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Best management practices for hatcheries culturing African catfish

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Terms	Definition
African catfish	"*Clarias gariepinus*" alone, not its hybrids.
Catfish broodstock	Sexually matured catfish males and/or females capable of being used for spawning. They should already have viable eggs and milt.
Catfish fingerlings	Young African catfish that weigh 0.5–1.5 g and are incapable of ingesting 2 mm pellets. In the industry, post-fingerlings refer to those weighing 1.6–1.9 g.
Catfish fry	Young African catfish 4–14 days old. Depending on their weight, those 15–21 days old are called post-fry.
Catfish hatchery	A facility where fertilized African catfish eggs are incubated, hatched and raised to either fry, fingerlings or juveniles.
Catfish juveniles	Young African catfish weighing 2–5 g that display all the phenotypic features of an adult but are not sexually mature. They are capable of ingesting 2–3 mm pellets. Post-juveniles and those weighing more than 5 g are, in some places, called "jumbo."
Fish seed	Fry, fingerlings and juveniles.
Full-sibs	Offspring from the same father and mother, in this case African catfish seed.
Gonado Somatic Index	The percentage of the weight of eggs divided by the weight of the fish.
Half-sibs	Offspring from either the same father but different mother or same mother but different father.
Hybrids	The results of crossing *C. gariepinus* with either *Heterobranchus longifilis* or *H. bidorsalis*
Nursery	A facility where fry or post-fry are raised either to fingerlings, juveniles or post-juveniles. It can constitute plastic, concrete or fiberglass tanks located either indoors or outdoors. Some nursery facilities are made of earthen ponds.
Runts	Slow growing African catfish fry, fingerlings or juveniles that are often less than half the average size of their cohort members and are mostly cannibalized if not separated.
Shooters	Fast-growing African catfish fry, fingerlings or juveniles that often reach 3–7 times the average size of their cohort members and mostly cannibalize smaller members.
Siphoning	Removes uneaten feed and waste produced by fry, fingerlings or juveniles usually from the bottom of the tank by suction through a flexible hose.
Sorting	Grading fish to remove shooters and runts into separate tanks, ponds, vats, etc., to prevent losses, especially from cannibalism.
Vitellogenesis	Egg development in fish, in this case African catfish.

Table 1. Definition of terms as used in this document.

Executive summary

This document was put together with the aim of providing best management practices (BMPs) to small and medium-sized hatcheries producing African catfish (*Clarias gariepinus*) fingerlings or juveniles. Adhering to these practices will not only increase efficiency and profit for farmers but will also minimize losses and key negative environmental and social impacts of African catfish hatcheries. This document contains performance-based practices derived from a combination of survey of a hatchery practices in Nigeria, the author's experience and the literature.

Key issues

As required in the Global Seafood Alliance's draft of its hatchery standards, hatcheries need to conduct risk assessments to determine any potential operational risks to humans. These include assessing the types, quantities and safety of antibiotics and chemicals used in a hatchery.

This document discusses the following points:

- the need for establishing a minimum wage for hatchery employees, maximum working hours and other requirements for the welfare, health and safety of workers
- the employee-employer relationship, gender participation and the ideal minimum amount of training or qualifications
- the production of hybrids and the use of shooters as broodstock
- monitoring effluent and escapes and understanding the limitations of different production systems regarding water use and water quality
- stocking density issues, time and types of first feeding, frequency of feeding and grading, ideal sizes of fingerlings and juveniles, standard transportation methods and packaging materials
- origin, sources and number of broodstock, mating systems, sex ratio, handling and management of broodstock and broodstock production
- proposals for traceability models.

1. Introduction

African catfish (*Clarias gariepinus*), from the *Clariidae* family, is the most cultured species in Nigeria, the second-most in Africa and the fastest growing aquaculture candidate in Sub-Saharan Africa. Because of its fast growth rate, adaptation to various culture systems and environmental conditions, it is a favored aquaculture species in Nigeria, where there are more hatcheries for this species than any other country. In Nigeria, African catfish are farmed in concrete tanks, plastic tanks, wooden vats, fiberglass tanks, steel bathtubs, earthen ponds and any other structures that can contain them.

1.1. Life cycle of African catfish

The life cycle of African catfish is usually 10 months. In the wild, broodstock eggs mature at the start of the rainy season and spawning takes place during the rainy season, from May to October. African catfish are seasonal spawners and nocturnal in nature. Mature males and females engage in courtship and then spawn, laying their eggs on grasses in the shallows of freshwater in the wild, where the adhesive eggs attach to the grasses until they hatch. Hatchlings absorb their yolk sac within 2–3 days, depending on the temperature, and swim up in search for feed, such as zooplankton. As they grow, they begin to feed on smaller fish, other smaller aquatic animals and sometimes plants. They start exhibiting sexual dimorphisms 4 months after hatching, and become sexually mature at 7–8 months old. They pair up, court and spawn as water levels increase and river banks flood, which provides food for their offspring. However, this depends on many factors, such as availability of feed, water temperature, water volume and seasonality.

In the early days of aquacultutre operations, African catfish hatcheries first collect mature mature broodstock from the wild and put them into ponds to acclimate them to their new environment and to feeds. They then establish procedures for broodstock maturation, water systems for incubation, hatching and fry rearing and also fry feeding and management. Over time, the hatchery is able to produce, raise and spawn its own broodstock.

2. Site selection

Selecting a suitable site for an African catfish hatchery is important. Many hatcheries in Nigeria were set up in hopes of successfully breeding and managing African catfish fry following a successful grow-out cycle. However, many of them were not located at a suitable site. To appropriately select a site for this operation, it is necessary to first understand the different types of African catfish hatcheries and their requirements.

2.1. Types of African catfish hatcheries

African catfish hatcheries vary in size, scale, type of operation and location, either indoors or outdoors. The majority of catfish hatcheries in Nigeria are small-scale, using flow-through systems that are located indoors. Depending on their scale of operation, indoor hatcheries have multiple tanks made out of plastic, fiberglass, collapsible polypropylene, metal tubs or concrete. Large-scale indoor hatcheries either have larger tanks or a greater number of tanks. They also use more water, or reuse water if they have a recirculating aquaculture system (RAS). Outdoor hatcheries are located outside and use tanks and/or earthen ponds. It is important to note that, in some cases, incubation takes place indoors, while rearing of larvae, fry and fingerlings happens outdoors. This is usually because temperatures drop very low at night in some states in Nigeria, which could slow the embryogenesis and delay the incubation time, and even jeopardize the whole process if done outdoors.

2.2. Suitable sites for outdoor hatcheries

Tank-based outdoor hatcheries require a relatively flat land area, large enough to function as the base or platform for installing or constructing the tanks. The area must have an adequate volume of usable underground water, a reliable power source and suitable drainage. The site should be secure, predator-free and located outside of flood zones.

Pond-based hatcheries also require relatively flat land to build ponds. The area must have soil that retains water, a high water-table, good drainage, and be free of erosion, flooding, predators and run-off. These hatcheries can use good quality surface water, if it is free from refuse, oil and chemical spills, erosion and run-off from agricultural lands, which could bring in pesticides or herbicides. It is important not to site a pond-based hatchery too close to other farms for biosecurity reasons. Avoid sites with very acidic soil, or soil or water with significant traces of iron. Acidic soil will require periodic liming to maintain a suitable pH, while the iron can affect the respiration and health of fish.

In all cases, prospective hatchery owners must test underground and surface water before establishing a site, to determine the water's physico-chemical parameters. Avoid sites with high hardness, heavy metals or nitrite in underground water unless effective corrective measures can be put in place. The site should have minimal vegetation, as trees attract and shield predatory birds. The roots of large trees can also destroy pond dikes and cause leaks. In addition, bushy sites could harbor monitor lizards, which are known to cause serious production losses, and also snakes, which can be dangerous to workers.

2.3. Suitable sites for indoor hatcheries

Indoor hatcheries are usually tank-based, made from concrete, plastic, glass, fiberglass, polypropylene, wood or metal. Depending on the size of the operation, the size and number of tanks vary from one hatchery to another. It is important to establish the scale of operation intended, the level of intensity to be used, the type of nursery system required and the volume and quality of water needed.

Ensure the amount of land is adequate to accommodate the hatchery building or complex. Include a security post, a feed store and an office, together with the hatchery production area. Ideally a room should be available for staff working at night, as it might be necessary to carry out some operations at night, such as stripping and preparing fish seed for transportation. For large hatcheries with frequent large-scale deliveries, it is important to have a driveway and a parking area to make it easy to handle and transport fish.

It goes without saying that prospective hatchery owners must test the underground water on the site. This might not be possible before buying the land, unless it has an existing borehole or you can get permission to drill a test bore. If there are neighboring boreholes, however, it is possible to sample the water from three surrounding boreholes, ideally sunk at different depths. Information from these existing boreholes will guide your expectations and the quantity and quality of water likely available.

Access to the site is also important, with efficient drains to waterways or a central drainage system in the neighborhood. This is especially important because the volume of effluent water released from African catfish hatcheries daily can be high and, as such, requires treatment and effective discharge. To minimize or avoid conflict in the neighborhood, identify or plan adequate drainage channel(s) when selecting a site for a hatchery.

2.4. Other considerations

If the selected site is in an area within reach of numerous grow-out farms, this could simplify local marketing. Measure the total size of the site, record its coordinates and keep all land titles properly. There are different designs of African catfish hatcheries. Ideally, construct the building so that it is well ventilated when hot and well heated when cold. For small-scale hatcheries, construct buildings that are warm enough to maintain optimal temperatures for the fish seed when the windows and doors are shut. Such structures can support year-round fish seed production by lowering the cost of heating during cold weather. Furthermore, using underground water tanks for storage can help keep water warm, since the surrounding soil insulates them better than the overhead tanks commonly used in Nigeria. If the buildings cannot maintain appropriate temperature ranges, hatcheries can make use of heaters and chillers in their water treatment systems.

Keep incubation tanks small to medium in size, ideally no larger than 1000 L. This makes it easier and more efficient to replace the water and to remove dead eggs and larvae. Larval rearing tanks can be similar in size to the incubation tanks. They should be shallow, no deeper than 60 cm, with a water level below 24 cm. For rectangular tanks, the length and breadth can vary depending on the design. For circular tanks, the diameter can be up to 1.5 m.

Hatcheries must maintain swim-up fry in shallow waters so that the fry do not to expend too much energy swimming up to the feed. The fingerling production tank can be the same as the fry rearing tank or different depending on the size, design and mode of operation of the hatchery. As the fish grow, the water level is increased, until they become fingerlings.

At this stage, the fish start jumping and responding to sudden sounds or banging, especially at night, causing them to drop on the floor of the hatchery. If this happens, move them into tanks that are 1–1.5 m deep and increase the water level up to 50%–75% of the tank's depth to prevent them from jumping out. All tanks, whether for incubation or for rearing larvae, fry or fingerlings, should have a gentle slope toward the middle of the tank, especially in the case of circular tanks, or to one end of the tank in the case of rectangular tanks. This slope helps collect any solid waste at the deepest point, which makes it is easy to remove by manual siphoning or by self-cleaning.

Hatchery owners need to construct concrete harvesting slabs at the deepest point of earthen ponds to make it easy to harvest the fish seed completely (Plates 1 and 2). The base or bottom of the ponds should gently slope from the inlet side of the pond to the outlet side.

For ponds, it is important to design them in such a way that workers can completely net the top (Plates 3 and 4) and/or use deterrents such as installing a scarecrow with non-uniform noise and motion to keep away predators and restrict access.

The size of operation and number of broodstock are what determine the size of the broodstock ponds or tanks. This document includes instructions on how to predetermine the required number of broodstock (Sections 3.3 and 3.4).

Hatcheries must also calculate the amount and cost of power required and conduct a load analysis. Proximity to power and its reliability are important, as is the need to have a backup or full-time diesel generator or access to another power source. Hatcheries need power is to pump water, run aerators and to operate other water treatment or filtration equipment. A more sustainable and potentially reliable approach is to integrate solar power or other alternative energy sources into the hatchery. Alternative energy sources can be more expensive to install, but they are cheaper to operate in the long run.

Plate 1. Construction of a concrete catchment at the lower end of an earthen pond.

Plate 2. Construction of a concrete catchment at the lower end of an earthen pond.

Plate 3. Netting an African catfish pond to protect the fish from predators.

Plate 4. A set of nursery ponds netted to prevent predators from eating the fish seed.

3. Broodstock selection and management

3.1. Broodstock origin, identification and replacement

It is important for hatcheries to select broodstock from known sources. Make sure the source has a good track record of survival and growth, with a good feed conversion ratio (FCR) and harvest weight from fingerlings it sells to farmers. If sourced from the wild, record the location, time of year, weight and sex of the fish (Table 2).

Where available, use passive integrated transponders (PIT) to tag the fish. If PIT are not available, keep broodstock from different populations in separate tanks or ponds, if possible. The Dutch domesticated *C. gariepinus* dominates the industry in Nigeria. However, to avoid buying inbred fish, do not source broodstock from small hatcheries that produce less than 500,000 fish seeds annually and have a small broodstock population of less than 50 per year.

Replace broodstock as often as possible. For large hatcheries with hundreds of broodstock, replace used and reused broodstock after no more than 2 years to minimize the risk of inbreeding.

Vundu (*H. longifilis*) and Mari (*H. bidorsalis*) are two other species sourced from the wild in Nigeria and held in some farms. These species are crossed with African catfish to produce hybrids called *Heteroclarias* or *Clariobranchus*. In the wild, they live in the same areas but do not hybridize, as spawning only takes place within members of the same species. Ideally, hatcheries should identify broodstock of other species sourced from either the wild or farms and record the morphology. Hybrid catfish hatcheries are not covered in this publication in any detail.

	Record of new broodstock							
S/N	**Date sourced**	**Time sourced**	**Place of origin**	**Age of broodstock**	**Weight of broodstock**	**Health status**	**Visible deformities**	**Broodstock ID**

Table 2. Record of new broodstock.

3.1.1. Natural spawning

At the beginning of the rainy season, mature female African catfish begin the process of egg development (vitellogenesis). This is in response to rainfall, which is one of its cues for sexual maturation. As water levels increase, the fish move to the banks of rivers, lakes or seasonal pools and engage in courtship in the males' niche. There they release their eggs and the males release sperm at the same time. The fertilized eggs attach to the grass on the river bank until they hatch.

3.1.1.1. Induced artificial spawning

In hatcheries, African catfish do not reproduce naturally in captivity, so human intervention is required to aid the process. Female African catfish require stimulation of the pituitary gland with a hormone, either natural or synthetic, so that their eggs mature completely. However, it is not possible to strip the sperm of the males because they possess microfibrils at the end of the lobes of the testicles, which prevents the free flow of milt. As a result, they have to be dissected to induce artificial spawning.

3.1.1.2. Induced natural spawning

In induced natural spawning, hatcheries must prepare spawning tanks and proceed by inducing female broodstock with a synthetic or natural hormone and then placing them into the tank. Depending on the age and condition of the males, induce and then place them in the same tank as the females before spawning. To avoid contaminating the tanks, disinfect the broodstock using a 0.5% iodine solution before induction and place them in the spawning tanks. Courtship will follow immediately after they are acclimatized. Once vitellogenesis is complete, the females will shedd their eggs on the *kakaban* (a nest made from sacks) and the males will simultaneously fertilize them. Carefully remove both broodstock once spawning is complete, usually within 2 hours after it starts, i.e. when eggs are visible on the *kakaban* or the floor of the tank. Place at least two *kakabans* in the tank, and avoid using females that are too small or too big to prevent predation instead of courtship. Ideally, use males of similar age and size as the females, at least 12 months old and weighing 1.5–2 kg. For induced natural spawning, it is not necessary to kill or dissect the males.

Induced natural spawning is not as popular as induced artificial spawning because it is not possible to determine the quality of the sperm beforehand, so there is no room for replacement. Increasing the ratio of males to females in the tank can be detrimental because the males could fight for dominance while the females are laying their unfertilized eggs. Aggressive males can injure the females and vice versa. The main disadvantage of this method of breeding catfish is that it is not possible to determine the weight and, by extension, the number of eggs from the females and ascertain if an additional male is required. Weighing eggs can only be done after removing the females and weighing them to determine the difference from their initial weight before spawning. However, this is only for recordkeeping purposes, as there is no room for intervention.

3.1.2. Hybrids

In Nigeria, only 49% of hatcheries surveyed produce pure African catfish. Producing hybrids in Nigerian aquaculture is steadily increasing. Selecting broodstock from these fish is just as critical as selecting broodstock of African catfish. Although a lot of hatcheries are able to identify and differentiate between the *Heterobranchus* spp. cultured, many still find it difficult to distinguish between them. Plates 5, 6 and 7 show the phenotypic difference between these two species and also their differences from African catfish. They also differ in time of maturity, as mari males mature after 12 months and females after 24, while both sexes of vundu mature after just 12 months. Vitellogenesis can occur two to three times a year for vundu, but only once for mari, between May and July. It is important to understand that managing the fry of African catfish is different from those of hybrids regarding feeding behavior, growth curve and level of aggression, and under ideal conditions the incubation time for hybrids is about 2 hours longer. In hatcheries, hybrids of African catfish and vundu grow faster in the early stages. However, depending on the grow-out system used, both hybrids perform well when grown for 8 months and beyond. In earthen ponds, hybrids of African catfish and mari grow faster. In the South-West region of Nigeria, hybrids with vundu are more popular than those of mari, while the opposite is the case in South-South and most parts of North-Central.

The good growth recorded in under proper management and stocking densities stems from the fact that these hybrids do not produce viable eggs and sperm, especially in their first year, as they use most of their energy for growth.

As shown in Plate 5, mari has a dorsal fin that is twice as long as the adipose fin. It has reddish pectoral, pelvic and caudal fins, and generally a brighter coloration overall.

As shown in Plate 6, vundu has a dorsal fin equal to the length of its adipose fin. It is generally darker than mari and has a dark spot at the base of the adipose fin just before the caudal fin.

Hybrids inherit the broader head, aggression and a small adipose fin from their *Heterobranchus* parent, and long body from their African catfish parent. Cannibalism is higher in hybrids because of their inherent aggression, larger mouth (Plate 8) and appetite relative to African catfish. Mari has a broader head and a larger mouth than vundu, while African catfish have the smallest head-to-body ratio. Grading should start after 2 weeks and then continued weekly, if possible. In a hatchery, feeding is slower for hybrids, which take longer to eat than African catfish.

Plate 5. Mari.

Plate 6. Vundu.

Plate 7. African catfish with no adipose fin but a long dorsal fin.

Plate 8. Mari (left), Vundu (middle left and middle right) and African catfish (right).

3.2. Broodstock quality

Hatcheries must raise African catfish broodstock under good conditions. Avoid sourcing broodstock from small-scale operations that have only transitioned from grow-out within the same year; if not, you are likely to source sibs (siblings) to use as broodstock. If possible, only source on sex from a single farm. Do not select shooters to keep as broodstock. Maintain accurate records of broodstock sources and, if available, note their history.

Skeletal deformities such as eroded pectoral and/or pelvic fin(s), concave upper and lower jaws, lordosis and scoliosis are not uncommon in African catfish. Some of these deformities are from nutritional deficiencies and/or exposure to chemicals and viral diseases. However, increased homozygosity (possessing two identical forms of the same gene inherited from both parents) and inbreeding can also lead to skeletal deformities in fish (Berillis 2015). Identifying the actual cause(s) of certain deformities and whether they are heritable or not in African catfish is still understudied and poorly understood. As a result, most hatcheries in the industry ascribe deformities to inbreeding depression.

Although further studies are highly recommended, it is imperative for hatcheries to maintain good records, tracing which parents produced deformed fingerlings, their origin, nutritional status before breeding, health of the fish, whether or not they underwent any treatment during vitellogenesis, water temperature during incubation and hatching, and whether or not they have any skeletal deformity. Choose broodstock carefully and avoid using any deformed fish for breeding unless you understand the underlying cause and are sure that such deformities are not hereditary.

To avoid introducing diseases into the hatchery, do not use farms or waterbodies as broodstock sources if they have a history of diseased fish verified from records or reports of past incidences. Maintain strict biosecurity measures to avoid infecting broodstock with any form of disease. Take quarantine measures seriously, especially for broodstock. Ethically, hatcheries must avoid selling diseased broodstock. If there is a disease outbreak, take samples for diagnosis before treatment to (i) increase the efficacy of treatment, (ii) prevent antimicrobial resistance as a result of indiscriminate use of antibiotics and (iii) provide a history of the broodstock to any buyers intending to use them for breeding.

3.3. Broodstock numbers and reuse pattern

Several factors determine the number of broodstock kept on a farm or bought for use: the size of a hatchery, number of fingerlings produced per year, number of eggs required to produce such quantities of fingerlings/juveniles despite mortality, and the number of times broodstock are reused. The mating design and mating ratios determine the number of males and females to keep or buy. African catfish is highly fecund, with an average gonadosomatic index of 15%–20%. In the same study, 95% of hatcheries reused their female broodstock and 67.57% reused them three times a year. Going by the results of this study, a kilogram of female African catfish can produce up to 270,000 eggs per year in a hatchery. Only a little more than half of these eggs survive to juveniles. However, given these numbers, it is safe to assume that if the mating designs are not carefully monitored, hatcheries can easily slip into inbreeding, producing mostly different batches of half-sibs and selecting inbred shooters to eventually use as broodstock.

For example, if a hatchery produces and sells 2 million fish seed per year, assuming hatchability is 65%, survival is 50%, the average weight of females is 1 kg, with a use/reuse pattern of three times a year, each female effectively contributes 87,750 fish seed to the 2 million annually. Therefore, the hatchery only needs 23 female broodstock to achieve such production capacity. It is strongly recommended that hatcheries only reuse females once to increase the number of broodstock contributing to the overall population of fish seed used per year. This means 34 female broodstock are needed every year: 2,000,000 / (90,000*2) * 0.65 * 0.5 = 34.19. Not all gravid females are ripe for use at all times, not all induced females produce viable eggs at all times and not all broodstock are guaranteed to survive until the next year. Given this, hatcheries should add at least an extra 20% of these estimated female broodstock numbers.

More males are required than females because most males are killed afterward and not reused. Again, the sex ratio during commercial production varies from one hatchery to another, but it is strongly recommended that commercial hatcheries use a male to female sex ratio between 1:1 and 1:2. Although the industry currently favors between 1:2 and 1:4, hatcheries are advised to stick to the closest ratios to minimize inbreeding. Assuming commercial fingerling production employs a ratio of 1:2, then reusing the same female broodstock twice a year to produce 2 million fish seed theoretically requires an equal number of males to females (34.19). Better still, if a hatchery is using a 1:1 ratio, it will need to use 68 males and 34 females out of the total broodstock kept on the farm.

Hatchability, survival and weight of broodstock used vary within and between farms. But it is important to highlight the importance of planning the broodstock need, use and reuse patterns at the beginning of every operational season. Table 3 illustrates adequate records of fish used at any particular point in time for spawning or involved in any other activity, such as treatment, sampling and feed trial.

3.4. Broodstock mating design for broodstock replacement

To minimize inbreeding in African catfish hatcheries, it is essential to understand the concept of effective breeding number—the number of individuals contributing to the next generation. High mating ratios, such as 1:4 or 1:5, reduce the effective breeding number, which in turn reduces genetic variation in the population.

Not all hatcheries understand how to calculate the effective breeding number in a population, so a simple illustration will help them understand this concept and how to apply it.

For example, in a hatchery that produces broodstock and uses a mating ratio of 1:2 using 60 broodstock (20 males and 40 females), the effective breeding number (N_e) is calculated as follows:

$N_e = (4(N_m \times N_f)) / (N_m + N_f)$; where

N_e = effective breeding number

N_m = number of breeding males = 20

N_f = number of breeding females = 40

$N_e = (4(20 \times 40) / (20 + 40))$

$N_e = 53$

In this example, 53 of the 60 (88%) individuals will contribute to the next generation of broodstock.

If the ratio is 1:3, the effective breeding number involving 20 males and 60 females is

$N_e = (4(20 \times 60) / (20 + 60)$

$N_e = 60$

In this example, only 60 of the 80 (75%) individuals will contribute to the next generation of broodstock.

As the ratio becomes 1:1, 100% of the broodstock will contribute to the next generation. It is therefore recommended that hatcheries keep sex ratios close to increase the number of individuals contributing to the next generation of broodstock.

As much as possible, hatcheries should design mating systems so that the number of fish involved is large enough to ensure broodstock can be selected from the offspring. If the population size is low, despite the sex ratio, this will increase the coefficient of inbreeding and the rate of accumulated inbreeding.

For example, assuming a sex ratio of 1:2, with 2 males and 4 females, the effective breeding number (N_e) is 5.3. In this case, the rate of accumulated inbreeding is calculated as follows:

$F = 1/2N_e$ thus, $F_1 = 1/(2X53) = 0.94\%$ per generation and $F_2 = 1/(2x5.3) = 9.4\%$ per generation, where F1 and F2 are coefficients of inbreeding for a population size of 60 and 6, respectively.

This shows that hatcheries should keep a high number of broodstock required to breed for the next generation of broodstock in order to minimize inbreeding, especially for a large-scale hatchery. As such, it is recommended that hatcheries apply a sex ratio of 1:1 and design a mating system with a high number of broodstock. Be sure to take adequate record of fish involved in the mating design and sex ratio (Table 3).

Shooters can come from different batches. Again, reusing female broodstock twice increases the chances of inbreeding. Therefore, hatcheries must avoid selecting and using shooters as broodstock to minimize inbreeding.

In spawning that involves more than one male, do not mix the milt of the males before fertilizing the eggs. The viability and motility of sperm differs among males and could lead to competition among the sperm, which eventually allows only the dominant sperm to fertilize the eggs, further skewing the sex ratios. Rather, separate the eggs into different bowls equaling the number of males involved and then extract the milt from each male to fertilize one bowl at a time.

Assuming a simple mating design involving 10 males and 10 females, strip the eggs from the females separately and use the milt from one male to fertilize one female until all 10 males have fertilized eggs from the 10 females. This will guarantee that each male has contributed to the next generation and prevent sperm competition resulting from mixing the sperm and ending up with only one male fertilizing all 10 females. For breeding programs, the mating design is more elaborate and complex, involving setting up crosses to produce several full-sib and half-sib families. WorldFish projects will discuss mating designs for breeding programs. Selecting broodstock can occur at different stages, such as at the juvenile stage, at maturity or prior to use.

3.5. Broodstock nutrition, heath and water quality management

African catfish broodstock require a diet with 35%–40% crude protein (Ali and Jauncey 2007). For broodstock, most farmers use commercial grow-out feeds. Although broodstock feeds are now available, they are limited in supply and relatively expensive. Among dissected males fed commercial grow-out feed at high feeding rates, a practice that reduces spawning success, some have shown an accumulation of visceral fat. Many farmers in Nigeria assess the quality of broodstock diets based only on their crude protein content, ignoring the protein energy ratios, digestible and metabolizable energies, and other essential nutrients, such as amino and fatty acids. This makes it impossible to know if the commercial broodstock and grow-out feeds meet the nutrient requirements of African catfish broodstock. Therefore, the industry would benefit from the availability of good quality, traceable, affordable commercial broodstock feed to reduce the high production costs, making broodstock more affordable, especially for smaller hatcheries.

Hatcheries should store broodstock in cool and dry places. Remove any contaminated (rancid or moldy) feed from the storage area and do not feed it to the broodstock. Record all feeds bought and used (Table 3). Extruded broodstock feeds provide more digestible and metabolizable nutrients to broodstock than pressed pellets of the same formulation, so use extruded broodstock feeds wherever possible (Figure 7). Record the feed type and daily quantity fed on the broodstock use record sheet, as shown in Table 3. Skeletal deformities reported in the industry are often associated with inbreeding depression. However, the nutritional status of the broodstock influences egg quality and determines the amount of nutrients in the yolk sac, which the larvae feed upon before becoming swim-up fry. As such, it is important to make sure that broodstock are fed the right amounts of nutrients regularly to increase hatchability and survival, and to reduce deformities.

Broodstock health and well-being is important to operate a successful hatchery. Again, do not feed contaminated feed to broodstock, and maintain a maximum broodstock stocking density of no more than 10 kg/m^3 in earthen ponds or outdoor concrete tanks. Do not exceed stocking densities of 20 kg/m^3 in a flow-through system or 50 kg/m^3 in RAS. Overstocking can lead to poor water quality conditions. If dissolved oxygen falls below 2 mg/L, broodstock become stressed and stop eating, aggression sets in and cannibalism increases. Always ensure good water quality conditions in broodstock tanks or ponds, as it aids in proper metabolism, growth and gonad development.

Temperature, rainfall and length of daylight are some of the cues responsible for triggering vitellogenesis in African catfish. At low temperatures, especially in the cold dry seasons in many parts of Nigeria, metabolism slows down, and the catfish begin to reabsorb their eggs. As a result, it is important to design the hatchery in such a way that one can control the water quality conditions regardless of the season.

		Broodstock use data																	
		Male broodstock								Female broodstock									
S/N	Date	Broodstock ID	Origin	Sex	Age	Weight (kg)	Sperm quality	Activity	Sex ratio	Mate(s) ID	Origin	Age	Weight (kg)	Hormone type	Hormone dose (ml)	Egg weight (g)	GSI	Broodstock feed	% of weight/day

Table 3. Record of broodstock use.

Hatcheries should be able to manipulate and optimize the water temperature, dissolved oxygen and flow-rate at any time to ensure year-round vitellogenesis. During the dry months, from November to March, keep broodstock in the indoor broodstock facilities with an adequate flow of water and a sufficient amount of feed.

Do not introduce broodstock bought or sourced from the wild directly into the broodstock tanks. Instead, quarantine them to prevent the introduction or transfer of infection from one hatchery to another. If symptoms of infection or diseases occur, get proper diagnosis and treatment immediately. Do not use diseased fish or fish undergoing treatment for spawning until they are fully recovered. This will minimize stress on the fish, which can result in mortality, and also prevent the transfer of disease to other parts of the hatchery (spawning tanks, fry tanks and nursery) and the eventual fish seeds.

3.6. Frequency of spawning

In a hatchery, the frequency of spawning depends on several factors, including market demand for fingerlings and juveniles, the size of the hatchery and availability of spawning tanks, availability of gravid females and mature males, and the planned routine of the hatchery. Among these factors, the availability of gravid females is a major source of worry for many hatcheries, especially small-scale ones. Seasonality in egg production in African catfish is common among respondents holding broodstock in outdoor tanks and earthen ponds, as only 11% of them can produce gravid broodstock year-round. This is largely because broodstock raised or held in outdoor tanks and earthen ponds are exposed to cold weather conditions from December to the end of February, during which diurnal temperatures fluctuate from as low as 9°C at night to as high as 30°C in the afternoon. Suboptimal and fluctuating temperatures affect appetite, metabolism and egg production in African catfish broodstock, and growth in fingerlings (Hogendoorn and Vismans 1980; Britz and Hecht 1987; Richter et al. 1987; Sapkale et al. 2011). In many parts of the country, the absence of rain in these months contributes to a lack of egg production in outdoor broodstock facilities, as rainfall is a natural trigger of vitellogenesis in African catfish in the wild.

To ensure year-round availability of viable eggs in broodstock, hatcheries need to exchange water regularly using flow-through systems for better water quality, in terms of temperature and oxygen, and water levels. They also need to stagger their production of broodstock so that some mature when the weather is not necessarily favorable but still manageable. Polytunnel ponds and tanks system will help reduce diurnal fluctuation in temperature and increase the daily average temperature during the cold dry months. Incorporating flow-through in polytunnels will help provide the optimal water quality conditions needed for vitellogenesis. Monitoring water quality routinely to assess and arrest issues timely is highly recommended.

3.7. Sperm quality

Even though male African catfish attain sexual maturation at 8–10 months of age, they are not suitable for spawning. Ideally, use males that are at least 12 months old, as they usually attain better gonad maturation. It is difficult to assess the viability and motility of sperm in African catfish before dissection, since they cannot be stripped. So, if possible, sample males from a cohort (a group of fish produced and raised together), dissect and extract the sperm, and check it under the microscope to assess the quality. This can be expensive for small-scale hatcheries. However, large-scale hatcheries can benefit from the practice because it will help determine which group of broodstock to pick males from for spawning.

Generally, select male broodstock that are healthy, active and, in some cases, have a reddish tip on their genital papilla. Upon dissection, large milky lobes of sperm sacs are often an indication of highly concentrated and viable sperm. If using more than one male, do not mix the sperm from separate males together before fertilization. Keep them separate.

Extenders are often used to increase the volume of the sperm (not concentration), especially when the quantity of stripped eggs is large. Common extenders are a saline solution (7–9 ppt salinity) or clinically normal saline. Take care not to exceed this concentration to prevent sperm mortality.

On rare occasions, dissected males have only one sperm sac. In some cases, they have grayish-black looking sacs instead of milky white lobes. The underlying cause of this rare, but increasingly reported conditions are yet unknown and require research. Do not use grayish-black milt to fertilize eggs, as the viability of the sperm and consequently fertilization rate and hatchability are below 10%.

When males are considered very good or of high value because their growth, vigor and scarcity, such as male *Heterobranchus* spp., only part of the sperm sac is cut for use during breeding or sometimes only one of the two sacs is used. The males are stitched back for reuse. In this case, be careful during dissection so that only a small abdominal incision in made to locate a sperm sac so that recovery is easier and faster. Hatchery staff must undergo training before embracing such practice. Do not reuse the males until 6 months later to minimize inbreeding. Keep stitched males in isolation for at least 3 weeks before reintroducing them into the broodstock ponds or tanks.

3.8. Tagging broodstock with microchips

Using tags is highly recommended as many African catfish hatcheries do not have facilities to stock broodstock from different sources or locations separately. To succeed in fish seed production, hatcheries must ensure that they are not only able to source and/or produce different batches of broodstock, but also to identify the broodstock individually and according to their respective origins, batches, age group, etc. The traditional and most common way for both large- and small-scale hatcheries is to keep groups in separate tanks. Although this sounds practicable and affordable in the interim, it is an expensive opportunity cost in the long-run, because hatcheries could use these tanks or ponds for commercial production of fish seed, grow-out or broodstock.

Using tags could be cheaper than keeping different groups of broodstock in separate tanks or ponds, so farmers should consider them when planning and financing a hatchery. PIT tags are suitable for tagging African catfish and are user-friendly, though this does require training.

4. Hatchery pre-spawning preparation

4.1. Broodstock holding facility for spawning

At least 48 hours before spawning, select the broodstock, inspect them for readiness and keep them separately in holding tanks of 200–500 L to give enough space for comfort and movement. Replace all of the water within a 12-hour period, and maintain a depth in the tank such that the broodstock cannot jump out of it. Ideally, a depth of 1 m is recommended, where available, in which the water level does not exceed 30 cm. If the tanks are shallow, ensure they are securely covered with nets. Keep the water level low to minimize the tendency of the fish jumping out.

Do not feed the broodstock during this period in order to reduce excretion while stripping the females. After spawning, return female broodstock to the holding facility and keep them there for at least 48 hours before returning them to the spent fish ponds or tanks. Doing this will prevent attacks from other fish in the tank while the fish shed their remaining eggs and will allow them to regain their strength. If the males have been sutured, keep them in the holding tanks for 3 weeks before returning them to the pond or tanks to prevent other fish in the tank from attacking their fresh wound from the dissection and to enable a stress-free recovery.

4.2. Preparing hatching troughs

Wash the hatching troughs thoroughly before every breeding exercise. Although this is not common in Nigeria, use chlorine tablets to disinfect the tanks, then apply salt ($NaCl_2$) during the second wash and rinse properly. Leave to dry before filling the tanks with fresh water for incubation to eradicate any leftover fish fry, mosquito larvae or worms that could prey on the new batch of larvae. Make sure there is adequate aeration and flow in the incubation tanks. Place screens over the outlets to secure the larvae or fry immediately after hatching. Spread the incubation nets or *kakaban* in the tanks. Measure the dissolved oxygen level in the tank and make sure it is not lower than 5 mg/L. To avoid delays, these steps should be done in the latency period: during the 12 hours between injection and stripping.

Outdoor tanks are usually prepared in a similar manner as described for indoor tanks in the early part of this section. Net the top of the tanks to prevent dragonflies and mosquitos from laying their eggs in the water and also to prevent predators like pond skaters, water boatman, monitor lizards and frogs from entering the tanks and feeding on the eggs, larvae and fry. Fill the tank with fresh water an hour before stripping and fertilization while the tank is completely covered with the nets. When the weather is hot, provide shade to prevent the water from heating up to sub-optimal levels during the day.

4.3. Preparing the hatchery

It is important to clean and disinfect all tanks in the hatchery. At the start of the spawning season, it is advisable to fumigate the hatchery, (especially those located outside the cities and towns), as well as its environs to keep away all predators, reptiles and unwanted pests and diseases. This should be done at least 2 weeks before a new season for seasonal spawners. For non-seasonal spawners, take a break from production at least once a year to fumigate the surrounding environment and the hatchery.

Cover indoor hatcheries well to maintain optimal temperature at all times, especially during breeding. They are normally designed and built such that when covered the inside of the building warms up and remains warm. Flush and backwash storage tanks and filters at least once a year, though ideally twice. Hatcheries will benefit from testing the water quality periodically to determine the ideal time to flush or backwash the tanks. When total dissolved solids (TDS), turbidity and nitrite levels increase, it is time to flush or backwash the water system. Ensure that all inlet and drain pipes are adequately fitted, with no leaks. Also, make sure that all the screens in the incubation and rearing tanks for larvae, fry and fingerlings are also well fitted to prevent fish seed from escaping.

Ensure that all other required inputs apart from broodstock are in place. Before beginning spawning, be sure to have everything ready: nets, hand towels, dissecting kit, hormone for hypophysation, physiological solution, bowls, feathers, tissue paper, etc.

4.4. Water quality management

- Before siting a hatchery, operators must investigate the physico-chemical parameters of water. As shown in Table 4, the optimal water quality ranges for African catfish seed are as follows:
- dissolved oxygen: 5 mg/L or higher
- temperature: 27°C–32°C
- pH: 6–8.5
- Ca^{2+}: at least 20 ppm
- Mg^{2+}: 20–100 ppm
- NH_3^-N (total ammoniacal nitrogen (TAN)): no higher than 2 ppm
- Nitrite NO_2^-: 0.05 ppm
- Fe^{2+}: no higher than 0.05 ppm
- salinity: 500–1000 ppm
- TDS: less than 200 ppm
- conductivity: no higher than 1000 µS/cm.

Over 87% of hatcheries use boreholes as their source of water. Usually hatcheries only test for water quality issues after encountering problems. Although pH and hardness used to be the most reported issues with underground water in African catfish hatcheries, in recent years high nitrite and TAN levels have also surfaced. High nitrite levels are toxic to fry and fingerlings and require treatment of freshwater before use in the hatchery to prevent high mortality. High nitrogen levels in source water causes gas-bubble disease. This can also be treated by passing the water through filter blocks.

Fish stop eating when dissolved oxygen drops below 2 mg/L, leading to aggression and injuries. At low pH, ammonia toxicity increases, resulting in mortality. Although African catfish can survive in temperatures under 20°C, their metabolism drops significantly. In small hatcheries, use aerators to supplement dissolved oxygen from the air by pumping into the water.

Siphoning away waste and uneaten feed and increasing the flow rate will help reduce ammonia concentration. Closed hatchery systems with minimum windows and occasional heating can help maintain optimal water temperatures. As such, hatchery operators should check the water quality daily in the hatchery to prevent losses. If treatment plants for fresh water are installed, flushing or backwashing quarterly is recommended for effective continuous operation.

			Record of water quality										
	Date	Water source	DO_2	Temperature	pH	Ca^{2+}	Mg^{2+}	TAN - NH_3^-N	Nitrite NO_2^-	Fe^{2+}	Salinity	TDS	Conductivity
Optimal range			≥ 5 mg/L	27°C–32°C	6–8.5	≥ 20 ppm	20–100 ppm	≤ 2 ppm	0.05 ppm	≤ 0.05 ppm	500–1000 ppm	< 200 ppm	≤ 1000 mS/cm

Table 4. Record of water quality.

5. Spawning management

5.1. Mating design for commercial fingerling production

African catfish is highly fecund, with females averaging 60,000–120,000 eggs per kilogram of their weight. As such, this species requires few broodstock to produce thousands of fingerlings and juveniles for sale and farming. Although this is a beneficial characteristic to have, if not carefully exploited, it could lead to detrimental outcomes. For instance, if the mating designs are skewed too far, this could lead to accumulated inbreeding over a short period of time. To prevent this from happening, hatcheries must (i) be able to identify their broodstock, (ii) have a broodstock use and reuse plan and pattern in place, with a contingency plan in case of mortality or absence of viable eggs, (iii) and keep adequate records of broodstock used and fish seed produced (Table 7).

For commercial purposes, do not mate relatives and do not exceed a 1:2 male to female ratio at any time, but preferably use 1:1. Although males are often scarce, since they are usually killed, farmers tend to use high ratios of 1:4 or even 1:5 males to females, depending on the size of the females. However, if they are already using inbred stocks, and if within the mating design there are sibs, then they are actually producing a large number of half sibs that are already inbred. As a result, they are just increasing the levels of homozygosity and thus inbreeding depression. This is especially the case if the male has a low breeding value and is spread across four or five females. This increases the susceptibility of the fingerlings to pathogens and diseases, leading to poor growth performance and generally low yields. If 1:1 or 1:2 male to female ratios are used, farmers can use more males per batch and thus increase the effective breeding number, which in turn will potentially increase the levels of heterozygosity and genetic variation. By doing this, hatcheries can produce a more vigorous and resilient batch of fish.

- As an illustrative example, producing 200,000 fingerlings under ideal production and management systems requires the following:
- weight per broodstock = 1.5 kg
- GSI per female = 15% (150,000 eggs)
- hatchability rate: 60% (90,000 larvae)
- survival rate from larvae to fry: 75% (67,500 fry)
- survival rate from fry to fingerlings: 50% (33,750 fingerlings).

This example requires six females for breeding, which in turn requires six males for a sex ratio of 1:1 or three males for a ratio of 1:2. For a ratio of 1:2, do not mix the sperm from the three males and use it to pour on all six bowls of eggs. Instead, simply use the sperm from one male to fertilize two females. Do not mix the eggs together because the quality of the eggs could differ, and this could lead to low quality eggs polluting the good quality ones. Rather, fertilize each female's eggs separately and incubate them separately.

5.2. Selecting broodstock for spawning

Selecting broodstock for mating requires skill and experience. Hatcheries should complete this task 48 hours before spawning. Identify and record the tag number (if tagged), and keep them in a holding tank. As illustrated in Figure 1a, mature females have a large, distended, soft and round abdomen, with a swollen and reddish ovipositor, through which few eggs flow when slight pressure is applied. Use careful observation to select females that have eggs (visible upon application of slight pressure) of uniform diameter with the visible dark point of a nucleus. Males have a swollen, vascularized genital papilla, which could have a reddish tip (Figure 1a). As stated in Section 3.7, age is an important consideration as well. Broodstock should be at least 12 months of age at the time of first use. Under ideal conditions, this ensures that the gonads are fully matured.

5.3. Hypophysation, spawning and management of hatchlings

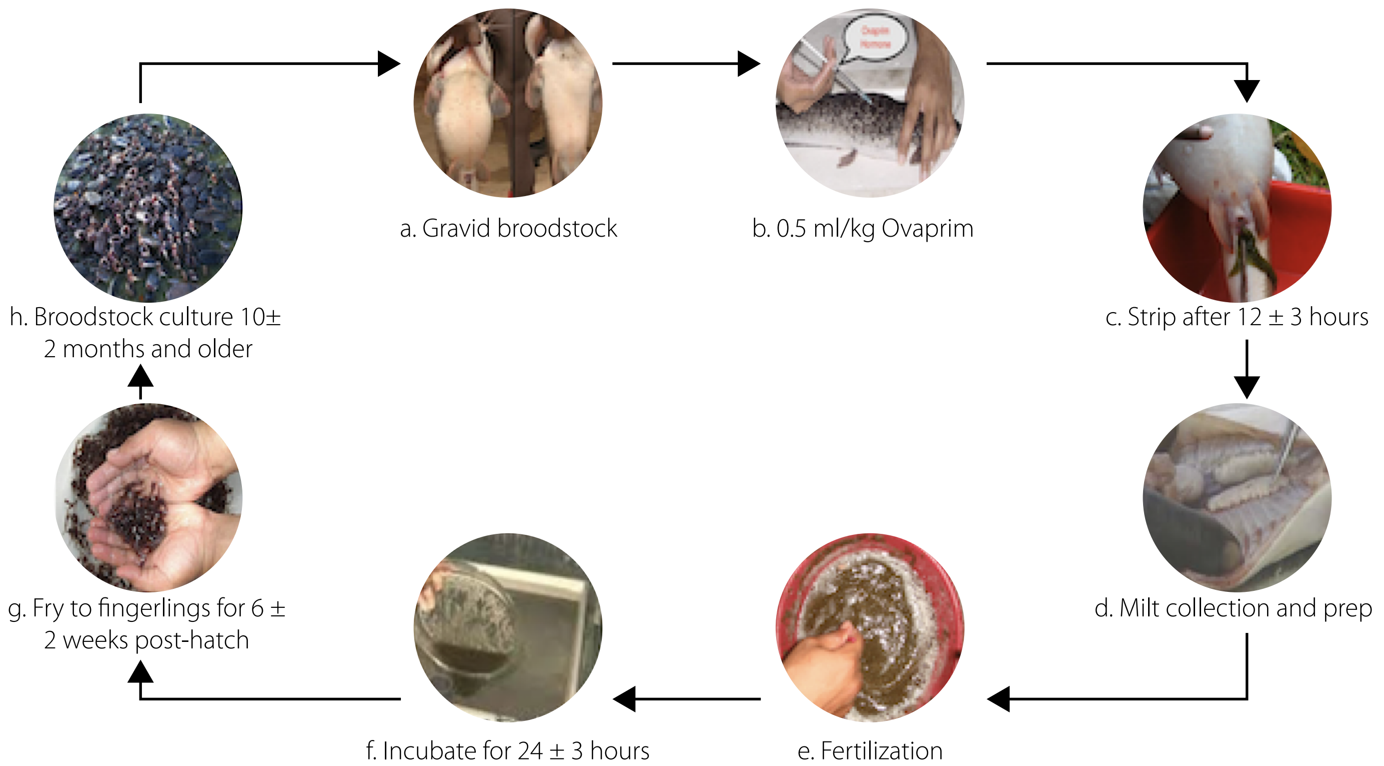
5.3.1. Hypophysation, and collecting eggs and sperm

Hypophysation is using natural or synthetic pituitary hormones to breed female broodstock. Females are induced with 0.5 mg/L of Ovaprim, Ovulin, Ovatide or extracted pituitary gland. This induces the gonadotropin hormone in the female broodstock at the start of breeding. For best results, inject the hormone either into the muscle (Figure 1b) or in the space right under the pectoral fin. Remember to record the type and dose of hormone used (Table 3). Under optimal temperatures of 27°C–32˚C (Table 5), leave the broodstock for 10–14 hours and strip the females to collect the eggs (Figure 1c). Dissect the males to access the milt sacks (Figure 1d), then macerate the sacs to access the sperm. Using a 7–9 ppt salt solution, rinse the macerated sacs to extend the milt.

5.3.2. Incubating eggs

Pour the sperm on the stripped eggs and stir gently to encourage fertilization (Figure 1e). Set *kakaban* or nets in the incubation tanks and carefully spread the eggs on them using a plastic spoon or feather (Figure 1f). Avoid lumping or clustering too many eggs on the same spot because this can lead to poor hatchability as a result of poor oxygen supply to some eggs trapped below or within a clump of eggs. Depending on the design and size of the hatchery's tanks, set your flow rate at a minimum of 1 L per minute (0.017 L per second) for a 200 L hatching trough containing a maximum of 30,000 eggs. Under these conditions, aeration is optional during incubation. If the temperature is within 27°C–32˚C, hatching will begin 18–24 hours after incubation (Table 6). Record the hatchability percentage (Table 7), and remove all dead eggs and *kakaban* or nets once hatching is complete. Depending on water temperature, this is usually about 28 hours after incubation begins.

Hatcheries can increase flow rates to 1.5—2 L per minute 10 hours before hatching. This will increase the supply of oxygen and get rid of any contamination from the dead eggs. Keep accurate records of breeds (pure African catfish and its hybrids between *Heterobranchus* spp.) at every stage, as well as the number, age and species of broodstock. Also, keep records of any imported strains of catfish used together with the import permit and date of the broodstock purchase or production.



Source: Isa et al. 2019.

Figure 1. Life cycle of African catfish under hatchery conditions.

Water temperature (°C)	Latency period (hours)
20	21.0
21	18.0
22	15.5
23	13.5
24	12.0
25	11.0
26	10.0
27	9.0
28	8.0
29	7.5
30	7.0

Source: Hogendoorn and Vismans 1980; de Graaf and Janssen 1996.

Table 5. Time between hypophysation and stripping (latency period) of female African catfish.

Water temperature (°C)	Incubation period (hours)
20	57.0
21	46.0
22	38.0
23	33.0
24	29.0
25	27.0
26	25.0
27	23.0
28	22.0
29	21.0
30	20.0

Source: Hogendoorn and Vismans 1980; de Graaf and Janssen 1996.

Table 6. Time between fertilization and hatching (incubation period) of African catfish eggs.

6. Rearing fry for fingerling production

6.1. Yolk sac stage and rearing fry

African catfish hatchlings feed on their yolk sacs for the first 3 days of their lives before swimming up to look for food or feed, so it is important that the yolk is rich in all essential nutrients, especially amino and fatty acids. Although many reports of skeletal deformities in fish seed are often attributed to inbreeding depression, as farmers claim, many times it is a result of nutritional deficiencies.

On the second day after hatching, separate the larvae into different tanks and maintain a density of no more than 10,000 hatchlings/m^2. Siphon away all dead eggs and shells to prevent any fungal infection (Saprolegnia). Use a proper stocking density to avoid overcrowding, as this can also lead to skeletal deformities in the catfish larvae. After 2 weeks, move the fry into larger tanks, either indoors or outdoors, or into ponds for nursery culture to grow them up to fingerlings (0.2–2 g) or juveniles (2.5– 5 g).

6.2. Feeding

The best first feeds for African catfish fry are zooplankton, such as daphnia, rotifers and at a later stage, copepods. Wherever possible, hatcheries must set up live feed production systems for zooplankton. Where there is none, hatch live artemia and feed them to the fry. The complexity of setting up a zooplankton production system, the labor required and the low yields from some systems have made it impractical for many hatcheries to do. The high cost and/ or lack of power to hatch and store live artemia prevents many farmers from producing them.

Shell-free artemia and, in recent years, microdiets are used for first feeding. Give fry small quantities of feed as often as possible, usually every 2–3 hours. Spread the feed on the surface of the tank, adding small quantities at a time, multiple times throughout the day, to ensure all fry get to eat. Be sure to watch their feeding behavior. Pause and move to other tanks. Upon return to a tank, add more feed only if the feed on the surface and bottom of the tank is completely eaten and the fry are still actively swimming in search for more.

Where live feed is not accessible, use shell-free artemia or microdiets (such as Gemma Wean, Coppens or Aller Aqua) exclusively in the first 5 days of exogenous feeding. As the size of the fry increase, stop feeding them artemia and continue giving them microdiets adjusted to the size of the fish (0.2 mm, 0.3 mm, 0.5–0.8 mm, 0.8–1.2 mm, 1.2–1.5 mm, 1.5–1.8 mm and then 2 mm). Feed them diets with a minimum of 50% crude protein as soon as first feeding is complete and throughout the hatchery phase. Record all types and quantities of feed given to each batch of fish seeds produced (Table 7). Do not overfeed as this can lead to pollution, oxygen depletion, infection and mortality. Ideally, use a feeding table or feed the fish until they reach satiation. During feeding, observe the fish to see whether they are active, inactive, respond slowly or swimming listlessly, and take appropriate action where needed.

Do not underfeed the fish, as this increases cannibalism, leading to uneven growth, malnutrition and higher mortality rates. Always store feed in a cool dry place to prevent rancidity from the oxidation of fatty acids triggered by high temperatures and moisture. Record the types of feed used, duration of use, quantities used, the crude protein on the label and the dates of change from one size to another. Do not use old or expired feed because its nutritional value decreases over time and increases the risk of organisms such as fungi growing on the feed. Check for changes in behavior when introducing new feed. Note the proximate composition of the feeds and any other details provided by the manufacturer. Make sure to give African catfish a diet with 50% crude protein following first feeding. At the end of every batch of fish seed produced, calculate the FCR, specific growth rate and the conditions. This will help hatcheries select the ideal or most suitable feeds for their operation.

6.3. Siphoning and cleaning tanks

Remove solid waste and uneaten food daily to reduce the chances of pollution and infection. This, however, depends on the culture system and operating principles in place. In a flow-through system, siphoning and cleaning tanks is usually done once a day. This prevents the build-up of waste and uneaten feed that leads to increased levels of ammonia and nitrite, reduced levels of dissolved oxygen and a lower pH. These conditions can stress African catfish fry and fingerlings, potentially resulting in increased mortalities. It also paves way for opportunistic pathogens such as bacteria and fungi to attack vulnerable fish. Inadequate cleaning of fish tanks can cause low oxygen levels. As a result, African catfish eat less and become more aggressive, leading to increased cannibalism. All hatcheries must take daily measurements of dissolved oxygen, ammonia, nitrite and pH to help detect issues early for timely intervention. Siphoning can only remove undissolved waste and uneaten food from the fish tanks. Use filtration to remove dissolved wastes such as ammonia, nitrite and carbon dioxide in an RAS, or increase the flow rate and aeration in flow-through systems.

6.4. Cannibalism and sorting/grading

Start feeding on the third day after hatching to prevent cannibalism. In Type 1 cannibalism, fry bite off parts of other fry, but are not able to swallow a fry whole because their mouth is too small. This is common in African catfish fry if feeding is delayed. To avoid this, create a feeding regimen that ensures every fry has access to good quality palatable, digestible and metabolizable feed every 2 hours. Type 2 cannibalism sets in when fry have gained a size advantage (Plate 9) over other fry and have grown a big enough mouth that they are able to swallow other fry whole within the same cohort. Cannibalistic fish (shooters) within the population will continue to feed on smaller fish unless they are graded out of the tank. If feed and water quality are regularly added and checked, this should delay the emergence of shooters and minimize their impacts on other fish.

Unless there are visible shooters in the tank, start sorting or grading the fish seed 3 weeks after hatching, and then continue on a weekly basis. To minimize stress and losses during sorting, use graders of different sizes to separate the fish into different group sizes and record the percentages of shooters, the main population and runts, as shown in Table 7. Sorting will help minimize losses from cannibalism, increase uniformity in the growth rate and increase the yield and thus the income of hatcheries. To minimize stress from handling, grade the fish before counting them for sale, but be sure not to grade them under the hot sun.

Photo credit: ADAFF Limited

Plate 9. Shooters in a tank, usually selected and kept as future broodstock.

		Fish seed production data																		
	Production record							Feed record								Performance data				
Batch number	Date of hatching	Broodstock ID	Weight of eggs incubated	% of hatchability	% of survival to fry	% of survival to fingerlings	% of survival to juveniles	First feed type	Duration of first feeding	0.3—0.5 mm (qty/ brand)	0.5—0.8 mm (qty/ brand)	0.8—1.2 mm (qty/ brand)	1.2—1.5 mm (qty/ brand)	1.5—1.8 mm (qty/ brand)	2 mm (qty/ brand)	Weight of fish seed (g)	Age of fish seed (weeks)	% of shooters	% of main population	% of runts

Table 7. Fish seed production data.

7. Biosecurity, fish health management and fish welfare

When infections occur, it is important to get a proper diagnosis from a reputed aquatic veterinarian before administering treatment. Although there is a lack of qualified fish vets in most parts of Nigeria, hatcheries should make every effort to locate laboratories, especially in tertiary institutions, for help. Several studies have reported excessive use of antibiotics in hatcheries, including oxytetracycline, keprocyril, floxinor and chloramphenicol. Hatcheries should avoid such practices to prevent antimicrobial resistance and potential residual effects and to guarantee food safety.

Research is needed to establish safe levels, critical limits and corrective measures of operations in African catfish hatcheries. Given this lack of research, a hatchery level hazard analysis and critical control point plan would help identify, evaluate and control food safety risks that occur during production. Some hatcheries use antibiotics as prophylactics instead of probiotics. However, this would not be necessary if they adhered to good farm hygiene and adopted strict biosecurity measures, including installing footbaths and handwashing stations for staff and visitors. Each tank should be capable of being isolated from the entire system whenever the need arises, such as for treatment. Hatcheries should also take measures to prevent other domestic animals, pets and wild birds from entering their farms.

Put quarantine measures in place to ensure that broodstock arriving at the hatchery from other farms or the wild do not transfer pathogens. If broodstock arrive with injuries, place them in a 2 mg/L potassium permanganate bath for 4 hours. For all imported broodstock, it is important to obtain a health certificate from the exporting country that confirms the broodstock are free of certain pathogens.

Customers coming to pick fish should not bring their containers into the hatchery. Isolate any diseased fish immediately, and ensure that each tank has its own siphoning hose, nets and bowls. Carefully and safely dispose of all dead fish, according to local regulations, by burying them in pits and lacing them with lime. But make sure this is done far from production ponds, waterways and predatory birds to prevent the spread of disease. This should be done post-mortem to determine the cause of death and possible treatment to administer to surviving fish. Wash all equipment with chlorinated water or salt and rinse it properly before and after each use, and sanitize visitors properly before they enter the hatchery.

If a disease outbreak does occur, report the event and take prompt action. Keep proper records of any antibiotics, chemicals, hormones, anesthesia, etc., used in the hatchery, and note how long they were used and how effective they were (Table 8). A disease and treatment logbook is an important record to have in a hatchery.

Do not use steroids as growth promoters nor any prohibited chemicals and antibiotics. Clean and disinfect the facility thoroughly between batches of fish seed produced. When transporting live fish seeds and/or broodstock, use only acceptable, non-hazardous chemicals that do not foam (e.g. palm oil) or cause stress (e.g. glucose) to the fish. For transportation, do not exceed a stocking density of 2000 fingerlings or 1000 juveniles in a 50 L jerrycan. Oxygenated bags are not common for transporting catfish seed in Nigeria, but they have great potential. Ideally, use benzocaine, MS 222 or clove oil to tranquilize broodstock before stripping females to collect eggs and dissecting males to collect milt. Seek proper advice to know the effects of the various sedatives and the appropriate withdrawal period.

			Record of fish health																	
Date	Batch number of affected fish	Observed symptoms	Number of mortality pre-treatment	First aid treatment	Number of samples collected	Type of diagnosis	Name of laboratory consulted	Address of laboratory	Name of fish health specialist consulted	Date of consultation	Date of treatment	Duration of treatment	Type of treatment	Type(s) of antibiotics used	Dose of antibiotics	Type(s) of chemicals used	Dose of chemicals	Other forms of treatment	Date of complete recovery	Number of mortality post-treatment

Table 8. Record of fish health.

8. Marketing

8.1. Standardizing fish seeds

There are some disparities in the sizes of fingerlings and juveniles in different parts of Nigeria. In some parts of the country, fingerlings are actually post-fry, and juveniles are actually fingerlings. What is generally acceptable is that juveniles are expected to be able to gulp and swallow 2 mm pellets. It is well established that farmers producing grow-out feeds mostly begin with juveniles' feeds (2mm). In view of this, a correlation of studies between the size of fish seed and the size of feed they can swallow would be a good way to set standards for determining size.

For length, two-thirds of respondents (67%) reported an average of 4–5 cm for fingerlings. For duration, slightly less than half (48%) said it takes 4–6 weeks for them to grow, while more than a quarter (29%) said it took more than 6 weeks. On the other hand, the vast majority of respondents said that juveniles were longer than 8 cm (88%), weighed more than 2.5 g (86%) and took 8–10 weeks to produce (69%).

From the results, it is apparent that the average weight of fingerlings is 0.5–1.5 g and that African catfish of this size cannot gulp and swallow 2 mm pellets. There is more consensus on what size juveniles are, as those weighing 2.5 g can comfortably feed on 2 mm pellets. The results also show that body length is a dependable measure of the size of fish seed.

Therefore, the standard size for fingerlings is 0.5–2 g and 4–6 cm, while juveniles weigh more than 2.5 g and are longer than 8 cm. It takes 35 days to produce fingerlings and 56 days for juveniles.

8.2. Fish handling, packaging, stocking densities and transportation

Fish seed are mostly sold as fingerlings, juveniles, post-juveniles (10 g) or jumbo (20 g). Depending on market demand and the objective of the hatchery, production usually targets fingerlings and juveniles for sale. At whatever stage the fish are sold, it is important to remember the following:

Plate 10. Kegs and oxygen bags used to transport and deliver fingerlings.

- Make sure the fish seed are evenly graded to minimize cannibalism within the hatchery and on grow-out farms.
- For those using earthen nursery ponds, make sure to completely harvest the fish. Do not leave any behind, as they will feed on the next batch of fish seed introduced into the ponds.
- Determine the location of the farmer and the distance to cover to deliver the fish seed in order to know when to stop feeding before transportation. Typically this is between 24 and 48 hours. This prevents water contamination and reduces the stress on fish during transit. If they are being transported over long distances of 300 km or more, do not feed the fish for at least 24 hours before packing them. If within town, skip feeding for 12 hours before transportation.
- Do not sell or transport fish under hot or sunny conditions. Make sure to have ice blocks or cooling systems in place to add to the water in the jerrycans or around the bags to lower the temperature during transit and sales.
- Do not stress the fish while packing them, and make sure not to overcrowd the fish in oxygen bags or 50 L jerrycans as described in the earlier part of this section. Do not exceed stocking densities of 2000 fingerlings or 1000 juveniles for a 50 L jerrycan.
- Apply a drop of palm oil on the surface of the water in each jerrycan containing fish. This will minimize foaming on the surface of the water during transit.
- Transport the fish in clean water. If transportation takes more than 24 hours, drain about half the water midway through the journey and replace it with fresh water. Do not drain and replace all of the water, because a complete change in the water parameters can lead to mortality from temperature shock or a drastic change in pH.
- Upon arrival, do not put the fish into the ponds immediately. Place the jerrycans in the fish tank or pond, and then gently add the tank or pond water into the jerrycans. Do this slowly and patiently over 20–30 minutes to equate the water chemistry in the jerrycans and the tank or pond (Plate 12). This will help the fish acclimate to the water in the new pond to prevent stress from temperature shock, which could lead to mortalities.
- For receiving farms, do not feed the fish upon arrival, as they need to acclimatize to the water. Wait 24 hours after arrival to begin feeding, though this depends on the distance covered.
- Record the number of fish supplied, mortalities and numbers received from customers. As much as possible, keep track of how the fish perform, as this will help passively assess the quality of broodstock, fingerlings and crosses used (Table 8).
- Place a screen or a net over all containers to prevent any fish from escaping during transit.

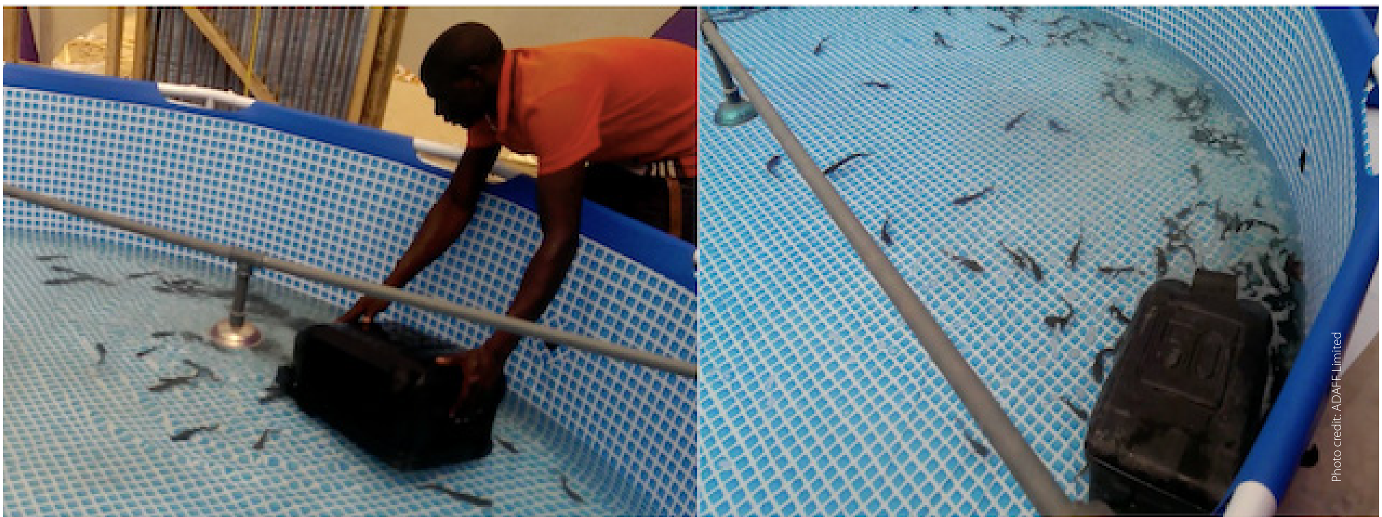


Plate 11. Fish received and gently released into the tank.

Record of fish sales

Date	Batch number of fish seed	Stage of fish seed	Age of fish seeds (weeks)	Weight of fish seed (g)	Number of fish seed sold	Unit price	Type of customer	Destination of fish seed	Type of packaging	Stocking density on transit	Type of antifoam	Time of arrival at destination	Number of mortalities on transit	Production system on receiving farm	Feed type(s) to be used	Feeding regimen recommended	Average weight at 6 months

Table 9. Record of fish sales.

9. Human resource and personnel management

Hatchery operations often require work beyond 8 hours a day, so it is ideal to have multiple workers on shifts to cover the needs of the operation. Resident staff also come in handy, especially when activities need to be carried out at night. Shifts give room for more women to participate in hatchery operations, as they can work during the day. Hatchery owners are required to audit staff periodically to determine if they need any training. The welfare and safety of staff should be a top priority for all hatcheries. Provide a clear description of terms and terms of reference to all workers before employment, and hold periodic meetings to review activities, roles, responsibilities and any shortfalls. The hatchery manager should be in charge of making sure every worker does their work effectively while at the same time ensuring that workers are safe, healthy and happy with their jobs. The biosecurity manager is in charge of implementing and enforcing all biosecurity plans. Both hatchery and biosecurity managers will provide training where necessary, while they themselves get trained on the basic reproduction and genetics of African catfish and fish health management, respectively.

It is necessary for hatcheries to set a minimum wage for employees that at least meets the national average and to have maximum working hours. Workers should have the freedom of association and the right to collective bargaining. Hatcheries must comply with national labor laws, register all staff with the National Pension Commission and properly store PENCOM certificates. Incorporate bonuses and other forms of reward for hard work into personnel management. Hatchery owners should make overtime optional and paid for. They should also keep the environment clean and ensure there is adequate water, toilets, breaks, national holidays, maternity and annual leave.

Minimize operational hazards and risks and bring all safety procedures to the attention of each worker. In case of emergency, make sure each worker receives training on how to use fire extinguishers and first aid kits and knows where they are located in the building. Establish appropriate communication, conflict mitigation and resolution channels, and set clear boundaries against sexual harassment, child labor, forced labor, and any discrimination against ethnicity, race, religion, gender and people with disabilities. Failure to comply should attract penalty, as proscribed within the national labor laws.

10. Sustainability issues

Although hatchery businesses are profitable when best practices are adhered to, the sustainability of the business and operations requires proper planning and setting short-, medium- and long-term goals.

10.1. Environmental sustainability

This is of critical importance. Hatcheries must minimize the smell associated with effluent and pollution of the waterways by treating effluent water before discharge. There are no known set limits or concentration of wastes in effluents discharged from African catfish hatcheries in Nigeria. However, biological filters can reduce the concentration of wastes, especially nitrogenous wastes, in the effluent water and possibly increase the oxygen to at least 5 mg/L. Monitor secchi disk measurements and phosphorus levels, and treat the water before discharge when necessary. Check the quality of the receiving water periodically at different points and cross-reference it against points of contact with effluent to measure impact. Send samples to a laboratory for analysis.

The use of duckweed ponds and azola ponds are recommended as natural filters, since they use nutrients in the waste water for growth and multiplication. Remove sludge from such ponds once a year, during the dry and off-peak periods. Create proper drainage pipes or canals for the effluent to prevent soil erosion and conflicts with neighbors.

To prevent fish seed from escaping into the wild, install several layers and mesh sizes of screens at different points along the drain and effluent treatment system. This is especially important because only 49% of hatcheries surveyed in Nigeria produce pure African catfish, while 51% produce both pure African catfish and their hybrids with vundu and mari. There is no documented evidence from studies in Nigeria on the impact of these hybrids when they escape from hatcheries. However, there is a lot of speculation that they could endanger the native wild populations of both African catfish and *Heterobranchus* spp.

Take care at all stages to prevent losses of eggs, larvae, fry, fingerlings and juveniles in the hatchery or during transit. Put strict measures in place to prevent escapes, such as installing containment facilities. These facilities should have screens and be connected to the effluent if the hatchery only uses underground water. For hatcheries using surface water, however, build containment facilities at both the inlet and outlet, and inspect all containment facilities daily. This will help if timely interventions are needed.

Ensure compliance with the environmental laws of the land. Large-scale hatcheries should conduct an environmental impact assessment before setting up their projects. Contact local environmental agencies for guides and information on regulatory requirements and laws to ensure proper compliance.

10.2. Financial sustainability

This is a complex subject, as there are different scales, designs, levels of intensity, production systems, management and marketing in the African catfish hatchery value chain. Based on current issues facing productivity and profitability in this subsector, hatcheries must begin to think of incorporating broodstock management systems into their operations to reduce the impact of inbreeding depression.

Make investments in training staff to understand the causes and implications of certain practices on inbreeding and how it affects the outgrowers and by extension their own business, which hinges entirely on the performance and patronage of the outgrowers. Invest in buying, producing or managing good quality broodstock. Avoid selection and use of shooters as broodstock. This is a dangerous practice in the industry because shooters constitute only about 2% of the population of every batch of fish hatched. From a genetics point of view, this could further deepen inbreeding in an already speculated inbred population. Although further research is required in this field, it is important to understand the implication of using shooters with cannibalistic tendencies as parent stock. This practice could prove detrimental and unsustainable.

High costs of feed and fuel are other factors affecting hatchery production of African catfish. As the majority of the hatcheries in Nigeria run on flow-through systems, the volume of water required daily is usually very high. The lack of power supply to pump such volumes of water, coupled with the high cost of diesel associated with the war in Ukraine and the current devaluation of the local currency (Naira), has made many hatcheries produce either below their capacities or shut down entirely. In view of this, current and prospective hatchery owners should look at solar energy as a more viable and sustainable source of power for the future.

As for the cost of feed, research is needed on sustainable alternatives, using live feed and possibly biofloc for producing African catfish seed. Production in earthen ponds or outdoor concrete tanks is a sustainable alternative to reduce feed and fuel costs, but these require a lot of skills and experience to perfect and get the required numbers for the market. Hatcheries must also have land titles and other statutory documents in place. Register with associations and the Federal Department of Fisheries, as well as other relevant institutions. This makes government interventions easier, and land titles come in handy when dealing with financial institutions for loans. Hatcheries must also keep records of tax payments and evidence of payment (tax certificates).

10.3. Social sustainability

This report has outlined the impact of hatcheries on the local environment. However, their impact on the lives and livelihoods of the local communities need to be assessed. It is advisable to employ suitable members of the communities to be part of the hatchery security staff. This will help minimize praedial larceny and create employment for members of the community. Furthermore, engaging in corporate social responsibilities will further strengthen the position of hatcheries in their local communities, increase security, create indirect advertising, and strengthen and increase their customer base.

Hatcheries should use effluent to raise at least 50 seedlings and/or commercial trees to donate to the communities on a monthly basis for economic purposes in order to curb desertification and combat climate change. They should engage with community leaders who have a known presence and ensure an easy path to resolving conflict. Hatcheries should enrol for certification and traceability schemes whenever available. This will get them familiarized with such schemes before actual breeding programs, certification and traceability schemes become available. It is important for hatcheries to treat common property resources, such as water, with consideration of others to avoid conflict.

11. Recordkeeping and traceability

Many issues face the African catfish industry because of a lack of traceability. Many hatcheries in the country have changed from outgrowers to fish seed producers simply because they had gravid fish at harvest and a good source of water and because they feel fish seed production will be a better business for them because of its short life cycle. The shooters from these gravid fish automatically become broodstock for that particular hatchery and others within the locality. The story is similar for most hatcheries. The origin of the fingerlings can only be traced to either a middleman or a hatchery that probably does not have records of the broodstock used to produce the fingerlings, the sex ratios, whether they are full-sib or half-sibs, or whether the parent stock themselves were products of a similar event.

Accurate and timely recordkeeping is key to setting up traceability models. Hatcheries must keep proper records of the following:

- origin of their broodstock
- individual data used in mating
- mating design and sex ratio
- quantity and quality of eggs and milt
- hatchability
- survival
- growth rate
- feed used
- treatment administered
- customer's name
- farm name
- address
- quantity bought
- distance traveled
- production system of customer
- feed used by customer
- harvest weight and duration of culture
- sales point and intended use, such as smoked, fresh fish market, restaurants.

Keep daily records of feed type, size, quality and quantity, mortality and water quality. This data is important in pointing out areas needing intervention should there be any issue. If the hatchery can trace the origin of fingerlings back to the broodstock's ancestry and avoid mating sibs, this could minimize inbreeding before implementing an actual breeding program. Other advantages of traceability include identifying disease-free farms and farms producing fingerlings with good commercial traits, as is evident from data produced by the outgrower. Hatcheries that adhere to best management practices and keep records enabling traceability can be easily identified and certified during any certification scheme. As presented in this document, all the record sheets developed will make it easier to trace fish seed and/or broodstock in the subsector if properly adhered to.

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