, which was adequate for trout farming (Table 3).

The total suspended solids, turbidity and color showed values less than 4.88 mg L^{-1}, 3.75 NTU, and 11.77 CU, respectively (Table 1). These values are comparable to drinking water standards (World Health Organization, 2011). Also, ammonium, nitrite, and nitrate were detectable under 1.0 mg L^{-1} (Table 2). Overall, the total dissolved solids were not more than 20.56 mg L^{-1} (Table 1). The pH was from 7.11 to 7.17 and showed a slight difference between the samples with a coefficient of variation of 2.95% (Table 2). The fecal coliform reached an average of 7.8 UFC/100 mL,
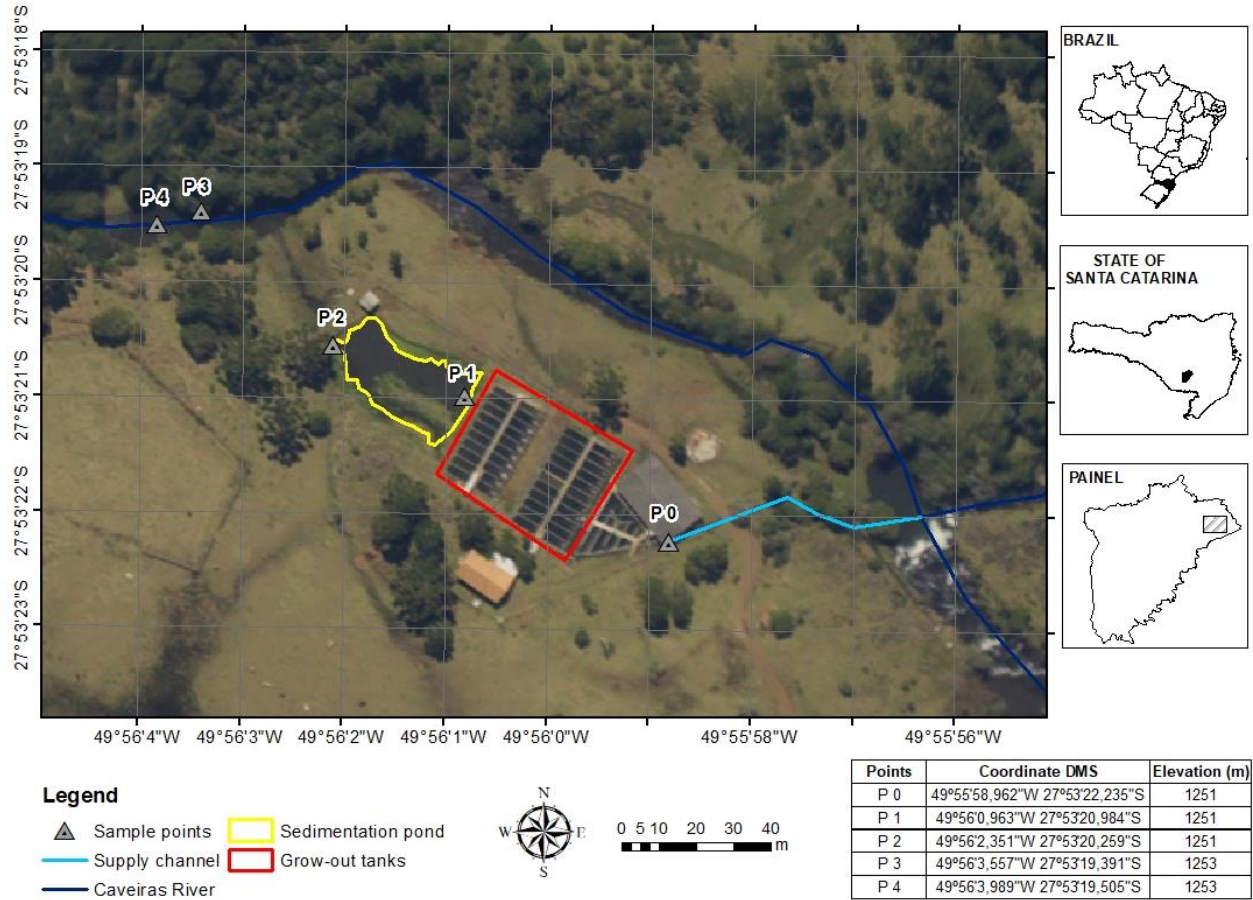
Figure 1. Schematic diagram of the hatchery facility.

Table 1. Physical parameters of the water (mean ± SD) from trout farming in the hatchery (n = 7). TDS: total dissolved solids, TSS: total suspended solids.

	Temperature (°C)	Color (CU)	Turbidity (NTU)	TDS (mg L^{-1})	TSS (mg L^{-1})
P0	12.56 ± 1.99	8.35 ± 2.47	2.14 ± 1.21	18.36 ± 1.21	3.33 ± 3.20
P1	12.66 ± 2.01	11.36 ± 3.97	3.63 ± 1.85	20.22 ± 1.32	5.33 ± 3.37
P2	12.71 ± 1.97	10.69 ± 3.04	3.29 ± 1.38	20.56 ± 0.77	4.29 ± 0.95
P3	12.76 ± 2.01	11.77 ± 5.54	3.75 ± 1.83	17.99 ± 2.02	4.88 ± 1.64
P4	12.76 ± 1.92	10.73 ± 4.09	2.38 ± 1.06	17.03 ± 1.39	4.63 ± 2.72
CV%	14.69	51.94	53.22	11.66	52.46

and in some cases, no fecal coliforms were detected (Table 3).

The data shown in Table 4 are the stream flow rates of the river immediately upstream of the diversion point for the hatchery, the stream flow rates of the water diverted for the hatchery, and the percentage of the water diverted from the river to the hatchery.

The streamflow of the river showed high variation during the measurements, with flow rates ranging from 269 to 1385 L s^{-1}. In other words, the stream flow increased 5.15-fold during the study. Despite the discharge in the river, the water diverted to the hatchery showed a smaller variation and the values were between 174 and 236 L s^{-1}.

DISCUSSION

The water quality in rivers depends on a series of parameters that involve analytical measures of physical-chemical and microbiological nature. The pre-

Table 2. Values of the pH, dissolved oxygen (DO), ammonia, nitrite, and nitrate (mean ± SD) of the different points at the hatchery (n = 7).

	pH	DO (mg L^{-1})	Ammonia (mgNH$_4$ L^{-1})	Nitrite (mg NO$_2$ L^{-1})	Nitrate (mg NO$_3$ L^{-1})
P0	7.12 ± 0.28	9.28 ± 0.31	0.05 ± 0.09	0.08 ± 0.05	0.39 ± 0.45
P1	7.12 ± 0.25	8.66 ± 0.63	0.05 ± 0.10	0.09 ± 0.05	0.46 ± 0.44
P2	7.11 ± 0.19	8.93 ± 0.56	0.09 ± 0.10	0.09 ± 0.05	0.43 ± 0.43
P3	7.12 ± 0.14	9.18 ± 0.41	0.10 ± 0.08	0.11 ± 0.06	0.43 ± 0.37
P4	7.17 ± 0.09	9.22 ± 0.28	0.07 ± 0.11	0.09 ± 0.05	0.34 ± 0.29
CV%	2.95	5.64	130.83	50.59	88.96

Table 3. Values of the BOD, and fecal coliforms (mean ± SD) of the different sampling points at the trout farm in Painel-SC (n = 7). P0: raw water upstream from the farm, P1: output from the trout rearing tanks, P2: output from the sedimentation pond (wastewater), P3: river (mixing zone), 15 m downstream from the release and P4, 30 m downstream from the release. No significant difference was shown between the different sampling points (*P* > 0.05).

	BOD (mg L^{-1})	Fecal coliforms (CFU 100 mL^{-1})
P0	0.86 ± 0.90	5.00 ± 11.18
P1	0.50 ± 0.84	7.80 ± 13.29
P2	0.33 ± 0.82	6.80 ± 11.45
P3	1.00 ± 1.10	6.20 ± 7.92
P4	1.25 ± 1.04	7.00 ± 8.46
CV%	31.61	30.94

Table 4. Data of the stream flow rates of the river upstream from the diversion point and the stream flow rates used on the hatchery.

	Streamflow (L s^{-1})	
	Water diverted to the hatchery	River upstream from the diversion point
Minimum	174	269
Mean	199	649
Maximum	236	1385

One of the main water quality parameters evaluated for trout farming is the suspended compounds derived from uneaten feed and feces (Maillard *et al*., 2005; Stewart *et al*., 2006). In the present study, the color, turbidity, TDS, and TSS in the mixing zone were similar to water sampled upstream from the hatchery, demonstrating that the use of feeds and the release of fish waste metabolites do not significantly change the number of suspended solids in the water.

An increase in turbidity directly interferes in aquatic environments by impeding the penetration of light into the water. As a result, primary production is reduced, which ultimately alters the other links of the aquatic food chain. According to Lloyd (1987), an increase of 5 NTU in the turbidity of a lake may decrease the production volume by 80% while in rivers and clear water streams, turbidity must not exceed 25 NTU to protect the ecosystem. Results obtained in the present study demonstrate lower levels of turbidity, suggesting that trout farming not cause deleterious effects to the ecosystem from turbidity, considering the low number of fish produced by this hatchery. Consequently, the alterations on the water quality by the effluents depend on the size and technology used in the hatchery.

The TSS values observed in the present study conform to recommendations for trout farming, which range from 1-97 mg L^{-1} according to Stewart *et al*. (2006). Furthermore, considering the reference values

sent study analyzed the main substances found in wastewater released into the environment from trout farming according to Heinen *et al*. (1996) and Maillard *et al*. (2005), but no differences in the water qualities were shown between the sampling points. These results indicate that small-scale trout farming contributed no significant impact on the river water quality. Previous studies also found no significant changes in water quality (Maillard *et al*., 2005), but evidence suggested that the management conditions can affect the evaluated parameters (Stewart *et al*., 2006).

The temperature limit to produce rainbow trout is 0 to 25°C, with the recommended range being between 10 and 20°C for intensive productions (Tabata & Portz, 2004). According to Boyd & Tucker (1998), the optimal range is 5 to 20°C. The best growth rates and feed conversions are observed around 15 and 17°C (Logan & Johnston, 1992). Adequate growth rates are observed between 10 and 16°C (Boyd & Tucker, 1998), similar to the temperature range recorded in the present study.

for color, it is possible to attain a value of 15 CU in conventional treatment plants when the raw water shows color below 75 CU (USEPA, 1986). The 15 CU is comparable to drinking water (World Health Organization, 2011). Thus, water from trout farming can be used for other applications, since the average color value observed in the river downstream of the hatchery was 11.77 CU.

In trout production, the stream flow rate should be calculated based on drought periods, and the dissolved oxygen level based on the critical limit of 5.0 mg L^{-1} (Colt & Tomasso, 2001). The present study recorded levels of dissolved oxygen above 8.10 mg L^{-1}, which is higher than the minimum concentration of 6.0 mg L^{-1} recommended for natural waters USEPA, 1986). In addition to ensuring adequate dissolved oxygen for the trout, the dissolved oxygen in the river should be measured to ensure the use of water for other purposes in the surrounding watershed basin. Therefore, the BOD was also evaluated in the water from the various collection points. The values observed in the present study were below 1.25 mg L^{-1}, which is above the adequate concentration of 1 mg L^{-1} for conserved rivers (Sawyer *et al*., 2003). Thus, a degree of concordance between the values of DO and BOD exists. In another word, if the BOD in the wastewater were to present higher values, an oxygen demand may exist in the water to stabilize organic matter, which could affect the availability of oxygen in the water and consequently affect the aquatic ecosystem downstream from the release of wastewater.

For the nitrogenous compounds, the value of the total ammonia was below 0.10 mg L^{-1}. Ammonia is toxic in its non-ionized form, which is found in equilibrium with its ionized form depending on the temperature and pH of the water. For the preservation of aquatic species in natural waters, the highest value recommended is 2.2 mg L^{-1} for the total ammonia depending on the temperature and pH observed in the samples (USEPA, 2013). Nitrite and nitrate did not exceed 0.11 and 0.45 mgN L^{-1}, respectively. MacIntyre *et al*. (2008) described the lethal concentration of nitrite as ranging from 0.19 to 12.6 mgN L^{-1} with 96 h of exposure for the rainbow trout. In most trout farms, the increase of nitrite is not a problem due to the types of facilities used for production. The main source of elevated nitrite concentrations is often of anthropogenic origin from outside of the hatchery (Wedemeyer, 1996).

Adult salmonids are relatively unaffected by nitrate when compared to the initial stages of the species (McGurk *et al*., 2006). The effect of nitrate on rainbow trout has been studied, yet little information is available on the chronic toxicity. Rainbow trout fingerlings

should not be exposed to chronic levels of nitrate above 57 mg L^{-1}. However, levels of only 5.7 mg L^{-1} can influence the health and growth of this species (Westin, 1974). Rainbow trout juveniles are unaffected with chronic exposure at levels below 75 mgN L^{-1} (Davidson *et al*., 2014). For natural waters, the recommended values are 10 and 1 mgN L^{-1} for nitrate and nitrite, respectively, to avoid human toxicity (World Health Organization, 2011). These values are consistent with those required to ensure the quality of drinking water. Conventional water treatment plants do not remove nitrate and nitrite due to being water-soluble, requiring the control to occur in natural springs.

From a microbiological standpoint, the presence of thermotolerant coliforms did not differ between the different points. The maximum value observed was 8.0 CFU 100 mL^{-1}, which is considered low value. Thus, the water quality was not changed in relation to the thermotolerant coliforms, which does not prohibit the use of the water for other applications. As a reference, the maximum concentration recommended for recreational activities is 126 CFU 100 mL^{-1}. For more restrictive uses such as the culture of mollusks, the limit becomes reduced to 15 CFU 100 mL^{-1} (USEPA 1986). The amount of thermotolerant coliforms in waters destined for aquaculture and the fishing industry (class 2) should not exceed 1,000 NMP 100 mL^{-1} of water (Mara & Cairncross, 1989) as the microbiological composition of the cultivation water is reflected in the variety of bacteria present in the different marketed fish cuts (El-Shafai *et al*., 2004). The number of coliforms found in the present study was extremely low when compared with the limits of the Brazilian resolution.

The water consumed by the hatchery was on average 148 m^3 kg^{-1} of fish. This value is consistent with previous studies such as Maillard *et al*. (2005), which studied a hatchery that demanded approximately 105 m^3 kg^{-1} of fish. Chen *et al*. (2015) evaluated the environmental impact from 24 properties in France and verified that water use varied between 117-196 m^3 kg^{-1} of fish in function of the desired weight of the fish. Roque *et al*. (2009) evaluated properties with water demands of 52 to 173 m^3 kg^{-1} of fish. Thus, the water used by the farm in the present study is considered sufficient for this activity. Therefore, the quantity of water used in the hatchery must not be reduced, raising the discussion on the criteria to allocate water for this activity.

The concern with the water quality resulted from trout farming has also been previously studied. Buenaventura *et al*. (1997) studied trout production in Portugal in a hatchery with a water demand of approximately 149 m^3 kg^{-1} of fish. The authors observed changes between the water quality upstream

and downstream from the hatchery, but the parameters evaluated were below the maximum environmental limits. Nonetheless, recirculation systems combined with wastewater treatment plants may decrease the water necessary to renovate the system of up to 1 m^3 kg of fish^{-1} without affecting the system productivity (Blancheton *et al.*, 2007; D'Orbcastel *et al.*, 2009).

Wastewaters are treated in the hatchery with a decantation pond of 200 m^2. For the average stream flow rate of the water used in the hatchery, the applied surface hydraulic load is approximately 86 m^3 m^{-2} d^{-1}. The values for the sedimentation tanks used to treat the wastewater vary. Some authors report conservative values such as 14.8 m^3 m^{-2} d^{-1} (Stewart *et al.*, 2006) and 48.9-77.4 m^3 m^{-2} d^{-1} (Maillard, 1998). High application rates in the order of 171-342 m^3 m^{-2} d^{-1} (Idaho Department of Environmental Quality, 1998) and 0.0031 m^3 m^{-2} s^{-1}, equivalent to 268 m^3 m^{-2} d^{-1} (Davidson & Summerfelt, 2005) are also recommended. Thus, the sedimentation tank involved in the present study demonstrates an intermediate operational value when compared to published values.

Furthermore, Stewart *et al.* (2006) estimated a minimum sedimentation rate of 0.2 m s^{-1} for suspended particles (sludge) in effluent waters from trout farming. A basic theory of designing sedimentation tanks describes that the surface hydraulic load should be numerically equal to the sedimentation rate of the suspended particles when they are not considered coefficients of security in the project (Metcalf & Eddy, 2013). Thus, the recommended value for the surface hydraulic load is 173 m^3 m^{-2} d^{-1} (equivalent to the sedimentation rate of 0.2 m s^{-1}). Despite this principle, the sedimentation tank of the hatchery in the present study shows about twice the area required for sedimentation. The concentration of suspended solids decreased on average from 5.33 to 4.29 mg L^{-1}. Turbidity was also reduced from 3.63 to 3.29 NTU. This reduction in the suspended solids, of which are effectively removed with decantation, is verified by the accumulation of sludge. Thus, the decantation pond effectively participates in the treatment and maintenance of the quality of the water used in the hatchery.

CONCLUSIONS

The present study demonstrated that trout farming has no significant impact on the quality of the water supplied by the river. Furthermore, the water quality enhances the practice of trout farming in this region. The stream flow rate applied combined with the conventional decantation system ensure the maintenance of the water quality in the hatchery by diluting and removing suspended solids, respectively. Therefore,

despite the activity often being carried out in a basic manner, the systems are highly productive and can be very profitable with low environmental impact.

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