7 Aquaculture Practices in the Temperate Himalayan Region

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Abstract

The aquaculture production potential of the Himalayan region has not been exploited to its fullest. Though this farming practice has a great potential to support the livelihood, the current practice is an almost traditional approach with poorly adopted technologies. Carp farming, integrated fish culture, and trout farming are the major features of temperate aquaculture in the Himalayan region. The existing practice is three-pronged in nature, integrating with horticulture and animal husbandry. Culture of exotic trout farming at high altitudes, exotic carp farming in mid-altitudes, and integrated carp farming in foothill areas are the existing aquaculture practices. Hence, aquaculture productivity in this region is below the average of world standards, with limited candidate species and culture systems. There is a vast scope and potential for improving fish production in the hills by bringing the Himalayan region under scientific management for temperate aquaculture. This would probably reduce the gap between actual fish yield and production potentials.

Keywords

Hill aquaculture · Polyculture · Carp farming · Trout culture · Mid-altitudinal fish farming · Jhora fishery · Pengba culture

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7.1 Introduction

Agriculture including other allied activities such as horticulture, apiculture, piggery, fish farming, etc. is the basic occupation of hill dwellers of the country to support their livelihood. Farmers of the temperate region have several constraints such as small land holdings, short period of cultivation, and low productivity due to lower thermal regime and climatic variation. Hence, farmers also practice the allied activities, and the temperate agriculture is almost an integrated type of farming pattern. Among the allied activities, vegetable cultivation, animal husbandry, and aquaculture support the livelihood of the majority of small and marginal hill farmers as an additional source of income. Cultured as well as captured fish is the best substitute of the cheapest and easily digestible animal protein which supports the nutritional requirement and alleviates malnutrition to the hill dwellers. Therefore, aquaculture is just a traditional and auxiliary practice in integrated rural and family-based temperate agriculture. Though the history of aquaculture in Indian Himalayan region is more than 180 years old, due to variable climatic conditions and low thermal regime in hills, the development of hill aquaculture is still at low level with hardly contributing 1.0% in the total national aquaculture production. Presently, this practice is just a traditional rural aquaculture, which is practiced as subsistence aquaculture. The present aquaculture practice in hill states varies with the geographical altitudes (400–3000 m asl) and location-specific climatic conditions. The low altitude (less than 400 m asl) provides maximum opportunities for fish farming, while the high altitudinal area (>1200 m asl) has limited fish farming activities. Cyprinids are the major candidate species of Indian aquaculture, but due to low thermal regime, Indian major carps are not suitable for hill aquaculture, and only exotic carps are the candidate fishes for the vast mid Himalayan region. Culture of these exotic carps is in practice under monoculture, polyculture, and rice and fish farming system. The high altitudinal area is blessed with cool, clean, and continuous flowing water and culture of rainbow trout (*Oncorhynchus mykiss*) is practiced in this area which has scope of multifold increase and transforming the traditional aquaculture into the entrepreneurship-centric commercial practice. Only high altitudinal areas with sufficient water are suitable for rainbow trout culture. Apart from this, traditional aquaculture with some of the indigenous minor carps is also in practice which is totally unorganized. These species include *Labeo dyocheilus*, *Labeo pangusia*, *Bangana dero*, *Neolissochilus hexagonolepis*, *Osteobrama belangeri*, and *Cyprinion semiplotum*.

7.2 Historical Perspective of Aquaculture in the Himalayan Region

Hill aquaculture was initiated with the introduction of exotic fishes in the Himalayan region. Prior to the introduction of the exotic fish species, there were only a few indigenous fishes such as snow trout and mahseer, which could provide valuable fishery in the hill states, and aquaculture activities were confined only to the breeding and seed production of these fish species. British settlers in India brought some cold-water fishes from overseas during the period of 1810–1939, mainly from the United Kingdom. There is a historical account of transplantation of five fish species, viz., tench (*Tinca tinca*), golden carp (*Carassius carassius*), German strain of common carp (*Cyprinus carpio*), brown trout (*Salmo trutta fario*), and rainbow trout (*O. mykiss*). Mclvor introduced tench during the year 1810 in the Ootacamund Lake which attained the size of 1.2 kg and remained confined to Nilgiri area and did not spread elsewhere in India. Golden carp was also introduced during the year 1870 in the same lake which was a plankton feeder fish and attained the size of 1.2 kg but was not propagated further in uplands. Among these five introduced fishes, common carp and trout were successfully propagated for sport fishing and aquaculture purpose.

British settlers introduced different species of trout in the Indian subcontinent basically to meet their needs for sport fishing or recreational angling during early period of the last century primarily. The very first attempt to implant trout from New Zealand was made in 1863 by Sir Francis Day in Nilgiri hills, and later efforts were followed from 1866 to 1906 that were aimed at brown trout but with little success. Mr. H.C. Wilson, Consultant, Pisciculture, Madras Presidency, constructed a hatchery at Avalanche (Tamil Nadu) in 1909–1910 for brown trout (Sultan 2012). However, due to failure in the case of brown trout, the focus shifted toward the rainbow trout. The first attempt to introduce the brown trout (*S. trutta fario*, Linnaeus) in the Himalayas dates back to 1899 when Mr. F.J. Mitchell brought the eyed-eggs, but he did not succeed due to loss of eggs during the transportation. Further, eggs of brown trout were procured during the year 1900 from Jioweitonin in Scotland and successfully propagated as first success at Harwan hatchery near Srinagar, Kashmir. Therefore, Mitchell established a first regular trout hatchery at Harwan in the history of cold-water aquaculture. The brown trout was spread to other section of Himalayas from this hatchery. This species was transplanted to almost all suitable streams and lakes of Kashmir, Gilgit, Abbolabad, Chitral, Kangra, Kullu, Shimla, Nainital, and Shillong. Himachal Pradesh procured the brown trout eggs from Kashmir during the year 1911 and introduced them in three streams of Kangra and Kullu area of Himachal Pradesh, namely, Baner, Awa, and Binun. Regular efforts were made to establish the brown trout in these streams, but did not succeed due to unfavorable thermal regime, and the stock was completely decimated due to the devastating flood during the year 1947. Mr. Howell, warden of fisheries, Punjab, brought eyed-eggs of brown trout from Kashmir during the year 1909 and got the success to produce swim-up fry and stocked them in streams of Manali and Katrain. Adult specimens of brown trout were found in the streams of Manali and Katrain during the year 1912. This wild stock was brought to Barot in Uhl valley during 1916 and established a brown trout hatchery. Presently, this is the only brown trout hatchery in the Himalayas, and stock was spread to different parts of Himachal Pradesh and hill states. Effort was made to transplant the brown trout in Uttarakhand (erstwhile Uttar Pradesh) and establish a hatchery at Bhowali near Nainital during the year 1911–1913, but it did not succeed due to comparatively high summer temperature prevalent in the area. The initial success was found during the year 1966 for brown trout at Kalyani hatchery in Uttarakhand. Brown trout fingerlings were also provided by Kashmir to Eastern Himalayas and transplanted directly into the streams of Darjeeling and Shillong, but it was not established. Effort was made to establish a brown trout hatchery near Sela Lake in Arunachal Pradesh during the year 1967, but did not get the success for eyed-eggs incubation. Hence, yearlings of brown trout were directly transplanted in certain streams and lakes of Arunachal Pradesh and Sikkim, where they were reported to establish successfully. During the year 1931, brown trout eggs were provided by Kashmir to Jaghoor near Chitral in Pakistan, where they hatched successfully and further propagated to stock in the streams. Yearlings of brown trout were also brought from Kashmir to Nepal and Bhutan during the year 1970–1972 and reported to establish in the streams.

Mitchell achieved the success for hatching and rearing of rainbow trout during the year 1912 which was brought from Blagdon, England, and incubated at trout hatchery, Harwan, Kashmir. This introduction was the formal beginning of rainbow trout culture in India. This species was introduced from Kashmir to trout hatchery Mahili, Himachal Pradesh, during the year 1919 and attained the maturity in the introduced stock during the year 1922. Eyed-eggs of rainbow trout were also transplanted from Trout hatchery, Achabal, Kashmir, to trout hatchery Barot and Patlikuhal in Himachal Pradesh. During the year 1976, rainbow trout eggs were brought from Kashmir to trout hatchery Talwari and Kalyani in Uttarakhand. These hatcheries were established to provide stocking material for the rivers Pinder, Birahi Ganga, and Asiganga which were kept in reserve to provide angling pleasure in Uttarakhand. The European Economic Community (EEC) assisted a project in Jammu and Kashmir with Fish Farms Development Internationals (FFDI) Scotland and Ramboll and Hannemann, Denmark, during the year 1984 at Kokernag in Kashmir. This project is still a landmark milestone in the establishment of rainbow trout culture in India. Further, Norwegian government funded a project for transfer of technology and production of trout in Himachal Pradesh during 1988, which primarily established trout farming activities at large scale in Himachal Pradesh. Under this project, fresh stock of rainbow trout was introduced, and health service was provided in association with the National Veterinary Institute, Oslo, Norway. In peninsular India, eyed-eggs of golden rainbow trout and ordinary rainbow trout were imported from Nikko Laboratory Japan during the year 1968 and incubated at Avalanche trout hatchery. Further, *O. nerka* was also imported from Canada at this hatchery during the year 1969. But, only golden strain of rainbow trout could establish well as a dominant strain from among the all introduced fishes. During the year 2019–2021, the Govt. of India imported more than 25 lakhs of eyed ova of improved strain of rainbow trout from Denmark (Aqua Search Fresh) to India to fulfill the seed requirement of the trout growers of Kashmir, Himachal Pradesh, Uttarakhand, and Sikkim. However, this imported stock was completely female stock and could not propagate further. For many decades, rainbow trout was recognized only for angling and sports purpose. Later on, this species was also realized as food fish, and culture and seed production was started in farm conditions. However, its culture was confined only in some selected locations of Kashmir, Himachal Pradesh, and some parts of the Peninsular India. Presently, the culture and breeding of rainbow trout is being practiced with greater success and accuracy in mid and higher altitudes.

During the past two decades, three more species of salmonids, viz., the eastern brook trout (*Salvelinus fontinalis*), the splake trout (hybrid of lake trout and brook trout), and the landlocked variety of Atlantic salmon (*Salmo salar*), were procured from Canada and North America and kept at state trout hatcheries of Kashmir, but did not get the success in breeding and their survival. Arctic char (*Salvelinus alpines* Linnaeus) were transplanted in Himachal Pradesh during the year 2006, which did not breed due to the unfavorable environment.

Mirror carp, a variety of common carp (*Cyprinus carpio var. specularis*), was imported from Sri Lanka to India during the year 1939 and transplanted in Nilgiris area. Further, this species was transplanted from Nilgiri to Bhowali hatchery during the year 1947. This fish was propagated well and planted in different Kumaon lakes, Himachal Pradesh and Kashmir. ICAR-Directorate of Coldwater Fisheries Research, Bhimtal, Uttarakhand, imported improved Hungarian strains of common carp, “Ropsha scaly (*C. carpio var. communis*)” and “Felsosomogy mirror carp (*C. carpio var. specularis*),” during 2006 at the Experimental Fish Farm, Chhirpani, Champawat, Uttarakhand, where these strains were raised, bred, and assessed for growth performance, both in polyculture system and in monoculture. The imported parental stock showed better growth and breeding response, but the progeny of these strains did not show desirable growth and survival.

7.3 Aquaculture Trends in the Himalayas

The culture systems, adopted in the Himalayan region, vary greatly depending on the altitude and are almost location- and situation-specific.

7.3.1 Carp Farming

Culture of exotic carp fishes in small-sized ponds (0.01–0.03 ha) is a very popular practice in the temperate region. This is a low input culture system and integrated with horticulture and animal husbandry practices. This practice varies from monoculture of common carp to polyculture of three exotic carps, viz., grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), and common carp (*C. carpio*). Integrated carp farming with horticulture and animal husbandry is popular in rural areas with reduced input cost. Monoculture of grass carp is also popular as low-cost hill aquaculture practice in mid and low altitudes. Basically, this fish feeds on aquatic vegetation of the pond, and farmers also provide supplementary feeding with terrestrial soft plants and grass of the horticultural plots. This practice has been adopted in the Northeastern and Central Himalayan regions.

7.3.2 Monoculture of Common Carp (*C. Carpio*)

Monoculture of common carp in small-sized pond (50–150 m^3) is popular in different Himalayan states. Fingerlings of the size 6–7 cm are stocked in the density of 3–4 fish/m^2. Water temperature has the profound role in determining the growth rate. Higher growth rate is achieved at the water temperature range of 20–25 °C, but lower thermal regime of 9–18 °C reduces the fish growth and results in low production. The average fish production is achieved in the range of 1300–1700 kg/ha/year.

7.3.3 Culture of Exotic Carps in Mid-altitudes

Polyculture of three exotic carps, viz., grass carp (*C. idella*), silver carp (*H. molitrix*), and common carp (*C. carpio*), in earthen ponds of the mid-altitudinal region (800–2000 m asl) is a common practice in most of the Himalayan states. Fish farmers use the ponds of 100–150 m^2 size for this practice. Raw cow dung (RCD) is applied at 9000 kg/ha/year for consistent plankton production in the pond water. Fish seed of the fingerling size is stocked at the rate of 3–4 fish/m^3 with species composition of 4–5:2–2.5:3–3.5 for grass carp, silver carp, and common carp, respectively. Though the average fish production of 0.34–0.48 kg/m^3/year (3400–6800 kg/ha/year) is in lower side with this practice, this is a common rural aquaculture practice in hills by using earthen ponds (Fig. 7.1).

7.3.4 Integrated Fish Culture in Polytanks

Due to low thermal regime in mid hills (1000–2000 m asl), the growth of carps is slow, and the fish remain in hibernation during the entire winter season. In this context, a refined model of carp farming with lining of plastic film in earthen ponds is used by the fish farmers (Fig. 7.2). This practice has numerous merits as it is easily affordable by local poor farmers, and at the same time, it reduces the unproductive hibernation period of fish, thereby giving more profit. This multitier model for carp farming provides increased water temperature for better growth of fish, buffer water stock for irrigation of vegetables' plots, and minimal loss of stored water by seepage due to soil porosity. These polytanks are stocked with exotic carps, and supplementary carp feed is provided at 2–3% of growing fish biomass. Polyfilm in the pond conserves the sunlight energy and keeps the pond water temperature 2–6 °C higher than the conventional ponds which favors the increasing feed intake and faster metabolism resulting in better growth of fish compared to conventional tanks. This polyfilm also acts as insulation between pond water and pond bottom soil and reduces the water seepage from the pond. These polytanks remain comparatively deep (2.0 m) and also retain the buffer stock of water for irrigating the horticulture crops. Fish farmers in mid-altitudes are getting an average fish production of

Fig. 7.1 Carp farming in earthen ponds

0.6–0.7 kg/m^3/year with this refined culture model, which is higher than the conventional carp farming in earthen ponds.

7.3.5 Culture of Pengba Along with Exotic Chinese Carps

Culture of Pengba, *Osteobrama belangeri*, along with Chinese carps for production and livelihood is popular in Manipur (Das and Singh 2017). Farmers of Manipur, India, do polyculture of grass carp, silver carp, and pengba with species composition of 30:30:40 and get average production of 4300 kg/ha/year. The combination of pengba and khabak (*Bangana devdevi*) in the ratio of 50:50 with other exotic carps is also in practice in some parts of the Manipur state.

7.3.6 Jhora Fishery for Rural Aquaculture

Jhora fishery is a low-cost traditional practice in rural areas with culture of exotic carps in unmanaged village ponds. This practice is popular in northeast Himalayan region particularly in the part of West Bengal and Meghalaya state. This is a low

Fig. 7.2 Carp farming in polytanks

input practice with less stocking density and rare supplementary feeding, and hence, low biomass production is achieved which also varies from pond to pond with average fish production in the range of 1700–3500 kg/ha/year. A refined model of this practice has been adopted by the farmers of Kalimpong area in West Bengal for this practice with almost 20% higher fish production. These farmers use multispecies stocking of chocolate mahseer (*Neolissochilus hexagonolepis*), common carp (*C. carpio*), and grass carp (*C. idella*) in village ponds.

7.3.7 Paddy-Fish Culture in Northeast Region of India

This is a traditional fish farming practice which is very popular in Arunachal Pradesh and Manipur. Prepared fields are planted with local variety of paddy and also stocked with common carp. The estimated production in this practice is 683.0 kg/ha of common carp in rearing period of 237 days without any supplementary feeding (Das 2017).

7.3.8 Integrated Fish-Pig Farming in the Northeast Region of India

Integrated fish farming in small scale by resource-poor small and marginal farmers is very common in most of the northeast region. This is low input cost culture practice with better economic efficiency. Integration of pigs with small fish ponds is popular in Tirap district of Arunachal Pradesh, Kamrup district of Assam, and East Khasi hills and West Khasi hills of Meghalaya. During the culture period of 8 months, the pigs attain an average growth of 68–72 kg, while an average production of 5300–5700 kg/ha of fish is achieved in 8 months' culture duration. Generally, they use exotic carps for the culture.

7.3.9 Rainbow Trout Farming

Rainbow trout farming is a high income generating farming practice for better livelihood support to the rural people of higher altitudinal areas in hills. Farmers primarily culture the rainbow trout in earthen or concrete flow-through raceways or ponds in a conventional manner (Figs. 7.3 and 7.4). At present, total annual production is nearly 2500 tons, with an average unit productivity of 10–15 kg/m^3. Based on available resources, the potential scope for sustainable expansion and intensification is enormous across a vast geographic area. Presently, more than 80% of the rainbow trout production comes from only two hill states, viz., Kashmir

Fig. 7.3 Rainbow trout farming in earthen ponds

Fig. 7.4 Rainbow trout farming in raceways

and Himachal Pradesh. However, other hill states, like Uttarakhand, Sikkim, and Arunachal Pradesh, are also coming forward for rainbow trout farming.

Presently, conventional raceway culture with running water system having continuous flowing cool, clean, and highly oxygenated water is in the practice. The average size of this culture raceway remains at 30 m^2 (15 m length and 2 m width) with 1 m depth toward inlet and 1.5 m depth near the outlet. Generally, fish takes 12–14 months to attain marketable size (250–260 g) with this conventional culture system in Kashmir, Himachal Pradesh, and Garhwal region of Uttarakhand. However, comparatively better growth of 500–600 g was also achieved in 12 months in Sikkim state having favorable thermal range of water (14–18 °C) for maximum culture cycle (8 months) and availability of sufficient water volume. In Nepal, the marketable size of 200–300 g is achieved in culture duration of 14–16 months, and fingerlings are stocked at the density of 50 fish/m^2. The marketable size of 300–350 g was achieved in 8 months at trout farms of Idaho, USA, under the raceway culture. In general, production level of rainbow trout in Indian conditions is 300–500 kg per raceway of the size of 15 × 2 × 1 m (30 m^2) in 12 months, which is almost similar to the European countries. However, high productivity of 1 ton per raceway or more has also been achieved by the trout growers of Sikkim and Himachal Pradesh in India with better management practices (Fig. 7.5).

Generally, stocking density of 45–50 fish/m^2 is adopted by the trout growers of Himalayan region, which has the scope to increase up to 100 fish/m^2 with better management practices and sufficient water flow in the raceways. Size and shape of the raceways also varies location-wise without any standard. Earthen raceways are

Fig. 7.5 Entrepreneurship in trout farming

also in practice at few locations of Arunachal Pradesh and Kashmir. Generally, Indian trout farming is conventional type having flow-through systems, in which stream water is used by making a check dam across the adjacent stream at higher elevation and water flows to the farm by gravity without the use of or only minor use of pump energy. Hence, trout raceways are constructed directly into the soil of river valleys close to the stream banks. Generally, a flow rate of 4 L/s is used to support 20 kg/m^3 fish biomass in raceways. However, minimum of 500 m^3/day of water flow is needed for 1 ton of trout produced (Stevenson 1987). Rainbow trout farming is also practiced in mid-altitudes and in the Central Himalaya; average growth was recorded as 300 g (range 260–400 g) at thermal regime of 5.0–22 °C (Vass et al. 2010). This indicates the scope of rainbow trout farming with marketable size trout of 240–400 g within a period of 12 months at marginally higher thermal regime in mid-altitudinal areas of the Himalaya. Integration of rainbow trout farming with cardamom cultivation is an innovative approach for multiple use of water and better

Fig. 7.6 Integration of cardamom crop with rainbow trout farming

production of trout and cardamom at higher altitudes in Sikkim state. The nutrient-rich drain water of a raceway is used for irrigation of 0.4 ha cardamom cultivation plot which results in 30% increase in yield of cardamom (Fig. 7.6). The average net profit to the farmers in this integrated trout and cardamom cultivation is Rs. 214,000 in 0.4 ha farming area. In Indian conditions, the annual rate of return in trout farming is nearly 50–60% of the total annual investment having net profit of Rs. 137,000 in 30 m^3 in 12 months, while it is 39% in Nepal.

The ICAR-Directorate of Coldwater Fisheries Research is the nodal institute responsible for research and development in rainbow trout farming in India. Over the last decade, this institute has made significant contributions to improve rainbow trout production in the country by developing, validating, and introducing new production system models (recirculatory aquaculture systems), high energy feeds with an FCR of 0.8–1.1, pathogen and disease surveillance programs, antimicrobial resistance monitoring, engineered therapeutics, unraveling stress adaptations, stock characterization, and GIS-based site selection tools. In the next 5 years, the target is to sustainably increase the productivity to 20–25 kg/m^3 in flow-through systems and 60–80 kg/m^3 in RAS with minimum use of resources and culture duration through technological interventions.

7.3.10 Entrepreneurship with Ornamental Fishes

There are some fascinating fish species inhabiting in the Himalayan region, in which some indigenous fishes have high ornamental value. The northeast region of the Himalaya has 187 indigenous fish species of ornamental value. Some farmers of

Uttarakhand and the northeast are practicing small-scale enterprise in ornamental fish trade, as a backyard activity in rural areas with exotic fish such as gold fish and koi carp along with other indigenous fish species such as *Garra gotyla*, *G. lamta*, and some species of loaches.

7.3.11 Carp Farming at Higher Altitudes

At high altitude, some farmers are doing exotic carp farming in polyhouse covered polytanks. The size of the polytanks remains at 9.8 × 3.0 m with 1.2 m depth and 1:1 side slope. These polytanks have the capacity of 20 m^3 water volume. This structure remains covered with dome-shaped galvanized iron (GI) pipe polyhouse having the size of 11.0 m length, 4.2 m width, and 1.0 m span with central height of 3.0 m (Fig. 7.7). Polyhouse helps to increase the water temperature by 3.7–9.6 °C and supports better fish growth. Hence, these low-cost polyhouse structures support the increasing water temperature and protection from frost condition. The growth of exotic carps in this culture practice remains in the range of 270–300 g in 12 months' rearing period. Though this practice is not very popular, fish production with this practice at higher altitude supports the livelihood and nutritional security to the unprivileged and resource-poor people.

Fig. 7.7 Carp farming at higher altitudes of the Himalayas

Fig. 7.8 Rainbow trout farming in floating cages

7.3.12 Rearing of Rainbow Trout and Mahseer Seed in Floating Cages

Open water bodies in hills provide opportunities for in situ seed rearing in floating cages, and produced seed is used for the stock enhancement program. Fingerlings of golden mahseer (*Tor putitora*) are being reared with appropriate stocking density and feeding practices in Bhimtal Lake. Floating cages for rainbow trout fingerling rearing are used in Menmoitso Lake of East Sikkim (Fig.7.8). These types of cages are also being used in Gobind Sagar reservoir of Himachal Pradesh for rearing of rainbow trout.

7.4 Constraints in Hill Aquaculture Development

1. Slow growth in culture system due to low thermal regime.
2. Limited candidate fish species for culture.
3. Nonavailability of seed of high valued fish species such as rainbow trout in sufficient quantity.
4. Nonavailability of seed of potential candidate indigenous fish species such as minor carps and barbs.
5. Need to replace the inbred rainbow trout stock by improved strain varieties.

6. Large-scale commercial rainbow trout farming is not in vogue.
7. Trout seed production and trout feed supply are mostly confined in public sector.
8. Need of high input and high output practices such as recirculatory aquaculture system (RAS).
9. Call for soilless aquaponics farming with integration of fish and vegetables for resource-poor farmers.
10. Fish feed for diversified fish species for different developmental stages not available.
11. Poor availability of formulated feeds and higher cost factor.
12. Principle of cluster farming not in vogue which may provide benefit on inputs and marketing of fish.
13. Non-adoption of location- and system-specific culture models which may provide optimum production at low input cost.

7.5 Species Diversification for Hill Aquaculture Development

Exotic carps and rainbow trout are the major candidate fish species for hill aquaculture. But carp farming in hills does not support the good farming economics due to the low valued fish in the domestic and international market and low cost–benefit ratio in comparison with the culture of other valued fish species. Further, consumers today with their increased purchasing power prefer wide spectrum of fish protein. In this context, diversification of the system and species is required for aquaculture in the coming years. Diversification with high valued fish species is needed to make aquaculture more remunerative to encourage the entrepreneur investment. But, introducing any new species into the mainstream aquaculture practice includes consumer preference, seed availability, rearing technology along with the knowledge of their nutrition, physiology, and health management. A number of indigenous fish species have the potential to be a candidate culture species in the Himalayan region particularly in northeast zone having high consumer preference as well as good market value. Some farmers are practicing the culture of indigenous fishes such as chocolate mahseer (*N. hexagonolepis*), *B. dero*, *L. dyocheilus*, *L. pangusia*, *L. gonius*, *Chagunius chagunio*, *O. belangeri*, and *Cyprinion semiplotum*, but the culture of these species is not based on any standard culture system.

7.6 Need for Intensification of Rainbow Trout Farming

Trout farming is coming up as a lucrative venture at higher altitude, and present trout production of the country has gone up from mere 147 tons to over 2500 tons in the last decade that further can be enhanced through expansion and increase in productivity that needs intensification as well as location- and situation-specific efforts in terms of quality seed, low-cost feed, and health management. For vertical expansion, there is a need to develop innovative practices such as RAS-based rainbow trout farming, aquaponics-based rainbow trout farming, efficient fish feed, and climateresilient trout production. Most of trout farms are distantly located in difficult terrain and have poor accessibility to the market where quick transportation of fish is difficult; hence, the sale of fish is confined to local markets. Being highly perishable commodity, there is a need of value chain and cold chain to ensure high quality of trout meat. The sale of fish is confined to local markets. New trade channels are expected to come up soon, once production blooms with upcoming infrastructure and technological advancement. It required to overcome the deficiencies by adopting cluster-based approach to cover all the segments like culture operation, fingerling rearing, feed supply, and marketing through large-scale operations at potential sites. Respective agencies may develop suitable spots as “trout village” for bulk production and employment using the commerce to involve private sector, especially in feed, marketing, and value addition to bring resiliency.

7.7 Conclusion

Fish is now not only an important source of food and income but also as a commodity for trade and export as blue economy. Considering the vast resources available, there is immense potential to draw economic benefit for the prosperity of the people residing in hill states through multifold increase in aquaculture production by horizontal expansion, intensification diversification, and better management practices. Presently, the temperate aquaculture is almost a traditional aquaculture in most of the hill states. Therefore, standard culture protocols would be the key for way forward. Suitable sites are available in different parts of the hill states, which would be brought under anyone of the three-pronged fish farming having location-, situation-, and system-specific culture models. Further, there is a need to introduce large-scale farming to bring the Himalayan region on international scenario by implementing scientific management practices with a very honest and clear aim to provide protein locally at cheap price and to export the fish and fishery products to gain the foreign currency. Decision support system in the form of GIS and remote sensing would be helpful not only for resource assessment but also for aquaculture development in the hills. Ornamental fish culture for small-scale enterprises in the hills can provide an alternative source of employment. Hence, temperate aquaculture has potential and opportunities to provide animal protein to the people and also supports the other agriculture activities for improving their socioeconomic life.

References

Das SK (2017) Technology for fisheries and aquaculture under mid hill condition. In: Bordoloi R, Deka BC, Singha AK, Kumar B, Jat PC, Sarma CK, Borgohain R (eds) Technology inventory for Northeast India. Chapter 10. ICAR ATARI, Zone-III, Meghalaya, pp 313–317

Das SK, Singh TN (2017) Captive breeding and embryonic development of endangered, *Osteobrama belangeri* (val., 1844) under mid-hill condition in north East India. Indian J Anim Sci 87(12):1546–1550, December 2017, /Article. ICAR
Stevenson JP (1987) Trout farming manual, 2nd edn. Fishing News Books, England, p 259
Sultan S (2012) Trout in India. National Fisheries Development Board, Hyderabad
Vass KK, Raina HS, Haldar RS (2010) Prospects of rainbow trout, *Oncorhynchus mykiss*, walbaum culture in mid altitudes of Central Himalayas, India. J Inland Fish Soc India 42(1):1–7