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Towards the maximum profitability of smallholder catfish nurseries: Predator defense and feeding-adapted stocking of *Clarias gariepinus*

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Abstract

To determine how best smallholders could maximize the profitability of their catfish hatcheries, the cost/benefit analyses of using fences, hapas and bird nets to exclude predators; as well as over-stocking to create food shortage, were conducted. As compared to the typical production system (fertilized unfenced ponds) and at a stocking density of 10 two-day old fry/m^2, survival increased by 28% in fenced ponds, 34% in open hapas and 55% in bird-netted hapas. These increases were believed due to the respective exclusion of adult amphibians, aquatic insects and flying predators, implying that they would be respectively responsible for 28%, 6% and 23% of the fry mortality which was observed in unfenced ponds. When the stocking density of closed hapas (predator-free systems) was increased from 10 to 40 fry/m^2, fry survival significantly dropped ($P<0.002$), indicating a shortage of adequate food/fry. Consequently, the maximum yield was only 29 out of 40 fingerlings/m^2 (though up from 10 out of 10 in the lowly stocked systems) and 29 larvae/m^2 appeared to be the stocking density which could optimize the profitability of smallholder *C. gariepinus* hatcheries. Calculations based on corresponding survivals, final average weights and size-dependent selling price showed that stocking at this (optimum) density could significantly improve profitability, as for instance, from −184 francs to +982 francs/m^2 through the use of closed hapas. Smallholders should therefore determine and stock their nursing systems at optimum densities as well as defend the stocked fry against predators, in order to maximize their profits.

Keywords: Clarias; Predation; Food shortage; Stocking density; Profitability

1. Introduction

Fast growing, omnivorous and air-breathing, the African catfish, *Clarias gariepinus*, would be excellent for aquaculture, if not for generally low and highly variable fry survival in nursing ponds (de Graaf and Janssen, 1996). Mortality causes have been summarized by Hogendoorn (1979), as predation by various organisms, shortage of adequate feed and poor water quality. According to Viveen et al. (1985), predators can either enter the pond through the inlet pipes (eggs and larvae of, as well as some adult frogs and toads), through

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the soil (adult frogs and toads) or through the air (insects and birds). Although water quality is seldom a problem in well-managed derivation ponds, Yong-Sulem and Brummett (2006) could not raise fry survivals above 65%, despite barring of all possible predation routes. The usual solution is to over-stock so that, despite all fry mortalities, yields can still suffice for local distribution. Yet this strategy is inappropriate under smallholder circumstances as egg hatchability remains low (Yong-Sulem et al., unpublished), yielding a number of larvae which is too low for over-stocking.

The aim of this work was to successively exclude each predator type and introduce food shortage per fry, in order to estimate the responsibility of each for usual mortalities in earthen ponds; as well as to analyze the costs and benefits of exclusion techniques; to inform small-scale catfish hatcheries on how best to fight fry predators and at what density to stock so as to maximize their profits.

2. Materials and methods

The mortalities caused by adult amphibians, aquatic insects, flying predators and food shortage were estimated through the use of peripheral fences, open hapas and covered (bird-netted) hapas as well as through over-stocking predator-free hapas to create food shortage per fry. Treatments were based on observation of predator behavior over more than 10 years of pond-based culture of *C. gariepinus* at the Participatory Aquaculture Research Center (PARC) in Yaoundé, Cameroon.

Treatment A was designed to estimate total mortality under unfenced pond conditions. Triplicate 85 m^2 earthen ponds at the PARC were weeded, dried and limed with quicklime (CaO) at a rate of 250 kg/ha and fertilized with fresh pig manure at a rate of 800 kg/ha. Any leaks in the ponds were also located and blocked by stuffing with clay soil and compacting with a club. Ponds were stocked at 10 fish/m^2 with two-day old *Clarias gariepinus* larvae resulting from artificial reproduction of broodfish captured from a local reservoir. Supplemental feed was added daily in the form of a 50:50 mixture of dried brewery waste and wheat bran at a rate of 100 kg/ha.

Treatment B differed from treatment A only by the fact that the ponds were fenced. The fence was1.0 m high (de Graaf et al., 1995), manufactured from locally available nylon bags, cut and sewn together, buried 10 cm into pond dikes and supported by wooden stakes. In addition, filters of doubled-layered mosquito netting were put over water inlets. Treatment C consisted of identical stocking of triplicate 1 m^3 hapas fabricated from the same material (mesh size = 1 mm) as the frog fence. Treatment D differed from C only by the fact that its hapas were covered. Covers consisted of curtain material with a mesh size of 3 cm. Treatment E differed from D only by the fact that its stocking density was 40 fry/m^2, i.e. four times as much as in the other treatments.

Inter-treatment differences could not be further minimized because it is impossible to evaluate a fenced and an unfenced pond approach in the same pond and because installing hapas in fenced ponds can complicate the question of how much survival improvement is afforded by the fence or by the hapa. However, each replicate hapa of each of treatments C, D and E was installed in each replicate unfenced pond of treatment A to avoid differences that additional ponds could introduce. Installing of hapas was by attaching their eight corners to four wooden stakes so as to have them completely unfolded with their bottoms completely in contact with pond floors and they received a 10 cm thick layer of mud from the pond floors. This was in order to encourage development of benthic food organisms. They were limed, fertilized and fed just like the ponds. Larval mortality in *C. gariepinus* at the PARC is sometimes caused by surface growth of the duckweed, *Lemna paucicostata*, which impedes light penetration, competes for oxygen by night and leads to low morning dissolved oxygen concentration (DO). To rule this out as a possible source of mortality, pond surfaces were raked on a weekly basis, water was input in form of aerating jets and DO concentration was measured daily at 0600 (time at which DO is usually lowest at the PARC) with an Otterbine Sentry III Oxygen/Temperature Monitor. Temperature, pH and transparency were also measured respectively using the Otterbine Sentry, a LaMotte Wide range pH model P-5100, Code 2120 and a sechi disk. Any amphibians (*Ptychadena oxyrhinchus* and *Bufo regularis*), insects (*Orthetrum* sp., *Ranatra* sp. and hemerodrominae larvae) and birds that could jeopardize fry survival (Yong-Sulem et al., in press) were observed.

All expenses incurred per treatment were recorded and costs of cheap inputs (lime, manure, brewery waste and wheat bran) which were identical/m^2 across the treatments were integrated into collection and application-labor costs. While 1 m^2 of an 85 m^2 pond shared only 0.4 m^2 of polythene material for fencing and only 64 francs for sewing labor, a m^2 of open hapa required 5 m^2 (more than twelve-fold) of the material and 1200 francs (more than eighteen-fold) for sewing. Bird-netting the hapa further increased the material cost by 20% and the sewing cost, by 50%. Table 1 presents the

Table 1
Costs, revenues and profits (CFA francs) per square meter of pond/hapa area, for various nursery systems of *Clarias gariepinus* in Cameroon

System	Larvae	Labor	Dp	TC	GR±SD	NP±SD
A) Unfenced ponds	23	233	17	273	596±104 [a]	322±113 [b]
A*) Optimum density, unfenced ponds	67	233	17	317	870*	553*
B) Fenced ponds	23	577	24	624	917±261 [a]	293±107 [b]
B*) Optimum density, fenced ponds	67*	577*	24*	668*	1500*	876*
C) Open hapas	23	606	82	711	1100±361 [a]	389±219 [c]
C*) Optimum density, open hapas	67*	606	82*	755	1588*	833*
D) Low-density closed Hapas	23	1000	111	1134	950±58 [a]	−184±158 [c]
D* Optimum density, closed hapas	67	1000	111	1178	2110*	982*
E) High-density, closed Hapas	92	1000	111	1203	2025±277 [b]	822±65 [a]

Production cost of 1 larva=2.3 CFA (Yong-Sulem and Brummett (2006) and 1 U.S. dollar=500 francs CFA.
N.B.: Starred entries have been obtained by calculations based on a stocking density of 29 fry/m^2, suggested by real yields as the maximum stocking density. Dp=Depreciation, TC=Total Costs, GR=Gross Revenue, NP=Net Profit & SD=Standard Deviation.

costs which differed with production systems. After 42 days of nursing, fingerlings were harvested, counted and weighed to calculate survival, average weight and number/m^2. These production data were compared via analysis of variance (ANOVA) followed by Duncan's new multiple-range test (Zar, 1974) while multiple regression (STATISTICA, StatSoft, Tulsa, OK, USA) was used to compare gross revenue and net profits across all treatments with costs, final average weights and number of fingerlings harvested/m^2.

The highest final density of fingerlings observed in the predator-free hapas was considered as numerically equal to the appropriate stocking density which minimizes the ratio of fry costs to fingerling sales, maximizes profitability and just avails enough food/fry to maintain observed survival rates. Yong-Sulem and Brummett (2006) found that although survival is not always linearly related with the stocking density in predator-exposed systems, it is directly proportional to food availability (below satiation point) and thus inversely proportional to stocking density in protected systems with fixed food inputs. Under such conditions, the number of fingerlings harvested per square meter increased with stocking density until it became so high that each fry could not ensure its minimum food needs. Since the threshold appeared to be 29 hatchlings/m^2 within the conditions of this experiment, estimates of net profit based on this density were calculated for all experimental systems to provide potential adopters with approximate expected yields.

Final fingerling weights are inversely proportional to their final density (Hogendoorn and Koops, 1983), but we assumed that they would fall as low as if the optimum density (29/m^2) were up to 40/m^2, to ensure that the estimated expected yield was a pessimistic value which does not over-raise the hopes of investors. Stocking at the average final density would most likely return relatively less profits than stocking at the maximum because fingerlings are almost forty-fold more expensive than larvae and stocking at lower than the minimum fingerling density would always return lower profits, even at a survival of 100%.

3. Results

Morning temperature, pH, dissolved oxygen concentration and transparency respectively ranged from 24 to 27 °C, 6.5 to 7, 4 to 5 mg/l and 17 to 30 cm.

Toads and frogs as well as insects and birds were regularly observed in the unfenced ponds. Fencing succeeded to shut out only the adult amphibians. Screening inlets with mosquito netting to exclude their eggs and larvae as well as other aquatic predators, was not feasible as the netting was frequently clogged by

Table 2
Survival, final average weight and number of six-week old *C. gariepinus* fingerlings harvested per square meter from increasingly protected production systems in Cameroon

	A	A*	B	B*	C	C*	D	D*	E
Survival (%)	40	40*	68	68*	73	73*	97	97*	67
±SD	5		16		6		6		5
Superscript	a		b		b		c		b
A. Weight (g)	10	3*	8	3*	8	3*	6	3*	3
± SD	1		2		2		1		1
Superscript	a		a		a		c		b
Number/m^2	4	12*	6	20*	7	21*	10	28*	27
± SD	1		1		1		1		2
Superscript	c		c		c		b		a

(Fingerling prices are size-dependant: 1–3 g=fcfa 75, 4–6 g=fcfa 100, 7–9 g=fcfa 150,>10 g=200 fcfa). Values of the same line with different superscipts are significantly different (α=0.05).
N.B.: Starred entries have been obtained by calculations based on a stocking density of 29 fry/m^2, suggested by real survivals as the maximum stocking density.

debris. Consequently, tadpoles and insects remained as abundant in fenced as in unfenced ponds. Some predators like dragonfly (*Orthetrum* sp.) larvae had fingerling heads in their mouths while others like hemerodrominae larvae had gripped fingerlings with their scissors-like labiums. Moreover, on the pond floor could be found several heads and tails of both fingerlings and tadpoles; probably cut up by hemerodrominae. Water boatmen (*Ranatra* sp.) were also found, although no signs of their predation could be observed.

The only resident predators that persisted in open hapas were dragonfly larvae. Kingfishers were often seen (fingerling in mouth) escaping from both ponds and open hapas but not from closed hapas. No predators could be found in closed hapas. Partially digested fingerlings were found within the stomach contents of amphibians. Table 2 shows how fences, hapas and bird nets afforded a progressive increase in fry survival from less than 40% to more than 96% as well as how a high stocking-density could increase average yields from 10 to 27 fingerlings/m^2.

Each of the protective measures conferred significantly higher survival than unfenced ponds ($P<0.05$) and closed hapas were most protective ($P<0.008$). There were no significant differences between the survivals of fence-protected and open hapa-protected fry. The number of fingerlings harvested per square meter on day 42 from the low density treatments ranged from four in open ponds to almost ten in the closed hapas. Like survival, the number was directly proportional to the level of fry protection. Based on the kind of predators which were excluded through barring specific routes; 28% mortality could be attributed to adult amphibians, 6% to aquatic insects and 23% to aerial predators (Fig. 1).

As compared with lightly stocked closed hapas, densely stocked ones conferred significantly lower survivals ($P<0.003$) but higher yields (number of fingerlings/m^2) ($P<0.0002$). They also conferred significantly lower average weights ($P<0.007$) and suggested 29 hatchlings/m^2 as the optimum stocking density of such systems. The average weight of fingerlings which were harvested per treatment was inversely proportional to conferred survivals and thus to final densities.

Cost/benefit analysis showed that profitability was more dependent on fingerling production costs as well as on their number, size and selling price than on survival. Thus, fenced ponds did not return higher profits than unfenced ones and open hapas returned even less profits than fenced ponds, not withstanding their

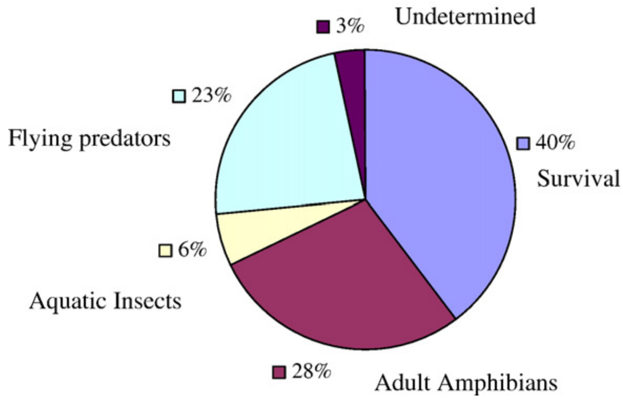

Fig. 1.

improved survivals. Although low-density closed hapas returned financial losses, high density ones returned the highest profits and extrapolation to an optimal stocking density showed that its profits could further rise to 976 francs, up from −184 francs. Extrapolation predicted similarly high profit increases from the other 3 systems and a direct proportionality between protectiveness of systems and their profitability.

4. Discussion

Since the study took place under actual field conditions, the possibility for some treatments to differ by more than one factor could not be completely ruled out. Yet, observations of vain attempts by adult amphibians to breach peripheral fences and their presence in unfenced ponds as opposed to absence from fenced ones, along with expected reduction of mortality, justify assumptions that even if the amphibians were not solely responsible, they were at least predominantly so, for higher fry mortalities in unfenced ponds. This holds true with respect to observation of aquatic insects and/or traces of their predation outside but not inside the hapas as well as observation of dragonflies and king fishers in open but not in closed hapas; re-enforced by the fact that no water-quality difference was observed between experimental ponds and hapas.

That adult amphibians could account for 28% of unfenced pond mortalities underscores the necessity for fencing of ponds (de Graaf et al., 1995). On the other hand, despite observed traces of predation by aquatic predators, excluding them reduced mortalities by a mere 6%, confirming findings of Nguenga et al. (2000) on insignificance of tadpole predation and suggesting that, conspicuous though their traces were, aquatic predators are less harmful and the mesh size of inlet filters should be increased to avoid clogging, even if filters would consequently bar only the bigger adult amphibians. Other solution strategies consist of increasing filter surface areas by using the netting to make a long "tube" (sock) and of removing larger debris by providing (1 or 2) pre-filters.

The argument that dragonfly larvae could have entered the open hapas by crawling from the pond, is cancelled by the fact that none were found in closed hapas although they were smaller than the mesh size of bird-net covers (3 cm). It would appear that these larvae (self identified as *Orthetrum chrysostigma*) could not climb the vertical hapa walls as pre-required for entering and that those which were found in open hapas, developed from aerial oviposition by gravid females directly into the open hapas. Another flying predator that was often found perching on hapa pecks, the kingfishers, could have preferentially targeted nearer fingerlings in the open hapas than in open ponds where fingerlings could swim farther away. The significant survival increase (23%) resulting from closing of hapas should therefore be thanked to barring of adult dragonflies and king fishers. Bird-netting of on-farm nursery systems is therefore a necessity where these predators exist.

On the other hand, the mortalities that arose from increasing the stocking density (30%) in predator-free systems indicate a shortage of adequate food (Hogendoorn and Koops, 1983), possibly exacerbated by increased competition and cannibalism (Hecht et al., 1988), a common problem that can lead to mortality rates in the region of 98%, particularly at stocking densities of about 100 fry/m^2 (de Graaf and Janssen, 1996). The lower average weight of fingerlings obtained at the higher density lend credit to the view that it decreased the quantity of food available/fry. That the survivals approximate those obtained by Yong-Sulem and Brummett (2006) in bird-netted ponds, implies that such ponds are similarly predator-free as well as that their survivals were limited by shortage of food and not by predators. A cost/benefit comparison of bird-netted ponds with bird-netted hapas would inform the preference of the one or the other system.

The fact that up to 29 fingerlings could survive/m^2, indicates that lower stocking densities amount to under-utilization of system niches. Conversely, that 29 fingerlings was the highest number to survive/m^2, implies that there is no need to increase this density as long as holding systems depend only on natural and low-cost feeds. Hence, 29 hatchlings/m^2 was identified as an optimum stocking density; since a lower stocking rate would under-utilize the pond and a higher stocking rate would waste fry. An analysis of de Graaf and Janssen's (1996) data reveals an inverse proportion (correlation coefficient = −0.42) between fingerling yields and hatchling stocking densities of 29–87 per m^2 as well as an average yield of less than 11 fingerlings/m^2 from five unprotected ponds that were stocked with 100 hatchlings/m^2 in Congo Brazzaville. This not only upholds the proscription of stocking lowly fed ponds at more than 29 hatchlings/m^2, but also challenges the practice of 'self insuring' through over-stocking. It is worth noting that intense fertilization of fenced ponds with chicken dung (50 kg/100 m^2) 1 week prior to stocking with 80 hatchlings/m^2 could improve the yield to a maximum of 35 fingerlings/m^2.

That such improvement results from development of natural feeds during the period between fertilization and stocking is corroborated by the fact that provision of both live and complete feed pellets enables successful stocking of up to 2000 fry/m^2 in South Africa (Hecht et al., 1996). Such a period should be avoided in unfenced ponds as fry predators would quickly infest them and defeat the purpose. Although importation, decapsulation or incubation of *Artemia salina* cysts, remains unfeasible for African smallholders, WorldFish (2005) has developed a low-cost technique by which farmers can pellet and/or flake their fish feeds as required for increasing *C. gariepinus* stocking densities and thus, yields. In this experiment, wheat bran and brewery wastes would have served as fertilizers instead of feeds as, in form of flour, their nutrients would have dissolved prior to ingestion of mostly insoluble low-nutrient seed coats (Pouomogne, 1994).

That fencing increased fry survival to 68% implies that, under the optimum stocking density here determined (29 fry/m^2), the yield would have risen to almost 20 fingerlings/m^2. Thus, the concomitant elimination of adult amphibians and appropriate stocking would increase net profits to 876 CFA francs/m^2 (Table 1). Similarly, optimum stocking of closed hapas would change the observed loss of 184 CFA francs/m^2 into a net profit of 982 CFA francs. Therefore, while increasing the cost (protectiveness) of lowly stocked systems did not always result in increase of revenue, calculations revealed that combining the protectiveness with appropriate stocking would result in progressive increase of revenue. Over all, experimental results portrayed profitability as a complex function of survival and thus number harvested/m^2, growth and thus final average weight as well as production costs and selling prices. Maximal protection of fry at the lowest cost and stocking as much as permitted by food availability were identified as baseline pre-requisites for maximization of profits.

References

de Graaf, G., Janssen, H., 1996. Artificial reproduction and pond rearing of the African catfish *Clarias gariepinus* in sub-Saharan Africa. FAO Fisheries Technical Paper, vol. 362. Food and Agriculture Organization of the United Nations, Rome, Italy.

de Graaf, G., Galemoni, J.F., Banzoussi, B., 1995. Artificial reproduction and fingerling production of the African catfish, *Clarias gariepinus* (Burchell, 1822), in protected and unprotected ponds. Aquaculture Research 26, 233–242.

Hecht, T., Uys, W., Britz, P.J., 1988. Observations on interspecific aggression and coeval sibling cannibalism by larval and juvenile *Clarias gariepinus* (Clariidae: Pisces) under controlled conditions. Journal of the Zoological Society of London 214, 21–44.

Hecht, T., Oellermann, L., Verheust, L., 1996. Perspectives on clariid catfish culture in Africa. In: Legendre, M., Proteau, J.-P. (Eds.), The Biology and Culture of Catfishes. Aquat. Living Resour., vol. 9, pp. 197–206. Hors serie.

Hogendoorn, H., 1979. Controlled propagation of the African catfish, *Clarias lazera* (C & V) 1: reproductive biology and field experiments. Aquaculture 17, 323–333.

Hogendoorn, H., Koops, W.J., 1983. Growth and production of the African catfish, *Clarias lazera* (C&V). I: Effect of stocking densities, pond size and mixed culture with tilapia (*Sarotherodon niloticus* L.) under extensive field conditions. Aquaculture 4, 227–248.

Nguenga, D., Forbin, I., Teugels, G., Ollevier, F., 2000. Predation capacity of tadpoles (*Bufo regularis*) using African catfish *Heterobranchus longifilis* larvae: impact of prey characteristics on vulnerability to predation. Aquaculture Research 31, 931–936.

Pouomogne, V., 1994. L'alimentation du tilapia du Nil, *Oreochromis niloticus* en etang. These de Doctorat d' Halieutique, Ecole Nationale Superieure de Renne. 101 pp.

Viveen, W.J.A.R., Richter, C.J.J., Van Oordt, P.G.W.J., Janssen, J.A.L., Huisman, E.A., 1985. Manuel Pratique de Pisciculture du Poisson-Chat Africain (*Clarias gariepinus*). 94 pp.

WorldFish Center, 2005. Nutrition des poissons à base des granulés piscicoles (Aliments artificiels granulés). Fiche Tecnique, vol. 7.

Yong-Sulem, S., Brummett, R.E., 2006. Intensity and profitability of *Clarias gariepinus* nursing systems in periurban Yaoundé, Cameroon. Aquaculture Research 1–5, 601–605.

Yong-Sulem S., Brummett R.E., Tchoumboué J., in press. Hatchability of *Clarias gariepinus* (Burchell, 1822) eggs in hapas and in basins: a diagnostic study of occasional inhibition by rainfall and water stagnation. Manuscript 2468, Accepted for publication in Tropicultura, January 22nd 2007.

Zar, J.H., 1974. Biostatistical Analysis. Prentice–Hall, Engl-wood Cliffs, NJ, US.