values for PAR measurements with similar instruments. However, in this study, since the same equipment was used throughout and comparisons were made between readings taken within a short duration, relative values should be reliable.

Further research using a different BP pattern and taller rice varieties was undertaken, the results of which will be published shortly.

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Breeding and Propagation of Tilapia (*Oreochromis niloticus*) in a Floating Hatchery, Gabon

Patrick Gilbert

Background

The grow-out of tilapia species in floating cages is practised in tropical countries world-wide and is well documented. Typically, production units are stocked with fingerlings usually obtained from land-based hatcheries. Few producers attempt to carry out the entire culture cycle, from breeding to nursery stages and grow-out, in floating cages.

It has been suggested that breeding tilapia in cages may be an economic and practical way of improving fish production in freshwater lakes and reservoirs, and coastal lagoons, especially in African countries. The aim of this study was therefore to improve fish production in the freshwater lakes of the Lambaréné area, and in the numerous coastal lagoons of Gabon, to compensate for the current overexploitation of natural stocks, or the alternative of introducing other species, and to reduce the drift of the fishing population away from the lakes.

The target of increased fish production needed to reverse the economic and social trends in the region was estimated at 400 t/year in the short term, increasing to about 1 000 t/year in the long term to stabilize the local fisheries sector. Some or all of this target could be achieved through aquaculture practices with species for which breeding techniques are well-established and reliable, and where suitable supplementary feed is available. In addition, in view of the large numbers of fingerlings required to meet the quantified goals, it would be an advantage to carry out all aquaculture activities in one place to reduce risks of transporting fingerlings over great distances in unfavorable physical and climatic conditions.

Methods for the production of *Oreochromis niloticus* described by Campbell (1985), Kestemont et al. (1989), Satia (1989) and Mires (1995), among others, show that propagation of fingerlings is almost entirely carried out in small outdoor ponds, often using 'hapas' (inverted mosquito nets), or in tanks and other containers or in greenhouses. Because of seasonal heavy rains in many tropical countries, many of the hatcheries and nurseries are not necessarily located adjacent to farms or stocking areas, and fingerlings have to be transported over long distances. Little information is available regarding propagation in floating cages, except for experiments (Powles 1985).

Early work on breeding tilapia in cages was carried out in Mexico by Sipe (1981). He held broodstock in simple rectangular cages (2.2 x 0.6 x 0.5 m) in which buckets of sand were placed as 'nests'. Stocking densities were 10 fish/m^2 in a ratio of two females to one male. Since then, variations in densities and ratios have been tested by Guerrero and Garcia (1983). The same method was tried in the lagoons of Benin by Morrissens et al. (1986).

Based on the encouraging results obtained by earlier workers, the concept for a floating hatchery was developed for producing tilapia for both farming and enhanced fisheries in the freshwater lakes and coastal lagoons of Gabon. The research and development work to test this concept was undertaken with Nile tilapia (*Oreochromis niloticus*). Two places in Gabon were selected, representing climatic and environmental conditions similar to other parts of the country.

Materials and Methods

Description of the Structures

Two identical floating hatching units were built, one on a private farm in a coastal lagoon near Libreville, and the other on a state farm on Lake Onangue, near Lambaréné.

THE SUPERSTRUCTURES

All hatchery operations were carried out within and around a central superstructure, made of one or more floating pontoons. Each pontoon was constructed from *padouk*, a local hard-wood (*Pterocarpus soyauxii*), and supported by 40 sealed polypropylene barrels (200-250 l size) which provided flotation. *Padouk* is water-resistant and has a life in water of at least 10 years. All metal parts used in constructing the pontoon (screws, bolts, rivets, etc.) were made of stainless steel.

The framework of the pontoon was 12.8 m long and 8.8 m wide, with six work spaces (3.2 x 3.2 m) linked by foot-bridges (0.8 m wide). Four of the six work spaces held two cages for broodstock (eight in all), and the other two work spaces held 16 pre-growing cages of 1 m^3 each (Fig. 1). The framework was constructed with standard rails (8 x 8 cm section), except for the foot-bridge (8 x 2.5 cm). The whole pontoon weighed about 2 t.

Each pontoon was attached to concrete posts fixed into the substrate. This system prevented lateral movement of the cages but allowed vertical movement.

BROODSTOCK CAGES

The framework and solid floor of the broodstock cages (1.5 x 3 x 1 m) were also made of *padouk*. The framework was covered with

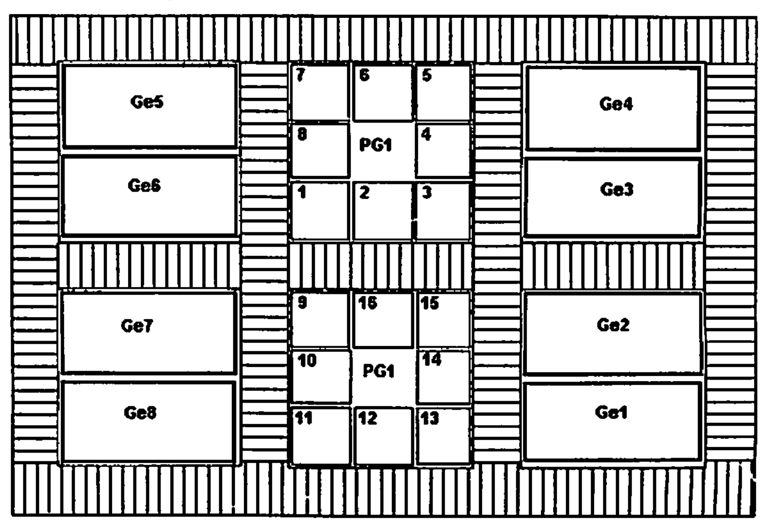


Fig. 1. Schematic diagram of the pontoon and cages, Gabon. (Ge: broodstock cages; PG: pre-growing cages).

mosquito netting (1-mm mesh), and attached in such a way that sections could be removed periodically for cleaning.

The cages were made sturdy to exclude large predators, and the assembly was covered to protect against birds. Below the water surface, the submerged cages were further protected with a large surround net (14-mm mesh) to prevent fish and other predators damaging the fine mosquito net.

Breeding units were designed based on the fact that *O. niloticus* is both a nest-builder, preferring a sandy substrate, and a mouthbrooder. Therefore, the cages for the broodstock were constructed with a solid base divided equally with a strong vertical board. On one side, the base was covered with a layer of sand (25 cm), for nest-building, and the other side held a feeding-trough. This separation into feeding and reproduction areas was important to keep the nesting places clean.

Each cage weighed about 250 kg without sand, and about 500 kg with sand.

PRE-GROWING CAGES

The pre-growing cages (1 x 1 x 1 m) for fry were constructed with *padouk* rails (2.5 x 2.5 cm in section) and covered with mosquito net (1-mm mesh).

A set of larger pre-growing cages (10 m^3) were constructed for young fish. The structures were framed with black nylon cord (210/12 gauge, without knots) containing a fine (4-mm mesh) net bag. These cages were fixed within a second but more simple pontoon, with dimensions as before.

Operating Technology

BROODSTOCK

Broodstock cages were stocked at a density of 4 fish/m^2 in a ratio of one male to three females. The weight of the broodstock varied, with smaller females (about 150 g) and larger males (about 250 g), to guarantee successful breeding. Each cage held 5 males and 15 females, with a total population of 160 breeding adults.

Broodstock were provided with supplementary feed containing 30% protein, which was placed in the feeding-trough and carefully lowered into each cage. The daily ration was 5% of the fish biomass in the cage, shared between two feedings at 1000 and 1600 hours.

About 12 to 15 days later, the first fry appeared and began to shoal on the surface. They were removed with a fine hand-net, and counted before transferring to the pre-growing units.

Fry from each cage were transferred to the same pre-growing cage, for the purpose of record-keeping. There was no consistency in fry production by the broodstock, and fry appeared at any time of the day, or throughout the day. Collection and transfer of the fry therefore depended on the cycle established in the first two weeks of production.

Every two months, the cages were thoroughly cleaned with a motorized vacuum pump, and every six months, they were removed from the water and the sand was changed. Every two weeks, the mesh frames were replaced by clean ones to make certain that water renewal was adequate. For normal management operations, one person was required for each unit, but five people were required to lift the cage out of the water for cleaning.

The broodstock were replaced every 12 months, or sooner if fry production greatly decreased. Lovshin and Ibrahim (1989) recommend broodstock be replaced every 21 days.

FRY (ZERO TO TWO MONTHS OF AGE)

Fry from broodstock cages were removed daily with a fine-mesh hand net, and transferred to pre-growing cages nearby. It was important to control the stocking density for good survival, and the fry in the pre-growing cages were all of the same age (within one week) to prevent cannibalism.

For the first two weeks, the fry were fed with a mixture of cooked egg yolk and protein/flour sieved (250 μ) onto the surface of the water in the cage. After this, the fry were fed the same prepared feed as the adults, a mixture of 30% protein and flour. For the first few days, the feeding rate was carefully controlled to avoid starvation and minimize mortality, and the fry were fed with small quantities of fresh feed at least four times every day. When the fry were well-established, after about 15 days, the daily rate was increased to 10% of the biomass, evenly distributed four times a day. At the end of the first pre-growing stage (two months), the average weight of the fry was 2.5-3 g.

The fry kept the inside partitions of the cages clean, by browsing on the algae and fine particulate matter as it settled on the inside surfaces. The outside of the cages was cleaned by wild ichthyofauna attracted by feed residues. For this reason, water circulation was generally better in the fry cages than in the breeding cages.

YOUNG FISH (TWO TO FIVE MONTHS OF AGE)

After two months, the young fish were transferred to larger pre-growing cages (10 m^3) fitted with 4-mm mesh netting for a further three months, with physico-chemical parameters measured as before. The initial stocking density was 800 fish/m^3.

The young fish were fed with the same feed at a daily rate of 10% of the biomass during the first month, 7.5% in the second month, and 5% in the third month. Feeding was carried out four times a day.

After five months in the cages, the fingerlings weighed about 25-30 g and were ready for transfer to the grow-out cages or net pens.

Results and Discussion

The results cover a full year of production, so that all climatic conditions in dry and rainy seasons were experienced.

Fry Production in the Breeding Units

Optimal periods for fry production were when water temperatures were above 26°C. Production was more inconsistent and noticeably lower when water temperatures were below 26°C, but this also depended on the site and water renewal.

In inland waterbodies, such as lakes, the dry season is bad for production as water temperatures fall below average. On the other hand, the rainy seasons are good because the humidity and air temperatures are high and the large volume of water buffers any sudden changes in water temperature.

In the coastal lagoon, production was low after heavy rains, as colder waters from rivers lowered the temperatures. During the dry season, water temperatures were constant at around 29°C, which is excellent for good production.

The results of fry production in the eight broodstock units showed significant variation from one unit to another (Table 1). The average monthly production per cage was 1 866 fry, with a range of 839 to 2 763.

Although some of the differences may have been due to human interference in and around the units, the principal cause was most probably the natural variation in individual fertility (Mires 1983) and egg-laying frequency, and asynchronous development of the reproduction cycles of the females (Jalabert and Zohar 1982). This was apparent during the four-month period when there was no production at all from any of the units for 20 days.

The number of females in the cage is therefore important to maintain regular fry production. Female tilapia can breed every 40 to 90 days. Over the four-month period in the cage, each female should have spawned between one and three times, with a potential for 15 to 45 spawnings per cage of 15 females.

The essential components of good fry production appear to be the number and quality of the broodstock, constant daily production and collection of fry, and a good quality feed rich in protein (above 25%).

The results of fry production per unit surface area, or per female, are encouraging. Guerrero and Garcia (1983) projected a potential output of 53 fry/m^2 per month. In Gabon, outputs ranged from 186 to 614/m^2 per month, with an average of 414 for the whole operation for four months. These results are closer to those obtained

Table 1. Fry production from the breeding units, Gabon.

	Cage								
	1	2	3	4	5	6	7	8	Total
Monthly production									
1	3 644	1 752	3 110	482	1 885	3 029	2 327	856	17 085
2	1 717	1 267	2 618	1 839	906	767	893	855	10 862
3	2 340	1 899	1 799	4 514	2 288	1 894	384	672	15 790
4	3 354	739	2 831	2 229	2 324	1 349	2 181	973	15 980
Total	11 055	5 657	10 358	9 064	7 403	7039	5 785	3 356	59 717
Average/cage/month	2 763	1 414	2 590	2 266	1 850	1 759	1 446	839	14 929
Daily average/cage	92	47	86	75	62	59	48	28	498
Maximum production/day	618	873	1 460	1 270	1 205	866	1 035	445	3 180
Number of days of production	50	33	43	32	38	34	27	33	102
Production/female/day	6	3	6	5	4	4	3	2	4
Production/female/month	183	91	180	152	122	121	92	62	122
Production/m²/day	21	11	19	17	14	13	10	6	14
Production/m²/month	614	314	575	503	411	390	321	186	414

by Sipe (1981) using reproduction buckets for outputs averaging 400/m² per month from 10 breeders/m², and a ratio of one male for two females. Production in hapas varied from 40 to 70 fry/m² per day, with each female producing between 4 and 20 fry per day. Results in Gabon averaged only 21 fry/m² per day, and only 2 to 6 fry per female. The best results of production in cages have been reported by Hughes and Behrends (1983) with 29 fry/m² per day.

By extrapolation of the four-month fry production data, the floating hatchery unit in Gabon can produce about 179 000 day-old fry annually.

PRODUCTION OF FINGERLINGS (ZERO TO TWO MONTHS)

Survival of fry through the first two months in pre-growing cages is shown in Fig. 2. Densities were somewhat arbitrary, depending on the numbers of fry available from the same population when stocking. The results show that the survival rate was generally high (above 60%) at densities up to about 3 000 fry/m³, but were less consistent and generally lower above this.

The results show that survival rates of 75% and above can generally be obtained in the pre-growing units from stocking densities of 1 000-3 000 fry/m³.

For future stocking of these units in a production system, it would appear most practical and productive to propose an initial stocking density of 2 000 fry/m³ for the two-month growing period. Kestemont et al. (1989) proposed a density of 3 000 fry/m³.

Based on the proposed assembly of 16 pre-growing cages, the system could accommodate 192 000 day-old fry taken from the breeding cages and, with a survival of 90%, 172 800 fingerlings of two months of age, weighing between 2.5 and 3 g each, could be obtained.

PRODUCTION OF FINGERLINGS (TWO TO FIVE MONTHS)

The results showed that, at the stocking density of 1 000/m³, there was little or no mortality. During this period, size difference between males and females became apparent. This is not a problem unless the age difference is above 1.5 months, when the large males can become cannibalistic in the absence of adequate food.

The Influence of the Physico-chemical Parameters of the Water

The waters in Gabon are slightly acidic. The pH, which varies between 5.3 and 6.2, affected

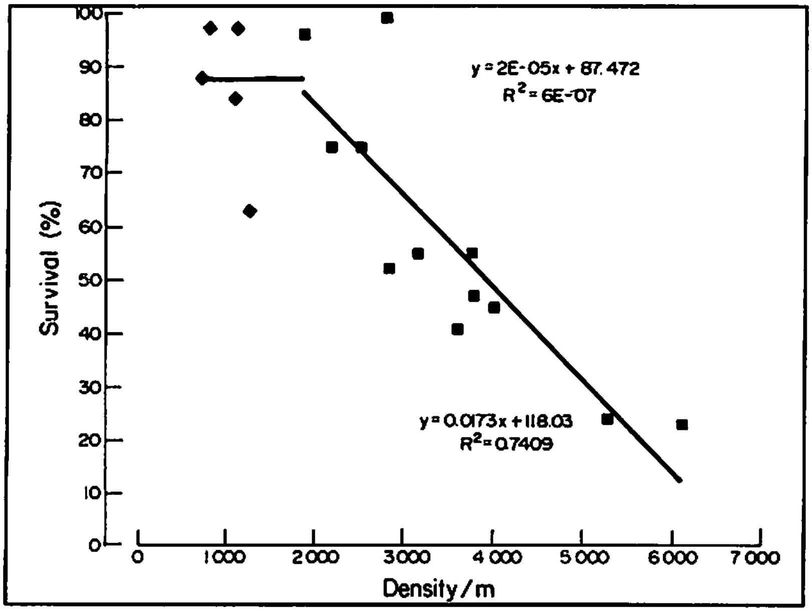


Fig. 2. Survival of two-month old fry in pre-growing cages.

the cages more than the fish, and quickly hydrolyzed the metallic parts of the structures that were not of good quality stainless steel.

Dissolved oxygen was around 3.5-4 mg/l and frequently higher. Low oxygen levels in highly-stocked pre-growing cages encouraged outbreaks of *furunculosis*, but the signs quickly disappeared with an increase in the level of dissolved oxygen, or a reduction in density.

Water temperatures varied mostly between 27 and 30°C, which was good for fry production. When temperatures fell below 26°C, fry production decreased. This was most noticeable in the units in the lagoons during the rainy season, when the influx of cooler rainwater slowed and stopped fry production for several days.

Turbidity fluctuated between 0 and 120 ppm, the higher levels being associated with periods of heavy rain and obvious run-off from farmlands into the rivers. Thus, variations in turbidity were usually associated with variations in temperature (as noted above) potentially influencing fry production.

In summary, the physico-chemical parameters of the sites were generally stable and did not impact the system except during the heavy rains, which lowered water temperature and increased turbidity.

Standardization of a Model Floating Hatchery System

The Facilities

Based on the results, it is possible to plan and cost a model floating hatchery system for the commercial production of *O. niloticus* in Gabon which, with minor adjustments for differing costs, would be appropriate for other tropical countries.

The target capacity of a model hatchery is 194 000 five-month old fingerlings. Such a yield would provide fingerlings for: 2 ha of net-pen enclosures (10/m^2 fish stocking density); or 1 200 m^3 of floating cages (80/m^3 fish stocking density); or 9.6 ha of earthen ponds (2/m^2 density), to give an average production of 30-40 t/year.

In order to meet this production, the following calculations for the annual bio-program can be made, based on sub-optimal (but better than average) results obtained during the experimental period.

As each second pre-growing cage accommodates 8 000 fingerlings per three-month cycle (or 32 000 fingerlings per year), six pre-growing cages are required to hold and produce 194 000 fingerlings for three months, without loss.

As each first pre-growing cage accommodates 2 000 fry per two-month cycle (or 12 000 fry/year), 18 pre-growing cages are required. Based on 90% survival in these units, the yield from 215 000 fry is 194 000 fingerlings after two months.

Based on the production parameters for the hatchery and broodstock described above, the facility requirements for the hatchery are summarized in Table 2.

The critical point in the proposed operation is the regular and reliable daily production of fry from the females. Therefore, 120 is the proposed minimum number of females in the system, and these should be replenished every year or possibly more frequently. Accuracy in collecting and counting at transfer is also important, and

Table 2. Hatchery facilities required for the proposed bio-program.

	Broodstock	Pre-growing 1	Pre-growing 2
Size	4.5 m^2	1 m^3	10 m^3
Number	8	18	6
Density	4/ m^3	2.000/m^3	800/m^3
Total production	215 000	194 000	194 000

therefore it is necessary to have trained and reliable operators.

Costs and Financial Profitability

Based on the current prices of construction materials and other inputs including labor, the total required investment is Francs CFA 4 744 000 (US$1:Francs CFA 500), with the financial amortization of CFA 713 000 per year. We consider an insurance at 1% on the assets and 3% on the stocks. Under these conditions, the total operating cost of the model hatchery is Francs CFA 5 903 000 per year, with a production cost of Francs CFA 30.4 per fingerling (Table 3). At current prices, this is comparable to the net cost of Francs CFA 23.8 estimated by Parrel et al. (1986) in Niger before devaluation of currency.

The cost of feed is high, due to the fact that it is a special product imported from Cameroon at Francs CFA 360 per kilogram. Local or other options could reduce this expense. However, the imported feed performs well, and alternatives tried so far have not been at all successful, causing heavy pollution in the cages and fish mortality.

The fingerlings could be sold for Francs CFA 35 if the hatchery was considered as a profit center. With 40% income tax, the net profit is Francs CFA 532 000 per year.

With the hypothesis of average stocks, buying, and turnover, the working capital requirement is estimated at Francs CFA 1 037 000. With a half production in the first year, the required capital is CFA 5 400 000: CFA 1 700 000 by equity and CFA 3 700 000 by loan. This would be a loan for eight years with a grace period of three years, at 11% interest. Under these conditions, the internal rate of return on invested capital would be 21% and the economic rate of return of the hatchery, 33%.

Conclusions

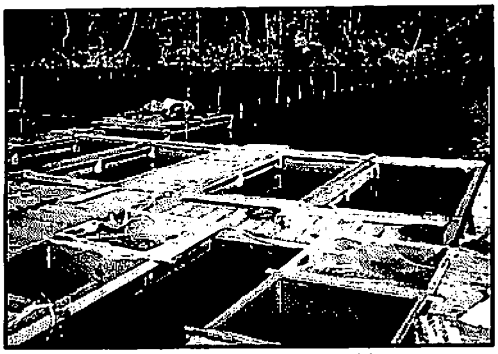
The principal advantage of the hatchery is that it can be located right on the waterbodies where stock enhancement is needed, or adjacent to commercial grow-out farms. It also has many technical and operational advantages over a land-based hatchery: no movement or transportation of fish, which can cause stress and mortality; a simple technology, with no mechanical components; limited logistical problems; minimum of technical staff; easy maintenance of locally available equipment; reliability in terms of production; suitability for a variety of locations, and according to season; and easy to expand.

The floating hatchery has some disadvantages, but these are mostly operational and managerial in nature: the need to monitor density and feeding closely; 24-hour presence to collect the day-old fry; vigilance to deter predators; and finding a site for suitable anchorage, with access.

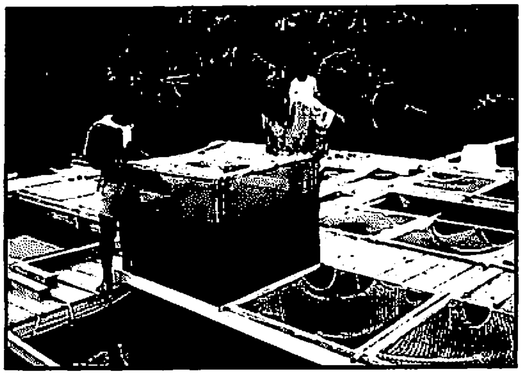
The success of the floating hatchery, in terms of reliability and production costs, demonstrates that a rational development of tilapia fisheries in the lakes

Table 3. Costs and returns of hatchery operation (US$1 = Francs CFA 500).

Item	Costs/Returns (Francs CFA 000)
Operating costs	5 903
Labor	960
Feed	3 589
Fish culture material	100
Insurance	60
Depreciation	713
Limited interest	381
Overhead	100
Returns (@ CFA 35 per fingerling)	6 790
Gross profit	887
Income tax (@ 40% of gross profit)	355
Net profit	532



A view of the floating hatchery: pontoon with cages.



Inspection of a pre-growing cage.

and lagoons of Gabon, and many other African countries, may be contemplated. It is readily adaptable to many locations where the climate and hydrobiological conditions are characteristic for the species. For example, such a hatchery would be useful in the Sahel, where most of the waterbodies are seasonal artificial lakes, or in the lagoons of Benin where the unit could be moved about to avoid seasonal variations in salinity, or wherever seasonal rains make it difficult to find a safe land-based location close to the receiving lakes and lagoons.

The hatchery is semi-intensive in operation, but the use of locally available materials makes construction and operating costs reasonable for most rural areas. Consequently, the hatchery is suitable for the establishment of a commercial grow-out farm using a system of large floating cages or net-pen enclosures, or a 'Nucleus Estate', with the hatchery providing fingerlings to a number of small-scale farms distributed in the area. Such an Estate is now being proposed in Gabon.

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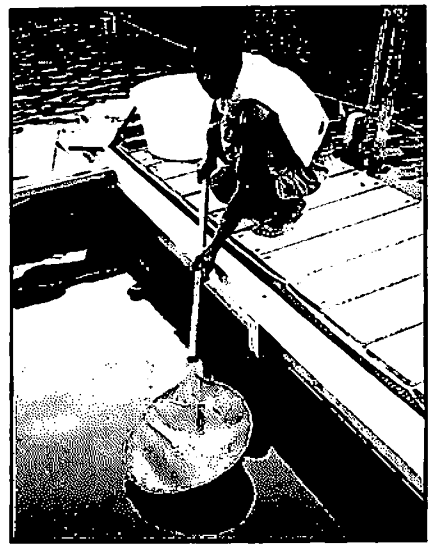

Fry harvesting from broodstock cages.

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