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A synopsis of the scientific information and utilization potential of the Assamese Kingfish

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Abstract
Assamese kingfish is one of the important cyprinids endemic to the Trans-Himalayan states of southern Asia, with considerable subsistence fishery value. As such it plays a crucial role in local livelihood, food security and occupies a prominent place in the diet of the hilly populace with traditionally identified pharmacological benefits in treating smallpox, stomachache, urinary and digestive problems. The kingfish reportedly withstands a wide range of temperature and exhibits herbivores, but opportunistic feeding behavior. In recent times, it has been identified as a potential species for diversification in hill aquaculture. On the other hand, *C. Semiplotum* population is declining in its natural habitat due to overexploitation and related anthropogenic pressures. Presently, it has been classified as vulnerable in the IUCN red list of threatened species. In scientific terms, key questions regarding its breeding biology, culture aspects, and conservation measures remain unanswered. Considering all the above, we have summarized the outcome of various studies carried on this vulnerable species regarding its taxonomic ambiguity, ecology, behavior, growth, reproduction, nutrition, pharmacological benefit, fisheries, and conservation. Further, we have suggested future research directions to bridge the existing knowledge gap.

Keywords: Assamese kingfish, candidate species, hill aquaculture, pharmacological benefits, vulnerable

Introduction
Cyprinion semiplotum is a prominent fish species endemic to the cool freshwater riverine stretches in the Himalayan states of Southern Asia. It is commonly known as Assamese kingfish due to its aesthetic value and overwhelming preference among the kings of Assam in India as a dinning delight [1]. Vernacularly, it is designated by various names among different tribal regions *viz*. emperor fish, kissing Prochilodus, Khurpi, Cheptiputhi, Bedangi, Perballey, Sundari, Orche, Ngogir, and Pech [2, 3]. It is well-recognised as a food as well as aquarium fish and occupies a substantial place in the diet of local hilly populaces [4, 5, 6]. In Nepal, *C. semiplotum* is even considered as an auspicious item and used in all social and religious ceremonies [7]. In terms of human nutrition; it is an excellent source of high-quality protein, essential minerals and fatty acids. Besides, based on indigenous traditional knowledge, it is highly valued as a therapeutic agent in treating smallpox, stomachache, urinary and digestive problems by local communities in Northeastern India [8-10]. However, the fishery for *C. semiplotum* is presently driven by unsustainable and destructive fishing practices. As a result, its natural population is reported to be declining in the wild and it is classified as vulnerable in the red list of threatened species [11].

On the other hand, scientific efforts on the taxonomic ambiguity, geographical distribution [12, 13], habitat features [14], length weight relationship age, growth, reproduction [15], nutritional values [16-18,], therapeutic potential [8-10], chromosome facts [19], indigenous fishing practices [20] and threatened status [21, 22] has been inadequate.

For instance, despite its nutritional, medicinal and economic importance, there is a lack of basic knowledge in specific areas such as captive breeding, larval nutrition, grow out culture and population genetics, which is quintessential for its prioritized propagation as potential candidate for species diversification in hill aquaculture in South Asian countries. Based on its suitability for hill aquaculture, it has been prioritized as a potential species for diversification of aquaculture in South Asian countries particularly India, Nepal, Bhutan, and Myanmar [23- 27]. In order to address these concerns and opportunities, this article summarizes the findings and reports of various studies on Assamese kingfish and proposes future priorities for scientific research.

Taxonomic ambiguity and species identification

Assamese kingfish has an unstable and convoluted taxonomic history with numerous changes in its scientific name. Its specific taxonomic position continues to be under debate even today. The species was originally described by McClelland (1839) [28] as *Cyprinus semiplotus* from Brahmaputra River in upper Assam, but Bleeker (1859) [29] allocated *Cyprinus semiplotus* to a newly established genus *Semiplotus* and Day (1870) [30] later reassigned the species name *Semiplotus semiplotus* as *S. mcclenllandi*. In the twentieth century, Hora (1937) [31] considered *S. cirrhosis* as a synonym of *S. semiplotus.* However, on the basis of jaw synapomorphies, hyoid bones, cranial and vertebral feature, Howes (1982) [32] regarded *Semiplotus* as a junior synonym of the genus *Cyprinion* and this was supported by Talwar & Jhingram (1991) [33]. In this dilemmatic situation, Banarescu and Straschil (1995) [34] described the independent status of these two genera *Cyprinion* and *Semiplotus* by mentioning the sharp differences in the number of branched dorsal rays and the absence of barbels, which was subsequently supported by Jayaram (1999) [35]. In the following year, Vishwanath and Kosygin (2000) [12] highlighted the early efforts of Hora (1937) [31] to indicate the erroneous consideration of many researchers concerning the absence of barbels in *Semiplotus* [29, 30, 36, 37, 38]. Later, in the year 2014, Vishwanath detailed the presence of small maxillary barbels as a distinct character of the genus *Semiplotus* and continued to use the scientific name *Semiplotus semiplotus* to mention the Assamese kingfish [1]. We also observed a pair of maxillary barbels in Assamese kingfish during our recent sampling in the Senki River, Arunachal Pradesh (Fig 1). Nevertheless, we have scanned and followed the popular public databases of fish species like Fish Base, International union for conservation of nature (IUCN), National center for biotechnology information (NCBI) and Indian biodiversity portal which cites the fish under the scientific name *Cyprinion semiplotum* [11, 39, 40].

Regardless of slight variations in species within the genera *Semiplotus* and *Cyprinion* that are not easy to discriminate, *Cyprinion semiplotum* can be identified by the combination of the following key identification characters. In live condition, the body is laterally silvery, dorsally dark extremely deep and laterally compressed. Except for dorsal fin, all fins are yellowish orange in color. The dorsal fin has four osseous simple and 23-25 branched fin rays. The snout has a transverse row of 10-12 open pores. A single maxillary barbel pair is present in the groove at the corners of the mouth (Fig 1). Lateral line has 31-33 scales [12, 41]. However, integrative taxonomy approach which is a combination of morphological and molecular approaches could be crucial in overcoming the taxonomic controversy and in expanding our understanding of the taxonomy and diversity of Assamese Kingfish.

Fig 1: Assamese kingfish caught from the Senki River, Arunachal Pradesh

Geographic distribution

C. semiplotum is native to South Asian countries (India, Nepal, Bhutan, and Myanmar). The fish inhabits a varying tropical relief from 500 meters to 1000 meters, with a restricted area of occupancy. In the Eastern Himalayas, the species occurs in the following twenty tributaries of river Ganga and Brahmaputra, *viz*, Dikrong, Gadadhar, Gandak, Jaldhaka, Kaljani, Karala, Khowai, Mahananda, Mechi, Pachin, Raidak, Reli, Kolodyne, Sankosh, Senkhi, Siang, Sipu, Siyom, Teesta and Torsa [10, 13, 14, 42-55]. Moreover, the species is also reported to be present in the tributaries of the Gandaki riverine system namely Baghmati, Rapti, Trishuli and Kali Gandaki in Nepal [25] and river Phepsu in Bhutan [56, 57].

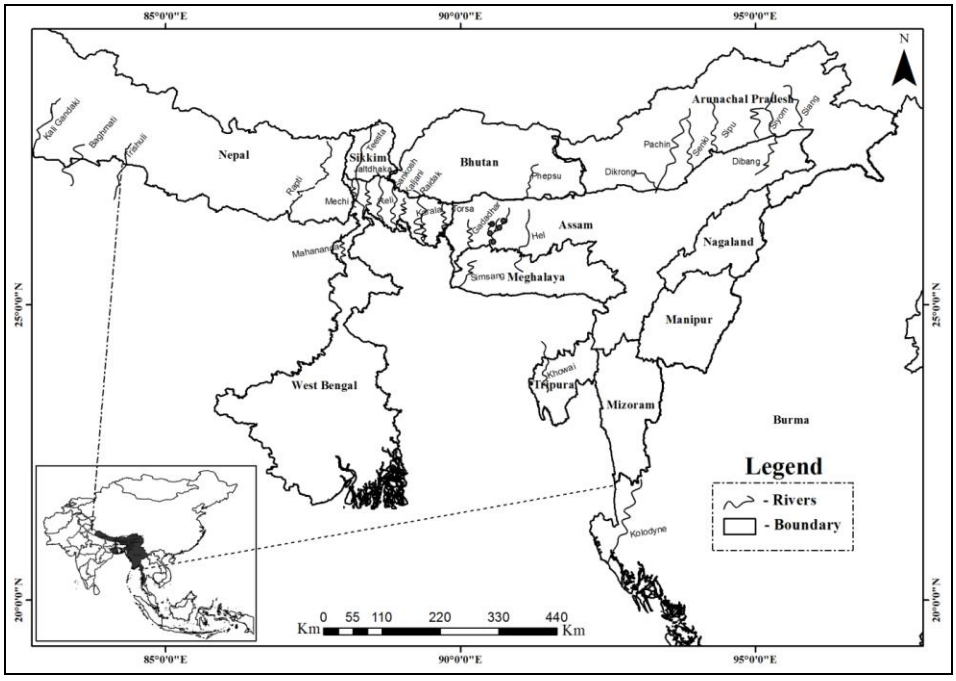

Fig 2: Geographical distribution of Assamese kingfish in Eastern Himalayas

Habitat

Being a benthopelagic fish, *C. semiplotum* thrives in moderate to fast-flowing mountain streams and rivers with rocky beds. Juveniles prefer shallow and fast flowing water, whereas adults inhabit deeper waters where water current is comparatively slow [11]. Overall, the abundance of this species is more in the zones of turbulence and hiding areas as it is apparently a dominating and vital factor for its foraging ecology. An investigation regarding the water quality parameters and temperature in the Sipu river basin ascertained *C. semiplotum* as a eurythermal fish and reported the temperature preferendum limit from 14.27 °C to 25.78 °C. In flowing waters, *C. semiplotum* prefers substantial resting and hiding areas comprising refuges, boulders, cobbles, pebbles and gravels [13, 58]. The abundance of vegetation along the river bank has been reported as a optimistic factor in proclaiming the profusion of the species. Like other hill stream fishes, *C. semiplotum* also prefers the congenial habitat for spawning which is marked by these factors namely heavy river flow, enormous water volume, slightly acidic pH (5.74 to 6.16) and increased dissolved oxygen levels (7.66 to 9.34 mg/l) [13].

Food and feeding habit

Cyprinion semiplotum is a voracious grazer. Like other *Semiplotus* species, it has an oral morphology consisting of an inferior, broad mouth with an exposed cornified mandibular cutting edge and a dentary with a broad deflected labial surface to scrape algae off the bottom rocks [59]. In addition, it has modified gill rakers for plankton feeding [15]. It is reported that the species migrates upstream in shoals at night to feed on the algae on bottom rocks. Bagra (2012) [15] reported the presence of highly coiled intestine with a relative gut length which is similar to other herbivorous fishes. Gut content analysis of the specimens collected from Marshyangdi River, Nepal revealed the presence of phytoplankton (*Oscillatoria* and *Vallisneria*) and zooplankton (*Penaeus, Anax,* etc.) in the intestinal tract [60]. Likewise, a comprehensive study on the feeding ecology of congeneric species *C. mhalensis* described a significant diet overlap among different size groups and suggested the absence of stage-specific food habit [61]. Unfortunately, similar studies on diet overlap index, diet breadth index, stage-specific food preference and the role of digestive enzymes are limited in *C. semiplotum.* Therefore, the generalized picture that emerges from the reported studies indicates that the fish is a herbivore with opportunistic omnivorous tendency.

Growth pattern and reproduction

Generally, longevity of the species belonging to the genus *Cyprinion* has been estimated as 7+ years. With a distinct head shape and great body depth, the fish grows to a maximum total length of 60 cm [3, 31, 39]. This fish apparently does not retain an identical growth pattern throughout their lifespan, which is evident from the length-weight regression coefficient values (b), indicating an isometric growth pattern in the adult male and female fish, but a negative allometric growth pattern in case of juveniles [14, 62] (Table 1). Although this distinctive minor carp is reported to grow to larger size [33], scientific records on its growth rate during different life stages are limited. A recent study suggested that length at first maturity in male *C. semiplotum* ranges between 151 to 160 mm, whereas in female it ranges between 146.22 to 154.51 mm [15].

Table 1: Values of various parameters in the relationship $W=aL^b$ between the length (L) and weight (W) from different riverine systems

Riverine system	Sample description	Sample size	Total length (mm)	b	a	r^2	References
Dikrong river, Arunachal Pradesh	Male	29	132-285	3.0926	0.0019	0.9067	Dutta and Das. 2014 [14].
Dikrong river, Arunachal Pradesh	Female	40	212-273	3.2592	0.0017	0.9810	
Dikrong river, Arunachal Pradesh	Pooled sex	69	132-285	3.0426	0.0019	0.9421	
Dikrong river, Arunachal Pradesh	Juvenile (Unsexed)	51	80-116	2.6135	0.057	0.959	
Torsa River, West Bengal	Pooled sex	436	30-153	2.897	0.0137	0.939	Koushlesh *et al.* 2017 [62].

a, Constant; b, Exponent and r, Correlation coefficient

In the wild, the Assamese kingfish breeds during the monsoon season and the peak breeding season lasts from June to September in Northeast India. During this season, increased river flow and water volume along with lowered pH (5.23 to 6.21) and alkalinity (60.89 to 72.61) of the river water play a vital role in breeding. Sexual dimorphism is evident among the adult male and female fishes during the breeding season. Males bear keratinized anal fin tubercles while the females exhibit smooth anal fins. In addition, the percentage of anal fin height on the standard length of the female was found to be more than that of the male [63]. The reproductive potential with respect to fecundity is estimated to be ranging in between 3425 to 6958 eggs per 100 gram of the body weight [15]. However, there is still great progress to be made in understanding several aspects of breeding such as induced breeding, latency period, fertilization, embryonic development and larval rearing of this commercially promising species.

Promising nutritional profile for human consumption

Fishes are rich in nutrients and *C. semiplotum* is not an exception. It is an excellent source of high-quality protein and other nutritional components that are positively correlated to human health. In terms of nutritional composition, 100 grams of the fish muscle contains on an average 18.12 g protein, 7.72 g crude fat and 142 calories [16]. Its muscle protein has a well-balanced amino acid composition with glycine being the major constituents (9.01 %), followed by methionine (8.45 %) and phenylalanine (8.07 %) (Table 2). It is reported that more than twenty-five fatty acids are present in its muscle with a higher proportion of saturated fatty acids (SFA). The most abundant fatty acids present in *C. semiplotum* are Palmitic acid, Stearic acid and Palmitoleic acid. Besides, the fatty acid profile indicates the dominance of n-3 fatty acids over n-6 fatty acids and acknowledges the high content of EPA and DHA in its muscle (Table 2) [16]. Regarding minerals, macro minerals such as potassium, calcium, sodium and micro minerals such as iron, manganese, zinc, and selenium are present in high quantity [16, 24]. Compared with other freshwater fishes like, Indian major carps, tilapia and catfishes, the Assamese kingfish has higher amount of crude protein, crude fat, n-3 and n-6 fatty acids in the muscle [64-70]. Hence this fish can be a healthy addition to the human food basket.

Table 2: Key amino acids, fatty acids, and minerals present in the Assamese kingfish

Nutritional component	Individual component	Content
Amino acids (%)[a]	Glycine	9.01
	Methionine	8.45
	Phenylalanine	8.07
	Hydroxylysine	7.77
	Valine	7.64
	Tyrosine	4.53
	Arginine	3.36
	Histidine	3.27
	Isoleucine	3.04
	Serine	2.12
	Aspartic acid	1.76
	Glutamic acid	1.42
	Threonine	1.33
	Alanine	0.78
	Lysine	0.55
Fatty acid profile		
Saturated Fatty acids	Palmitic acid	2392.94
(mg/100 g)	Stearic acid	1042.49
	Myristic acid	352.70
Monounsaturated Fatty acids	Palmitoleic acid	1019.47
(mg/100 g)	Oleic acid	379.11
	Paullinic acid	99.00
Polyunsaturated Fatty acids	Alpha-linolenic acid	597.90
(mg/100 g)	Eicosapentaenoic acid	319.49
	Docosahexaenoic acid	273.69
	Linoleic acid	188.19
	Ecosatetraenoic acid	92.12
Macro mineral (mg/100g)	Sodium	133.41
	Potassium	701.29
	Calcium	467.12
Micro mineral (mg/100g)	Iron	4.00
	Zinc	1.70
	Manganese	0.21
[a] percentage of total amino acids		

Medicinal value

Besides its nutritional composition, it is highly valued for its medicinal properties. Based on the indigenous traditional knowledge, the recognition of *C. semiplotum* as a therapeutic agent is linked to the traditional belief in its efficacy in treating smallpox, stomachache, urinary and digestive problems. For instance, children suffering from smallpox were prescribed to eat the whole body of the fish in combination with earthworm by the Nyishi tribal community in Arunachal Pradesh (North Eastern India). Such prescription was offered under the vernacular names Ngui and tadar given by the tribes of Nyishi. Further, the tribes used smoked intestines, gut, cervical vertebrae and stomach of the fish with rice to treat the stomachache and digestive problems [8-10]. The medicinal effects of the fish could be possibly attributed to the abundance of specific essential nutrients like methionine, phenylalanine, eicosapentaenoic acid, docosahexaenoic acid, potassium, iron, zinc, selenium and other therapeutic factors (Table 2). Although, *C. semiplotum* and its congeneric species have been attested to have traditional pharmaceutical benefits [71, 72], studies on elucidating the possible compounds that results in the observable therapeutic effects, have not been paid much attention.

Fishery

C. semiplotum is a common food fish of Eastern Himalayas and it is being exploited throughout its distribution range using various fishing contraptions of indigenous origin and different types of scoop nets. The main fishing gears that are specifically used to catch Assamese kingfish are takomgaanam, tasumkunam, lipum paanam, ishir, edir, and cast net [73, 74]. Among which, lipum fishing, an eco-friendly fishing method is the most commonly practiced in the perennial rivers *viz*, Koyu, Sio-Dobung, Ledum, Simang, Ego, kidi, Heei, Heipu and Siyom, flowing through Arunachal Pradesh. It involves the preparation of artificial dwelling place for fishes in the river by stacking up stones in circle of around 2 m diameter and 0.8–1.0 m height. The trap is usually installed during November and December and harvesting of fish is done during the months of January and February. This fishing method has the capacity to catch 4-10 kg of fish per lipum [20, 73, 75]. Though *C. semiplotum* is caught using various fishing gears throughout the year, the highest catch was recorded in the month of July [13].

Conservation

Due to unregulated fishing, the Assamese kingfish is considered as vulnerable in the IUCN red list of threatened species [11]. It is estimated that in the last ten years the species have declined by 30 percent and may decline by 50 percent in the near future due to over-exploitation, habitat loss, fragmentation, and pollution. It exhibits low population resilience with a minimum population doubling time of 4.5 - 14 years [39]. At present, as the fishery is unregulated, it poses a significant threat to the species. Irrational exploitation of fingerlings as small as 30 mm and brood fishes during the breeding season using various destructive fishing traps (tip and thokre) and small mesh sized fishing gears is regarded as the root cause of sharp decline in population [74, 76, 77]. On the whole, as the fishery for *C. semiplotum* appears to be unsustainable and driven by destructive fishing practices, it is crucial to limit catches in critical riverine habitat through legal protections like the implementation of seasonal ban on fishing during the breeding season, regulation on fishing gear size and fishing method. Similar strategies have been suggested for golden mahseer conservation and well implemented in marine fisheries [78]. As an ex situ conservation measure, efforts are being taken to artificially propagate *C. semiplotum* by developing brood bank and captive breeding technology in India [79]. As an ideal example for conservation, community based eco-friendly fishing practices have been adopted by the local populaces of Arunachal Pradesh and certain in-situ conservation measures like social fencing and aquatic sanctuary concept for the protection of native fishery resources [13]. Hence, the rivers in Arunachal Pradesh still have a good distribution and abundance of Assamese kingfish.

Future research perspective

Despite the fact that Assamese kingfish has a high market price and represents a good potential for mid-altitude aquaculture, there has been limited efforts on understanding its basic biology related to captive breeding, and management. It is the need of the hour to understand its captive breeding, potential embryonic development, nursery rearing, nutritional requirement, health management and the impact of husbandry related environmental stressors. At the same time, as its taxonomic position contiues to be under debate, it is also important to understand the systematics, phylogenetic position and evolutionary biogeography of *C. semiplotum* using the integrative taxonomy approach. Further, to

implement suitable fishery management plans, it is vital to understand the genetic structure of the different populations which are known to be intensively exploited. Although a considerable amount of information is available on the nutritional and medicinal benefits of eating *C. semiplotum*, limited nutritional interventions are carried out concerning vitamin content in fish. Further, it is also important to back its traditional belief as a therapeutic agent by elucidating possible compounds that may underlie the beneficial effects through *in vitro* as well as *in vivo* studies.

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