Fisheries *vis-a-vis* watershed management: A plea for inclusive development in Indian Himalayas

M. Muruganandam[1], P K Mishra[2] and G P Juyal[3]
Central Soil and Water Conservation Research and Training Institute (CSWCRTI),
218-Kaulagarh Road, Dehra Dun-248 195. mmm20@rediffmail.com

[1] Sr Scientist (Fisheries), [2] Director and [3] Head (Hydrology and Engineering Division), CSWCRTI

Abstract

Water resources are often viewed as lifeline for development, more particularly in Indian Himalayas, where large network of streams and rivers traverse forming the "Water Tower" for plains, valleys and downstream. Streams and rivers, comparable to veins and arteries of watersheds face various problems due to increasing demands from them for socio-economic and ecosystem or environment related goods and services. The potential of water resources is variously affected by mismanagement of watersheds and resultant soil erosion and floods, which in turn affect human life, animals and other natural resources including fishes immensely in Himalayan region. One of the important goods and services received from water resources is the environment for fish production or fisheries development for food or trade.

Fisheries sector contributes greatly to the livelihoods and food security of people besides to recreational benefits and ecosystem services. Fish farming in farm ponds and Water Harvesting Structures (WHS) yields 3.5-4.5 t ha^{-1} $year^{-1}$ and integrated fish farming enhances profit while minimizes resource use. Streams and rivers serve as source of fish food in varying degrees for about 40% of the households, depending on the distance of settlement from rivers in mid-Himalayas and fishing sustain huge population of the region. Fishing is more intense in the rivers above 4^{th}-orders and hence they face severe problems mainly due to prevailing unscientific fishing, which warrants corrective managerial inputs. Nonetheless, the water resources of Himalayan region have not been managed potentially for fisheries development. Watershed-based Fisheries Development Plans (WFDP) has the potential to renovate landscapes, aquatic resources and fisheries production besides improving agricultural production and aggradations of natural resources. The contribution of CSWCRTI towards watershed-based fisheries development over 15 years, and the needed research, policy and strategies to improve fisheries production are identified. The need to incorporate fisheries dimensions into ecosystems and water management approaches have been discussed in this communication.

Introduction

Rivers, ponds and other aquatic resources provide various goods and services for the mankind and nature variously *viz*; i) give food fish for consumption and trade, ii) regulate climate, iii) contribute to ecosystem and production systems: recycle plant nutrients, absorb pollutants from point- and non-point sources, sequestrate carbon etc. iv) supply water for various purposes including irrigation, generation of electricity, grinding water-mills, transport, water-based sports, recreation, fish farming etc. Fishing forms one of the important livelihood activities and fishes from streams or rivers contribute immensely as a source of food resource to rural poor and marginal farmers in most parts of the world including India and the Himalayan region. Fishing, fish farming and fish consumption are widely known to improve physical health and socio-economic benefits. Aquaculture production has grown tremendously from mere 1 million ton (mt) in 1950 to 52 mt globally (FAO, 2012). Similarly,

almost 11-fold increase in fish production from mere 0.75 mt produced during 1950-51 to 8.3 mt (4 mt capture and 4.3 mt culture) during 2011-12 with the annual growth rate of 4.5% has been achieved in India (Ayyappan, 2012). Nonetheless, present fish production stands far behind the target or demand of 16 mt of fish to be met from culture (10 mt) and capture (6 mt) by the year 2025 in India. Although the potential of fisheries in mountain (coldwater) region of India to the national fisheries production is huge, presently its contribution is very meagre with only 1.5% of total, mainly due to technological inadequacies, limited infrastructure and lack of effective promotion policies or support mechanisms. The opportunities available within natural streams, irrigation networks, channels, drainage systems and watersheds to promote complementary development of fish production have not yet adequately been exploited in the whole country including Himalayan States. This situation requires effective research and development approaches to generate innovations so as to transform the fisheries sector to be more productive.

About two decades of watershed-based research at Central Soil and Water Conservation Research and Training Institute (CSWCRTI), ICAR, Dehradun have evolved or refined many technologies for soil-water conservation and integrated farming. Also, the institute has advanced the knowledge on traditional farming, fishing and their impacts on watershed basis. The accrued knowledge at the CSWCRTI have been shared with various stakeholders including developmental agencies, farmers etc. through different outreach programs and one such effort is this communication for the discussion at the Sustainable Mountain Development Summit 2013. Fisheries development drawing reference to existing fish diversity, fishing tradition, constraints in fisheries development, lack of data, growing demand, stagnating production, traditional fishing and farming, conservation needs etc. will be discussed in the summit. A plea to include fisheries aspects in to water, watershed and river management programs has been tagged in the communication.

Importance of Himalayas and upstream regions

Mountainous and Himalayan regions (Photo 1) are important not only for the sustainability of the local environments, but for the well-being of human, animals and other natural resources of plains, valleys and downstream reaches as well. For example, transport of organic materials from riparian sources of upstream contributes to large amounts of phytoplankton and zooplankton in downstream, which help fishes in their habitats. Any activity executed in the upland catchment in an unplanned manner or excessively is likely to affect aquatic ecosystems and fishes along the drainage line. Faulty farming practices, excessive soil working, land cuttings and construction of roads or dams induce server soil erosion, sometimes beyond soil tolerance ("T") limit of the given location or region, which causes large scale movement of soil and huge amount of runoff and sediments to downstream reaches. These aggravate the damages caused to land-water resources, particularly affecting various physical, biological, chemical, and physico-chemical properties of aquatic resources besides *in situ* productivity locally or regionally. Resultantly, turbid or sediment laden flows and alteration of structure or features of streams or rivers, especially channel width, gradient, depth, sediment size etc., river-bed morphology-pools, riffles and glides etc. and flow regimes occur that immensely affect fishes and fisheries resources.

Traditions affect fisheries resources in Himalayas

While little above fifty percent of the people consumes fish in India, it is up to 95% of the population in most Himalayan region accept fishes. Native people of the Himalayas use fishes and its habitats variously as food item (Photo 2), gift item for guests (Photo 3), medicine and recreational avenues (Photo 4). Fishing provides fish food in varying degrees

for about 40% of the households, depending on the distance of settlement from rivers in mid-Himalayas and it is more intense in the rivers above 4th-orders. Most of the traditional knowledge prevailing in the region may have positive impacts on Natural Resource Management (NRM), but they are gradually vanishing due to increasingly changing lifestyle or livelihood avenues contributing little for the NRM. Also, some of the traditional knowledge or practices like that of the popular fishing festivals using powder prepared from locally available medicinal shrub, *Zanthoxylum armatum* (D.C.; *timru*) practiced in Uttarakhand Himalayas are known to cause environmental, biodiversity and production losses in the long run if not immediately (Muruganandam, 2013). The unrefined traditional beliefs or myths prevailing amongst the people contribute to the unscientific exploitation of fishes and fisheries or water resources in the region (Photo 5). Consequently over years, availability of fishes in natural environments of the Himalayas has declined affecting large number of local people mainly due to continuing unscientific fishing using destructive gears or methods like bleaching powder, dynamites, damming of water, plant poisons etc. that cause over exploitation of fishes, catching of young ones or brooders, destruction of habitats etc.

Floods affect fishes

Intense rainfall and flashfloods that occur frequently in Himalayas affect fish population in the river courses variously as briefed below. The local farmers and fishermen are the worst affected by the loss caused to fish resources by the floods.

Impacts of flooding and temporary habitats

Floods cause extensive submergence of riparian ecosystems due to the extension of the river bed, water course or adjacent floodplains and subsequent receding of water level after few days, which leave fish populations trapped in the newer or temporary habitats formed that became without water and finally killed.

Impacts of moving sediments, silts and boulders on fishes

During the recurring phenomena of floods in monsoon months every year, fishes reach sides, particularly after gills and eyes chocked heavily by silts and sediments that in turn facilitate villagers to fish out easily, even very big fishes beyond 20-30 kg, mostly by bare hands. The excessive silt and sediment laden flows and movement of boulders kill fish populations, particularly the bottom dwelling fishes and species with small operculum or gill openings like *Mastacembelus armatus* (Lacepède, locally known as *gooj* or *baam*) and *Lepidocephalus* spp. by gill chocks, smothering of eggs and young ones and physical injury to adults and sub-adult species and organisms. Because at times, complexity of substratum, high current velocity, depth and lack of needed local shelter make fish species incapable to tolerate continuous turbid water and heavy siltation. The impact of floods is often sever since it coincides with breeding periods of most aquatic species including fishes.

Breaching of ponds and other resources near the river course

Often, breaching of fishponds, river courses and water-mills are also not uncommon during flood periods (Photo 6). During floods, the stocked fish biomass present in ponds flow away along with the overflows causing huge financial loss to the farmers and sometimes ecological problems as well, if the stocked species belongs to carnivorous feeding habits like *Clarias gariepinus,* (Thai *magur)*. This requires construction of ponds away from the drainage line and with sufficiently stronger and higher water holding structures including inlet and outlets with net lines.

On the impacts of flood occurred during June 2013

The recent flash floods occurred in Uttarakhand Himalayas during June 2013 has also not left fishes and their habitats unaffected, whose impacts however were subdued by the huge damages occurred to the tune of few thousands human life, household resources, over 20,000 ha of agriculture lands and 15,000 animals.

Interface of water and fisheries resources poorly recognised

Fisheries sector has suffered a neglect in the past ignoring the untapped potential for food production and income generation nationally including the Himalayan region. Farmers in the Himalayan region have many myths and negative apprehensions on fish and fish farming (Muruganandam, 2009; Muruganandam *et al.,* 2011). Majority of the existing water resources and ponds are not used for fish production optimally in the region. Despite the presence of good amount of water yield and economically viable and ecologically sound fish farming technologies suitable for Water Harvesting Structures (WHS) and harvested water (Muruganandam and Sastry, 1997; Muruganandam and Sharda, 2007; Muruganandam, 1999; 2010), fish farming interventions and management of aquatic ecosystems have not been adequately emphasized or accommodated in Integrated Watershed Development Programs (IWDP) executed in the country. Largely, aquatic and fisheries resources and their management continue to remain the interests of only aquaculturists or fisheries professionals in isolation against the requirement of making them everybody's interests and the task of multidisciplinary people or considerations. Even the calculations of soil tolerance (T) limits and the green Gross Domestic Products (g GDP) or Gross Environmental Products (GEP) for a given location or region are often assessed only with reference to productivity of crops and such other water uses, but largely not account the attributes of aquatic lives and fishes.

Most of the soil and water conservation and NRM interventions are executed only on land, soil or land-based farming resources in the region and not necessarily extended to river courses or associated water resources and their inhabitants, making such interventions incomplete. Presently, streams, rivers and their components such as contributing watersheds, river channel, riparian floodplain and flowing water or its constitutions (Sharda *et al.,* 2006) are not usually managed in a holistic approach to bring out sustainable tangible and intangible benefits. The water resources are often left to take their own natural course or as influenced by human deeds that are mostly unplanned. The influences or cause and effect of various water management and soil-water conservation measures executed in catchment and drainage-line on river stabilization, water quality, distribution or assemblages of fish biodiversity, linkages in catchment, aquatic ecosystems and farming potential present in them are not largely studied.

The uses or services of streams, rivers or other aquatic resources of the region and their potential for fisheries development and the support given to local people for sustenance need adequate characterization or quantification using suitable tools and techniques. Similarly, baring few exceptions, the linkages or associations existing between watershed management, water harvesting, fishing and fish farming or fisheries development have not been understood adequately or harnessed for the benefit of society and environment. Research on interface between various issues of fisheries and integrated watershed management are scanty, particularly with reference to specification of critical limits, decision rules for resource use and generation of suitable prototypes or generic models with user-friendly components. Before such studies could take a lead most aquatic resources maybe depleted without even being documented. All these could be the reasons for the continuing

decline and insignificant contribution of fisheries production to the regional or national productivity.

Effective Integrated Watershed Management Programs (IWMP) needed

Survivability and sustainability of fishes and fisheries resources invariably depends on the righteous management of catchment, land resources, farming activities etc. through effective soil and water conservation or management interventions besides the management of drainage-line, rivers and other aquatic resources *per se*. In effect, existence of fishes and their habitats depend on management of catchment and their resources. The challenge of improving fisheries in mountainous region (coldwater fisheries) lies in bringing out meaningful strategies and workable action plans making necessary adjustments in agricultural production systems, keeping in view the social and developmental priorities, needs and traditional wisdom of people. The gap in potential and production or demands and supply of fisheries resources, especially in under-developed regions like Himalayan States warrants multifarious developmental plans, which again necessitates comprehension, categorisation and management of aquatic resources by all the stakeholders. This can be achieved through Integrated Watershed Management Programs (IWMP), which normally internalises ecosystem principles or approaches.

In the IWMP, multi-tier, ridge-to-valley approach progressing from first-order to higher-order springs or rivers and integration of interventions from various disciplines are planned or accommodated to sustain benefits out of available or developed resources. Use of different structures or approaches such as Gabion structures, check dams, retention walls, spurs, retards, stonewall, vegetative barriers, geo-jute layering etc., WHS, conservation agronomy, agro-forestry, promotion of Integrated Farming Systems (IFS) with low input accommodative agriculture, grassland management, protective forest cover management in up-hills etc. are usually contemplated in the watershed approach. The IWMP aims to control soil erosion, silts and sediments reaching river courses or water bodies, land degradation and extension of torrents and improve productivity of arable or stabilise non-arable lands. Also, optimum use of water resources, marginal lands and farming opportunities through integration of various farming systems or components incorporated effectively into existing land-use pattern as innovative multi-tier farming for production of multi-commodities from common infrastructural bases is contemplated.

In the next-generation watershed development or watershed-plus programs, attributes related to fishes, fisheries and aquatic resources need proper recognition or inclusion decisively. While evolving various soil and water conservation or management techniques, concepts and evaluation of programs, fisheries concerns need accommodation, especially in dealing with fisheries-sensitive watersheds as that of other counties like Canada and USA, where they are well recognised. Accommodation of fisheries issues in water or watershed management programs promote thrusts to reduce loss of soil and water resources, water harvesting etc. in watersheds and river management, which in turn improve health of watersheds and rivers benefiting many other production avenues. Here, strengthening of fisheries management capacity, especially under IWMP is another fundamental need in developing countries like India, particularly at a time when increasing population growth and declining natural resources are experienced. Overall, multidisciplinary experts and various stakeholders including farming communities and government machinery who plan or execute various activities in the catchment need to consider the plight of fishes and fisheries resources and cooperate radically to bring multidisciplinary interventions in catchment, drainage-line and aquatic resources towards the betterment of society and environment.

Watershed-based Fisheries Development Plans (WFDP): A proposal

Watershed-based Fisheries Development or Sustainability Plans (WFDP) introduced in British Columbia (BC), Canada as a new approach to the management of fish stocks and fish habitats in 2001 (Tamblyn and Croft 2003; Muruganandam, 2012) is worth emulating to India and the Himalayan region. The WFDP becomes necessary since all aquatic ecosystems, watersheds, rivers, oceans are interconnected through upstream-downstream cords and riparian-upland ecosystems affecting one another and in-stream conditions. In the plan, watersheds, associated processes and inter-connections of both in-stream and upland are planned and managed with "fish first approach". Trade-offs between upstream and downstream is internalized in the approach, wherein the restoration or management of streams or watersheds and opportunities within them are identified for promotion of sustainable fisheries development. The approach recognizes that ecological, social, political and economical factors influence the status of fishes and habitats, which need categorical consideration.

In the approach basins, watersheds, habitats, fish species etc. are prioritized for protection, restoration and sustainability enhancement with the principle that prevention is better than cure or restoration. The WFDP works from river basins, sub-basins to watershed-scale based on identified priority watersheds, species or habitats at risk. The WFDP builds on the lessons of the past to help government agencies and other stakeholders including fish interests and non-fish interests. It may be an innovation that helps avoid water use conflicts, promote conservation and sustainable use of resources in an equitable way or rights, and bring a commitment to work jointly in watershed-based fish production planning processes on consultation with stakeholders.

At present, various components of the WFDP are executed in bits and parts by various agencies or groups in India, which needs consolidation through concerted effort towards the unified approach. Normally, above 3rd-order rivers are subjected to intense fishing with the maximum in 5th-order onwards and hence they are more important for fishing and fisheries management. Nonetheless, all the streams or rivers need to be managed including the feeder or lower-order streams since they contribute immensely to higher-order Rivers for their geomorphic conditions, riparian features, water chemistry, flow characteristics, sediment regimes, nutrients, silt loads, composition of aquatic organisms and other biotic components. More specifically, fisheries-sensitive watersheds and streams or rivers maybe identified by looking at the presence of erosion-proneness, excessive water yields or runoff potential, rich fish resources and fish demands for their specific and categorical management.

Immediate needs of technological, policy and societal reforms for fisheries development

The present situation of poor productivity or production from fisheries resources warrants multi-dimensional interventions. Some of them are:

1. ***Developmental and extension needs***

i. Development of situation-specific integrated farming systems,
ii. Value addition to existing ponds, WHS etc. (provision of proper inlet, out let, etc.),
iii. Production and distribution of bigger size fish seedlings for culture,
iv. Networking farmers and consumers to facilitate production of seeds and feeds, their distribution, culture and marketing or market development,
v. Capacity building and human resource development.

2. ***Policy reforms***

i. Policies for leasing of land, pond or specific stretches of streams for farming or fishing,
ii. Use of electricity for fish farming as that of agriculture,
iii. Supply of quality and bigger size fish seeds for farming.

3. ***Fishing regulations and rivers management***

i. Revival of the loosing symphony between the traditional fishing and the communities' lifestyle by promoting regulations of fishing in wild environments in accordance with the practicable rules and laws promulgated.
ii. Celebrate fishing festivals with lesser impacting alternatives.
iii. Regulation of extraction of river-bed materials in order to sustain fishes in stream or river courses is yet another need.
iv. Provision of fish sanctuaries and refuge shelters along the stream or river courses in suitable locations would improve *in situ* conservation of fish resources.
v. Ranching of fish species, particularly the ones under threats by producing their seeds through artificial propagation may ensure their continued availability in nature.

4. ***Institutional arrangements***

i. Cost-effective financial and institutional arrangements to complement government or donor resources would augment delivery of goods and services from water resources and fisheries sector.

5. ***Cooperation of local people***

i. Cooperation of local people for management of rivers and fisheries resources maybe sought by devising suitable means or mechanism and by making them as partners with the government machinery in development plans or programmes to manage the vast water resources.

Research needs on watershed-based fisheries development

I. ***On streams, rivers and watersheds related***

1. Extensive surveys to create data-banks on various aspects of fishes and fisheries resources, linkages between catchment and water courses, contribution of riparian vegetation to streams etc. including biological, physical, chemical, physico-chemical, social, economical and environmental attributes.

   Information need to be generated on stream features, fish species distribution, trend variations etc., conservation status, spawning details, habitat features, in-stream flow and stream channel, management needed etc. for planning. It may require an inter-agency effort coordinated by Riverine Fisheries Information System (RFIS) that maybe established.

2. Integrative parameters for evaluation of habitant condition-substrate composition, flow velocity, water depth, percentage occurrence of various in-stream structures, *e.g.* undercut banks, overhanging vegetation, roots, weeds, debris etc., benthic and transported organic matter and indices like Index of Biotic Integrity (IBI) and Qualitative Habitat Evaluation Index (QHEI) need to be studied or used to reflect naturalness of streams or rivers, ecological health or integrity, habitat-physical environment, key functions and processes occurring in the streams and rivers present in the region.

Four groups of evaluation criteria with reference to aquatic ecosystems and their vitality to identify severity of human impacts on them *viz.* i) discharge regime, ii) morphological characteristics, iii) lateral connectivity, iv) longitudinal corridor maybe studied.

3. Analysis on fisheries dimensions from "coast to mountains": Monitoring and assessment of existing upstream-downstream variations or linkages in selected watersheds or river systems and altitude-wise distribution of fish species in catchments.
   i. Evaluation of elevation or altitude-(<500-1000, 1000-2000, 2000-3000 and >3000 m amsl) and land use (forest, agriculture, settlement etc.)-dependent variations in water quality, fish diversity, population dynamics, distribution, assemblage, ecology etc. and availability of fish farming related inputs and production potential or threats in selected tributaries of major river systems or their catchments using modern tools and techniques like RS, GIS and Google Earth along with periodical ground truthing surveys so as to derive or help the execution of WFDP. Length frequency analysis of different fishes in fish catches may identify altitudinal and longitudinal changes in size composition of fishes.
   ii. Studies on water balance or budgeting with reference to specific farming systems and their components or features, and overall fisheries development.
   iii. Tolerance limit of various fish and aquatic species to varying levels of turbidity and sediment loads in river courses need understanding.
   iv. Extent and damages of temporary habitats caused by floods and expanded riparian zones that recede after few days succumbing fishes or aquatic species in such habitats to die out of water need quantification.
   v. Impacts of extraction of river-bed materials on riverine habitats and fish diversity so as to suggest ways and means to regulate the extraction activity.

4. Studies to define limits and regulation of fish harvests in rivers and wild environments.

5. On issues of watershed-based fisheries development and fish farming.
   i. Identification, characterisation and management of fisheries-sensitive watersheds and streams for their conservation and sustainability of fisheries development.

   ii. Impact assessment of various developmental or farming activities or land use pattern followed in catchment on runoff water quality *vis-à-vis* aquaculture or fisheries production.

   iii. Identification of reach-specific and cumulative watershed impacts of soil-water conservation measures or structures (*e.g.*, various conservation agriculture practices, WHS, Gabion, trenches etc.), timber harvesting, grazing etc. on wetlands, various aquatic lives or their attributes including fish habitats, biodiversity, distribution, abundance, growth and production in cognate watersheds or downstream.

   iv. Identification of effective soil-water conservation measures to reduce erosive velocity of runoff, soil loss and sedimentation and hence to improve fish stocks in inland water and rivers.

   v. Identification, assessment and exploration of the opportunities within natural streams, irrigation networks, drainage systems and agricultural ecosystems including WHS or ponds using suitably designed production systems or engineered structures like cages, pens, dividers, water or flow regulators like net barriers, gate valves etc. to

accommodate or promote complementary fish farming and fisheries development under IWM programmes in suitable agro-ecosystems.

6. Carbon sequestration potential of fishponds and wetlands in watersheds.

7. The Indigenous Technical Knowledge (ITK) associated with fish and fisheries sector in relation to water management and fisheries production. Evaluation of fish anaesthetics or fish poisons like *Zanthoxylum armatum* (D.C.; *timru*) for productive uses in transport or harvesting of fishes based on the ITK.

II. ***On emerging issues of fish farming related***

8. Identification and evaluation of physiographic and compromised design parameters suitable for WHS or ponds in view of improved aquaculture management practices compatible for watershed management programs.

   i. Water budget specifying water resources available, potential of seepage, percolation and evaporation loss seasonally and required water loss control measures in WHS, farm ponds, wetlands etc.

9. Domestication of various fish species by evolving suitable technologies for breeding and seed production, culture, harvest and post harvests based on scientific studies and data-base created.

10. Development and demonstration of situation-specific IFS and technologies along with crop or species diversification suitable for multiple uses of water.

III. ***Overall capacity building***

11. Capacity building of various functionaries and stakeholders of natural resources on WFDP and fish farming through tailor-made courses, advisory, technical support and by expanding existing training and demonstration programs or facilities as a continuous process.

On the experiences at the CSWCRTI

The Institute

The Central Soil and Water Conservation Research and Training Institute (CSWCRTI) has roots from 1954 and functions under ICAR since April 1st 1974 to tackle problems of soil-water conservation and promote IWM through various modes of research and training. The CSWCRTI with its headquarters at Dehra Dun and 8 research centres across the country, *viz.* Agra, Bellary, Chandigarh, Datia, Koraput, Kota, Udhgamandalam and Vasad has the national mandate to conduct research, impart training and provide consultancies on soil and water conservation, NRM and IWM. The Institute has developed many successful watershed models like Sukhomajri, Relmajra, Fakot, Sainji and Kalimati in different locations of the country.

The institute has been training various clients including local, regional, national and international farmers, technocrats, scientists, planners and students through regular (5½ months biannually, now it has been rescheduled to 4 months) and many demand-based short term (1-30 days) training programs since its inception during 1950s. A total of over 10,000 beneficiaries from various organizations directly besides an equal number through indirect ways have been trained on soil-water conservation and watershed management by the

Institute. The Institute has evolved or refined many technologies and published brochures on over 50 technologies related to soil-water conservation, resource conserving farm technologies including 6 brochures related to watershed-based fish farming and livestock management in user friendly language, few of which are available at <www.cswcrtiweb.org>.

The fisheries section at the Institute

Inception

The purview and scope of IWMP at the Institute has been expanded to include fisheries and livestock management in 1996 with the introduction of few scientific and technical positions for organized research and training. The Institute has hands-on experience of introducing and managing the fisheries and aquatic science based interventions in to NRM and IWM by creating integration with several agricultural disciplines. Promotion and demonstration of fisheries, fish farming and animal husbandry interventions under IWMP in various parts of the country through various research and extension activities are continuing ever since the subjects were introduced into the ongoing themes and programs of the Institute.

Achievements

The section has completed eight fisheries related research and demonstration projects during last 15 years. Various aspects of both river fisheries, ethno-biology of traditional fishing, fish farming and IFS in clusters of watersheds are addressed since the problem of over-fishing and increasing demand for fish needs to be tackled simultaneously and aquaculture has the potential to reduce investment requirement in capture fisheries or reduce fishing pressure in wild environments. The accrued information generated from research on watershed-based fisheries development at CSWCRTI, ICAR, Dehradun have culminated into refining of integrated fish farming technologies suitable for WHS, farm ponds etc. and advancement of knowledge on traditional fishing and their impacts (Table 1).

Table 1. Technologies and knowledge gendered or refined at the CSWCRTI

1. First time formatting of watershed-based fisheries and aquaculture research and training under integrated natural resource management programs.
2. Developed or refined following aquaculture and Integrated Farming Systems (IFS) with refined farming calendar and techniques suitable for western Himalayas.
   i. Composite carp culture in Water Harvesting Structures.
   ii. Water-mill based Integrated Farming System (IFS) suitable for western Himalayas.
   iii. Paddy-fish integrated farming system for western Himalayas.
   iv. Transport techniques of fish seeds and live fishes to and fro watershed ponds.
   v. Design and construction techniques of water harvesting structures for fish farming.
   vi. Livestock based micro-enterprises for watershed development in western Himalayas.
3. Optimization of fisheries resources for aquaculture and integrated watershed management.
4. Appraisal of ethno-biological issues and traditional knowledge on fisheries, particularly on centuries-old fishing festivals of Himalayas.
5. Effective aquaculture and livestock extension approaches and methods.

Watershed-based fisheries development promoted

The institute has comprehended various aspects of traditional fishing, gears and methods of fishing, fishing festivals, fish diversity, fish consumption pattern, fish farming etc. through various watershed development based projects and programs. The IFS model developed (Photo 7) and composite carp culture in rain water harvested ponds or WHS in foothill and mil-hill Himalayas have proven useful to recycle wastes by-products, nutrients

and resources including water between different farming components and promote multiple use of water and management for overall improved productivity through sectional synergism. It had organised tailor-made training courses besides routine trainings on watershed-based fisheries development by mobilizing funds from donor agencies (Muruganandam *et al.,* 2012; Muruganandam and Mishra, 2012) to various clients. An indicative brief on the achievement of the fisheries section at CSWCRTI are briefed hereunder.

Comprehension on the traditional fishing made

The Himalayan region is found to have rich traditional knowledge on fishing. Many unscientific gears or methods of fishing are prevalent in the region. Community-based traditional fishing festivals, locally known as *mound* have many socio-cultural instincts and cause damages to aquatic resources greatly. Fishing intensity is higher from 5th-order Rivers onwards. Closer the settlements to streams or rivers maximum are the frequency of fishing in the region. Fishing during nights and flood periods give more fish catches. *Tor putitora* (mahseer), *Schizothorax* spp. (snow trout), *Mastacembalus armatus (*spiny eel), *Labeo* spp. (minor carps) etc. are most preferred or harvested species in western Himalayas.

Integrated Fish Farming System developed

An IFS comprising of water mill, fish farming, poultry, piggery and agriculture was developed in Sainji village of Tehri-Garhwal in Uttarakhand. Water from existing water mill functioning on flow-through water from a 3rd-order stream was channelized in to two cemented water harvesting ponds (100 + 160 m^3) constructed in vertical series. Grownup fish seedlings of Indian and exotic major carps weighing between 20-50 gm were stocked in the ponds @ 1-2 fishes/m^2 for composite carp culture. Bigger size fingerlings register minimum mortality and predation by birds or snakes. A poultry hut (11.6 m^2) and pigsty (6.7 m^2) were constructed above the ponds, where 100-120 *Kuroilers* (a hardy multipurpose fast growing poultry breed) and 4 pigs (Large white Yorkshire) were reared. Leftover from water mills, poultry and pigsty and poultry or pig excreta were used as feeds for fishes or pigs to reduce cost of feeding. Water used for rearing fishes recycled for paddy and vegetable fields through gravity. It was observed that the IFS has potential to yield 40-50 kg fish/100 m^2, 200-250 kg live weight pigs for pork within 6-7 months, 500-650 kg poultry meat and 20-38% additional grain or vegetable yield over and above income received from tradition water mill (Rs. 10,000). Farmers can recover initial investments of about Rs. 70,000-1,20,000 within a period of 3-4 years with overall B:C ratio of 1.9:1.

Paddy-fish integration for western Himalayas

Fish culture in paddy fields with a loss of 4% paddy area in refuge pond and trenches yielded about 600-900 kg fish ha^{-1} $year^{-1}$. An additional net profit of about Rs. 600-800 per 100 m^2 is realized from paddy fields on integration of fish culture with bare minimum inputs at a unit cost of Rs. 120 per 100 m^2.

Composite carp culture in Water Harvesting Structures (WHS)

Stocking of grownup seedlings (Photo 8 and 9) at 2 fish per m^2 during March-April for composite carp culture, feeding daily with agricultural by-products like mustard oil cake, rice barn and poor quality wheat or paddy at 2-4% of biomass and harvesting during Dec.-Feb. yield 3.5-4.5.0 t ha^{-1} for a net annual profit of about Rs. 90,000-1,00,000 ha^{-1} $year^{-1}$. More than profit, it helps to ensure much needed quality animal protein to supplement dietary needs.

Conclusion

The Himalayan region with abundant water resources has immense scope for fisheries development. Equally, the region has many constraints for effective water management and fisheries development, which needs to be resolved through renewed research, policy and developmental initiatives. The existence of fishes and their habitats depend on righteous management of catchment and their resources besides the management of drainage-line, rivers and other aquatic resources *per se*. Innovations, technologies and policy refinements towards water conservation or management are the needed continuum. Multidisciplinary experts and various stakeholders including farming communities and government machinery need to consider the plight of fishes and fisheries resources and cooperate radically for the betterment of society and environment. The Watershed-based Fisheries Development Plans (WFDP) and participation of local people seem to have immense potential for development of water resources and fisheries in Himalayas.

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