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Content

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Status and development trend of aquaculture and fisheries in Nepal

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ABSTRACT
Aquaculture is one of the fastest growing agricultural subsectors in Nepal. The current total national fish production is 86544 t of which 24% is contributed by capture fisheries while 76% is from aquaculture. Aquaculture and fisheries together has generated direct employment for 587,172 people. Fish consumption trend is increasing in Nepal. During the period of 1981/82 to 2017/18 annual per capita fish availability by national production has been significantly improved from 330 g to 3010 g. Timely supply of quality seed is essential for aquaculture development. Private sectors are encouraged for seed supply while government has confined its role in quality control. Different fish marketing strategies exist in Nepal. Fish are sold either by the producer themselves from production site or through agent, contractor or whole-seller. Fish demand in market varies from month to month. Higher fish demand is found in winter while least fish consumption is found in rainy season June to September. In fiscal year 2017/18, domestic production occupied 88.2% and imported fish occupied 11.8% of the total national fish consumption whereas fish export remained negligible.

Keywords: Fish production, pond productivity, employment, per capita production

INTRODUCTION
Aquaculture is one of the fastest growing agricultural subsectors in Nepal. Having landlocked in nature, Nepal depends only on inland aquaculture with finfish farming. Climatic condition favors cultivation of both warm and cold-water species. The most common species under cultivation are indigenous and exotic carps, pangas, tilapia, catfish and rainbow trout. Institutional development of aquaculture in Nepal started almost seven decades ago but its development pace was rather slow. Nevertheless, the progress achieved by this sector in last decade is highly commendable. Government programs like fish mission, one village one product, resource center establishment, Prime Minister Agriculture Modernization Project (PMAMP) etc. are the key factors in the development of this sector. Fish consumption in Nepal is rather low compared to poultry, pork, buff and mutton. Increasing health awareness among people has led to rise in fish consumption demanding more aquaculture industries. Government of Nepal is also providing support to establish commercial farms which generate employment as well as income in rural areas. Most of the newly established farms are run by the youths those are back from abroad employment and have contributed in reduction of youth migration to some extent.

This paper discusses present status of aquaculture and fisheries, its contribution in economic development and employment generation and provides information on aquaculture/fisheries sector and its development trend in Nepal. This paper will be useful to planners and policy makers in identifying intervention areas and developing appropriate fisheries and aquaculture policies, plans and programs for sustainable development of this sector.

ORGANIZATION DEVELOPMENT
History of Nepalese aquaculture is very short however, catching fish from nature is being practiced since ancient time. In Nepal, aquaculture development was institutionalized in 2003 BS (1946/47 AD) by establishing fisheries unit under Agriculture Council. This fisheries unit faced several phases of

organizational modification time to time passing through the golden era of fisheries, in terms of organizational strength, when department of fisheries was established.

The first ever fisheries program in Nepal was initiated in 2004 BS (1947/48 AD) and aquaculture started from late 1950s by introducing Common carp (*Cyprinus carpio*) whose successful breeding took place in mid 1960s. Three cultivable species of Chinese carps (*Ctenopharyngodon idella, Hypophthalmicthys molitrix, Aristichthys nobilis*) were introduced in the early 1970s followed by their successful induced breeding in mid 1970s. In the late 1970s, breeding techniques of indigenous major carps (*Labeo rohita, Cirrhina mrigala and Catla catla*) were established (Singh and Yadav, 1996) which was significant achievement in aquaculture history that provided momentum to polyculture system in Nepal.

Previously, Directorate of Fisheries Development (DoFD) and Fisheries Development Centers (FDC) were under Department of Agriculture (DoA), Ministry of Agricultural Development (MoAD) being the focal government organization for aquaculture development whereas fisheries research were carried out by the Fisheries Research Division (FRD) under Nepal Agricultural Research Council (NARC). Aquaculture and Fisheries education is being provided mainly by Agriculture and Forestry University (AFU) and Tribhuvan University (TU) in Nepal. Recently, reconstruction of entire government organization according to the Constitution of Nepal (2072) was carried out which separated the role and responsibilities of different organizations under federal, state and local government. According to this new governmental structure, the Directorate of Fisheries Development (DoFD) got its role as Central Fisheries Promotion and Conservation Center (CFPCC) under the federal government in the fiscal year 2074/75 BS (2017/18 AD). The fisheries and aquaculture development program is one of the important commodity program carried out by Central Fisheries Promotion and Conservation Center under the Department of Livestock Services (DoLS), Ministry of Agriculture and Livestock Development (MoALD). The Center is the commodity specific national focal body. It is responsible for central level policy issues, planning, monitoring and supervision, database, regulatory functions etc. It also coordinates with national and international fisheries and aquaculture related institutions. There are three centers under the CFPCC:

- Fisheries Human Resources Development and Technology Validation Center, Janakpur
- Natural Water Fisheries Promotion and Conservation Center, Hetauda
- Fisheries Pure Line Breed Conservation and Promotion Resource Center, Bhairahawa

There are seven provincial Directorate of Livestock and Fisheries (DLF) one each in seven provinces, responsible for carrying out Livestock and Fisheries program, regulatory functions within the province and coordination between federal and local level institutions. Under DLF, there are forty-seven Veterinary Hospital and Livestock Services Expert Centers (VHLSECs). Out of forty-seven VHLSECs, twenty-one have fisheries technician, who are responsible for carrying out aquaculture and fisheries extension program within their respective districts. Likewise, there are seven provincial Fisheries Development Centers (FDCs), mandated for fish seed production and distribution, technical support services and basic laboratory services.

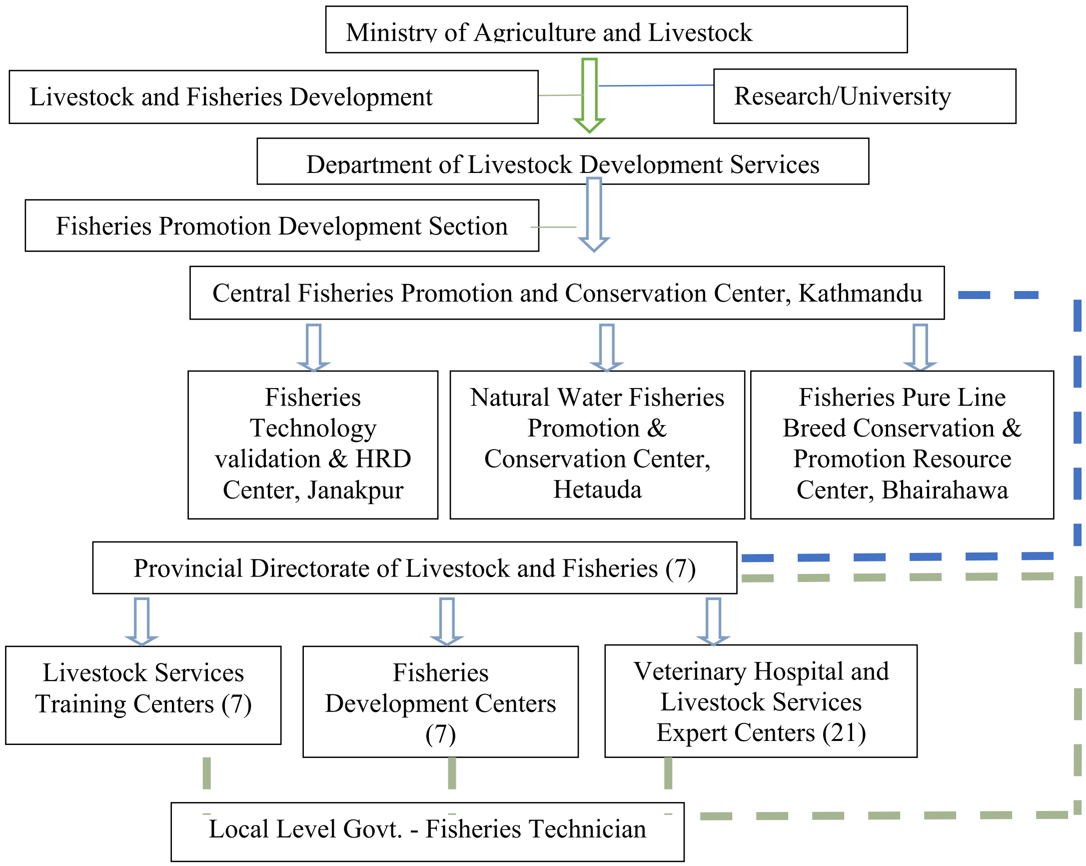

Figure 1: Institutional Frameworks for Fisheries and Aquaculture in Nepal

NATURAL WATER RESOURCES

Nepal is rich in natural water resources. Rivers, lakes, reservoirs, swamps and low land irrigated paddy fields are the major source of fresh water in Nepal (Figure 2). Among them rivers and low land irrigated paddy fields are the most dominant natural water resources. Besides, these natural waters, Gurung (2014) has reported 7,900 km of irrigation canals in the country.

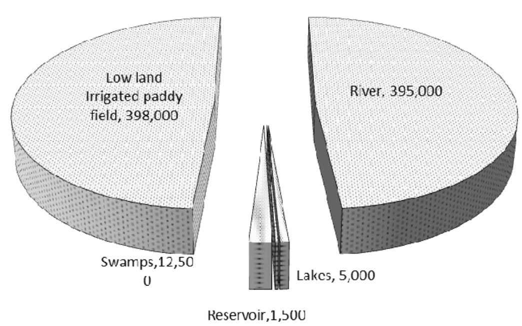

Figure 2: Natural water resources (ha) in Nepal

Capture fisheries is an important sector because of its role in fish production as well as employment generation. Capture fisheries production is 21,000 mt which seems almost constant from last several years. Irrigated paddy fields, rivers and swamps have significant contribution in capture fish production whereas reservoirs and lakes have least contribution (Figure 3). Lakes and reservoirs occupies less water surface area compared to other natural water resources as well.

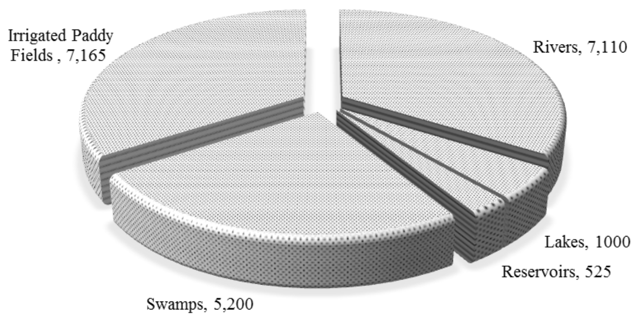

Figure 3: Fish capture (t) from various water bodies

STATUS OF AQUACULTURE AND FISHERIES

Various types of aquaculture practices are being adopted that has produced 65,544 mt fish in fiscal year 2017/18 (CFPCC, 2017/18). Pond aquaculture is the major contributor which alone generated 89.1% (58,433 t) of the total aquaculture production (Table 1). In pond aquaculture, Chinese carps and Indian major carps are the dominant species with average productivity of 4.91 t/ha. These species are generally stocked under polyculture system. However, monoculture of common carp, tilapia, pangas and catfish have also been reported in some places. Interest in aquaculture is growing and has expanded to 55 districts out of 77districts compared to 30 districts a decade ago.

Table 1: Status of aquaculture and fisheries in 2017/18 (CFPCC, 2017/18)

Particulars	Pond (no)	Total Area (ha)	Fish Production (t)	Productivity (t/ha)
A. Fish Production from Aquaculture Practices			65544	
A1 Pond fish culture	45,431	11,895	58,433	4.91
A2 Other area (swamps)		3,550	6,390	1.8
A3 Paddy cum fish culture, government farms and enclosure		150	98.8	0.94
A4 Cage fish culture (m^3)		71,800	302.28	4.2 kg/m^3
A5 Trout culture in Raceway		3.2	320	100
B. Fish Production from Capture Fisheries			21,000	
B1 Rivers		395,000	7,110	18 kg/ha
B2 Lakes		5,000	1000	200 kg/ha
B3 Reservoirs		1,500	525	350 kg/ha
B4 Swamps		9,000	5,200	578 kg/ha
B5 Low land irrigated paddy fields		398,000	7,165	18 kg/ha
Total Fish Production (t)			86,544	

Pond aquaculture has been categorized into extensive, semi-intensive and intensive farming. Intensive farming of *Cirrhina mrigala* under single stocking and multiple harvesting to produce finger size fish, called Chhadi, is also a successful farming system in Nepal. Now it is popular in Central Terai and gaining popularity in other regions. Farmers have reported productivity of Chhadi system up to 12-15 mt/ha. Such finger sized fish are demanded in hotels and restaurants mainly on highways as snacks.

After pond aquaculture, second contributor in fish production is swamps. There are 3,500 ha area of swamps being used in aquaculture with 6,390 mt production in 2017/18. Most of these swamps are concentrated in mid-western and far-western Terai region of Nepal. Fish culture in cage produced 302.2 mt fish in 2017/18. Cage technology was used for the first time in 1972 in Lake Phewa to raise brood fish of common carp. Current data shows that cages occupy 71,000 m^3 with average productivity of 4.2 kg/m^3. This is a proven technology of income generation for land less fisher communities who rely on water resource for their livelihood. However, cage culture is confined to only few lakes of Pokhara Valley and Kulekhani reservoir which can be extended in other potential water bodies in future. Vast area of reservoirs will be added when all the hydroelectric projects are accomplished, which shows great potential for cage culture in Nepal.

Rice cum fish culture is a popular farming technique in India (Asam, Meghalaya), Indonesia, China and Bangladesh. Rice field is not only used for fish but also for duck, ornamental fish species, crab and prawn production. Rice cum fish culture is successful in neighboring countries but this farming system could not get much attention in Nepal due to which only limited area of paddy fields are used for this culture system.

Rainbow trout, a cold water species, was introduced for the first time in 1969 from India and re-introduced from Japan in 1988 (Rai, 2010). Commercial farming started from Rasuwa and Nuwakot district under one village one product (OVOP) program. With the technological innovation of highly commercial rainbow trout aquaculture, today trout culture has spread to 24 hill and mountainous districts of Nepal with prospects to expand in all hilly areas. Among these districts, Kaski is the leading trout producing district in Nepal. By the end of fiscal year 2018/19, trout production has reached to 320 mt. Trout is a unique and the most expensive fish species in Nepali market because of its taste and high nutritional value. Trout farm integrated with restaurant is a common and successful practice in Nepal which is necessary mainly for small-scale farmers to sustain their business. So far, National Inland Fisheries and Aquaculture Development Program (NIFADP) and Fisheries research centers are the focal government organization that provides technical support and monitors trout development programs in the country.

EMPLOYMENT GENERATION BY FISHERIES SUBSECTOR

Like other developing countries, employment is a serious problem in Nepal. Large number of youth emigrates annually in search of job. In this context, fisheries sub-sector can be an alternate to minimize youth migration by providing them employment opportunities in various fisheries and aquaculture related activities. Nepali economy is largely dependent on remittance. Such economy may crash anytime and it's not reliable. Therefore, expansion of aquaculture might be one of the options to overcome such outmigration problem and create jobs within the nation to attract youngsters and utilize them in national development.

Aquaculture in employment generation

Aquaculture is still a small and primitive sub-sector in Nepal, however it plays significant role in employment generation. People of different age and sex are involved in aquaculture from equipment preparation, fish husbandry to marketing of fish and fisheries items. There are about 138,439 people directly engaged in this sub-sector among them male covers 68% while female occupies only 32%.

Capture fisheries in employment generation

Natural water especially rivers and lakes are the source of economy to many fisher communities. Approximately twelve different ethnic communities are involved directly or indirectly in fisheries (Gurung, 2005). These communities live near water resource and depending on such resource for their livelihood from generation to generation. There are 448,734 people engaged in capture fisheries among them 60% are female. Females are not only engaged in capturing fish but also in preparing fishing gears and equipment, as well as selling fish in the market.

DEVELOPMENT TREND

Among the various culture practices, pond culture is the dominant fish farming practice and is increasing rapidly while other aquaculture activities remained standstill in last decade. From the very beginning of the aquaculture development in Nepal major aquaculture species were finfish culture and very little and unrecorded amount of indigenous aquatic plants and other aquatic animals were as aquatic products. The major part of the finfishes was occupied by major carps with exotic common carp and other three exotic Chinese carps and were principally used for the carp polyculture. Then and after carp polyculture has huge contribution for the aquaculture development in Nepal. Development of aquaculture has boosted up with the new technology and the species introduced with the time. Introduction of the Rainbow trout lift up the production amount of cold water aquaculture. With the introduction of Tilapia and Pangas has showed the new path and dimension for the monoculture system of aquaculture. Innovation of new technology as Chhadi fish has also added the amount of fish in the national fish production which is increasing rapidly in Nepal. It has been increased by more than five folds during last 18 years from 17,100 in 2001-02 to 65,544 in 2017/18 (Figure 4).

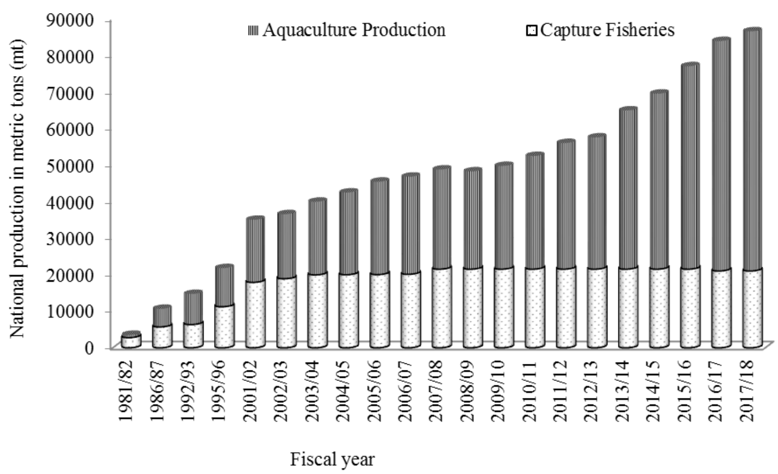

Figure 4: Fish production trend in Nepal

Expansion of pond area

Aquaculture sector in Nepal has become good money returning sub-sector of agriculture. In Terai area of Nepal consumers are also increasing with the availability of the fish in market. From the beginning time of the aquaculture technology introduction in Nepal very few farmers had come to the front in this sector due to high investment in initial stage. Many program and projects has helped and facilitated to subsidize for different inputs which brought of significant change in the development of the aquaculture effectively in Nepal. Government of Nepal has initiated with the subsidy program for the pond construction that really cost high in beginners of this sector. The successful implementation of that program influence the planners as well as farmers to give the aqua-business a new platform. Presently government of Nepal has many more subsidy program for the high investment inputs in aquaculture business. The area expansion program was the breakthrough for the aqua-business sector of Nepal. The highest pond construction (734 ha) was achieved in the fiscal year 2015/16 which is due to introduction of special program for pond construction (Figure 5). Pond fish culture is dominant in Terai belt but its expansion in hill regions has also accelerated after implementation of pond expansion program in mid-hill districts from fiscal year 2011/12 by Nepal government.

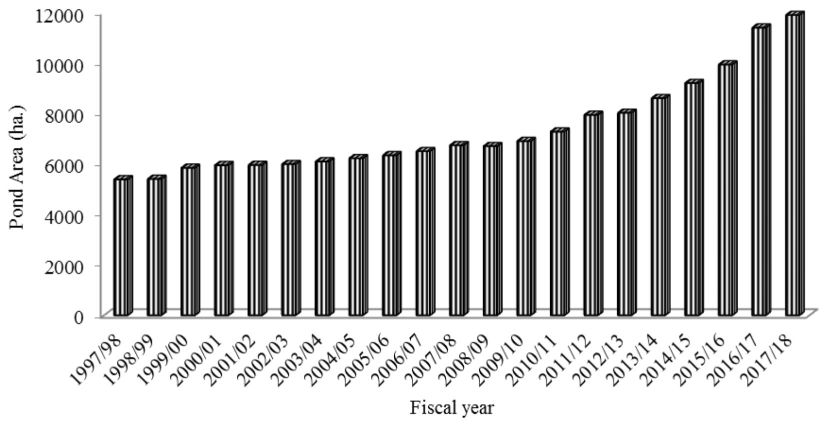

Figure 5: Expansion trend of pond area

Pond productivity in 1981/82 was only 0.8 mt/ha, which is increased to 4.91 mt/ha in 2017/18. This increased productivity has significant impact on national fish production. Improvement in technology, mechanization and good management practices (GMP) are the reasons for increased productivity. Government of Nepal always give emphasis to farm mechanization like using pellet machines to produce farm made cheap and quality feed and using aerators to improve water quality and enhance stocking density for higher production per unit area.

National production

FAO country profile of Nepal reports only 500 mt of national fish production in 1950. This production was entirely contributed by capture fisheries. Aquaculture production was recorded only from 1966 with total of 3 mt of fish production. Aquaculture production kept increasing slowly and steadily because of growing concern on aquaculture education, research and technology dissemination. Capture fisheries shows increasing trend in the beginning but remained more or less constant since the beginning of 21st century. Even keeping this capture at standstill is a big challenge for us. Production status of fiscal year 2017/18 shows that out of 86,544 mt fish production 24% comes from capture fisheries where as 76% from aquaculture (Figure 4).

Per capita consumption of fish has also significantly changed from 330 g/yr to 3,390g/yr since 1981/82 to 2017/18, which may be credited to increase in national fish production. However, is still very blow compared to global average per capita consumption of 16 kg/yr (Gurung, 2014).

FISH SEED SUPPLY

Seed is one of the most important inputs in aquaculture. Quality seed is must to enhance productivity of aqua farms. In Nepal, fish seed are distributed in three forms: hatchlings (4-5 days), fry (2-3 cm or ~1 g) and fingerlings (5-7 g). Both public and private sectors are contributing for seed supply. There are 14 Governments (CFPCC & NARC) and 83 private hatcheries, 235 Nursery and 30 fish seed traders working in Nepal.

In last decade seed supply by public sector remained more or less constant while private sector has jumped from 5.7 million in 2001/02 to 220 million in 2017/18 (Table 2.) this is because government has given priority to private sector in seed supply (Figure 6). To empower private sector, various supportive programs are being launched like establishing fish seed resource centers under private ownership.

Table 2: Status of fish seed production in 2017/18 (CFPCC, 2017/18)

A. Fish seed production/distribution (No. in ’000)	295,130
A[1] Public Sector	75,505
a. Hatchling*	257,425
b. Fry	18,037
c. Fingerling	16,650
A[2] Private Sector (Fry)	220,625

*Hatchling of public sector is distributed for fry production in private sector

Because of increasing demand, seed supply is challenging not only in terms of quantity but also in terms of quality. Government is responsible in providing financial and technical supports as well as monitoring their activities. Nepal government is preparing fisheries policy which is on the process of approval. This policy will be a milestone in assuring quality seed supply within the country. Fish seed production and distribution trends of both public and private sectors are illustrated in Figure 9.

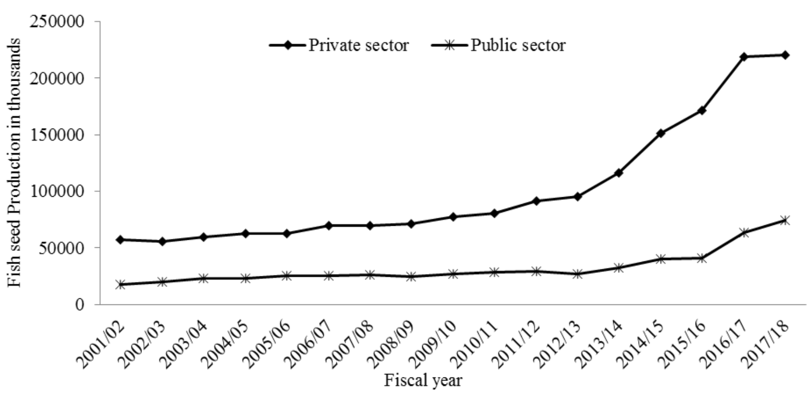

Figure 6: Fish seed (fry) production and distribution trend

FISH MARKET

There is no single fish marketing strategy in Nepal. It varies from place to place. Farmers themselves sell their fish from the production site or send it to local markets. In case of huge production, fish is generally marketed through contractors. There are also farmers' organizations that produce fish and sell them through cooperatives. Harpan Phewa Matsya Sahakari working in Kaski district is a successful example of practicing such fish marketing system. There are also such cooperatives in Nawalparasi, Rupandehi and Kanchanpur districts (KBNPK, 2010). Recently concept of live fish marketing system has emerged, and the number of live fish shop is increasing. Government is also providing financial support to establish fish marketing stalls and collection centers. Most of the live fish stalls are concentrated in the capital and other big cities where demand of such fish is high. At present, it is reported to have around 50 live fish stalls in Nepal.

In last ten years, price of most of the agricultural commodity including fish has hiked. In 2001/02 price of fresh fish was reported to be Rs 100 per kg which is now Rs 300 per kg on average, but this price is still lower than price of other animal meat products. Therefore, it is the accessible source of animal protein for lower and middle-class citizens. Fish price varies from place to place and are more expensive in metropolitan and capital cities. Fish demand also varies from month to month. Study report shows higher fish demand in winter. The least fish consumption was reported to be in June to September (KBNPK, 2010)

The demand of fish is not entirely full filled by national production, therefore huge amount of fish is imported. India is the major fish exporter while China, Vietnam, Bangladesh are other fish exporting nations to Nepal. According to the quarantine data, certain amount of fish is also exported from Nepal, but this is negligible (Table 3). Due to long open boarder with India, all import/export dealings might have not been recorded properly in government channel. In fiscal year 2016/17, domestic production occupies 88.2% and import occupied 11.8% of the total national fish consumption which is higher than the import recorded in fiscal year 2015/16

Year	Import						Export	
	Fresh Fish (mt)	Boneless fresh fish (mt)	Fish seed (no.)	Dried fish & Sidra (mt)	Fish meal (mt)	Aquarium fish (no)	Fresh Fish (mt)	Fish seed (no.)
2004/05	2547.38	-	949235	74.75	166.43		1.56	233475
2005/06	2058.11	-	1884200	246.07	1602.95		6.42	113000
2006/07	2261.23	-	849270	2510.83	30.02	549764	2.86	
2007/08	2034.77	-	172590	277.12	351.2	2611884	4.15	22300
2008/09	3469.94	-	14212	313.68	1097.75		134.65	25100
2009/10	4334.86	253.2	7493	315.23	432.2		850	
2010/11	5370.20	18	3287834	335.71	481	11158	0.36	
2011/12	7424.94	381.82	8975129	581.81	272.33	28972	0.095	
2012/13	9963.06	270.8	14564100	519.49	214.12	104548	0.2	
2013/14	12869.49	109.5		19882.79	82.86	217248		
2014/15	11176.87			825.4	376.11	256824	0.4	
2015/16	7153.48	125.6	7512360	2589.8	295.45	269825		
2016/17	11220.00	443.4	3781592	683.2	258.7	270979	0.115	
2017/18	10757	491				273528		

Table 3: Import/Export fish and fisheries products
Source: Adopted from Mishra and Kunwar (2014); CAQO (2016/17)

CONCLUSION AND RECOMMENDATION

Aquaculture is highly blooming sub-sector in Nepal. The growth rate of aquaculture is around 13% which is the highest among the SAARC nations which is highly commendable. Realizing its importance and potential, aquaculture is receiving attention from the government as well.

Increased demand of fish has created market opportunity and has attracted to establish commercial fish farms. Technical support to newly established farm is necessary to make them competitive in local, regional and global market. The knowledge of our technical manpower is inadequate to represent aquaculture of 21st century due to limited exposure to study and training programs. Specialized hands-on trainings and studies in specific field like fish breeding, disease, nutrition, genetics and water quality is necessary which should be addressed by concerned authorities in coming days. Strong coordination mechanism is also required among development, research and educational institutions for capacity building and implementing aquaculture and fisheries program effectively and efficiently.

Pond aquaculture is the dominating and prioritized fish farming practice. However, marginal swamps occupying 12,500 ha area should not be neglected. So far only 28% of them are utilized in aquaculture, therefore proper planning and management is required for their optimal utilization in fish production which can provide employment and income opportunities to many land less people. Availability of natural water resources like lakes, reservoirs, swamps make the nation highly potential for culture-based fisheries which are still in underutilization for fish production. Water resource and climatic condition also favors cold water fisheries in Nepal and it is doing well specially in trout farming. To promote trout culture, it is must to minimize production cost that can attract more and more farmers in future and trout can be accessible to middle class consumers as well. To sum up, aquaculture being an important and potential agriculture sub-sectors an appropriate fisheries policy, which is currently lacking, is necessary to boost up the overall development of this commodity in Nepal.

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Aquaculture diversification for sustainable livelihood in Nepal

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ABSTRACT
Nepal is known as 'the water tower' having seven tallest peaks of the world including Mt. Everest, as the point source of many rivers flowing down from high, mid hills and Tarai agro-ecological zones endowed with finfish, shellfish and edible aquatic macrophytes. These resources of inland aquaculture contribute about 2% of GDP. However, climate change, seismic activities, urbanization, small holding and youth migration etc. are main challenges to sustainability of freshwater aquaculture. To overcome these challenges diversification of aquaculture might be one of the options. Therefore, we aim to elucidate common and potential aquaculture diversification applicable to all seven provinces of federal Nepal. For that we assessed present status, research activities; published papers; with performing simple mapping analysis of agro-ecological zones of Nepal with the mean temperature zones of the world. Evidences showed that carps, tilapia and rainbow trout are the major finfish used for aquaculture. For future aquaculture diversification, inclusion of Pangas, *Arctic charr*, *Acipenser*, prawn and several others commodities might be beneficial. Developing freshwater shellfish aquaculture might also be the options along with bio flock technology, recirculating aquaculture systems and use of army insect pupae as cheaper fish feed ingredients along with newer technologies for more opportunities. Micro-nutrient rich small fish are also recommended for aquaculture diversification, wherever adoptable in all provinces. The simple mapping analysis reflected that Nepal would be feasible for freshwater aquaculture technologies used elsewhere in the world because of her vertical gradients endowed with wide array of temperature variations and similarities in several ecological parameters.

Key words: Hydropower, recreation, finfish, shellfish, mapping

INTRODUCTION

Generally farming of freshwater organisms is inland aquaculture. Nepal has unique land linked landscape surrounded by India from south, east and west and China from north having subtropical flat land averaging 64 m elevation in south to world's highest mountain on earth of 8848 m in north within a width and length of 193 km and 885 km, respectively in the areas under active monsoon zone. These mountains along with the monsoon are the main sources of abundant water resources, offering ample opportunity for diverse aquaculture practices with finfish, amphibians, reptiles, crustaceans, mollusk, algae and plants in different agro-ecological locations. The finfish biodiversity is represented by about 232 fish species including numerous small indigenous species (SIS) Nepal. The SIS are generally argued to be contributing much higher nutritive values to global communities (Thilsted et al., 1996; Hossain, 1999; HLPE, 2014; Belsan, 2016; Pradhan et al., 2019).

Aquaculture activities could be performed in all over Nepal, especially after the technological innovation of cold water technologies. However, its mountainous landscape, climate change, seismicity, rapid urbanization, land fragmentation, small holding, youth migration and theirs compounding interactions may poses threat and challenges to sustainability of inland aquaculture (Donnelly, 2011; ADB, 2011; Troell et al., 2014; Tewabe, 2015). To overcome these challenges adopting diversification of aquaculture practices might be a surviving strategy (ICAR, 2010; Nathalie et al., 2010; Schmidt et al., 2011). Therefore, the aim of the present paper is to elucidate the scope of aquaculture diversification for sustainable livelihood in Nepal.

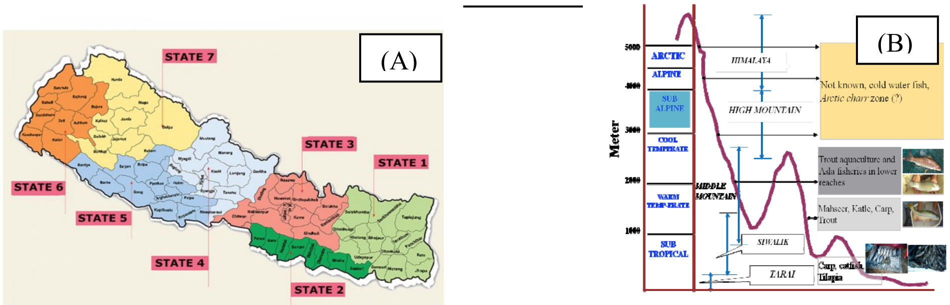

Figure 1: Map of Nepal showing seven provinces (A) with general pattern of vertical cross section of the country (B).

METHODOLOGY

Nepal in general is a mountainous country with the GPS coordinates of 28.3949° N, 84.1240° E having at least three layers of agro-ecological conditions along with many ecological niches and pockets with unique climatic features (Figure 1). Several research articles and reports on aquaculture in Nepal were consulted by desk work and internet search etc. Some of the preliminary information on cultivation, growth and breeding of Pangas, Tilapia, shellfish (Crab, prawn, snail and native shrimp) and summary reports were collected from published resources. To conceptualize the general idea for future potential of aquaculture diversification analysis, we obtained the air temperature distribution map of the world from internet and compared with general climatic conditions of at least three vertical layers of Nepal.

FINDINGS

Present status of aquaculture diversification

Aquaculture is one of the fastest growing food sectors in Nepal (Gurung, 2016), having diversified fin fish farming practices limited to inland water such as cage and raceway aquaculture, fish culture in ponds in integration with, rice, poultry, horticulture, livestock (Gurung, 2012; Shrestha et al., 2002). In Tarai plains, fish species which are popularly used in aquaculture are Chinese and indigenous carp. On addition, recently Tilapia and cat fishes such as *Pangasius* and African catfish have intervened to be additional warm water aquaculture commodities.

In mid hill lakes and reservoir cage fish farming of planktivorous carp (Swar and Pradhan, 1992; Shrestha et al., 2002; Gurung and Bista, 2003; Gurung et al., 2005; 2009) is one of endeavors which required to be multiplied to enhance production for food and nutrition security (Funge-Smith, 2018). Recent studies have shown that SIS (Small Indigenous Species) of finfish could contribute to food and nutrition security and livelihood (Thilsted et al., 1997; Rai et al, 2012). More research towards the determination of nutrients and vitamins in small indigenous finfish for human nutrition would be desirable to highlight the importance of SIS. Similarly, the contribution of freshwater shellfish (snail, bivalve, crabs and shrimp) might add immense food and nutritional value in national total fisheries contribution (Gurung, 2016) as these are being consumed since ancient time among many ethnic communities in Nepal. Moreover, Nepalese finfish has potentiality to diversify towards ornamental, recreational and game fisheries to add benefits for society in multiple dimensions (Shrestha and Pant, 2009; Gurung and Thing, 2016).

It is mainly finfish (a true fish, as distinguished from a shellfish) which has been prioritized in policies and practices in union and provincial governmental agencies in Nepal. As a part of aquaculture, shellfish and aquatic plant farming have yet to be prioritized in national and provincial plans. However, shellfish and aquatic plant products are consumed since tradition in Nepal. The markets of aquatic plant products were well organized in ancient times especially across locations in Nepal bordering with Bihar of India (Jha, 2005).

The freshwater native shellfish such as shrimp, crab, mussel, and mollusk are collected from ditches, streams, canals, wetlands, lakes, ponds, rivers, rice fields as the food resources by rural women and men. The shellfish are one of primitive traditional foods of many ethnic communities' in southern Tarai and mid hills of Nepal. Recently, trend of household consumption of shellfish are in increasing trend because of changing social dimension, awakening from food taboos to health and nutrition conscious population. These facts are evident that native shellfish are sold along with vegetables, meat and fish products in Kathmandu and numerous local, haat-bazar, the traditional market places of southern Tarai. The prioritization of shell fish cultivation as a part of aquaculture diversification in government plans and policies might add additional opportunities for food and nutritional security in the country.

In mid hills and higher mountain, Rainbow trout farming has demonstrated to be successful enterprises (Gurung, 2008; 2010; Pokharel, 2014; Gurung et al., 2017). While working with the rainbow trout, it was realized that this species do not well represent to all cold water agro ecological regions for commercial production. Instead only covering up to certain altitude and water temperature range, generally in an elevation upto 2800 meter having highest water temperature of about 12-14°C for rapid growth. The areas situated above 2800 m having mostly the water temperature range below 12-14°C demands newer species for commercial cultivation. Above 2800 m higher elevation cold water resources may be used for aquaculture, requiring cold tolerant species, such as *Arctic charr* for diversification. Since there are human settlements beyond 2800 m elevation, therefore opportunities prevail to utilize such agro-ecological areas to develop fish farming.

For finfish aquaculture diversification in higher altitude focus might be paid on developing cultivation technologies of three endemic species (*S. raraensis, S. macrophthalmus*, and *S. nepalensis*) inhabiting in Lake Rara (3600 m) as reported by Terashima (1983), Dimmicka and Edds (2002); and *Oxygymnocypris stewartii* of Lhasa River of Tibet (3,656 m) in China (Ng, 2010).

Principles of aquaculture diversification

The principle of aquaculture diversification is associated with food and nutrition security, livelihood, climate change, socio-economic development and sustainability of aquaculture. Therefore, aquaculture diversification is a tool for sustainable approach against climate change. In general, aquaculture diversification meant to reduce drudgery, support to poor and marginalized communities by promoting market opportunities of aquaculture products. Aquaculture diversification provides option associated with demand, knowledge gaps, market, business opportunities and climate change for using suitable fin- and shellfish species which might resist low or high water table, temperature, dissolved oxygen, turbidity, eutrophication and other water quality parameters in aquaculture systems.

It is indispensable that species selection for aquaculture diversification must be compatible with local agro ecological systems, national and international codes of conduct, conventions, laws and bylaws, reduction of pathogen and predator risk and promotion of the local aquatic biodiversity has been described by Pullin (1993). To be sustainable in aquaculture production, the diversification could be a useful tools and strategy, especially in countries like Nepal where climate change are likely to be major challenges for sustainable aquaculture.

Incorporation of institutional, managerial, value chain and policy diversification for aquaculture research and development would also certainly amplify the aquaculture diversification. Recently Agricultural Development Strategy (ADS, 2015) has emphasized strengthening of fisheries sector by establishing Fisheries Research Institute in the country. Such national institute is expected to be instrumental for aquaculture diversification for sustainable development supporting food and nutrition security in the country.

Policy and institutional interventions for aquaculture diversification

In Nepal, finfish has the priority in aquaculture sector; additionally there are opportunities to begin the research on shellfish farming, marketing and other value chain as 30% of total population consume varieties of shellfish in Nepal (Gurung, 2016). Earlier, Nepal has centralized unitary state; recently, the new constitution of Nepal has reformed the country into seven provincial states. This federal system might have advantages for aquaculture diversification at policy and institutional stages. For example the State No 2 might focus for investment on warm water fish cultivation and shellfish farming initiatives, while the provinces in covering mid hills and mountain areas may focus to produce cold water fish species as priority. Similarly other provinces may prioritize aquaculture diversification from their policies. It is strongly recommended that inclusion of shellfish should be initiated as one of the animal food contributors in human diets soon from provincial and union agriculture and livestock ministries.

Among the shellfish, crabs and shrimps are widely accepted as delicacies in all agro-ecological zones, while snail and mussel are consumed by majority of communities in Tarai and inner foot hills. Snail as food is being popular in mid hills of Nepal. The shellfish has greater nutritional advantages as these possess high amount of Calcium (Ca) than in finfish species (Gurung, 2016). Freshwater shellfish are commercially cultivated in many countries (Cholik, 2001; Chopin et al., 2011; Harvey et al., 2017). Research on shellfish cultivation has been started; however, addition of these programs for promotion in national fisheries programs has yet to be initiated in Nepal for more promising aquaculture sustainability. Besides the shellfish, aquatic products such as water chest nut and *Makhana* are produced and harvested from wetlands of Tarai and mid hills since time immortal (Gurung, 2016).

Main drives of aquaculture diversification

The primary drivers for aquaculture diversification are technologies, resilience, competitive advantages, sustainability, environment and market demand climate change, policy, market, economics and social factors (Table 1). Aquaculture diversification offers opportunities for fin and shellfish production at different agro-ecological zones for better economic, social and ecological assurance to aquaculture systems (Harvey et al., 2017). At present, substantial amount of finfish are imported in Nepal (Gurung, 2014) indicating that there are ample market opportunities of aquaculture production, if suitable fish farming technologies were offered to Nepalese farmers. Recently, the Government of Nepal has declared that within few year fish production in Nepal would achieve self-sufficiency; to achieve such target the aquaculture diversification could also play much important roles.

Table 1: Main drivers of aquaculture diversifications

Drivers	Opportunities
Climate change	Changing climate forcing to introduce and examine the potentiality of newer fish species for sustainability of inland aquaculture
Resilience	Being landlocked and mountainous country Nepal has limited opportunity to produce sustainable fish production for resilience, however, aquaculture diversity might increase the resilience opportunities
Competitive advantage	Nepal has diverse ecological niches where only limited volume of aquaculture production can be obtained, however, such niches in other hands might be advantageous offering competitive advantages for variety of fish production
Sustainability	Being mountainous scaling from 60 m elevation from sea level to highest peak on the earth aquaculture diversification is the only option for sustainable production.
Environment	Prevailing environment and agro ecology offers the immense opportunity of aquaculture diversification
Market demand	Day by the demand of fish has been immensely increased in the country almost importing fish equivalent to 3 billion each year.

AQUACULTURE DIVERSIFICATION BY USING SMALL INDIGENOUS SPECIES

Thilsted et al (1997) and Rai et al. (2012) argued that small SIS are enriched with nutrients, vitamins, essential amino acids and fatty acids as an excellent sources for human health, thus such species should be prioritized for aquaculture species diversification. In general, focus on developing cultivation practices of small fish species has not been prioritized due to limited scientists and funding resources. Thus, there should be investment to develop farming practices of SIS from the government for aquaculture diversification. Generally, the advocacy for inclusion of new species in aquaculture practices should be performed by researchers and academicians. After developing technologies adaptable to local socio-economic conditions and ecology SIS commodities could be displayed into the farmer's field for adoption, uptake pathway, piloting and scaling up.

Aquaculture diversification potentialities in provinces

The Constitution of Nepal, Schedule 4 adopted on 20 September 2015 provisioned to have 7 federal states. In all these provinces there remain huge potentialities of aquaculture diversification, however, the existing aquaculture practices and potential diversification in provinces based on the agro-ecological zones has been shown in Table 2.

Table 2: Provinces, existing practices and future potential diversification in aquaculture

State No	Districts	Existing Practices	Diversifications Potentialities
1	Taplejung, Panchthar Ilam, Sankhuwasabha Terhathum, Dhankuta, Bhojpur, Khotang, Solukhumbu, Okhaldhunga, Udayapur, Jhapa, Morang, Sunsari	• Pond aquaculture with carp, Tilapia, catfish (Pangas and African cat fish) • Raceway aquaculture with rainbow trout • Integrated rice-fish farming and others	• Cold water aquaculture with *Arctic charr* • *Acipenser* (Sturgeon) production • *Carp, Tilapia, Pangas, Prawn* aquaculture • Shell fish farming • Pearl farming • Cage fish farming • Frog culture • Macrophyte aquaculture

2	Saptari, Siraha, Dhanusha, Mahottari, Sarlahi, Rautahat, Bara, Parsa	• Pond aquaculture with carp, Tilapia, Catfish as above • Integrated rice-fish farming and others	• *Carp, Tilapia, Pangas, Prawn* aquaculture • Shell fish farming • Pearl farming • Cage fish culture with tilapia • Frog culture • Macrophyte aquaculture
3	Dolakha, Ramechhap, Sindhuli, Kavre, Sindhupalchok, Rasuwa, Nuwakot, Dhading, Chitwan Makwanpur, Bhaktapur, Lalitpur Kathmandu	• Pond aquaculture with carp, Tilapia, catfish (Pangas and African cat fish) • Raceway aquaculture with rainbow trout • Integrated rice-fish farming and others	• Cold water aquaculture with *Arctic charr* • *Carp, Tilapia, Pangas, Prawn* aquaculture • *Acipenser* (Sturgeon) production • Shell fish farming • Pearl farming • Cage fish farming • Frog culture • Macrophyte aquaculture
4.	Gorkha, Lamjung, Tanahun, Kaski, Manang, Mustang, Parbat, Syangja, Myagdi, Baglung Nawalparasi (east)	• Pond aquaculture with carp, Tilapia, catfish (Pangas and African cat fish) • Raceway aquaculture with rainbow trout • Integrated rice-fish farming and others	• Cold water aquaculture with Arctic charr • *Carp, Tilapia, Pangas, Prawn* aquaculture • Shell fish farming • Pearl farming • Cage fish farming • Frog culture • Macrophyte aquaculture • *Acipenser* (Sturgeon) production
5	Nawalparasi (west), Rupandehi, Kapilvastu, Palpa, Arghakhanchi, Gulmi, Rukum (east), Rolpa, Pyuthan, Dang Deukhuri, Banke, Bardiya	• Pond aquaculture with carp, Tilapia, catfish (Pangas and African cat fish) • Raceway aquaculture with rainbow trout • Integrated rice-fish farming and others	• Cold water aquaculture with Arctic charr • *Carp, Tilapia, Pangas, Prawn* aquaculture • Acipenser (Sturgeon) production • Shell fish farming • Pearl farming • Cage fish farming • Frog culture • Macrophyte aquaculture
6	Rukum (west), Salyan, Dolpa, Jumla, Mugu, Humla, Kalikot, Jajarkot, Dailekh, Surkhet	• Pond aquaculture with carp, Tilapia, catfish (Pangas and African cat fish) • Raceway aquaculture with rainbow trout • Integrated rice-fish farming and others	• Cold water aquaculture with Arctic charr • *Carp, Tilapia, Pangas, Prawn* aquaculture • Acipenser (Sturgeon) production • Shell fish farming • Pearl farming • Cage fish farming • Frog culture • Macrophyte aquaculture
7	Bajura, Bajhang, Doti Achham, Darchula,	• Pond aquaculture with carp, Tilapia,	• Cold water aquaculture with Arctic charr • Carp, Tilapia, Pangas, Prawn

	Baitadi, Dadeldhura, Kanchanpur, Kailali	catfish (Pangas and African cat fish) • Rainbow trout farming • Integrated rice-fish farming and others	aquaculture • Shell fish farming • Pearl farming • Cage fish farming • Frog culture • Macrophyte aquaculture • *Acipenser* (Sturgeon) products

To support the further aquaculture diversification, innovation on producing cheaper and nutrient rich pellet feed made up of rice, wheat & maize straw with other important additives would be a mile stone achievement. Nepal has developed the technological capacity to produce dry pellet feeds by the year 1993 (Gurung et al 2017) Some recent technological interventions for example use of black soldier fly (*Hermetia illucens*) maggots as protein sources in fish feed has been achieved elsewhere. It is learned that South African entrepreneur have earned millions US$ from maggot production for fish feed (Baker, 2015).

In general, it seems there are rarely identified finfish species which can perform in cool water (min 15 to max 25°C water temperature in pond conditions) regions of Nepal. For such water range conditions it is assumed that freshwater sturgeon (*Acipenser* sp) might perform well, however, the target product of such aquaculture diversification should prioritized to be the high value caviar over the meat.

The other high important aquaculture diversification potentiality in near future would be prawn (*Macrobranchium* spp) and pearl farming in most provinces of Nepal. Experimentation on pearl cultivation using the indigenous bivalve species has already been started. The experiment at Pokhara Fisheries Research Station showing positive signs of pearl deposition in the shells, such diversification could be applied in most provinces bordering with southern warmer and mid hill mountain areas.

Constraints of aquaculture diversification

- Cost involvement in new species research and development activities
- Long time involvement to develop aquaculture diversification
- Regulation and biodiversity laws
- Area for farming could be limited with increasing aquaculture diversification
- Limited trained human resources
- Issues of diversification on environment and ecosystem

Way forward

Many studies (Paudel, 2016; Gurung, 2017) revealed that Nepal is endowed with diverse agro-ecological conditions. Such agro-ecology is comparative to diverse global agro ecological conditions available in the world (Figure 3). Ensuring that Nepal could adopt the aquaculture technologies practicing elsewhere as has been projected using simple mapping analysis based on the temperature suitability. In general, because of higher altitudinal gradient, Nepal is known to be representing most of average annual temperature range found in worldwide. Therefore, we assumed that the aquaculture technologies developed elsewhere could be adopted with further research and verifications in specific local conditions.

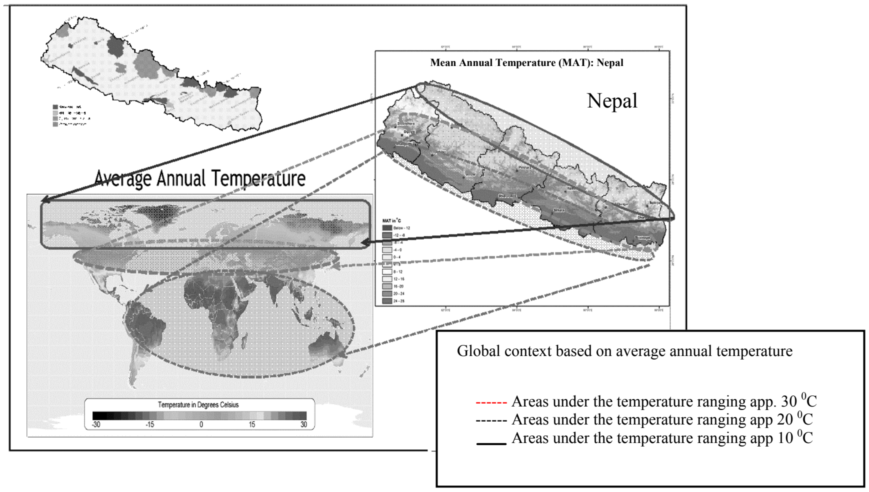

Figure 2: A comparative agro-ecological similarity based on average annual temperature worldwide and Nepal

Recently, Song et al (2018) suggested that inland fisheries are closely impacted by other essential human activities such as hydroelectricity generation, irrigation activities, agricultural run-off etc. Therefore, an understanding of aquaculture interactions with many other sectors would be pre requisite for intersectoral governance for achieving sustainability.

CONCLUSION

By 2050 the population of Nepal is expected to reach approximately 35 million, therefore the government strategies should also be focused on sustainability of its freshwater aquaculture production. The contribution of inland aquaculture is vital from food, nutrition and livelihood perspective to marginalize communities and especially to women. The Government of Nepal recommended 30 g/d fish or meat per capita, i. e., 10.50 kg/y. The present mean consumption of fish from 2.06 kg, per year should reach 9-10 times more to reach average global consumption. Thus, to meet the ever-increasing aquaculture products in the market diversification of aquaculture practices in the country would be inevitable.

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Research status of sahar (*Tor putitora*) aquaculture in Nepal

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ABSTRACT
Sahar (*Tor putitora)* is a high valued indigenous riverine fish of Nepal. It is listed as an IUCN endangered species for its decreasing population in natural waters. The Fisheries Research Center Trishuli succeeded sahar breeding for the first time in 1990 by capturing and stripping wild ripe spawners from tributaries of the Trishuli River. Breeding of pond-reared sahar from river-collected fry was successful in 2000 at Pokhara and Trishuli Research Stations. Trishuli, Pokhara and Kaligandaki Research Stations are currently producing fry of sahar in limited amount. Very recently, the Agriculture and Forestry University, Chitwan, and Center for Aquaculture Agriculure Research and Production (CAARP) Farm in Kathar, Chitwan has succeeded to breed this species with or without using synthetic hormones. Growth experiments with sahar have been conducted since 2003 in several locations and climatic conditions of Nepal: Pokhara, Trishuli, Kaligandaki, Tarahara, Rampur, Kathar, Bhairahawa and Dayanagar. Experiments were also conducted using different culture systems and combinations. The results from all these experiments reveal that sahar can grow to 100-150 g in the first year of culture and 300-400 g in the second year. Results showed higher growth in subtropical climates of Chitwan, Rupandehi, and Sunsari than in the cooler climates of Trishuli, Pokhara and Kaligandaki. Based on the results achieved in sahar breeding and production, we expect sahar to become a species for aquaculture in the near future.

Key words: Sahar, *Tor putitora, endangered species, sahar breeding, sahar aquaculture*

INTRODUCTION

Tor putitora, a cyprinid fish, commonly known as sahar in Nepal and also called golden mahseer, is an indigenous species that inhabits major rivers as well as Phewa and Begnas lakes in Nepal. The species is migratory, over long distances, and also occurs in the South Asia region (Rai, 2008). Sahar is reported its distribution from most of trans-himalayan countries ranging Afghanistan, Bhutan, China, India, Myanmar, Nepal and Pakistan including Bangladesh. Studies have shown that it can survive water temperatures ranging from 7-38 °C (Rai, 2008); however, spawning and growth is better in warm water, temperature ranges from 20-30°C (Rai et al., 2001; Sah, 2006). It formed a substantial natural fishery in the major riverine and lacustrine ecosystem of Nepal (Wagle et al., 2012). This species is greatly valued as game fish for sport fishing. It has high economic value, typically selling for NRs 800-1000 per kg (US$ 8.00-10.00) which is 3-4 times higher than cultured carps and tilapia in local market. However, this fish has not yet been come in commercial production and still under capture fisheries in lakes and rivers. Now a days, sahar population is declining and is in threat due to habitat loss and over fishing, ecological alterations, and physical changes in the natural environment such as damming and degradation of their habitats (Gurung et al., 2002). These has resulted in depletion of natural stocks of sahar to such an extent that they have been identified as critically endangered species (Gurung et al., 2002; Islam, 2002; Rai, 2008).

The culture technology for sahar has not been commercialized as yet; however artificial propagation techniques have been developed successfully in Nepal following many years of research (Rai, 2008; Bista et al., 2012). The Fisheries Research Center Trishuli succeeded breeding sahar for the first time in 1990 by capturing and stripping wild ripe brooders from tributaries of the Trishuli River (Rai, 2008).

Similarly, the Fisheries Research Center Pokhara initiated breeding activities on wild ripe sahar from rivers upstream of Begnas and Phewa lakes. Breeding of pond-reared sahar from river-collected fry was successful in 2000 at Pokhara and Trishuli Research Stations (Gurung et al., 2002). This allowed ranching and stock enhancement of this species in rivers and lakes to increase natural populations to some extent. Trishuli, Pokhara and Kaligandaki Research Stations are currently producing fry of sahar (Bista et al., 2012). Very recently, the Agriculture and Forestry University, Chitwan, and Center for Aquaculture Agriculure Research and Production (CAARP) Farm in Kathar has succeeded to breed this species with or without using synthetic hormones (Jha et al., 2017; Bista et al., 2018). Many factors including spawning and growth characteristics and many subjects have yet to be studied.

Growth experiments with sahar have been conducted since 2003 in several locations and climatic conditions: Pokhara- Kaski, Trishuli- Nuwakot, Kaligandaki- Syangja, Tarahara- Sunsari, Rampur- Chitwan, Kathar- Chitwan, Bhairahawa- Rupandehi and Dayanagar- Rupandehi (Bista et al., 2008; Shrestha et al., 2018). Experiments were also conducted using different culture systems and combinations: cage culture in lakes (Bista et al., 2008), pond culture in concrete and earthen ponds (Sah, 2006; Acharya et al., 2007; Paudel, 2003), polyculture with mixed-sex tilapia in a cage-pond system (Yadav et al., 2007), polyculture with mixed-sex tilapia in concrete and earthen ponds (Acharya et al., 2007), and polyculture with carps and tilapia (Shrestha et al., 2018; Pandit et al., 2018). The results from all these experiments reveal that sahar can grow to 100-150 g in the first year of culture and 300-400 g in the second year. Results showed higher growth in sub-tropical/tropical climates of Chitwan, Rupandehi, and Sunsari than in the cooler climates of Trishuli, Pokhara, and Kaligandaki. Based on these researches, it can be expected that sahar can be a good candidates for aquaculture in the near future. They may be preferred locally, may contribute to preservation of biodiversity, and help maintain integrity of aquatic communities and ecosystems by appropriate management.

Although an omnivorous species, mature sahar are predatory (Shrestha, 1990; Acharya et al., 2007; Paudel, 2003) and their inclusion in tilapia culture systems is believed to limit tilapia recruitment (Shrestha et al., 2011; Yadav et al., 2007). Incorporating sahar into existing carp polyculture systems can aid in their conservation by relieving consumptive pressures on wild stocks and by providing individuals to help reseed natural populations (Rai et al., 2005). In addition, as omnivorous fish, sahar also feed on filamentous algae, insect larvae, and small mollusks. This diet generality and potential to control excessive Nile tilapia recruitment in carp ponds make sahar a perfect candidate species for inclusion in carp polyculture systems in south Asia (Shrestha et al., 2011; Pandit et al., 2018).

HISTORY OF DOMESTICATION

Wild brood fish of sahar were collected from the lakes (Phewa and Begnas) and rivers (Tadi River at Gadkhar and Devighat near Trisuli River) and have been reared in earthen ponds for domestication at the Pokhara and Trishuli Fisheries Research Stations, since 1989, with studies into its spawning behavior (FRC, 2001). The brood fish were fed 2-3% body weight of a 35% crude protein content pellet made locally. Females spawned on and off in the past but not regularly each year. At the beginning breeding activity was carried out using mature wild brood fish in August-September. But at present the brood fish are domesticated and spawn regularly in FRC, Pokhara.

ARTIFICIAL PROPAGATION

A significant progress in artificial propagation of sahar has been achieved in Nepal. In Nepal, the Fisheries Research Center Trishuli succeeded breeding of sahar for the first time in 1990 by capturing and stripping wild ripe spawners from tributaries of the Trishuli River (Gurung et al., 2002; Rai, 2008).

Similarly, the Fisheries Research Center Pokhara initiated breeding activities on wild ripe sahar from rivers upstream of Begnas and Phewa lakes (Gurung et al., 2002). The brood fish were fed 2-3% body weight of a 35% crude protein content pellet made locally (Rai, 2008). Breeding of pond-reared sahar from river-collected fry was successful in 2000 at Pokhara and Trishuli Research Stations (FRC, 2001). This allowed ranching and stock enhancement of this species in rivers and lakes to increase natural populations to some extent. Trishuli, Pokhara and Kaligandaki Research Stations are currently producing fry of sahar. Very recently, the Agriculture and Forestry University, Chitwan, and Center for Aquaculture Research and Production Farm in Kathar has succeeded to breed this species and producing fry (Jha et al., 2017; Bista et al., 2018).

Gurung et al. (2002) reported breeding of pond reared sahar in Pokhara, Nepal. Female sahar of 3-5 years old spawned without hormonal use when reared in ponds at the rate of 1000 kg/ha with 30-40 percent crude protein supplementary feed. Males of more than 2 years age were maintained with similar feed. Ova from mature females were obtained by simple hand-stripping method. Out of 50 females only 4-6 percent released viable ova in April, August, September, October and November 2000, while 12-16 percent of females responded in March and April 2001. Data on breeding of naturally mature brood collected from inlet streams of lakes revealed that golden mahseer could spawn in July, August, September and October. Breeding response studies of pond reared broodstock and data from the field (inlet streams of lakes) both showed that golden mahseer could breed most months of a year when water temperature ranged between 18.5 and 33°C. This study indicated intermittent breeding characteristics of pond-reared sahar. Females released 550 to 19795 ova at single response. Most ova were successfully fertilized and hatched out. During bi-weekly breeder maturity examination in August-November 2000 and March-April 2001 much brood were found over-matured implying that breeders should be examined more frequently. This study suggested that mass scale breeding of sahar is possible by maintaining a reasonable number of broodstock.

After compilation of breeding data, Bista et al. (2012) reported that sahar could breed in most of months of the year but females were not observed ripening during January in FRC Pokhara. It is not yet clear either they could response in January or not. Results showed that Sahar could spawn from March to the first week of December at water temperature ranging from 19 to 32°C, where average water temperature was recorded at FRC, Pokhara (Begnas) from 15-31°C in 2010, while pH values ranged 7.0 to 9.0 and dissolved oxygen from 3 to 9 mg/L.

Bista et al. (2011) evaluated the breeding performance of sahar. The results showed that 60% female responded during autumn season (mid-September to early December) when water temperature ranged from 27-22°C, whereas most of the females (>90%) responded during spring season (late February to late March) at 19-25°C. The fertilization and hatching rate of sahar eggs ranged between 50-95%. Most of the females showed intermittent spawning behavior releasing eggs more than one season. All 100% female were responded for releasing eggs during spring season (February-March). Among them about 58% released viable eggs with normal spawning, 12% released poor quality eggs (low fertilization and hatching rate) and rest 30% were found over matured in spring 2010, whereas only 60% female were responded for releasing eggs and 10% females released viable eggs during autumn (September-October) of 2009. The fertilization and hatching rates were ranged as 50-95%.All the experiments on reproductive behavior suggests that pond-reared sahar could breed at 19-32°C from March to December by simple hand stripping without any hormone use and brood loss. The broods about 30% in spring and 50% in autumn showed over mature ova during routine check, which implied that broods should be examined more frequently.

Jha et al. (2017) explored the breeding performance of sahar in the subtropical/ tropical region of Nepal. The study was conducted at the Department of Aquaculture and Fisheries, Agriculture and Forestry University, Rampur, Chitwan during August 2014 to April 2015. Twenty eight male (0.5-1.5 kg) and 35 female (0.8-2.5 kg) brood fish were reared in ponds at 1000 kg/ha and provided 35% protein feed at 3% body weight per day. Maturity was observed by sampling fish and applying pressure to the abdomen to express gonads biweekly during off-season; this frequency was increased to every third day as breeding season approached. One female sahar of 3-5 years old was ready for breeding in March when the water temperature was 23.3-25.2°C. In the same month, another female responded to injection of inducing hormone (ovaprim) at the rate of 0.5 mL/kg when the temperature was 25.3-28.7°C. Males about 1-2 years old were expressed milt in almost all months during experiment. Ova from mature females were obtained by simple hand stripping method and fertilized with milt collected from males manually. The fertilized eggs were incubated in Atkin hatching trays. Survival and growth of the fry were high (Table 1) and maturation details were similar to fish spawned under temperate conditions. Similarly, breeding has been successful at Center for Aquaculture-Agriculture Research and Production (CAARP) farm Kathar Chitwan during 2017 (Bista et al., 2018). This study demonstrated that natural and induced breeding and fry rearing is possible in the Terai region of Nepal.

GROWTH AND PRODUCTION

Growth experiments with sahar have been conducted since 2003 in several locations and climatic conditions of Nepal such as Pokhara- Kaski, Trishuli- Nuwakot, Kaligandaki- Syangja, Tarahara-Sunsari, Rampur- Chitwan, Kathar- Chitwan, Bhairahawa- Rupandehi and Dayanagar- Rupandehi (Bista et al., 2008; Shrestha et al., 2018). Experiments were also conducted using different culture systems and combinations: cage culture in lakes, pond culture in concrete and earthen ponds, polyculture with mixed-sex Nile tilapia in a cage-pond integration system, polyculture with mixed-sex Nile tilapia in concrete and earthen ponds, and polyculture with carps and Nile tilapia (Rai et al., 2005; Rai et al., 2007). The results from all these experiments reveal that sahar can grow to 100-150 g in the first year of culture and 300-400 g in the second year. Results showed higher growth in sub-tropical climates of Chitwan, Rupandehi, and Sunsari than in the cooler climates of Trishuli, Pokhara, and Kaligandaki (Bista et al., 2008; Shrestha et al., 2018).

Sahar is found at the altitude of 600-2000 m asl and tolerates temperature up to 35°C (Ogale, 2002), which shows the possibilities of its culture in sub-tropical climate too. Some preliminary experiments conducted at Chitwan, Nepal has demonstrated that the southern warmer climate (20-30°C) is more suitable for sahar growth than the mid hills (Shrestha et al., 2005; Bista et al. 2008). Similarly, experiment conducted by Rahman et al. (2007) on polyculture of sahar with Indian major carp shows that sahar would be the best alternative of mrigal in polyculture system. In polyculture, sahar is also more suitable species with Nile tilapia for controlling tilapia recruitments (Shrestha et al., 2011; Acharya et al., 2007; Paudel; 2003). Enhanced growth in tropical and subtropical ponds, as well as the recent breeding success in hatcheries, has raised new hopes on the prospects of sahar aquaculture in Nepal (Shrestha et al., 2005, 2012; Bista et al., 2001; Rai, 2008), with that the species has shown the good results in different polyculture system in terai region which also encourage the seed production technology in terai.

The results of experiment on different culture system and combinations are summarized as follows:

a. Sahar as a candidate to control tilapia recruits

Although an omnivorous species, adult sahar are predatory and their inclusion in mixed-sex tilapia culture systems has been proved to limit tilapia recruitment (Shrestha et al., 2011; Yadav et al., 2007) in ponds.

Growth performance of sahar in monoculture and polyculture with Nile tilapia was evaluated by Acharya et al. (2007). The experiment was conducted for 161 days in 9 cemented tanks (24 m^2) at the Institute of Agriculture and Animal Science, Rampur, Chitwan. There were three treatments replicated thrice: (1) Sahar monoculture at 1 fish/m^2; (2) Nile tilapia monoculture at 1 fish/m^2; and (3) Sahar at 1 fish/m^2 + Nile tilapia at 1 fish/m^2. The mean stocking size of sahar and Nile tilapia were 25.5 and 22.5 g, respectively. Fish were fed with 35% CP pellet feed at the rate of 3% body weight daily. At the end of experiment, sahar attained mean size of 78.0 and 77.6 g, in monoculture and polyculture, respectively with survival rate of 92% and daily growth rate of 0.32 g/fish/day for both systems. Sahar effectively controlled the recruits of Nile tilapia. The mean number of Nile tilapia recruits were 1745.0 and 2.7 per tank in monoculture and polyculture, respectively.

Yadav et al. (2007) used sahar in cage-cum-pond integration system of mixed-sex Nile tilapia.This experiment was conducted in 15 outdoor cemented ponds of 24 m^2 size placing a cage of 1.2m× 1m × 1m size holding 1 m^3 water at the center of each pond at the Institute of Agriculture and Animal Science, Rampur, Chitwan, for 158 days. The treatments were: large sized Nile tilapia in cage and small sized Nile tilapia in pond (cage-cum-pond system) (T_1); cage-cum-pond system with 2 sahar (T_2), cage-cum-pond system with 4 sahar (T_3), cage-cum-pond system with 8 sahar (T_4) and cage-cum-pond system with 16 sahar (T_5). Stocking density of caged and pond tilapia was 1 fish/m^2 and 2 fish/m^2, and size was 78-90 g and 15-16 g, respectively. The feed, containing 20% crude protein, was supplied for caged tilapia at the rate of 2% body weight daily. Results showed that mean stocking size, harvest size, survival rate, daily weight gain and net fish yield of both caged and pond Nile tilapia were not significantly different among treatments ($p>0.05$). Mean harvest weight and daily weight gain of sahar in treatment 2 (268.0g and 1.1 g/fish/day) were significantly higher than other treatments. Higher numbers of recruits were observed in control (603 recruits/tank) and lowest in the treatment 5 (6 recruits /tank) suggesting that higher number of sahar in this system effectively controls the tilapia recruits.

Shrestha et al. (2011) conducted an experiment in 100 m^2earthen ponds at the Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal for 8 months to determine the predatory effects of sahar in Nile tilapia ponds. The experiment had four treatments with three replicates each: tilapia monoculture (T_1), 1:16 sahar to tilapia ratio (T_2), 1:8 sahar to tilapia ratio (T_3), and 1:4 sahar to tilapia ratio (T_4). Tilapia were stocked at 2 fish/m^2 (average size 11.3 g), and sahar were stocked at treatment densities (15.2 g average size) in each pond. The ponds were fertilized weekly using di-ammonium phosphate (DAP) and urea at the rate of 0.1 g P/m^2/day and 0.4 g N/m^2/day, respectively. Tilapia were fed with 27% crude protein home-made pelleted feed at the rate of 2% body weight in alternate day after attaining a size of 100 g. Results showed significantly increased average harvest size of tilapia for treatment 2 (112.0 g), when sahar were stocked with tilapia compared to the tilapia monoculture. (92.4 g). The number of recruits significantly decreased when sahar were stocked, and recruit numbers were inversely proportional to stocking density of sahar. Stocking at a 1:16 sahar to tilapia ratio gave the best overall performance. This experiment was repeated in farmers' field at Kathar, Chitwan, Nepal to verify the results and similar result was observed. Sharma et al. (2009) and Gharti et al. (2011) also observed similar results.

b. Integrated cage-cum-pond culture system with sahar in cages suspended in carp polyculture ponds

This experiment was conducted for 150 days in 15 earthen ponds, 100 m^2 in surface area and 1.2 m in depth, at the Institute of Agriculture and Animal science (IAAS), Rampur, Chitwan, Nepal **(**Shrestha et al., 2005**)**. One cage (1.5 x 1.5 x 1 m and water volume of $2m^3$) covered with 1 cm mesh net was suspended in each of the treatment ponds. There were one control and four treatments with three replicates each: carps at 1 fish/m^2 in open ponds without cages (control); sahar at 5 fish/m^3 in cages and carps at 1 fish/m^2 in open ponds (5 fish/m^3); (3) sahar at 25 fish/m^3 in cages and carps at 1 fish/m^2 in open ponds (25 fish/m^3); sahar at 50 fish m-3 in cages and carps at 1 fish/m^2 in open ponds (50 fish/m^3); sahar at 100 fish/m^3 in cages and carps at 1 fish/m^2 in open ponds (100 fish/m^3), giving ratios of caged to open-pond fish of 0:1, 0.1:1, 0.5:1, 1:1, and 2:1. Caged sahar were fed with a locally made pelleted feed (28% crude protein), while no feed or fertilizer was added into open water of treatment ponds. The control ponds were fertilized weekly using DAP and urea at rates of 4 kg N and 2 kg P /ha/day. Survival of sahar was high without significant differences among treatments. Daily weight gains of sahar, ranging from 0.11 to 0.25 g/fish, were significantly higher at low stocking densities of sahar. Feed conversion ratio (FCR) of sahar ranged from 2.2 to 2.8, and was not significantly different among treatments. The total net and gross yields of all carps were significantly higher in the control than in treatments. The total net and gross yields of carps in the control were significantly higher than the combined net and gross yields of sahar and carps in all treatments. The overall FCRs in the treatments were 0.15–0.95, and were significantly better in the lower sahar density treatments. The control and all treatments produced positive net returns, and the highest net returns were produced by the control, followed by treatments with high to low stocking density of sahar. This study demonstrated that high-valued sahar has potential to be cultured in an integrated cage-cum-pond system, but it is necessary to fine-tune stocking ratios of sahar to carps. This can be accomplished by adjusting stocking density of sahar in cages, cage size, or cage number. Growth could also be improved by providing higher quality feed.

c. Carp-tilapia-sahar polyculture

Two trials were conducted by Shrestha et al. (2018) to evaluate the benefits of adding Nile tilapia and sahar to carp polyculture ponds. The first on-station trial was conducted in 9 earthen ponds for 240 days with three treatments: a) carp only (C); b) carp + tilapia (C + T); and c) carp + tilapia + sahar (C + T + S). Combined net fish yield at harvest was significantly higher in the C + T + S system (2.58 t/ha/crop) compared to the C system (2.01 t/ha/crop). Additionally, gross margin was significantly higher in the C + T + S system (2357 USD/ha) compared to the C system (1300 USD/ha), but not compared to the C + T system (1569 USD/ha). The second on-farm trial was conducted in 12 farmer-managed earthen ponds for 165 days. This trial focused on two treatment types: a) C and b) C + T + S. Combined net fish yield at harvest was significantly higher in the C + T + S system (2.78 t/ha/crop) compared to the C system (2.06 t/ha/crop). Gross margin was also significantly higher in the C + T + S system (3219 USD/ha) compared to the C system (1800 USD/ha). The use of these alternative species, along with traditional carp, has the ability to increase fish yield and raise profits in polyculture systems.

Pandit et al. (2018) compared the production and economics of Carp + Mixed-sex Tilapia + sahar and Carp + Mono-sex Tilapia culture systems at the Aquaculture farm of Agriculture and Forestry University, Chitwan, Nepal in 12 earthen ponds of 150 m2 for 150 days. There were two treatments in triplicate: a) Existing carp polyculture (10,000/ha) + mixed-sex tilapia (3,000/ha) + sahar (1,000/ha) (T1) and b) Existing carp polyculture + monosex tilapia (3,000/ha) (T2). Ponds were fertilized weekly at 4 kg N and 1 kg P/m2/day with di-ammonium phosphate (DAP) (18% N and 46% P_2O_5) and urea (46% N). Feeding was done with commercial pellet feed (24% CP) at 2% of total carp biomass per day. At harvest, the gross fish yield in T1 and T2 were 2.93 and 3.29 t/ha/crop, respectively with gross profit margin of 2569.1 and 3491.9 USD/ha/crop. The number of tilapia recruits in the carp-tilapia-sahar system was quite low.

Shrestha et al. (2012) conducted an experiment for 180 days in 12 earthen ponds (110-150 m^2in surface area and 1.0 m in depth) at the Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal to assess the growth, production, and productivity of carps, tilapia and sahar indifferent polyculture combinations. There were one control and three treatments in triplicates: (1) Existing carp polyculture (silver carp, bighead carp, common carp, grass carp, rohu, and mrigal in the ratio of 3:2:2.5:0.5:1:1 and stocking density of 7000 fish/ha) (control); (2) Control + tilapia (3000/ha); (3) Control + tilapia (3000/ha) + sahar (500/ha); (4) Control + tilapia (3000/ha) + sahar (1000/ha). The ponds were fertilized weekly at 4 kg N and 1 kg P/ha/day using di-ammonium phosphate and urea. Fish were fed on alternate days with a locally made pelleted feed (20% crude protein) at rates of 2% body weight per day. Results showed that survival of carps (68-89%), tilapia (69-83%) and sahar (43-49%) were not significantly different among treatments. All carp species showed better performance in all treatments than sahar or tilapia with a daily weight gain of 1.0 to 2.4 g/day. The combined net and gross yields of all carps in T1 and T2 were significantly higher than T3 and T4. The combined net and gross yields of all fishes were significantly higher in T2 than other treatments. The number of tilapia recruits was significantly higher in T2 (798±32) than T3 (676±51) and T4 (603±72). There were no significant differences in any water quality parameters among treatments. All treatments produced a positive gross margin, with the significantly highest gross margin in T2 (7938 USD/ha/year).

D. Monoculture of sahar in pond

Sah (2006) evaluated the growth performance of fry and yearling of sahar in earthen pond at the Institute of Agriculture and Animal Science, Rampur, Chitwan for 180 days. The experiment was laid out in 2 x 2 factorial with three replications. The treatments were: (1) large pond + fry; (2) large pond + yearling; (3) small pond + fry and (4) small pond + yearling. The stocking density of sahar in all systems is 1 fish/m^2. The mean stocking size of fry and yearling were 1.1 and 20.8-22.4 g, respectively. Fish were fed with 28% CP locally made pellet feed at the rate of 3% body weight daily. Results showed that there was no significant effect of pond size on growth rate (0.50-0.60 g/fish/day) and survival (63-83%) of fish. However, the growth rate and survival of yearling (0.83 g/fish/day and 88%) were significantly higher than those of fry (0.34 g/fish/day and 63%). The apparent food conversion ratio of sahar ranged from 4.7-5.0.

Paudel (2003) evaluated the growth performance of sahar in monoculture and polyculture with Nile tilapia. The experiment was conducted for 160 days in 8 earthen ponds (40 m^2) at the Institute of Agriculture and Animal Science, Rampur, Chitwan. There were two treatments replicated four times each: (1) Sahar monoculture at 1 fish/m^2 and (2) Sahar at 1 fish/m^2 + Nile tilapia at 1 fish/m^2. The mean stocking size of sahar was 5-6 g. Fish were fed with 35% CP pellet feed at the rate of 3% body weight daily. The mean daily growth rate and survival of sahar in mono- and polyculture were 0.13 g/fish/day and 51.3%, and 0.10 g/fish/day and 70.0%, respectively.

Bista et al. (2008) carried out participatory studies in three terai district (Kanchanpur, Chitwan, Sunsari) and one hill district (Kaski) to evaluate the growth and production of sahar in pond condition.

Larvae of hatchery bred sahar were stocked at a density of 20-30 larvae/m^2 and reared for 90 days. Later the fry was stocked at density of 10000 fry/ha in grow out systems for 210 days. Result showed that survival of sahar fry was 87.3 and 91.6 percent in hill and terai, respectively. At the end of 210 days culture period, fish reached to a size of 39.0 g in mid-hill and 60.8 g in terai with average growth rate of 0.28 g/fish/day in terai and 0.18 g/fish/day in hill.

Bista et al. (2011) evaluated the growth performance of sahar. Results also showed that growth of sahar was faster in warmer temperature (26-29°C) compared to cooler temperature (less than 26°C). The growth of sahar was varied with stocking size. Sahar stocked with initial average weight of 4 g grew at the rate of 0.40 g/day while the growth rate 25 g size stocked fish was 0.49 g/day during February to June in mid-hill. One-year old fingerling of Sahar (50 g) grew much faster, 1.12 g/day and attained final weight of 219.4 g within 150 days in Terai region.

Bista et al. (2002) reported that sahar growth rate is slower than that of cultured carps, i.e. common carp (*Cyprinus carpio*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*).

Paudel (2003) evaluated the growth performance of sahar in cages fitted in earthen pond. The experiment was conducted for 160 days in 4 nylon cages (1.5m x 1.5m x 1.1m) fitted in earthen ponds (450 m^2) at the Institute of Agriculture and Animal Science, Rampur, Chitwan. The mean stocking size and stocking density of sahar in all cages were 5-6 g and 5 fish/m^3, respectively. Fish were fed with 35% CP pellet feed at the rate of 3% body weight daily. Result showed that the mean daily growth rate and survival of sahar were 0.07 g/fish/day and 100%, respectively.

FEEDING HABIT AND ARTIFICAL FEEDING

Sahar has variously been described as a herbi-omnivore, carnivorous and omnivore that feeds on insects, molluscs, micro-vegetation and algae. Shrestha (1997) reported that adult sahar feed on gastropods, plant debris and algae whereas fingerlings feed mainly on algae. Although an omnivorous species, mature sahar are predatory (Shrestha, 1997; Acharya et al., 2007; Paudel, 2003; Shrestha et al., 2011).Gut analysis of sahar showed that it feeds on small fish, insects, molluscs, insect larvae and vegetable matter (Bista et al., 2002; Rai, 2008). A study conducted on diet development for sahar showed promising results when fed a mixture of plant and animal protein sources (Bista and Yamada, 1996). This study carried out for 210 days based on diets of 30% and 40% protein content; to about 6 g size growth was significantly higher ($P<0.05$) until 90 days when fed with 30% protein content diet, but after 90 days the larger fish growth was reversed and was significantly higher on the 40% protein diet. Moreover, the diets contained 38% protein showed higher growth than the diets of 42% protein. However, 35% protein content diet showed comparable growth.

Inadequate knowledge on dietary formulation of sahar feed is one of the major impediments in development of its production system. To fill this gap of knowledge on nutrition, feed and feeding of sahar. Bista et al. (2002) performed series of experiments with different life stages of sahar. They found that the most effective food for hatchlings and fry stage of sahar is natural zooplankton, while the effective diet for the growers are feed dominated with animal matter rather than plant origin.

The hatchling group fed with zooplankton showed highest growth response, while group fed with silkworm pupae showed lowest growth response. Other hatchlings fed with micro-feed prepared at Fisheries Farm Pokhara and Japanese crumble showed moderate growth response. The group fed with Japanese crumble showed better growth than locally made micro-feed. This might be due to their preference for animal food. Gut content analysis of mahseer ranging from 250 to 3000 g confirmed their preference for food of animal origin. Similarly, in fry rearing experiment, the highest growth of fries occurred in treatment fed with D-8 (live zooplankton). Other treatment did not show substantial changes in body weight during the study period. The survival rate of fry ranged from 33.3- 92.1%. The highest survival occurred in the group fed with live zooplankton. The results of fingerling rearing experiment showed that sahar fingerlings well accepted both 30% and 40% crude protein diet and fish fed actively. There was no significant difference between 30 percent and 40 percent diet in weight gain till 150 days but after 150 days there was a significant difference between two diets. The mean value of body weight of sahar obtained at harvest were 19.5 g and 22.5 g from 30 percent and 40 percent protein diet fed group, respectively.

Bista et al. (1999) carried out and experiment in floating net cage for 180 days in Phewa lake of Pokhara to develop appropriate diet of sahar. The yearlings of sahar with an average weight 40.4 g was stocked at a density of 295- individuals in 8 m^3 of net cages. Fish diets, with and without methionine supplementation were provided daily to the experimental fish at the rate of 3% body weight. At the end of experimental period, the average body weight of fish was significantly higher in methionine supplemented soya-based diet (94.0 g) than normal diet (90.7 g).

FUTURE PROSPECTSAND CONSTRAINTS

The development of its breeding technology leads a very positive development with the mass production of fingerlings, which can be stocked in the natural water bodies to maintain or increase its population as well as to support aquaculture industry. Sahar is very popular and has a very high demand and sells for a higher price than other cultured carp species. The study has shown that sahar culture is suitable in warmer areas particularly in terai region of Nepal, though the mid-hill region is more suitable for breeding area and for egg development. Based on the results achieved in sahar breeding in the sub-tropical region of Nepal, we expect to increase seed availability somewhat to support aquaculture of this species. Moreover, polyculture of sahar with carps and tilapia will reduce the seed demand required for monoculture of sahar.

One of the major challenges for developing the aquaculture production technology of sahar is its slow growth compared to the growth of cultivated carps (Gurung et al., 2003; Shrestha et al., 2018). It has intermediate feeding habit and to some extent more likely to carnivorous. Adult sahar showed encouraging growth with feed containing high animal low plants source. Efforts are being made to formulate high quality feed for exploiting growth potential of sahar. One of the major problems of formulation of quality feed for sahar is high price and unavailability of protein rich ingredient like fish meal. Other constraints include difficult of mass production of fish seed due to lack of induced spawning techniques. Over maturation of brood fish is also a major constraint of breeding, which implied that broods should be examined more frequently (Jha et al., 2017; Bista et al., 2018). Economics of sahar production is also need to be studied. Recently, Fisheries Development Centers Janakpur, Bhandara and Kulekhani has started study of sahar production under their “Prabhidhi Parimarjan Program”.

CONCLUSION

The results from all experiments conducted in Nepal reveal that sahar can grow to 100-150 g in the first year of culture, 300-400 g in the second year, and perhaps 800 g to 1.0 kg by the third year. Results showed higher growth of sahar in subtropical climates of Chitwan, Rupandehi, and Sunsari than in the cooler climates of Trishuli, Pokhara and Kaligandaki.We expect sahar to become a species for aquaculture in the near future.The growth potential of sahar observed in captive environment in different ecological regions provides the opportunity to include this species in current aquaculture setting of the country. However, sustainable inclusion of sahar in aquaculture could be assured by the development of a suitable breeding and rearing technology which requires knowledge on the nutritional requirement and feed formulation for different development stages of sahar. At present very limited information on feed, feeding and nutritional requirement of sahar is available. Nutritional studies, focusing on requirement level of different nutrients for the different stages of fish and utilization of locally available resources, are needed to accelerate the growth and to ensure affordability by the growers. Further, well designed multidisciplinary experiments could explain the pond productivity of sahar in mono and polyculture as well as the level of interaction with other carp species for production and economics in polyculture fish farming.

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Cage fish farming in lakes and reservoirs of Nepal: a mini review and update

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ABSTRACT
Cage fish culture was introduced in Nepal in 1972 at Lake Phewa, Pokhara Valley as a means of holding brood of common carp. The farming of cage culture have been carried out in three lakes of Pokhara valley and in Kulekhani reservoir only. Traditionally, subsistence cage farming by use of planktivorous fish species (silver carp, *Hypophthalmichthys molitrix* /bighead carp, *Aristichthys nobilis*) in nylon cage of 50 m^3 cage volume with bamboo frame have been practiced by farmers and this technology is still popular. The production of planktivorous fish in extensive cage fish farming was found very low. Cage fish farming of grass carp in monoculture feeding with aquatic macrophytes was found profitable in comparison to planktivorous fish species. Recently, slow growth fish in cage culture due to change of Lake Environment, the cage numbers have been reduced in Phewa Lake by 83%, Begnas Lake by 88%, and Kulekhani reservoir by 62% in year 2017 as compared to 2011. Low productivity of cage culture from lakes and reservoirs in extensive cage culture (productivity≈1.0kg/m^3/2year) experienced by farmers of lakes and reservoirs. The unavailability of large size fingerlings to stock cages and quality cage knitting materials are the constraints faced by farmers.

Kew words: Cage culture, Indrasarober reservoir, Phewa Lake, Begnas Lake

INTRODUCTION

Cage culture of fish consists of raising fish from the juvenile stage to commercial size in a volume of water enclosed on all sides, including the bottom, while permitting the free circulation of water through the 'cage' (Coche, 1979; Schmitton, 1969). It is a method of farming aquatic organisms in the enclosure placed in a body of water (Beveridge and Stewart, 1998). Floating cage fish culture was probably originated from lower Mekong basin in Kampuchia, as a convenient holding facility for marketable fish (Pantulu, 1979). In freshwater cage fish farming, China dominates with a production exceeding 68.4 percent of total reported freshwater cage aquaculture, followed by Vietnam 12.2 % and Indonesia 6.6 % (Tacon and Halwart, 2007). Cage fish culture is considered to be an old tradition that has developed into a major sector in aquaculture only in the recent past (De Silva and Phillips, 2007; Tacon and Halwart, 2007).

Cage fish culture was introduced in Nepal in 1972 at Lake Phewa, Pokhara Valley as a means of holding brood of common carp (Swar and Pradhan, 1992). The farming of cage culture has been carried out in three lakes of Pokhara valley and in Indrasarober reservoir (Kulekhani) only. The total volume of cages for fish culture in Nepal is 70,000 m^3 (DOFD, 2014/15). Traditionally, subsistence cage farming by use of planktivorous fish species (silver carp *Hypophthalmichthys molitrix* /bighead carp *Aristichthys nobilis*) in nylon cage of 50 m^3 cage volume with bamboo frame have been practiced by farmers(Fig.1 A,B) and this technology is still popular (Gurung and Bista, 2003; Wagle et al., 2007).

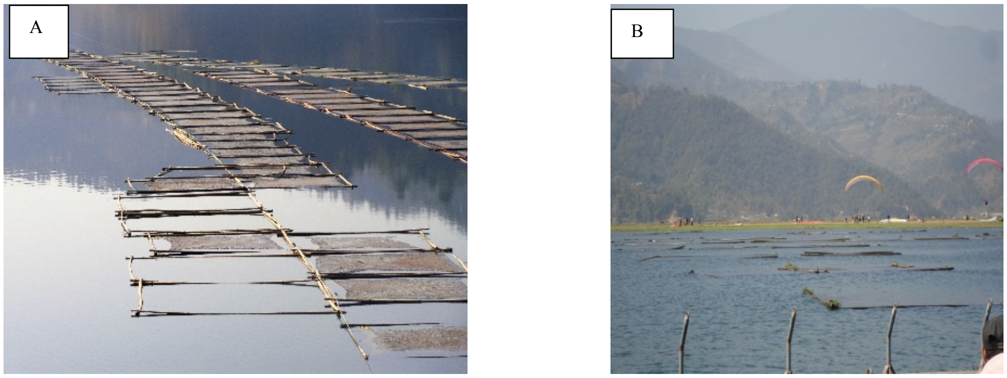


Figure 1: Fish culture in cages of Kulekhani Reservoir (A) and Phewa Lake (B)

This technique has extended to Kulekhani reservoir in 1984 for the local people as part of the mitigation efforts following reservoir construction and loss of farmland. Introduction of cage fish farming in the reservoir became successful strategies for an alternative livelihood option and also stimulated the development of a capture fishery, based on escapees and naturally recruited species, all of which have significantly contributed to increasing a fresh affordable animal protein source to the nearby communities (Gurung et al., 2009).

MATERIALS AND METHODS

Study sites

Phewa Lake is situated in the southwestern part of the Kaski district at 28.1°N and 82.5°E, 742 m above mean sea level (Fig. 2A). The watershed area of this lake is 110 km^2 (Ferro and Swar 1978). Lamichhane (2000) estimated the water surface area of this lake to be 443 ha with a maximum depth of 23 m. Phewa Lake is fed by two perennial streams. This lake fluctuates between mesotrophic and eutrophic in different seasons (Husen and Dhakal, 2009; Husen et al., 2012a).

Begnas Lake is the second biggest lake (328 ha) at 28°10'26.2″N and 84°05'50.4″E, 650 m above mean sea level (Figure 2A). It is fed by a perennial stream with a catchment area of 19 km^2 and an average depth of 6.6 m (Rai et al. 1995). This lake fluctuates between oligotrophic and mesotrophic in different seasons (Husen et al., 2012a).

Lake Rupa (100 ha) is the third biggest lake and its watershed is located between 28°08'N to 28°10'N and 84°06'E to 84°07'E, at 600 m above mean sea level (Gurung, 2007) (Figure 2A). The lake's total catchment area is 30 km^2. The surface area, maximum depth, and average depth of the lake are 1.35 km_2, 6 m, and 3 m, respectively. This lake is eutrohic (Husen et al., 2012a, Husen et al., 2013)

Kulekhani Reservoir (27°23'25″–27°41'31″N; 85°2'46″–85°16 '16″E) is located in the northeastern part of Makawanpur district situated in the mid hills of central Nepal at 1,430 m above sea level. It was impounded in 1982. It is a small reservoir (220 ha) with a catchment of 126 km^2 water body (Figure 2.B). The reservoir was designed with an anticipated lifespan of more than 50 years (Gurung et al., 2009).

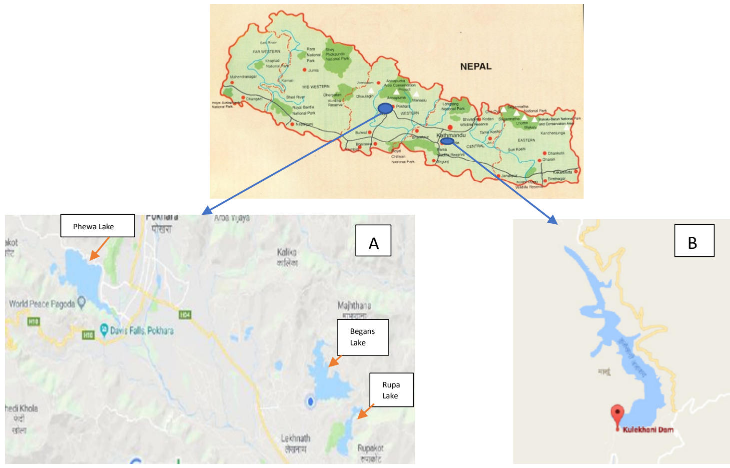


Figure 2: Nepal map showing location of lakes of Pokhara valley (A) and Kulekhani reservoirs (B).

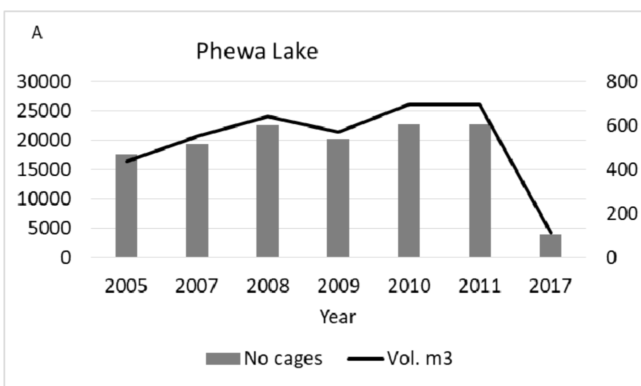
Data collection

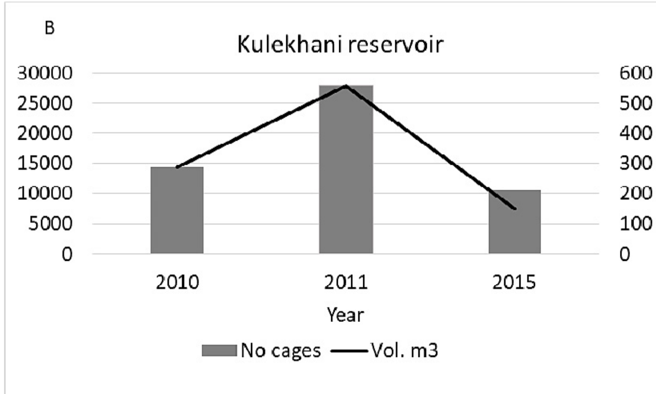
Field survey were carried out to gather information's about the present status of cage culture in lakes of Pokhara valley and Kulekhani reservoir. The cage fish farming farmers were interviewed with developed questionnaire. Interaction meetings with stakeholders, key informants were carried out to obtain information on cage fish farming. Literature review of published article in the journal, proceeding were done to compare the present data to the past.

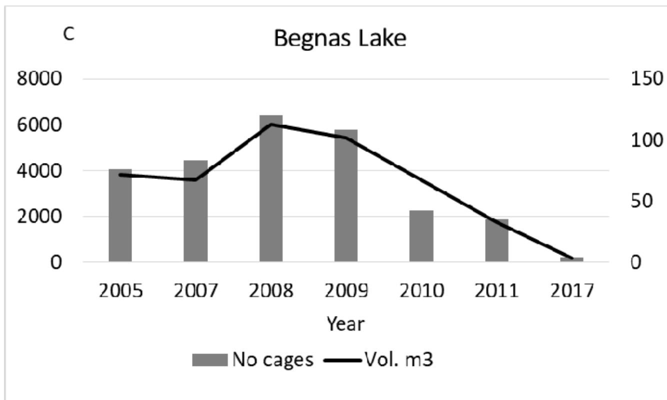
RESULTS AND DISCUSSION

Cage volume and number

At present, the number of cages are only 521 with volume 21,712 m^3 in which fish farming in cages is still continuing in the lakes of Pokhara Valley and Kulekhani reservoirs. The cage numbers have been reduced in Phewa Lake by 83%, Begnas Lake by 88%, Indrasarober reservoir (Kulekhani) by 62% in year 2017 as compared to 2011 while it has been increased in Rupa Lake (Figure 3 A-D). In 2011, 35,750 m^3 of cages were used for cage culture in the Pokhara valley lakes (Prasad et al., 2013). Likewise, 230 farmers (110 women and 120 men) involved in fish culture in the Kulekhani reservoir using 75,000 $m^3$of cage volume for production, nursery and grow-out and cage volume has increased to 81,500 m^3 (Shrestha et al., 2012), however, it reduced to 27,900 m^3 in 2011 (Prasad et al., 2013).







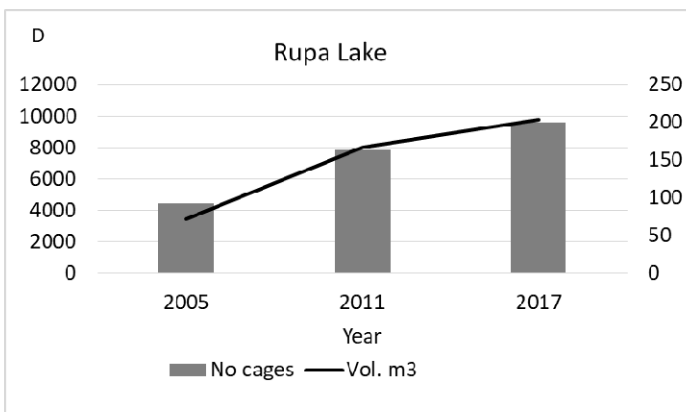


Figure 3: Cage number and volume (m^3) in lakes and reservoir: Phewa Lake (A), Kulekhani reservoir (B), Begnas Lake(C), and Rupa Lake (D).

Cage type and fish species

Nylon or polyethylene net cage have been most popular among cage fish farmers of lakes of Pokhara valley. Generally, farmers are using nylon or polyethylene knot-less floating type cages of size 50 m^3

(5m x 5m x 2m) and cage frame of bamboo structure act as frame and float (Wagle et al., 2007; Gurung et al., 2009). Local fisherman could weave their own netting of mesh size more than 25 mm locally. Almost 90% of nursery cage is made by netlon cage (Kalo jal) and production cages by nylon or polyethylene threads (Husen, 2010).

The fish species used for culture in cages were silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*) and grass carp (*Ctenophyryngodon idella*) in the lakes of Pokhara valley and reservoirs. Monosex Nile tilapia *(Oreochromis niloticus*), Common carp (*Cyprinus carpio*) could be used in the cage culture of lakes and reservoirs. Studies have shown that trout farming in lakes and reservoirs of the mid-hills in winter could be one of the alternative opportunities for cage farmers to increase their income (Bista et al., 2004; Gurung, 2008).

Stocking density

Generally, at stocking density 10-12 fingerlings/m^3 of 20-25-gram size recommended for the stoking in cages of lakes and reservoirs. In the Pokhara valley, farmers have been used to grow the 1-2 gram of silver carp and bighead carp in the nursery cages around 9 months reached to sizes of 50-100 g and then stocked to production cages (Wagle et al., 2007; Husen, 2010). Depending upon the type of plankton dominance and the market, stocking usually constitutes 60% bighead carp and 40% silver carp and vice versa (Wagle et al., 2007). The best stocking density in Phewa Lake found was 70% bighead and 30% silver carp at 10 fingerlings/m^3 of cage volume (Husen et al., 2012b).

Productivity of cage fish farming

According to Wagle et al. (2007), fish production ranged from 1.3-5.0 kg/m^3/yr in 12-18 months from cage culture in the Pokhara Valley Lake. Nepal (2008) reported that the average yield in cage fish culture of Phewa Lake was 1.41 kg/m^3/yr. In an experiment, the cage productivity was found 1.55 kg/m^3/yr at 3:7 stocking ratio of silver carp to bighead carp at stocking density of 10 fingerlings/ m^3 in Phewa Lake at Khapuadi in the year 2010 (Husen et al., 2012b). The fish production from cage was 4.0kg/m^3 / yr. during early year into Kulekhani reservoir. Later the production from cage decreased in the reservoir due to slow growth of fish. This problem of slow growth is due to the shortage of natural food, which is associated with the increased volume of cages and number of fish in the reservoir (Shrestha et al., 2012). The production of planktivorous fish in extensive cage fish farming was found decreasing from lakes and reservoirs (Prasad et. al. 2013). Cage fish farming of grass carp in monoculture feeding with aquatic macrophytes was found profitable in comparison to planktivorous fish species as it approximately doubles the fish production (Prasad et al., 2012).

At present, low productivity of fish from lakes and reservoirs in extensive cage culture (productivity≈ 1.0kg/m^3/2year) experienced by farmers of lakes and reservoirs. It is due to slow growth fish in cage culture due to change of Lake Environment and low stocking of fish. To solve the problem of low productivity, recently, cage fed aquaculture have been tested in Kulekhani reservoir and Begnas Lake. The results showed that feeding with 20% CP feed, fish yield was significantly higher in supplementary feeding (1.25 kg/m^3/year) in comparison to without feeding (0.89kg/m^3/year) in Kulekhani reservoir in 2016 (Prasad et al., 2017). Likewise, in Begnas Lake, fish yield of supplementary feeding was higher (0.75±0.1 to 0.92±0.1 kg /m^3/year) of cage volume in comparison to without feeding (0.33±0.1 kg /m^3/year) in 2016 (FRS, 2017).

The unavailability of large size fingerlings (20-25g) to stock cages, quality cage knitting materials over siltation, landslides, periodic heavy storm in lakes are the some constraints faced by cage fish growing farmers. Fish fry nursing in the community nursery of fisher group will be an option for the timely stocking of cages with large size fingerlings (20-25g) in the lakes and reservoirs.

WAY FORWARD

The potential of cage fish culture in the upcoming reservoirs of hydropower and in irrigation canal is tremendous in Nepal. It is estimated that 92,400 ha of reservoir will be available for the cage fish farming in near future (Pradhan, 2009). Cage culture could be a livelihood option for displaced people due to hydropower dam construction in the country. Possibilities of cage culture in irrigation canal should be explored. Cage culture should be extended other potential lakes of Nepal.

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Gonadosomatic index, egg size and fecundity of chocolate mahseer, *Neolissochilus hexagonolepis* (Mcclelland, 1839) from Tamor river, Nepal

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ABSTRACT
The present study was carried out to assess gonadosomatic index (GSI), egg size and fecundity of Chocolate mahseer, *Neolissochilus hexagonolepis* from Tamor river, Nepal. The maximum mean GSI values for both male and female fishes were calculated in the month of July. Absolute fecundity ranged from 2038.56 to 11423.9 with its mean value equal to 6262.25 ± 2868.43. Similarly, the sizes of eggs of the fish were found to vary from 1.22±0.07 mm to 2.34±0.05 mm in diameter. Fecundity showed positive correlations with BW (r= 0.75), TL (r= 0.75) and GW (r= 0.75). Egg size was found to have significantly positive correlation with GW (r=0.60, P<0.05) but very weak positive correlation with fecundity (r= 0.13). GSI and GW were positively correlated for both the sexes with the value of correlation coefficient (r) for female equal to 0.92 and that for male equal to 0.55.

Keywords: *Neolissochilus hexagonolepis*, Gonadosomatic index, Egg size, Fecundity, Tamor River.

INTRODUCTION

The study area for this research is the Tamor river, which lies between the latitude and longitude co-ordinates of 26˚54'46.80" N and 87˚09'25.20" E respectively (Google maps, 2014). This river meets the confluence of Arun and Sunkoshi at Tribenighat to drain into the giant Saptakoshi. The total length of this river is about 190 km with 5817 km^2 catchment area (Shrestha et al., 2009).

Neolissochilus hexagonolepis is commonly known as Chocolate or Copper mahseer and locally as Katle. It is one of the dominating species in the snow fed torrential rivers of Nepal. Unfortunately, its population is in sharp decline due to the loss of its habitat and over-exploitation.
The total number of eggs present in the ovary of a gravid fish just prior to spawning is termed as fecundity. The evaluation of fecundity finds an important place in monitoring the reproductive potential of a species and study of its biology. Several ichthyologists have defined fecundity and emphasized its significance from time to time.

Simpson (1951) came up with the idea that the data pertaining to fecundity are useful in determining the density dependent factor affecting population size and for separating different fish stocks from the same population. Lagler (1956) opined that the knowledge about fecundity of a fish is essential for evaluating the commercial practical culture and actual management of the fishery potentialities of its stock, life history.

GSI gives indication of the gonadal development of a species and is thus, useful in the study of reproductive biology of the species. Shabana et al. (2013) opined that the Gonadosomatic Index (GSI) is widely used by biologists to indicate the maturity and periodicity of spawning and predicting the breeding season of a fish.

The fishes that produce a large number of eggs and deposit them over a short period are referred to as total spawners. On the other hand, multiple spawners have a longer breeding period and deposit only a portion of eggs during one spawning. Total spawners are said to have a higher GSI than multiple spawners (Wooton, 1990).

Various imminent ichthyologists have studied fecundity and GSI of cold-water fishes from time to time. Swar (1994) assessed the fecundity of *N. hexagonolepis* in a Nepalese reservoir and river and reported that the species is a low fecund fish. Mahapatra and Vinod (2011) studied the reproductive biology and artificial propagation of N. *hexagonolepis* in Meghalaya, India and reported on the GSI and fecundity. Among other hill stream fishes, Shabana et al. (2013), Kharat and Khillare (2013), Ulfat et al. (2014), Wagle (2014) and Muddasir & Ahmed (2016) reported on the fecundities of *Tor Putitora*, *Nemacheilus moreh, Schizothorax esocinus and Schizothorax richardsonii* respectively.

Although studies on reproductive biology of cold-water fishes, encompassing gonadal cycle, GSI, fecundity and egg size have been reported frequently it appears that there is poor reporting on the biology of this species. The present study is, therefore, an attempt to fill up this void situation.

N. hexagonolepis is considered as a near threatened species and hence due care and attention should be given for its conservation (Arunachalam, 2017).

MATERIALS AND METHODS

Fish sampling and sex identification

Fish sampling was carried out for two years commencing from the second week of December 2014 till the end of November 2016. Samples were collected from the catch landings of fishermen who used hooks, cast net, gill net, traps and other conventional local techniques for catching the fishes.

The samples were sexed by external observation and later confirmed through observation of gonads after dissection. Body weight (BW) was measured using a digital balance with the precision of 0.01 g. Total length (TL) was measured from the tip of snout to the distal tip of the longest caudal fin ray. The measurement was taken in full stretched condition to the nearest 1mm using a measuring tape and graduated ruler.

Fecundity assessment

For fecundity assessment, ovaries from matured fishes were preserved in Gilson's fluid for over two weeks to loosen the tissue surrounding the eggs during which the eggs were agitated several times. The eggs were then washed with distilled water and gently teased with needle and forceps until they became disentangled from ovarian tissues. The eggs were then spread over blotting paper to remove excess moisture and the clamped eggs gently separated. The eggs were then air dried.

Gravimetric method was followed to estimate the fecundity. This method is one of the most common method used to estimate fecundity and is based on the relation between ovary weight and oocyte density in the ovary. The eggs liberated from the ovarian tissue were thoroughly washed and spread on blotting paper to dry in air. Three sub-samples of eggs, each weighing 1 gram and each obtained from the anterior, middle and posterior part of the ovary were considered. After that the number of eggs in each sub-sample was counted and mean value of the three sub-samples calculated. The total number of eggs in the ovary was then weighed.

Absolute fecundity was then calculated by using the formula:

$$Fecundity\ (F) = Total\ weight\ of\ eggs\ in\ ovary * Mean\ count\ in\ 1\ g\ of\ egg\ mass$$

In case of the ovaries weighing less than 10 g, count in 1 g egg mass was simply multiplied with the total weight of eggs in the ovary to work out the absolute fecundity.

During the present investigation, the advanced yolked oocytes or vitellogenic oocytes were only included in the count. The vitellogenic oocytes were easily identified through visual observation as they appeared larger and yellowish opaque due to the accumulation of yolk and cortical alveoli.

Fifteen eggs were randomly selected from ovaries at III (Ripening), IV (Mature) and V (Spawning) stages and diameters measured to the nearest 0.01 mm. After that, the eggs were grouped in the intervals of 0.2 mm and their frequencies calculated.

The least–square linear regressions between fecundity (F) and body weight (BW), total length (TL) and gonad weight (GW) were calculated according to the method described by Bagenal (1968).

Egg size

To determine the size of eggs, fifteen eggs from each of ovary were picked at random. The eggs were spread on blotting paper and dried and the diameter of the eggs measured using a calibrated micrometer mounted on the eyepiece of a monocular microscope (1 division = 0.05mm). From this, the mean size of egg for each ovary was then estimated.

Gonado-somatic index (GSI)

The gonado-somatic index (GSI) was calculated for each fish every month using the formula:

$$GSI = \frac{Weight\ of\ the\ gonad}{Total\ Weight\ of\ the\ fish} X\ 100$$

RESULTS

Though one of the dominating species in the torrential rivers of the country several studies have already confirmed that the population of *N. hexagonolepis* is declining at an alarming rate.

A total of 198 samples were examined from December 2014 till the end of November 2016, among which 89 were males and 109 were females. The overall male to female ratio was 1: 1.2.

Gonado-somatic index (GSI)

The GSI ranged from 0.084 % (in a fish of TL 19.5 cm and BW 95 g) to 16.47 % (in a fish of TL 30.2 cm and BW 340 g) for female fish and 0.086% (in a fish of TL 16.5 cm and BW of 70g) to 4.78 % (in a fish of TL 19.5 cm and BW 85 g) for male. The mean GSI of female fish varied from minimum (0.19±0.05) in January to maximum (7.75±4.40) in July and the mean GSI of male fish varied from minimum (0.25±0.17) in December to maximum (2.33±1.38) in July (Figure 1).

Gonadosomatic index (GSI) and gonad weight (GW) were positively correlated for both the sexes with the value of correlation coefficient (r) for female equal to 0.92 and that for male equal to 0.55.

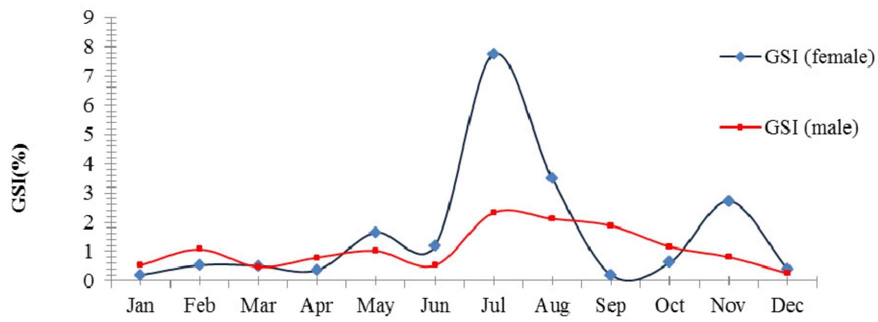

Figure 1: Graph showing monthly mean GSI of male and female *N. hexagonolepis* from Tamor River, Nepal.

Fecundity and egg size

Absolute fecundity of *N. hexagonolepis* ranged from 2038.56 for fish of TL 33.2 cm, BW 430 g and GW 3.58 g to 11423.9 for fish of TL 37 cm, BW 710 g and GW 102 g. The mean value of fecundity was found to be 6262.25 ± 2868.43 with a mean TL of 35.6cm ± 4.22cm and 586.5g ± 261.14 g BW.
The relative fecundity to weight ranged from 4.74 to 18.60 while the relative fecundity to length ranged from 61.40 to 308.76. Fecundity showed positive correlations with BW (r= 0.75), TL (r= 0.75) and GW (r= 0.75).

When log transformation of fecundity was regressed against log transformations of total length, a significant linear relationship emerged (Figure 2). The slope of the relationship was estimated to be 3.1059 with a standard error of 0.7957. Similarly, when log transformations of fecundity were regressed against log transformation of total weight, a significant relationship emerged (Figure 3) with slope of the relationship 0.9250 with a standard error of 0.2291.

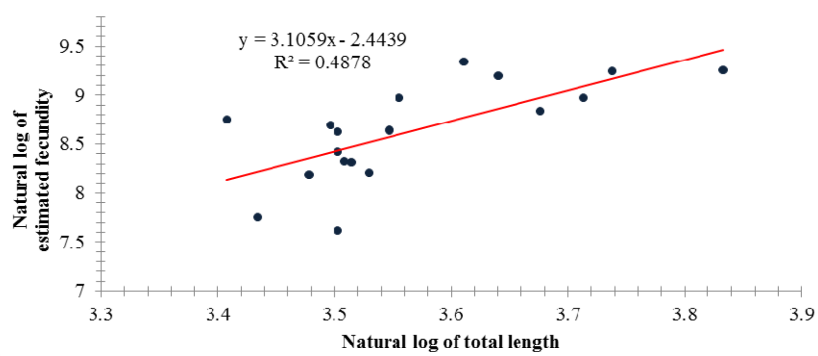

Figure 2: Graph with regression equation and coefficient of determination (R^2) showing estimated linear relationship (indicated by solid line) of log transformations of estimated fecundity with total length of *N. hexagonolepis* from Tamor river, Nepal.

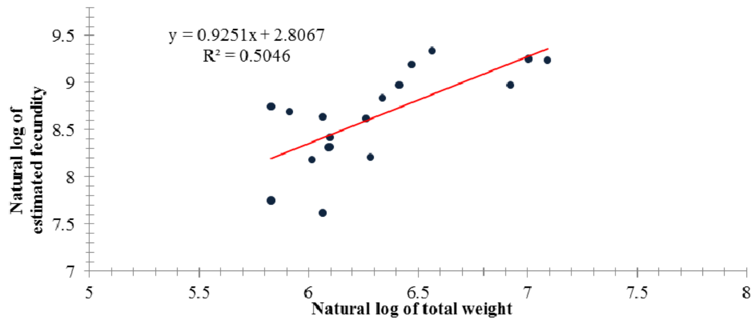

Figure 3: Graph with regression equation and coefficient of determination (R^2) showing estimated linear relationship (indicated by solid line) of log transformations of estimated fecundity with total weight of *N. hexagonolepis* from Tamor river, Nepal

The smallest size of eggs measuring 1.22 ± 0.07 mm in diameter was recorded from a fish sample that measured 33.2 cm in TL, 430 g in BW, 3.58 g GW and 2038.56 numbers of eggs. The largest eggs measuring 2.34 ± 0.05 mm in diameter were recorded in a fish that measured 33.6 cm in TL, 442 g BW, 38.42 g GW and 4092 numbers of eggs.

Most of the eggs were in the size range of 1.21 to 1.4 mm in the ovaries in III stage or ripening stage. No eggs larger than 2.2 mm in size were encountered in stage III ovaries.

In stage IV (Mature) majority of the eggs were in the range of 2.21 to 2.4 mm. No eggs in the range of 1.01 to 1.80 mm in size were encountered in stage IV ovaries.

Similarly, in stage V (Spawning) majority of the eggs were in the range of 1.81 to 2.0 mm. No eggs in the range of 1.01 to 1.2, 1.21 to 1.4 and 2.41 to 2.6 mm in size were encountered in stage V ovaries.

Frequencies of egg size ranges in the ovaries of katle at III (Ripening), IV (Mature) and V (Spawning) stages are presented in figure 4.

Egg size was found to have significantly positive correlation with GW ($r=0.60$) and GSI ($r= 0.68$) but very weak insignificant positive correlations with fecundity ($r= 0.13$) and BW ($r= 0.02$) at $p<0.05$. It showed insignificant negative correlation with TL ($r = -0.11$).

DISCUSSION

The mean value of fecundity of *N. hexagonolepis* (6262.25 ± 2868.43) in the present study was rather low as compared to that enumerated for the same species in Meghalaya, India (Mahapatra and Vinod, 2011). This variation may be due to the difference in size of the samples investigated.

Swar (1994) reported that the fecundity of *N. hexagonolepis* varied considerably from individual to individual ranging from 1,387 to 33, 270 in reservoir populations while from 760 to 8,951 in riverine population. He found that the fishes from river were less fecund than those from reservoir. He attributed this variation to the difference in feeding conditions. Nikolsky (1963) reported that the food consumed by the fish plays an important role not only in the fecundity but also the quality of the eggs and their fertilization.

The average relative fecundity was estimated to be 10.94 ± 3.77 eggs per gram in the present study. In comparison to this, the finding of Swar (1994) was higher where he reported 19.13 ± 1.56 eggs per gram for reservoir population and 22.57 ± 1.41 for riverine population. The difference in average relative fecundity from that of the present study may be attributed to the difference in the size range of the fishes investigated and also upon the variations in environmental factors. Kharrat and Khillare (2013) opined that considerable variations in the fecundities among fishes of equal lengths are common and are due to environmental factors including temperature, availability of food and differences in the genetics. As with other species, Khaironizam and Ismail (2013) reported that the absolute fecundity of *N. soroides* (Duncker, 1904) ranging from 803 to 6218 which is quite low as compared to the values obtained for this species in the present study.

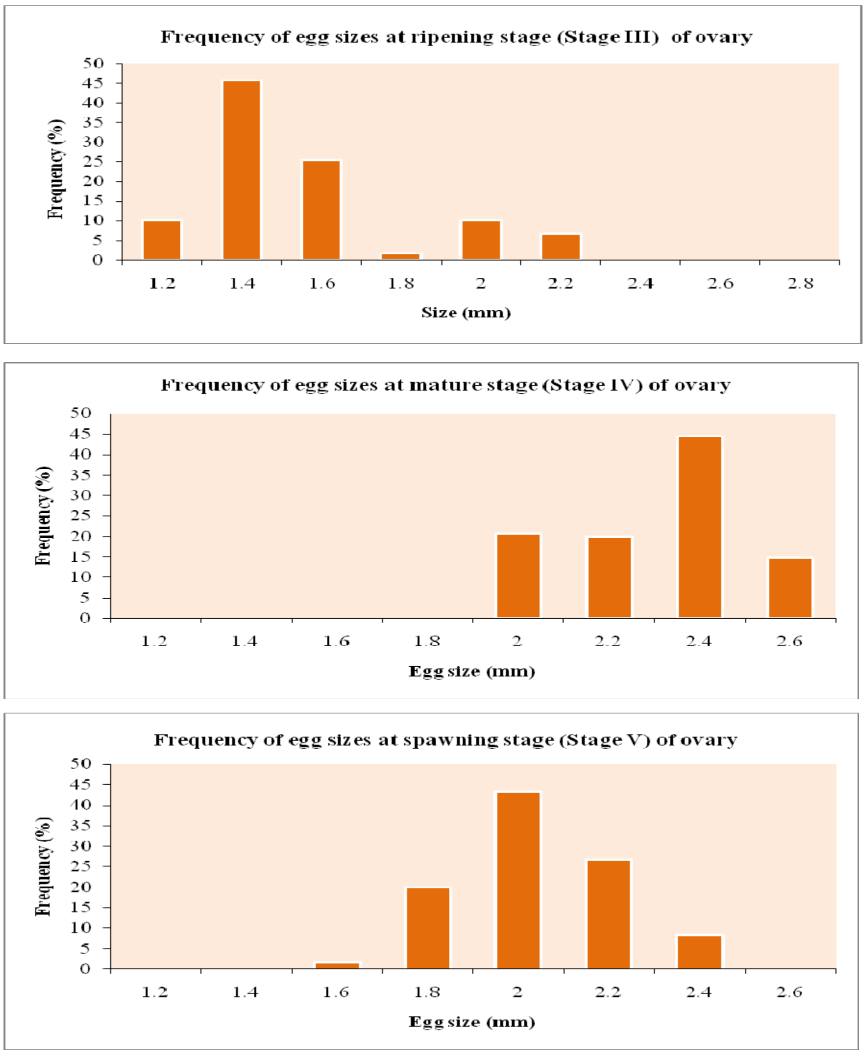

Figure 4: Frequency of egg size ranges in the ovaries of Katle at III (Ripening), IV (Mature) and V (Spawning) stages (Egg size ranges: 1.2 = 1.01-1.2; 1.4 = 1.21-1.4; 1.6 = 1.41-1.6; 1.8 = 1.61- 1.8; 2 = 1.81-2; 2.2 = 2.01-2.2; 2.4 = 2.21-2.4 and 2.6 = 2.41-2.6 mm)

Muddasir & Ahmed (2016) reported the mean fecundity of *Schizothorax plagiostomus* from a river in Kashmir to be equal to 12964.62 ± 7385.54 with relative fecundity ranging from 9.696 to 56.704 per gram and 64.52 to 834 per cm. These values were way too higher compared to that of the species investigated. They suggested that the contributing factors for the variation in the fecundity among the fishes of the same as well as different species include size, age and condition of fish and not excluding the food intake and the space.

Still comparing with other species, the fecundity of a fresh water hill stream teleost *Nemacheilus moreh* (Sykes) ranged from 142 to 1197 with the mean value of 546 (Kharat and Khillare, 2013) is rather low. Similar situation was also seen when compared with the fecundity range of *Barilius bendelisis* (Ham. 1809) from Manas river, Assam, India (Jabeen et al., 2016). But, the value of absolute fecundity of the fish under study was little lower as compared to that of *Ompak pabo* (Ham. 1822), with the mean value of 9857.315, from Gomati river of Tripura (Bhattacharya and Banik, 2015).

Hence, the present study revealed that *N. hexagonolepis* is a low fecund fish as compared to other high fecund fish with tens of thousands of eggs. This finding agreed in terms with the finding of Dasgupta (1988) who described *N. hexagonolepis* as a low fecund fish, although a prolific breeder.

Fecundity showed positive significant correlations with all the morphometric parameters investigated viz. body weight, total length and gonad (ovary) weight. This revealed that the fecundity is dependent upon the size of the body of the fish. This may be due to the fact that the increment in size of the body allowed the gonad (ovary) to accommodate larger number of eggs.

Positive relations between the fecundity with total length and total weight were also reported in *Tor putitora* (Shabana et al., 2013), *Neolissochilus soroides* (Khaironizam and Ismail, 2013), *Schizothorax richardsonii* (Wagle, 2014), *Barilius bendelisis* (Jabeen et al., 2016) and *S. plagiostomus* (Muddasir & Ahmed, 2016).

In the present study, fecundity showed strong positive correlation with gonad GW which agreed with the finding of Shinkafi et al. (2011) and Khaironizam and Ismail (2013) in *Auchenoglanis occidentalis* and *N. soroides* respectively.

The finding of the present study revealed that the fecundity varied among the individuals of the same size. Similar result was also reported by Bhattacharya and Banik (2015). Environmental factors and food supply affect the fecundity of a fish (Simpson, 1951) and the diet, age, condition of fish, disease, and atmospheric conditions play an important role in fish health and on its fecundity (Ulfat et al., 2014).

The higher values of GSI recorded for both male and female during the months of July and August suggest that these months indicate the spawning season of *N. heaxagonolepis* in Tamor River.

Kharat and Khillare (2013) suggested that the increase in GSI during the period of gonad maturation is mainly due to the deposition of large amounts of proteins and lipids directly from ingested food during the active feeding season.

The GSI values for *N. hexagonolepis*, in the present study, were found to show their peak only once a year, coinciding in the month of July. This clearly indicated that the species breeds annually. Similar breeding behaviour was also reported in *Labeo rohita* (Alam and Pathak, 2010), *Pomadasys jubelini* (Agbuigui, 2013) and *Tor putitora* (Shabana et al., 2013). However, unlike these, several other fish species breed twice a year round as indicated by their GSI values with two peaks a year round. Such situations were reported in *N. soroides* (Khaironizam and Ismail, 2013), *Nemacheilus moreh* (Kharat and Khillare, 2013), Schizothorax *plagiostomus* (Muddasir & Ahmed, 2016) and *S. richardsonii* (Wagle, 2014).

Eggs of different size groups were found in the mature ovaries of the fish which clearly suggested that this species spawns more than one time in a single breeding season. Similar result was also reported by (Mahapatra and Vinod, 2011) and Swar (1994) for the same species. The finding of the present study revealed that the species shed only a fraction of eggs during a single spawning act and that the spawning takes place over a protracted period. This is in contrast to the total spawners. Multiple spawning in fishes is only possible where there is a long period of adequate food supply (Nikolsky, 1963).

Egg size and GW showed significant positive correlation with each other ($r = 0.60$) suggesting that the heavier ovaries held larger eggs. This was due to the rapid accumulation of yolk protein or vitellogenin in the developing oocytes. Fecundity and egg size were found to show a weak positive correlation ($r = 0.13$) suggesting that more eggs do not always mean smaller egg size. This finding was in contrast to the opinion forwarded by Bagenal & Braum (1978). Also the insignificant correlations observed between the egg size and other morphometric parameters like BW and TL suggested that the larger fishes do not necessarily carry larger eggs in their ovaries. This anomaly may be attributed to the low fecund nature of the species.

Elevated GSI values accompanied with the maximum egg size in the month of July and August suggested that these months corresponded to the breeding season of the fish. These months actually fall in the peak monsoon time of the region, during which the river experiences flood with increased water current. Flood water with abundant food nutrients and high water current seemed to trigger the spawning activity for the fish.

CONCLUSION

The prime objective of the present investigation was to assess GSI and to enumerate the fecundity and size of eggs of *N. hexagonolepis* with the aim to generate additional knowledge on the reproductive biology of the species.

The finding of the present investigation revealed that the fish is a low fecund compared to other high fecund fishes with tens of thousands of eggs. Since fecundity showed more positive correlation with GW as compared to others morphometric parameters, it was concluded that among all, GW does the better prediction of the fecundity of the fish.

The higher values of GSI recorded for both male and female fish during July and August suggested their spawning season during these months with the peak activity in the month of July.

Oocytes of different size groups were found in the ovaries of mature fish. This suggested that *N. hexagonolepis* spawns more than once in a single breeding season. The fractional spawning nature of this fish can be seen as an adaptive behaviour of the fish to compensate higher mortality of its juveniles in the hill streams due to high monsoon flooding.

Fecundity and egg size showed weak positive correlation indicating that the more eggs in the ovary of the fish do not always mean smaller eggs and that the larger fishes do not necessarily carry larger eggs in their ovaries.

Having found the breeding season of the fish during the peak monsoon season, it was concluded that the flood water with abundant food nutrients and high current triggers the spawning activity for *N. hexagonolepis* in the river.

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Efficacy of praziquantel bath treatment against *Dactylogyrus vastator* infestation on common carp (*Cyprinus carpio*) fingerlings

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ABSTRACT

An external parasite *Dactylogyrus vastator* of sizes (0.3003±0.0961 mm TL) was naturally infected common carp fingerlings of average weight 1.47±1.00 g and length 6.68±0.94 cm were experimentally treated using praziquantel in glass aquarium at localities of Godawary fish farm, Lalitpur at 1576 masl elevation in central Nepal during August, 2017. Monogenean (*D. vastator*) infected fish were exposed to praziquantel in baths for 72 h period at each of three different concentrations 7.5, 10 & 15 mg/l with a control (0mg/l) treatment. A significant reduction ($p<0.05$) of *D. vastator* intensity (0.0±0.0)/infected common carp was observed treated with 15 mg/l praziquantel during 24 h period. However, praziquantel concentrations of 7.5 and 10 mg/l were equally found effective ($p<0.05$) in reduction of *Dactylogyrus* intensity/infected fingerlings at 48 h treatment period. However there was no significant control in the parasitic intensity/infected fingerling in control (untreated).

Keywords: *external parasite*, *Dactylogyrus vastator*, *common carp*, *praziquantel, treatment*

INTRODUCTION

Dactylogyrus are aquatic external small flatworms of phylum Platyhelminthes and class Monogenea, creates the major threats to aquaculture. The lack of proper management practices in intensive carp fish farming is one of the reasons of monogenetic proliferation (Koskivaara et al., 1991), which reflects in clinical signs; anorexia, gill lamellae inflammation, asphyxia and death. Since frequent use of chemicals as a control measures has been caused parasites to develop resistance to treatments and also resulted in damage to the environment (Hoài & Vạn, 2014). Therefore, alternative chemical treatments and methods of control which is more effective, sustainable and ecofriendly has required. However, most studies on using praziquantel to control external parasites have focused on marine fish but there is little study has carried on its effect on treating external parasites infecting freshwater fish (Hoài & Vạn, 2014). Therefore, the aim of the present study was to investigate the effect of bath treatment of praziquantel against severity (intensity) of parasite *Dactylogyrus* infecting freshwater common carp fingerlings.

MATERIALS AND METHODS

A total of 120 fingerlings of Common carp (*Cyprinus carpio*) of average weight 1.47±1.00 g and length 4.68±0.94 cm that naturally infected with *D. vastator* were experimentally treated using praziquantel in baths for period of 0-72 h at each of three different concentrations 7.5, 10 and 15 mg/L with a control (0 mg/L) treatment in a glass aquarium (density 10 fish/15 L) at localities of Godawary fish farm, Lalitpur central Nepal at altitude N 27º35.989' and latitude E 085º23.246' and 1576 masl elevation during August, 2017. Praziquantel (Praziquantel BP 600 mg with Titanium dioxide for colour) was dissolved into ethanol: distilled water 1.75:3.25 to obtain the stock solution for individual concentration used in experiment. The efficacy of Praziquantel was evaluated by the comparison of degree of infestation (prevalence and intensity rate) of *Dactylogyrus* parasite. Prevalence and mean intensity of parasite *Dactylogyrus* infecting fish were calculated according to the formulas suggested by Margolis et al. (1982) - pevalence (%) = (total number of individual infected fish/total number of fish examined)×100; mean intensity = number of collected parasite/number of infected fish. The anti-parasitic efficacy of praziquantel was calculated using the following equation (Wang et al., 2009) - AE = (Iu-It) / Iu) x 100 %, where, AE: anti-parasitic efficacy; Iu: mean number (intensity) of *Dactyogyrus* parasite in untreated fish; It: mean number (intensity) of *Dactyogyrus* parasite in treated fish. Wet smear of gills/individual fish were checked thoroughly for *Dactylogyrus* parasite under compound microscope. Parasite was fixed in glycerin and identification of *Dactylogyrus* spp. was performed according to characteristics described by Yamaguti (1963). Fish sampling and wet mount of gills/fish (three fingerlings/praziquantel concentration) was performed before and after treatment at 0, 24, 48 & 74 h period. Water quality parameters such as temperature, dissolved oxygen, H-ion concentration (pH) and ammonia were determined. Data were statistically analyzed by IBM statistical package SPSS (version 20) and comparisons were made at 5% probability level & the graph was obtained using Microsoft Excel Spread Sheet.

RESULTS

Mean intensity of *Dactylogyrus vastator* (0.3003±0.0961 mm TL) parasite on gills of infected common carp fingerlings were increased in number from 25.33±11.68 to 98.00±46.89 in control (0 mg/L) including the *Dactylogyrus* prevalence was observed 100% during 0 h to 72 h period (Table 1, Figure 1, 2). *D. vastator*, was appeared vigorous in the wet mounts of gills taken out from control. Praziquantel concentrations at a dose rate of 15 mg/L was significantly effective ($p<0.05$) in eradicating all *Dactylogyrus* parasite from gills of infected fingerlings of the common carp applied for 24 h. Praziquantel concentrations at 7.5 and 10 mg/L applied on common carp fingerlings in bath treatment can significantly remove *Dactylogyrus* intensity, relative to control group (untreated) within 48 and 72 h period. Though, Praziquantel at concentration of 7.5 mg/L could make it free 90% in 48 h and 99% in 72 h period from *Dactylogyrus* parasite and praziquantel at concentration of 10 mg/L could make it free from *Dactylogyrus* parasite 99.7% in 48 h period. Fingerling mortality was not observed during 72 h period at all three treatments of praziquantel (7.5, 10 & 15 mg/L) including control (0.0 mg/L). Hence, the experimental doses and treatment duration of praziquantel are safe for fingerlings of common carp.

Ammonia (NH_3) profile of untreated and treated with different concentration of praziquantel indicated that ammonia at 10 & 15 mg/L was significantly different ($p<0.05$) during 24-72h exposure period, though ammonia at 7.5 mg/L including control (0.0 mg/L) was not significantly different ($p>0.05$) over 0-72 h exposure period (Table 2). The ammonia concentration of trial water in aquarium glass was obtained from 0.12-1.46 mg/l (Table 2). Dissolved oxygen concentrations was significantly different ($p<0.05$) at 15 mg/L during 24 h to 72 h period (Table 2). Though there was no significant difference ($p>0.05$) in 0.0, 7.5 & 10 mg/L in 24 h and 48 h period. The oxygen concentration was obtained from 6.27-4.97 mg/L. During trial, pH was significantly different ($p<0.05$) in 15 mg/L praziquantel treatment at 48 h and 72 h period, however pH was not significantly difference at 0.0, 7.5 and 10 mg /L praziquentel concentration over 0 h-72h exposure period (Table 2). The pH of trialed aquarium glasses was obtained from 6.92-6.50, while water temperature ranged between 22.23-22.77ºC, over 0 h-72h (Table 2).

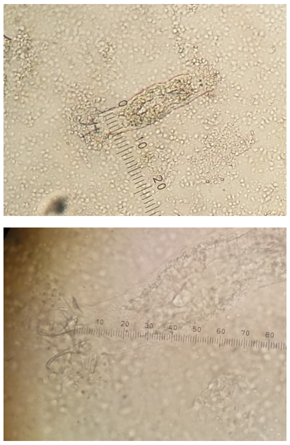

Figure 1: *D. vastator* isolated from gills (10x) (above); *D. vastator w*ith distinct marginal hooks (40x) (below)

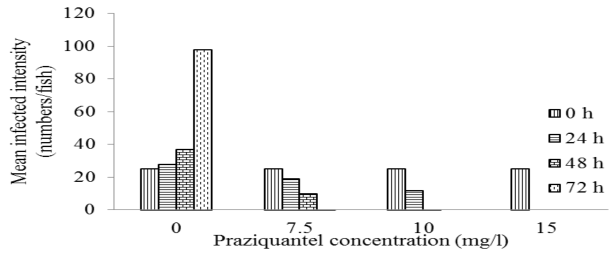

Figure 2: Relationship between mean intensity of infection & concentration of praziquantel on common carp infected with *D. vastator*.

Table 1: Intensity of *Dactylogyrus vastator* infecting Common carp fingerlings exposed to praziquantel at different doses and duration.

Praziquantel treatment (mg/L)	Intensity of *Dactylogyrus vastator*/fish in treatment period			
	0 hour	24 hour	48 hour	72 hour
0	25.33±11.68[a]	28.00±10.58[c]	37.00±10.58[b]	98.00±46.89[b]
7.5	25.33±11.68[a]	19.00±3.46[bc]	10.00±8.19[a]	1.00±1.73[a]
10	25.33±11.68[a]	12.00±3.61[b]	0.33±0.58[a]	0.0±0.0[a]
15	25.33±11.68[a]	0.0±0.0[a]	0.0±0.0[a]	0.0±0.0[a]

Table 2: Water quality in 0 h to 72 h trial period.

Water parameters	Praziquantel concentration (mg/L)	0 h	24 h	48 h	74 h
Temperature (average)	0.0	23.00	22.77	22.76	22.6
	7.5	22.73	22.50	22.30	22.23
	10	22.80	22.63	22.47	22.40
	15	22.77	22.67	22.62	22.60
pH (average)	0.0	6.92[a]	6.85[a]	6.84[b]	6.85[b]
	7.5	6.92[a]	6.89[a]	6.88[b]	6.85 [b]
	10	6.92[a]	6.90[a]	6.84[b]	6.77[b]
	15	6.92[a]	6.85[a]	6.56[a]	6.50[a]
Oxygen (average)	0.0	6.27[a]	6.40[b]	6.33[b]	6.47[c]
	7.5	6.27[a]	6.57[b]	6.47[b]	6.30[c]
	10	6.27[a]	6.23[b]	6.03 [b]	5.87[b]
	15	6.27[a]	5.57[a]	5.27[a]	4.97[a]

Ammonia (average)	0.0	0.12[a]	0.13[a]	0.13[a]	0.14[a]
	7.5	0.12[a]	0.14[b]	0.17[b]	0.20[a]
	10	0.12[a]	0.22[c]	0.25[c]	0.51[b]
	15	0.12[a]	0.78[d]	1.29[d]	1.46[c]

DISCUSSION

Praziquantel is in the anthelmintic class of medications that expel parasitic worms (helminthes) and other internal parasites from the body by either stunning or killing them and without causing significant damage to the host. It works partly by affecting function of the worm's sucker. Praziquantel has been used as a cleaner of residue at bottom of the ponds which can in turn improve water quality. Studies demonstrated the effectiveness and safety of praziquantel for fish parasites (Katharios et al., 2006). In current study, treatment with praziquantel resulted can significantly ($p<0.05$) remove *Dactylogyrus* intensity. The present study provides a significant basis for use of praziquantel solution at a concentration of 7.5, 10 & 15 mg/L for the treatment of *D. vastator* on common carp fingerlings. A significant p-value ($p<0.05$) indicates that difference detected between untreated control and treated at dose of 7.5-15 mg/L within 24-72 h period. During trial period, ammonia profile at 10 & 15 mg/L in praziquantel exposure was significantly different in 24-72 h period, but its concentration (0.12-1.46 mg/L) was within the optimum range. Toxic levels for un-ionized ammonia for short exposure usually lie between 0.6-2.0 mg/L for pond fish (Bhatnagar & Devi, 2013).

CONCLUSION

Present study provides a significance basis for use of Praziquantel bath treatment against *Dactylogyrus vastator* on Common carp fingerlings. The antiphrastic activities indicated that the praziquantel (pipeline) have the potential to be developed as a new drug for treatment against *Dactylogyrus* spp. However, further studies are required for field evaluation in the practical system.

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Effect of water temperature on induced breeding of common carp *(Cyprinus carpio)* in Trishuli, Nepal

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ABSTRACT
The cyprinid fish common carp (*Cyprinus carpio)* is known as multiple spawner however, general practice is to breed during March- April because the brood gets gravid with increasing water temperature during this period and reabsorption of eggs occurs afterward because of further rise in temperature. Study was carried out on the effect of water temperature and breeding time to enhance the breeding period of common carp. Eighty-one broods of common carp with mean age of 3.0±1.5 years and size 2.3±0.6 kg were divided in three batches comprising of nine females and 18 males in each. All batches were reared in earthen ponds at temperature between 13 to 19°C in 2016. Broods were induced with ovulin (GnRH-A) at the rate of 0.50 mL/kg body weight for female and 0.25 mL/kg for male which was done in March-May (29.0± 0.6°C), June-August (24.9±0.5°C) and September- November (20.8±0.8°C) for batch 1, 2 and 3 respectively. The results revealed that latency period decreased with increase in temperature. Latency period was 12h, 14h and 17.2h for batch 1, 2 and 3 respectively. Fertilization (63.5%) and hatching rate (60.5%) both were significantly higher ($P<0.05$) for batch 2 than in batch 1 and 3. The lowest value of fertilization (12.6%) and hatching rate (11.3%) was for batch 3. Increasing temperature leads to decrease in incubation period. The mean incubation period were 36.0±1.1h, 36.5±0.3h and 41.5±0.3h for batch 1, 2 and 3 respectively. The findings of present study suggested that the breeding period of common carp could be extended from March to August as water temperature ranged between 24.9 to 29.0°C if pre-spawning water temperature for brood rearing is maintained between 13 to 19°C.

Keywords: Common carp, temperature, latency period, hatching rate, breeding period

INTRODUCTION
The common carp is known as multiple spawner in a year. General practice is to breed this species during March- April. Breeding performance is an important parameter to evaluate the success of artificial reproduction of fish species in captive, which also depend on the environmental conditions, type of hormone used and its strength, dose of hormone and maturity status of the fish (Sahoo et al., 2007). The success of induced breeding also depends on the latency period (Bogdan et al., 2010).Fish reproduction is regulated by a number of environmental factors which stimulates internal mechanisms into action; the final product of the reproductive cycle is the release of eggs and sperm, which can be controlled by either placing fish in an appropriate environment or by stimulating the fish's internal regulating factors with hormones or other stimulants (Amer et al., 2009).

Temperature is the main environmental factor governing the development of eggs in fish embryonic development (Nwosu and Holzlohnev, 2000).Temperature is known as to influence the efficiency of yolk utilization although it has been reported that growth rate increase with increasing water temperature but when it becomes super –optimal this negate the fish's growth (Yang and Chen, 2005).In addition temperature determines the development of certain morphological features, hatching rate (El-Gamal, 2009).

Temperature is one of the most decisive environmental variables affecting the maturation and embryonic development of fish eggs. Determination of optimal temperature for common carp brood stock conditioning after inducement with hormone and egg incubation is necessary to maximize the fish seed production. The main objective of the study was to identify the influence of water temperature on fertilization and hatching rate in common carp.

An essential step in successful breeding of any fish species is to understand the optimal temperature for brood stock conditioning and egg incubation. Deformity in fry can be a result of wrong timing of stripping, especially when ova are either premature or overripe (Legendre and Otémé, 1995).The "fecundity‟ of a fish is defined as the number of eggs that are likely to be laid by the fish during reproduction. The fecundity and its relation to female size makes it possible to estimate the potential of eggs output and potential number of off springs in a season which determine the reproductive capacity of fish stock. This reproductive potential is an important biological parameter that plays a significant role in evaluating the commercial potentials of fish stocks (Gomez-Marquez et al., 2003).

A relatively new development in the technology of induced breeding is the stimulation of endogenous gonadotropin released from the pituitary of the treated fish by the use of inducing agents such as the synthetic analogue of gonadotropin releasing hormone (GnRH) (Mylonas et al., 2010). However, the injection of GnRH analogues alone is generally ineffective in inducing ovulation in cyprinids fish species where there is a strong dopamine inhibitory tone on gonadotropin secretion, which facilitate the gonadotropin releasing activity of the GnRH analogue that is combined with a dopamine receptor antagonist (Peter et al., 1988).

The usual practice for the breeding of carp fish is to administer the hormone in two consecutive injection dose, that is the priming and resolving dose (Amin, 2006), others still make use of pituitary extracts as the priming dose in combination with synthetic hormone as the resolving dose. The work of Nandeesha et al. (1990) on the breeding of Indian major carp through the single application of ovaprim has made a major breakthrough in the breeding of carp and farmers have adopted the single application of ovaprim to cause ovulation in carps (Haniffa et al., 2007). Hence the single application of ovaprim to induce ovulation in common carp is adopted for this research

MATERIALS AND METHODS

Brood stock Collection

Mean age of 3.0 ± 1.5 years old brood stocks of *Cyprinus carpio* weighing 1.7 to 2.9kg were collected from different earthen pond of Fisheries Research Station Trishuli, Nuwakot. All collected broods were stocked in cool water temperature (13-16°C). During March - November the brood stocks were fed on commercial feed containing about 35% crude protein. The fish were fed one time daily at the rate of 3% body weight and starved 24 hours prior to the breeding exercise.

Identification of Gravid Brooders

At the time of breeding the male and female brood fishes were identified on the basis of their secondary sexual characters. The ripe males were identified by roughness of the dorsal surface on the pectoral fin, which on the contrary was very smooth in the female. The roughness in pectoral fins was felt by touching the surface of fin close to the body. The matured male and female fishes were also distinguished from the shape of their body, condition of the vent and secretion of milt in males (Charula, 2008).

Experimental Design

A total of Eighty one (81) brood stock (27 female and 54 male) having body weight ranging from 1.7 to 2.9kg were used for this experiment.

Table 1: Experimental Design

Group	Ratio of Females to Male breeders	Temp(^{0}C)	Period
I	2/1	29.0 ±0.6	Mar –May
II	2/1	24.9 ±0.5	Jun – Aug
III	2/1	20.8 ± 0.8	Sep –Nov

The brooders were divided into three groups (I, II and III) of 9 females and 18 males, each of the group of brooders were bred with different water temperatures. Group I were bred in March-May with water temperature of 29±0.6°C, June- August with water temperature of 24.9±0.5°C for group II and September – November with water temperature of 20±0.8°C for group III.

Inducing Agent (OVAPRIM)

Ovulin (Ningbo Sansheng Pharmaceutical Co. Ltd., China) contains the synthetic salmon gonadotropin releasing hormone analogue (sGnRHa) and domperidone, a dopamine antagonist dissolved in distilled water at 20 µg/ml and 10 mg/ml respectively.

Single application of ovulin was used as described by Nandeesha et al. (1990), both female and male *C. carpio* were administered single dose of the inducing hormone intramuscularly at the base of the last ray of the dorsal fin with a hypodermic syringe after cleaning the area with a clean dry towel. Female brooders received a dosage of 0.5 mL/kg body weight while males received 0.25 mL/kg body weight.

Latency Period of *C. carpio*

The brood stock were administered with ovulin and returned to the iron frame cage Size (1.5*2) 3 m^2.The fish were left undisturbed for about 10 h after which period they were checked at 30 minutes interval for ovulation indicated by the release of eggs in the experimental tank (Arabaci et al., 2001). When eggs are observed at the bottom of tanks the fish are immediately brought out and stripped. The duration of time from inducement with ovulin to ovulation was recorded for the latency period of the fish.

Fertilization Rate

Estimation of the fertilization rate, three sub samples' of water hardened eggs were taken from each set and the number of fertilized egg out of total eggs produced in each sub sample was counted (Garg et al., 2002). The fertilization rate was then calculated by the following formula:

$$\text{Percentage Fertilization} = \frac{\text{Total Number of fertilized eggs}}{\text{Total no of egg produce}} \times 100$$

Incubation period

The incubation period is the average time required from initiation of incubation process to complete incubation of eggs in each set of experimental trial. The duration of time from the fertilization to the hatching of the eggs of *C. carpio* was observed and expressed in hour as the hatching time in each of the temperature groups.

$$\text{Percentage Hatchability} = \frac{\text{Total Number of hatched larvae}}{\text{Total no of fertilized eggs}} \times 100$$

Data Analysis

The statistical analysis of the data was done using the analysis of variance (ANOVA) to test for significance difference at $p \le 0.05$. ANOVA was also carried out to test for the significance difference ($p \le 0.05$) between the different temperature of *C. carpio* and weight of eggs produced, hatching rates and fertilization. Where there was significant difference Duncan's Multiple Range Test (DMRT) was carried out to separate means.

RESULTS

The results regarding the various aspects of breeding performance on the basis of temperature performance on latency period, fertilization rate, incubation period, hatching rate, of *C. carpio* induced ovulin as affected by different temperatures from the experiment.

Effect of temperature on the latency period

The results in Table 2 shows that latency period reduces with increased in temperature, at 20.80 ± 0.81°C the latency period was 17.17 ± 0.60h, at 24.93 ± 0.52 and 29.00 ± 0.58, latency was 14.00 ± 0.00 and 12.00 ± 0.58h respectively. From the same table, the statistical analysis of result (ANOVA) indicates that there was significant difference ($p \le 0.05$) between latency periods at different temperature regimes.

Table 2: Water temperature and breeding parameters of *C. carpio*

Parameter	Temperature		
	29.00 ± 0.58[a]	24.93 ± 0.52[b]	20.80 ± 0.81[c]
Female body wt (gm)	6750.00 ± 144.34[a]	4900.00 ± 404.15[b]	4660.00 ± 196.30[b]
Latency periods (h)	12.00 ± 0.58[b]	14.00 ± 0.00[b]	17.17 ± 0.60[a]
Fertilization (%)	46.33 ± 0.88[a]	63.50 ± 7.79[a]	12.60 ± 6.21[b]
Incubation period (h)	36.00 ± 1.15[b]	36.50 ± 0.29[b]	41.50 ± 0.29[a]
Hatching rate (%)	50.00 ± 2.31[a]	60.50 ± 6.64[a]	11.27 ± 6.57[b]

Effect of temperature on the fertilization rate

The result in Table 2 shows that fertilization rate increase 63.50±7.79% in group II fish induced at temperature of 24.93±0.52°C to 46.33±0.88% at 29.00 ± 0.58 °Cthen decreases drastically 12.60±6.21 at 20.80±0.81°C. The statistical analysis of results of fertilization rate shows a significant difference ($p \le 0.05$) in the fertilization rate between fishes induced in the months (September -November) (20.80 ± 0.81°C) and March-May (29.00±0.58°C) while there is no significant difference between fishes induced in June-August (24.93 ± 0.52°C) and March-May (29.00 ± 0.58°C), there The fish induced in the month of June-August had the highest fertilization rate while those induced at 29.00±0.58°C temperature had the least fertilization rate.

Effect of temperature on the incubation period

The results of incubation period in Table 2 shows that increase in temperature leads to decrease in the hatching duration of *C. carpio*. The incubation periods were 41.50±0.29 h, 36.50 ± 0.29 h and 36.00 ± 1.15 h at 20.80 ± 0.81°C, 24.93 ± 0.52°C and 29.00 ± 0.58°C, respectively. The eggs in group III with 20.80 ± 0.81°C incubating water temperature had hatching duration of 41.50 ± 0.29 hours, at 24.93 ±

0.52°C the hatching duration was 36.50±0.29 hours while 29.00 ± 0.58°C the hatching duration was 36.00 ± 1.15 hours. Statistically there was a significant difference (p≤0.05) in the hatching duration of *C. carpio* eggs at 20.80 ± 0.81°C incubated at 20.80 ± 0.81°C water temperatures.

Effect of temperature on hatching rate

The result in Table 2 shows that temperature also affects hatchability rate of *C. carpio*. The hatching rates were 50.00 ± 2.31%, 60.50 ± 6.64% (maximum) and 11.27 ± 6.57% (minimum) at 29.00 ± 0.58°C, 24.93 ± 0.52°C and 20.80 ± 0.81°C respectively.

Group 1 fishes had hatching rate of 50.00 ± 2.31%, group 2 had the maximum percentage hatchability of 60.50 ± 6.64% while the group III had the minimum percentage hatchability of 11.27 ± 6.57%. The statistical analysis of results of hatching rate indicates a significant difference (p≤0.05) between fish incubated in the three temperature groups.

DISCUSSION

Latency period

During the experiment, the longest latency period was observed, 17.17±0.60 h in the groups of fish which were induced with Ovulin at the temperature 20.80±0.81°C while the fish induced at 29.00±0.58°C had the minimal latency period of 12.00±0.58h. The findings of this research on the effect of temperature on latency period of *C. carpio* also correspond with the result of Drori et al. (1994) who obtained a latency of 14-16 hours when the fish was induced at 23°C.

At lower temperature the case is different because metabolic activities are slow, hence the release of gonadotropin by the pituitary gland into the blood stream is slower thereby retarding the duration between inducement and ovulation of the female fish (Usman, 2015).

Fertilization rate, incubation period and hatching rate

Fertilization rate of *C. carpio* was highest (63.50±7.79%) in the second batch June-August at 24.93±0.52°C and the lowest fertilization rate (12.60±6.21%) was found in the 3rd group spawned on September –November at 20.80±0.81°C. These results corresponds with the findings of Orina et al. (2014) when *Labeo victorianus* was induced with ovaprim 0.5 mL/kg at different temperatures where fish spawnedat 26±1°C had excellent fertilization rate, 93% while those induced at 22±1°C had 73.8±1.1%. It was therefore concluded that temperature had effect on the fertilization rate of *L. victorianus*. Malik et al. (2014) found 75.2% fertilization rate in Koi carp induced with ovaprim at temperature of 22-24°C, similar results was obtained in the present study on *C. carpio* which were induced at 23±1°C with fertilization rate of 76.67±23.15%. Nandeesha et al. (1990) reported fertilization percentage of 85.43% in the Indian major carp (*Cirrhinus mrigala*) with the use of ovaprim in India during May to July at temperature of 25-30°C. These results are about similar with the fertilization rate of *C. carpio* in 2nd group (26±1°C) in this experiment. The significant decrease in fertilization rate at higher temperature of 29±1°C could be that the temperature closer to thermal tolerance limit of eggs of *C. carpio*. Water temperature affects the quality and size of produced eggs (Kucharczyk et al., 2014). Moreover, temperature in fish is responsible for the period of final gamete maturation and can even inhibit the reproduction process or reduce the larvae survival rate to 0% (Bromage et al., 2001; Kupren et al., 2011).

The spermatozoa are motile for longer period at lower temperature of 20°C than at elevated temperature of 26 or 30°C in common carp or 30°C in grass carp (Jezierska and Witeska, 1999). After ovulation increase in temperature leads to significant decrease in the duration of hatching of egg of *C.*

carpio. The hatching duration in this research tend to be lesser as compared to findings of Haniffa et al. (2007) who reported hatching of *C. carpio* eggs after 72 h of fertilization at water temperature of 26-28°C, the fishes were induced with ovaprim at a dose of 0.3 mL/kg. In comparison with the present study Charula (2008) also found a higher incubation period of 58.54±0.347 hours when *C. carpio* was induced with ovaprim (dose 0.4 mL/kg) at temperature range of 23-26.5°C. Ghosh et al. (2012) found a hatching duration of 36-48 h at temperature of 28-29°C when Koi carp was induced with ovaprim, this incubation period was also higher than the incubation period of the 3rd group eggs (28.98±0.96 h) in the present study. The incubation period of *C. carpio* eggs as affected by temperature in the present study was less than all the other incubation period of *C. carpio* reported in related researches which could be attributed by other unknown factors (environmental, water quality, maturation of the breeders etc.) in Nigeria which may favor the hatching process of *C. carpio*.

The hatching rate 46.33±0.88, 63.50±7.79 and 12.60±6.21% for group 1, 2 and 3 respectively were affected by temperature The group 2 fishes spawned in June- August and incubated at average temperature 24.93±0.52°C had the highest percentage hatchability followed by group 1 spawned during March-May and incubated with average temperature 29.00±0.58°C while the group 3 fishes with incubation temperature 80 20.±0.81°C had the least hatching rate. El-Gamal (2009) documented hatching rate of 48.0±0.118% for eggs of *C. carpio* incubated at 24°C temperature, 74.53±0.232 and 54.20±0.273% hatchability of *C. carpio* eggs was also found for the incubation temperature of 27 and 30°C respectively. Orina et al. (2014) in comparison with the present study found a higher percentage hatchability of the cyprinids fish (*Labeo victorianus*), when the fish in Yala River was induced with ovaprim (0.5mL/Kg) at temperature of 22±1 and 26±1°C the hatchability was found to be 62.7±0.9 and 83.0±1.0%. The reason for the reduced hatchability rate at elevated temperature of 29±1°C could be due to the lethal effect of higher temperature on the developing embryos; since the developing embryos are fragile their resistance to environmental stress is minimal. Every organism have tolerance limit to every environmental condition which it survive and when these conditions are exceeded the resultant effect is the deformity and subsequently mortality of the organism.

CONCLUSION

In present study monthly variation in water temperature showed significant effect on induced breeding of *Cyprinus carpio*. Latency period increases at lower water temperature and shortest latency period remains at comparatively higher but limited water temperature. Incubation period was significantly affected for longer period by lower temperature. Incubation period was comparatively medium (17.17±0.60 h) while average water temperature at 24.93±0.52°C and hatching rate remained better (60.50±6.64%) at this temperature. It seems optimum in June-August followed by 50.00±2.31% at temperature (29.00±0.81°C) during March-May. The least hatching rate remained at lower temperature (20.80±0.81°C).Temperature has significant effect on latency period. Increase in water temperature leads to significant decrease in the latency period and hatching rate as well of *C. carpio*.

Considering the fact that *C. carpio can* be successfully bred artificially in hatchery condition at Fishery Research Station's environment. It is therefore recommended that the water temperature range of 23±1-29±1°C is suitable and performs best for breeding of *C. carpio*, where brood fish are stocked at water of 15-20°C. However, it is first experiment, which is needed to verify by further experiments.

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Estimation of fish catch and maximum sustained yield in a part of Trishuli river

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ABSTRACT
Daily fish catch data was collected from upstream (Betrawati, 20ha) and downstream (Devighat, 60 ha) of Trishuli hydro-dam from July 2016 to June 2017 to determine actual fish yield and compare with estimated fish catch per unit area and Maximum Sustained Yield (MSY) of fishing area. The fish yield in upstream computed from Ryder's Morphoedaphic Index (MEI) model and Wellcomme's was 25.00 kg/ha/yr and 22.56 kg/ha/yr respectively but actual fish yield was 5.00 kg/ha/yr. Similarly MSY and OFY computed by the regression model were 100.00 kg/ha/yr and 129.33 kg/ha/year. But the actual fish yield resulted from daily fish catch data was 5.00 kg/ha/yr, which is 5 times lower than previous model. The fish yield in downstream computed from Ryder's MEI model and Wellcomme's was 18.70 kg/ha/yr and 17.03 kg/ha/yr respectively but actual fish yield was 4.32 kg/ha/yr. Similarly, MSY and OFY computed by the regression model were 87.78 kg/ha/yr and 88.14 kg/ha/year. But the actual fish yield resulted from daily fish catch data was 5 kg/ha/yr, which is 5 times lower than previous model. Regarding the species composition, Hile (*Channa puctata*) was the dominant fish and constituted 50.74% which was followed by 20.72% Chuchhe asala (S*chizothorax* spp.) and 7.44% Buduna (*Garra gotyla*) respectively in upstream. Similarly, Fageta (*Barilius* spp.) was the dominant fish and constituted 22.54% followed by 17.75% Katle (*Neolissocheilus hexagonolepis*) and 11.50% Buduna (*Garra gotyla*) respectively in downstream. MSY was near about optimum sustainable yield which indicate the overfishing.

Key words: MSY, OFY, species richness and fishing effort.

INTRODUCTION

Trishuli river originating from Tibet plateau is one of the big river of Narayani river basins. A dam is built across Trishuli river at Betrawati for hydropower generation which is extended into 20 ha with depth ranging from 1.5 to 4.0 meter. The river joins with the Tadi river at Devighat and is then called Trishuli River. It is nearly 9 km downstream from the dam site. The River is about 120 km long from the point of its appearance to Mungling where it joins Marsyangdi river. It is one of the seven rivers of Gandaki river system and finally flows down to Narayani river. Multiple species of indigenous fish has been reported in Kali Gandaki River and its tributaries (Edds, 1986) which is a tributary of Narayani river. Number of fish species inhabiting the various river systems increases with the increasing size of the river and river basin (Welcomme, 1985). This is because the number of ecological niches remains greater in larger river systems than in small ones. It is necessary to have information on existing fish species, fish catch, catch per unit effort and fish yield per unit area for planning the fisheries management.

Morphoedaphic index (MEI), which predicts potential fish harvest as a power function of total dissolved solids divided by mean depth, is regarded as a model of fish production systems. Henderson et al. (1973), and Henderson and Wellcomme (1974) have demonstrated its applicability as an estimator of fish yield and standing crop in reservoirs. The applicability of MEI to estimate fish yield in river is still unknown. The main objective of present study was to determine fish yield based on MEI models and compare its value with the actual fish catch data collected from up and downstream of Trishuli hydroelectric dam (Figure 1 and 2) to estimate the maximum sustained yield.

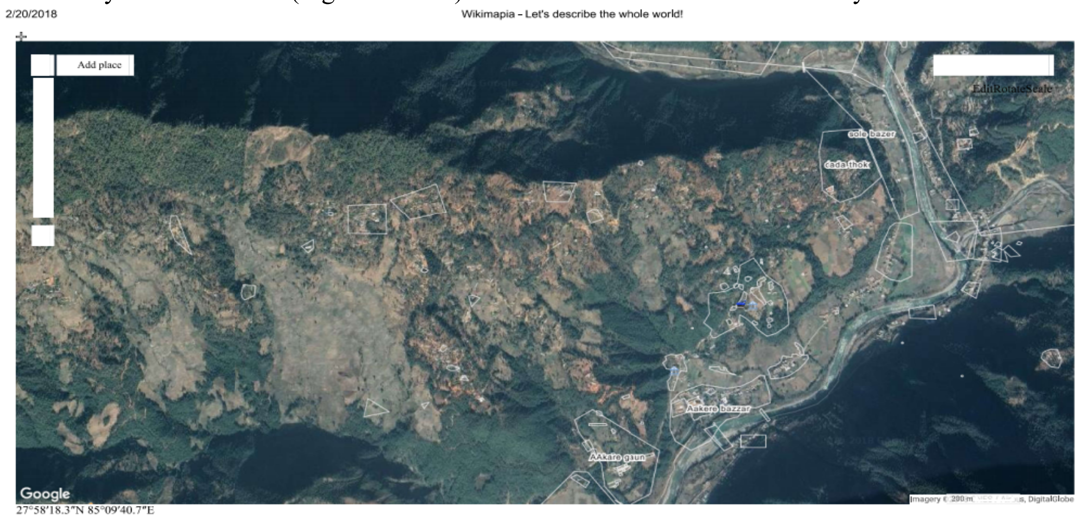

Figure 1: Fish catch area of Trishuli river hydroelectric dam to Shantibazar (20 ha with annual average depth 2m)

Figure 2: Fish catch area of Trishuli river hydroelectric powerhouse to Chaatrephat (60 ha with annual average depth 4 m)

MATERIALS AND METHODS

Fish catch data were collected from the commercial fishermen all the year round from July 2016 to June 2017. Species, respective numbers and collective weight sorted out the fish. Fishing effort was expressed as fishermen because there was not any standards in the use of fishing gears, which varied from cast net, gill nets, lift nets to long lined loops and angling rods. In upstream, the fishing area including Betrawati and Santibazar covered nearly 20 ha and the annual depth averaged 2 meter. In downstream, the fishing area from Devighat to Chaatrephant covered 60 hectare of Trishuli river and the annual depth averaged to 4 m. Conductivity was measured every month at different depths to obtain the mean value. Conductivity meter was used to measure the conductivity. The average depth was determined measuring the mean cross sections of the river.

Estimated fish yield

Computed using Morphoedaphic Index (MEI) of Ryder (1965);

$MEI=T/Z$ Yield = $2\sqrt{MEI}$

Where, T= designated as the total dissolved solids,

Z= the average depth in meter.

Conductivity factor (μ mhos/cm) =0.65

Estimated Fish Catch (C)

Henderson and Wellcomme's morphoedaphic model was used to calculate estimated fish catch (C) expressed as kg/ha/yr;

Estimated Fish Catch as kg/ha/yr (C) $=14.3136 \times MEI^{0.4681}$

Maximum Sustained Yield (MSY)

The maximum sustained yield (MSY) and optimum fishing effort (OFE) were calculated using the formula

$MSY= a^2/4b$

$OFE = a/2b$

Where, a and b were intercept and slope of catch effort curve.

RESULTS AND DISCUSSION

Table 1: Fish catch data collected from Betrawati (20ha) and Devighat (60) used to estimate maximum sustained yield and optimum fishing effort, 2016/2017

	Catch (Number)		Catch (Kg)		Effort (No. of gears)		Catch/effort	
Months	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Jul 016	1423	374	111.45	36.49	120	126	0.93	0.29
Aug	736	1332	33.38	207.49	69	77	0.48	2.69
Sep	1105	1558	34.1	168.72	35	38	0.97	4.44
Oct	1670	384	152	24.53	25	84	6.08	0.29
Nov	942	46	77	9.4	36	92	2.14	0.1
Dec	776	13	50.6	3.6	27	78	1.87	0.05
Jan 017		226		20.2		30		0.67
Feb		519		28.73		30		0.96
Mar	572	434	22.17	38.25	30	97	0.74	0.39
Apr	753	630	38.6	24.67	65	188	0.59	0.13
May	632	1118	65.11	77.76	65	184	1	0.42
Jun	254	622	1.9	5.1	76	168	0.03	0.03
Total	**8863**	**7256**	**586.31**	**644.94**	**548**	**1192**		

Table 2: MEI, MSY, OFY and actual fish yield of Trishuli river in Betrawati and Devighat

Parameter	Betrawati	Devighat
Mean of total dissolve solid (μ mhs/cm)	76.92	115.08
Annual water depth (m)	2.00	4.00
Conductivity factor	0.65	0.65
Morphoedaphic Index (MEI) (kg/ha/year)	25.00	18.70
Estimated fish yield (kg/ha/year)	5.00	4.32
Estimated fish catch(C) (kg/ha/year)	22.56	17.03
Regression Value of a intercept	1.55	1.99
Regression Value of b intercept	0.0060	0.0113
Maximum Sustained Yield (MSY) (kg/ha/year)	100.363	87.789
Optimum Fishing Effort (OFE) (kg/ha/year)	129.333	88.142

Table 3: Species composition of fishes caught in upstream and downstream

Fish Species	Upstream		Downstream	
	Number	**%**	**Number**	**%**
Sahar, *Tor putitora*	6	0.03	287	3.72
Rajbam, *Anguilla bengalensis*		0.00	32	0.41
Sahar, *Tor tor*		0.00	51	0.66
Asala, *Schizothorax plagiostomus*	3736	20.72	762	9.87
Asala, *Schizothorax richardsonii*	813	4.51	100	1.30
Jalkapoor, *Pseudotropius murius*		0.00	128	1.66
Katle, *Neolissocheilus hexagonalepis*	599	3.32	1351	17.50
Gardi, *Labeo dero*		0.00	55	0.71
Buduna, *Garra gotyla*	1342	7.44	888	11.50
Lahare, *Garra annandelai*	219	1.21	6	0.08
Bage, *Botia lohachata*	315	1.75	358	4.64
Bhedra *Glyptothorax cavia*	308	1.71	464	6.01
Kavre, *Glyptothorax annandalei*	902	5.00	466	6.04
Fageta, *Barillius sps*	640	3.55	1740	22.54
Hile, *Chana punctate*	9150	50.74	273	3.54
Sidre, *Puntius sps*	4	0.02	498	9.83
Total	**18034**	**100**	**7459**	**100**

The mean conductivity of upstream area was 76.92 μ mhos/cm and the mean depth was 2 meter. Based on the MEI model (Henderson and Wellcomme, 1974) the fish catch remained 22.56 kg/ha/yr. On the contrary the yield equaled to 25.00 kg/ha/yr (Ryder, 1982). But the actual fish catch based on daily collected data reached to 5 kg/ha/yr, which is 5 times lower than the Ryder's model. The mean conductivity of downstream area was 115.08 μ mhos/cm and the mean depth was 4 meter. Based on the MEI model (Henderson and Wellcomme, 1974) the fish catch remained 17.03 kg/ha/yr. On the contrary the yield equaled to 18.70 kg/ha/yr (Ryder's model, 1965). But the actual fish catch based on daily collected data reached to 4.32 kg/ha/yr, close to Ryder model. Similar result of catches obtained from 6 flood plain rivers in Asia ranged from 24.17 kg/ha/yr to 78.17 kg/ha/yr (Wellcomme, 1985), and the catch of upstream close to the lower range and the catch of downstream came up almost half of the flood plain rivers of Asia. Joshi and Nepal (2004) studied on fish catch data from Rijalghat, a part of Trishuli river and reported the fish yield from morphoedaphic model, actual fish yield and maximum sustained yield were 61 kg/ha/yr, 53 kg/ha/yr and 93 kg/ha/yr respectively. In upstream and downstream, similar fish yield was 22-17 kg/ha/yr but it seemed as lower in context of river productivity. The production of fish in the river will increases over the pre-impoundment conditions. The fish catch increased with the increased efforts. Both catches and efforts remained highest from December until March (Table 1). The highest catch and effort in those particular months was attributable to lower water velocity and upstream moving of fishes during spawning period. Fishing efforts declined in the monsoon on account of heavy flood and the catch dropped accordingly. The catch per unit effort was 0.5 kg/head/yr in downstream. Fishing efforts declined in monsoon on account of heavy flood and the catch dropped accordingly. The catch per unit effort averaged was 1.09 kg/head/yr. in upstream. In upstream, actual use of fishing efforts were 548. More use of gill nets and hooks will build-up dense population of small fishes. Application of higher fishing efforts may mean the overexploitation but the exploitation rate was quite reasonable to maintain the desired fish population in the natural water. In downstream, actual use of fishing efforts was 1192.The concept of maximum sustained yield (MSY), the largest number of individuals that can be removed from the population without long term changes has been extensively used as the management basis for many fisheries. MSY computed by regressing the catch per unit effort as the dependent (Y) variable and the effort as independent (X) variable remained 100 kg/ha/yr in upstream and 87kg/ha/yr in upstream (Table 2). But the actual fish yield was very low, just 5 kg/ha/yr in upstream and 4.32 kg/ha/yr in downstream which are far below the value of MSY, an indication of under exploitation. Regarding the species composition, Hile (*Channa puctata*) was the dominant fish and constituted 50.74% and it was followed by 20.72% Chuchhe asala (S*chizothorax sps*.) and 7.44% Buduna (*Garra gotyla*) respectively in upstream. Similarly, Fageta (*Barilius sps*) was the dominant fish and constituted 22.54% and it was followed by 17.75 % Katle (*Neolissocheilus hexagonolepis* and 11.50% Buduna (*Garra gotyla*) respectively in downstream (Table 3). In upstream, the estimated fish density based on collective catch data was 900/ha. Fish stocking in the reservoir ranges from over 100 to 500 depending upon the natural food availability (Sreenivasan and Sreenivasan, 1977). In downstream, the estimated fish density based on collective catch data was 11/ha. Fish density seemed quite low for natural water body. These resulted data must be reconfirmed by the further study.

CONCLUSION

The fish catch was observed upstream and downstream of Trishuli hydro–dam. From the two model Ryder's Morphoedaphic index and Wellcommes a total of 25.00 kg/ha/yr and 22.56 kg/ha/yr was recorded at upstream and 18.7 kg/ha/yr and 17.03 kg/ha/yr was recorded at downstream during the study which were 5 times lower than previous model study. This indicates that fishing efforts has positive impact on catch. Current fishery yield and effort are optimum to maximum sustainable yield. From the two model, it was understood that fishing has already attained the sustainable level at upstream as well as downstream of Trishuli hydro-dam.

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