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Effect of Substrate on Capture and Culture Fish Quality: A View Point

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Abstract

India has a large spread of freshwater resources in the form of rivers, reservoirs, lakes and ponds. For aquatic fauna, the nature of substrate assumes substantial importance in terms of quantity and quality of their productivity. Substrate includes both solid, liquid and gas which have complimentary effects. For brevity, this paper discusses the effect of solids with special reference to soil substrate and its effect on meat quality.

Matter suspended in water may be organic and inorganic, as is common in soils. Inorganic matter constitutes ~ 99% and the rest is organic in most of the tropical soils. In aquaculture, organic matter should be 1.5-2.5% with an average C: N ratio of 10-20 since it indicates moderately fast mineralization. Although the crucial importance of sediments in aquatic systems is well known, sediments are not considered as a factor in the evaluation of water quality assessment. Few studies with zebra fish *Danio rerio* (a freshwater fish) showed that river samples comprising both water and sediment exert pivotal effects in embryos, whereas surface water alone did not. This is in contrast to the findings of German rivers (Neckar, Rhine and Danube) showing high to very high embryotoxic potentials in sediments. Nevertheless this serves as a reminder that sediments have to be taken into account for the biological assessment of ecosystem quality. Urbanization and increased agricultural activities caused long term changes to many of the key physical characteristics in coastal environment. Many shallow water coastal habitats have already been severely modified through changed sedimentation regimes, increased nutrient loading, elevated turbidity and reduced light penetration. The effects of fine sediments on fish have been especially well documented. Increased turbidity and reduction of instream habitat heterogeneity are often cited as critical factors affecting fish community diversity, community structure and productivity. Influence of coarse sediment on fish productivity has not yet received much attention. In some aquaculture experiments, *catla, rohu,* silver carp and common carp were raised with organic manures for organoleptic evaluation. Odour of flesh and texture of meat of *rohu* were found better suggesting no adverse effect on the acceptable qualities of the carps by treated sewage. However, the growth, morphometry and keeping quality of fish from river channels with eutrophication indicated body deformities, reduced growth rate, and flesh quality deterioration. In-depth studies are necessary to assess the biological and structural fish quality from stresses using environmental descriptors, isotope studies and molecular markers.

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Introduction

Indian reservoirs, being in the tropics have high primary productivity with the capacity to produce more fish than the present average productivity of 29.7 kg ha^{-1} yr^{-1}. There are 1, 93,750 reservoirs in the country with a total area of more than 3.15 m ha (Table 1) (Annon 2015). Nature of substrate has greater impact on the quantity and quality of fish productivity. Substrate includes both solid, liquid and gas, which could have a complimentary effects. In this paper, discussion is limited only to solids with special reference to soil substrate and its effect on meat quality.

In India tastes and flavour of river fishes vary depending on the locations. This is similar to the tastes of vegetables and other cereals. It is probable that geology, soil, topography and agro-ecosystems have an influence in the produce human consumes with special reference to different nutrition and nutritive elements (Figure 1). While dealing with this study we undertook the help of different national and international literature. It is

Table 1. Ideal soil parameters for fish production

pH	Organic Carbon (%)		C:N ratio	
			rate of breakdown (Mineralization)*	
< = 7	Unproductive	< 0.5	Very fast	<10
	Medium Productive	0.5-1.5		
	Highly productive	1.5-2.5	Moderately fast	10-20
	Unsuitable	>2.5	Slow	>20

*In general, soil C:N ratios between 10 and 15 are considered favourable for aquaculture and a ratio of 20:1 or narrower gives good results. Source: TNAY, Agr Portal (2009-2015)

a humble effort to inform the readers about the link between the source (geology and soil) and sink (here, fishes) in wild and farmed fish systems.

Indian Scenario

Water and sediment quality

Water quality is a dynamic property of an aquaculture system and is influenced by chemical, biological and physical factors. These factors regulate the aquatic environment and productivity of the systems. Mohanty et al (2014) assessed the variations in water and sediment quality of freshwater polyculture system (fish and prawn) under different management practices (Table 2). The results of these experiments showed that the regulated water exchange system yielded

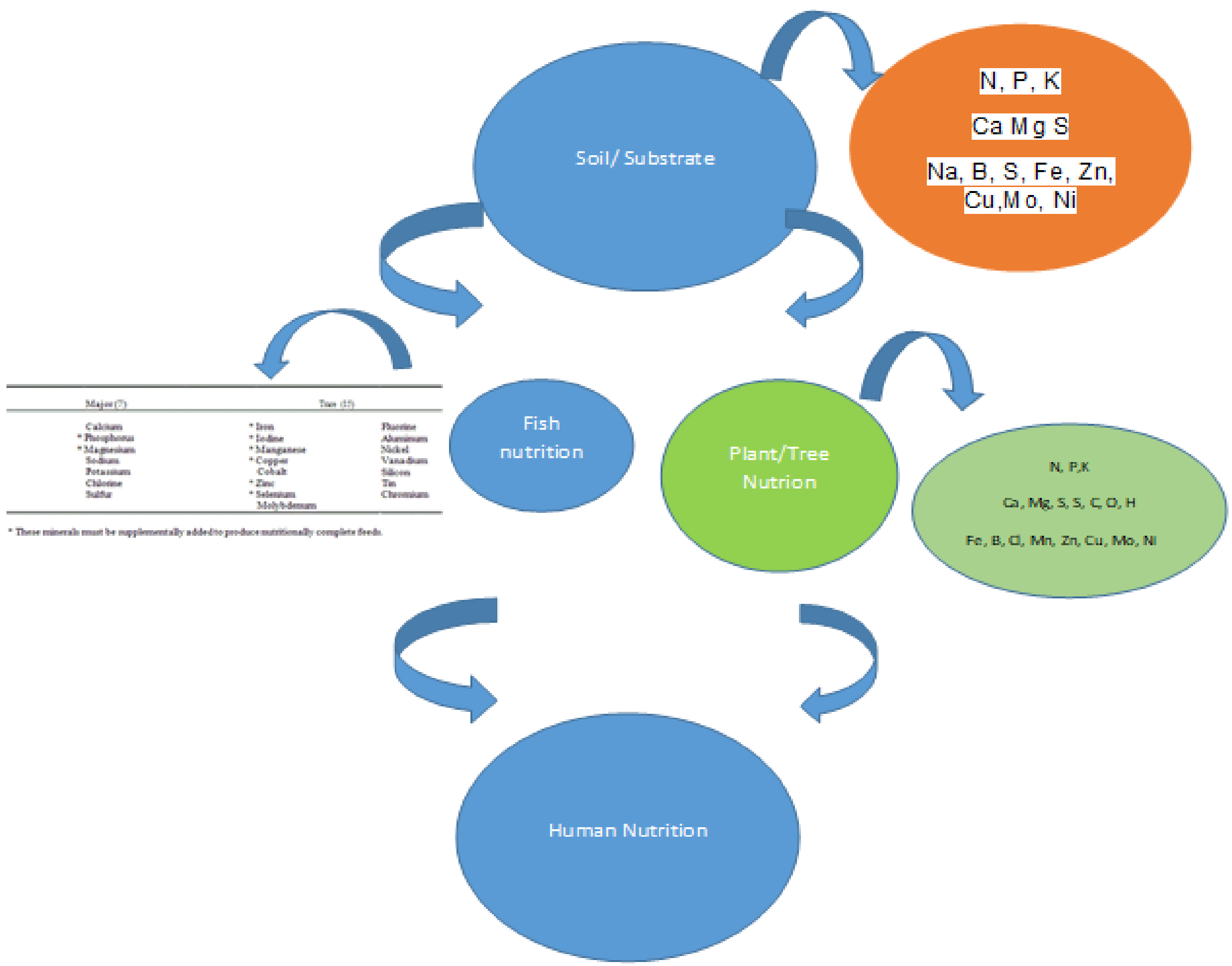

Figure 1. Link between natural resources and fish nutrition

Table 2. Treatment-wise variations in the water and sediment quality parameters in freshwater composite fish-prawn culture under different water management protocols (Mohanty *et al*. 2014)

Parameters	No water exchange	Periodic water exchange	Regulated water exchange
Water quality parameters			
Water pH	7.5	7.3	7.6
Dissolved Oxygen (ppm)	4.9	6.1	5.2
Temperature (^{0}C)	29	28	28
Total alkalinity (ppm)	89	96	108
Nitrite – N (ppm)	0.03	0.04	0.03
Nitrate – N (ppm)	0.36	0.37	0.36
Phosphate – P (ppm)	0.26	0.21	0.21
Sediment quality parameters			
Available-N in soil (mg $100g^{-1}$)	20.3	19.3	19.8
Available-P in soil (mg $100g^{-1}$)	2.11	2.23	2.21
Organic carbon in soil (%)	0.63	0.64	0.61
Soil pH	6.9	7.0	7.0

better water and sediment quality features compared to control and periodic water exchange treatments. Among the treatments, the average primary production improved with the advancement of the culture period. This may be attributed to the fixation of nutrients by suspended clay particles as reported by Mohanty (2003). The soil reaction (pH) was acidic in nature and organic carbon, available nitrogen and phosphorous increased with the advancement of the culture system. The addition of nutrients from fish waste, the nutrient cycling with fish as a major consumer component, limiting the loss of N and facilitating P release from sediment could be an acceptable reason for improvement in nutrient availability within the culture system (Banerjee 1967, Breukelaar *et al.* 1994, Mohanty *et al.* 2009).

Reservoir

The physical and chemical parameters of soils were analysed to explain the fish productivity in the aquatic system. Soil and water reactions (pH) were slightly alkaline to help promoting plankton growth resulting in better fish productivity (Banerjee 1967) (Figure 2). The reservoirs hold rich organic matter and found suitable for the benthic feeding fishes. Moreover, the dimensions of the specific conductivity (Figure 3), organic matter (Figure 4) and available P (Figure 5) indicated suitability for subsurface and bottom -feeding fish species for stocking and culture. Shinde and Singh (2014) provided the range of physical-chemical parameters of water in reservoirs for optimizing the fish production (Table 3).

Saline water

The coastal saline ponds along the Indian coast are suitable for prawn and fish farming. Thane, Raigad, Ratnagiri and Sindhudurg districts of Maharashtra are along the coastal line and the area is estimated to be 65,465 ha. The saline soil is a characteristic of these coastal areas due to the periodical inundation of cultivable land by intrusion of saline water during high tides. The variability of the sediment characteristics of saline ponds in these ecosystems are given in Table 4 (Gaidhane and Saxena 2007, Gupta *et al*. 1993, 1999, Rajyalakshmi *et al*. 1988, Chattopadhyay *et al*. 1988, Chattopadhya and Mandal 1986, Nasnolkar *et al.* 1996). The reports from these ecosystems underline that soil composition (sand, silt and clay) with increased concentration of clay, high specific conductivity, total dissolved solids, organic matter and available N offer adequate feeding habitats for the prawns and brackishwater fishes including their foraging niche.

International Scenario

The research around the world suggest that dedicated efforts are required in the assessment of sediments in aquatic ecosystems and their impacts on the aquatic biota. Recommendation of sediments levels to protect the aquatic animals was given by Birtwell (1999) (Table 5). He has also presented the limits of sediment levels with risk involved in the fisheries (Table 6). Schweizer *et al.* (2018) evaluated developmental toxicity of native river samples on fish embryos (Figure 6). Fish embryos were exposed to surface water and water containing sediment from different field sites. From sampling sites upstream the rivers (water and sediment) induced more frequent effects at considerably

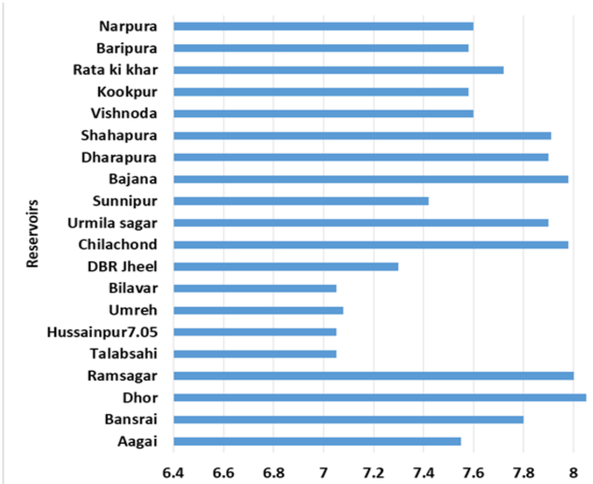

Figure 2. Variation in soil reactions (pH) in all the reservoirs in Rajasthan, India (Sengar *et al.* 2015)

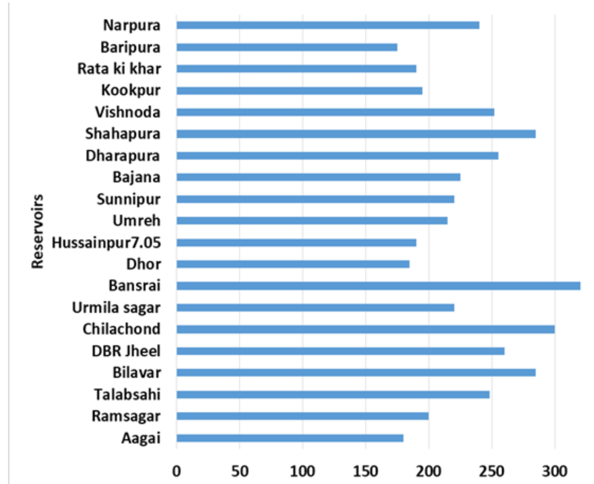

Figure 3. Variation in specific conductivity in all the reservoirs in Rajasthan, India (Umavathi *et al.* 2007)

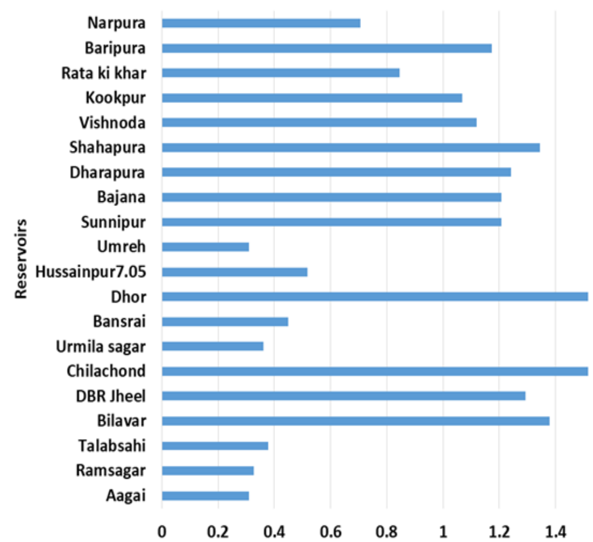

Figure 4. Variation in organic matter (%) in all the reservoirs in Rajasthan, India (Umavathi *et al*. 2007)

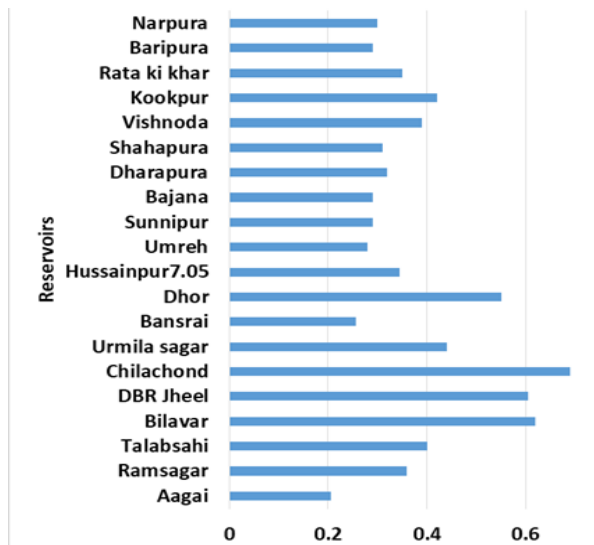

Figure 5. Variation in Available P (mg $100g^{-1}$ soil) in soil in all the reservoirs in Rajasthan, India (Umavathi *et al.*

higher levels in exposed embryos. Nitrate at the early developmental stages of fish is considerably less toxic than nitrite and even for nitrite, high concentrations are needed to induce effects in embryos or larvae (Simmons *et al* 2012, Luo *et al* 2016). The fish communities in the upstream are also impacted by the river channel morphometry (Shields *et al.* 1994, Sullivan *et al*. 2006). The natural and anthropogenic stressors increase the sediment loads and affect the fish communities. Through these factors, the increase in turbidity and reduction in habitat diversity negatively balance fish communities (Mol and Ouboter 2004). Sediment load has serious impacts on channel aggradation, reduced flow capacity, flooding and channel instability. Reproductive and feeding stress and loss of the normal body condition are noticeable in the fish communities (Sullivan and Watzin 2010).

Sedimentation has several adverse impacts on the coral reef habitats and fish assemblages since they are sensitive to sediment deposition and re-suspension (Wenger *et al.* 2011). Increased sediment concentrations leads to

Table 3. Range of physical-chemical parameters of water in Mod Sagar in India for fish production (Shinde and Singh 2014)

S. no.	Parameters (units)	Range*		Inference
		Observed	Recommended	
1	Water Temperature (ºC)	17.1 - 32.0	25.0 - 31.0	Suitable for fish production
2	pH	7.6 - 8.8	6.5 - 7.5;	Suitable for fish production
3	Transparency (cm)	19 - 62	0.45 - 0.57	Water contains adequate nutrients suitable for fish
4	Dissolved Oxygen (mg l^{-1})	5.4 - 10.4	>5.0	Suitable for fish production
5	TDS (mg l^{-1})	180 - 330	~400	Suitable for fish production
6	BOD (mg l^{-1})	3.2 - 5.65	~5.0	Water is pollution free and in favour
7	Alkalinity (mg l^{-1})	168 - 290	>100	Suitable for fish production
8	Hardness (mg l^{-1})	162 - 222	40 - 200	Most suitable for fish production
9	Calcium (mg l^{-1})	18.0 - 33.2	>25	Mod Sagar can be classified as rich
10	Chloride (mg l^{-1})	22 - 36	~8.3	Water is slightly polluted. Not
11	Phosphate (mg l^{-1})	0.25 - 1.26	>0.2	Water is quite productive.
12	Nitrate (mg l^{-1})	0.28 - 0.98	<90	Water does not have any effect on

Table 4. Variation of saline water sediment characteristics of ponds used for fisheries

Soil Parameters (%)	Kharland Ponds	Gopalapuram, and Nellore	Chilka lake, Odisha	Chilka lake fringe area ponds	Coastal saline Pond soils, West Bengal	soils of fish and prawn culture pond of West Bengal	Mandovi estuary, Goa
Reference	Gaidhane and Saxena (2007)	Gupta *et al.* (1999)	Gupta *et al.* (1993)	Rajyalakshmi *et al.* (1988)	Chattopadhyay *et al.* (1988)	Chattopadhya and Mandal (1986)	Nasnolkar *et al.* (1996)
Sand	40-70	52-80	--	--	--	--	--
Silt	18-50	7-14	--	--	--	--	--
Clay	6-20	10-35	--	--	--	--	--
pH	5-8	--	6.2 to 9.4		7-8.3	7.90 to 8.40	
Specific Conductivity (ms)	0.4-17	--	--	--	--	3.0 to 8.3 m mho cm^{-1}	--
Total dissolved solids (ppt)	0.2-8	--	--	--	--	--	--
Available N (mg 100^{-1} g soil)	1-27	0.9 * 20	11-24	13- 20	--	--	3 - 33
Organic matter (%)	0-5	--	--	--	0.5 -2.2	0.4 - 1.0	--

Table 5. Sediment Levels to protect aquatic animals (Birtwell 1999)

Suspended solids Range (ppm mg l^{-1})	Remarks
<25	No bad effects on aquatic animals
25-80	Good to Moderate fisheries; Reduced yield
80-400	Fisheries unlikely
>400	Bad fisheries

Table 6. Risk in fisheries with the increase in sediment load (Birtwell 1999)

Sediment load (mg l^{-1})	Risk in fisheries
0	Nil
<25	Very Low
25-100	Low
100-200	Moderate
200-400	High
>400	Unacceptable

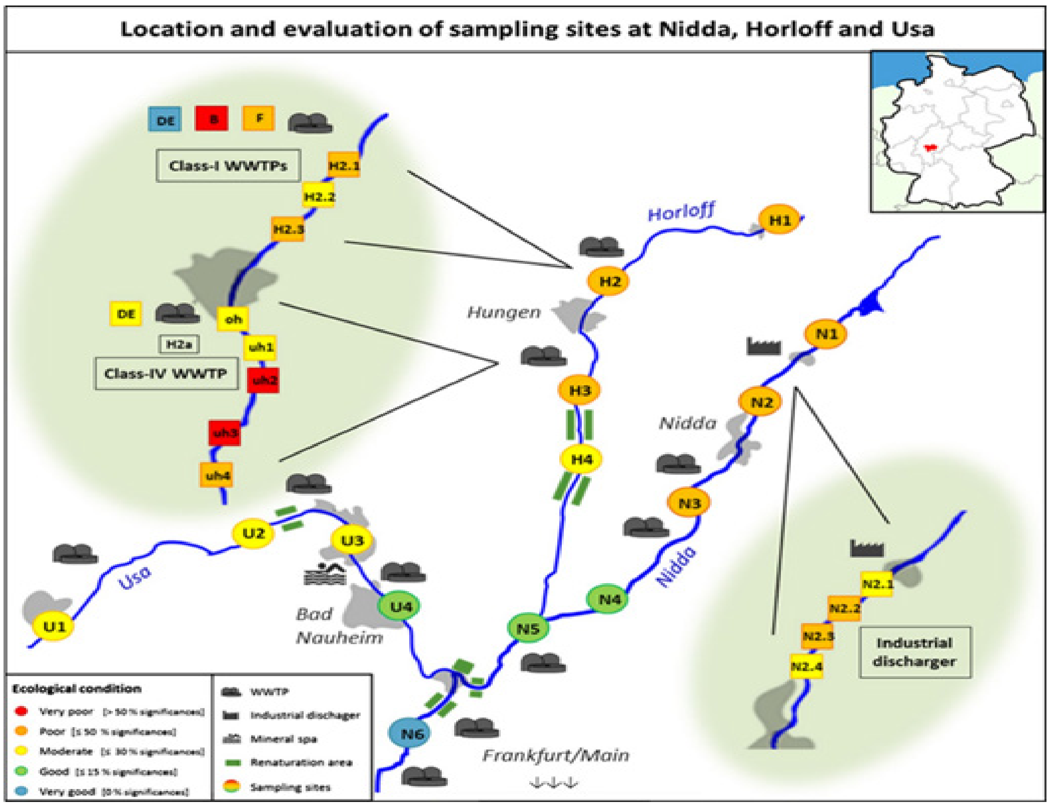

Figure 6. Map of the sampling area in Central Hesse, Germany including locations of sampling sites and their evaluation based on the percentage of significant endpoints compared to control treatments, as well as prominent points of discharge (Schweizer *et al.* 2018).

increased turbidity and reduced light attenuation resulting in reduced photosynthesis, decreased calcification rates and a shallower depth range of coral (Fabricius 2005). The suspended sediment loads divert fish species/larvae in coral reef habitats. Suspended sediment can also affect the foraging success planktivorous coral reef fish. It might result in lethal effects on food acquisition, reduced body condition, slower growth and increased mortality. If such trend continues, the threshold tolerance limit might exceed to have a permanent ecosystem loss for these invaluable coral reef fauna and flora. Anthropogenic activities causing sedimentation requires a check.

Effect on fish quality

In recent years, there has been a considerable progress in effort at harnessing the fishery potential of both marine and inland water to meet the worlds increasing demand of fish as human food due to its unique nutritive value

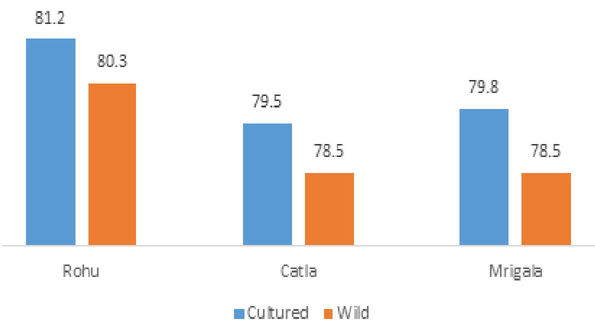

Figure 7. Moisture content (%) in freshwater fishes: a comparison (Gupta *et al.* 2013)

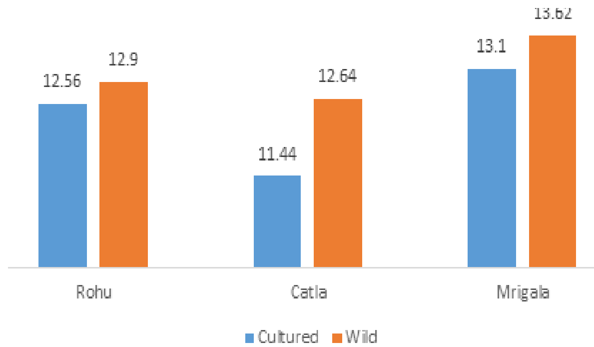

Figure 8. Protein content (%) in freshwater fishes: a comparison (Gupta *et al.* 2013)

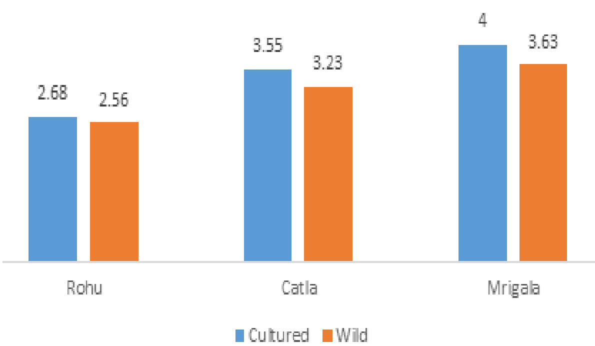

Figure 9. Fat content (%) in freshwater fishes: a comparison (Gupta *et al*. 2013)

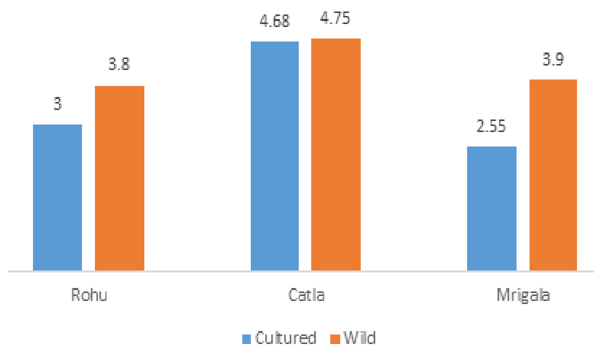

Figure 10. Ash content (%) in freshwater fishes: a comparison (Gupta *et al*. 2013)

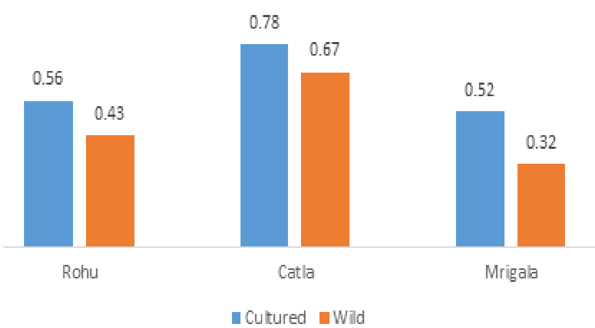

Figure 11. Nitrogen Free Extract (NFE) (%) in freshwater fishes: a comparison (Gupta *et al.* 2013)

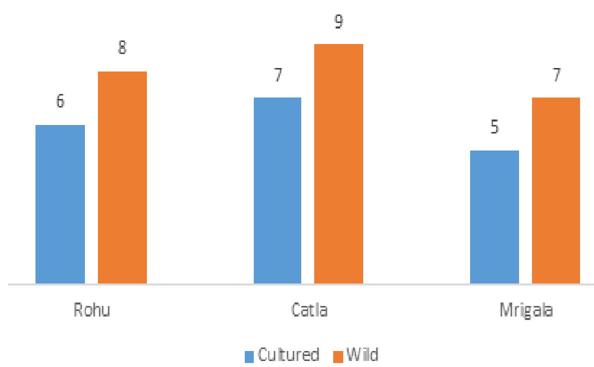

Figure 12. Textural quality (out of 10 score) of freshwater fishes: a comparison (Gupta *et al.* 2013)

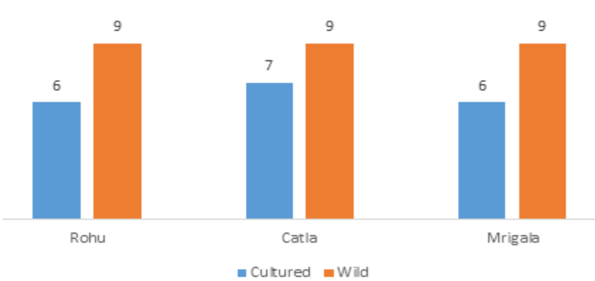

Figure 13. Colour (out of 10 score) as a quality parameter of freshwater fishes: a comparison (Gupta *et al.* 2013)

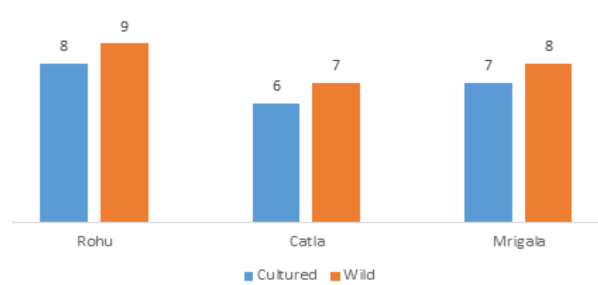

Figure 14. Taste and flavour (out of 10 score) of freshwater fishes: a comparison (Gupta *et al.* 2013)

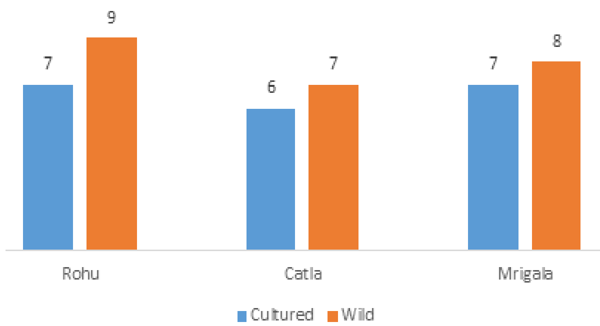

Figure 15. Overall acceptability (out of 10 score) of fresh water fishes: a comparison (Gupta *et al.* 2013)

and taste. The supply of fish and other organisms from marine water, is already giving out warning signal of stagnation. Inland waters such as rivers, lakes and reservoirs are becoming increasingly prone to pollution due to industrialization, urbanization, and anthropogenic activities. This is decreasing their value as a source of supply of animal protein (Pagarkar 1991). Modern day consumer is health conscious, and is more aware of possible hazards due to extrinsic and intrinsic quality factors.

In aquatic ecosystem, among intrinsic quality, fish substrate or fishing ground is one of the factors which play an important role not only on quality of fish but also on water quality, productivity, biodiversity, habitat, physiology (including reproduction), and microorganisms. Geographical and environmental factors also influence the composition of edible flesh.

One of the means of enhancing growth rate of fish in static environment is to fertilize the ponds periodically with organic and/or inorganic fertilizers. Unlike feeds, which are directly consumed by fish, manures indirectly affect the fish growth, through the production of fish food organisms. Flavour- producing organisms and decomposing organic matter are known to influence organoleptic qualities of fish flesh (Spinelli 1978; Nandeesha *et al.* 1984). Any flavor that appears in the ecosystems is quickly absorbed by fish (Lovell & Sackey 1973). Conversely, if fishes develop undesirable flavor from the poor habitat conditions, marketing of fish and its product will be a problem.

Cultured and wild fish quality

The differences between pond- cultured and naturally-occurring (wild) Indian major carps (*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*) from the reservoirs in terms of proximate composition of the fishes and sensory evaluation of fish curry made out of them are compared. higher protein and ash but lower fat and carbohydrate were observed in wild fish species. The cultured fishes possessed high moisture and fat content. Fish curry prepared from *Labeo rohita* was adjudged better than others. Due to stronger texture, required elasticity of chewing, pleasant taste and more delicious flavour, the curry prepared from the wild fish was preferred over the cultured fish . Wild fish is a prferred choice due to its firm texture, excellent affable taste and flavour (Gupta *et al.* 2013).

Moisture

Moisture content of all cultured fish species was found to be marginally higher than the wild fish species (Figure 7). Taking wild as standard the changes are positive and follow the trend of *rohu<mrigala<catla.*

Protein

Protein was found to be higher in wild species than in cultured species. This increase in average protein level was about 0.69%. The maximum decrease of 9.5% in protein content was encountered in *C. catla*, minimum of 2.6% in *L. rohita* and *C. mrigala* accounted for a decrease of 3.8% than wild fishes of same species (Figure 8).

Fat

Fat content in wild fishes was lower than the cultured fishes (Figure 9)., Commonly, wild fish species conatin lipid lower than the cultured ones (Ozawa et al. 1993, Alasavar *et al.* 2002, Chuang *et al.* 2010, Gupta *et al* 2013). The increase in the fat content ranged from 4.7 to 10.2% in cultured fish. Relatively white appearance in cultured fish may be due to more fat content (Howaida and Gab-Alla 2007). High lipid in cultured fish is attributed to high energy consumption and limited activity (Otwell and Rickards 1981). Active state of reserve lipid is related to physiological condition of fish (Mustafa *et al*. 1995). Generally, wild fishes spend much of their energy for their activity as well as fast swimming in the closed reservoirs which may not allow fats to get accumulated (Gupta 2009, Gupta *et al.* 2013).

Ash

Wild species contain more ash than the cultured fishes (Figure 10). The cultured fishes has 1.5 to 34.6% less ash than the wild ones. The percentage of ash content in natural and wild fish is usually more due to the higher inorganic content in the form of calcium and phosphorous (Huang *et al.* 2007; Gupta *et al.* 2013).

Nitrogen-free extract (NFE)

The Nitrogen-free extract (NFE) value was higher for cultured fishes than wild ones. The species- wise difference was found to be maximum in cultured *C. mrigala* (62% over wild), followed by *L. rohita* (30%) and *C. catla* (16%) (Figure 11). The higher value of NFE in cultured fishes may be due to incorporation of rice bran in their supplementary feed and use of starch as binder in feed. The lower moisture and lipid levels accounted for higher protein content in wild fish species (Gupta *et al.* 2013, Howaida and Gab-Alla 2007).

Taste of fresh water fishes in wild and culture: a comparison

Mean scores of 10 judges for the sensory evaluation of fish curry made from the cultured and wild varieties of fish are discussed in the following paragraphs.

Texture of fish

Among cultured fishes, the best result for the textural quality was obtained in *C. catla* in both wild and cultured fishes (Figure 12). Fish species with less moisture and higher protein content is firm when cooked (Hatae *et al.* 1990). Differences in texture of fish muscles are related to the lipid, protein and moisture contents which may influence textural properties. Therefore the texture in wild fishes with more protein and less moisture showed firmer texture (Gupta *et al.* 2013).

Colour of fish

of Wild fish takes darker colour after cooking. The colour of the fish meat was white in the curry prepared from cultured fishes while the fish curry prepared from wild fishes indicated slightly darker colour. This might be the reason of choosing rohu over other fishes (Jena 2006) (Figure 13).

Taste and flavour of fish

Firm texture, elasticity and stretchable qualities determined the taste of fishes (Gupta *et al.* 2013). These qualities also help the consumers to segregate meat and non-meat portion to improve the culinary properties to enhance tastes. The wild fishes score more than the other counterparts in this respect (Figure 14). More acceptability of wild fishes due to better taste and texture was also reported by others (Webster *et al.* 1993, Prescott and Bell 1992, Sylvia *et al.* 1995, Gupta *et al.* 2013)

Acceptability

Judging by all the above parameters of fish quality it was reported that wild fishes are more preferred; and within the three types, rohu was the most acceptable (Figure 15).

Effect of sewage on fish quality

Although there are reports with regard to the effects of feeds on the organoleptic qualities of fish (Mann 1969, Ghittino 1972, Venugopal 1980, Jayaram *et al.* 1980, Anil 1981, Nandeesha *et al*. 1984, Gupta 2009, Gupta *et al*. 2013), there is paucity of information on the influence of organic manures vis-a-vis flesh quality. In view of this, Nandeesha *et al.* (1984) evaluated of organoleptic qualities of fish catla, rohu, silver carp and common carp raised employing different organic manures. The study was undertaken wherein the influence of poultry manure, silkworm faecal matter and sewage on the organoleptic qualities of carps was investigated.

The combination treatment of poultry manure and silkworm faecal matter had a positive effect on colour and glossiness of skin and colour of flesh in common carp. Though no significant difference was observed in the overall quality, odour of flesh and texture of meat, rohu was found to be better in sewage treated and poultry manure treated ponds, respectively. It seems thatthe treated sewage has no adverse effect on the acceptable qualities of the carps studied.

Effect of inland saline water on shrimp quality

Pacific white shrimp, also known as white leg shrimp (*Litopenaeus vannamei*), is an important aquaculture species with high market value all over the world. *Litopenaeus vannamei* has become the preferred species for low salinity culture because of its ability to grow and survive in low saline environments study. Mohammed (2018) recently studied comparative meat quality and shelf life in ice and frozen storage of brackish water reared *vannamei* (BWRV) in the pond of Valsad district of Gujarat and Inland saline reared *vannamei* (ISRV) in the pond of Rohtak district of Haryana culture with the salinity of 24 ppt. In his comparative yield study, headless (HL) and peeled undevained (PUD) shrimp from both waters cultured showed higher yield in ISRV sample.

Proximate composition reported that the moisture content was higher in ISRV sample, whereas protein content was observed higher in BWRV sample. There was no significant difference observed in fat and ash content of both the samples. Biochemical analyses, showed that pH, NPN, TVB-N, TMA-N was higher in ISRV sample. There was no significant difference observed in PV and FFA values of the samples. The TBARS value was reported higher in BWRV sample. Instrumental colour results, the L* value, whiteness index and chroma value were found to be higher in BWRV sample. The total viable count of the BWRV sample was found 4.62 log CFU g^{-1} and ISRV was 4.52 log CFU g^{-1}. Sensory results indicated that all attributes had excellent scores in both the samples. The total amino acid and PUFA content of BWRV and ISRV was 17.38 g $100g^{-1}$ and 16.21 g $100g^{-1}$, 41.67% and 46.50% respectively.

Moisture content increased and all other proximate parameters decreased throughout the storage period in both BWRV and ISRV samples (Mohammed 2018). Biochemical analyses indicated that there was an increase in pH and decrease in NPN content. Increase in TVB-N and TMA content increased up to certain period of storage and thereafter the values started decreasing due to leaching of volatile nitrogen materials by ice meltwater. The whiteness index of BWRV and ISRV sample also showed an increasing trend and reached the maximum value of 50.37 and 43.02 respectively at the end of storage study. Decreasing texture parameter was observed for both BWRV and ISRV sample. Sensory scores for ice stored BWRV and ISRV decreased gradually with increase in storage period. The viable plate count of both the samples decreased on the 3rd day and subsequently increased and reached the rejection level on the 15th day of the storage. Based on the microbial and sensory evaluation, the *vannamei* (reared in brackish water and inland saline water) did not affect its shelf life. It can be stored in ice up to 12 days in edible condition.
Freezing is an effective way of long term preservation, which helps in keeping the product stable up to three months under ideal conditions. The frozen storage was also found that the L.*vannamei* reared in brackish water and inland saline water can be kept in good condition in frozen storage up to 5 months (Mohammed 2018).

Way Forward

The studies conducted on the impact of sediments on the fish quality and fish community structure are limited and it needs lot of quality reserach on this subject in future. In-depth studies are recommended to assess the biological and structural fish quality from stress environments using environmental descriptors, isotope studies and molecular markers. The studies should be carried out in such a way that the assessment of any fisheries system in wild or cultured should accompany the sampling for biotic and abiotic variables, which can yield more clues on their impact on aquatic communities. This, however, requires an integrated and interdisciplinary approach. Moreover, a focus on fish information system including the habitat characteristics is the need of the hour. Regional information systems can be developed in the initial phase and further can be upgraded to suit the international framework of fisheries database structure.

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