Current Status of Rainbow Trout, *Oncorhynchus mykiss* (Walbaum, 1792), Fisheries in Munnar Hills of South India

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Abstract

Rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792), is a popular cold-water fish species widely distributed and farmed across the globe. In India, rainbow trout fisheries are common in the Himalayan states and the Western Ghats of South India. The introduction of brown trout, *Salmo trutta fario* (Linnaeus, 1758), in Munnar, Kerala, India, dates back to 1909. As the farming of brown trout was not successful, rainbow trout were introduced in 1932. However, no data regarding trout fisheries post-1970 are available. Hence, this study aimed to assess the current scenario of *O. mykiss* fisheries by analysing the existing angling and production records and interviewing the officials in charge. The results showed that *O. mykiss* fisheries in Munnar are currently endangered, and only a few numbers of *O. mykiss* stock are found in Rajamallay Stream, which is the present stocking site. Studies have shown that destructive fishing, pollution, siltation, and animal intrusion contributed to the decline of trout stocks in this region. Proper conservative measures, good hatchery conditions, adequate broodstock management, feed improvement, and regular seed stocking can improve the production of *O. mykiss* in Munnar.

Keywords: CPUE, *Salmo trutta fario*, conservation, Western Ghats, trout introduction

Introduction

Rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792), is found in a few hilly regions such as Ooty, Kodaikanal, and Munnar of the Western Ghats of South India. The habitats of *O. mykiss* in Munnar are found in high-altitude areas at 6475 feet above mean sea level near the Anamudi Peak, the highest of South India situated 8842 feet above mean sea level (10°10′09″N 77°03′38″E). Water quality parameters, suitable spawning grounds and water temperatures between 5 ºC and 20 ºC (Behnke and Tomelleri, 2002) are significant criteria to rear trout. As *O. mykiss* can adapt to different habitats, such as rearing systems, reservoirs and natural waters, they were introduced in other parts of the world such as eastern Asia, western North America, and central and western Europe for aquaculture purposes (MacCrimmon, 1971).

Francis Day first introduced trout to India in 1863 in Ooty, Tamil Nadu (Day, 1873; Sehgal, 1999), and other cold-water regions of North and South India. *Oncorhynchus mykiss* plays an important role in sports and recreational fishing in India. These fish are reared in Indian uplands, and they significantly contribute to the revenue and economy of people living in these regions. They are also considered a rich source of polyunsaturated fatty acids, accounting for 25 % of the total fatty acids (Sheeshka and Murkin, 2002). As polyunsaturated fatty acids such as linoleic acid (C18: 2n-6), docosahexaenoic acid (DHA; C22: 6n-3), arachidonic acid (AA; C20: 4n-6), and eicosapentaenoic acid (EPA; C20: 5n-3) are acquired only from diet and cannot be synthesised by humans (Alasalvar et al., 2002; Sarma et al., 2018), these trout fish are considered an important part of a healthy diet.

Trout fisheries in India have become economically significant, especially in the Himalayan regions, and

are widely known for producing table-sized trout in high demand. The fisheries department of the Jammu and Kashmir government has achieved remarkable success by importing and exporting quality trout, eyed ova, and trout seeds. Currently, there are 59 trout rearing units in various districts of Jammu and Kashmir (http://jkfisheries.in). Further, there are seven trout farms in Himachal Pradesh and they significantly contribute to the economic development of this state (Sharma, 2019). Quality seeds from the trout farms of Himachal Pradesh are supplied to other north-eastern states such as Sikkim that has currently 349 trout raceway units (Sharma et al., 2018). Trout farming has also flourished in the State of Arunachal Pradesh, with hatcheries being established in Tawang and Shergaon regions, and is thriving in the upland streams of Nuranang and Choskorong Kho rivers and Siyom River (locally known as Yargyap Chu), which serves as a suitable habitat of *Salmo trutta fario* (Linnaeus, 1758) and *O. mykiss*. Adaptation of trout in this part of the north-eastern state provides an excellent opportunity for game fishing and trout culture (Baruah et al., 2017).

Thus, trout fisheries (farming and angling) have flourished in the Himalayan regions of North India and are economically viable. However, although *O. mykiss* stocks are available in the high ranges of Rajamallay Tea Estate, Munnar; Upper Bhavani reservoir and Avalanche Lake, Ooty; and Gundar Stream, Kodaikanal (Sehgal, 1999; Kuruppan, 1989), the status of trout fisheries in South India is not fully understood. *Salmo trutta fario* was the first trout introduced in 1909 in Munnar by Koechlin, John Charles, Daisy Bell, and George Howlett of the Kanan Devan Hills Plantations (KDHP) Company. This was initially successful, but further maintenance and stocking operations were not possible due to the First World War. In 1932, rainbow trout (*O. mykiss*) was introduced by A.W. John and a hatchery was established in 1941 in the Rajamallay Tea Estate (Mackay, 1945; Sehgal, 1999); however, angling data regarding these fisheries are available only until the 1970s. Therefore, this study aimed to understand the current status of the *O. mykiss* stocks in Munnar, Kerala, India.

Materials and Methods

Data collection

The current status of the *O. mykiss* fisheries in Munnar (Fig. 1) was assessed by analysing the angling and production records from the High Range Angling Association, Munnar, followed by an interview with the officials in charge, who practised angling in Munnar (n = 5). The main purpose of the interview was to record the current status of water bodies other than Rajamallay stream post-1970 and to collect data about hatchery production. The interviewees were sampled based on their knowledge of previous trout fisheries in Munnar High Range. Every interviewee had a compulsory membership of the High Range Angling Association with an angling license. The total time for interviewing every angler was 30–45 min. See Table 1 for the questionnaire.

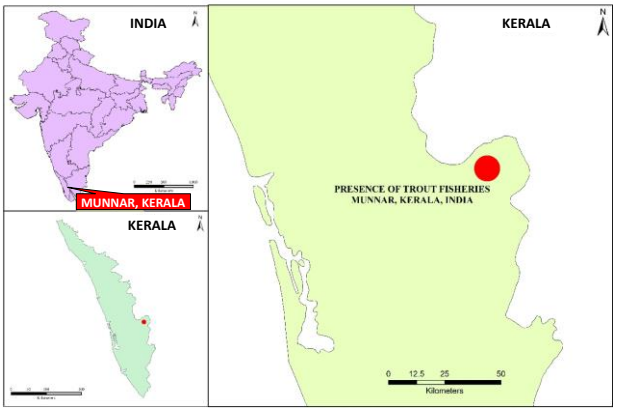

Fig. 1. *Oncorhynchus mykiss* fisheries in Munnar, Kerala, India.

Statistical analysis

Data about angling in Rajamallay Stream (current stocking site) for years 1988–2020 were collected and the following criteria were analysed to explore the status of *O. mykiss* stock: catch per unit effort (CPUE = number of fish caught in each year/total number of angling visits done each year), total number of catches per year (number of fish caught in each year), individual catch (a single fish caught by a single angler each year) and length and weight of a fish and catch hauls (two or more fish caught by a single angler each year) and the total weight of the fish. Significant differences in the length and weight of fish of individual catches were analysed using ANOVA. Statistical analyses were done using GraphPad Prism, version 6.

Results

Information obtained on interviewing the management officials (Post-1970)

Oncorhynchus mykiss stock

The data obtained from the officials showed that healthy *O. mykiss* stocks were found in water bodies, namely, Kaniamallay, Lakkam, Chokanad, and Eravikulam streams; Devikulam and Letchmi lakes; and Madupatty and Kundale reservoirs. However, after 1970, the fish stocks disappeared from all the sites due to illegal fishing, pollution, siltation, and animal intrusion. But a few catch were recorded before the stocks disappeared completely. Currently, only the Rajamallay Stream is considered safe for *O. mykiss* species for stocking and angling.

Hatchery production

Currently, Rajamallay hatchery is the only hatchery in operation, and it produces approximately 10,000

Table 1. Questionnaire for the officials of the High Range Angling Association, Munnar.

Q1.	What is the status of the rainbow trout stocks in sites such as Eravikulam, Lakkam and Kaniamallay streams, Letchmi and Devikulam lakes, Madupatty and Kundale reservoirs?
Q2.	Name the sites where rainbow trout are presently stocked?
Q3.	What are the reasons behind the disappearance of rainbow trout in the sites mentioned in Q1?
Q4.	Will rainbow trout be stocked again in water bodies where trout have disappeared?
Q5.	Are there any possible plans for the restoration of water bodies for reintroduction?
Q6.	Is rainbow trout being sold or commercialised?
Q7.	How productive is the Rajamallay hatchery?
Q8.	Can data with regard to hatchery production be shared?
Q9.	Are fingerlings stocked in other sites besides Rajamallay Stream?

fingerlings per year. Nearly 5000–7000 fingerlings are stocked in the Rajamallay Stream for angling activities. The production of fingerlings was higher during 2013–2014 and lower during 2016–2017, which was 7800 and 1721 fingerlings, respectively. The commercialisation is on a small scale, with table-sized trout (3- to 4-year-old fish weighing 250–500 g) sold at INR800 kg^{-1} (USD10.74 kg^{-1}) to popular hotels and restaurants. Fish are sold by the Munnar Supplies Association, KDHP Company. Fingerlings are also sold for research (to test water quality) and medicinal purposes at INR5 $fingerling^{-1}$ (USD0.067 $fingerling^{-1}$). Fingerlings grown from this hatchery were stocked in other sites like Kaniamallay and Lakkam streams, Devikulam and Letchmi Lakes, and Madupatty and Kundale reservoirs for angling activities; however, fingerlings are no longer stocked in the Kaniamallay and Lakkam streams, and Madupatty and Kundale reservoirs from 2000 and Devikulam and Letchmi Lakes from 2015 onwards. Currently, the hatchery has two circular ponds, five grading tanks, and a spawning pool. As the numbers of broodstock used are insufficient and most of them are immature, there was a reduction in the fingerling production from 2014 onward.

Data on Rajamallay Stream (Post-1970)

The Rajamallay Stream, also known as "Gravel Banks" (10°09'13.1"N 77°00'17.1"E), has been an angling spot since 1941, with fingerlings stocked continuously. The KDHP Company maintains the angling records from 1988 to 2020. The highest and lowest numbers of fish caught in a year were 326 fish with a CPUE of 19.17 in 17 angling visits in 1990 and 8 fish with a CPUE of 8 in 2020 in 1 angling visit, respectively (Figs. 2–4). The highest number of individual catches and the maximum weight of an individual catch were recorded for 2000 – 32 fish and 3 kg, respectively. However, catches with a minimum weight of 0.1 kg were observed for nearly 8 years, i.e., 1991, 1996, 2001, 2009, 2012, 2017, 2019, and 2020. The maximum length of an individual catch recorded was 19 inches in 2013, and the minimum was 5 inches in 2000 and 2006 (Table 2).

A significant difference (ANOVA, $P < 0.0001$, $P < 0.05$; Table 2) was noted for the length and weight of individual catches for all the 33 years recorded. However, a year-wise significant difference was not observed. The highest catch haul was 60 fish (weight not reported), recorded in 1993, and the lowest haul was 2 fish, observed for 24 years with its total weight recorded accordingly (Figs. 5–8). Angling records were available for all months of the years, i.e., from 1998 to 2018, except in 2019 and 2020, it was available for one month (Figs. 2–8; Table 2). Angling data regarding the length and weight of all individual catches and hauls for 1998–2018 were inconsistent (Figs. 5–8; Table 2).

Discussion

Current status of rainbow trout fisheries

The *O. mykiss* fisheries in Munnar are currently endangered, and these trouts are cultured only on a small scale (Singh et al., 2017). These fisheries are under the sole control of the KDHP Company. Only a few *O. mykiss* stocks are now found in the Rajamallay Stream, and stocks from other sites have disappeared. Due to insufficient numbers, immaturity, and poor quality of broodstock, the production of fingerlings from 2014 to 2019 significantly dropped (Fig. 9), and as a result, the process of stocking ceased after 2015. However, the management is currently taking measures to improve trout fisheries. For the past 80 years, *O. mykiss* fisheries in Munnar has been a significant spot for recreational fishing (angling) for many higher officials of the company and visiting guests (members of the High Range Angling Association). Fingerlings were produced not only for angling activities but also for sale purposes.

However, the expansion of *O. mykiss* fisheries can only be done if all sites are restored for stocking, and new hatcheries are established. The KDHP Company protected the fish stocks by allowing only registered members (management officials and company guests) of the angling association access to angling activities.

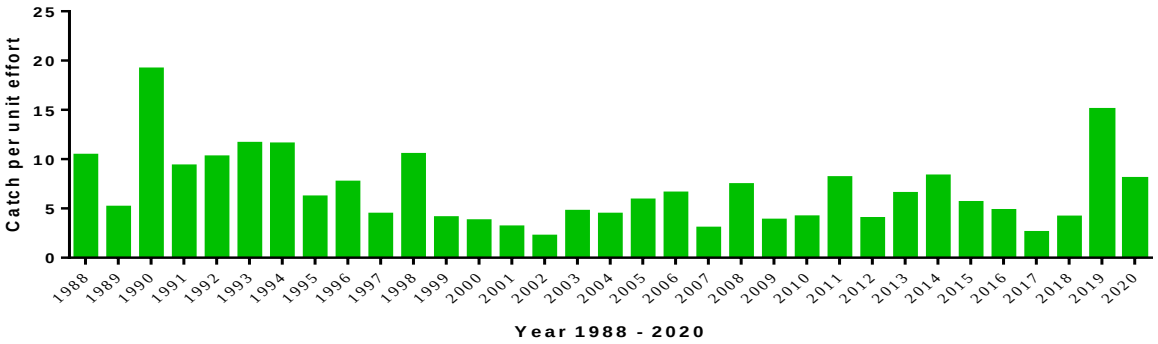

Fig. 2. Catch per unit effort of *Oncorhynchus mykiss* according to the angling records of Rajamallay Stream from 1988 to 2020 (Source: High Range Angling Association, Munnar).

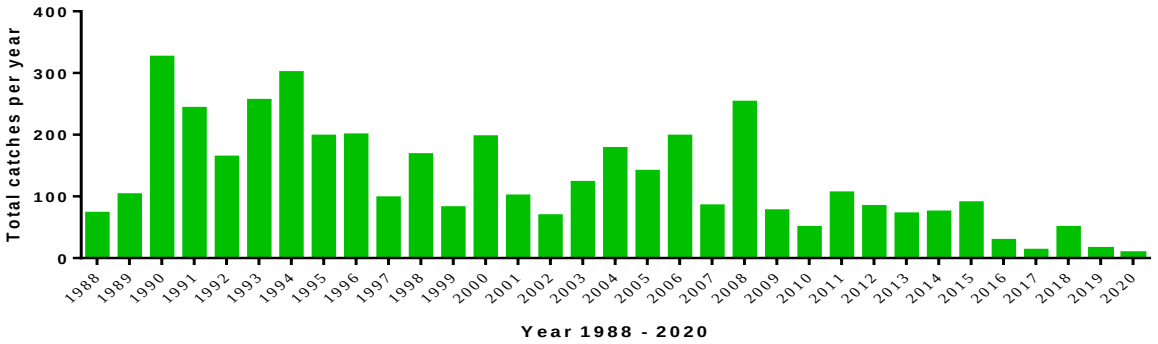

Fig. 3. Total number of catches per year of *Oncorhynchus mykiss* according to the angling records of Rajamallay Stream from 1988 to 2020 (Source: High Range Angling Association, Munnar).

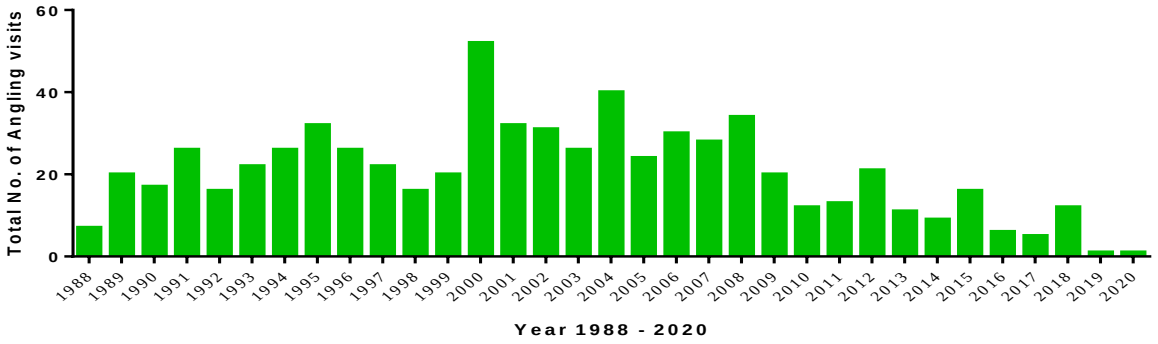

Fig. 4. Total number of angling visits for *Oncorhynchus mykiss* according to the angling records of Rajamallay Stream from 1988 to 2020 (Source: High Range Angling Association, Munnar).

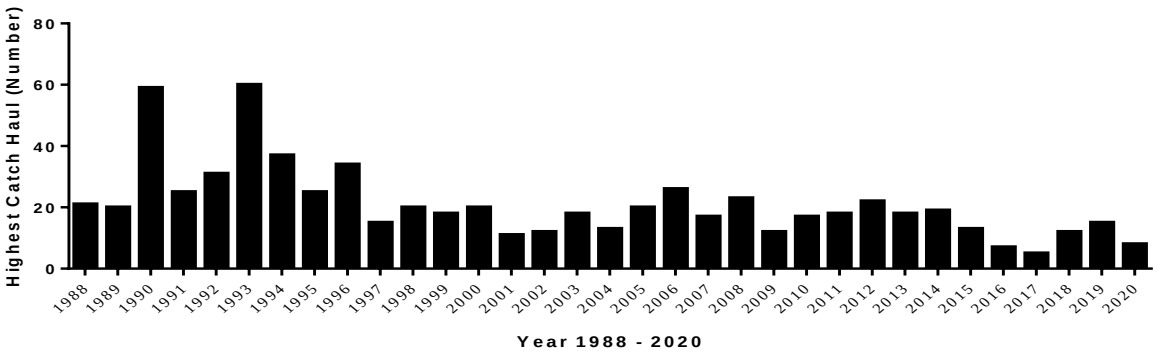

Fig. 5. Year-wise data on highest catch haul of *Oncorhynchus mykiss* according to the angling records of Rajamallay Stream from 1988 to 2020 (Source: High Range Angling Association, Munnar).

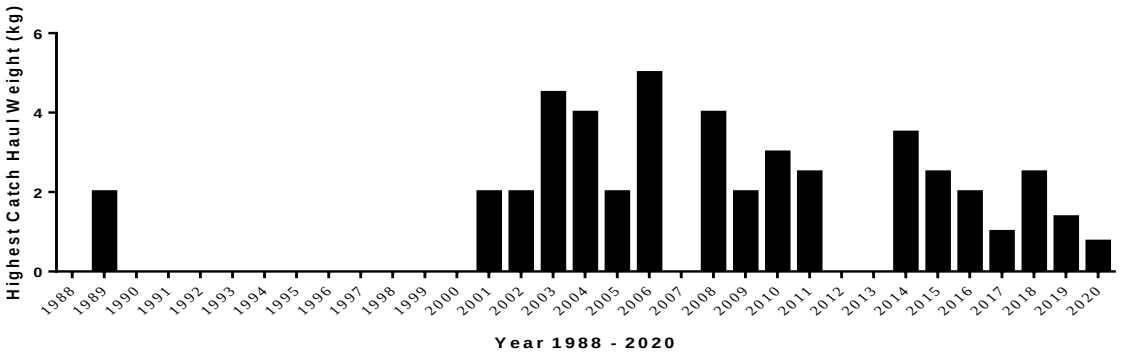

Fig. 6. Total weight of highest catch hauls of *Oncorhynchus mykiss* according to the angling records of Rajamallay Stream from 1988 to 2020 (Source: High Range Angling Association, Munnar). Note: The total weight has not been recorded for all highest catch hauls by the anglers.

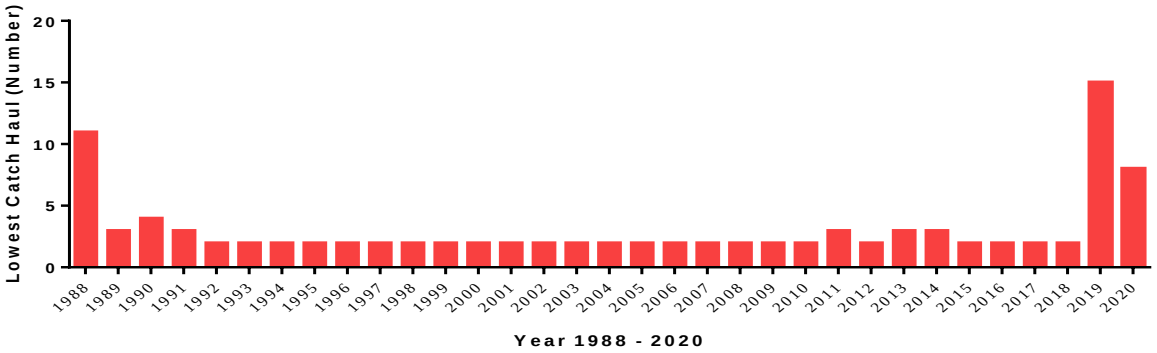

Fig. 7. Year-wise data on lowest catch haul of *Oncorhynchus mykiss* according to the angling records of Rajamallay Stream from 1988 to 2020 (Source: High Range Angling Association, Munnar).

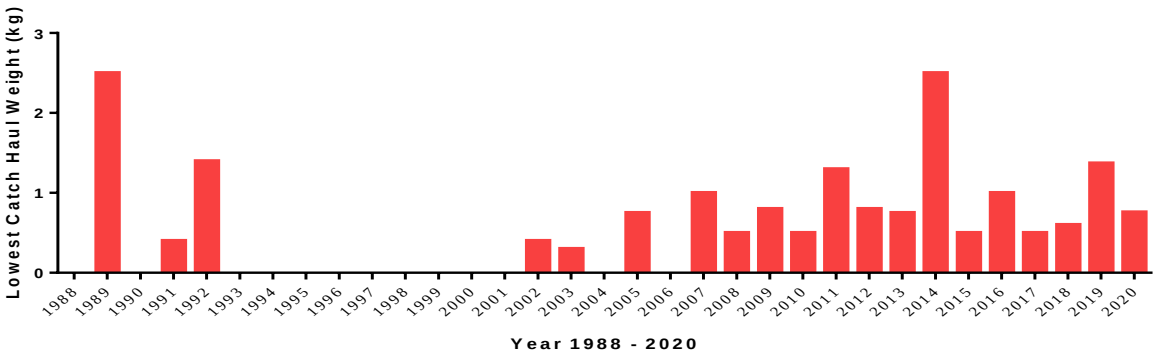

Fig. 8. Total weight of lowest catch hauls of *Oncorhynchus mykiss* according to the angling records of Rajamallay Stream from 1988 to 2020 (Source: High Range Angling Association, Munnar). Note: The anglers did not record the total weight or all the lowest catch hauls.

Any human activity in the stocking/angling site without permission is prohibited. In addition, the company has implemented the "Wild Life (Protection) Act, 1972", an act of the Parliament of India, for the protection of trout fish. It has also initiated severe actions against the company's individuals who were found guilty of illegal fishing.

Rajamallay Stream (Post-1970)

The Rajamallay Stream has been a stocking site since 1941, which had a self-sustaining trout population in the early 1940s (Mackay, 1945). This scenario has drastically changed due to illegal fishing by locals, fishing pressure exerted by anglers and animal intrusion over the years. However, measures were taken in the past years to increase the stocks, but data regarding the annual recovery rate after stocking are unavailable. Unregulated angling activities resulted in high fishing pressure, limiting the probability of spawning. Further, catch rates were influenced by angler's efficiency (Cabanellas-Reboredo et al., 2017), fish behaviour, and catchability (Young and Hayes, 2004).

Table 2. Individual *Oncorhynchus mykiss* catches according to the angling records from Rajamallay Stream, Munnar (1988–2020). (Source: High Range Angling Association, Munnar).

Year	Total no. of individual catches	Length of the individual catches (inches)		Weight of the individual catches (g)	
		Maximum length	Minimum length	Maximum weight	Minimum weight
1989	10	-	-	1.0 kg	0.30
1990	1	-	-	-	-
1991	9	14	9	1.5 kg	0.12
1993	3	-	-	-	-
1994	2	-	-	-	-
1995	10	11	9	0.45	-
1996	8	13	-	0.15	-
1997	4	12	8	-	-
1998	1	11	-	-	-
1999	7	13	8	0.8	0.30
2000	32	14.5	5	3.0 kg	0.20
2001	21	12	9	0.9	0.10
2002	28	12	9	1.5 kg	0.20
2003	17	10	8	0.75	0.20
2004	28	10	7	0.75	0.20
2005	16	15	8	0.4	0.25
2006	22	15	5	1.0 kg	0.20
2007	17	12	9	1.5 kg	0.25
2008	11	12.5	8	1.0 kg	0.20
2009	10	11.5	8	0.4	0.17
2010	6	14	8	0.25	-
2011	7	14	8	0.6	0.30
2012	8	18.5	11	0.72	0.10
2013	9	19	6	0.75	0.20
2014	7	13	7	0.2	0.15
2015	12	17	8	1.5 kg	0.20
2016	6	12	8	0.6	0.40
2017	4	14	8	0.6	0.11
2018	9	13	9	0.5	0.29
2019	15	8.26	6	0.9	0.10
2020	8	9	7.12	0.9	0.10

Data show significant difference in the length ($P < 0.0001$; $P < 0.05$) and weight of individual fish ($P < 0.0001$; $P < 0.05$).
The length and weight data are not available for all individual fish catch.
Catches weighing 1 kg and above are indicated in kg.
(-) unavailable or not recorded.

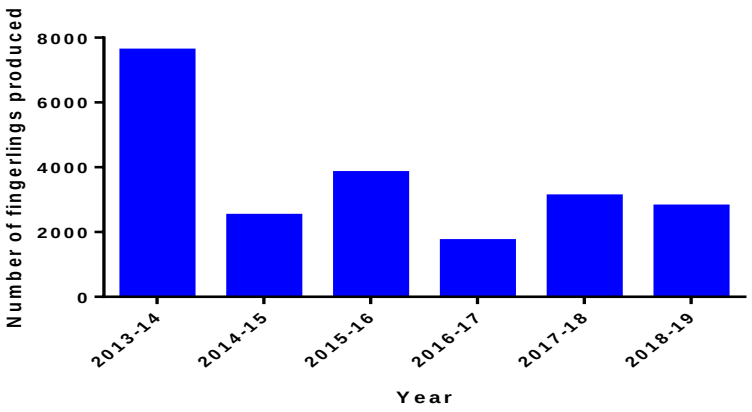

Fig. 9. Production of *Oncorhynchus mykiss* fingerlings from 2013 to 2019 in Rajamallay hatchery (Source: High Range Angling Association, Munnar).

Angling data extracted from the logbooks were highly reliable, especially concerning sites where regular scientific observations were not possible (Sampson, 2011). The records contained promising data regarding relative distribution and the total number of fishing attempts involved in fisheries (McGarvey et al., 2005; Cooper, 2006). Catch and release angling can be an excellent monitoring tool for fish conservation, further encouraging the protection of resources and the ecosystem (Pinder and Raghavan, 2013). Certain catches in the Rajamallay Stream were released, but data on such activities are scarce. Size limits and constant monitoring of angling activity can help the conservation of *O. mykiss* fisheries (Almodóvar and Nicola, 2004).

Stock reduction in Rajamallay Stream (Post-1970)

Generally, excess fingerlings produced in the hatchery were stocked for angling activities. Data on the past angling activities showed that in the 1940s, the catch sizes were bigger (1.81 kg and 2.26 kg), but the size declined from 1.92 kg in 1964–1965 to 110 g in 1968–1969, with no reports post-1970 (Sehgal, 1999). Angling data from 1988 to 2020 showed a steady decline in the total number of catches, the number of angling visits, and CPUE over the years (Figs. 2–4). The salmonid stock in the Rajamallay Stream has been gradually decreasing from 1988, with fluctuations in CPUE, the total number of catches each year, and angling visits. The stocks were under continuous fishing pressure due to regular fishing by licensed anglers. Moreover, most catches below the legal size of below 25 cm were not released, and local villagers and tribes (Muthuvan hill tribe) inhabiting near the stream were involved in illegal fishing. Earlier studies showed that increased fishing pressure and overfishing with illegal gears had decreased the number of catches (Vu et al., 2021).

Furthermore, animal intrusion around the stream was also one of the reasons for the decrease in stocks; for example, wild otter packs (*Lutra* sp.) often visit the study site for their meal because fish is their staple food (Kruuk, 2007). The fact that *O. mykiss* are cannibals can also have an impact on the mortality rates of these fish and population dynamics (Vik et al., 2001). All these criteria led to the reduction of stocks in the Rajamallay Stream in the past 33 years.

Length, weight and number of catches in Rajamallay Stream (Post-1970)

The angling records (1988–2020) on the length and weight of all individual catches showed a significant difference. There were variations in length and maturation of fish, which significantly affected the weight of all individual catches in terms of time shifts in catch-size spectra (Table 2; Ngor et al., 2018). There were no significant year-wise differences in the length and weight of the fish as there were no consistent data (Table 2). However, there was a gradual inconsistent decrease in the length and weight of individual catches in the past 33 years. This might be due to unprecedented fishing. A decline in fish length also impacted the total biomass of the catch (Audzijonyte et al., 2013; Vu et al., 2021). There was no data regarding a trophy-sized fish (22 inches) in the stream. However, data for the past 23 years showed that 12-inches fish were caught in maximum fishing efforts (Table 2). This indicates that the environment seemed conducive to fish growth despite fishing pressure.

Catch hauls during the study period increased the fishing efforts; this indicates that the stock number can be maintained if the fishing pressure is stable (Baer et al., 2007). The number of hauls taken each year corresponds to the fishing pressure by an angler. Data about the highest and lowest numbers of hauls taken each year in terms of weight were inconsistent; however, the data showed that a minimum number of hauls (2 fish) was taken during the study period (Figs. 5–8). This proved that anglers made a continuous effort to adhere to the minimum annual catch limit strictly. Angling data also showed minimum number of catch hauls for all 12 months of a year. The maintenance of stock in the natural environment of the Rajamallay Stream mainly depends on food availability, water and stocking conditions, and angling impacts. In summary, the self-sustaining capacity of *O. mykiss* stock in the Rajamallay Stream has decreased and is vulnerable to regional extinction. Therefore, proper conservative measures must be taken to support the stock in the long run.

Current status of trout fisheries in other water bodies of Munnar (Post-1970)

Devikulam Lake

Various factors contributed to the disappearance of *O. mykiss* stocks from different sites of Munnar. Data showed a reduction in trout numbers in Devikulam Lake due to the presence of common carp, *Cyprinus carpio* Linnaeus, 1758. These carps are invasive and dominant, and their territorial expansion can degrade water quality, cause turbidity, and reduce macrophytes. Previous studies have proved that the Devikulam Lake was turbid and lacked macrophytes in the littoral zone (Sehgal, 1999). In the absence of natural predators or commercial fishing, these carp populations can alter the aquatic environment due to their rapid reproductive rate (carps spawn twice a year).

Furthermore, these carps feed on bottom sediments and destroy and consume submerged vegetation such as macrophytes. Macrophytes are aquatic plants that aid in the removal of minerals from sediments, fight pollution, and help in water conservation, thereby sheltering other fish populations like the *O. mykiss*

(Devaa and Ramesh, 2021). These carps also decimate invertebrate density, suitable food for *O. mykiss*, in the benthic zone (Matsuzaki et al., 2007; Kulhanek et al., 2011) and thus decrease the heterogeneity of the habitat (Perrow et al., 1999). This further depletes the number of *O. mykiss*, which depends on the biomass of the carps. Besides all these factors, illegal fishing has also taken a toll on the trout stock in Devikulam Lake.

Conservation of *O. mykiss* is essential and can be done by implementing catchment management practices that can reduce the number and growth of carps and cut down their nutrient process (Weber et al., 2010). In addition, the presence of water reeds in the Devikulam Lake has also negatively impacted the *O. mykiss* stock. These tall reeds cause waterlogging (Al Masud et al., 2014), release ammonia on decaying (Sparacino-Watkins et al., 2014; Devaa and Ramesh, 2021) have become a spawning place for the carps and thus alter the water quality index. The reeds are considered unsuitable for trout life as decayed plants consume oxygen and release unpleasant sulphurous odours. Earlier studies have suggested cutting and burning reeds (Mackay, 1945) for trout conservation. Other problems such as siltation have also been reported, which can be reduced by constructing silt traps and reed beds on inflows (Giles et al., 2004). Silt covers the spawning beds by filling the space between the gravels, which reduces the food supply. This causes respiratory problems resulting in fish kill (Merrington et al., 2002). However, rarely, one or two *O. mykiss* catches were recorded.

Post-1970 data on trout catches from the Devikulam Lake showed that trout weighing 500–750 g (measuring 24 cm) were caught in 2000. The largest catch (fish weight 1.7 kg; length 48 cm) was recorded in 2011, followed by another catch (fish weight 1.1 kg; length 63 cm). However, the last catch (length and weight unknown) was in 2014, after which no catches were recorded (Devaa and Ramesh, 2021). Plans to restore Devikulam Lake are in the initial stages.

Letchmi Lake and Kaniamallay Stream

Letchmi Lake also encountered similar problems as seen in Devikulam Lake. Water quality issues and the presence of many otters drastically reduced the number of trout. In Letchmi Lake, post-1970, a haul of five to six fish was recorded in a year. The last catch (a maximum length of 10–12 cm) was reported in 2010, after which no catches were recorded. The data on the Letchmi Lake showed that from 1970 to 2010, only 100 fish were caught. Studies showed that cattle grazing, animal wastes, and human activities like washing/cleaning have significantly reduced *O. mykiss* stocks in Kaniamallay Stream (Devaa and Ramesh, 2021).

Further, water quality deteriorations due to increased ammonia levels from tea wastes derived from nearby tea factories (Devaa and Ramesh, 2021) and destructive and unprecedented fishing by the local hill communities also reduced the number of stocks. According to the data on Kaniamallay Stream, post-1970, a catch (fish weighing 1.36 kg) was recorded in 1971 and several good catches (size and number unknown) were recorded in the 1980s, after which no catches were reported (Devaa and Ramesh, 2021).

Madupatty and Kundale reservoirs

Analysis of data on Madupatty and Kundale reservoirs showed that these reservoirs currently contain no *O. mykiss* stocks. The reduction and disappearance of trout stocks in these areas might be correlated to several factors. Studies have shown that predation pressure of common carp and catfish, *Ictalurus punctatus* (Rafinesque, 1818) was the reason for the decline in the number of rainbow trout (Devaa and Ramesh, 2021). Further, human activities such as intense destructive fishing also diminished the number of salmonids (Boulêtreau et al., 2018). It has been shown that a predator (Johnsson, 1993) subjects the habitat in which it is present to predation risk that affects the growth of other fish species (Haddix and Budy, 2005). Earlier studies have shown a higher number of catfish population downstream of the dam (Baumgartner, 2007; Agostinho et al., 2012; Schmitt et al., 2017) and other reservoir regions increased the predator pressure.

Studies have also shown that water quality deteriorations by ammonia, nitrite and nitrate derived from touristic activities (horse and elephant riding), constant animal excretory runoff from horse and elephant riding, food litters (waste), runoffs caused by soil erosion, dead plant matters by deforestation (by releasing toxins into water), and intense destructive fishing (use of night lines, nets, and bamboo sticks) by local communities all have drastically decreased the *O. mykiss* stocks from these reservoirs. According to the data on the Madupatty Reservoir, a fish weighing 1.3 kg was caught in 1981, followed by a fish weighing 2.72 kg and measuring 55.8 cm in length in 1982, after which no catches were recorded. Similarly, in the Kundale Reservoir, a maximum haul of 38 fish weighing 400–600 g and measuring 30.4 cm in length was caught in the 1980s, after which no catches were reported (Devaa and Ramesh, 2021).

Eravikulam, Lakkam and Chokanad streams

According to the angling data on Eravikulam Stream post-1970, in 2007, 15 trout measuring around 5–6 inches were caught by an angler, after which no angling activities were recorded. Currently, the Eravikulam Stream is administered by the Kerala Department of Forests and Wildlife, therefore stocking is no longer possible in this water body. *Oncorhynchus mykiss* stocks have also disappeared from Lakkam and Chokanad streams due to destructive fishing and animal intrusion, mainly by

otters, *Lutra nair* (Linnaeus, 1758). According to the data post-1970, in the Lakkam Stream, a haul of two to three fish measuring 15.2–20.3 cm in length and weighing 300–400 g was recorded in 1980, followed by a haul of two fish measuring 15–17 cm in length and weighing 200–300 g, after which no catches were recorded (Devaa and Ramesh, 2021). In the Chokanad Stream, however, the last catch (fish weighing 0.9 g) was recorded in 1977.

Therefore, based on the above data, *O. mykiss* can no longer be stocked in Kaniamallay and Lakkam streams, Devikulam and Letchmi Lakes, and Madupatty and Kundale reservoirs as salmonids cannot thrive in these areas in the long run.

Genetic and health status of the Munnar rainbow trout

Earlier studies carried out to analyse the genetic variability in different populations of *O. mykiss* in India (Dachigam, Bairangana, Champawat and Patlikul of North India and Munnar of South India) showed significant genetic variability between the populations. Microsatellite loci analysis proved that the Munnar *O. mykiss* stock exhibited low genetic variability and therefore differed from the other stocks examined (Barat et al., 2015). No data are available on the health status of *O. mykiss* from Munnar. However, in 2015, a disease outbreak was reported in the Rajamallay hatchery and a few broodstocks suffered from fin and tail rot disease, which recovered on treatment with potassium permanganate. Thereafter, remedial measures were taken to improve the water quality of raceways, quarantine of diseased fish, and other measures such as improving food quality, hatchery cleanliness and optimised water flow into the raceway tanks.

Conservative measures for future management of O. mykiss fisheries in Munnar

In Chile, the aquaculture production of rainbow trout has grown into a multibillion-dollar business, second only to Norway (FAO, 2020). *Oncorhynchus mykiss* farming in the North Indian regions such as Kashmir, Himachal Pradesh, Sikkim, and Arunachal Pradesh has improved the economic status of rural communities fish farmers (private), and unemployed families and youths. However, the hatchery and existing trout stock need to be conserved. The infrastructure of the Rajamallay hatchery has to be upgraded by constructing more tanks according to fish size, especially fish of sub-adult and adult sizes. Also, extra hatching sheds need to be constructed for maintaining trout ova and fries, as currently, the hatchery functions with only one flow-through system for hatching trout ova. Sanitary measures to prevent infectious disease are strictly followed to avoid disease outbreaks. Implementation of recirculating aquaculture system needs to be considered as the water levels in the mainstream is reduced during the pre-monsoon season – low water levels in the streams are a persistent problem as these streams receive water mainly from the southwest monsoon (Sehgal, 1999). Stocks should be improved by introducing genetically upgraded new strains. The existing trout stock in the Munnar region is 80 years old since the last stock introduced was from Ceylon in 1941 (Mackay, 1945). Efforts are currently being taken to increase the production of fingerling, seed stocking, or ranching. This can be achieved by increasing the number of healthy broodstock and the number of fry. Furthermore, constructing a new hatchery will help improve seed stocking operations.

Regulations on angling need to be revised; for example, fish above legal size (above 25 cm) and spawn-bound fish must be released when caught, and artificial baits must be used. Any violation of angling rules should result in the cancellation of the license. All anglers (visitors, guests, company managers) should be advised to register their catches in the angling logbook. The angling association management should implement stringent action against destructive fishing. The KDHP Company should hire experts with knowledge on trout breeding, aquaculture, and the diagnosis and treatment of fish diseases, which is the urgent need of the hour. The KDHP Company should also increase human resources to restore all water bodies in which *O. mykiss*, were previously found (restoration is not possible in the Madupatty and Kundale reservoirs as they belong to the government). The hill communities (people residing near and adjacent to the stocking sites) should also be educated on the protection and conservation of fish. Strict implementation of all the above factors can help flourish trout aquaculture in the High Ranges of Munnar in the future.

Improvements in the Rajamallay hatchery

The current conditions of the rainbow trout hatcheries in the Munnar region are being improved, as fisheries experts from ICAR-DCFR (Indian Council of Agricultural Research-Directorate of Coldwater Fisheries Research, India) frequently visit the hatchery to help in the conservation of the fish population. Rajamallay hatchery production facility currently produces nearly 10,000 fingerlings annually. From 2020 onward, measures have been taken to improve the feed and water quality to increase production. The hatchery manager regularly checks the water quality. Fish feed-tripes mixed with beetroot remained a significant issue until 2017. However, during 2018–2019, food pellets were formulated and validated by the ICAR-DCFR, Uttarakhand, India, with improved nutritious value. The improved feed has shown excellent length and weight results when fed to fish. The authorities of KDHP Company currently have adopted this strategy. ICAR-DCFR also trained hatchery workers on breeding

and hatchery management and feeding practices for fry and grow-out stages in February 2019 (ICAR–DCFR 2019).

Conclusion

This study surveyed the *Oncorhynchus mykiss* fisheries in Munnar after 45 years. The results showed that these fisheries are endangered, and the only existing suitable stocking site in operation is in the Rajamallay Stream. Steps to increase the production and small-scale commercialisation of fingerlings are underway. *Oncorhynchus mykiss* farming can be a boon if other water bodies in Munnar are restored. Although *O. mykiss* was widely found in all water bodies in Munnar, now they are found only in the Rajamallay Stream. Therefore, conservation of salmonids in the High Ranges of Munnar becomes crucial because they contribute toward sport and recreational fishing (catch and release angling). In addition, they also have significant ecological (a good indicator of water quality), medicinal (for patients with cardiac diseases and rheumatoid arthritis), and nutritional (contains polyunsaturated fatty acids) properties.

There is a high potential for *O. mykiss* production when proper conservative measures such as good hatchery conditions, adequate broodstock management, feed improvement, and stocking stream protection are followed, contributing to the rural economy and developing aquaculture. Experts like fisheries specialists and scientists should educate people of hilly regions about trout fisheries, which can help conserve these fisheries in the long run. In summary, although *O. mykiss* production sites in Munnar have a high potential for angling activities, only active participation and commitment by the authorities and experts will help develop and protect trout fish. All these measures will result in developing farming areas in Southern Peninsular India.

Conflict of interest: The authors declare that they have no conflict of interest.

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