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Genetic health of Indian major carps: Assessment of effective population size and rate of inbreeding in fish hatcheries of Tamil Nadu, South India

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Abstract

The present study evaluated the genetic health of hatchery populations of the Indian major carps (IMCs), catla *Labeo* (=*Catla*) *catla*), rohu *Labeo rohita* and mrigal *Cirrhinus mrigala* in Tamil Nadu, South India. The study was based on the data collected during the 2023-2024 breeding season from 16 private hatcheries and 3 government hatcheries in Tamil Nadu. The estimated effective population size (N_e) ranged from 13 to 640 for catla, 18 to 1015 for rohu and 9 to 474 for mrigal. Correspondingly, inbreeding rates varied from 0.08% to 3.89% in catla,0.05% to 2.75% in rohu, and 0.11% to 5.63% in mrigal, indicating varying levels of genetic risk among hatcheries. Effective ways to control and prevent further accumulation of inbreeding are discussed in this paper, in order to improve the genetic quality and long term sustainability of captive seed production of IMCs.

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Introduction

Carp culture is the backbone of freshwater aquaculture in India, with Indian major carps (IMCs) contributing over 70% of the country's freshwater fish production (Das *et al.,* 2022). This increase in production levels has been possible only due to the sustained seed production in hatcheries. Even though captive seed production contributed to the sustained and increased levels of fish production, it has also led to the decline in the genetic diversity of hatchery-bred stocks. The target of production to be achieved by the hatcheries has increased over the years. and this has led to the increase in number of broodstocks being maintained in the hatcheries. Even though the number of brooders maintained in hatcheries has increased compared to the past years, it remains minimal compared to the high fecundity of carps. In addition, brooders within hatcheries are often closely related as the hatcheries do not exchange brooders. At times, wild stocks are occasionally introduced to replenish broodstocks. However, records on the number, origin and genetic contribution of such brooders introduced are seldom maintained. Thus, most of the broodstock used currently in hatcheries are the descendants of a limited number of founder population of the hatchery, increasing the risk of inbreeding. Elevated levels of inbreeding may contribute to reduced performance in grow-out systems, including lower productivity, poor disease resistance, stunted growth and redused feed conversion efficiency. These genetic effects often unnoticed due to the absence of systematic genetic monitoring and record keeping, making it difficult to identify the causes of declining seed quality and production performance.

Estimates of effective population size, inbreeding rate, and cumulative inbreeding have been reported for carp hatcheries of Karnataka, Maharashtra, Gujarat, Uttar Pradesh, and Assam (Eknath and Doyle, 1990, Mishra and Jain, 1993; Badiger, 1994; Jahageerdar *et al.*, 2004, Das, 2012). However, the status of genetic aspects of Indian major carps (IMCs) in fish hatcheries of Tamil Nadu has not been evaluated so far. This study is the first large-scale attempt focusing on the genetic aspects of IMCs in carp hatcheries of Tamil Nadu. This study was undertaken to evaluate the effective population size and inbreeding rate in IMCs maintained in 16 private and 3 government hatcheries in Tamil Nadu, India. The findings reveal the current levels of inbreeding in hatchery stocks and offer a scientific basis for formulating a better breeding strategy to enhance the quality of fingerlings produced and overall carp productivity.

Materials and methods

Data collection

A total of 19 fish hatcheries (16 private and 3 government) (Table 1) were selected based on their seed production levels. Private hatcheries (Fig. 1) were located in Tanjore and Tiruvarur districts while the Government hatcheries (Fig. 2) were located in Bhavanisagar (Erode District), Manimutharu (Tirunelveli District), and Mettur (Salem District). The data were collected in the year 2023 during the major breeding season of IMCs , from April to August. A bilingual questionnaire comprising of 25 questions in English and Tamil was prepared, in order to collect the required information. The questionnaires were given to each hatchery owner followed by personal interactions to clarify the questions. Later, the data were compiled through physical verification

Data analysis

The formula from Falconer and Mackay(1996) was used to calculate the effective population size and inbreeding rate from the recorded data.

Effective population size, $$Ne = \frac{4Nm \times Nf}{Nm + Nf`}$$

where N_m = No. of males contributing to the next generation and N_f i= No. of females contributing to the next generation. The inbreeding rate was calculated with the formulagiven by Wright, (1921):

Annual rate of inbreeding, $$\Delta F = \frac{1}{2Ne}$$

Ne = Effective population size. The mean and variance of the effective population size and inbreeding rate were calculated using MS Excel.

Table 1. Dimensions selected to measure governance quality

S. No.	Hatchery	Latitude	Longitude
1	Vaduvoor	10.700854	79.3296395
2	Palliagraharam	10.835	79.1463
3	Thittai	10.83557971	79.16543718
4	Karandhai 1	10.8091	79.1318
5	Karandhai 2	10.827495	79.140971
6	Karandhai 3	10.809108	79.132179
7	Karandhai 4	10.808938	79.132325
8	Karandhai 5	10.817243	79.136685
9	Surakottai	10.75313	79.160674
10	Savalakaran	10.696711	79.491349
11	Thirumeineri	10.562476	79.458979
12	Swamimalai	10.96406	79.331762
13	Orathanadu 1	10.60921	79.243315
14	Orathanadu 2	10.608847	79.243324
15	Orathanadu 3	10.631263	79.262116
16	Kilvelur	10.698839	79.674715
17	Bhavani Sagar	11.471251	77.133834
18	Mettur	11.797344	77.804341
19	Manimutharu	8.652149	77.438742

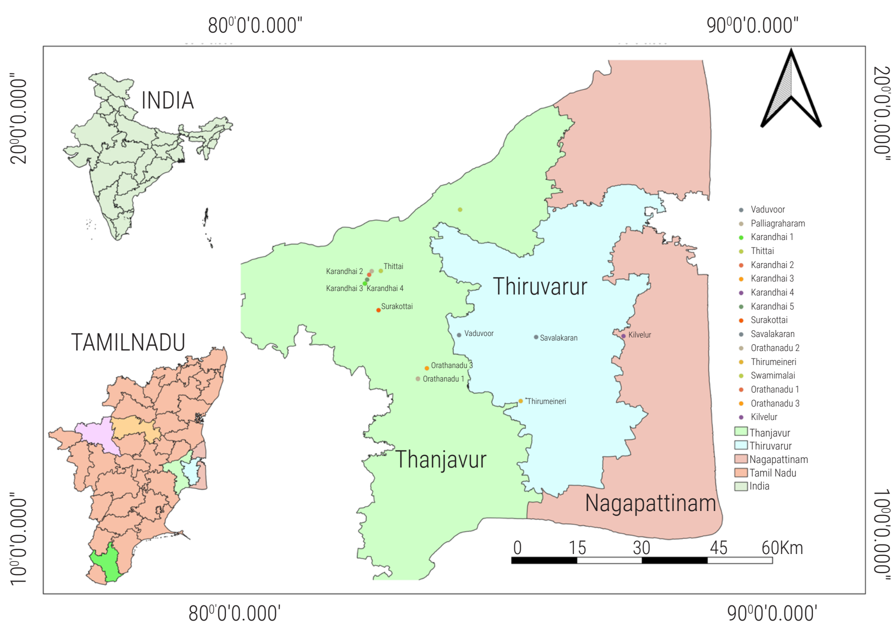

Fig. 1. Study area map (Private hatcheries)

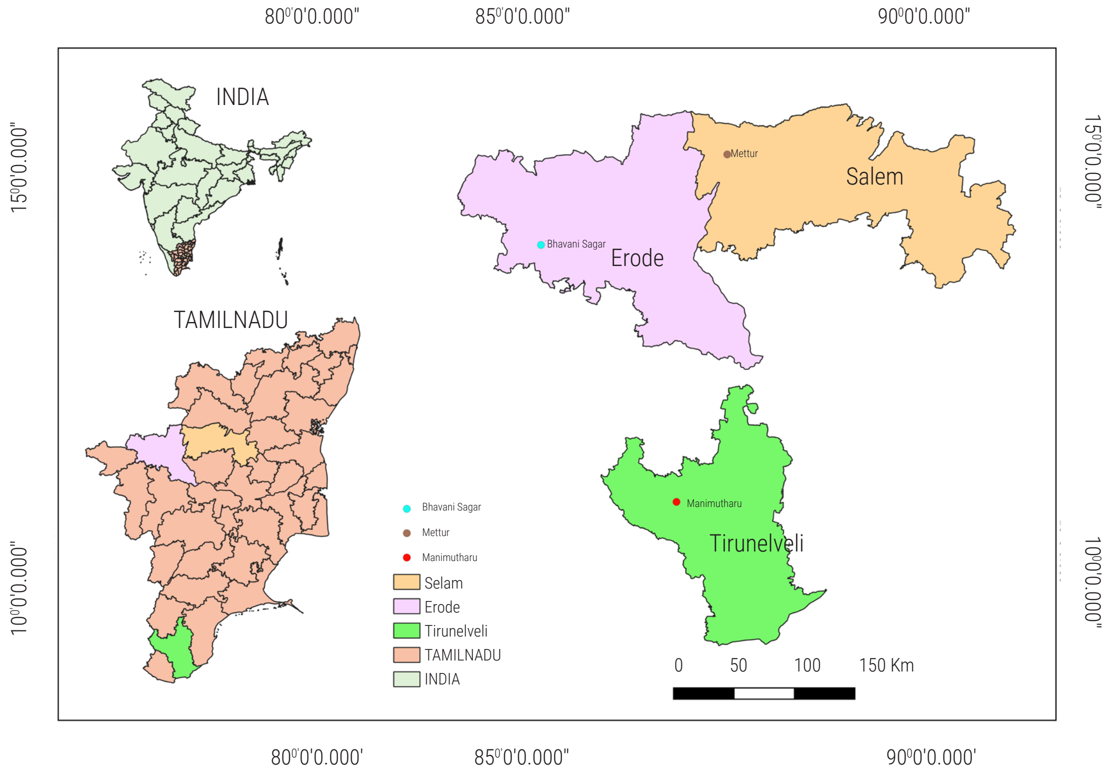

Fig. 2. Study area map (Government hatcheries)

Results and discussion

In Tamil Nadu, the average early fry production target fixed for the three government hatcheries under study was 22.33 crores during the period of study. In addition, average late fry target fixed was 3.25 crores. In case of private hatcheries, the fry production is purely based on the customer demand and fluctuates over the years. Currently private hatcheries produce lesser number of fries than government fish hatcheries. Hence the effective population size was found to be significantly high in government compared to private hatcheries. This leads to the lower inbreeding levels in government hatcheries compared to private hatcheries.

The estimated levels of effective population size and accumulation of inbreeding are presented in Tables 2, 3 and 4 for catla, rohu, and mrigal, respectively. Effective population size of catla ranged from 13 to 640, while 18 to 1015 for rohu and 9 to 474 for mrigal. Inbreeding rates varied from 0.08% to 3.89% in catla, 0.05% to 2.75% in rohu, and 0.11% to 5.63% in mrigal. The average effective population size was 182, 245, and 106 for catla, rohu, and mrigal respectively. The average inbreeding rate was 0.93%,0.55%, and 1.4% for catla, rohu, and mrigal, respectively. The variance values for effective population size were 31,975.38, 56,342.37 and 15,202.02 for catla, rohu and mrigal, respectively, while the variance values for inbreeding rate were 1.08, 0.42 and 2.56.

Karandhai 5 hatchery, had the least effective population size of 13, 18 and 9 for catla, rohu, and mrigal, respectively. Hence, inbreeding rates were also high (3.89%, 2.75%, and 5.63% in catla, rohu, and mrigal, respectively. The government hatcheries had the maximum effective population size. Manimutharu hatchery had the maximum effective population size of 640 in catla (Table 2) while Mettur hatchery had the maximum effective population size of 1015 for rohu (Table 3) and of 474 for mrigal (Table 4).

The effective population size (N_e) ranged from 3 to 30 and rate of inbreeding (ΔF) for one generation in catla was 3.1 to 13.2%, 6.0-12.6% in rohu and 4.0 to 12.0% in mrigal in fish hatcheries of Karnataka (Eknath and Doyle, 1990). The annual inbreeding rate was 4.24-15.87% for catla, 7.63% for rohu, and 5.66-10.90% for mrigal in two representative hatcheries of Uttar Pradesh (Mishra and Jain, 1993). The annual rate of inbreeding was 0.13-6.13% for catla, 0.16-1.16% for rohu, and 0.35-2.84% for mrigal in different hatcheries of Gujarat State (Badiger,1994). The cumulative inbreeding rates of IMCs in Maharashtra State hatcheries recorded were 0.71-19.09%, 0.05-5.23% and 0.11- 4.24% for catla, mrigal and rohu, respectively (Jahageerdar *et al*., 2004). The effective population size and cumulative inbreeding rate in Gujarat State hatcheries were estimated in 2005. The effective population size for catla ranged from 55 to 431. It was 11 to 152 in mrigal and 48 to 268 in rohu. The cumulative inbreeding rate ranged from 0.42 to 1.63, 3.18 to 5.91, and 0.73 to 1.71% for catla, mrigal, and rohu, respectively (Deepak *et al*., 2005). The effective population size and cumulative inbreeding rates of IMCs in Karnataka and Maharashtra State hatcheries were estimated similarly to those reprted by Jahageerdar *et al*. (2004). The effective population size for catla ranged from 5 to 204 in the hatcheries of the two states and it was

8 to 285 in mrigal and 8 to 540 in rohu. The cumulative inbreeding rates ranged from 2.69-13.75%, 3.02-5.88%, and 8.63-15.21% in Karnataka State hatcheries and 7.81-39.34%, 2.46-10.20% and 5.84-14.09% in Maharashtra State hatcheries for catla, rohu and mrigal, respectively (Deepak *et al.*, 2006). Evaluation of effective population size (N_e) in different government and private carp hatcheries of Assam (Das, 2012) showed that the effective population size ranged from 5.23 + 2.88 (N_e+SD) for catla, 13.50 + 6.68 for rohu, and 11.80+5.67 for mrigal. Assessment of inbreeding rates in carp hatchery in Thanjavur District of Tamil Nadu, South India revealed effective population sizes in the range of 3 to 49, 8 to 39 and 3 to 49 for catla, rohu, and mrigal, respectively. The inbreeding rate ranged from 1.50 to 24.63, 3.75 to 19.53, and 1.50 to 24.63% for catla, rohu, and mrigal, respectively. It was found that inbreeding rate was maximum in catla due to their smaller effective population size (Suresh *et al.*, 2019).

Catla stocks were moderately inbred in the hatcheries under study. Karandhai 5 hatchery had the least effective population size of 13 for catla and the inbreeding rate was 3.89%. Manimutharu and Bhavanisagar state hatcheries had the maximum effective population size of 640 and 512 for catla. Inbreeding rates were 0.08% and 0.1%, respectively in these two government hatcheries. Bhavanisagar was popularly known as the “Catla breeding centre” among the state fish hatcheries of Tamil Nadu. Although catla is strongly driven by customer demand, its breeding frequency was comparatively lower than that of rohu due to lower survival rates from fry to fingerling stages and a weaker response to hormones, as revealed through interaction with the hatchery operators. Earlier studies in Maharashtra State hatcheries reported similar results (Deepak *et al*., 2006). These findings contrast with the results of Suresh *et al*. (2019), who reported comparable levels of inbreeding in catla and mrigal from fish hatcheries in Tanjavur. This may be due to the relatively lower preference for catla among pond owners and consumers during the earlier years, which likely influenced broodstock management and breeding practices.

Table 2. Effective population size and inbreeding rate of catla reared in different hatcheries of Tamil Nadu

Sl.No.	Hatchery	Number of brooders contributing to the next generation		Effective population size	Rate of inbreeding (%)
		Male	Female		
1	Vaduvoor	121	72	181	0.28
2	Palliagraharam	18	12	29	1.74
3	Thittai	36	19	50	1.01
4	Karandhai 1	198	260	450	0.11
5	Karandhai 2	18	10	26	1.94
6	Karandhai 3	144	75	197	0.25
7	Karandhai 4	128	66	174	0.29
8	Karandhai 5	9	5	13	3.89
9	Surakottai	18	10	26	1.94
10	Savalakaran	132	70	183	0.27
11	Thirumeineri	165	85	224	0.22
12	Swamimalai	12	7	18	2.83
13	Orathanadu - 1	136	68	181	0.28
14	Orathanadu - 2	42	23	59	0.84
15	Orathanadu - 3	60	32	83	0.6
16	Kilvelur	42	20	54	0.92
17	Bhavani Sagar	359	199	512	0.1
18	Mettur	234	140	350	0.14
19	Manimutharu	383	275	640	0.08
Average				182	0.93
Variance				31975.38	1.08

Table 3. Effective population size and inbreeding rate of rohu reared in different hatcheries of Tamil Nadu.

Sl. No	Hatchery	Number of brooders contributing to the next generation		Effective population size	Rate of inbreeding (%)
		Male	Female		
1	Vaduvoor	190	120	294	0.17
2	Palliagraharam	27	16	40	1.24
3	Thittai	45	24	63	0.8
4	Karandhai 1	329	222	530	0.09
5	Karandhai 2	26	13	35	1.44
6	Karandhai 3	163	82	218	0.23
7	Karandhai 4	143	72	192	0.26
8	Karandhai 5	13	7	18	2.75
9	Surakottai	36	17	46	1.08
10	Savalakaran	156	85	220	0.23
11	Thirumeineri	182	90	241	0.21
12	Swamimalai	91	53	134	0.37
13	Orathanadu - 1	161	82	217	0.23
14	Orathanadu - 2	140	75	195	0.26
15	Orathanadu - 3	87	43	115	0.43
16	Kilvelur	70	36	95	0.53
17	Bhavani Sagar	334	190	484	0.1
18	Mettur	603	438	1015	0.05
19	Manimutharu	290	223	504	0.1
Average				245	0.55
Variance				56342.37	0.42

Rohu stocks were extensively bred in all the hatcheries under study and hence were least inbred among the IMCs. Karandhai 5 hatchery had the least number of effective population size of 18 for rohu and the inbreeding rate was 2.75%. Mettur state fish hatchery had the maximum effective population size of 1015 and an inbreeding rate of 0.05% for rohu. Mettur was popularly known as the “Rohu breeding centre” among the state fish hatcheries of Tamil Nadu. Rohu was bred throughout the year in hatcheries due to its higher consumer demand, ease of breeding, better market price and higher survival rates. These results are in agreement with the earlier studies reporting that rohu is extensively bred in hatcheries thoughout India (Deepak *et al*., 2006; Suresh *et al*., 2019).

Mrigal stocks exhibited high levels of inbreeding in all surveyed hatcheries. Karandhai 5 hatchery had the least effective population size of 9 and the highest inbreeding rate of 5.63%. Mettur state hatchery had the maximum effective population size of 474 and least inbreeding rate of 0.11%. Mrigal was not bred during the 2023-

Table 3. Effective population size and inbreeding rate of mrigal reared in different hatcheries of Tamil Nadu

Sl No.	Hatchery	Number of brooders contributing to the next generation		Effective population size	Rate of inbreeding (%)
		Male	Female		
1	Vaduvoor	82	48	121	0.41
2	Palliagraharam	7	5	12	4.29
3	Thittai	18	11	27	1.83
4	Karandhai 1	144	99	235	0.21
5	Karandhai 2	12	7	18	2.83
6	Karandhai 3	83	39	106	0.47
7	Karandhai 4	72	35	94	0.53
8	Karandhai 5	5	4	9	5.63
9	Surakottai	14	8	20	2.46
10	Savalakaran	70	33	90	0.56
11	Thirumeineri	84	41	110	0.45
12	Swamimalai	9	5	13	3.89
13	Orathanadu - 1	65	35	91	0.55
14	Orathanadu - 2	45	24	63	0.8
15	Orathanadu - 3	42	23	59	0.84
16	Kilvelur	66	34	90	0.56
17	Bhavani Sagar	251	149	374	0.13
18	Mettur	298	197	474	0.11
19	Manimutharu	0	0	0	0
Average				106	1.4
Variance				15202.02	2.56

24 breeding cycle in the Manimutharu hatchery. The species was generally bred at lower frequencies due to lower customer demand in Tamil Nadu, resulting in smaller effective population sizes and consequently higher levels of inbreeding. Earlier studies in Karnataka state hatcheries revealed similar results (Deepak *et al*., 2006).

Steps to prevent inbreeding in hatchery stocks

Inbreeding accumulates over the years from one generation to another; and hence, cumulative inbreeding rates provide a more representative measure of genetic status than annual inbreeding estimates. As the present study was conducted over single year, cumulative inbreeding could not be computed. Moreover, systematic breeding records were absent in most of the hatcheries. In the few hatcheries where breeding data was available (all three government hatcheries and two private hatcheries), the data were recorded in terms of the broodstock weight, rather than the exact number of fish used for breeding, making it difficult to accurately determine the exact number of breeders that have contributed to the next generation, and to precisely calculate the effective population size. Hence the results may not reveal the exact scenario regarding genetic status of the hatchery stocks. In addition, the hatcheries (both private and government) did not maintain any pedigree records, further limiting the accuracy of inbreeding assessments and highlighting the need for improved record-keeping and genetic monitoring practices.

The breeders were used continuously for three years in most of the hatcheries, after which they were replaced with new broodstock. The current scenario of replenishment of broodstocks in the hatcheries is represented in Fig. 3. This indicates that the chances of inbreeding is higher in the hatcheries with the ongoing practices. Therefore, stringent measures need to be implemented immediately to prevent further loss of genetic variability in hatchery stocks. The steps to be taken are discussed below. In all the hatcheries the number of male brooders was more than the female brooders and therefore the sex ratio of 1:1 is not being maintained. Reduced number of female brooders lowers the effective population size, thus leading to increase in inbreeding rate. The Food and Agriculture Organisation recommends maintaining an effective population size of at least 50 for short-term genetic stability and 500 for long-term sustainability (FAO,1981). Accordingly, hatcheries should maintain a balanced sex ratio (1:1) of male and female brooders to enhance effective population size and minimise inbreeding.

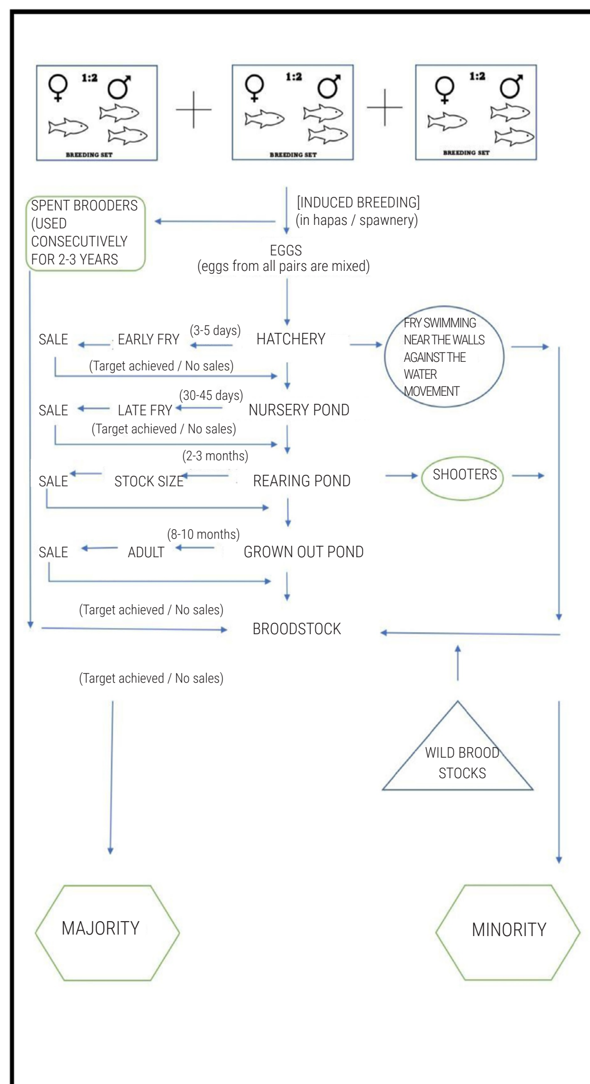

Fig. 3. Flow chart depicting replenishment of broodstocks in hatcheries

Tagging of broodstock is essential to identify individual brooders and to prevent the repeated use of brooders in consecutive breeding cycles. This will help to maintain genetic diversity in the population and to help reduce inbreeding, particularly during the initial stages. It will also help to increase the accuracy of records maintained and will provide insightful data to policymakers and researchers.

Inbreeding rates in the hatchery stocks can be lowered through management interventions sucha as: (i) Increasing the effective population size; (ii) Maintaining a balanced male-female sex ratio (1:1); (iii) Maintaining pedigree records, and (iv) Periodically exchanging or replacing broodstock with individuals from other hatcheries, research centres, or wild populations. As a practical outcome of this study, Tables 5, 6, and 7 provide templates for broodstock management, breeding, and larval-rearing records. Adoption of these templates will facilitate effective genetic tracking and contribute to the long term sustainability of hatchery operations.

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Table 5: Broodstock management record

Date	Species	Broodstock ID	Sex (M/F)	Age (Years)	Weight (g)	Source (Hatchery/Wild)	Tag No.	Breeding history	Remarks

Table 6: Breeding and spawning record

Date	Species	Male ID	Female ID	Breeding hormone used	Hormone dosage (ml kg^{-1})	Fertilisation rate (%)	Hatching rate (%)	Survival rate (%)	Remarks

Table 7: Larval rearing and survival record

Date	Species	Tank No.	No..of hatchlings stocked	Initial length (mm)	Initial weight (mg)	Survival rate (%)	Days of culture	Final length (mm)	Final weight (g)

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