The Culture of African Catfish, *Clarias gariepinus* (Burchell) in Africa, with particular reference to controlled hatchery production

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For Albert, and his family

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ABSTRACT

A rationale is presented for a primary nursing strategy and an on-growing strategy for *Clarias gariepinus* (Burchell) culture in Africa, thus providing a potential model for the development of culture technology for the species. Existing information pertaining to the production strategies identified is reviewed, highlighting the attributes of African catfish for aquaculture. Some of the current deficiencies and inconsistencies in available information pertaining to controlled hatchery production are addressed.

The early developmental stages of *Clarias gariepinus* are defined, in order to promote consistent use of terminology and help farmers better address the changing needs of their developing stock. The pattern of growth and survival of larvae and fry is investigated at higher stocking densities than those used experimentally to provide a database for planning full-scale commercial operations. Tank design and water flow rates appropriate for *Clarias gariepinus* in hatcheries are investigated and recommendations made.

Finally, in order to promote maximal growth rates of hatchery stocks the maximum daily feed intake of larvae in relation to different feeding regimes is estimated based on rates of gastric evacuation and return of appetite.

An overview of the controlled hatchery production of *Clarias gariepinus* is presented.

Tables

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Chapter 1: Introduction

It is important, if we aim to study and manipulate the 'food system', to do so as advocates for those who are disadvantaged within it.

Arnold Pacey and Philip Payne 1985

1.1 AFRICA'S[1] DEVELOPMENTAL DISADVANTAGE

Few parts of the developing world have had such a sad agricultural history as the countries of tropical Africa in the last forty years. In 1950 available supplies of food were low, often below estimated requirements, malnutrition and under nutrition was widespread (Grigg, 1985). Since 1950 the population of tropical Africa has increased far more rapidly than of any other region (Eicher 1984). Initially food production kept up with population growth (FAO, 1958) but since the 1960's output per capita has fallen dramatically (FAO,1979; USDA,1981; Shapouri *et al.*, 1987). In many parts of Africa needs would not be met, even if food were distributed according to requirements rather than income or by possession of land (Grigg, 1985).

Within the development context Africa starts at a disadvantage for a variety of reasons. Only half of Africa has sufficient rainfall for rainfed agriculture (Higgins,1981) and in much of this zone rainfall and yields fluctuate considerably from year to year (Gregory, 1969; Higgins, 1981; Harrison

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[1]Africa is defined here as to include all states in sub- saharan Africa except the Republic of South Africa (after Eicher, 1984)

1987). Soils on the continent are poor (Lele, 1981). Much of Africa has been without earth movements for huge geological periods and as a result there are few recent deposits to form the parent material of soils. Furthermore the long periods of stability mean that the upper layers of deposits have been subject to chemical decomposition and leaching for long periods (Grigg, 1985) ; only 19% of the soils on the continent have no inherent fertility limitations (Harrison, 1987). In addition, diverse ecological conditions within individual countries make overall efforts to raise productivity through research and development relatively more complex than in uniform terrain (Lele, 1984).

A variety of socio-cultural and historic factors also contribute to Africa's developmental disadvantage. Limited growth of settled cultivation has resulted in more limited evolution of indigenous technology and skills (Lele, 1984). Many farm implements and animal driven modes of transport used extensively in other parts of the developing world are not prevalent in much of rural Africa today (Grigg, 1985). Instead with colonialism came a technological 'leap' forwards in the form of tractors and mechanical technologies without the supporting industrial infrastructure to be sustainable post independence. In 1945 all but Ethiopia and Liberia were European colonies (Harrison, 1984; Grigg, 1985). Though European colonial power, which began with the Berlin congress of 1884, and finally ended when Mozambique became independent in 1974, a terrible legacy remained. Many African countries have not yet fully achieved national unity or gained domestic political stability, often as a result of the arbitrary boundaries set by colonial powers without regard to traditional land rights and tribal cohesion (Lele, 1984).

In addition a protracted development of administrative capability has resulted from the virtual absence of strong national, regional and local government administration at independence (Lele, *op. cit.*). Yet without a condusive political environment and strong administrative framework little development is possible.

1.2 ADDRESSING THE FOOD DEFICIT

Colonial agricultural policies were geared almost exclusively to the expansion of export crop production (Evenson, 1981; Eicher, 1984). This unfortunate legacy was compounded by changes in population growth. Whereas in every other region the rate of increase in the 1970s was lower than in the 1960s, Africa's population size has risen continuously since 1945. As a result food output per head has declined in most of tropical Africa (Grigg, 1985).

Clearly food importation is not sustainable from an economic stand point. In 1962-64 Africa's food self-sufficiency ratio was 98%, by 1972-74 it had fallen to 90% (Grigg, 1985). The volume of food imports trebled between 1962-64 and 1972-74 and doubled in the 1970s (FAO, 1979; Hartmans, 1983). Indeed the financial burden of imports has been greater than these figures suggest: from 1960 to 1970 the price of cereals, the major part of food imports, rose by 50%, but between 1970 and 1980 increased sixfold (Grigg, 1985). By 1980 the cost of food imports was almost equal to Africa's agricultural export earning (USDA, 1981; Grigg, 1985).

Many would advocate the developement of national food strategies as part of the process of addressing the food deficit (Timmers, 1984; Eicher, 1984).In 1987 only Mali, Kenya, Rwanda and Zambia had operational National Food Strategies (NFS) (Lipton, 1987). However, each of the NFS's state explicitly and most sub-Saharan African (SSA) countries food policies imply a very specific agenda. The four most important goals are (Lipton, 1987):

1. Reduced net *Food imports*
2. Higher *Small Farm Productivity*
3. Greater Food *Security**
4. Improved *nutrition* for persons at risk from inadequacy**

* ie lower risk of fluctation in food availability at a national and household level.

** mainly children under 5, in big households among the poorest rural quintile.

In addition, less explicit though pertinent political goals include

5. to *finance* the state
6. to increase *political stability* by food-cheapening for organised urban groups.

as well as the environmental goal

7. *sustainability*

There is a growing understanding in Africa today that a single minded commitment to one goal is not compatible with the resource allocation

required to optimise all goals. A popular approach is a comprehensive rural development programme and in particular one that addresses the needs of the small farmer.

1.3 AQUACULTURE DEVELOPMENT IN AFRICA

Fresh fish is both a popular and important component of the African diet (Msiska, 1991; Ayode, 1991; Bangura and Cole, 1991). Despite the lowly position of sub-Saharan African countries in the world economy, five of the top fifty principle importers of fisheries commodities in the world, are from sub-Saharan Africa (Table 1.1). The value of fishery product imports by these five countries alone totals 434 million US $, of which almost 87% is spent on imports of fresh fish (FAO, 1991a).

It can be argued that as the yields of capture fisheries either become stabilized or depleted as a consequence of over fishing, with the concomitant rise in the price of imported goods, commercial aquaculture could develop to top up the eroded supply of fish (ICLARM and GTZ, 1991). Any workable program for the development of aquaculture would have to conform to the overall food policy goals outlined in 1.2. The possible advantages of developing aquaculture, particularly integrated agriculture-aquaculture farming systems, are manifold (Edwards, Pullin and Gartner, 1988). The small scale farmer would probably be the mainstay of the industry in Africa (FAO, 1975) where most external assistance projects have been aimed (FAO 1985).

Table 1.1 *International Trade in Fishery Commodities by sub-Saharan African Countries 1988* (FAO, 1999a)

Principal Importers Country	Position in World	Import Value (in 1000's US $)	Fresh Fish as a % of import	Increase/decrease since 1987
Cote d'Ivoire	25th	149,185	96.6	increase
Nigeria	32nd	109,050	91.5	decrease
Angola	36th	73,845	73.3	decrease
Zaire	43rd	52,647	66.8	decrease
Cameroon	46th	49,266	88.5	increase

Principal Exporters Country	Position in World	Export Value (in 1000's US $)	Increase/decrease since 1987
Senegal	32nd	245,580*	decrease
Cote d'Ivoire	45th	126,906†	increase

* 48% crustaceans
28% fresh fish

† 70% canned fish

Recent statistics on aquaculture in Africa are both incomplete and contradictory so that no accurate assessment of its present status in the continent is considered possible (Coche, 1983). Aquaculture production from sub Saharan African countries is probably rather low. Unlike Asia, the history of aquaculture in Africa dates back only to about 1930 when around 300,000 fish ponds were in operation principally for tilapia culture. The development did not result in much successful fish production and interest dwindled. The principle species cultured in Africa today are still tilapias (Kutty, 1986; FAO, 1991b) including *Oreochromis niloticus, Oreochromis mossambicus, Oreochromis shiranus, Sarotherodon andersonii* and *Tilapia rendali.* Various species have been introduced such as Chinese carps, particularly *Cyprinus carpio* as well as trout, *Oncorhynchus mykiss,* and salmon, *Salmo* spp. Their culture however is constrained by the environmental concerns of African governments (e.g. Malawi) regarding the introduction of exotics and in the case of salmonids by temperature (i.e. altitude); as well as by the limited African market for such species in view of their unfamiliarity and high price.

Other species cultured include catfish such as *Chrystichthys* spp and *Heterotis* spp. and mullet (*Mugil* spp).

In particular over the last quarter of a century considerable interest has been generated in the potential of an indigenous catfish, *Clarias gariepinus* (Burchell, 1822) for aquaculture in Africa. Pure and applied research, field trials and commercial culture have been variously undertaken across the length and breadth of Africa as well as in Asia, The Netherlands, Israel, China and

Scotland. The African catfish is now widely accepted as a most distinguished candidate for African aquaculture (El Bolock and Koura, 1959; Micha, 1971; 1976; De Kimpe and Micha, 1974; Richter, 1976; Hogendoorn 1979; Hecht, 1984; Huisman, 1985; Huisman and Richter, 1987; Hecht, Uys and Britz, 1988 and Haylor, 1989).

1.4 OBJECTIVES OF THE PRESENT WORK

In view of the developmental disadvantage and the associated food deficit which faces parts of sub Saharan Africa, the importance of fish on the continent and the potential for aquaculture and in particular the culture of the African catfish, the objectives of this piece of work are:

- First, to identify an appropriate strategy for the development of culture technology for the species in Africa; thus providing a potential model for the development of African catfish farming in developing Africa countries.

- Second, to provide a synoptic review of the biology and culture of the African catfish with particular reference to developing African countries. In order to provide available information and references for current and would-be researchers and extensionists thereby maximizing the utilization of current knowledge.

- Third, to attempt to address some of the current deficiencies or inconsistencies in available information pertaining to the culture strategy identified.

Chapter 2: A Strategy for the Development of Culture Technology for *Clarias gariepinus* in Africa

2.1 INTRODUCTION

2.1.1 Guiding Principals

Any workable program to develop the aquaculture of a species will need to conform to the overall development goals and policies of a country as well as the socio-cultural norms of the recipient society (ICLARM and GTZ, 1991). In addition, such a programme should be appropriate to the local biological and physical environment and be complementary to (Jamu, 1991; Costa-Pierce, 1991; Noble and Chimatiro, 1991; ICLARM and GTZ, 1991) and where possible become integrated with other production systems (Little and Muir, 1987; Lightfoot, 1991b; Gopalakrishnan, 1991; Pullin, 1991).

The principal goals of an operational or implicit national food strategy as well as a defined role for aquaculture in national development will be two of the most important 'external' variables acting on the development of a culture system. Whereas an ability to become integrated within the comprehensive framework of socio-cultural and socio-economic factors will also be critical to the success of the strategy (Ruddle, 1991; Likongwe, 1991; Kishinode, 1991; Mills, 1991, Ng'ong'ola, 1991). In particular constraints to the introduction of innovations at the household level (Mills, 1991) such as: allocation of time and labour (Ruddle, 1991) as well as the elements of decision making and risk taking processes (Banda, 1991). At the community level, factors such as organisational structure (Banda, 1991; Ng'ong'ola, 1991), the distribution of

power and prestige (Mills, 1991), beliefs and attitudes (Ng'ong'ola, 1991), access to resources (Ng'ong'ola, 1991; Ayode, 1991) and consumption preferences (Ayoade, 1991) will be relevant.

Finally, the culture system adopted will need to operate in tandem with and not in opposition to the prevailing environment, both in terms of the climate and conditions and the level of physical and institutional development.

2.1.2 Objectives and target groups

Aquaculture (FAO, 1988) constitutes the farming of aquatic organisms throughout their rearing period under individual or corporate ownership of the stock being reared, ie. where production is enhanced by the activities of farmers, or small corporate groups like families, villages (or others) of a stock to which they have a right of ownership. The principal objectives of aquaculture as a food production system in Africa will mirror those of the national food strategies outlined in 1.2

By implication the principal target group will be small scale farm families. The principal objective of aquaculture development in Africa, as elsewhere, will be to enhance the production of fish as a human food and to raise the livelihood of farm families by improving household nutritional status or income or both (ICLARM and GTZ, 1991).

2.1.3 Assessing the comparative feasibility of different systems

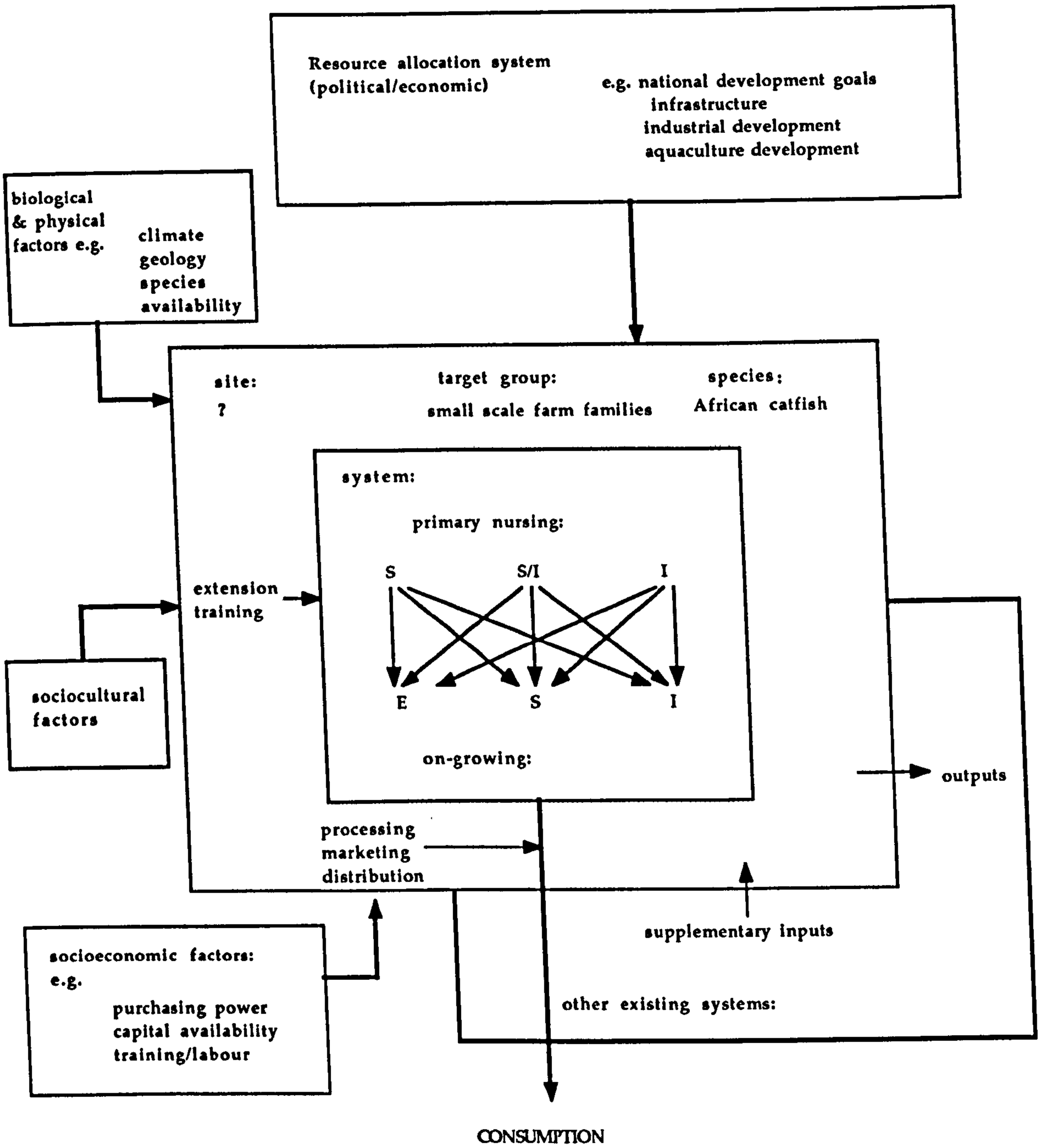
When assessing the comparative feasibility of different systems of aquaculture,

a consideration of the intensity of inputs to the system is often found to be of most practical value (Pullin, 1989). For simplicity three categories of systems will be defined; 'extensive systems' characterised by little investment in farmers' time, energy or resources; 'semi-intensive systems' with greater investment in farmer effort and inputs, often through integration with other resource systems; and 'intensive systems' which often depend principally on external inputs with high investment in time and energy.

In addition to the above categories the culture of many fish species in practice can be divided into two rearing periods: 'primary nursing' - which involves the production of eggs from broodstock and the hatching and rearing of the early life stages; and 'on-growing' - to produce market sized fish from young seed stock.

The factors affecting the choice of an appropriate system for the culture of a species, when a particular group are defined as the principal target recipients, are summarised in Figure 2.1.

The 'system component' of Figure 2.1 presents nine potential pathways; in order to examine the most promising path(s) to develop for *Clarias gariepinus* culture, the primary nursing phase and on-growing phase will be considered separately.



S = semi-intensive production methods
E = extensive production methods
I = intensive production methods
(The shaded area represents intrinsic system factors, these are modified by extrinsic contextural forces)

Figure 2.1 : The factcrs affecting the choice of an appropriate system for the culture of a species when a particular group are the principal target recipients

2.2 AN ASSESSMENT OF FARMING STRATEGIES FOR THE PRIMARY NURSING PHASE OF *CLARIAS GARIEPINUS* CULTURE IN AFRICA

2.2.1 Introduction

A range of different methods have been attempted for rearing *Clarias gariepinus* larvae. These are summarized within the context of the three primary nursery system types outlined in Table 2.1.

2.2.2 'Semi-intensive' methods of fry production

Semi-intensive systems commonly involve the rearing of larvae in static, enriched, usually drainable nursery ponds. However, many factors interfere with larval rearing in fertilized ponds. These factors have been summarised by Hogendoorn (1980b) as predation by various aquatic organisms, shortage of adequate food and poor water quality.

Predators include insects and insect larvae, amphibians as well as wild piscivorous fish as are listed in Table 2.2. Under natural conditions planktonic crustaceans are the most important food items of *Clarias gariepinus* larvae (less than 20mm total length) (Greenwood, 1956; Holl, 1968; Bruton, 1979b). Their growth and production is stimulated by adding fertilizers (De Kimpe and Micha, 1974; Hogendoorn and Wieme, 1976; Kelleher and Vincke, 1976; Hogendoorn, 1979; Christensen, 1981a). These are listed in Table 2.3. Associated with the production of food items in nursery ponds, however, is the rapid development of zooplankton and insect larvae, ie. populations of predators and/or organisms which compete for prey items.

Table 2.1 *A summary of different methods to culture Clarias gariepinus larvae*

Semi-intensive	Semi-intensive/intensive	Intensive
- natural spawning in fertilized ponds (De Kimpe and Micha, 1974; Hogendoorn, 1979; Christensen, 1981a) - stocking eggs immediately post fertilization in fertilized ponds (Hogendoorn, 1979) - stocking free swimming larvae in fertilized ponds when yolksac absorption is almost complete (Micha, 1975; Kelleher and Vinke, 1976; Hogendoorn, 1979; Viveen, Richter, Van Oordt, Janssen and Huisman, 1985)	- Stocking larvae in nursery ponds after a few days of rearing under controlled hatchery conditions feeding with live feed (Hogendoorn, 1980a; Hecht, 1981, 1982; Meske, 1984; Huisman and Richter, 1987) - stocking larvae in nursery ponds after a few days of rearing under controlled hatchery conditions - feeding with dry feed (Hecht, 1981, 1982; Uys, 1984; Hecht and Appelbaum, 1987; Appelbaum and Van Damme, 1988)	-mass rearing under controlled hatchery conditions until the fry stage when they can be introduced directly into ongrowing facilities. Intensive larval rearing to the airbreathing stage so far remains largely unreported.

The different levels of intensification are discussed in Sections 2.2.2, 2.2.3 and 2.2.4 with regard to how appropriate they may be as strategies for primary rearing.

Table 2.2 *Predators of young Clarias*

Predator	Reference	Control	Reference
Insects and insect larvae Nonectid insects, most common the backswimmer *Buenoa morgaritacea* adults invade ponds within 12-18h and multiply rapidly	Carreon *et al* (1976)	Screens placed below water surface for 30 minutes	Carreon *et al* (1976)
Water beetles, water boatmen, water scorpion, water beetle larvae, dragon fly larvae	Hogendoorn (1979)	Drying of pond bottom for 2 weeks. Application of a surface layer of diesel fuel	Hogendoorn (1979)
Amphibians High rates of predation by frogs, toads and their tadpoles	Micha (1973) Hogendoorn (1979)	removal of frogs, toads and spawn	Hogendoorn (1979)
Frogs account for 10% of 'fry' mortalities	Kelleher and Vincke (1976)		
Fish Wild piscivorous fish eg. *Pseudocrenilabrus philander, Glossogobius giurus, Ctenopoma multispinis, Clarias theodorae*	Kelleher and Vincke (1976) Bruton (1979a)	Complete draining of ponds, use of screens and perimeter fence	Viveen *et al* (1985)

Few records of water quality parameters appear to have been reported during primary nursing trials in ponds. Kelleher and Vincke (1976) did not monitor water quality but suggest that dissolved oxygen may have been limiting. Heavily fertilized static water bodies under tropical conditions would be expected to experience marked fluctuations in temperature and particularly dissolved oxygen (Boyd, Romaire and Johnston, 1978). Indeed this was documented by Christensen (1981b) who reported that dissolved oxygen at dawn dropped to 2.3mgl^{-1} and was 5.7mgl^{-1} at 2.00pm. A diurnal temperature range of 18-32°C was also recorded by Christensen (1981b) in nursery ponds.

During the initial period of larval rearing, prior to the development of functional accessory breathing organs, severe oxygen stress would almost certainly result from such low levels of dissolved oxygen. In this regard the 85% survival from one week old *Clarias macrocephalus* larvae to marketable fingerling size reported by Carreon *et al.* (1976) may be partially attributable to daily flushing for 6-8h with 3.8 1 per minute of fresh water. However Carreon *et al.* (*op. cit.*) consequently report a scarcity of zooplankton. Some other authors have also considered the provision of adequate food a problem (Hogendoorn, 1980b; Christensen, 1981b). Serious, too, is the stressing of larvae when setting them out in ponds. Towards the end of yolksac absorption, this may represent an interruption of the weaning process. Micha (1973) reported heavy mortality after 5 days, whilst Kelleher and Vincke (1976) who transferred larvae to ponds at 5-6 days old reported poor survival following long handling and counting periods. In contrast to carp larvae

Table 2.3 *Fertilization regimes in nursery ponds*

Feed/fertilization for nursery ponds	Reference
Brewery waste and peanut cake	De Kimpe & Micha (1974)
Pig manure and/or dried wheatbran-bloodmix, (best results following addition of daily wash-water from blood receptacle)	Hogendoorn & Wieme (1976)
Chicken manure extract (2-3 kg chicken manure, 500 1^{-1} water, stored 18-24 h before use), seeded with zooplankton, 3-5 1 extract 1.05 per m^3	Carreon *et al* (1976)
i. Organic and mineral fertilizer* ii. Fertilization by pigs iii. Fertilization and feeding	Kelleher & Vincke (1976)
Ruman content of cows + 1 kg superphosphate, 100 m^{-2} pond area After 6th day addition of bloodmeal, ground cotton seed cake and wet brewery waste	Hogendoorn (1979)
6 kg superphosphate } per hectare per week for a month 6 kg urea }	Christensen (1981b)

*Peanut oil cake 5 kg 100 m^{-2}
Bone meal 5 kg 100 m^{-2}
Chicken meanure 2 kg 100 m^{-2}
Dried blood 2 kg 100 m^{-2}
Inorganic fertilizer (ammonia and phosphate) 1.045 kg 100 m^{-2}
15.045 kg 100 m^{-2}

which usually begin exogeneous feeding after 2-4 days (Vankaecke and Sorgeloos, 1983; Michaels, 1988), catfish larvae are nourished by their yolksac for 3-6 days (De Kimpe and Micha, 1974; Carreon *et al.*, 1976; Hecht, 1981; Zaki and Abdula, 1984).

Although controlled propagation of *Clarias gariepinus* fry in ponds has been considered satisfactory by some authors (Hogendoorn, 1979; Hogendoorn and Vismans, 1980; Christensen, 1981b), pond rearing practices generally have not provided the required numbers of fingerlings (Micha, 1975; Nugent, 1975; Kelleher and Vincke, 1976). Therefore in view of the difficulties of providing an abundant natural food supply whilst limiting competitive and predacious organisms and maintaining water quality it may prove desirable to have an additional growth phase indoors where better control of the environment is possible (Hogendoorn, 1980b; Hecht, 1981).

2.2.3 Semi-intensive/intensive methods of fry production

Methods which combine intensive and semi-intensive larval culture generally involved an initial period of intensive larval rearing in a hatchery (Hogendoorn, 1980b; Hecht, 1981, 1982; Uys, 1984; Verreth and Den Bieman, 1987; Uys and Hecht, 1988). After about 10 days, first feeding larvae are introduced into nursery ponds (Hecht, Uys and Britz, 1988).

From two to four days after hatching, larvae in the hatchery are offered exogenous feed, which may be live, such as algae, *artemia*, rotifers or other zooplankton (Hogendoorn, 1980b; Hecht 1981, 1982; Meske, 1984; Huisman

and Richter, 1987) or a dry prepared diet (often based on yeast and/or fish meal) (Uys, 1984; Hecht and Appelbaum, 1987; Uys and Hecht, 1988; Appelbaum and Van Damme, 1988).

However the increased investment cost associated with hatchery construction, operation and management is not rewarded by a commensurate increase in overall survival for on-growing, because larval survival during the semi-intensive nursery pond phase is poor (Hecht, Uys and Britz, 1988). Mortalities in nursery ponds at this stage are principally due to predation (particularly by amphibians eg. Xenopus toads) uncontrolled cannibalism, asphyxiation or infection (Hecht, Uys and Britz, *op.cit.*).

2.2.4 Intensive methods of fry production

Intensive rearing throughout the larval stage up to the point where airbreathing fry may be liberated into on-growing facilities remains largely undocumented.

2.2.5 A primary nursing strategy for African catfish in Africa

A reliable supply of stocking material is a basic condition for successful planning in fish culture (Allain and Morrison, 1978; Huisman, 1979). It is commonly, however, a constraint. The supply of fry has been cited as a major constraint to the commercial production of tilapia (Mires, 1983; Balarin and Haller, 1982; Loushin, 1982), milkfish (Bardach, Ryther and McLarney, 1972) and mullet (Nash and Konigsberger, 1981). Also in the case of the African catfish the need to produce considerable numbers of larvae to stock on-

growing ponds is widely believed to constrain the expansion of *Clarias gariepinus* culture (De Kempe and Micha, 1974; Van der Waal, 1978; Hogendoorn, 1980a,b; Hecht, 1982; Janssen, 1984; Uys and Hecht, 1985 and Appelbaum and Van Damme, 1988).

The semi-intensive nursery pond system outlined by Viveen *et al.* (1985) where larvae are introduced into ponds after 3 days (at 7-10mm) is characterised by low and variable survival, 10-90% (Huisman, 1985). Also, the combination of intensive and semi-intensive production where first feeding larvae are introduced into ponds (at 16-30mm) after 10 days in a hatchery is similarly characterised by low and variable survival, 10-50% (Hecht, Uys and Britz, 1988).

A general trend in overcoming the problem of inadequate fry production in the aquaculture of most finfish species has been to move to more intensive production of larvae and fry in hatcheries (Nash and Kno, 1975). Where fry production is based wholly on intensive hatchery production as opposed to semi-intensive pond rearing (or wild fry collection) the cost tends to be lower and less variable because production is more consistent and reliable (Shang, 1981).

The development of culture technology for intensive hatchery production may therefore prove to be the most appropriate strategy for primary nursing of *Clarias gariepinus* in terms of reliable fry production in Africa.

A recommendation which involves a financial risk or a risk of an extended period of lost opportunity (ie. instead of carrying out other work) such as hatchery construction and operation is probably inappropriate for small scale or resource-poor farmers.

For this reason fry production in aquaculture is typically initiated by regional hatcheries, often government run, which may later be taken over by the private sector once the techniques are established and a market developed (M.C.M. Beveridge *per. comm.*). The enthusiasm with which this section of the industry is taken up by entrepreneurs eg. in southeast Asia, is a testament to potential returns on investments (N. Innes-Taylor *per. comm.*).

Given the short history of modern aquaculture in Africa and its little developed present status (ICLARM and GTZ, 1991), it is likely that fry provision together with extension of appropriate on-growing technologies will form the basis of aquaculture development in the near future.

The necessary quantity of good quality seed to sustain the growth of the industry may most appropriately be supplied by hatchery production. It would be particularly effective if hatcheries could also act as extension and fry distribution centres.

2.3 AS ASSESSMENT OF THE FARMING STRATEGIES FOR THE ON-GROWING OF AFRICAN CATFISH IN AFRICA

2.3.1 Introduction

Clarias gariepinus have been grown on to market size by a range of different methods. The different methods and their relative merits are discussed in section 2.3.2, 2.3.3 and 2.3.4 and summarized in table 2.4.

2.3.2 Extensive and semi-intensive on-growing

This type of aquaculture is commonly undertaken in ponds built by individual small scale farm families and are often grouped around a village or close to sources of irrigation (ICLARM and GTZ, 1991) or near to a water course. Pond design and layout can vary widely though construction costs are often low. A survey of 559 small scale farms in Malawi revealed that pond construction cost rarely exceeds 100MK (= £17, 1991) (Kandoole and Mkwezalamba, 1991). Lower still was the mean level of working capital identified (for seed stock, inputs, labour and equipment), which was usually 25MK (= £4.25, 1991) or less (Kandoole and Mkwezalamba, *op.cit.*). The power to purchase off-farm resources as pond inputs for semi-intensive culture is often limited amongst this group.

Small holder on-farm resources on the other hand are often fully utilized by other components of the farming system, eg. maize stover and rice straw are commonly returned to the fields whilst chicken manure is applied to vegetables (Lightfoot, 1991a). Also, in many cases the recommended level of pond inputs identified for semi-intensive culture exceeds the total production

Table 2.4 *A summary of the methods used to on-grow Clarias gariepinus in Africa*

Extensive	Semi-Intensive	Intensive
In ponds without: inputs of fertilizer or feeds (El Bolock, 1975) unfertilized experimental ponds (A.O. Maluwa, CNRFFP, pers. com.)	In ponds with: poultry manure (Bok and Jongbloed, 1984) cow manure (Hogendoorn and Wieme, 1975) Animal and vegetable products (El Bolock, 1975; Hogendoorn and Wieme, 1975; Hasting, 1973; Clay, 1979; Hecht, Uys and Britz, 1988)	In ponds with: prepared feeds (Uys, pers. com.; Britz, 1991)

of the small-holding (Lightfoot, *op.cit.*.); whilst in addition some inputs are required seasonally for human consumption eg. Madeya (maize bran) in the late dry season (M. Dixon, CNRFFP, pers. com.). In a farm survey by Mills (1991) 31% of fish farmers reported disagreements over the allocation of Madeya, between household subsistence needs and pond inputs.

To a large extent therefore the level of 'intensification' and hence the degree to which supplements are added to fish ponds will depend upon availability of household or farm residues as well as information about requirements and an ability to identify other inexpensive potential pond inputs (Lightfoot, 1991b). Extensive and semi-intensive culture systems therefore may be more properly regarded as a continuum rather than separate culture strategies.

2.3.3 Intensive on-growing

Intensive aquaculture systems develop through either private sector investment or government corporate activity. They commonly involve high capital outlay, centralized management and a degree of vertical integration (ICLARM and GTZ, 1991). Such systems are characterised by the dominantly commercial objective of maximising a return on investment, they are most usually conducted on a large scale and depend heavily on off-farm inputs (ICLARM and GTZ, *op.cit.*). Intensive pond systems are densely stocked, inputs include formulated feeds, aeration and waste removal. Farm infrastructure and equipment are expensive.

In Europe, African catfish are reared in tanks in controlled conditions (Stickney, 1991). Tanks and raceways have been used in Kenya for tilapia (Balarin and Haller, 1982) as well as in Egypt, Zambia and Zimbabwe. Tank culture requires abundant fresh or recycled water and/or aeration. In addition balanced compound feeds which supply all the fishes' nutritional requirements are needed. These often account for 50-60% of operation cost (Greenfield, 1970; Giachelli, Coats and Waldrup, 1982; ICLARM and GTZ, 1991).

2.3.4 An on-growing strategy

Intensive aquaculture systems represent an important sector of the worldwide aquaculture industry. They must however be supported by a sufficiently large potential market and are constricted by the purchasing power of consumers. The overriding constraint to be addressed by development policy in Africa is the alleviation of the all-pervasive poverty. Most households lack the money to buy their preferred types of food, often fish, to supplement their subsistence production (ICLARM and GTZ, 1991). This low to non-existent purchasing power, combined with the tradition of bartering for necessities, is a strong disincentive to private sector aquaculture development (ICLARM and GTZ, 1991). Additionally, before large-scale intensive systems of aquaculture can address the commodity deficit of the rural populous, appropriate systems must be planned and implemented to establish good linkages between producers and consumers. Distribution requires infrastructure for handling, processing, storing, transportation and selling of commodities as well as a paralleled management and monitoring structure (ICLARM and GTZ, 1991).

The paucity of commercial intensive aquaculture operations reflect the difficulties involved. At present there are only 15 to 20 viable public or private commercial aquaculture enterprises in operation in the whole of Africa, a similar number in operation which have yet to demonstrate commercial viability and another 10 projects in planning (FAO, 1985). A total of 23 countries record intensive, large-scale aquaculture activities though few amongst these are profitable (ICLARM and GTZ, 1991).

Extensive and semi-intensive aquaculture on the other hand has been described for 37 African countries, though 85.6% of the recorded ponds are found in 7 countries: Cameroon, Central African Republic, Congo, Egypt, Kenya, Madagascar and Zaire (ICLARM and GTZ, 1991). Semi-intensive practices are widespread and large integrated agriculture-aquaculture projects are underway in Central African Republic, Côte d'Ivoire, Kenya, Madagascar, Nigeria and Zambia (ICLARM and GTZ, *op.cit.*).

Most fish ponds in tropical Africa have limited water exchange, they are however subjected to consistently high light intensities and water temperatures. Therefore a potentially high rate of productivity may be expected from fertilized ponds throughout the year. The period may be limited to 200 days or less in subtropical regions (Hecht, *et. al.*, 1988). The practice of 'semi-intensive' integrated aquaculture has met with considerable success in many other parts of the world. Traditional Chinese and European aquaculture has relied almost exclusively on the resources shared and recycled

locally with animal and crop production (Little and Muir, 1987). China, for example, has not only been culturing fish for longer than most other nations but it has evolved a highly productive form of semi-intensive aquaculture capable of meeting a large demand with a limited resource base (Little and Muir, *op.cit.*). In Eastern Europe (Hungary) an integrated approach to Cyprinid culture (ducks/carp) has been extraordinarily successful (K. Jauncey, pers. com.).

In many parts of the world the integration of aquaculture with other systems is expanding (Little and Muir, 1987). In Taiwan for instance, it has been estimated that over one third of all fish ponds are integrated in some way (Crocker, 1983).

Since most small-scale aquaculture in Africa is of the extensive type and most farmers are unable to purchase pond inputs it is probably of most value to investigate and promote integrated systems of agriculture-aquaculture, combining catfish culture with agro-industrial processes, crop cultivation and animal husbandry.

2.4 CONCLUSIONS - A MODEL FOR THE DEVELOPMENT OF CULTURE TECHNOLOGY FOR AFRICAN CATFISH

As the history of past failures in Africa demonstrates, the development of sustainable aquaculture requires sound policy, well conceived planning and proper implementation via biotechnical and socio-economic research which works in tandem with a dedicated extension service (ICLARM and GTZ, 1991).

Where contextual factors support the development of a catfish culture industry (see figure 2.1) the first overriding constraint to be addressed is a shortage of seed stock.

Investment in intensive fry production may represent the best way forward; in order that sufficient quantity of robust (air-breathing) fry can be produced for on-growing. The hatchery recently established at the research and extension centre of the Central and Northern Regions Fish Farming Project, Mzuzu (Haylor, 1992a) is an example.

The availability of fry opens the way for research into optimal on-growing strategies for small scale integrated catfish farming. This type of farming is most likely to succeed if, when presented within the right contextual framework it can be shown to synergistically integrate with the small scale farm family economy. A model for the development of culture technology for *Clarias gariepinus* is summarized in Figure 2.2.

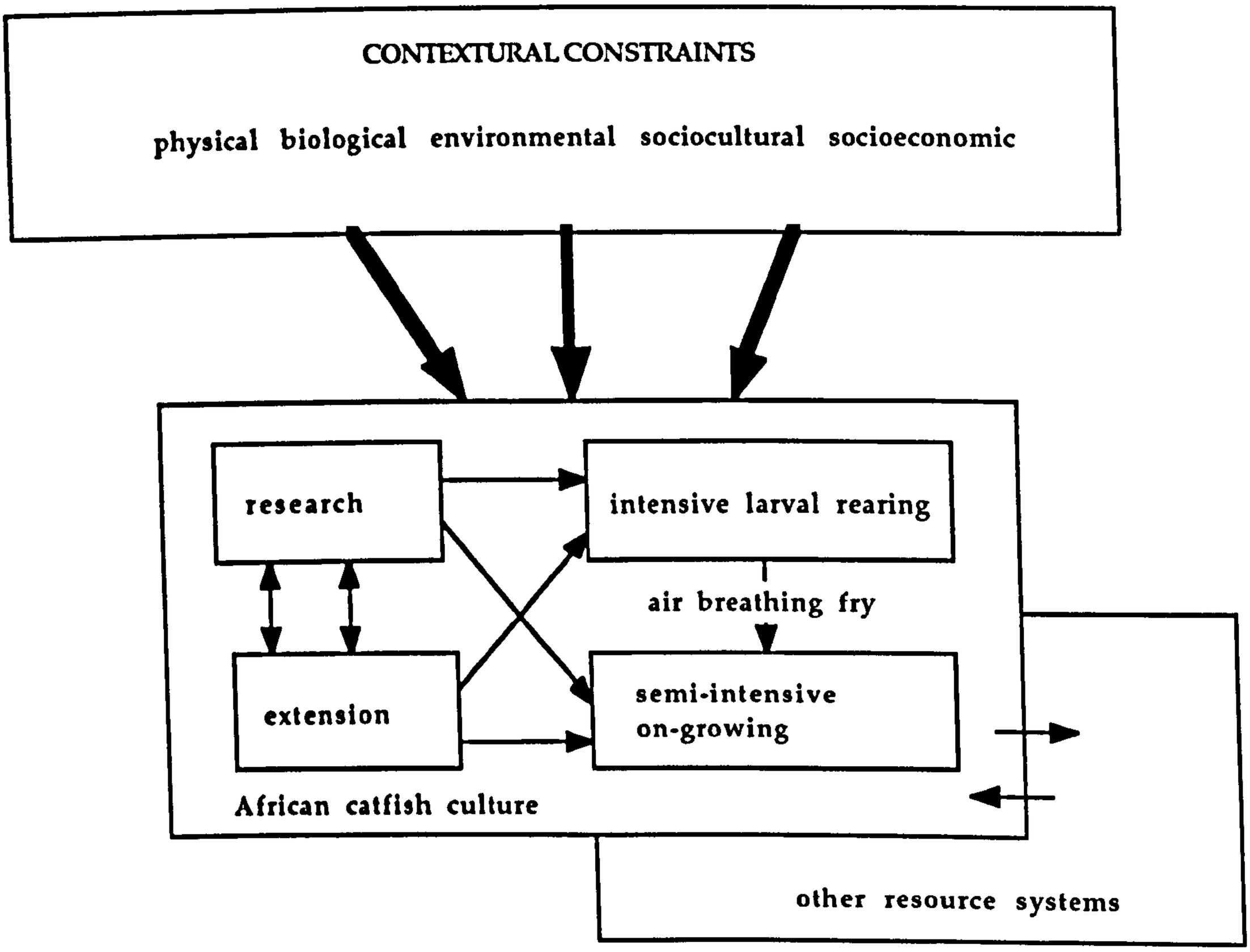


Figure 2.2 : A model for the development of culture technology for Clarias gariepinus

Chapter 3: Some Aspects of the Biology and Culture of the African Catfish *Clarias gariepinus* (Burchell, 1822).

One may not doubt that somehow good shall come of water and of mud;
And, sure, the reverent eye must see
A purpose in liquidity.

Rupert Brooke 1887-1915

The information contained in Chapter 3 has been accepted for publication in 'Recent Advances in Aquaculture' Volume IV Edited by Roberts, R. J. and Muir, J. F. published by Blackwells.

3.1 INTRODUCTION

This synoptic review outlines some of the techniques available for the culture of *Clarias gariepinus* (Burchell, 1822) and is supplemented by relevant aspects of the biology of the species. Culture methods are reviewed within the framework of the model for the development of culture technology for *Clarias gariepinus* outlined in Figure 2.2. Highlighted are those advances in propagation techniques and intensive primary nursing procedures which fall within the scope of trained fisheries personnel. Descriptions of on-growing procedures are limited to those requiring little capital investment and restricted input costs.

3.2 SOME ASPECTS OF THE BIOLOGY OF *CLARIAS GARIEPINUS* OF RELEVANCE TO ITS CULTURE

3.2.1 Introduction

A good understanding of the natural history of a cultured species is an important prerequisite to planning and designing effective aquaculture systems. It also presents a framework for efficient management practices in order to reduce stress and disease loss, and to optimize growth performance.

Fundamental aspects of the biology of *Clarias gariepinus* relevant to its culture include: taxonomy, distribution, breeding biology, natural diet, feeding and airbreathing habit. These are discussed in the following sections.

3.2.2 Classification

Until recently only the keys of the Boulenger (1911) and David (1935) were available for identification of the genus *Clarias* in Africa. Both keys, according to Teugels (1982a), are based on doubtful criteria and employ many overlapping characteristics.

A systematic revision of the genus has been undertaken by Teugels (1982a,b; 1983 a,b; 1984). Morphological and anatomical studies as well as biogeographical studies of museum specimens and field work conducted in West Africa form the basis of the research. Of 120 nominal *Clarias* species only 32 are recognised as valid.

The classification recognises six subgenera, *Clarias (Dinotopteroides)* Fowler, 1930; (*Brevicephaloides)* Teugels 1982; *Clarias (Plalycephaloides)* Teugels 1982; *Clarias (Clariodes)* David and Poll, 1937; *(Anguilloclarias)* Teugels, 1982; and *Clarias (Clarias)* Gronovius, 1781.

The species that are most often referred to in fish culture in Africa all belong to the subgenus *Clarias (Clarias)* Gronovius, 1781; in the new classification this contains two species.

Clarias (clarias)

- *Clarias anguillaris (Linnaeus,* 1758) synonym: *Clarias senegalensis* (Cuvier and Valenciennes, 1840). Distribution for Senegal to the Nile.
- *Clarias gariepinus* (Burchell, 1822) synonyms: *Clarias lazera* (Cuvier and Valenciennes, 1840) *Clarias mossambicus* (Peters, 1852). Distribution from Asia-Minor to South Africa (Teugels, 1982b).

3.2.3 Distribution and Translocation

3.2.3.1 Distribution

Clarias gariepinus is distributed throughout Africa from the Nile delta to the Orange river (Clay, 1977a; Bruton, 1988). It is the freshwater species with the widest latitudinal range (about 70°) in the world (Hecht, Uys and Britz, 1988).

Clarias lazera and *Clarias mossambicus* previously described through west, central and east Africa are now considered junior synonyms of *Clarias gariepinus* (Teugels, 1986). Although the distribution of *Clarias gariepinus* overlaps with that of *Clarias anguillaris* in west Africa (also known under one of its junior synonyms *Clarias senegalensis* (Cuvier and Valenciennes) it is widely accepted to be specifically distinct from the latter (Teugels, 1982a, b; 1983a, b; 1984, 1986). This is however, at variance with Viveen *et al* (1985), who describe *Clarias senegalensis* as specifically indistinct from *Clarias lazera, Clarias mossambicus* and *Clarias gariepinus* and of east African origin.

3.2.3.2 Translocation and its risks

Moving a species outside of its native range is associated with many risks. This is a particularly important consideration with *Clarias gariepinus*. The species has all the qualities of an aggressive and successful invader which readily adapts to new habitats, i.e. high fecundity, flexible phenotype, wide habitat preferences and environmental tolerances, an ability to feed on a wide range of prey, rapid early development and fast growth (Bruton, 1986).

Introducing *Clarias gariepinus* outside catchments in which it naturally occurs can devastate indigenous populations of fish and aquatic invertebrates. Bruton, in Hecht, Uys and Britz (1988), for example, reports that catfish in the eastern Cape are threatening populations of indigenous *Sandelia bainsii* and *Barbus pallidus* as well as the indigenous crab *Potamonautes perlatus*. Weir (1972) has reported studies in east Africa where introduced *Clarias gariepinus* have decimated aquatic invertebrate populations.

At least 20 species of parasites are carried by *Clarias gariepinus* (Van As and Basson, 1984) and therefore translocation of disease may also be important.

Clarias gariepinus was introduced in 1981 into China (Zheng *et al*, 1988) where it is now cultured (Zheng *et al*, ibid) and has more recently been introduced into the Philippines (N. Nochefranca, pers. comm.) and Thailand (A. Yakaputyagi, pers. comm.) and Bangladesh (J. F. Muir, pers. comm.). The Philippine freshwater catfish, *Clarias macrocephalus* has already become completely dominated by *Clarias batrachus*, imported from Thailand during the

craze for catfish farming following its rapid commercial success there (Juliano, Guerrero and Ranquillo, 1989).

If international translocations of *Clarias gariepinus* continue without proper consideration of the possible ecological impacts there could be serious and deleterious results. Many countries have little existing legislature to control the introduction of aquatic species [e.g. India, Indonesia, Japan, Philippines, Sri Lanka and Taiwan (De Silva, 1989)]. In these circumstances, to prevent adverse consequences the dangers associated with introduction should be appreciated and acted upon by the aquaculturists themselves.

3.2.4 The Breeding Biology

3.2.4.1 Size at first maturity

The size of fish at first maturation in various *Clarias* populations shows a remarkable variation (Bruton 1979a). Investigations in Lake Sibaya (32°40'E, 27°25'S) in southern Africa revealed that after less than one year a minority of *Clarias gariepinus* reached maturity at lengths of 200-300 mm (Bruton, 1979a). Most populations throughout Africa, however, appear to reach maturity after the second year. Table 3.l, below, indicates the median size at first maturity (i.e. the length at which 50% of the catch is sexually mature) for different populations around the continent.

The data in Table 3.1 can not accurately be related to growth rates of these populations as the latter are not always available, but it can be noted that populations which exhibit the largest median size at first maturity tend to be

Table 3.1 *Median size at first maturity for different Clarias populations in Africa (from Bruton, 1979a)*

Species[a]	Total Length (mm) Male	Total Length (mm) Female	Location	Reference[b]
C. anguillaris	-	200	Lake Chad	Blache (1964)
C. gariepinus	380	380	Rhodesia	Holl (1966)
C. gariepinus	430-450	430-450	Vaal River	Mulder (1971)
C. gariepinus	350-400	350-400	Transvaal	Van der Waal (1972)
C. gariepinus	260	260	Malawi	Willougby & Tweedle (1976)
C. gariepinus	650-750	650-700	South West Africa	Gaigher (1977)
C. gariepinus	350	350	South Africa	Bruton (1979a)
C. lazera	-	250(SL)	Ghana	Loiselle (1972)
C. lazera	-	271	Central Africa Republic	Micha (1973)
C. lazera	650-700	650-700	Kenya	Hopson (1975)
C. lazera	320	320	(Review Paper)	Richter (1976)
C. mossambicus	250-400	250-400	Uganda	Greenwood (1966)
C. mossambicus	500	500	Uganda	Greenwood (1966)
C. mossambicus	285	260	Malawi	Kirk (1972)
C. mossambicus	300-400 (rarely 250-300)	400-440	Uganda	Rinne (1975)
C. senegalensis	320	320	Ghana	Thomas (1966)
C. senegalensis	320	273(SL)	Ivory Coast	Jocque (1977)

a see taxonomy section
SL standard length
b In Bruton (1979a)

found in 'large' lakes, e.g. Lake Victoria and Lake Turkana.

3.2.1.2 Fecundity (i.e. absolute fecundity of Bagenal 1973)

Fecundity is defined as the number of developing eggs in the ovary just prior to spawning. The fecundity of *Clarias gariepinus* is related exponentially to total length and linearly to weight. A range of expressions describe lines of best fit for these relationships, (Groenewald, 1957; Pott, 1969; Mulder, 1971; Van der Waal, 1972; Gaigher, 1977; Hogendoorn, 1977; Bruton, 1979a). Hogendorn (1977) suggests that an estimate of fecundity is given by the equation:

Total no. of eggs = 66.6 x female body weight (g)

Table 3.2 describes estimates of absolute fecundity from various authors.

3.2.4.3 The breeding season

The breeding season of *Clarias gariepinus* varies with location but correlates with periods of maximum rainfall locally (Greenwood, 1957; Holl, 1968; Bowmaker, 1973; Clay 1977b; Bruton 1979a). This is illustrated by Table 3.3, which describes periods of maximum rainfall in relation to the breeding season of *Clarias gariepinus* populations in various African countries.

This reproductive cycle was investigated in more physiological detail by Van Oordt *et al* (1987). It was demonstrated that *Clarias gariepinus* exhibits a discontinuous reproductive cycle regulated by annual changes in the activity of the gonadotropic cells in the pituitary. The critical points in these annual

Table 3.2 *Estimates of the absolute fecundity (Bagenal, 1973) of different Clarias species (from Bruton, 1979a)*

Species	Total length (mm)	Fecundity (1000's)	Reference
C. batrachus	315	11.6	Mookerjee & Mazumdar (1950)
C. gariepinus	600-930	293-446	Mulder (1971)
C. gariepinus	650-1200	70-1100	Gaigher (1977)
C. gariepinus	320-894	5-163	Bruton (1979a)
C. lazera	-	13.9-164.8	Nawar & Yoakim (1963)
C. lazera	-	3-328	Micha (1973)
C. lazera	(200-700g)	10-120	Richter (1976)
C. mellandi	482	134.8	Bowmaker (1961)
C. mossambicus	500-750	32-48	Greenwood (1956)
C. mossambicus	320-774	23-183	Bowmaker (1961)
C. mossambicus	-	5-192	Rinne (1975)
C. seneglensis	-	5-200	Jocque (1977)

Table 3.3 *Breeding season of Clarias gariepinus in relation to rainfall and locality*

Country	Rainy Season	Breeding Season	Author
Cameroon	July-October	July-October	Richter (1976)
Central African Republic	July-October	July-October	Richter (1976)
Chad	June-October	June-October	Blache (1964)
Egypt	March-September	March-September	Aboul-Ela *et al* (1973)
Gambia	July-October	July-August	Johnels (1954)
Ghana	April-September	April-May	Thomas (1966)
Malawi	November-April	September-March	Willoughby & Tweddle (1976)
Nigeria	May-October	May-October	G.S. Haylor (unpubl.)
South Africa	November-February	November-February (rarely Sept-April)	Bruton (1979a)
South West Africa	November-March	November-March	Gaigher (1977)
Transvaal	October-March	October-February) (rarely May)	Van der Waal (1974)
Uganda	Mar-May, Novem-Jan	April, December	Greenwood (1955)
Zimbabwe	November-April	November-February	Holl (1966, 1968)

changes are a pre-spawning gonadotrophic hormone surge and a post-spawning regression of the gonadotropes.

3.2.4.4. Spawning behaviour

Descriptions of spawning runs observed in the wild are commonplace within the literature (Greenwood, 1955; Holl, 1968; Bowmaker, 1973; Micha, 1973; Van der Waal, 1974; Bruton, 1979a).

Bruton described the event in Lake Sibaya as follows. Spawning takes place at night, usually after heavy rain in recently inundated marginal areas. There is massive aggregation of catfish before spawning and courtship is preceded by aggressive encounters between males. Mating takes place between isolated pairs in shallow water amongst inundated terrestrial or semi-aquatic grasses and sedges. There is no parental protection of the young except by careful choice of a suitable spawning site. This contrasts markedly with the parental care exhibited by other American, Asiatic and European catfish. The spawning behaviour of various catfish species is compared in Table 3.4.

Table 3.4 *A comparison of spawning and parental care in catfish species*

Species	Spawning Behaviour	Reference
Clarias batrachus (Asiatic)	Constructs nest in inundated vegetation eg. paddy field, and guards eggs and young.	Mookerjee & Mazumdar (1950); Sidithimunka *et al* (1966); Sidithimunka (1972); Jhingran (1977) (reported in Bruton, 1979a; Tonsanga, *et al* 1963).
Clarias macrocephalus (Asiatic)	Constructs nest in inundated vegetation, eg. paddy field, and guards eggs and young.	Mookerjee & Mazumdar (1950); Sidithimunka *et al.* (1966); Sidithimunka (1972); Jhingran (1977) (in Bruton, 1979a) Tongsanga *et al* (1963)
Parasiluris asotus	Scatters eggs on benthic objects.	Zaki & Abdula (1984)
Heterobranchus bidorsalis *Heterobranchus longifilis* (African)	Spawn on recently flooded grassland adjacent to rivers and streams.	Gosse (1963); Blache (1964); (in Bruton, 1979a)
Clarias gariepinus (African)	Scatters eggs on recently inundated vegetation; no other parental care.	Bruton (1979a)
Siluris glanis (European)	Scatters eggs on benthic objects and protects them.	Kryzhanovskiy (1949)
Ictalurus punctatus (American)	Constructs nests in substrate.	Timms & Kleerekoper (1972)

3.2.5 The Natural diet and feeding habit

3.2.5.1 Introduction

Early work on the feeding habit and natural diet of *Clarias gariepinus* concentrated largely on the anatomical features of the digestive system. The species was considered to be a carnivore because of a small gut:body length ratio in comparison with other species (Angeloupulo, 1947; Al Hussaini, 1947; El-Bolock and Koura, 1959) and because it lacked pyloric caecae (Thomas, 1966).

More recently many authors have reported that plant materials represented various proportions of the stomach content (Groenwald, 1964; Poll, 1964; Munro, 1967; Cockson and Bourne, 1972). This was interpreted by Groenwald (1964) as a consequence of an indiscriminate carnivorous mode and he suggested that mouth size and the presence of bands of cardiform teeth were adaptations for manipulating prey.

Munro (1965) found that the C*larias gariepinus* population in Lake McIlwaine fed on large amounts of plant material and two years later Jubb (1967) redefined the species as an omnivorous scavenger.

Since then the feeding ecology of *Clarias gariepinus* has been studied throughout Africa; in Malawi (Bourne, 1974), Uganda (Corbet, 1959; 1961), Egypt (El-Bolock and Koura, 1959), Zimbabwe (Weir, 1972; Bell - Cross, 1974 & 1976; Clay, 1977a), Ghana (Thomas, 1966), Swaziland (Clay, 1977a),

Botswana (Donnelly, 1966) and South Africa, (Bruton, 1978; Clay 1979). A wide range of habitats have been investigated including lakes (Corbet, 1959, 1961; Bourne, 1974; Bruton, 1978), a reservoir (Clay, 1979), ponds (El-Bolock and Koura, 1959; Weir, 1972), rivers (Donnelly, 1966; Clay, 1977a; Bell - Cross, 1974, 1976) and streams (Corbet, 1961). The following feeding patterns have emerged.

3.2.5.2 Feeding physiology and behaviour

After yolksac absorption and up to a length of 3 cm *Clarias gariepinus* larvae filter feed (Greenwood, 1955; Corbet, 1961; Holl, 1966; Munro, 1967; Clay, 1979). They consume neuston, plankton, (Bruton, 1979b) aquatic insects (particularly larvae) and ostracoda (Corbet, 1961).

A strong current of water is drawn into the mouth from the water surface and expelled through gill openings. The body is positioned perpendicularly, with the barbels spread across the water surface, supported by positive buoyancy and the surface tension of the water on the outspread barbels (Bruton, 1979b).

Gill raker spacing increases with fish length (Murray, 1975). The mean width between developed gill rakers varies between 0.1 and 0.6 mm thus allowing retention of particles of greater minimum width than the above.

Catfish from 3 cm to 30 cm successfully filter feed on high densities of zooplankton (Clay, 1979), adopting the same perpendicular position as the larvae, maintained at this stage by gentle undulating movements of the tail.

Larger *Clarias gariepinus* (> 20 cm TL) surface feed at an angle of bout 60°: sucking food into the mouth accompanied by loud smacking noises.

In addition to filter feeding, after about 3 cm the fish begin other modes of feeding. Most commonly, individual foraging; the catfish swims slowly forwards, swaying the head slightly from side to side with the barbels extended forwards in a cone. When prey is detected the fish responds rapidly and accurately. In *Clarias gariepinus* this feeding mode contains elements of non-randomness, for example;

- places not recently traversed are favoured
- localities where prey has recently been caught are searched with special attention
- there is a tendency in some environments to move inshore to feed, and
- if new food sources are located the destination of future explorations is altered

(Bruton, 1979b).

Where deposits of detritus cover the substrate *Clarias gariepinus* feeds by shovelling. The sloping anterior part of the head is used to lift up detritus. Any organisms that are disturbed are then captured.

Finally, a social feeding strategy has been reported, particularly in larger *Clarias gariepinus* (40-80 cm TL) (Donnelly, 1966; Pooley, 1972; Bell-Cross, 1974, 1976; Bruton, 1979b). Groups of catfish swimming closely together in a rough sickle-shaped formation 'herd' shoals of small (8 cm TL) fish, usually cichlids, driving them inshore on gently sloping beaches or in sparsely vegetated marginal pools. The dense, panic-stricken mass of prey are eventually

encircled and readily captured by the catfish. Social hunting increases the predatory efficiency of the individual predator and allow it to capture prey which is normally too elusive or dispersed (Bruton, 1979b).

3.2.5.3 Feeding Strategy

African *Clarias* species are commonly exposed to environmental features which favour an expansion of the food niche, these include:

(1) Weak predation pressure, (this is reduced by the catfishes large size, well protected head and pectoral spines).

(2) Varying but unrestrictive physiochemical conditions, (tolerance to changing conditions encountered during seasonal migrations and seasonal or diurnal changes in water level and oxygen concentration necessitate physiological versatility in the species).

(3) Strong intraspecific but weak interspecific competition for food; a changing food supply which also varies spatially and temporally.

Such factors have led to euryphagy in *Clarias gariepinus* (Thomas, 1966; Bruton, 1979b). After 3 cm in length they tend to feed on almost any food available, with a preference for animal material (Clay, 1979). Feeding is largely dependent on a combination of prey density and prey availability. When conditions are unsuitable for capturing a particular prey catfish switch their feeding to another. For example, *Clarias gariepinus* in Lake Victoria fed mostly on *Simulium* spp. (90% of the diet) until these insects were removed by DDT, when the fish changed to a diet of plants, molluscs etc. (Corbet, 1959). They can also switch from prey-specific methods to situation-specific methods and can optimize

predation by both social hunting and by temporal synchrony with temporarily vulnerable prey. Thus *Clarias gariepinus* have been observed to feed exclusively on chironomid larvae during their lunar emergence (Munro, 1965). Similar exclusive feeding has also been observed at Lake Kyle with termite flights following heavy rains and in Sand River Lake during a seasonal bivalve "spawning run" when the latter were concentrated in shallow water (Clay, 1977a, 1979).

When not engaging in exclusive feeding catfish have been found to feed on over 55 different items, with individual stomachs containing up to ten, rarely 13, different food species (Bruton, 1979b). The variety of dominant dietary components include: zooplankton (Bourne, 1974 - Lake Chilwa; Bruton, 1979b - Lake Sibaya); insects (Weir, 1972 - Wankie pools) and cichlids (Corbet, 1961 Lake Victoria).

3.2.6 Airbreathing

3.2.6.1 Introduction

As in other species of Clariidae the gill cavity of *Clarias gariepinus* is adapted for breathing air. It is enlarged and contains two highly vascular arborescent organs, the respiratory trees or dendritic organs. Several detailed descriptions have been published, e.g. Greenwood, 1956, 1961; Moussa, 1956 and Cockson, 1972. Morphological, histological and histochemical evidence suggest that these organs are derived from primary and secondary gill lamellae (Cockson, 1972).

According to Greenwood (1956) the arborescent organs develop late in post-larval ontogeny; a single knob associated with the fourth arch appears in fishes of c. 3 cm length. The anterior tree (second arch) develops later at c. 5 cm length. Branching then continues until the much branched definitive condition is reached in fish of about 30 cm long. Under experimental culture conditions, however, the onset of airbreathing in larval catfish has been observed in fish 13 mm long 14 days after first feeding (G. S. Haylor, unpublished observation).

The onset of aerial respiration as well as the relative dependence on branchial and pulmonary organs has implications particularly for larval rearing where branchial respiration and hence the dissolved oxygen level of the water are important. Aerial respiration has been shown to develop gradually with age, constituting 50-60% of the total oxygen consumption of mature fish (over 400 g) (Babiker, 1979). The same author, however, concedes that this is dependent upon the oxygen content of the water.

3.2.6.2. Oxygen Consumption

The total consumption of both aerial and dissolved oxygen by *Clarias gariepinus* receiving an optimal diet (resulting in minimal FCR) at 25° was found by Hogendoorn (1983b) to be related to fish weight by the equation:

$$0_2 \text{ consumption} = 0.449W^{0.75} \text{ m}10_2/\text{fish/h}$$

where W = body weight in g

From an aquacultural view point this is more usefully described in terms of mg oxygen per kg fish per hour, i.e. from Gay-Lussac's Law

$$0_2 \text{ consumption} = \frac{649{,}767\ W^{-0.25}}{1013 + 3.718\ (T)} \quad mgO_2/kg/h$$

W = body weight in g

T = Temperature °C

Fertilized ponds form the basis for many fish culture operations in the tropics. These enriched static water bodies however are commonly associated with extremely low oxygen concentrations, (in all but the top few millimetres during the day). In these circumstances (considering that air can contain 30 times more oxygen per unit volume than water) the potential for culturing *Clarias gariepinus* (or possibly other air breathing species) is therefore clear.

3.3 CULTURE

3.3.1 Spawning

3.3.1.1 Introduction

Fry and fingerlings of the African catfish are difficult to obtain in natural waters for stocking available ponds (Huisman and Richter, 1987). A reliable supply of good quality fry is however, an essential prerequisite to aquaculture development, and thus much attention and research has focused on the induction of spawning. *Clarias gariepinus* may be induced to spawn by altering environmental conditions or by manipulation of the hypothalamic-pituitary-ovarian axis of the fish.

3.3.1.2 Induced Spawning

The three most important stages to be considered when inducing spawning are:

(1) The development of postvitellogenic oocytes in the ovary.

(2) Oocyte maturation.

(3) Ovulation.

An inherent endogenous rhythm determines the cyclical changes in ovarian activity in *Clarias gariepinus* (Richter *et al* 1987a), resulting in a discontinuous cycle of egg production. These authors showed that the internal rhythm in adult female broodfish was already determined at an early stage of development by environmental factors. In feral catfish the presence of posvitellogenic oocytes corresponds to the local period of maximum rainfall, (as indicated in Table 3.3).

Thus, for individual spawning to be successful, promotion of oocyte maturation and ovulation will be restricted to this period. However, broodstock transferred from outside tanks to the hatchery maintain their annual reproductive cycle for about one year, after which time spawning can be induced monthly, (Janssen, 1984). Whereas broodstock raised entirely in captivity mature precociously at the age of 6-9 months, at which time postvitellogenic oocytes are present, there is no discontinuity of egg production (Richter *et al.*, 1987a).

Where postvitellogenic oocytes are present *Clarias gariepinus* can be induced to spawn by manipulating environmental conditions or by intervention at several levels of the hypothalamic-pituitary-ovarian axis (Donaldson & Hunter, 1983), which controls reproduction in female teleosts (Donaldson, 1973). Figure 3.1 describes the pathway for control of maturation and ovulation and

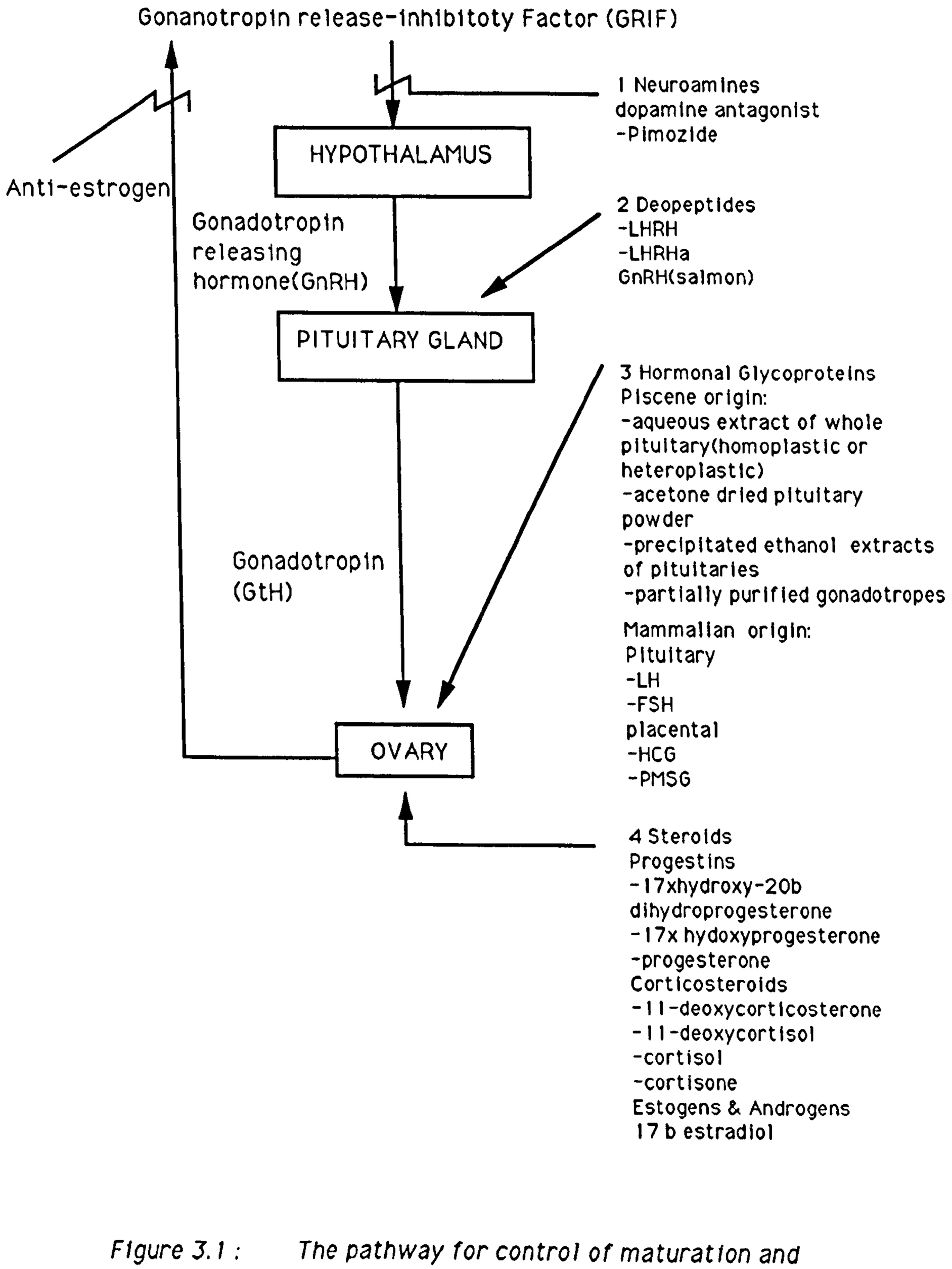


Figure 3.1 : *The pathway for control of maturation and ovulation and opportunities for inducing spawning.*

the opportunities for inducing spawning in *Clarias gariepinus*.

3.3.1.3 Induced spawning by manipulating environmental conditions

Rainfall and an increase in water level, resulting in inundation of grasslands bordering the shallow lakes in which the catfish live, appear to trigger spawning (Van der Waal, 1974; Bruton, 1979a). Bruton (1979a) hypothesized that a number of factors induce breeding, among them cold water, petirchor(geosmins) from newly-wetted soils and a change in pH. This was substantiated further by a practical method successfully employed by Christensen (1981a) in Kenya, in which 5-11 fingerlings per m^2 were produced by the following method:

(1) The pond was left empty over at least a 7 day period of strong sunlight.

(2) Gravid females, and males of the same or smaller size were stocked at 0700 h (following one week of feeding with waste fish)

(3) The ponds were filled completely in the evening with an application of 50 *l* dry cattle manure 25 *l* sun-baked red laterite soil and 25 ml of phosphoric acid per 100 m^2.

The same treatment was repeated every day for 3 days when the pond was topped up. The first filling was always done one week before new moon. Unfortunately pond size and method of application were not specified by the author.

Further environmental parameters identified as influential in induced spawning by Richter *et al.* (1987a) were feeding level, temperature, and the

presence of male conspecifics.

Feeding level has also been shown to affect ultimate absolute fecundity by Huisman & Richter (1987) who recommended a feeding level equivalent to that giving the most efficient food conversion namely 1% wet body weigh per day with 30% crude protein channel catfish pellets. However, this level will also be affected by the feeding frequency (Hogendoorn, 1981; Uys and Hecht, 1985).

High and constant water temperature (25°C) appears to enhance ovarian activity (Richter *et al.*, 1987b, Huisman & Richter, 1987), whereas temperatures of 30°C were shown to disturb reproduction (Huisman & Richter, 1987).

The presence of male conspecifics may indicate a role by male sex pheromones in follicle development and maintenance in the ovary. The steroid glucoronides produced by the testis and seminal vesicle (Lambert *et al.*, 1986; Schoonen & Lambert, 1987b; Schoonen*et al.*, 1987a, b; Resink *et al.*, 1987) could have such a pheromonal action (Richter *et al.*, 1987a). Seasonal changes in day length, however, do not influence the development and maintenance of ovaries filled with postvilelogenic oocytes (Richter *et al.*, 1987a).

3.3.1.4. Induced spawning in *Clarias gariepinus* by manipulation of the hypothalamic-pituitary-ovarian axis

3.3.1.4.1. The hypothalamic level: Gonadotropin release-inhibitory factor (GRIF) antagonists

A gonadotropin release-inhibitory factor (GRIF) has been shown to play a role in the regulation of gonadotropin release from the pituitary gland of some teleosts (Peter *et al.*, 1978; Peter and Paulencu, 1980; Chang and Peter, 1982). In goldfish this factor is believed to be dopamine (Chang and Peter, 1982, 1983; Chang *et al.*, 1983). Furthermore, injection of the dopamine antagonist, pimozide, has been shown to increase plasma gonadotropin concentration in goldfish, (Chang and Peter, 1982, 1983) carp (Billard *et al.*, 1983) and catfish (De Leeuw, *et al.*, 1985a, b).

The gonadotropin release-inhibiting activity of dopamine is restricted to the LHRH-induced GTH release (De Leeuw *et al.*, 1987). Therefore treatment of *Clarias gariepinus* with GRIF antagonists greatly enhances the effect of the releasing hormone or its analogue (see deca-neuropeptide section below). However, injection with a dopamine antagonist alone is not effective, (Van Oordt and Goos, 1987).

In many teleosts LHRH or its analogues alone can induce release of GTH but high doses or multiple injections are sometimes needed for the induction of oocyte maturation and ovulation (Donaldson and Hunter, 1983). However, a combination of pimozide-LHRHa requires no priming agent and one single intraperitoneal injection is sufficient to achieve ovulation (De Leeuw *et al.*, 1985a).

The minimal effective dosage for reliable induction of ovulation is 5 mg pimozide + 0.05 mg LHRHa per kg body weight (De Leeuw *et al.*, 1985a,b).

However, pimozide can not be used in fish farming because it is not commercially available for this purpose, (Goos *et al.*, 1987).

Other LHRHa potentiating drugs with a potent anti-dopaminergic character may therefore prove useful in conjunction with LHRHa. For example, 5 mg Org 30067 + 0.05 mg LHRHa and 5 mg Org 5222 + 0.05 mg LHRHa may be administered to induce oocyte maturation and ovulation with ease in *Clarias gariepinus*, (Goos *et al.*, 1987). Org 30067 has the chemical composition 6,7,8,9-tetrahydro -3, 7-dimethyl -5H -dibenx [b,i] [1,6] oxazecine (Z) -z-butene-dioate (1:). Org 5222 has the chemical composition trans-5-chloro -2,3,3a,12b-tetrahydro-2-methyl-1H-dibenz [2,3:6,7] oxepino [4,5-c] pyrrole (Z)-2-butenedioate (1:1).

3.3.1.4.2 The Hypothalamic level: Deca-neuropeptide stimulation of pituitary gonadotropin release

Gonadotropin release in teleosts is stimulated by a deca-neuropeptide (this is reviewed by Peter, 1982). The neurohormone referred to as gonadotropic hormone-releasing hormone (GnRH) in fish was purified and identified by Sherwood *et al.* (1983) and by Wu *et al.* (1986) in chub salmon and cod, respectively. It differs from mammalian luteinizing hormone release hormone (LHRH) in the amino acids at positions seven and eight. A superactive analog LHRHa Des Gly^{10} [D-Ala^{6}] ethylamine-LHRH is also available.

Clarias gariepinus do not release a large amount of gonadotropin under favourable husbandry conditions (Van Oordt and Goos, 1987). Therefore

oocyte maturation and ovulation must be induced and to this end deca-neuropeptide stimulation has been investigated (De Leew *et al.*, 1985a; 1986, 1987; Goos *et al.*, 1987; Richter *et al.*, 1987b).

The absence of a pre-spawning gonadotropin surge in *Clarias gariepinus* is not caused by insufficient storage of the hormone in gonadotropin cells (De Leeuw *et al.*, 1985a), nor is it due to a lack of gonadotropin release-inducing peptide in GnRH neurones (Goos *et al.*, 1985). It is more likely that GnRH is not released or is prevented from eliciting its effect (Van Oordt & Goos, 1987).

LHRH or its analogue can induce release of GTH, however high doses or multiple injection may be required to induce oocyte maturation and ovulation in teleosts (Donaldson and Hunter, 1983). This appears to be the case with *Clarias gariepinus*. Intraperitoneal injections with the peptide (0.05 mg per kg body weight) have been shown to cause gonadotropin levels in the plasma to increase within 30 min to a maximum at 4-8h post injection. Rarely, however, were ovulatory levels reached (De Leeuw *et al.*, 1985a,b, 1987).

Therefore, at present, deca-neuropetide stimulation of spawning at the practical level can be considered effective only when the release hormone is administered together with a potentiating drug of potent anti-dopaminergic character. (This is described in the section on GRIF antagonists.).

3.3.1.4.3 The pituitary level: Hormonal glycoprotein induction of spawning

Hormonal glycoproteins for inducing spawning may be of piscine or mammalian origin. Typical materials and their origins are shown in Table 3.5.

3.3.1.4.4 The ovarian level: Steroid hormone induction of spawning

The action of gonadotropin at the ovarian level is regarded as being largely mediated by the steroid hormones (Jalabert, 1976). These include:

(1) Progestins

17 α hydroxy -20 β dihydroprogesterone

17 α hydroxy progesterone

progesterone

(2) Corticosteroids

11 - deoxycorticosterone

11 - deoxycortisol

cortisol

cortisone

(3) Estrogens and Androgens

17 β estradiol

In several teleosts oocyte maturation and ovulation are accompanied by changes in ovarian steroidogenesis and steroid blood plasma levels (Scott & Baynes, 1982; Zoher *et al.*, 1982; Theofan & Goetz, 1983; Young *et al.*, 1983). In African catfish, 17 α hydroxy - 20 β dihydroprogesterone is produced in response to gonadotropin stimulations in addition to substantial amounts of 17 α hydroxyprogesterone (Lambert & Van der Hurk, 1982).

Table 3.5 *The origins of glycoproteins used for induction of spawning*

Piscine Origin (in increasing order of purification)	Mamalian Origin	
- Homoplastic or heteroplastic aqueous extract of whole pituitary	Placental	Pituitary
- Acetone dried pituitary powder	- Human chorionic gonadotropin(HCG)	- Luteinizing hormone (LH)
- Precipitated ethanol extracts of pituitary glands	- Pregnant mare serum gonadoropin	- Follicle stimulating hormone (FSH)
-Partially purified gonadotropins	(PMSG)	

A summary of the hormonal glycoproteins used to induce spawning in *C. gariepinus* is given in Table 3.6

Table 3.6 *Summary of the hormonal glycoproteins used to induce spawning in Clarias gariepinus*

Hormonal Glycoprotein and Origin	Notes	Reference
Fresh homoplastic hypophysation	Single intraperitoneal injection 1-1.5 glands per breeder Broodstock 200-380g	Carreon *et al.*, 1973
	Single intraperitoneal injections 50-100% response, 1.5-2 glands per female 0.9-1.2 glands per male best result 1.2 glands per female 0.9 glands per male	Carreon *et al.*, 1976 Hecht *et al.*, 1982
	90% response, 50% hatch, n = 10 Two intramuscular (nape region) injections - 100% response 1.5 glands per kg + 1.5 glands per kg (7h apart) - 100% response, 1 gland per kg + 1 gland per kg (8h apart)	
Alcohol preserved homoplastic hypophysation	Two intramuscular injections - 100% response, 1.3 gland per kg + 1.3 gland per kg (4h apart) n = ?	Schoonbee *et al.*, 1980
Acetone dried carp pituitary extracts (ADCP)	Single intraperitoneal injection 100% response, 4 mg glands per kg (female) no response, 4 mg glands per kg (male) Dissection of testis needed.	Hogendoorn, 1979; Adigun, 1986
	Single dorsal muscular injection. 100% response, 4 mg glands per kg best hatching rates at 21, 11 and 7h after hypophysation	Hogendoorn & Vismens, 1980

Hormonal Glycoprotein and Origin	Notes	Reference
Human Chorionic gonadotropin (HCG)	at 20, 25 and 30° Single dorsal muscular injection 58-69% hatch rate, 4µg per g body wt. maturation and ovulation not oviposition	Richter & Van Der Hurk, 1982
	Single injection intraperitoneal (?) 37% response 250-350 IU per female; 100-250 IU per male	Carreon *et al.*, 1973
	72% response 450 IU per female 250 IU per male	
	(Size of brookstock unknown)	Carreon *et al.*, 1976
	Single intramuscular injection 80% maturation 2.5 IU per g body wt. (16h at 25°C)	Eding *et al.*, 1982
	Single intramuscular injection 72.3% hatching 2 IU per g body wt.	Mollah & Tan, 1983
HCG* + Fresh homoplastic hypophysation (h) = time between injections	Two intramuscular injections 100% response with the following: 1 gland per kg + 350 IU per kg 7h 1.5 glands per kg 100 IU per kg 8h 1 gland per kg 500 IU per kg 8h 1.5 glands per kg	Hecht *et al.*, 1982
HCG* + ADCP	2 intramuscular injections 100% response 250 IU + 1 gland per kg 3h 250 IU + 1 gland per kg, n = 2 66% response 350 IU + 1 gland per kg 7h 150 IU + 1 gland per kg, n = 6 75% response 750 IU per kg 5h 1 gland per kg, n = 4	Schoonbee *et al.*, 1980

Origin		
	100% response 350 IU + gland per kg 7h 1.5 glands per kg n = 4 100% response 1500 IU per kg 7h 1.5 glands per kg n = 4	Hecht *et al.*, 1976
Synahorin**	Single intraperitoneal injection No response. 40 IU per female	Carreon *et al.*, 1976
Follicle stimulating hormone (F.S.H.) or Foligan (trade name) +Lutalyse***	Three injections intramuscular 100 IU Foligan per kg; 7h later 0.3 ml Lutalyse per kg 7 h 35 m later 5 IU Oxytocin per kg 100% response, n = 2	Hecht *et al.*, 1982
HCG** + Oxytocin	Two injections intramuscular 1500 IU HCG per kg; 8h later 5 IU Oxytocin per kg 100% response, n = 4	Hecht *et al.*, 1982

*Schoonbee *et al.*, 1980, used two commercial HCG preparations, *Pubergon* (which apparently has a mainly lutenizing hormonal function but also contains FSH), and *pregnyl* (a chorionic gonadotropin powder for reconstruction, apparently known for its LH potency. Hecht *et al.*, (1982) also used the commercial HCG preparation pregnyl.

(NB. Although HCG is of placental origin and LH of pituitary origin they have similar immunological and biological properties. The structural homology is particularly marked in the 'a' sub-units of these proteins (Harper *et al.*, 1977)

**Synahorin is a combination of mammalian and pituitary hormones

***Lutalyse is 7 - (3 alpha-hydroxy -2 beta - (35) - 3 hydrosy trans - 1 - octenyl) - 1 alpha - cyclopentyl - cis - t - heptenoic acid with 2 - amino - 2 - (hydroxymenthyl) - 1, 3 - propanedial).

Table 3.7 *Summary of the steroid hormones used to induce spawning in Clarias gariepinus*

Steroid Hormone	Notes	Reference
17 α hydroxyprogesterone	Two intramuscular injections 3 mg (in 0.75 ml vehicle) per kg body wt, 4h later 5 mg (in 0.75 ml vehicle) per kg body wt.	
	100% ovulation	Richter *et al.*, 1985
	80-90% fertilization	Richter *et al.*, 1987
11-deoxycorticosterone-acetate (DOCA)	Single intraperitoneal injection 15 mg DOCA per female broodstock (142-231g)	
	No success --- 30% spawning	Carreon *et al.*, 1976
	Single intraperitoneal injection 50 mg kg body wt. (0.5% oil suspension)	
	100% spawning	Hogendoorn, 1979
	Single intramuscular injection (near dorsal fin)	
	50 mg per kg body wt. all oocyte 1 mm matured ovulation and oviposition stimulated mechanically	Richter and Vand der Hurk, 1982

The latter steroid is probably a precursor of 17 α hydroxy β -20 dihydroprogesterone and has been shown to induce oocyte maturation and ovulation *in vitro* (Jalabert, 1976). Injection with 17 α hydroxy progesterone has been shown to cause a dramatic increase in 17 α hydroxy - 20 -β hydroprogesterone (Richter *et al.*, 1987a).

The spawning induction action of 11 - deoxycorticosterone and 11 - deoxycortisol may be the result of these steroids displacing 17 α hydroxy 20 β dihydroprogesterone bound to plasma protein (Jalabert, 1976).

A summary of the steroid hormones used to induce spawning in *Clarias gariepinus* is given in Table 3.7.

3.3.2 Egg Incubation

3.3.2.1 Growth and Development

Following oviposition of mature eggs, fertilisation initiates the first steps in a chain of embryonic development. Like those of other catfish the eggs of *Clarias gariepinus* are fairly large (c. 1.5 mm diameter). They develop into larvae with a large yolk sac which provides nourishment for 3-6 days (De Kimpe and Micha, 1974; Carreon *et al.*, 1976; Hecht, 1981; Zaki and Abdula, 1984). A period of embryonic and larval development follows hatching.

The early life history had been studied (Bruton, 1979a; Stroband and Kroon, 1981; Zaki an Abdula, 1984) and is represented in Table 3.8.

Table 3.8 *A summary of the development of the eggs and larvae of Clarias gariepinus*

24-27°C (Adapted from Zaki and Abdula, 1984)			AGE	19-33°C (Adpated from Bruton, 1979a)	
	Stanza I:	Mature eggs, spherical, 1.5mm (Fertilization + water) Eggs swell, become adhesive, 1.6-1.7 mm		0 0	Fertilized egg, adhesive .1.6-1.9mm
Embryonic Development	Stanza II:	Blastulation Morula stage begings	4h	1h 3h30	Blastula visible
	Stanza III:	Gastrulation	6h20		Gastrulation
	Stanza IV:	Organogenesis embryo formed	14h30	9h12	
	Stanza V:	Mobile state of embryo caudal section develops	24h 25h		larva hatches 3.6 mm
Pro larval Development	Stanza VI:	Hatching begins 4.6±0.2mm	33h	33h	Rudimentary intestine present
	Stanza VII:	Development of vascular system 5.00mm Mouth and barbels begin to form	39h 58h	44h 60h	Notochord prominent, large Olfactory sacs Can swim at 10-15 mm per sec 4.9mm Pigmentation prominent on head very active swimming 5.6 mm
	Stanza VIII:	Onset of exogenous feeding 6.00mm	98h(4d2h)	96h	Readily eat introduced zooplankton 6.3mm

	Stanza IX:	Complete change to exogenous feeding 7.00mm	6.5d		
Larval Development	Stanza X:	Development of dorsal and pelvic fins, dense	7d		Feed on Cordina nilotica and dead Catfish larvae 8.8 mm
		pigmentation 8.00 mm	8d	8d	First observation of aerial breathing 8.8 mm
		8.5 mm	11d	11d	Dorsal fin rays form 10.1mm
		Functional stomach present Strobard & Kroon, 1981	12d (23-24°c)		
		acidity increases 11mm	13d		
				14d	External morphology closely resembles that of adult 12mm
		12mm		30d	12.1mm
		4prs barbels 16mm body depth: length 0.15		39d	

3.3.2.2 Egg incubation systems

3.3.2.2.1 Incubation Funnels

The eggs of *Clarias gariepinus* become adhesive when they come into contact with water. As with other species such as common carp this is a serious obstacle to the large scale incubation of eggs in breeding funnels or zuger jars. This problem has been addressed in other species by washing the eggs prior to incubation in solution containing enzymes such as hyalurodinase or chemical such as urea or tannic acid or by coating the eggs with an inert powder (Woynarovich, 1962; Klotzsch *et al.*, 1977; Soin, 1977; Rothbard *et al.*, 1978).

By adapting the above methods, Schoonbee *et al.* (1980) found that adhesiveness in *Clarias gariepinus* eggs can be removed by any of the following:

(1) Washing for 45 minutes with a urea solution (3 g urea + 4 g sodium chloride dissolved in 1 *l* of water).

(2) Washing for 30 minutes in urea solution followed by 5-10 seconds rinsing in a full cream milk powder mixture (15-25 g/*l*).

(3) Continuous stirring for 35 to 40 minutes in a (15-25 g/*l*) full cream milk powder mixture at a volume ratio of 1:20, eggs to milk.

Following any of treatments 1-3 the eggs can subsequently be incubated in funnels. This method however requires additional expense in time, labour and chemicals and is not without risk of mechanical or chemical damage to the eggs. Reduction or cessation of water flow during incubation in funnels will

result in a potentially deleterious aggregation of the negatively buoyant eggs.

3.3.2.2.2 Incubation trays

A more efficient method is to distribute the fertilised eggs in a single layer on a horizontal 1 mm mesh. This is done between amphimixis and the time of development of adhesiveness, (Hogendoorn, 1977; also see Viveen *et al.*, 1985). The onset of stickiness is reported to occur within a few minutes of fertilisation. This has, however, often been observed by the author to occur within one minute, at temperatures between 27 and 31°C, (G. S. Haylor, unpublished observations).

Dead eggs and egg cases can rapidly become infected by fungus, principally the ubiquitous aseptate fungus *Saprolegnia*. The removal of unfertilized eggs and egg membranes from hatched larvae is facilitated when a monolayer of eggs can be spread out on a nylon mesh, (Chen, 1976; Britz and Hecht, 1988; Haylor, 1991). A 1 mm mesh restrains the eggs, which adhere to it, but allows the yolk sac larvae to pass through. (If suspended in water a few centimetres above the base of the tray or trough, then following hatching the larvae seek shelter beneath the mesh, which at the end of the hatching period can be removed).

This simplified approach is particularly relevant in *Clarias gariepinus* which are reported to be much more sensitive to disinfection and prophylactic treatment than for example carp, (Schoonbee *et al.*, 1980).

3.3.2.2.3 Induced natural spawning

This technique has resulted in more variable production of fry and is therefore less commonly undertaken. Broodstock are selected so that females are slightly larger than or of equal size to males. Females with a distended abdomen and red genital pore (Carreon *et al.*, 1976; Hogendoorn, 1979) are preferred, whilst males are chosen on the basis of aggressiveness (De Kimpe & Micha, 1974) or prominence and white colouration of papillae (Carreon *et al.*, 1976), or its slight vascularisation (Hogendoorn, 1979).

Females and sometimes males are often primed by injection of DOCA (Hogendoorn and Wieme, 1976; De Kimpe and Micha, 1974; Hogendoorn, 19798; Carreon *et al.*, 1976; Kelleher and Vincke, 1976), after which they are introduced into spawning ponds (Hogendoorn and Wieme, 1976; Hogendoorn, 1979; Christensen, 1981b) or tanks (De Kimpe and Micha, 1974; Carreon *et al.*, 1976; Kelleher and Vincke, 1976).

Spawning occurs 'naturally' and eggs adhere to vegetation (Hogendoorn and Wieme, 1976), gravel or pebbles (De Kimpe and Micha, 1974; Kelleher and Vincke, 1976) or spawning mats (G. S. Haylor, unpublished data).

In ponds, frogs, tadpoles, water-scorpions and the larvae of dragonflies and water beetles predate on small *Clarias gariepinus* (Hogendoorn, 1979). Fry production from this method is both low and variable (Table 3.9).

Table 3.9 *Example of Fry Production in spawning ponds after c. 6 weeks*

Country	Fry per m^2	Reference
Central Africa	1-2	De Kimpe and Micha, 1974
Kenya	5-11	Christensen, 1981a
Cameroon	17.4±14.4 (SD)	Hogendoorn, 1979

3.3.3 Hatching

In the wild, hatching often takes place during the night that follows spawning, although some *Clarias* eggs hatch on their second night, i.e. after 36-48 hours (Bruton, 1979a). The time which elapses between spawning of broodstock and hatching under experimental or culture conditions is variable typically 18-57 hours (see Table 3.10).

Table 3.10 *Incubation period (ie. time between fertilization and hatching) for Clarias gariepinus eggs at various temperatures*

Incubation Period (H)	Temperature	Reference
40-48	20-24	Holl, 1968
23-25	26-27	Van der Waal, 1972
28	26-29	Carreon *et al*, 1973
24	26	Micha, 1976
24-28	20-30	Carreon *et al*, 1976
48	19-20	Hogendoorn, 1977
21.5-24	28	H. Hogendoorn, (pers. com. in Bruton, 1979a), 1978
24-25	19-24	Bruton, 1979a
39-40	20.5-23	Schoonbee, 1980
33 (for 5h)	27	Zaki & Abdula, 1984
20-57	20-30	Viveen *et al*, 1985
36	28±0.5	Hecht & Appelbaum, 1987
18 (range 18-57)	31	G.S. Haylor (unpublished)

Teleost eggs, are poikilothermic, and a strong inverse relationship has been widely reported between development time within the egg envelope and ambient water temperature (Dannevig, 1895; Blaxter, 1969; Herzig and Winkler, 1985; Rana, 1986; Pauly and Pullin, 1988). This relationship has been described as exponential (Blaxter, 1969; Herzig and Winkler, 1985) or linear (Rana, 1986) depending on species.

Other factors are also believed to affect hatching time, e.g. oxygen levels, salinity, pH and egg size (Blaxter, 1969; Braum, 1978; Pauly and Pullin, 1988). The interpretation of available information for *Clarias gariepinus* (Table 3.10) is unfortunately made difficult by the absence of such data. In Figure 3.2 the incubation time over the temperature range 20-30°C indicated by Viveen *et al.* (1985) is amalgamated with data from other authors.

In the wild, *Clarias gariepinus* spawn at night (Aboul-Ela *et al.*, 1973; Bruton, 1979a) when they are less vulnerable to visually-orienting predators (Bruton, 1979a). There is no parental protection of the egg or fry and predation pressure is probably responsible for high rates of mortality. Bruton (1979a), for example, reported that one fifth of the fish population (at high lake level) in terrace and marginal pool habitats adjacent to spawning areas consisted of *Pseudocrenilabrus philander* (M. Weber), *Glossogobius giurus* (Hamilton-Buchanan), *Ctenopoma multispinis* Peters and *Clarias theodorae* M. Weber, all of which readily eat *Clarias gariepinus* fry in aquaria and would be capable of consuming large numbers of the fry if they could be located and captured. It could, therefore, be argued that fry survival at the vulnerable stage before the

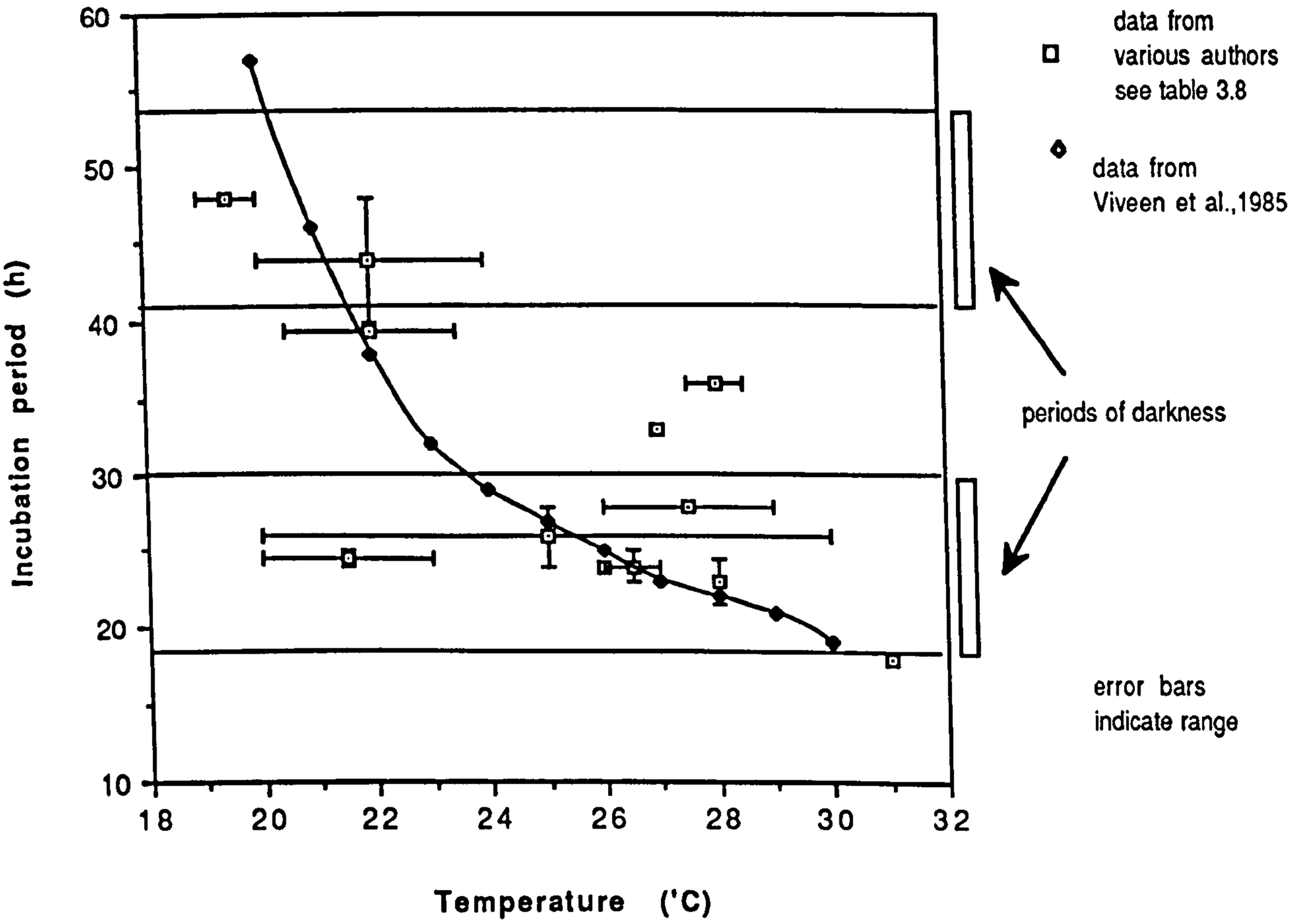


Figure 3.2 Incubation period for catfish eggs at different temperatures

onset of swimming would be favoured by the cover of darkness.

Although ontogenic development in teleosts is influenced by temperature, hatching is rarely a development threshold (Yamagami, 1981). It occurs earlier at low oxygen tensions (Dziekonska, 1956; Alderdice *et al.*, 1958; Hamdorf, 1961), or is dependent on other environmental cues (Muntyan, 1975; Balon, 1972; Yamamoto *et al.*, 1979; Gulidov and Popova, 1982).

It is interesting to note, therefore, that the incubation period for *Clarias gariepinus* appears to deviate most from the inverse curvilinear relationship with ambient temperature (suggested by Viveen *et al.*, 1985) at periods which would approximate to the first or second night following spawning. Should this prove to be the case, it would imply that the concept of degree-days can be less rigidly applied in the management of *Clarias gariepinus* culture than in other cultured species.

3.3.4 Larval rearing

3.3.4.1 Introduction

The need to produce considerable numbers of larvae of the African catfish to stock on-growing ponds is widely believed to constrain the expansion of its culture in Africa. An assessment of the farming strategies for the primary nursing phase is given in 2.2. For most fin fish a general trend in overcoming the problem of inadequate fry production has been to move to the more intensive production of larvae and fry in hatcheries (Nash and Kuo, 1975).

3.3.4.2 Larval feeds

Research into *Clarias gariepinus* culture has focused on different aspects of controlled hatchery production, with much attention given to larval feeding, (Jocqué, 1975; Pham, 1975, 1980; Hognedoorn, 1980b, 1981; Hecht, 1981, 1982; Meske, 1984; Uys, 1984, 1989; Uys and Hecht, 1985; Hecht and Appelbaum, 1987; Verreth and Den Bieman, 1987; Verreth *et al.*, 1987; Appelbaum and Van Damme, 1988).

The larval feeds used for primary nursing of *Clarias gariepinus* under controlled conditions are listed in Table 3.11. As might be expected, natural food organisms have proved successful. Additional time, space and energy, however, are required for their culture, whilst their addition to rearing tanks does not aid the maintenance of semi-sterile conditions, which are an important consideration in high-density culture of sensitive stages of the life history.

Processed or inert food organisms such as dried and decysted *Artemia* may also be used (Verreth and Den Bieman, 1987). However, their nutritional quality may vary considerably according to the geographical strain, processing batch and development stage (Léger *et al.*, 1986). The use of artificial dry feeds has proved more problematic, (Hogendoorn, 1980a; Msiska, 1981a) though satisfactory growth and survival has been demonstrated (Hecht, 1982; Uys and Hecht, 1985; Appelbaum and Van Damme, 1988).

Table 3.11 *Larval Feeds use for primary nursing of Clarias gariepinus*

Feed	Mortality	Growth	Notes	References
Live Feeds				
Zooplankton	-	-	First trials in trays and troughs with aeration	Jocque, 1975; Pham, 1975
Phytoplankton and zooplankton (predominantly *Daphnia pulex*)	2.8% first 10 days		Suitable first feed for larvae (10 days). Also suitable for second growth period (after 10 days) following a zooplankton or a yeast diet.	Hecht, 1981
Combination of Live and Dry Feed				
Zooplankton (10 days) -- shrimp meal (92%) plus vitamin mix (8%) plus tetramycin (0.5%), (11 days)	15% from 7 days to 28 days old	57 mg -- ca. 200 mg in 21 days	in ponds	Carreon *et al.*, 1976
Zooplankton plus trout starter feed	30-50%	2.3mg -- 844-1018 mg	28 days	Hogendoorn, 1980b
Artemia nauplii plus trout starter feed	4-33%	2.3mg -- 455-1027 mg	28 days	Hogendoorn, 1980b
Artemia nauplii (28 days) -- Trouvit "O" trout starter		0.5g -- 10g	3-4 weks	Hogendoorn, 1981
Plankton plus Torula yeast *Candida utilis*)(1:1)		2.3mg –13mg	10 days	Hecht, 1982

Artemia (5 days) -- *Artemia*/Salmon fry feed (7 days) -- salmon fry feed (24 days)	6%	First feeding larvae -- 1.71g	36 days	Meske, 1984
Artemia (10 days) -- *Artemia*/Salmon fry feed (7 days) -- salmon fry feed (19 days)	5%	First feeding larvae -- 2.52g	36 days	Meske, 1984
Artemia (15 days) -- *Artemia*/Salmon fry feed (7 days) -- salmon fry feed (19 days)	17%	First feeding larvae -- 3.85 g	36 days	Meske, 1984
Artemia/artificial dry diet** of Uys and Hecht (1985) (1:1) (10 days) -- artificial dry diet of Hecht and Appelbaum (1987)*** (40 days)	20.2%	First feeding -- 5.3g	50 days	Hecht and Appelbaum, 1987

Dry Feeds

Dry trout starter	90%	-	unsuccessful	Hogendoorn, 1980b
Dried inactive yeast	100%	-	unsuccessful	Hogendoorn, 1980b
Ground *Clarias* fingerlings	100%	-	unsuccessful	Hogendoorn, 1980b
Frozen zooplankton	100%	-	unsuccessful	Hogendoorn, 1980b
Frozen *Artemia* plus trout starter	26%	2.3 mg -- 330mg	28 days	Hogendoorn, 1980b
Soya		slow growth		Hecht, 1981

Tetramin (aquarium feed)		slow growth		Hecht, 1981
Ground trout pellets		slow growth		Hecht, 1981
Egg yolk		slow growth	very slow alimentary canal depletion rate	Hecht, 1981
Salmon fry diet) Eel fry diet)	93-96%		unsuccessful	Meske, 1984
Torula yeast (*Candida utilis*)	1.6%		10 days	Hecht, 1981
Ground trout pellets plus Torula yeast (1:1)		2.03mg – 5.5 mg slow	10 days	Hecht, 1982
Fish meal plus Torula yeast (1:1)		2.03mg – 12.5 mg	10 days	Hecht, 1982
Blood and carcasemeal plus torula yeast (1:1)		2.08 mg – 6 mg (slow)	10 days	Hecht, 1982
Ewos C10 'Larvastart'* plus torula yeast (1:1)		2.03 mg – 4 mg (slow)	10 days	Hecht, 1982
Decapsulated *Artemia* cysts	4-78%	First feeding – 50 mg	7.4-78.7 day (depending on feeding level)	Verreth and Den Bieman, 1987
-	4%	First feeding – 100 mg	14 days	Verreth *et al.*, 1987
Dry larval feed enriched with acetone extract of *Artemia*	80%	slow growth	Hepatic ultrastructure revealed nutritional deficiency	Verreth *et al.*, 1987
Microencapsulated egg diet	7-36%	slow and variable growth		Verreth *et al.*, 1987

Microencapsulated egg diet with addition of casein and vitamin/Mineral mix	8%	First feeding – 15.8 mg	14 days	Verreth *et al.*, 1987
Artificial dry diet of Appelbaum and Van Damme (1988)****	22%	First feeding – 141 mg	15 days	Appelbaum and Van Damme, 1988
Artificial dry diet of Uys and Hecht (1985)**	5%	2.89mg – 6.39-7.91 mg	10 days	Uys and Hecht, 1985

Table 3.11 Footnotes

* A formulated dry feed alternative to *artemia* nauplii for carp.

** Artificial Diet (Uys and Hecht 1985)

Dried Torula Yeast (*Candida utilis*)	69.8%
Brown fishmeal	23.3%
Vitamins	0.9%
Methionine supplement	6.0%
Furanace	4 ppm
Endox	250 ppm
plus fish oil (cod) and soya bean oil (1:1)	6.0% of total dry wt of feed

*** Artificial Diet (Hecht and Appelbaum, 1987)

Israel *Tilapia* pellet meal	55.5%
Yeast (*Candida* sp)	27.6%
Peruvian fish meal	13.9%
Spirulina platensis	2.95%
Vitamin C	0.05%
Soya bean oil	6% of total dry weight of feed (added prior to feeding)

**** Artificial Diet (Appelbaum and Van Damme, 1988)

Norwegian Fishmeal (70% Protein)	15.5%
Yeast (*Candida* sp)	63.5%
Cod liver oil and soybean oil (1:1)	11.5%
Bloodmeal (cattle)	2.5%
Vitamin premix	3.5%
Mineral premix	3.5%

One of the fastest larval growth rates to date has been recorded by Meske (1984) where an initial period of feeding with *Artemia* (10-15 days) was followed by a seven day weaning period before rearing exclusively with a dry feed.

One of the problems, however, with the present empirical approach of testing various diet formulations for *Clarias gariepinus* is that no theoretical basis exists for diet formulation, and that the available growth and survival data can therefore have little general applicability. This is particularly so as growth rate is dependent on a multiplicity of factors, significantly feed quality, feeding level and temperature, (Verreth and Den Bieman, 1987).

In order to create a more rational approach to the formulation of low-cost high quality feeds from cheap, locally available resources the specific nutritional requirements of larval catfish would have to be established. This is complicated by the fact that the qualitative and quantitative nutritional requirements of the larval stages of *Clarias gariepinus* would be expected to change rapidly during the early life history. Following the onset of exogenous feeding (at about day 4) many morphological, histological and functional developments take place (Stoband and Kroon, 1981). These will result in changes in the digestion, absorption, transport and assimilation of chemical compounds, and therefore the qualitative nutritional requirements will also change.

In a few days the larval weight increases 20 to 25 fold, its dry matter content changes considerably and the specific growth rate decreases continuously (Verreth and Den Bieman, 1987), thus altering the nutritional requirements.

A requirement for protein (40-42%), lipid (10-12%) and the protein to energy ratio of 26-29 mg protein per kg of digestible energy has been identified by Uys (1989) for *Clarias gariepinus* juveniles and adults.

3.3.4.3 Feeding and Growth

Rapid rate of growth is one of the favourable aspects of the biology of *Clarias gariepinus* in terms of its aquaculture potential. As a consequence however,the conventional approach to the assessment of growth performance and the calculation of feed requirements can not be easily adapted.

In many species, for short culture intervals the specific growth rate (SGR) remains rather constant and feeding level (expressed as % of BWd^{-1}) can therefore be kept constant over these intervals. The resulting growth performances may be compared by the SGR (% BWd^{-1}). In fast growing species, particularly at the larval stages, this is no longer reasonable.

Thus Hogendoorn (1980b) reported a reduction in the SGR of *Clarias gariepinus* larvae from 85% d^{-1} to less than 20% d^{-1} of the body weight in the first 28 days of feeding. For *Clarias gariepinus*, therefore, fixing the feeding level as a percentage of body weight and adjusting this periodically, following re-

weighing, would clearly give a very poor approximation of feed requirements, unless the changes in SGR over short successive periods was known.

An alternative method fixes the feeding level in terms of predicted growth performance, (Verreth and Den Bieman, 1987). This is based on the assumption that growth of larval fishes can be linearized over the entire larval culture period, i.e. the linear relationship described by Hogendoorn (1980b) between a cube root transformation of body weight and the length of the culture period.

Whereby:

$$Y_t^{1/3} = Y_o^{1/3} + g.t$$

where Y_t = weight at time t

Y_o = weight at start

g = regression co-efficient

t = length of culture period (days)

The feeding levels of Verreth and Den Bieman (1987) can be chosen according to predicted growth rates (g):

i.e. Food requirements $fish^{-1}$ on day t (mg wet weight)

$$= \text{change in } Y_t \ \frac{DM_f}{DM_a} \ .FCR$$

change in Y_t = $Y_{t+1} - Y_t$ (mg wet weight)

DM_f = dry matter content of fish larvae

DM_a = dry matter content of fed *Artemia*

FCR = Food Conversion Ratio

With this approach food conversion ratio (FCR) is assumed to be a constant derived from preliminary experiments. However, as the authors point out FCR is significantly affected by feeding level and temperature. It, can not therefore, logically be accredited with a constant value in order to determine feeding level. Also it is not known whether the growth index (g) used by Verreth and Den Bieman (1987) like SGR can vary significantly when measured over short successive intervals from first feeding. The formula may, however, serve as a guideline under specific conditions.

The temperature preference of larval and post-larval *Clarias gariepinus* and the optimum temperature for their growth was investigated by Britz and Hecht (1987) and found to be 30°C. At this temperature, growth rate increases with feeding level but food conversion is most efficient at a feeding level, FL = 0.2, when the average FCR = 2.57 (dry weight basis) (Verreth and Den Bieman, 1987). Therefore substituting g = 0.2 into Hogendoorn's (1980b) equation, the predicted increase in body weight each day can be calculated. Multiplying then by the average FCR for this temperature and feeding level a guide to the daily feed requirements can be determined Table 3.12.

3.3.4.4 Feeding Frequency

Hogendoorn (1981) investigated the effect of the frequency of feeding on growth, survival and feed conversion of *Clarias lazera* fingerlings (0.5 to 10 g). The highest average final weights were realised by groups of fish fed 24h per day. Fish which received feed 12h per night grew almost as rapidly but food

Table 3.12 *Calculated feed requirements of Clarias gariepinus*

(a) weight on day t $Y_t = (Y_o^{1/3} + gt)^3$
(from Hogendoorn 1980b)

(b) Feed requirement on day t = change in $Y_t \ \frac{DM_f}{DM_a}$.
FCR (from Verreth and Den Biemann, 1987)

(c) Feed = decysted *Artemia* (dried)

(d) Temperature = 30°C

(e) Feeding level = 0.2

(f) g = 0.2

(g) FCR = 2.57 (for this feed at this temperature and feeding level)

Day	DM_f	Y_t (mg)	Change in Y_t	Feed ration per fish (mg)	(%bw)
0	-	2.500	-	-	-
1	10	3.77	1.27	3.26	(130)
2	10	5.42	1.65	4.24	(112)
3	10	7.50	2.08	5.35	(99)
4	10	10.04	2.54	6.53	(87)
5	11	13.09	3.05	7.84	(78)
6	11	16.72	3.63	9.33	(71)
7	11	20.96	4.24	10.90	(65)
8	12	25.86	4.90	12.59	(60)
9	13	31.46	5.60	14.39	(56)
10	14	37.83	6.37	16.37	(52)
11	14	45.00	7.17	18.42	(49)
12	15	53.03	8.03	20.36	(46)
13	15	61.96	8.93	22.95	(43)
14	15	71.84	9.88	25.93	(41)
15	15	82.71	10.87	27.94	(39)
16	15	94.63	11.92	30.63	(37)
17	16	107.65	13.02	33.46	(35)
18	16	121.80	14.15	36.37	(34)
19	16	137.15	15.35	39.45	(32)
20	16	153.73	16.58	42.60	(31)
21	16	171.60	17.87	45.93	(30)
28	16	336.72			

conversion ratio was improved. The remaining fish received feed 2, 4 or 12h per day and grew more slowly with less efficient conversion of feed. All fish in the trial received 10% of their body weight daily.

Uys and Hecht (1985), who fed 25% of body weight daily, recommended feeding every 4h which resulted in faster growth than feeding every 2h for 12h per day or every 6h for 18h per day. The results indicate that the feed conversion and growth rate are significantly affected by feeding frequency as has been demonstrated with carp (Huisman 1974). They also suggest that vision is not essential for successful feeding in *Clarias gariepinus*. This has also been reported in the European catfish *Silurus glanis* by Hochman (1967).

The subject of maximizing daily feed intake of *Clarias gariepinus* in order to approximate a maximum growth rate clearly still remains to be addressed. According to Brett (1979) the most important factors which bear on the maximum daily food intake of fishes include: the duration of feeding (satiation time), individual meal size (stomach capacity), the time between meals (feeding interval) and interactions of these. When the above have been quantified for different life stages of the African catfish the size of ration and timing of its presentation can be favourably manipulated to maximize daily intake.

3.3.4.5 Stocking Density

Most experimental work with first feeding larvae has been carried out at densities between 1.25 and 10 larvae per *l*, (Carreon *et al.*, 1976; Hogendoorn,

1980b; Hecht, 1981; Meske, 1984; Uys and Hecht, 1985; Britiz and Hecht, 1987).

The effect of different stocking densities on growth has been investigated by Hecht and Appelbaum (1987) and Appelbaum and Van Damme (1988). The results are summarized in Table 3.13.

Table 3.13 *The effect of stocking density on growth of Clarias gariepinus (after Hecht and Appelbaum 1987, Appelbaum and Van Damme, 1988)*

Stocking density of first feeding larvae (Fish l^{-1})	Weight after 11 days (mg)	Author
5	156	Hecht & Appelbaum, 1987
10	120	
20	60	
20	59.5	
40	50.8	Appelbaum & Van Damme 1988
83	49.0	
300	12.5	Hecht 1982

In each of the trials the larvae were fed with a dry feed, the principal components of which were yeast and fishmeal. Hecht (1982) fed between 14% BW and 9% BW for 18h daily at 23°C, whilst the other authors fed every 2h to satiation at 28°C.

The results appear to illustrate the density dependence of larval growth. Commercial primary nursing, however, has been carried out at 250 fish larvae

per l (EWOS Fish Feed Programme 1980, S. Appelbaum, - pers. comm. reported by Hecht 1982) and at 300 fish larvae per l (Hecht, 1982). Mortality was reported by Hecht (1982) to be negligible and the flow rate and stocking density recommended by the author were 200 Lh^{-1} and 250-300 larvae per l respectively.

The growth and survival of larvae and fry clearly needs to be investigated in more detail at higher stocking densities in order to provide a data base for commercial larval rearing.

3.3.4.6 Behavioural Problems

3.3.4.6.1 Introduction

The rate of mortality and its causes is difficult to determine in larval populations, however, losses of healthy fry in good quality water in tanks are due to two main causes both of which are behavioural. Young African catfish are both cannibalistic and territorial (Hecht and Appelbaum, 1988).

3.3.4.6.2 Cannibalism

Larval and juvenile cannibalism occurs in important culture species such as yellowtail (*Seriola quinqueradiata*), turbot (*Scopthalamus maximus*), eels (*Anguilla anguilla*), Koi carp (*Cyprinus carpio*), sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*) (various authors reported in Hecht and Appelbaum, 1988). The same phenomenon has also been reported in wild populations of *Clarias gariepinus* (Corbet, 1961; Groenewald, 1964; Bruton, 1979b).

Under intensive culture conditions heavy losses have been attributed to cannibalism (Aboul-Ela, Amer and El Bolock, 1973; De Kimpe and Micha, 1974; Van der Waal, 1978; Britz, 1986) and the phenomenon has recently been the subject of detailed study (Hecht, 1986; Hecht and Appelbaum, 1988).

According to Hecht and Appelbaum (1988) the circum-oral barbels are more important for the capture than the eyes. Cannibalism begins on the fourth day of feeding and ceases to be significant 47 days after the start of feeding, (i.e. between 8-80 mm). Two types of predator-prey relationships are distinguishable: prey being caught tail first and swallowed up to the head, which is subsequently bitten off, (cannibalism type I), changing to swallowing of prey head first and whole (cannibalism type II). Type I is prevalent in fish of between 8-45 mm before the mouth width of the largest individuals in a population exceeds the head width of the smallest.

3.3.4.6.3 Territoriality

Both larvae and fry exhibit territoriality, or the defence of a piece of territory. This behaviour unlike cannibalism is initiated by the intruder making contact with the ultimate aggressor (defending a territory) Hecht and Appelbaum (1988). Usually territorial exchanges take the form of head to head contact between two siblings within the territory of one.

The relative importance of cannibalism and territorial aggression, their significance as causes of mortality particularly under high density culture

conditions and strategies to suppress their incidence require fuller investigation.

3.3.5 Disease

3.3.5.1 Introduction

Wedemeyer (1970) pointed out that disease in fish tends to be the end result of an interactions between host susceptibility, pathogen virulence and environmental factors. *Clarias gariepinus* are known to survive adverse environmental conditions (Bruton, 1979c; Clay, 1977a, b). Under environmentally controlled hatchery conditions only minor health problems have been encountered (Huisman and Richter, 1987).

However, as Bragg (1988) explained, the paucity of information about diseases of *Clarias gariepinus* may not be because all factors necessary for a disease are not present. Parasites and diseases of farmed fishes in developing countries have not been well studied (Zaman and Leong, 1987). The industry is also in the early stages of development; initial investigation of African catfish culture began in 1960 in Egypt (El Bolock and Koura, 1959) whilst in 1986 the estimated total production (from 30 producers) was only 1000 tonnes (Boon *et al.*, 1987). However, the development of intensive culture in South Africa will doubtless increase this total greatly (T. Hecht pers. comm.)

Information concerning diseases of wild as well as cultured *Clarias gariepinus* is outlined below.

3.3.5.2 Protozoan Parasitic Infections

Mild infestation of larvae by protozoans can result in heavy losses under culture conditions. High organic loading of the culture water has been associated with subsequent *Scyphidia* infections in *Clarias gariepinus* larvae (G. S. Haylor, unpublished observations). Other common protozoan infestations like *Costia* and *Chilodonella* are reported to occur quite often in tropical *Clarias gariepinus* ponds (Huisman and Richter, 1987).

Protozoan infestations of larger catfish, have been found only rarely in Southern Africa (Van As and Basson, 1988). However, *Ichthyophtherius multifilis* infections are reported to have occurred in *C. macrocephalus* adults imported into Malaysia from Thailand (Leong *et al.*, 1987).

3.3.5.3 Metazoan Parasite Infections

3.3.5.3.1 Platyhelminthes

Dactylogyrus infections are said to be common in *Clarias gariepinus* raised in tropical ponds (Huisman and Richter, 1987) whilst another monogenean *Gyrodactylus transvaalensis* (found particularly around the lower lip of *Clarias gariepinus*) had been reported from Southern Africa (Van As and Basson, 1984).

Digenean trematodes identified by Fischtal (1973) from the intestine of *Clarias mossambicus* in Ethiopia include *Orientocreadium indicum* and *Eumasenia ghanensis* (small intestine) and *Glossidium pedatum* (large intestine). The latter has also been observed in *Clarias gariepinus* from Southern Africa, as well as *Phyllodistomum vanderwaali* (urinary bladder), *Euclinostomum* sp. (body cavity),

Diplostomum mashoneuse and other *Diplostomum* spp. (in the brain cavity) (Van As and Basson, 1984).

Of particular interest to the consumer are the worms or encysted metacercaria present in the muscles. These include *Euclinostomum dollfusi* (around the dorsal fin) and *Clinostomum* sp. from *Clarias gariepinus* in Southern Africa (Van As and Basson, 1984) as well as *Strigeida* metacercaria from Nile *Clarias lazera* (Elmossalami and Sherif, 1964). The last named parasite, although transferable to aquatic birds, is not believed to be harmful to man. However, trematode metacercaria have been known to cause pharyngitis in man (Witenberg, 1944) and may be of significance where fish are consumed raw or after minimal drying or smoking. For example, incomplete processing of *Clarias gariepinus* is now commonplace around Lake Chad as a result of deforestation locally which has depleted wood reserves for fish smoking, (A. Neilland, pers. comm.).

Cestodes have been found to be the most prevalent parasites in Asiatic Clariids, particularly *Lytocestus lativitellarium* in *Clarias macrocephalus* (Zamon and Leong, 1987) and *Lytocestus lativitellarium* as well as *Lytocestus parvulus* in *Clarias batrachus* (Furtado, 1963).

In *Clarias gariepinus, Polyonchobothrium clarias* is known to infest the intestine and gall bladder and *Proteocephalus glanduliger* the small intestine (Van As and Basson, 1984).

3.3.5.3.2 Aschelminthes

Nematode infections are very common in *Clarias gariepinus* (Prudhoe and Hussey, 1977; Mashego and Saayman, 1980; Van As and Basson, 1984). *Skryabinocara* sp., as well as other unidentified nematodes and *Procamallanus laeviconchus,* infest the stomach and *Paracamallanus cyathopharymx* the posterior third of the intestine (Van As & Basson, 1984). The most common nematodes, often found in very large numbers around the viscera of large catfish belong to *Contracaecum* spp. (Van As and Basson, 1984).

3.3.5.3.3 Arthropods

Argulus spp. particularly *Argulus japonicus* have been found on the body and fins and occasionally the gills of *Clarias gariepinus;* whilst another crustacean *Dolops ranarum* is also known to infest African catfish.

3.3.5.4 Virus and Bacterial Infections

There is very little information on bacterial and viral diseases in *Clarias gariepinus,* (Bragg, 1988). When raised under controlled hatchery conditions the fish are rather sensitive to myxobacterial infections. The infection is mainly associated with environmental changes (temperature, water quality, handling of fish etc) and can cause great losses in high density fingerling culture (Huisman & Richter, 1987).

3.3.5.5. Fungal Infections

The ubiquitous and opportunistic secondary invader *Saprolegnia,* is known to cause infection in the ova and larvae of *Clarias gariepinus* as well as in larger

fish (Schoonbee *et al.*, 1980; Viveen *et al.*, 1985; Boon *et al.*, 1987; Van As and Basson, 1988). This does not represent a serious problem in well managed egg incubation systems since the period between fertilization and hatching is short (24h at 30°C). However, therapeutic treatment of fungi and protozoa in larvae with formalin and malachite green is not possible since the concentration required to control the pathogens exceeds the apparent tolerance of the catfish larvae (Schoonbee *et al.*, 1980; Van As *et al.*, 1984).

3.3.5.6 Diseases of Unknown Etiology and Culture Dependent Diseases

As larval culture becomes more intensified, ubiquitous pathogens such as *Saprolegnia* and *Myxobacteria* could become significant factors in the success of hatchery operations, particularly since ova and fry of *Clarias gariepinus* appear to be very sensitive to therapeutic or prophylactic treatment (Schoonbee *et al.*, 1980; Van As *et al.*, 1984; Van As and Basson, 1988).

Although the effects of nitrogen supersaturation or gas-bubble disease are little known in *Clarias gariepinus*, it can cause 75% mortalities in *Heterobranchus fossilis* even if the water is changed 48h after discovery of the disease (Kulshrestha and Mandal, 1982). Under the same conditions however, *C. batrachus* recover after 96h (Kulshrestha and Mandal, *ibid*).

A disease associated with management of feeding level, is 'ruptured intestine syndrome of unknown etiology' (R.I.S.u.e.) (Viveen *et al.*, 1985; Boon and Oorschot, 1986; Boon *et al.*, 1987; Huisman and Richter, 1987; Bragg, 1988). The syndrome sometimes called open belly disease can develop in fish aged

5-8 weeks (weighing 3-5 g) and is associated with high levels of feeding (Boon *et al.*, 1987). In the hatchery at Wageningen 10-70% mortalities have been attributed to R.I.S.u.e. (Boon and Oorschot, 1986).

Another syndrome of unknown etiology causes destruction of the arborescent organs and leads to inflammation of the skull resulting in a lateral skull fracture parallel to the skull plate joints. The so called broken head disease is particularly prevalent in catfish larger than 10 cm (Huisman and Richter, 1987). It has been observed in broodstock ponds, without vegetation in Israel (Viveen *et al.*, 1985) and in broodfish kept at high density in Central African Republic where it was associated with poor appetite and consequent high organic loading (Huisman and Richter, 1987). A similar condition known as 'crack head syndrome' is found in Asiatic catfish species (*Clarias batrachus* and *Clarias macrocephalus*) and has been attributed to vitamin C deficiency (Huisman and Richter, 1987).

3.3.6 On-growing and Production

3.3.6.1 Introduction

Many different systems and levels of intensification are conceivable when growing *Clarias gariepinus* fry to market size. Data already exist for low input pond production (Hogendoorn and Wieme, 1976; Bok and Jongbloed, 1984) and semi-intensive systems with various supplementary feeds (Hastings, 1973; El Bolock, 1975; Hogendoorn and Wieme, 1976; Clay, 1979; Egwai, 1986; Hecht and Lublinkof in Hecht, *et al.*, 1988), as well as intensified production based on more complete feeds (Hogendoorn, 1983a, b; Hogendoorn *et al.*, 1983; Hecht

et al., 1988 Balogun and Ologhobo, 1989; Degani *et al.*, 1988). An assessment of the farming strategies for on-growing African catfish in Africa is given in 2.3.

Semi-intensive culture operations appropriate to developing African countries are considered below. Socio-economic as well as ecological parameters would appear to indicate that such semi-intensive systems are most appropriate for *C. gariepinus* culture in these circumstances. Low consumer purchasing power severely limits the market for a higher priced product from the greater input costs of more intensive systems.

Difficulties in obtaining credit and more complex management practices can put intensive production outside the scope of the rural farmer, whilst competition for feed ingredients, their availability, difficulties of storage, poor infrastructure and the cost and servicing of processing equipment can also detract from the viability of intensive production systems. Conversely, organically manured ponds in which fish receive cheaply available local resources as supplementary feeds are both simple and flexible. They are not outside the scope of the local farmer, nor are they capital intensive and they can draw on resources which may be under utilized locally. In addition the climatic conditions in the tropical and sub-tropical regions of Africa are conducive to potentially high pond productivity.

Clarias gariepinus are particularly well suited to culture in intensely manured ponds because they are tolerant of a wide range of physio-chemical conditions,

and are able to utilize a broad spectrum of natural food items and unlike many other potential species they are not adversely affected by marked diurnal fluctuations in oxygen concentration.

3.3.6.2 Introduction of *Clarias gariepinus* to ponds

The introduction of *Clarias gariepinus* to ponds is a critical period, associated at present with very variable survival, typically 10%-90% (Huisman, 1985). Recommendations as to the age at which fish should be introduced into ponds range from 3 to 40 days after hatching.

e.g. El Bolock, 1975; 40 mm (c. 1g)

Viveen *et al.*, 1985; 7-10 mm (after 3 days)

Hecht *et al.*, 1988; 25-30 mm (10 days)

Zheng *et al.*, 1988; 50-100 mm (30-40 days)

Three different strategies are possible:

(1) Direct introduction into fertilized nursery ponds

before the onset of first feeding; (Viveen *et al.*, 1985).

(2) Weaning onto exogenous feed followed by primary nursing in a hatchery system before liberation into nursery ponds (Hecht *et al.*, 1988),

or

(3) Nursing in a hatchery system up to the fry stage

(until the development of accessary breathing organs) followed by direct introduction to on-growing ponds, (fig 3.3).

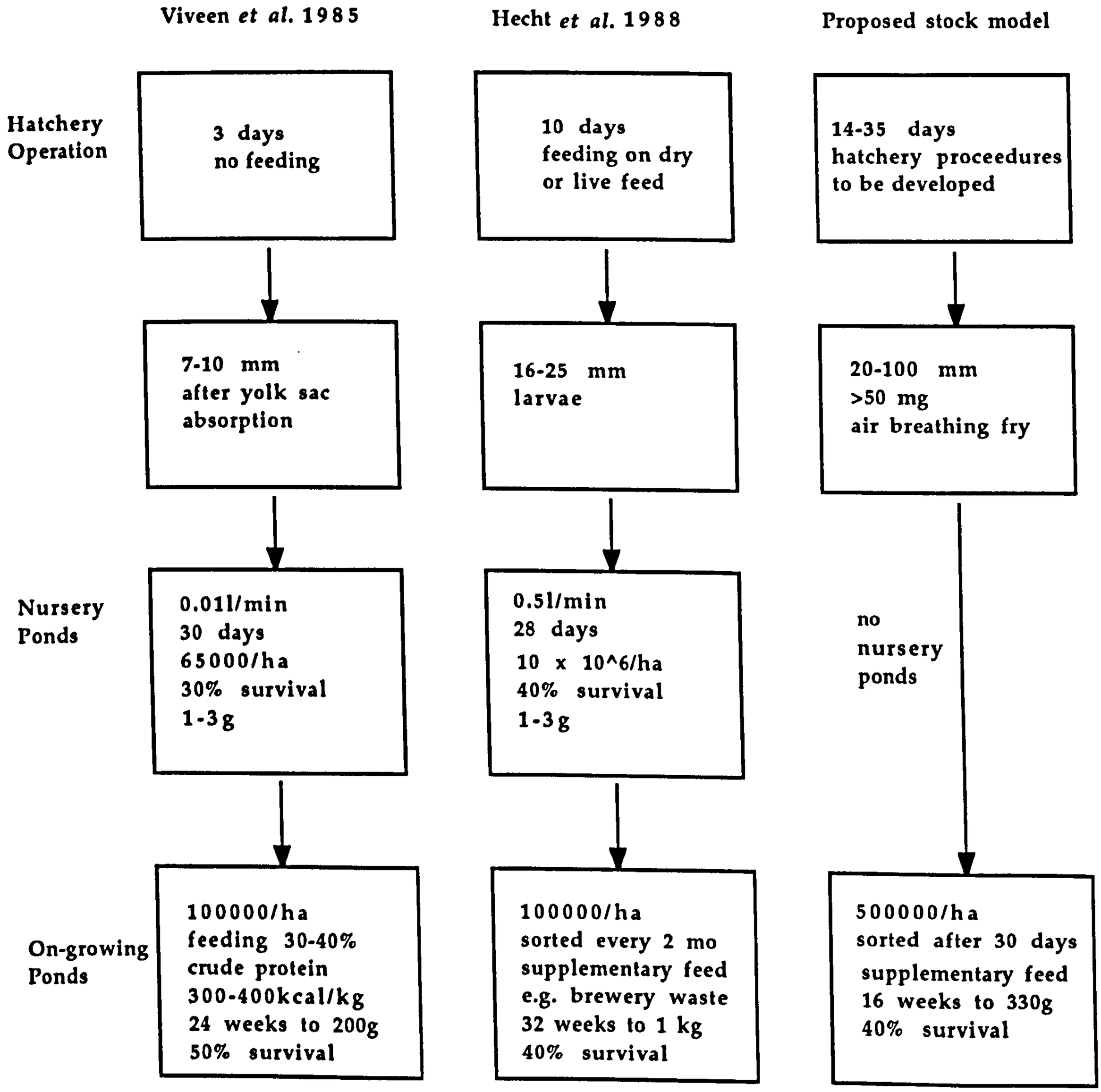


Figure 3.3 On-growing strategies for African catfish culture

Procedures for hatchery nursing need to be developed, particularly in the field of nutrition, because of the low or variable survival rates of fry in ponds, e.g. (10-50% (Hecht *et al.*, 1988), 10-90% (Huisman, 1985)). Mortalities in ponds are usually due to predation by insects, as well as their larvae and nymph stages, predation by *Xenopus* toads, cannibalism, asphyxiation or infection (e.g. monogenean trematodes, *Trichodina* etc.).

Poor fry survival represents a significant hindrance to the development and extension of *Clarias gariepinus* culture. More research would therefore be justified in ensuring reliable and controlled hatchery production of air breathing catfish fry for distribution and on-growing.

3.3.6.3 Fertilization

Most fish ponds in Africa have a limited water exchange. They may be fed annually or bi-annually by rain or have a restricted supply of water sufficient only to replace losses due to evaporation and seepage. If water supply is not limiting, the constant high light intensities and warm temperatures of tropical regions can permit high rates of productivity to be maintained throughout the year. In sub-tropical regions this high productivity period may be limited to 200 days.

In ponds with little water exchange, nutrients can build up and support quite high densities of natural feeds. As these are removed by the fish, nutrients must be supplied to maintain the pond productivity. This is usually done by adding organic or inorganic fertilizers. Inorganic fertilizers contain

concentrated amounts of nitrogen, phosphorus and potassium. They are less bulky than organic fertilizers and are easier to dose. However, they are expensive and can be absorbed into the mud at the bottom of a pond. Inorganic fertilizers act principally on the autotrophic pathway promoting primary production (Pruder 1985).

By contrast suitable organic fertilizers (Table 3.14) are often under-utilized by-products of other systems and may be conveniently and cheaply integrated with fish rearing. Production is promoted by stimulation of both the autotrophic and heterotrophic feeding pathways within a pond. Many organic fertilizers may also represent direct feed for the catfish.

The B.O.D. (Biochemical Oxygen Demand) generated by aerobic decomposers will, however, tend to reduce the pond's dissolved oxygen levels. The B.O.D. of wastes can be reduced by composting (Biddlestone and Gray, 1985). Also, if wastes are applied in mesh containers suspended in the euphotic zone of the pond early in the day, efficient decomposition will be facilitated by the high concentration of dissolved oxygen (often super-saturated) resulting from photosynthesis (Bok and Jongbloed, 1984). Use of a fine mesh ensures that small organic particles are dispersed throughout the water column.

Bok and Jongbloed (1984) suggest that catfish can utilize protein available in the form of bacteria and protozoa, which as pointed out by Schroeder (1978), flourish on small organic particles originating from added manure. This is

Table 3.14 *Examples of typical manure composition after Little and Muir (1982)*

Manure	Dry Matter	BOD $g0_2$ per kg per day at 30°C
Chicken manure (most types of poultry manure are in the form of combined faeces and urine output; they are low in fibre and finely fragmented) (a 2 kg chicken produces 0.7 kg wet waste per day)	95%	20-40
Cow manure	36%	10
(liquid cowshed waste)	12.5%	7
(Most cattle manure is collected from overnight shelters. They have a high moisture content) (a 500 kg cow produces 30 kg wet waste per day)		

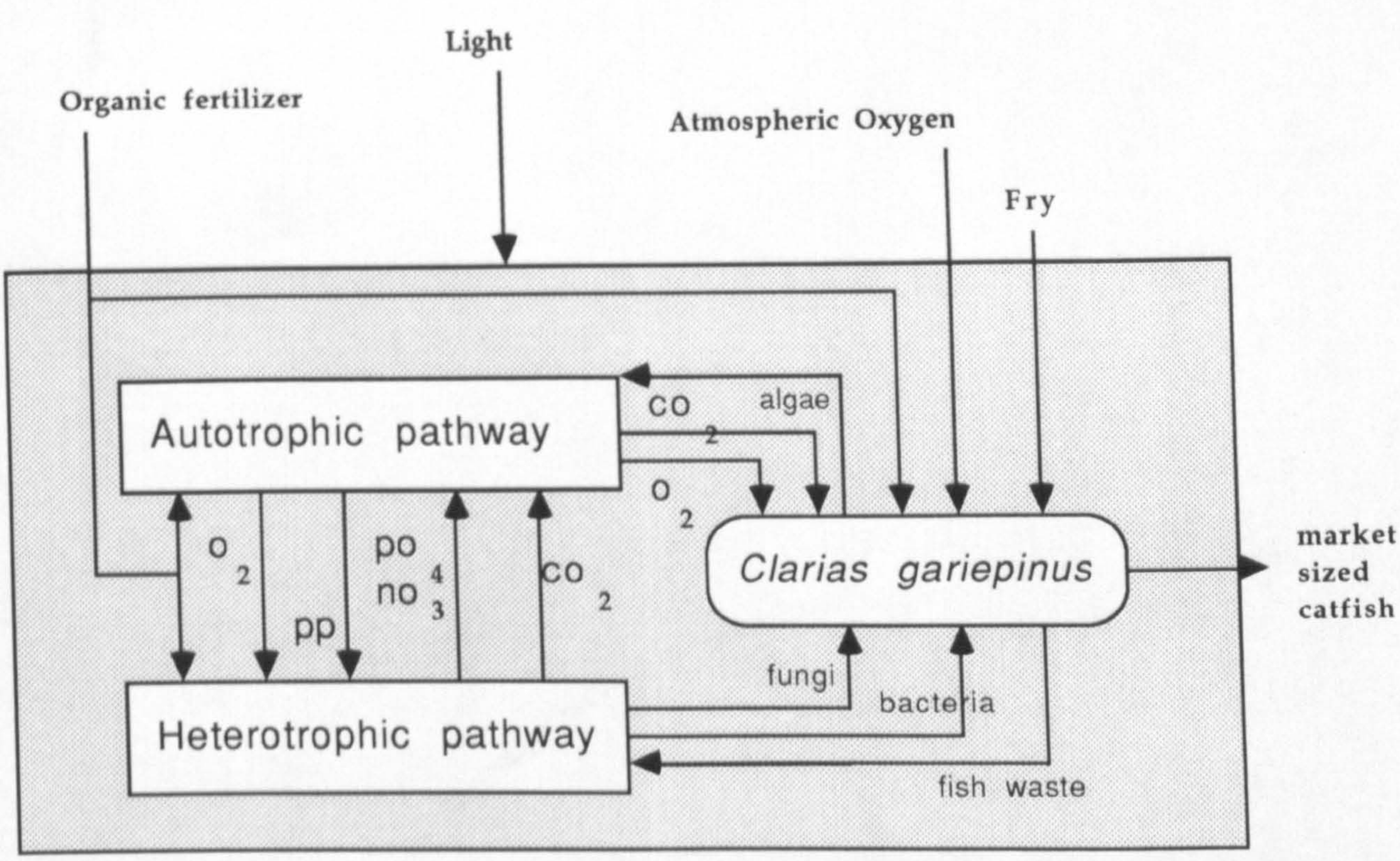
further supported by the high lysozyme levels recorded in *Clarias gariepinus* by Uys (1989), which were considered sufficiently high to suggest that they play a significant role in its nutrition in addition to their defence role.

Although *Clarias gariepinus* after the fry stage can survive low D.O. concentrations, manure should be added at rates which avoid anoxic conditions, since aerobic digestion can yield ten times the amount of bacteria compared with anaerobic digestion (McCarty, 1972, in Bok and Jongbloed, 1984).

Fig. 3.4. displays the material flows in a semi-intensive, organically fertilized catfish pond.

Manure should be applied frequently since large occasional doses tend to stimulate a massive and unstable growth of bacteria and phytoplankton, with a consequent risk of night time oxygen depletion. Frequent application on the other hand allows the establishment of a more balanced food chain which absorbs nutrients more effectively.

Maximum loading estimates range from 100 to 200 $kgha^{-1}d^{-1}$ dry matter, (7-140 kg organic matter $ha^{-1}d^{-1}$) (Little and Muir, 1987). These will be affected by the quality of manure, which is related to the quality of feed provided for the manure producing animals. Dose rates must also be adjusted in relation to temperature, which affects the rate of breakdown of manure and the rate of growth of the components of the food web. Thus, undesirable conditions can



pp = primary production

Figure 3.4: Material and gas flow in a semi-intensive organically fertilized African catfish pond. (adapted from Pruder,1985)

result when higher temperatures resume after a cooler period, owing to a build up of nutrients. Reduced light intensities due to cloud or dust will similarly reduce the rate of the light limited autotrophic activity in the food web and hence the rate of waste breakdown (Little and Muir, 1987).

3.3.6.4 Supplementary feeding

As the natural food in organically manured ponds is high in protein (Schroeder, 1978), catfish production in intensively fertilized ponds may be greatly increased by adding locally available, possibly under-utilized resources in the form of high-energy supplementary feeds which would enable more of the natural protein to be used for growth (Bok and Jongbloed, 1984).

Supplementary feeds include: brewery wastes, rice bran, cotton seed cake, blood meal, groundnut cakes, wheat bran, palm cake and wheat flour (El Bolock, 1975; Hogendoorn and Wieme 1976; Clay, 1979; Huisman, 1985; Hecht and Lublinkof (unpublished) in Hecht, *et al.*, 1988).

3.3.7. A stock model for semi-intensive *Clarias gariepinus* culture

A stock model is a useful aid to the planning and management of a catfish farm. An example is presented below:

Annual Production Target = 100 t

(assuming that farming operations are suspended for 95 days owing to seasonal rain, i.e. 270 days operation)

Pond Requirement 15 x 0.1 ha ponds

Fry Requirement 750000 x 2 g

Fry stocking rate 500000 ha

Harvest 300000 x 330 g

Survival rate from Viveen *et al.* (1985) (50%)

Growth rate

at 28°C from Hogendoorn (1983b)

System Three groups of 5 x 0.1 ha static earthen ponds organically fertilized receiving supplementary feeding.

Fifty thousand fry of uniform size (about 2 g) are stocked for 30 days in a 0.1 ha pond. These are then sorted and the stock split into two 0.1 ha ponds before ongrowing to c. 0.33 kg per fish. The faster growing individuals are stocked together and harvested after a total of 120 days. Those with a slightly slower rate of growth are harvested a week later. The stock model for one group of five ponds is detailed in Fig 3.5. Stocking of pond groups can be staggered to spread out harvesting.

3.4 PRODUCTION OF *CLARIAS GARIEPINUS* IN AFRICA

Table 3.15 summarizes data available in the literature for African catfish production over a range of intensity levels. Annual yields increase with increasing stocking density and level of intensification (i.e. promotion of

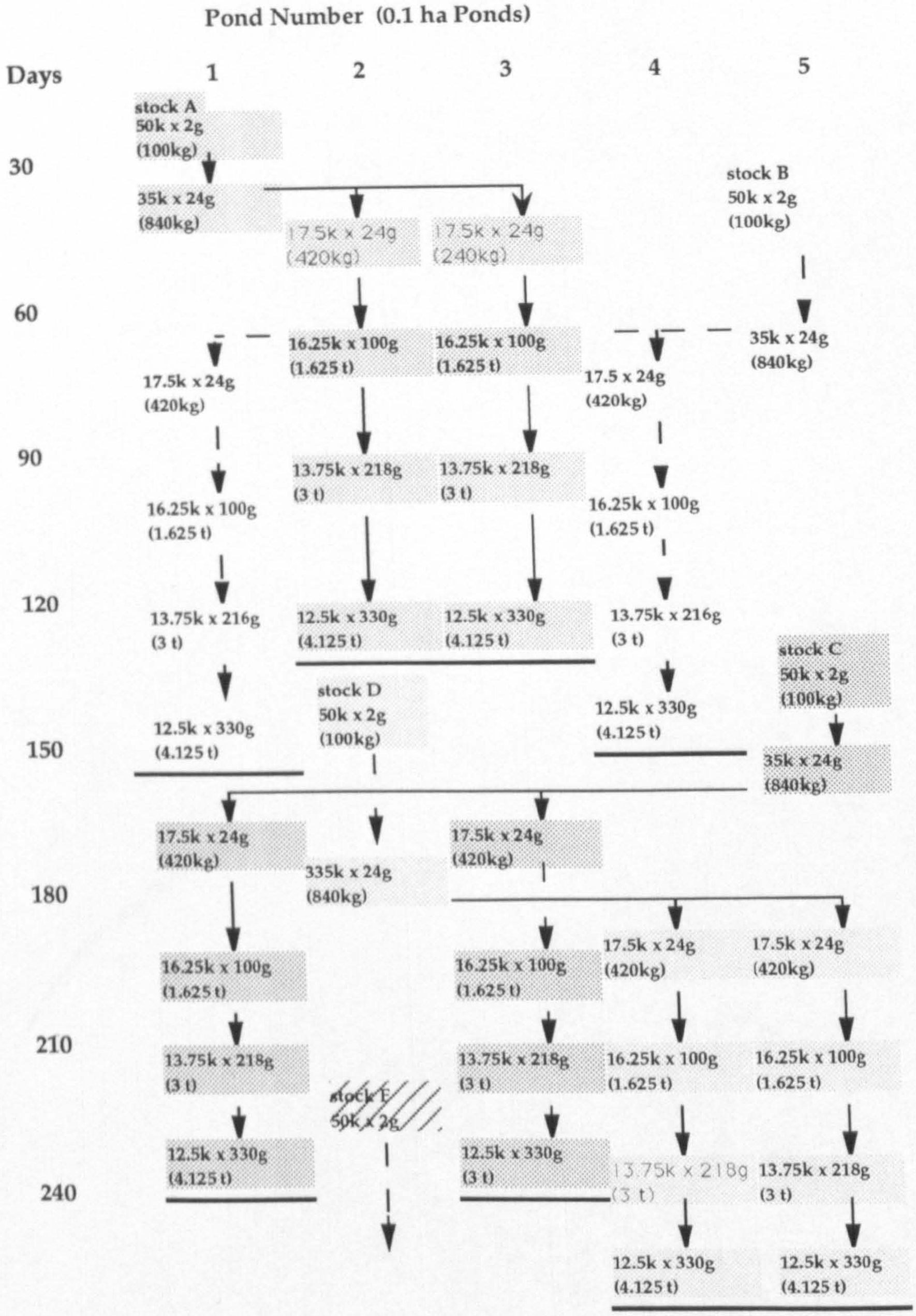


Figure 3.5: Example stock model for Clarias gariepinus

Table 3.15 *Clarias gariepinus production in Africa*

System	Stocking density per ha	Production t per ha	Time	Notes	Country	Reference
"Extensive"						
1 No feed	12,500	0.6175	6 months	0.34g per day	Egypt	El Bolock, 1975
2 No feed	27,400	1.3803	6 months	0.41g per day	Egypt	El Bolock, 1975
3 Poultry Manure (30-428 kgDMHa day)	10,000	1.0694	5 months	0.88g per day	E Cape South Africa	Bok & Jongbloed, 1984
4 Cow Manure	5,900	-	21 days	0.52g per day	Cameroon	Hogendoorn & Wieme, 1976
5 Cow Manure	13,200	-	21 days	0.14g per day	Cameroon	Hogendoorn & Wieme, 1976
"Semi-intensive"						
6 Fresh blood & rice bran	12,500	1.115	6 months	0.45g per day	Egypt	El Bolock, 1975
7 Fresh blood, rice bran, chicken offal (intestines and lungs)	26,200	4.1239	6 months	0.54g per day	Egypt	El Bolock, 1975
8 "	27,000	5.3866	6 months	0.99g per day	Egypt	El Bolock, 1975
9 Beer wastes, wheat bran, cottonseed cake, palm cake, bloodmeal, ground fish and wheat flour	-	8.65g-38-103g in 4 months		0.32-0.85g per day	Cameroon	Hogendoorn & Wieme, 1976
10 Bonemeal, vegetable by products	20,000	12.786	year		Central African Republic	Hastings, 1973
11 Cottonseed cake	-	16.0-18.0	year		Central African Republic	Clay, 1979
12 Brewery waste	100,000	65.0	8 months		Zambia	Hecht & Luclinkhof, (unpub) in Hecht, *et al*, 1988
13 Sun dried mixture of fishfeed pellets, groundnut cake and palm kernel cake 1:1:1 5% day	56,878	13.327	10 months	1.06g per day	Nigeria	Egwui, 1986

productivity - fertilization - supplementary feeding). Log_e Production = 0.612 + 4.05×10^{-5} Stocking density, R = 0.875, n = 13.

Although the modal stocking density, to date, is between 10,000 and 20,000 fish ha^{-1}, high yields have been achieved in Southern Africa by stocking 100,000 fish ha^{-1}. There is no evidence that production declines relative to stocking density up to at least 100,000 fish per ha, provided that manure is properly applied together with a supplementary feed, particularly brewery waste. (Hecht, *et al.*, 1988; Hecht and Lublinkof, (unpublished data) in Hecht *et al.* (1988)). This compares favourably with semi-intensive production of commonly cultured Tilapiine fishes in Africa (Haylor, 1989) and demonstrates the potential benefit of using air-breathing fishes for this form of aquaculture.

3.5 CONCLUSIONS

Modern aquaculture in developing African countries is still in its infancy. Initiatives since the 1940's, mainly in tilapia culture, have created little momentum and the impact of fish farming to date is insignificant, both in terms of overall production and local fish consumption.

The African catfish has been the focus of active research in many countries across the world and its suitability for aquaculture is no longer in doubt. The attributes of *Clarias gariepinus* of relevance to its culture are:

- Its wide native distribution (Clay, 1977b; Teugels, 1984; Bruton, 1988)
- Its ability to utilize atmospheric oxygen as well as dissolved oxygen (Moussa, 1956; Greenwood, 1956; Cockson, 1972)

- Its high consumer preference ranking (Mann, 1964; Balon, 1972; Richter, 1976; Huisman, 1985; Huisman and Richter, 1987)
- Its suitable reproductive strategy and behaviour, i.e. high fecundity, cessation of natural spawning in captivity, potential for year round induction of final maturation (Bruton, 1979a; Janssen, 1984).
- Its favourable nutritional efficiency and feeding habit, i.e. acceptance of a wide range of natural feed organisms, adoption of a variety of feeding modes in an expanded food niche (Bruton. 1979b), ability to accept and thrive on cheap feeds (Bok and Jongbloed, 1984) and efficient food conversion (Machiels, 1987).
- Its fast growth rate (Hogendoorn, 1981)
- Its tolerance of environmental extremes (Hecht, Uys and Britz, 1988)
- Its resistance to disease (Richter, 1976)
- Its tolerance to high density culture (Zheng, Pan and Liu, 1988; Hecht, Uys and Britz, 1988)

Some of the deficiencies and inconsistencies in the reviewed information pertaining to intensive rearing of the early life stages of the African catfish include:

- The inconsistent use of terminology for the early life stages amongst various authors and farmers.
- An investigation of the most important factors which bear on maximum daily food intake of young life stages
- A more detailed investigation of the growth and survival of larvae and fry at higher stocking densities than those used experimentally in order

to provide a database for commercial larval rearing.

- An investigation of the relative importance of cannibalism and territorial aggression as causes of mortality under high density culture conditions and strategies to suppress their incidence.
- The definition of an appropriate growth index for the comparison of growth performance in the early life stages of a species with fast and rapidly changing growth rate.

Research into semi-intensive on-growing of African Catfish will probably be most appropriately conducted in the form of applied, farmer centred research, in conjunction with interactive extension and training programmes. Account will need to be taken of the changing availability of inputs and the possibilities for integration with other resource systems in particular those accessible to resource-poor farm families.

African aquaculture may fulfil its potential when a broader range of indigenous candidate species have been evaluated and their culture developed. Twenty five years of research has identified the potential of the African Catfish. It is now appropriate to invest in applied research as well as interactive extension and training programmes to develop its culture.

Chapter 4: Terminology for the early developmental stages of *Clarias gariepinus* - Working Definitions for Aquaculture.

Words have users, but as well, users have words. And it is the users that establish the worlds realities.
Le Roi Jones 1966

The information contained in Chapter 4 has been accepted for publication in 'Aquaculture and Fisheries Management' Edited by D H Mills, R J Roberts and S J de Groot, published by Blackwells.

4.1 INTRODUCTION

There is a difficult path to tread between strictly accurate scientific nomenclature, which definitively and clearly characterises exact developmental stages, and the vernacular names popularly used in the fish culture industry. On the one hand, the recognition of early life stages by the culturist is important because the requirements of young fish change rapidly with age (e.g. Hogendoorn, 1980b; Verreth and Van Tongeren, 1989). On the other, recognition of microscopic changes can be more subjective than definitive and maybe of no actual benefit in fish culture. Working definitions of developmental stages for aquaculture are therefore most usefully practical ones. In response to calls for a clear definition regarding the length of the larval period, in order to enhance the comparability of different studies (Verreth and Van Tongeren, 1989), and to end the inconsistent use of terms amongst various authors the following definitions for African catfish are suggested.

4.2 LARVAE - A DEFINITION

The term larva accurately identifies a stage in the so called indirect

development (Lagler, Bardach, Miller and Passino, 1977; Kamler, 1992) of African catfish and differentiates them from commonly cultured catfish of the genus *Ictalurus* which exhibit direct development from "sac-fry" (or eleutheroembryonic phase) to the alevin stage.

4.2.1 The Onset of the Larval Period

The larval period in fish defined by Balon (1975, 1984) commences with the transition from yolk dependent nutrition to exogenous feeding. This transition is associated with elevated mortality rates and it is appropriate to identify the beginning of the larval phase as the successful introduction of first feeding.

In order to ensure comparability between studies or farm records, age should be counted from first feeding and not, as is common, from hatching for two reasons:

(1) The transition to exogenous feeding, rather than hatching, is the decisive threshold of ultimate survival value (Balon, 1984). Hatching is merely the point at which embryos leave the egg membrane and timing of this is not constant. In common with most life processes it is affected by temperature, but can also be affected by other environmental changes e.g. oxygen concentration (Dziekońska, 1956; Alderdice, Wickett and Brett, 1958; Hamdorf, 1961; Alderdice and Forrester, 1974) as well as a range of environmental cues (Muntyan, 1975; Balon, 1972; Yamamoto, Iuchi and Yamagami, 1979; Gulidov and Popova, 1982).

(2) With respect to stock modelling for aquaculture planning, it would be illogical to quote initial larval stocking densities immediately prior to a period often associated with elevated levels of mortality (i.e. the onset of exogenous feeding).

4.2.2 The End of the Larval Period

Developments that take place during the larval period include: morphological and physiological changes to the digestive tract, changes in body composition, changes in external morphology, the establishment of definitive body proportions and the development of functional arborescent organs (Greenwood, 1961; Bruton, 1979; Stroband and Kroon, 1981; Zaki and Abdula, 1984; Hecht and Appelbaum, 1987; Verreth and Den Bieman, 1987; Uys, 1989; Haylor, see Chapters 5 and 8).

According to Balon (1975) the larval period ends with the complete differentiation of the median fin-fold. The timing of this varies with different conditions and is further complicated by the descriptive definitions of various authors. Bruton (1979a) considered external morphology to resemble that of adults after 14 days whereas Hecht and Appelbaum (1987) reported the disappearance of the last rudiments of the caudal fin fold 15 days after first feeding. Differentiation of the fins broadly correlates with the onset of air breathing in African catfish reared intensively (See Chapter 5) and is characterised by increased mortality and a short period of depressed growth rate. The onset of airbreathing is a useful character with which to delineate the end of the larval period for four reasons:

(1) It is easily distinguished macroscopically e.g. on the farm. (Air breathing is easily distinguished from other activities which break the water surface by the release of two bubbles of gas just prior to air gulping.)

(2) It correlates with the timing of the differentiation of fins and is therefore consistent with Balon's (1975) standard definition of the end of the larval period.

(3) It represents the point at which the African catfish becomes independent of the common constraint of low dissolved oxygen levels in ponds.

(4) With respect to stock modelling for aquaculture planning it would be illogical to quote initial fry (for definition see under Juvenile) stocking densities immediately prior to a period often associated with an increased mortality (i.e. the onset of air breathing).

4.3 JUVENILE - A DEFINITION

The term juvenile is part of the standardised terminology of intervals in fish development of Balon (1975). It should begin with the onset of airbreathing and span the period up to the beginning of the first maturation of gametes. Early juveniles, by virtue of their airbreathing habit and completed external morphological development and pigmentation, represent hardy "seed" stock for on-growing.

For logistical and economic reasons it is usual for seed production and ongrowing to represent different sectors of a mature aquaculture industry. It

is juveniles, therefore, that will be purchased for on-growing.

Juveniles may be acquired at one of two stages - either directly following larval rearing or after a nursery period. It is therefore important to retain the vernacular terms fry and fingerling, to identify the desired size of seed stock.

In southern Africa the necessity to standardise terminology has already been realised (W. Uys, pers. comm.). A minimum size for fingerlings has been set at 50mm by the Catfish Growers Association of southern Africa (T. Hecht, pers. comm.).

Fingerling farmers in the Netherlands sell their fish for on-growing at a maximum size of about 5g (J. Verreth, pers. comm.). At which point they are less susceptible to bacterial infection particularly from *Flexibacter columnaris* as well as the so-called "Ruptured Intestine System" of Boon, Oorschot, Henken and Doesam (1987). Thus airbreathing catfish <50mm (often 600 - 1000mg) might be termed fry whereas catfish up to 5g might be termed fingerlings. Larger juveniles are often referred to as growers.

As final maturation of oocytes must be induced in captive African catfish, by definition, the end of the juvenile period will be determined by the farmer's choice of brood stock size.

4.4 A SUMMARY OF THE TERMINOLOGY OF EARLY LIFE STAGES

(1) In order to ensure comparability between studies or farm records age should be counted from first feeding.

(2) The larval period may be defined as the period between the introduction of first feeding and the onset of airbreathing

(3) The juvenile period may be defined as the period between the onset of air breathing and sexual maturation (induced spawning)

Table 4.1 *The early life stages of* ***Clarias gariepinus***

Life Stage	Definition
Larva:	A young fish which has successfully begun exogenous feeding but still lacks functional accessory breathing organs
Fry:	Airbreathing fish up to 50mm or 1g
Fingerling:	Immature airbreathing fish between 1g and 5g
Grower:	Immature airbreathing fish more than 5g

Chapter 5: The Growth and Survival of *Clarias gariepinus* larvae at high stocking density.

The information contained in Chapter 5 has been published in 'Aquaculture and Fisheries Management' 1992, 23, 303-314, Edited by Mills, D. H., Roberts, R. J. and Groot, S. J. de published by Blackwells.

5.1 INTRODUCTION

If the necessary quantity of good quality seed to sustain the growth of an African catfish industry is to be supplied by intensive hatchery production then detailed information will be required for planning and operation of hatcheries. Hatchery design and management as well as production and economic criteria will depend upon the biomass of the stock. Biomass in turn, is a function of growth rate and survival and its relation to stocking density.

The effect of stocking density has been investigated at 5, 10 and 20 larvae/l (Hecht and Appelbaum, 1987) and at 20, 40 amd 83 larvae/l (Appelbaum and Van Damme, 1988). 'Commercial' primary nursing however, has been attempted at densities as high as 250 larvae/l (Hecht, 1982).

In order therefore to provide a data base for commercial larval rearing, a more detailed investigation of the growth and survival of larvae at higher stocking densities is required.

The growth rate of *Clarias gariepinus* larvae is both rapid and rapidly changing (Hogendoorn, 1980b). As a result it has been suggested that the growth index, specific growth rate (% body weight per day) can not reasonably be

applied (Verreth and Den Bieman, 1987) when comparing growth performance. Presently growth studies with *Clarias gariepinus* larvae and fry can be split into those which use specific growth rate (eg. Hecht and Appelbaum, 1987; Appelbaum and Van Damme, 1988, Cleaver, 1991) and those which use, the regression coefficient of a cube root transformation of weight data (eg. Verreth and Den Bieman, 1987; Verreth and Van Tongeren, 1989, Verreth, *et al.* 1991).

The objectives of the present study are, to select an appropriate growth index to compare growth in young African catfish; to study the effect of stocking density on growth and survival of larvae and to use the selected growth index to delineate the relationship between growth rate and larval age as well as growth rate and stocking density.

5.2 METHODS AND MATERIALS

5.2.1 Production of First Feeding Larvae

Sexually mature broodstock maintained at the Institute of Aquaculture, University of Stirling, were induced to spawn by the method of Deleeuw, Goos, Richter and Eding (1985a).

To reduce genetic variability the ova of one female were fertilized by the milt of one male. Final induction of oocyte maturation and spermiation was begun at midnight, and running ripe ova were stripped 13h later. The male and female were maintained overnight in separate 1-m diameter tanks (with secured lids) supplied with recirculated water (30$\pm$ 1°C).

Milt squeezed from the excised testes of the sacrificed male was mixed with ova, collected in a shallow uPVC plastic tray, by gentle swirling. A small amount of water at 30°C was added to the swirling eggs to facilitate gentle movement and to activate amphimixis. After 30 s more water was poured into the side of the tray, resuspending the excess milt and washing it away. Two uPVC plastic frames were suspended horizontally in 500 x 300 x 100 mm egg rearing troughs through which water was recirculated. The fertilized eggs were spread in a mono-layer on 0.5mm nylon mesh stretched over the frames. A 200-W thermostatically controlled aquarium heater maintained the water temperature at 30°C (±1°C). Hatching occurred after 24h.

Four hours after the onset of hatching the horizontal meshes were removed together with adhering egg cases and dead or unhatched eggs. The hatched embryos were left undisturbed in their darkened environment for a further 48h. Air bubbles from circular difusers fitted around the outflows were used to keep the 0.5mm mesh screens free of debris. Two days after hatching exogenous feed was offered. A small quantity of decysted, hydrated but unhatched *Artemia salina* eggs (*Artemia* systems N.V. Ghent, Belgium) was evenly distributed by hand. Feeding behaviour, the presence of cysts in the gastro-intenstinal tract (observed through the unpigmented ventrum) and the appearance of faeces were used to identify the successful onset of exogenous feeding.

Once feeding was established the larvae were siphoned from the incubation troughs through 5mm clear plastic tubing into a bucket (placed 200 mm below

the trough). Counting was done at the point at which individual larvae entered the siphon tube. From the bucket larvae were gently poured into randomly allocated treatment tanks.

5.2.2 Feeding

Feed was offered three times daily at 4h intervals at 0800, 1200 and 1600. After reducing the water flow into a tank, small quantities of feed were evenly distributed over the water surface. When most feed particles had been ingested the process was repeated. Feed was administered until fish no longer responded but remained still on the tank bottom.

Following four days of feeding with decysted *Artemia* eggs the larvae were weaned over a period of five days onto a commercial trout ration (B. P. Nutrition No.2, 54% crude protein), crushed and sieved to give a particle fraction between 250 and 500 µm. Feed administration during weaning is shown in Table 5.1.

Table 5.1 *The administration of feed during weaning*

Day	*Artemia* offered*	Powdered feed offered*
5	80	20
6	60	40
7	40	60
8	20	80
9	-	100

* approximate % of total daily ration

NB Powdered feed was always introduced a few minutes before the introduction of *Artemia*

5.2.3 Larval rearing system

A warm water recirculating system was built in the tropical aquarium facility of the Institute of Aquaculture, Stirling. Air temperature in the building is maintained above 20°C and photoperiod is regulated, providing a 12:12 h light to dark regime (0800-2000, light period).

The system comprised 10 l cylindrical plastic tanks with lids. Each tank had a 3/4 inch outlet screened with a 0.5mm mesh and a double 4mm horizontal injection inflow. The tanks drained into two 230 l preconditioned biofilter tanks (with a total biofilter medium surface area of 75m^2) from which water flowed by gravity to a 500 l sump tank.

An electric pump (PV 100, Beresford, England) raised water to two 230l header tanks. More than 50% of the water from the header tanks overflowed through a solids filter (Filter mat 3.8.1, Dryden, Scotland) before returning to the sump. A ball valve controlled the water flow to the fish tanks via a ¾ inch ring main.

A 3kw thermostatically controlled immersion heater maintained the water temperature at 30±1°C. Freshwater was added to the sump tank continuously at the rate of 7×10^{-3}l per minute to replace losses. The system design maintained almost 100% saturation of oxygen constantly and nitrogenous metabolite levels remained negligible (below 0.1mg/l un-ionised ammonia) throughout.

5.2.4 A study of the effect of initial larval stocking density on growth and survival

First feeding larvae were stocked at 50, 100, 150, 200 and 250 larval per l in duplicate tanks of the recirculation system described. Half these tanks were provided with cylindrical shelters made from 4mm inert plastic mesh in-order to assess their effect on survival.

Debris was siphoned from all tanks prior to the first feed in the morning and any mortalities removed and recorded. A distinction was drawn between deaths resulting from tail-first attacks during foraging behaviour (type I cannibalism of Hecht and Appelbaum, 1987), detected by the presence of discarded heads in the tank and non-cannibalistic deaths.

The larvae were weighed five times over the experimental period (on day 0, 3, 6, 10 and 14) on a Mettler top pan balance (PC 4400) to the nearest 0.1mg, after drying in a handnet on absorbant paper for 5 seconds. On each weigh day whilst the fish were removed, the tanks and shelters were scrubbed clean. Larvae were always siphoned from tanks and gently poured back.

5.2.5 An investigation of changes in growth rate over the early rearing period

To investigate in more detail apparent changes in larval growth rate indicated by the first trial, larval growth data were collected over longer periods of rearing under the same conditions.

The growth of these populations of fish, two stocked at 25 larvae/l (over 20 and 30 days respectively), one at 50 larvae/l (over 16 days) and one at 30 larvae/l (over 14 days) was measured following the onset of exogenous feeding. Weighing schedules varied over the four trials which were not conducted concurrently.

5.2.6 Data Analysis

The following analyses were carried out:

1. A paired-sample test of mean difference in survival between larvae grown in the presence and absence of shelter
2. A paired-sample test of mean difference between initial measured weight and initial weight predicted by
   a. an exponential growth model and
   b. a cubic growth model.
3. Growth rate was measured as:
   i. specific growth rate (k) =

$$\frac{Log_e Y_t - Log_e Y_o}{t}$$

   ii. the regression coefficient of a cube root transformation of weight data (b) =

$$\frac{Y_t^{1/3} - Y_o^{1/3}}{t}$$

where

Y_t = weight at time t

Y_o = initial weight

t = time interval

e = the base of natural logarithms

4. 95% confidence limits were calculated as:

$$C.L. = \bar{Y} \pm t_{0.05[n-1]} \frac{S\bar{Y}}{\sqrt{n}}$$

5. A two way analysis of variance with equal replication within time periods and proportional replication within densities was carried out to investigate the effect of time period after first feeding, initial stocking density and interactions between these factors on (i) the specific growth rate (k) and (ii) the growth index (b) of the larvae. Equality of variances was confirmed using a Bartlett-test and normality could be demonstrated graphically.

6. The effect of initial stocking density on survival over the larval period was investigated with a non-paramentric analysis of variance (Kruskal-Wallis test) after a Bartlett test inferred heteroscedasticity of the arcsine transformed percentage survival data.

5.3 RESULTS

The increase in mean weight of larval catfish (ie. from first feeding to day 14) could be fitted to both exponential and cubic growth equations. The growth equations are presented in Table 5.2.

At most stocking densities, coefficients of determination were slightly higher for the cube root curve. The regression constants derived by the cubic model, however, differed significantly ($t = 2.88$, $P < 0.05$) from the measured mean initial weights. There was no significant mean difference at the 5% level between the regression constants of the exponential model and the mean initial weights measured.

Larval growth was negatively density dependent. The weight attained after 14 days could be related to stocking density by the equation

$Log_e (Weight, mg) = 5.61 - 0.524\ Log_e (Density, larvae\ l^{-1})$, $r^2 = 0.91, P < 0.05$.

Values of b (the regression coefficient of a cube root transformation of the weight data) and k (specific growth rate) were calculated for successive short intervals over the larval period (Table 5.3)

Both parameters were significantly affected by larval age ($k{:}F_{[3,32,0.05]} = 87$, $b{:}F_{[3,32,0.05]} = 28.46$), initial larval stocking density ($k{:}F_{[5,32,0.05]} = 16$. $b{:}F_{[5,32,0.05]} = 11.82$) and interactions between age and density ($k{:}F_{[15,32,0.05]} = 7$, $b{:}F_{[15,32,0.05]} = 3.55$. The same temporal pattern existed at each stocking density. About 6 to 7 days after first feeding specific growth rate reached a maximum value

Table 5.2 *Exponential and cubic growth equations for larval African catfish*

Exponential Growth Model

$$Y_t = Y_o.e^{kt}$$

where

Y_t = wet weight at time t
Y_o = initial wet weight estimate
k = specific growth rate
t = growth period
e = base of natural logarithms
(CL) = 95% confidence limits
r^2 = coefficient of determination
P = Probability

Density (larvae L^{-1})	Y_o (CL)	k (CL)	r^2	P
25	2.16 (0.31)	0.25 (0.02)	0.97	<0.01
30	2.28 (2.4)	0.21 (0.09)	0.99	<0.01
50	2.69 (0.17)	0.20 (0.04)	0.96	<0.01
100	2.63 (1.17)	0.16 (0.06)	0.94	<0.01
150	2.52 (0.7)	0.16 (0.13)	0.97	<0.01
250	2.60 (0.9)	0.15 (0.18)	0.96	<0.01

Cube root Growth Model

$$Y_t^{1/3} = Y_o^{1/3} + bt$$

where

Y_t = wet weight at time t
Y_o = initial wet weight estimate
b = cube root regression coefficient
t = growth period
(CL) = 95% confidence limits
r^2 = coefficient of determination
P = Probability

Density (larvae L^{-1})	Y_o (CL)	b (CL)	r^2	P
25	1.51 (0.42)	0.20 (0.027)	0.98	<0.01
30	1.71 (1.53)	0.156 (0.16)	0.99	<0.01
50	2.57 (1.54)	0.14 (0.01)	0.99	<0.01
100	2.43 (1.26)	0.10 (0.04)	0.98	<0.01
150	2.27 (1.17)	0.10 (0.04)	0.99	<0.01
250	2.38 (0.72)	0.09 (0.13)	0.98	<0.01

Table 5.3 *Growth indices (k and b) for larval African catfish, calculated for successive short intervals over the larval period.*

		Time interval (day from first feeding)			
Density	Growth index	0-3	3-6	6-10	10-14
25	k	0.24 (0.04)	0.30 (0.03)	0.34 (0.07)	0.09 (0.05)
30	k	0.20 (0.06)	0.27 (0.06)	0.22 (0.06)	0.18 (0.16)
50*	k	0.22 (0.03)	0.32 (0.1)	0.13 (0.04)	0.11 (0.06)
100	k	0.12 (0.13)	0.27 (0.54)	0.18 (0.13)	0.03 (0.23)
150	k	0.12 (0.02)	0.28 (0.38)	0.14 (0.06)	0.10 (0.17)
250	k	0.11 (0.18)	0.29 (0.45)	0.10 (0.11)	0.10 (0.18)
25	b	0.11 (0.017)	0.19 (0.03)	0.312 (0.07)	0.11 (0.05)
30	b	0.10 (0.36)	0.16 (0.06)	0.17 (0.06)	0.18 (0.27)
50*	b	0.11 (0.008)	0.22 (0.06)	0.12 (0.026)	0.08 (0.06)
100	b	0.06 (0.06)	0.16 (0.38)	0.13 (0.04)	0.03 (0.18)
150	b	0.06 (0.0)	0.16 (0.23)	0.10 (0.02)	0.08 (0.25)
250	b	0.05 (.12)	0.17 (0.36)	0.07 (0.12)	0.08 (0.06)

bracketed figures represent 95% confidence limits
*time intervals for 50 larvae L^{-1} were 1-3, 3-7, 7-11, 11-14

after which it decreased rapidly to a low value between day 10 and day 14. Growth rate decreased more rapidly following its initial peak in the fish populations grown at the highest densities. The pattern of change of b was similar though the relative change in magnitude over successive short intervals differed between the two measures of growth rate.

The increase in weight as well as the changes in specific growth rate for the three subsequent trials conducted at 25 and 50 fish L^{-1} over periods longer than 14 days is shown in Figure 5.1. The corresponding cube root and exponential growth equations are given in Table 5.4.

Figure 5.2 compares the temporal changes in the growth indices "k" and "b" with the % increase in body weight. In each case "k" and "b" peaked within the first 11 days of exogenous feeding, followed by a rapid depression of growth rate between day 10 and 15. In two of the trials, one at 25 larvae L^{-1} and one at 50 larvae L^{-1}, where changes in weight were recorded within the period between day 10 and day 15, "k" and "b" were demonstrated to decrease significantly to a minimum point before rising again. In the third of the trials, at 25 larvae L^{-1}, mean "k" values were measured over 5 day periods and no minimum point was identified. Instead, the rate of decrease of specific growth rate between days 10-15 was much more marked than over the subsequent 15 days. The mean b values over successive 5 day intervals between 0-10 days and 15-25 increased with increasing time and decreased between days 10-15

Table 5.4 *Exponential and cubic growth equations for young African catfish*

Exponential Growth Model:

Density (fish L^{-1})	Y_o	k	r^2	P
50	2.89 (0.23)	0.19* (0.03)	0.98	<0.01
25	2.61 (0.36)	0.22★ (0.01)	0.97	<0.01
25	2.81 (0.52)	0.17▲ (0.01)	0.99	<0.01

Cube Root Growth Model:

Density (fish L^{-1})	Y_o	b	r^2	P
50	2.12 (0.37)	0.15* (0.03)	0.99	<0.01
25	1.57 (0.41)	0.20★ (0.01)	0.99	<0.01
25	0.78 (0.04)	0.20▲ (0.03)	0.99	<0.01

* over 16 days
★ over 20 days
▲ over 30 days
(bracketed figures are 95% Confidence limits)

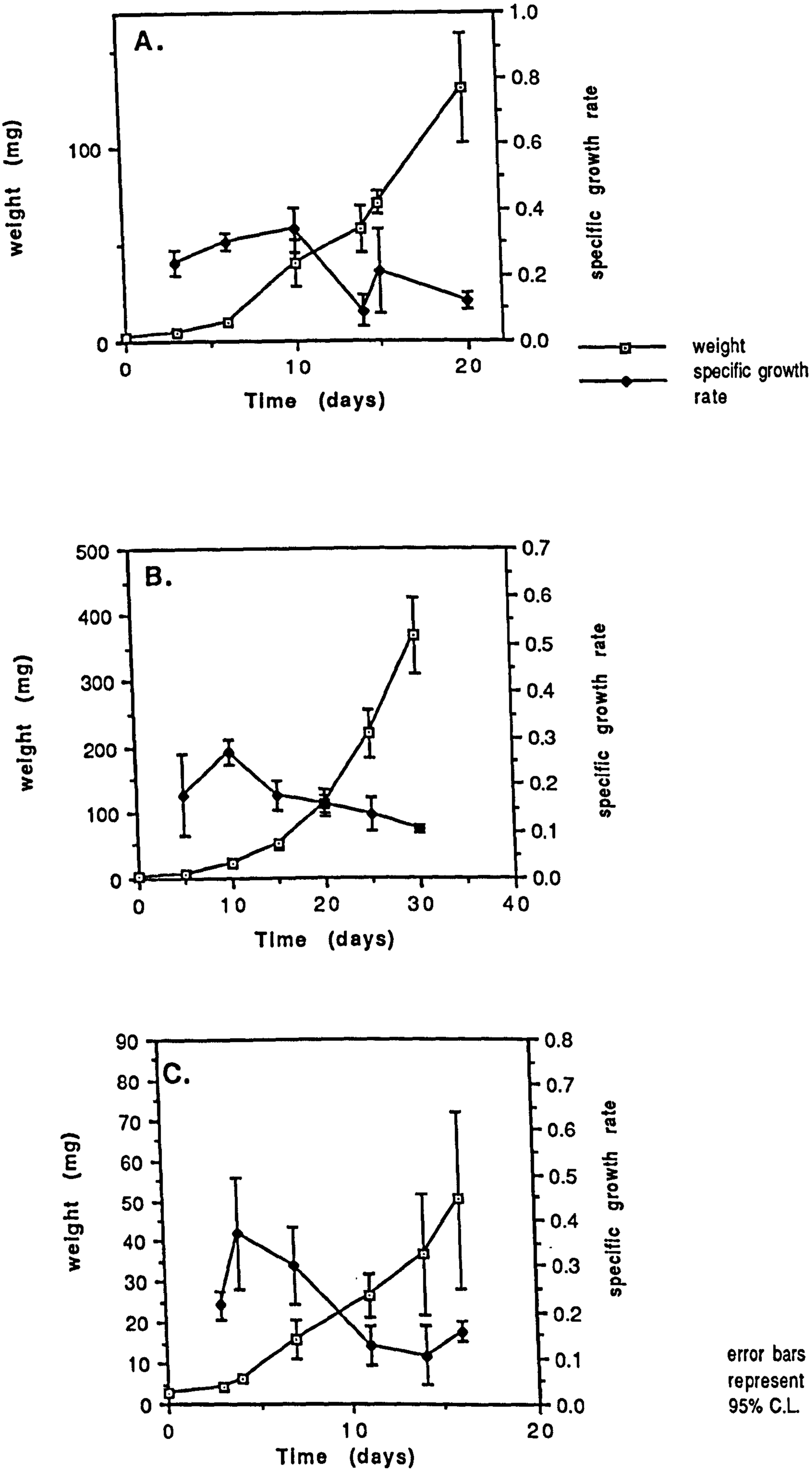


Figure 5.1: The Changes in Weight and Specific Growth Rate over Successive Short Intervals of C. gariepinus at A. & B. 25 fish/L and C. 50 fish/L.

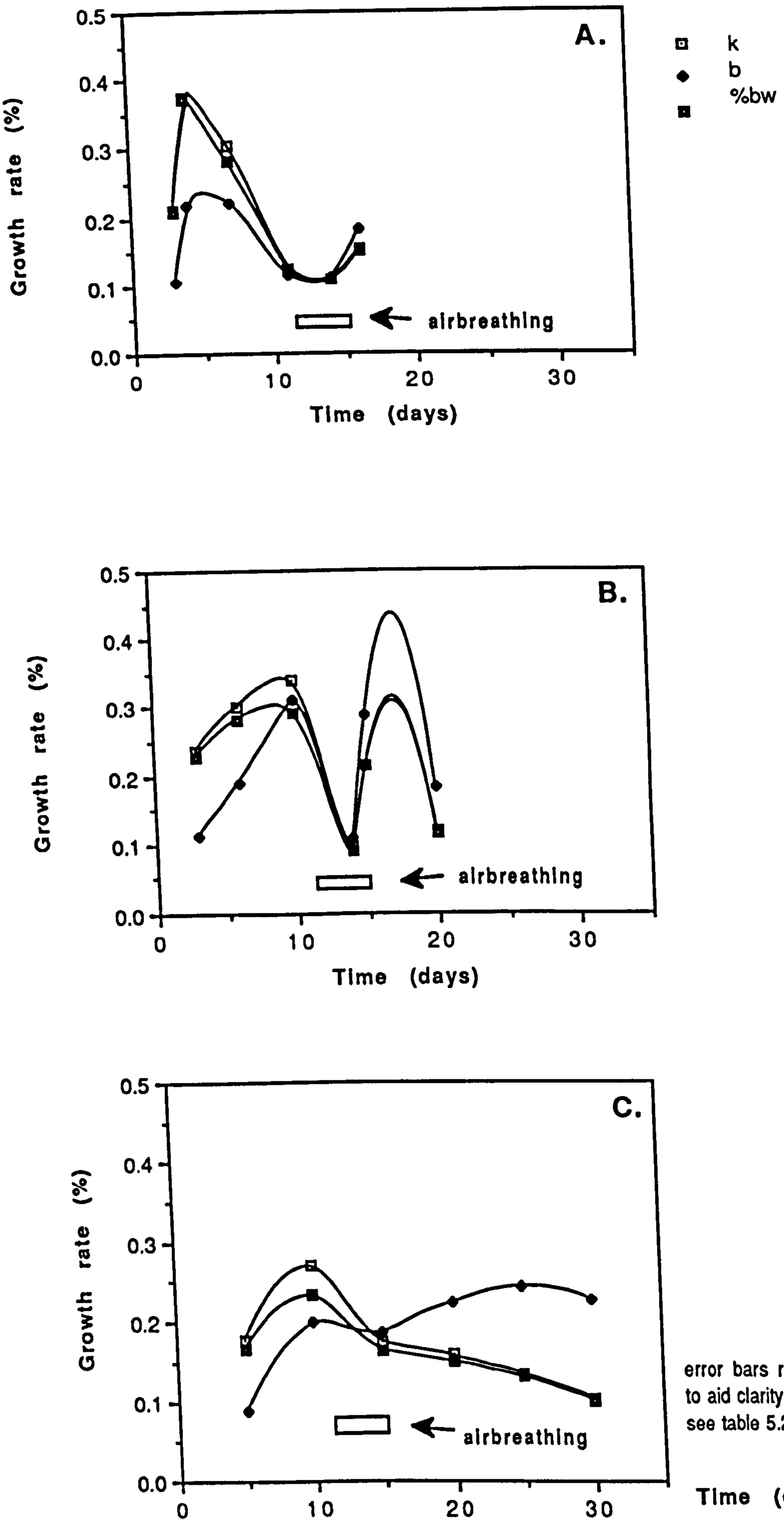


Figure 5.2: A Comparison of the Pattern of Temporal Changes in the Growth Indices k,b and % Increase in Body Weight per day in Larval/Juvenile African Catfish at A 50 & B & C 25 fish/l

and 25-30. It is clear from figure 5.2 that the growth index (k) more closely approximates the changes in % increase in body weight of young African catfish than the growth index (b).

Table 5.5 shows the survival of larvae between day 4 and day 14, after first feeding, cultured at different stocking densities in the presence and absence of shelter. Following an arcsine transformation of the binomially distributed percentage survival data, a Bartlett test revealed heteroscedasticity. The non-parametric analysis of variance (Kruskal-Wallis test) was therefore employed in order to assess the effect of stocking density on survival. Increasing initial larvae density between 50 and 250 larvae L^{-1} had no demonstrable effect on survival ($H = 3.97$, $P < 0.01$) and there was no significant difference in the survival of larvae cultured with or without shelter ($t = 1.65$, $P < 0.01$). In the absence of any detected treatment effect the mortality data was pooled and plotted against time (Figure 5.3). Only 5 deaths were attributable to type 1 cannibalism out of a total of 136 over the period from all treatments.

Larval production (g larvae L^{-1}) was highly variable (Figure 5.4). Although a significant linear relationship existed between mean larval production and initial stocking density over the range investigated, the increases in production were not significantly different at the 5% level.

Table 5.5 *Larval survival in relation to stocking density*

Stocking (larvae L^{-1}) Density		Days (from first feeding)												
		3*	4	5	6*	7	8	9	10*	11	12	13	14*	% survival overall
50	shelter	50	50	50	50	50	50	50	50	49	48	43	43	86
	no shelter	50	48	48	48	48	46	45	45	45	42	41	40	80
100	shelter	100	99	99	99	99	99	99	99	96	87	80	80	80
	no shelter	100	100	100	100	100	100	99	98	98	97	94	93	93
150	shelter	150	150	150	150	149	148	148	146	142	135	122	121	80.7
	no shelter	150	150	150	149	149	149	147	144	144	143	141	140	93.3
200	shelter	200	200	200	200	200	199	199	198	196	194	184	183	91.5
	no shelter	200	200	200	200	199	197	197	197	192	192	186	186	93
250	shelter	250	249	249	249	249	249	248	247	247	247	243	242	96.8
	no shelter	250	249	249	249	249	249	249	248	245	245	238	238	95.2

*Day on which fish were weighed

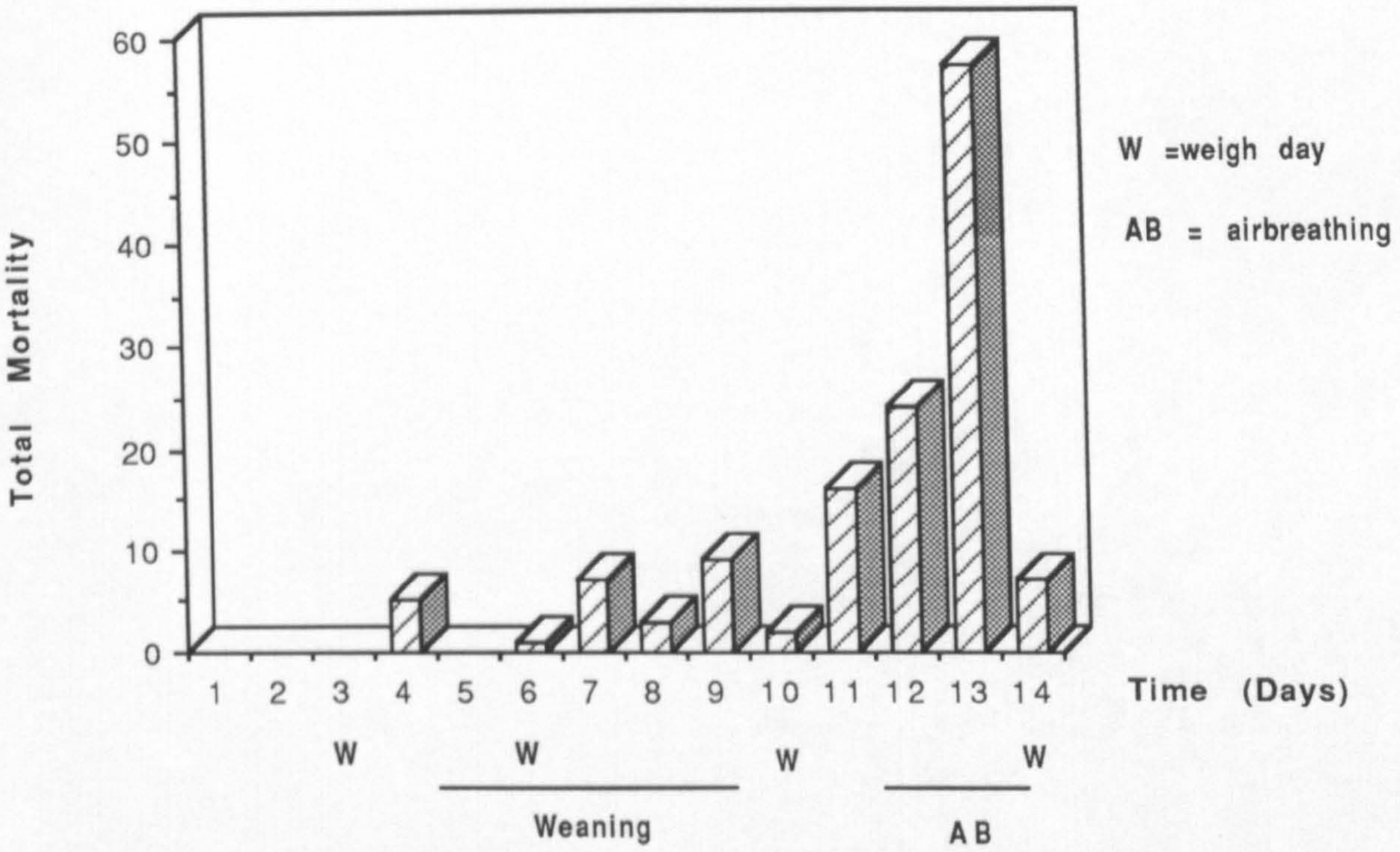


Figure 5.3 : Total Daily Mortality of C. gariepinus Larvae on each Day of the Larval Period

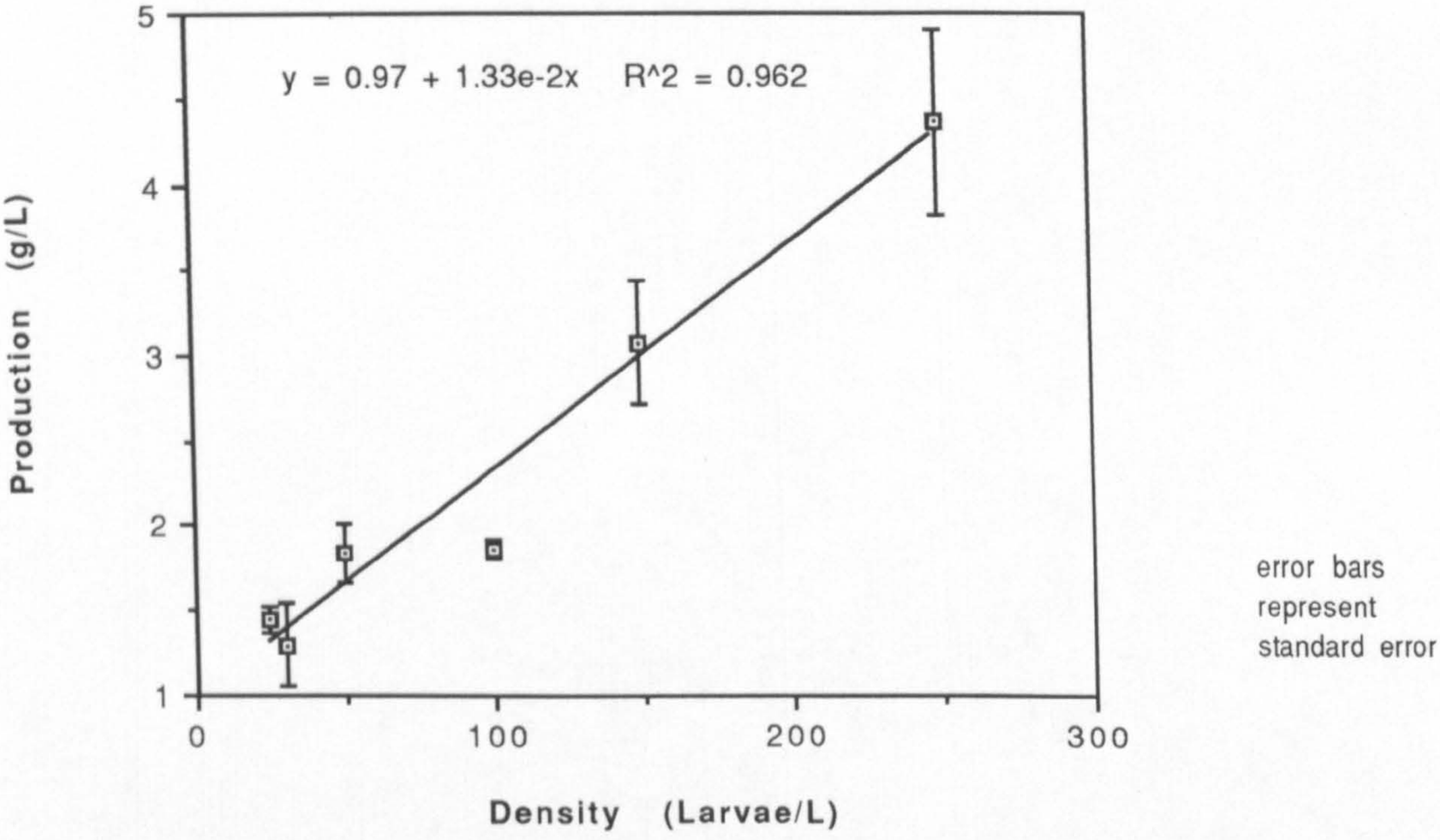


Figure 5.4: The Change in C. gariepinus Larval Production in Relation to Initial Stocking Density

5.4 DISCUSSION

From a biological perspective, describing fish growth by mathematical expressions is a complex problem (Moreau, 1987). The two most important criteria for choosing a growth curve are the quality of fit and the possibilities for appropriate biological interpretation. The ascending curvilinear relationship which exists between *C.gariepinus* larval weight and increasing time from first feeding can be approximated by an exponential or a cubic growth model, ($P < 0.01$).

The biological basis for an exponential growth model is that it represents organismic growth in terms of an initial size and takes into account that the amount of growing tissue is increasing and that new tissue begins to grow as soon as it is formed, ie. $Y_t = Y_o.e^{kt}$ (Brown, 1946).

The biological basis for the cubic growth model, suggested by Hogendoorn (1981) is that the cube root transformation of the body weight represents a length characteristic and that total length increases linearly with time.

The relationship between body weight (W) and the total length (L) defined by Elliot (1975c) can be represented by the equation, $W = \alpha L^{\beta}$ (or $\log_e W = \log_e \alpha + \beta \log_e L$). For a cube root transformation of weight data to represent total length implies that the length exponent (β) should approximate to 3. Unpublished observations by Haylor (see Appendices), however, of 375 larval and juvenile *C.gariepinus* cultured intensively and fed *ad libitum* over 24 days

(from first feeding) produced the relationship $W = 2.28 \times 10^{-3} L^{3.56}$ $r^2 = 0.99$ ie. where the length exponent is 3.56 suggesting that the length of catfish cultured in this way is poorly estimated by the cube root of their weight.

Earlier work on larval and juvenile specific growth rate in species such as carp, *Cyprinus carpio* (L.) (Bryant and Matty, 1980) and catfish, *C. gariepinus* (Hogendoorn, 1980b, Uys and Hecht, 1985) demonstrates that k can vary significantly over short periods. The assertion of Verreth and Den Bieman (1987) that a constant growth index over the entire larval period is given by a cube root transformation of the weight data (ie. that b does not vary) though not from a log transformation (because k does vary) is however unsubstantiated by the present investigation; since b (the regression coefficient of a cube root transformation) like k (the specific growth rate) varies significantly over successive short intervals throughout the larval period (Table 5.3 and Figures 5.1 and 5.2). As growth rate varies widely and rapidly in fast growing fish larvae, any constant value representing larval growth rate can only be considered accurate over very short intervals or can represent a mean value for a longer period. However, in order to accurately predict growth over the whole of the larval period (enabling determination, for example, of feeding level on a daily basis) a model would need to be developed incorporating a variable, not a constant growth rate; though *ad libitum* feeding or a model based on gastric evacuation rate would probably better address the larval requirements. Over short intervals where a constant growth rate model is valid, specific growth rate is probably a more useful parameter than the regression coefficient of the cube root transformation of weight data; since over

successive short intervals specific growth rate more closely approximates changes in the percentage increase in mean body weight day^{-1} (Figure 5.2).

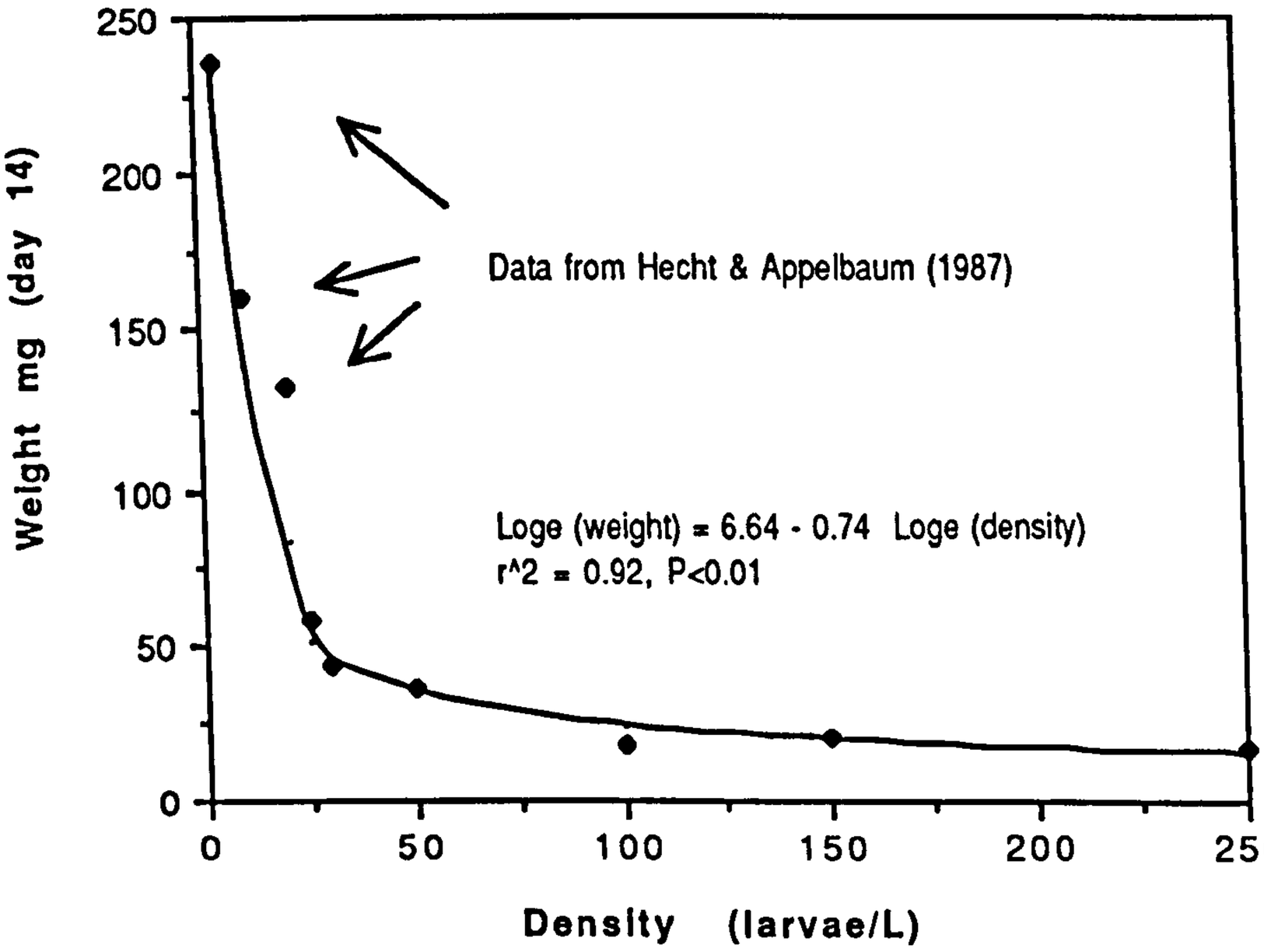
Growth rate according to Stauffer in Brett (1979) is principally influenced by three variables, ie. size, ration and temperature. The main factors contributing to the variability in development rate during early exogenous feeding are temperature and food (Kamler, 1992). On this basis since temperature remained constant during the present study, the variation in growth rate of larvae over time will have been influenced most strongly by ration. Uys (1989) demonstrated that the mean activity of protease, amylase, pepsin and cellulase in *C.gariepinus* all increased significantly between the onset of exogenous feeding and day 6 (post first feeding with dry feed). In addition Uys (*ibid.*) showed that the most rapid rate of increase in activity of pepsin and trypsin was between first feeding and day 3. Therefore one explanation for the gradual increase in growth rate over the first few days of exogenous feeding is that growth initially is limited by the relatively reduced proportion of the maximum voluntary intake of nutrients (particularly proteins) which are available to the larvae. In which case, the rate of larval growth will increase as the proportion of nutrients available increases, ie. as the fishes catabolic pathways become functionally established. The ontogeny of a functional digestive system is believed to be complete on day 5 after the start of exogenous feeding (Verreth *et. al.* 1991). The other explanation is that the maximum voluntary intake itself is proportionally smaller in early exogenous feeding because acquisition is less efficient.

Since growth rate in terms of proportion of body weight declines in response to increasing body size (Brett, 1979; Hogendoon, 1980b; Dabrowski, 1986; Kamler, 1992) the larval growth rate will eventually peak before decreasing with time.

Under intensive conditions at 30°C *C.gariepinus* larval growth rate peaks between 3 and 10 days (after first feeding). The subsequent pattern of steady decline in growth rate with fish size is interrupted when the young catfish begin air breathing after about 12-14 days under these conditions (Figures 5.1 and 5.2), during which time growth rate is temporarily depressed to less than one third of its peak.

C.gariepinus larval growth is negatively density dependent over the range of high stocking densities used in the present trial; the weight attained at the end of the larval period declining curvilinearly with increasing stocking density. Combining the present data with other larval growth data (of different biotic origin but grown in similar conditions over the same period) at lower density by Hecht and Appelbaum (1987) indicates curviliniarity over a wider density range (Figure 5.5). Log_e (Weight, mg) = 6.64 - 0.74 Log_e (Density, larvae l^{-1}) $r^2 = 0.92$ $P < 0.01$.

Survival rates of larvae (of 80% or more) at all densities indicates an amenability of *C.gariepinus* to intensive rearing practices. The present results provide no evidence that survival of larvae is affected by stocking density, in the range 50-250 larvae L^{-1} or by the provision of 4mm mesh shelters.



N.B. data is drawn from two studies with fish of different biotic origen

Figure 5.5: The Increase in Larval Weight over 14 Days of C. gariepinus Grown in Similar Conditions over a Wide range of Densities

Most deaths were recorded during the onset of air breathing. At this time the catfish, which tend to show negative phototaxis struggled against the increase in buoyancy associated with initial air gulping. The usual activity patterns of the fish including feeding were interrupted and excess powdered feed was observed adhered to the air water meniscus in the gill cavity. The increase in numbers of deaths at this time was possibly due to these factors. The few incidents of type 1 cannibalism observed occurred (a) during the onset of airbreathing, a time when the escape response of some siblings would be inhibited by their sudden increase in buoyancy and (b) at the beginning and end of a period of weaning larvae from *Artemia* onto a powdered diet ie. when a readily identifiable food source was either reduced or removed. On the days following weighing of the fish, higher levels of larval deaths were recorded indicating a sensitivity to handling stress.

The apparent linear increase in production per unit volume with increasing stocking density identified by the present trial agreed very closely with the finding of Britz (1988). However the production values calculated did not vary significantly ($P < 0.05$) with density though the small sample size involved increases the probability of making a type II error. It is likely, therefore, that the production capacity of a hatchery increases with stocking density apparently up to 450 larvae L^{-1} (Britz, 1988) and potentially above, however the individual larval size decreases curvilinearly with density.

5.5 SUMMARY

The mean increase in African catfish *Clarias gariepinus* (Burchell) weight with time over the entire larval period can be approximated by a cubic or exponential growth model. However the growth rate indices: specific growth rate (k) and the regression coefficient of a cube root transformation of the weight data (b), both vary significantly when measured over successive short intervals from first feeding. In particular the onset of airbreathing is associated with a significant depression in growth rate. The variation in specific growth rate (k) with larval age closely approximates the relationship between mean % increase in body weight per day and larval age; however the cube root regression coefficient does not share this property. In addition to the affect of larval age, the growth rate of African catfish larvae is significantly affected by the initial density at which they are stocked (between 25-250 larvae l^{-1}) and interactions between age and stocking density. Survival over the larval period, of 80% or more, is apparently unaffected by initial stocking density (between 50-250 larvae l^{-1}) however the onset of airbreathing in particular is associated with an increase in fish deaths.

Chapter 6: The Growth and Survival of *Clarias gariepinus* Fry at high stocking density.

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6.1 INTRODUCTION

The stocking densities which are commercially most appropriate for fry rearing will depend upon a multiplicity of factors, both biological and economic. The latter criteria will vary with such elements as capital and running costs as well as the frequency and timing of fry requirement for on-growing. The economic factors involved are often site specific and most accurately assessed for a given situation at the time of undertaking a feasibility study. The biological factors affecting the appropriateness of commercial stocking densities can be investigated by considering a range of densities and then measuring the resultant growth and survival of fry. This provides a data base for economic evaluation of particular stocking densities, and allows identification of trends or relationships between density, growth rate and survival.

In common with many other fish species of economic important *Clarias gariepinus* exhibits both territorial intraspecific aggression and sibling cannibalism (Hecht and Appelbaum 1987, 1988). The relative importance of both behaviour patterns as causes of mortality is largely unknown, though it has important implications in terms of optimal aquaculture provision.

Young *Clarias gariepinus* have been reared experimentally at a range of stocking densities, though mainly below 50 fish per l (Hogendoorn, 1980b; Uys and Hecht, 1985; Hecht and Appelbaum, 1987; Verreth and Den Bieman, 1987; Appelbaum and Van Damme, 1988; Verreth and Van Tongeren, 1989 and Cleaver 1991). However fry growth and survival at high density has not been the subject of detailed investigation, but may be commercially most productive.

The present study was therefore undertaken to investigate and quantify the pattern of growth and survival of *Clarias gariepinus* fry at high stocking densities.

6.2 METHODS AND MATERIALS

6.2.1 An investigation of cannibalistic mortality, non-cannibalistic mortality and growth rate in relation to stocking density during fry rearing

First feeding larvae were produced by the method described in 5.2.1. On day 2 larvae were transferred in the egg rearing troughs to two 1m diameter circular, mass larval rearing tanks. Water fed the two tanks from a 230l capacity header tank by gravity through a ½ inch single orifice horizontal inlet pipe. Each tank had a ¾ inch outlet, screened with a 0.5mm mesh. The tanks drained into two 230l preconditional biofilter tanks (with a total biofilter medium surface area of 75m^2) from which water flower by gravity to a 230l sump tank. An electric pump (PV 100, Beresford, England) raised water to the header tank, from which water overflowed through a solids filter

(Filtermat 3.8.1, Dryden, Scotland) before returning to the sump tank.

Larvae were fed as described in 5.2.2 except feed was offered four times daily at 0800, 1100, 1400 and 1700.

On day 13 fish were assigned to one of nine replicates of three stocking densities (50, 100 and 150 fry/l). The treatments were randomly allocated to 27 self-cleaning circular tanks of the recirculating system described in 5.2.3.

Any deaths were recorded and removed twice daily during cleaning. A distinction was drawn between cannibalism and non-cannibalistic causes of death. The former was detected by the presence of discarded heads in the tank resulting from tail first cannibalistic attacks (type I cannibalism of Hecht and Appelbaum 1988). The latter was identified by the presence of complete fry lying at the bottom of the tank. (If left overnight corpses were sometimes found with the abdomen removed but always remained uneaten). There were no fry losses attributable to type II cannibalism (Hecht and Appelbaum 1988), which is characterised by the consumption of whole siblings.

The mean fry weight in each tank was determined on five occasions during the 23-day trial every 5 days from day 15. In each case the fry were poured gently into a 0.5mm mesh hand net. Following drying for 5s on absorbent paper, the fry wet weight was recorded on a Mettler top pan balance ($\pm$ 0.1mg).

At the end of the trial a random sample (the population of three tanks) from each treatment was killed using an overdose of benzocaine and preserved in Bouins Solution. Fish length was subsequently measured (to 1mm).

A separate experiment was carried out to estimate the relative metabolic rate of fry kept at different densities. Two hours after feeding, fry were acclimatised for 15 min to tanks of the recirculation system described. Over five consecutive periods of 1 min the rate of surfacing to gulp air was scored for each tank. Surfacing to breathe air is distinguishable from other activities which break the water surface by the release of two air bubbles just prior to air gulping. Mean surfacing rate per fish per minute was then calculated for five stocking densities between 1 and 5 fry/l. (Scoring mean surfacing rate at densities higher than 5 fry/l proved methodologically too complicated.)

6.2.2 Data Analyses

The following analyses were carried out:

1. Growth rate was measured as

specific Growth rate (k) =

$$\frac{Log_e Y_t - Log_e Y_o}{t}$$

2. 95% Confidence limits were calculated as:

$$C.L. = \bar{Y} \pm t_{0.05[n-1]} \frac{S\bar{Y}}{\sqrt{n}}$$

3. The mean number of deaths from both cannibalistic and non-cannibalistic interactions, on each day, as a % of those surviving at the beginning of that day was calculated in order to demonstrate any variations in mortality from either source over time, ie.

$$\overline{C}\ \% = \frac{\sum^{a} \frac{C_{t+1}}{N_t} \cdot 100}{a} \qquad \overline{M}\ \% = \frac{\sum^{a} \frac{M_{t+1}}{N_t} \cdot 100}{a}$$

where:

C%	=	mean % per capita cannibalism
M%	=	mean % per capita non-cannibalistic interactions
a	=	replicates
N_t	=	number of fish alive on day t
C_{t+1}	=	number of fish cannibalised in one day
M_{t+1}	=	number of fish dying as a result of non -cannibalistic interations

Cumulative mortality, in each case, was calculated from the expressions:

$$\textit{Cumulative } \overline{M}\ \% = \frac{\sum^{a} \Sigma^{t} \frac{M_{t+1}}{N_t} \cdot 100}{a}$$

$$\textit{Cumulative } \overline{C}\ \% = \frac{\sum^{a} \Sigma^{t} \frac{C_{t+1}}{N_t} \cdot 100}{a}$$

4. In order to compare the total mortality for the period (day 12-day 35) from each cause, a single value representing mean % per capita mortality per day was calculated as follows:

$$\overline{M}\ \%\ day^{-1} = \frac{\sum^{a} \frac{\sum_{t=13}^{t=35} \frac{M_{t+1}}{N_t} \cdot 100}{22}}{a}$$

$$\overline{C}\ \%\ day^{-1} = \frac{\sum^{a} \frac{\sum_{t=13}^{t=35} \frac{C_{t+1}}{N_t} \cdot 100}{22}}{a}$$

The effect of stocking density on the rate of cannibalistic and non-cannibalistic mortalities was investigated by the non-paramentic analysis of variance (Kruskal-Wallis test) after a Bartlett test revealed that in both cases the data were heteroscedastic.

5. In order to assess any size hierarchy effect (Brown 1946) sometimes known as growth depensation (GD) (Brett 1979; Koebele 1985), the standard deviation was calculated as follows:

$$GD = \left[\frac{(n_1 - 1)\ S_1^2 + (n_2 - 1)\ S_2^2 + \ldots\ldots + (na - 1)\ S_a^2}{n_1 + n_2 \ldots\ldots na - a}\right]^{\frac{1}{2}}$$

(Dixon & Massey 1969)

where
n = number of fish per replicate
S_2 = the variance of growth within replicate a

6. Coefficient of variation was calculated as follows:

$$CV = \frac{S}{\bar{x}} \cdot 100$$

(Sokal & Rohlf 1969)

S = standard deviation
x = mean

The effect of stocking density on the coefficient of variation in length of 35 day old fry was investigated by the non-paramentic analysis of variance (Kruskal-Wallis test).

6.3 RESULTS

Figure 6.1 displays the change in weight over 35 days of *C. gariepinus* fry kept at three stocking densities between 50 and 150 fry/l. In all treatments fish increased rapidly in weight, with significant ($P < 0.05$) increases in weight for each successive 5-day period measured between day 15 and day 35. The greatest weight gains corresponded to the lowest stocking densities. At 50 fry/l fish gained significantly ($P < 0.05$) more weight over each 5-day period than at the higher stocking densities. All differences in weight gain between fish at 100 fry/l and 150 fry/l were not significant at the 5% level, except weight measured on day 30.

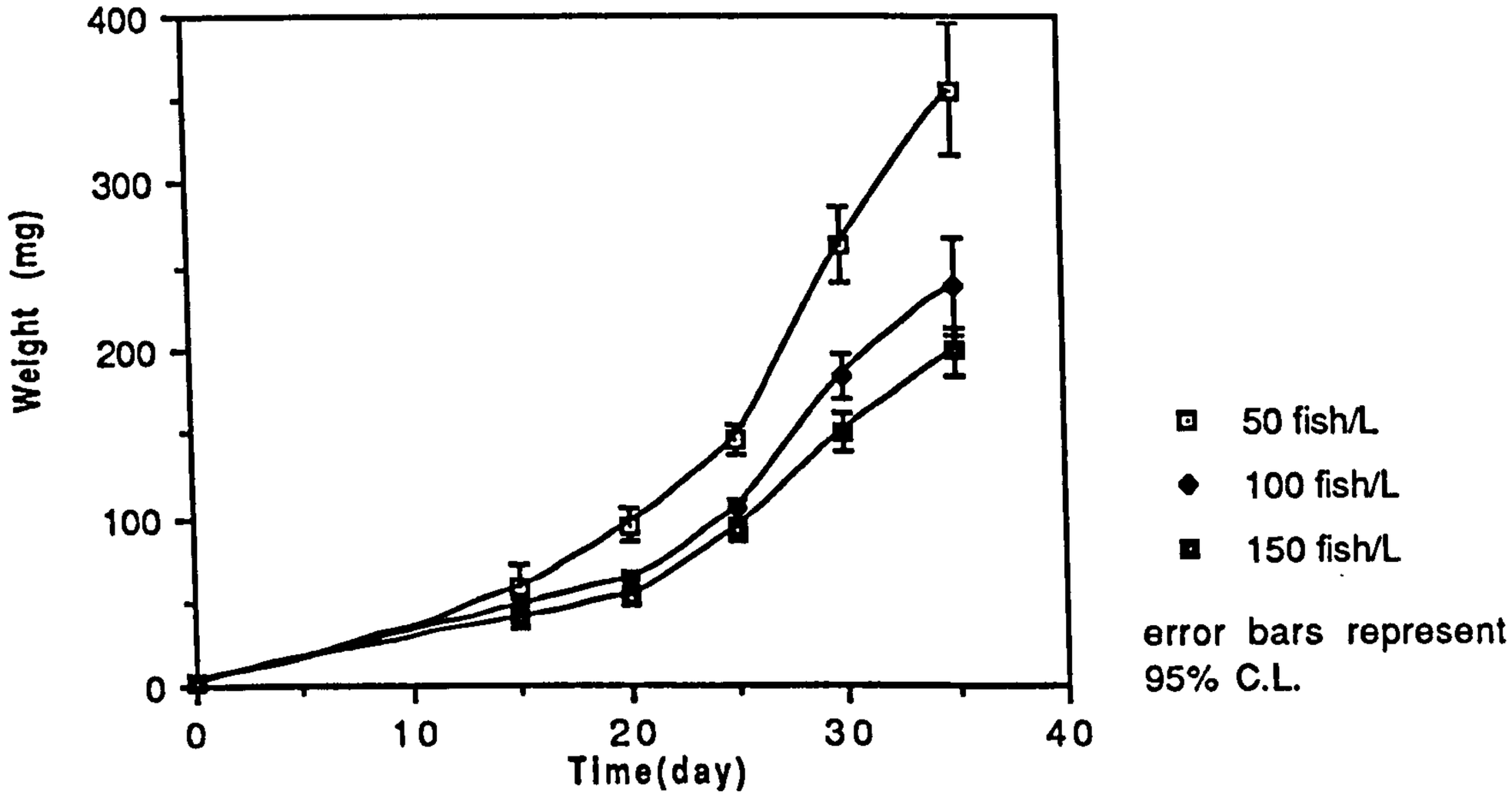


Figure 6.1: The change in weight over 35 days of C. gariepinus fry raised at three different stocking densities.

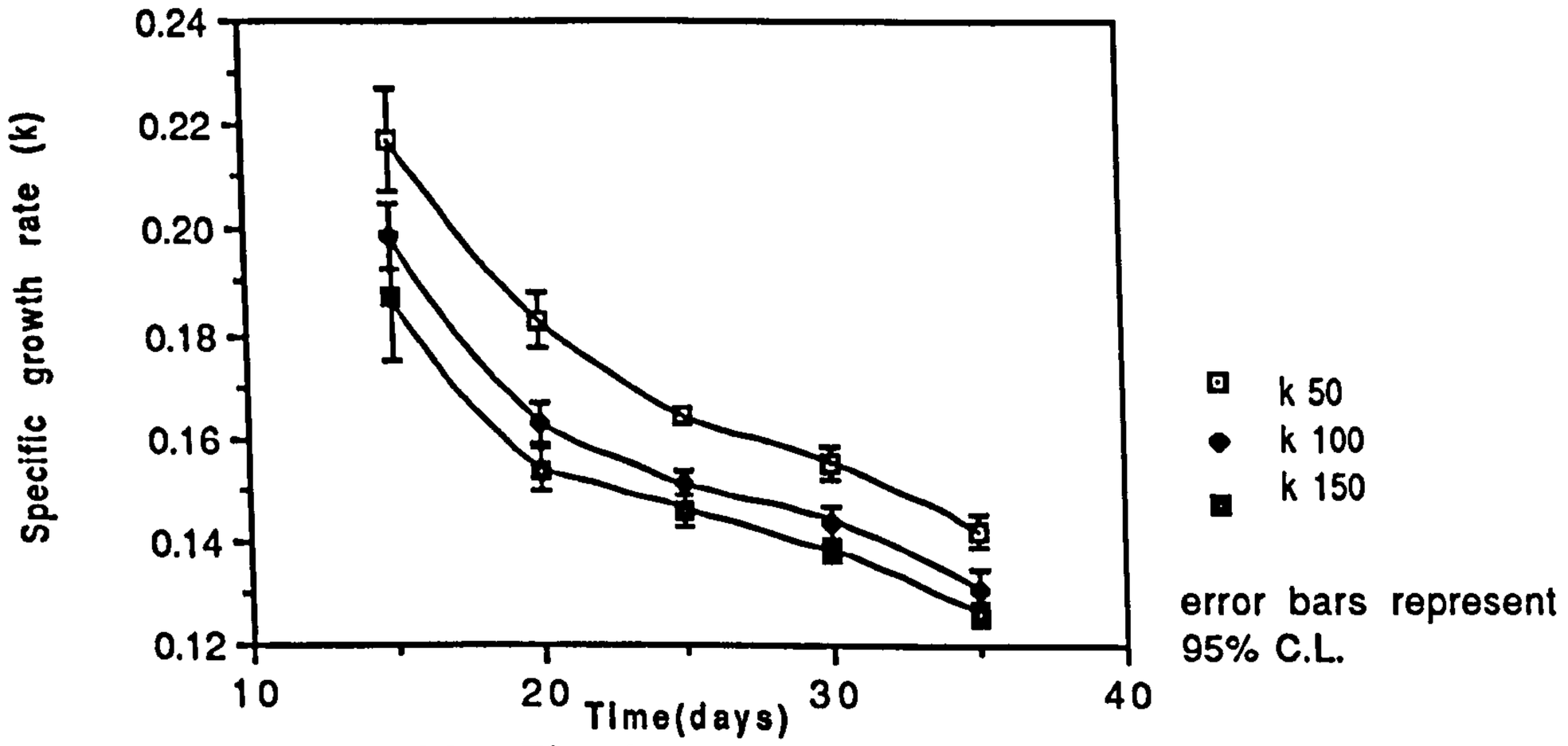


Figure 6.2: The change in specific growth rate over time of C. gariepinus fry raised at three different stocking densities.

The specific growth rate (k) decreased rapidly over the fry period in all treatments and is displayed in Fig 6.2. Significant decreases ($P < 0.05$) in specific growth rate were measured for each successive 5-day period, between day 15 and day 35, in all treatments.

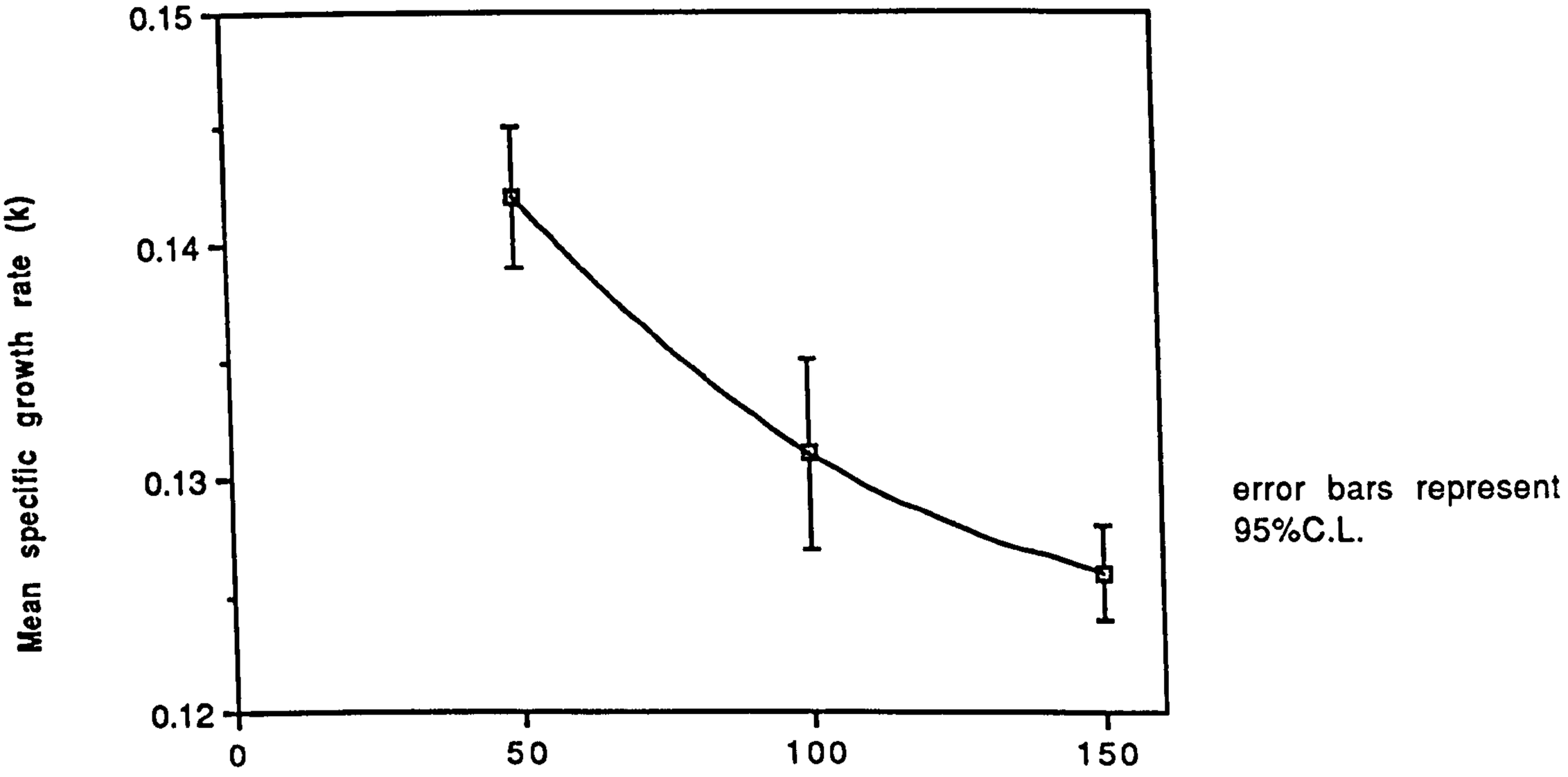
Specific growth rate (k) at 50 fry/l was significantly greater than specific growth rate at the higher stocking densities over the whole fry rearing period.

The mean (k) values over 35 days at 100 fry/l and 150 fry/l were not significantly different at the 5% level. On day 20 and day 30 significant differences ($P < 0.05$) in specific growth rate were, however, apparent between each of the treatments.

The change in mean specific growth rate of *C. gariepinus* fry in relation to stocking density is shown in Figure 6.3.

The % survival of fry was not significantly affected by stocking density ($P < 0.05$). Mean survival was in excess of 90% in all treatments over the 23-day trial (Figure 6.4). The % survival, % cannibalism and % non-cannibalistic death is documented in Table 6.1.

Weighing the fry did not increase the death rate and there were no large physiochemical fluctuations in conditions. No type II cannibalism took place. Mechanical damage to one of the tanks resulted in the death of 40% of the fry in one replicate tank (with 50/fry/l) on day 3 of the trial. All parameters were



error bars represent 95%C.L.

Figure 6.3: The change in mean specific growth rate in relation to stocking density.

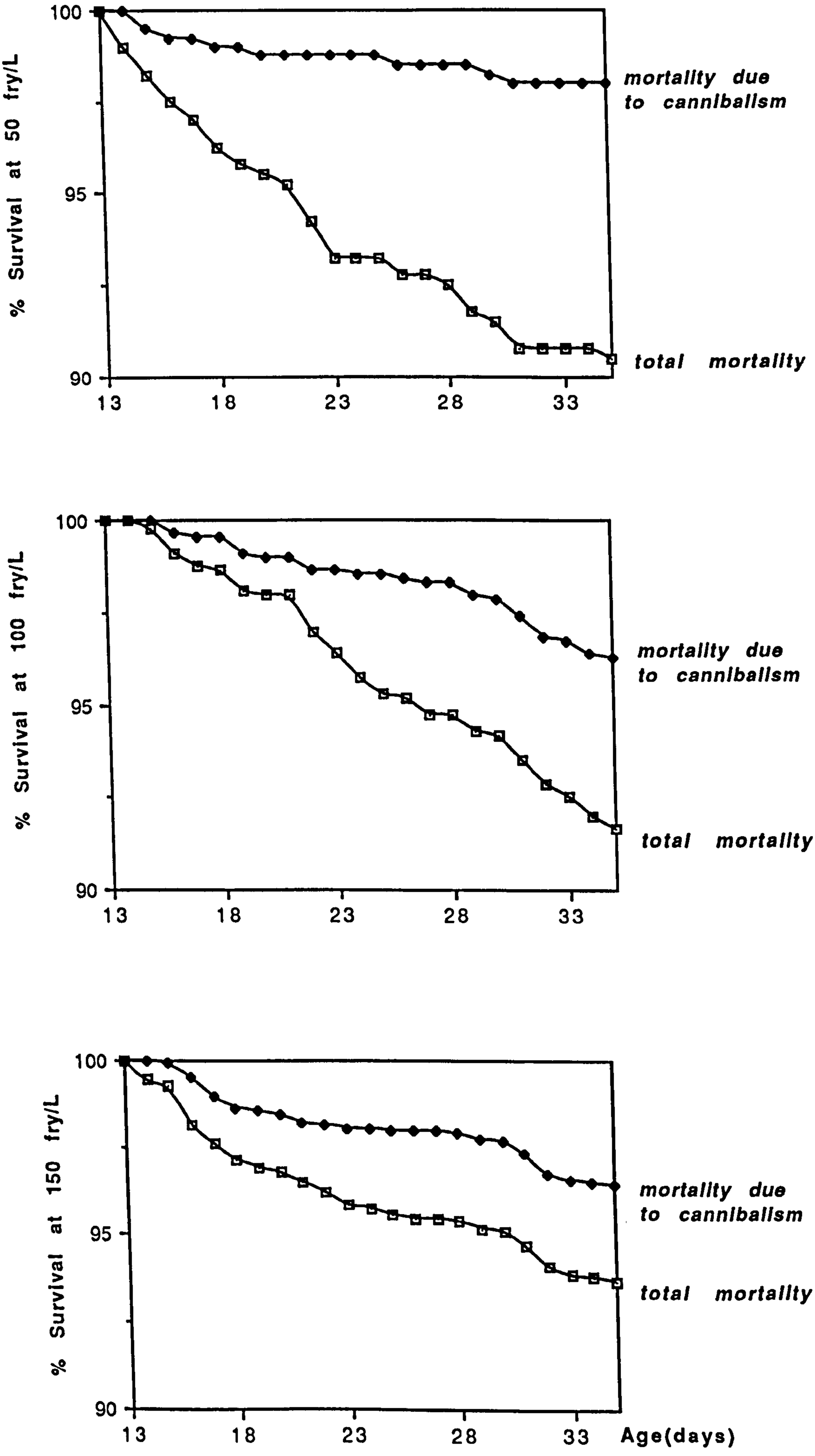


Figure 6.4 : The change in % survival over time of C. gariepinus fry at 50, 100 and 150 fry/l (also see table 6.2)

Table 6.1 *A summary of the survival, cannibalism and non-cannibalistic mortality resulting from territorial aggression at different stocking densities*

Stocking density (fry/l)	% survival	% cannibalism	% mortality
50	90.50[1]	2.00[1]	7.50[1]
100	91.67[1]	3.57[1]	4.66[1.2]
150	93.65[1]	3.59[1]	2.76[2]

Figures in columns bearing different superscripts are significantly different at the 5% level.

subsequently calculated from eight replicates for that treatment. Mean % per capita cannibalism varied with time (Fig 6.5). In all treatments there was an initial peak in cannibalism between days 13 and 17, followed by a lower level, and then a second peak between days 28 and 34.

The pattern of cumulative mean % per capita cannibalism (Figure 6.6) varied with stocking density. However, the rate of cannibalism (mean % per capita cannibalism per day) (Figure 6.7) was not significantly increased by the stocking density of fry ($H = 0.9375$, $P > 0.05$).

The mean % per capita non-cannibalistic deaths (Figure 6.8) decreased with time in all treatments. Cumulative mean % per capita non-cannibalistic deaths (Figure 6.9) were greater at the lower stocking densities. The rate of deaths (mean % per capita non-cannibalistic death per day) (Figure 6.10) decreased linearly with increasing stocking density ($A = 0.427$, $b = 2.29 \times 10^{-3}$, $r^2 = 1.00$). *Clarias gariepinus* maintained at 150 fry/l suffered significantly

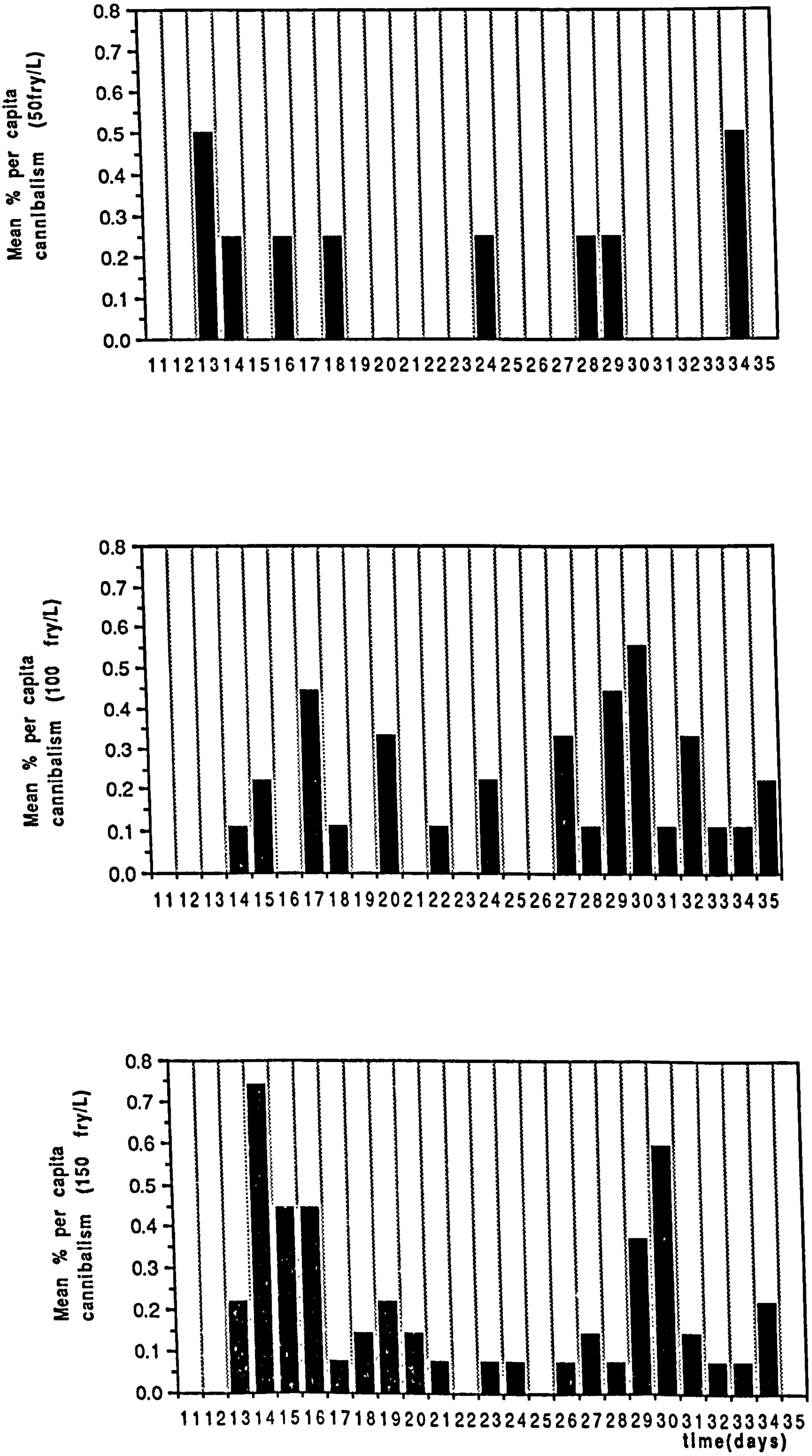


Figure 6.5: Mean % Per capita cannibalism in relation to time at 50, 100 and 150 fry/L.

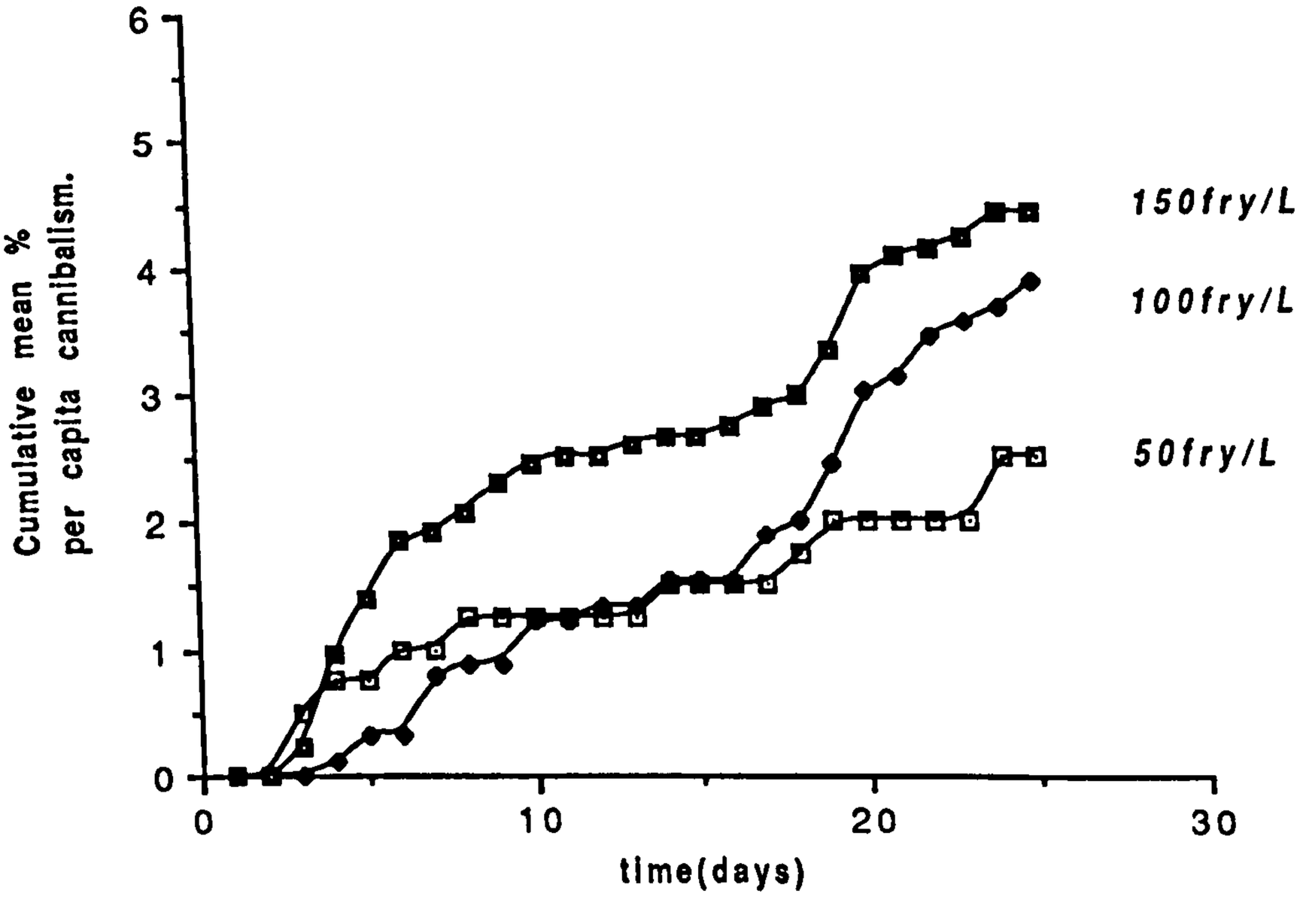


Figure 6.6: The change in cumulative mean % per capita cannibalism over time of C. gariepinus fry at 50, 100 and 150 fry/L

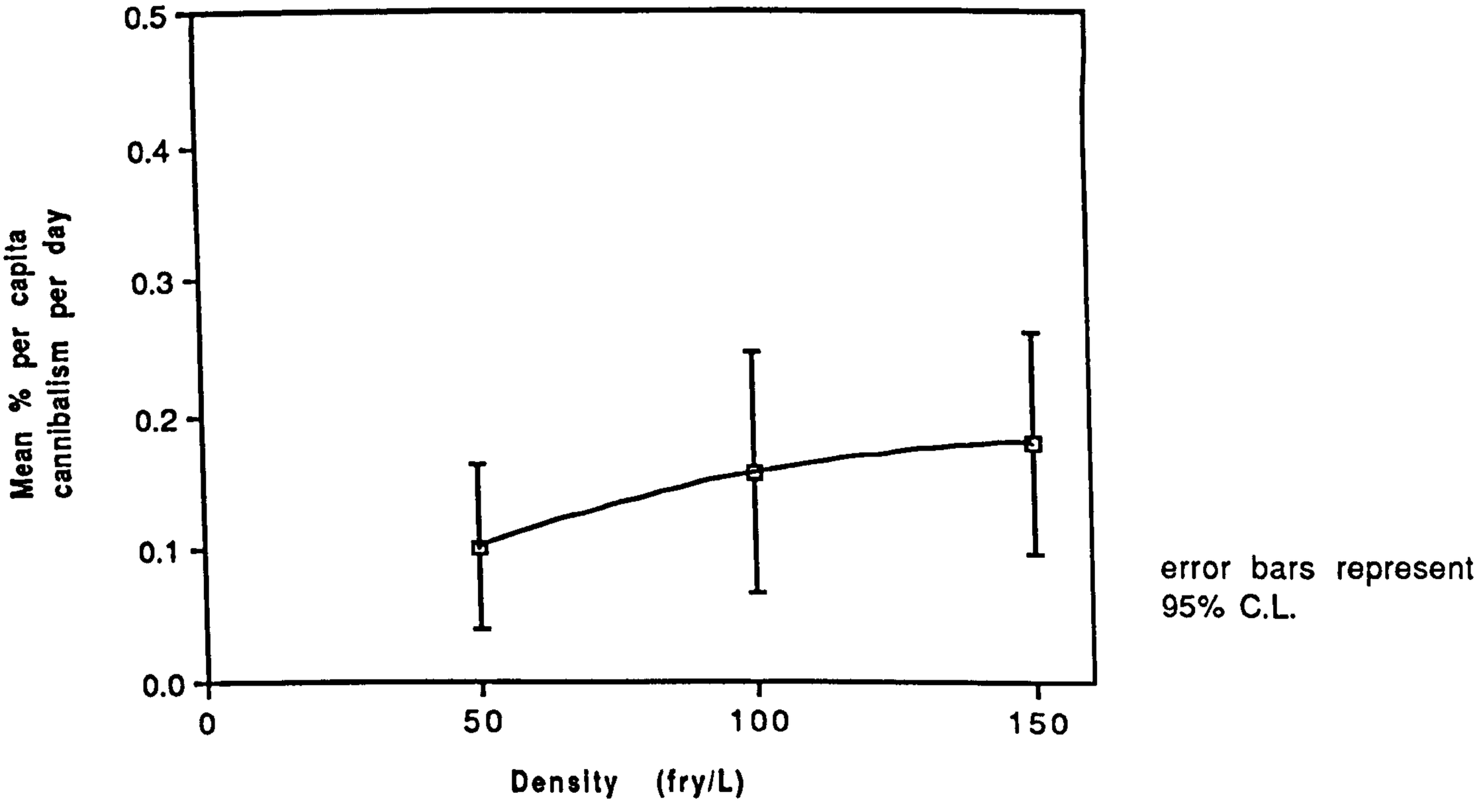


Figure 6.7: The change in mean % per capita cannibalism per day in relation to stocking density of C. gariepinus fry.

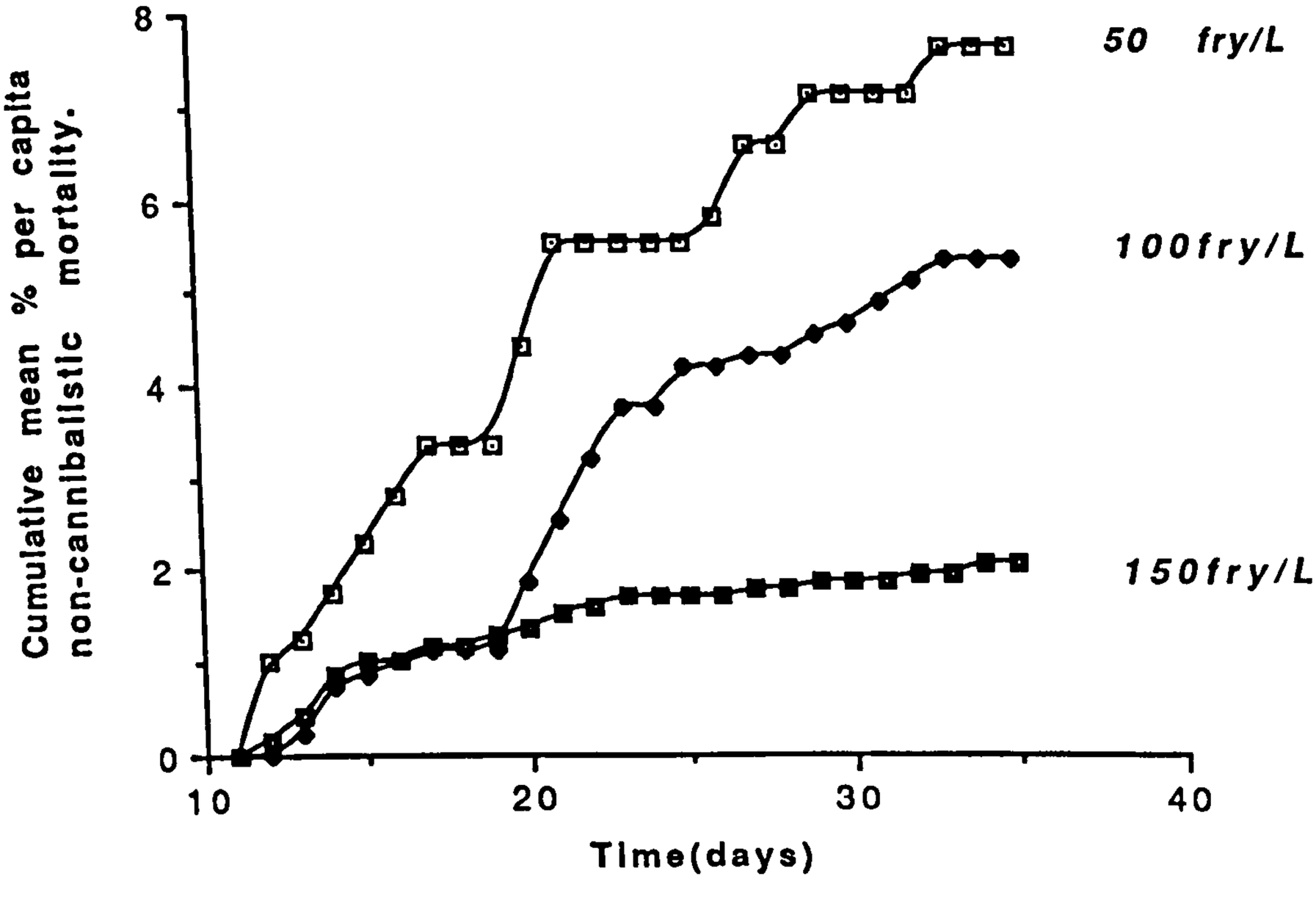


Figure 6.8 : The change in cumulative mean % per capita non-cannibalistic mortality over time at 50, 100 and 150 fry/L

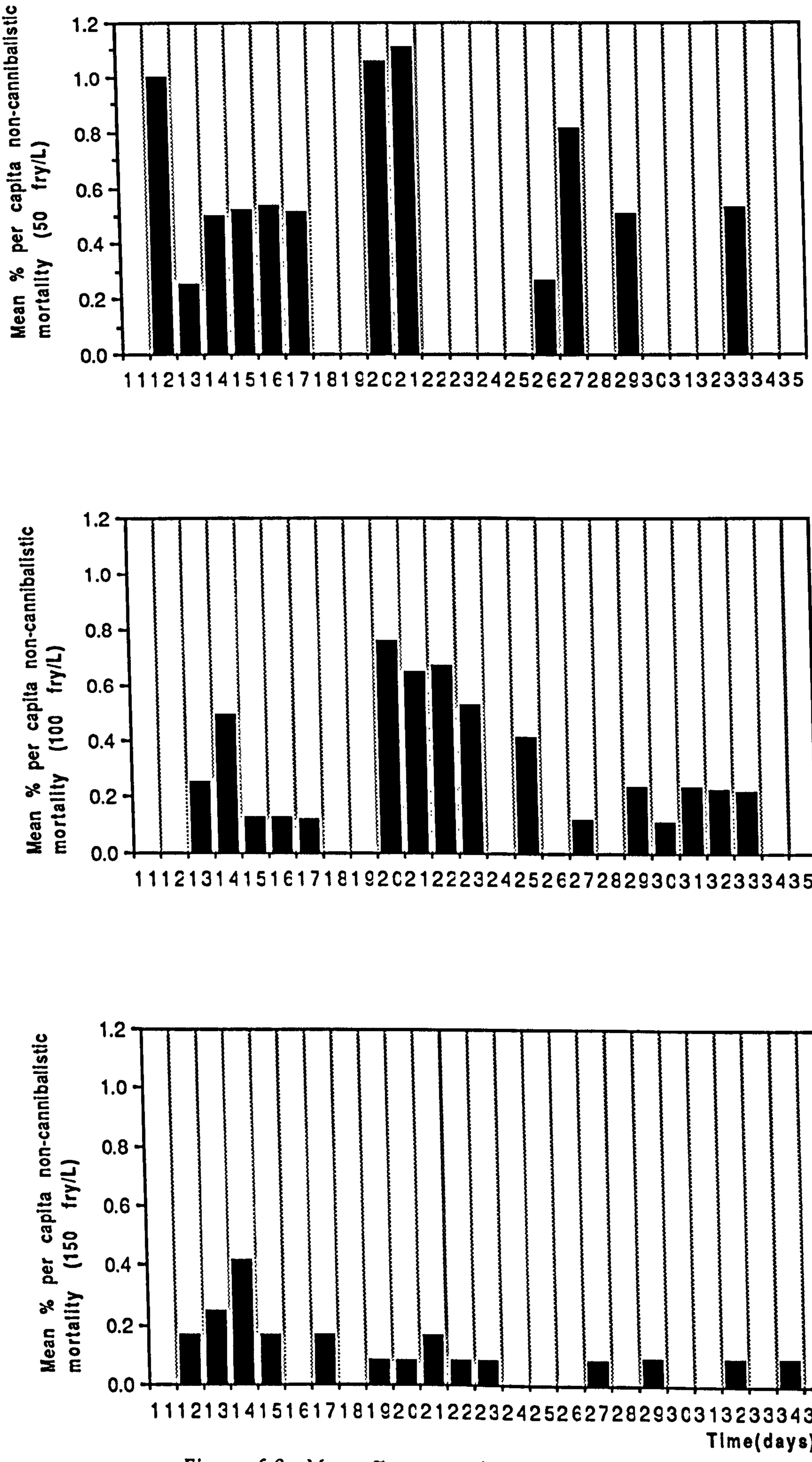


Figure 6.9: Mean % per capita non-cannibalistic deaths in relation to time at 50, 100 and 150 fry/L

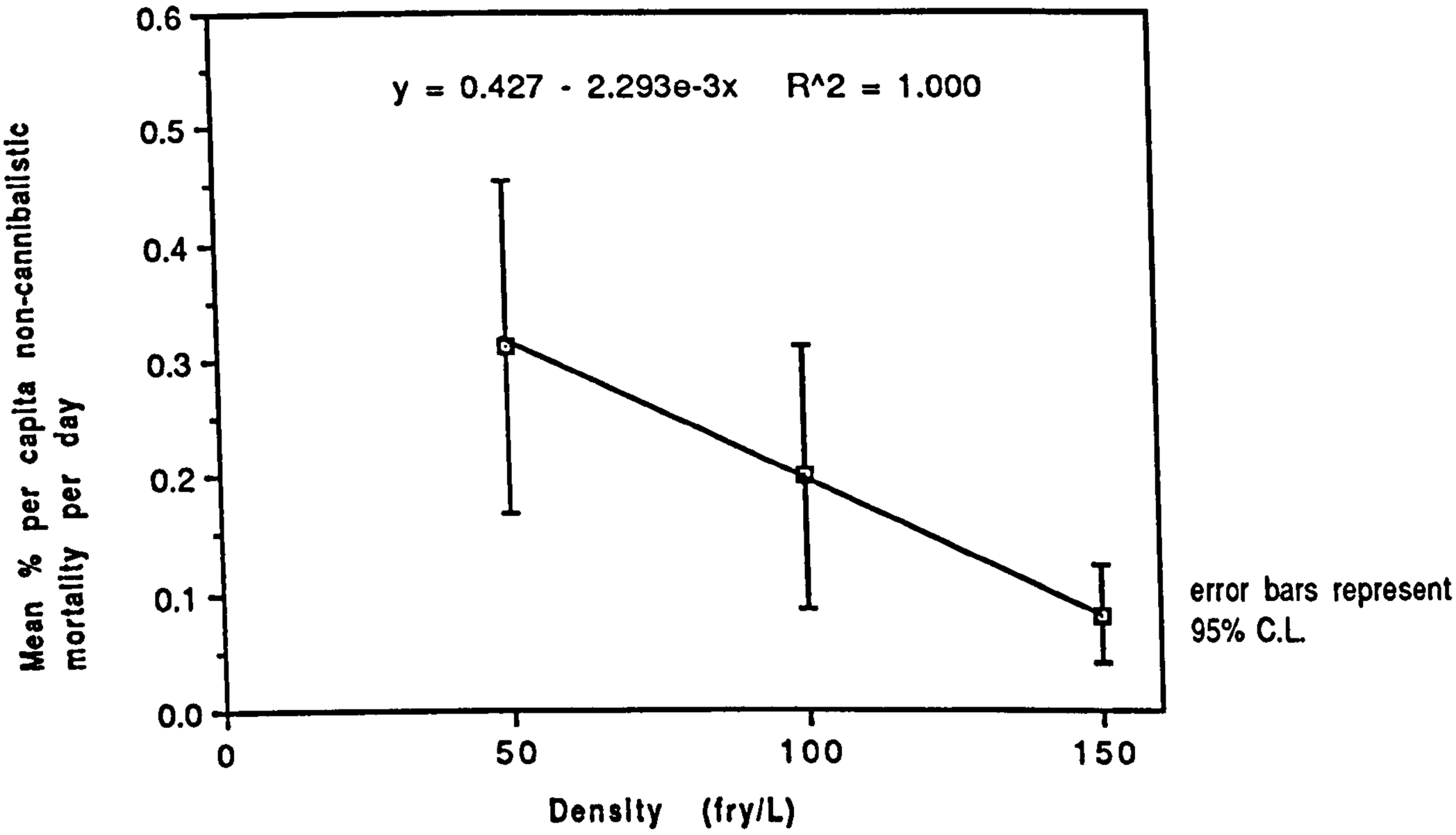


Figure 6.10: The change in mean % per capita non-cannibalistic deaths per day in relation to stocking density.

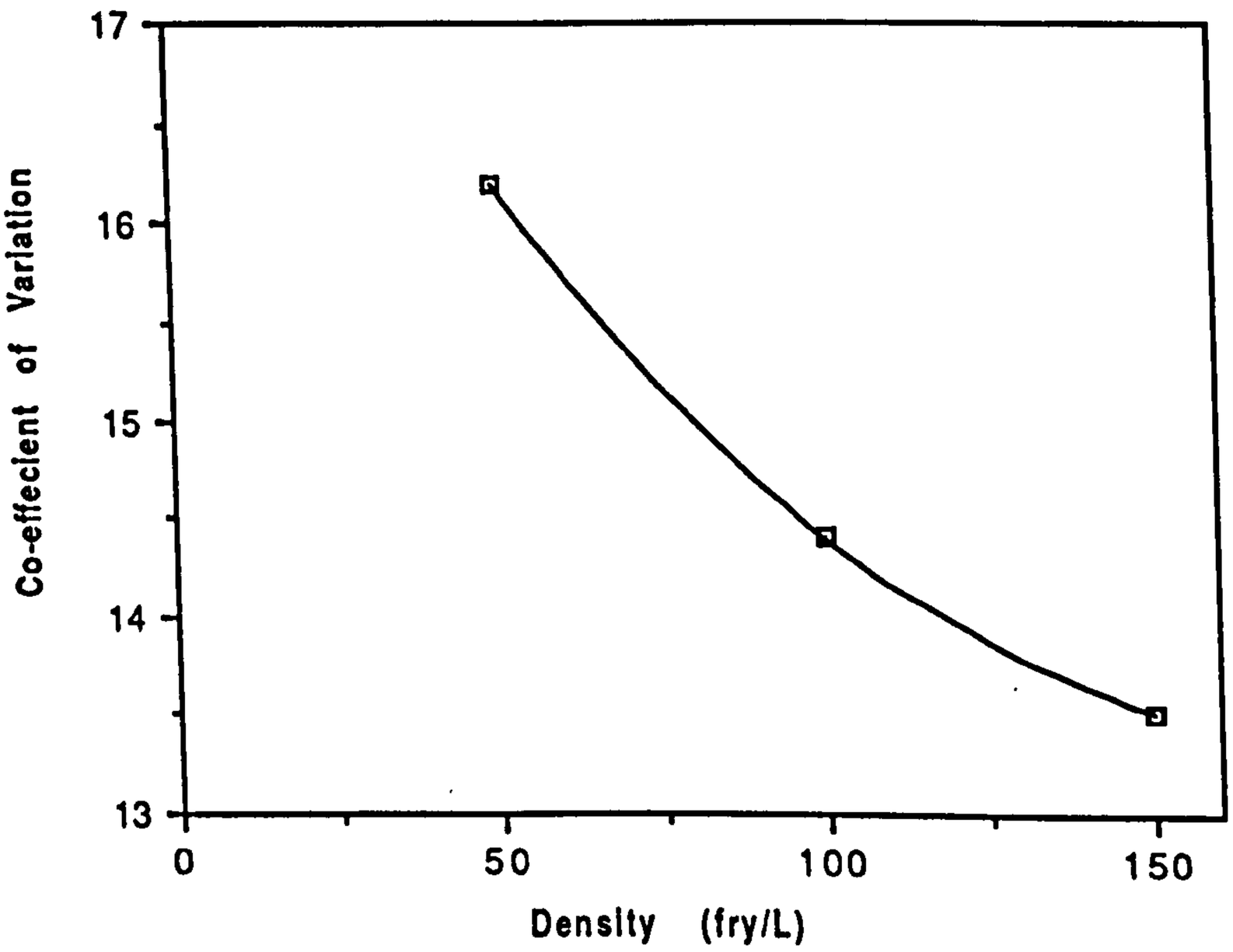


Figure 6.11: The change in mean coeffecient of variation in length of C. gariepinus fry in relation to stocking density

fewer non-cannibalistic deaths, than those maintained at 50 fry/l ($H = 6.353$, $D = 0.9985$, $P < 0.025$).

The size range of the population is presented as treatment growth depensation (Figure 6.11) for comparison with other studies. In addition, the mean coefficient of variation in length is presented for each treatment (Figure 6.12). Since the final treatment populations differed significantly in their means.

The size range of the fish, as measured by both parameters, decreased with increasing stocking density; however, these differences were not significant at the 5% level.

The mean surfacing rates of fry kept at different stocking densities are displayed in Table 6.2.

The fry production rates at high stocking density were calculated from the growth and survival data obtained, and are summarized in Table 6.3.

6.4 DISCUSSION

The very good survival rate of fry at high stocking density indicates an amenability to intensive culture practices. Fry deaths over the period were due to type I cannibalism or non-cannibalistic deaths. The principal component of the non-cannibalistic deaths was probably fatal aggressive territorial encounters between two or more individuals, which are common with

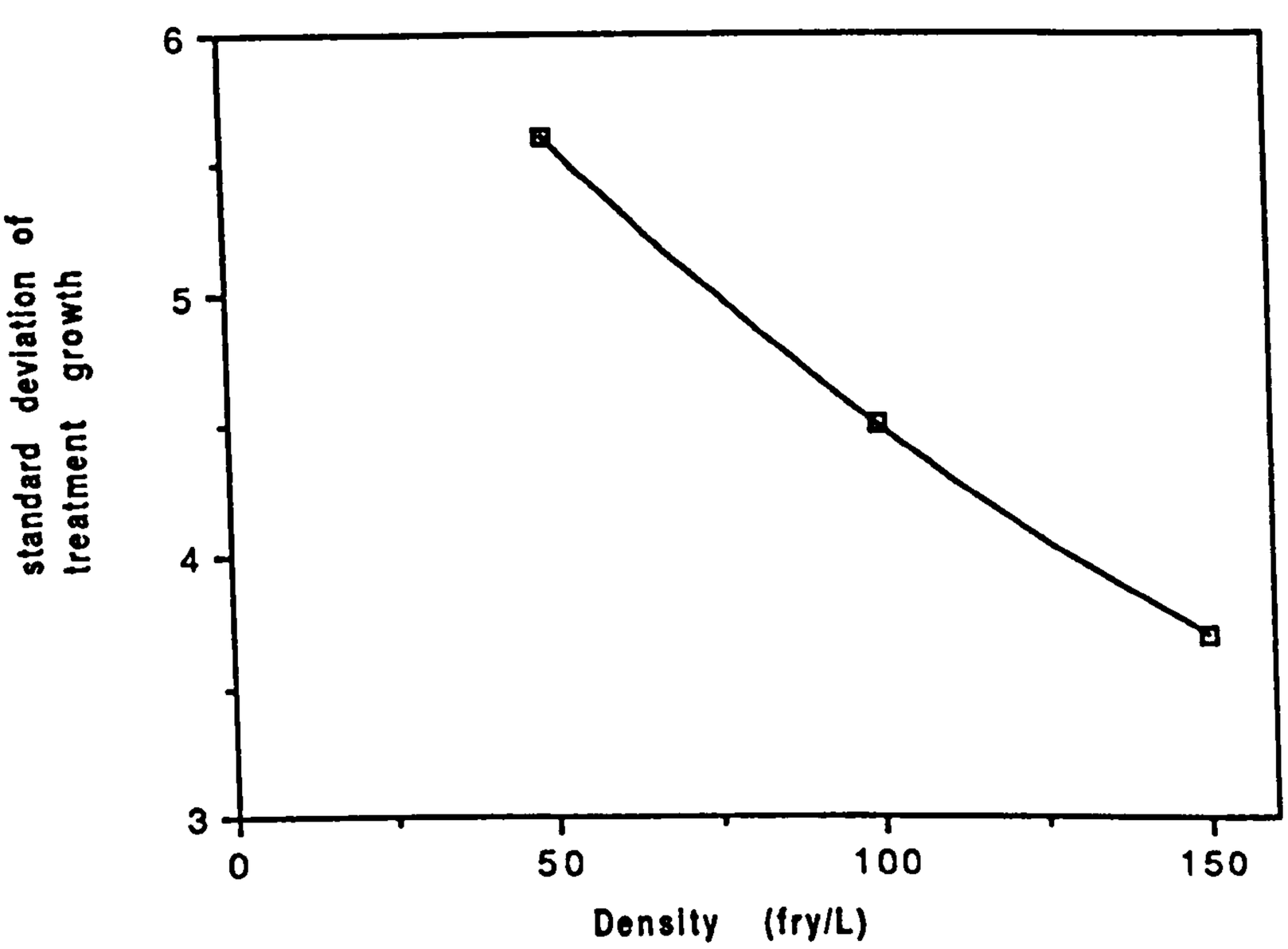


Figure 6.12: The change in standard deviation of treatment growth of C. gariepinus fry in relation to stocking density

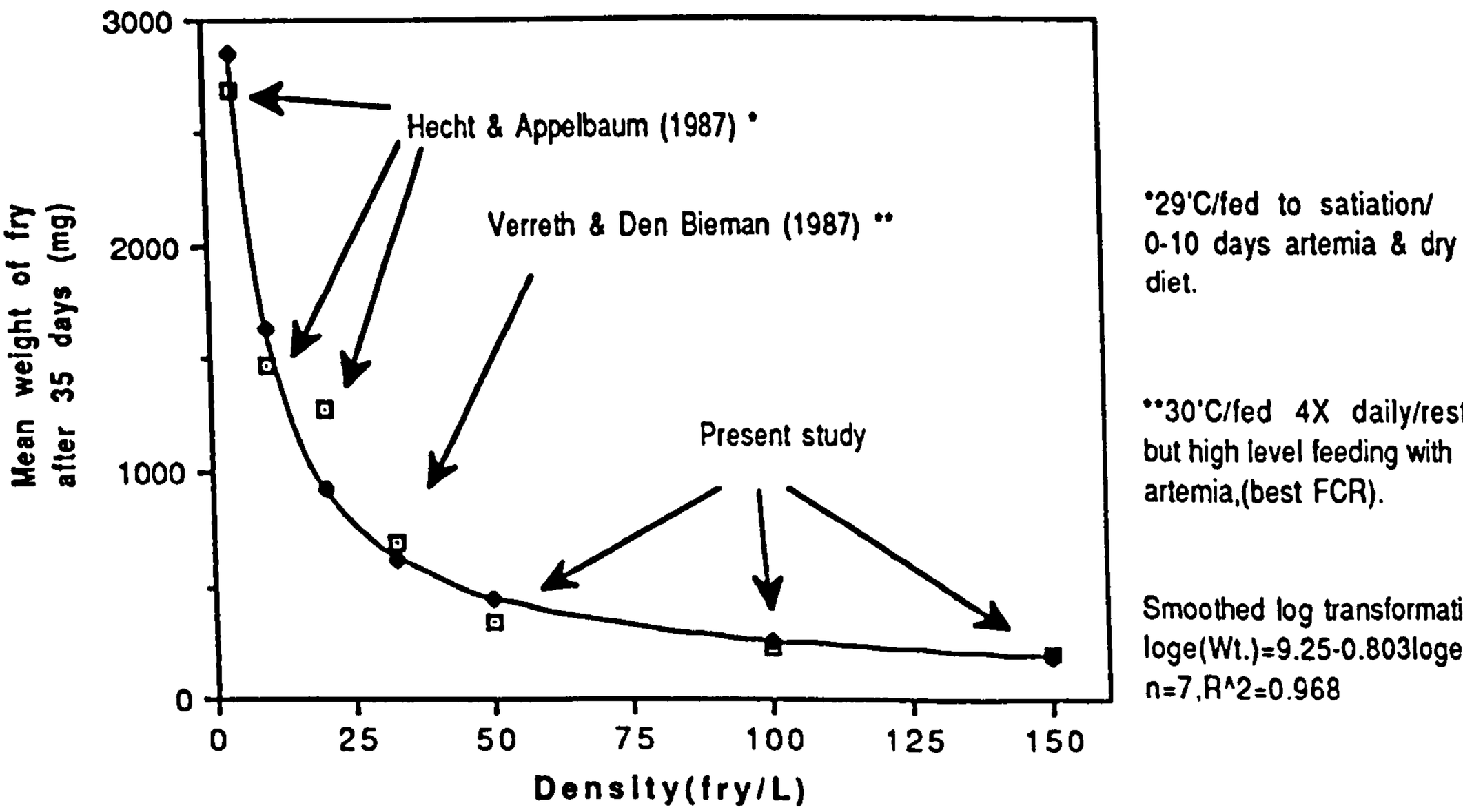


Figure 6.13: A comparison of the growth of C. gariepinus fry over 35 days from first feeding under similar conditions.

Table 6.2 *Mean surfacing rate of fry kept at different stocking densities*

Stocking density (fry/l)	Mean surfacing rate per fish per minute	Standard deviation	95% Cl
1	0.70	0.67	0.83
2	2.80	0.67	0.83
3	2.53	0.42	0.52
4	2.65	0.35	0.44
5	3.025	0.34	0.42

Table 6.3 *A summary of fry production of C gariepinus at high stocking density*

Stocking density (fry/l)	Mean fish weight (mg) after 35 days	% survival	Production g/l
50	360	90.5	16.290
100	240	91.67	22.001
150	200	93.65	28.095

young *Clarias gariepinus* (Hecht and Appelbaum, 1988); since there were no large or sudden physiochemical fluctuations, no disease problems, no type II cannibalism (consumption of whole siblings) and no evidence of handling stress (eg post weighing). This is in contrast to the effect of handling on larvae (discussed in 5.4) which are apparently less robust.

The relative importance of the two principal causes of death varied with stocking density, as is apparent from Figure 6.4 and Table 6.1. At above 100 fry/l cannibalism was the principle cause of fry death. At lower stocking densities aggressive encounters were more commonly observed and non-cannibalistic deaths accounted for nearly 79% of fry mortality at 50 fry/l. This may have implications for the type of culture environment which should be provided. At densities above 100 fry/l shelter (which suppresses cannibalism) (Hecht & Appelbaum 1988) could be provided. At lower densities, however, shelter, which has been shown to increase territoriality (Hecht & Appelbaum 1988) should not be provided. Survival rates in the present trial, without shelter, testify to the success of such culture conditions when sufficient feed is provided.

A similar pattern of aggressive behaviour in relation to density is discernable from the data of Hecht & Appelbaum (1988). The mean number of aggressive territorial acts was demonstrated to decrease with increasing stocking density, whereas the mean number of cannibalistic acts was demonstrated to increase.

High stocking density has been shown to reduce the rate of aggression in a range of other fish species, eg. trout, *Salmo trutta* L. (Kalleberg 1958), Atlantic salmon, *Salmo salar* L. (Kalleberg 1958; Keenleyside & Yamamoto 1962), medaka, *Oryzias latipes* (Temminck et Schlegel)Pisces, Cyprinodontidae (Magnusson 1962), rainbow trout, *Onchorynchus mykiss* (Walbaum) (Yamagishi 1962), and Siamese fighting fish, *Betta splendens* Regan (Goldstein 1975). The most probable reason for this is that benefits conferred by the dominance of a piece of territory at low density are outweighed by the inability or greater energy cost of territorial defence at high density (Li & Brocksen 1977). From non-cannibalistic death rates observed in the present study (Figure 6.9), it would appear that territoriality in *C.gariepinus* fry is significantly depressed by increasing stocking density, and a significant linear relationship exists between non-cannibalistic death (most probably due to territorial aggression) and stocking density over the density range studied.

No significant difference in the rate of cannibalism was demonstrable over the range 50-150 fish/l. The highest rates of cannibalism, however, relate to the most densely stocked fish (Figure 6.6); probably as a result of the greater likelihood of sibling encounters during foraging at higher stocking densities. This is is agreement with findings of Hecht and Appelbaum (1988), and in common with other cannibalistic species eg. koi carp, *Cyprinus carpio* L (Van Damme, Appelbaum and Hecht 1989), and walleye, *Stizostedion vitreum vitreum* (Mitchill) (Li and Mathias 1982; Krise and Meade 1986).

Although the rate of death from both causes varied with stocking density, there were marked similarities in the temporal pattern of deaths at the three densities. Within all newly established populations, individuals predisposed to cannibalism by virtue of their size or behaviour rapidly succumbed to those individuals best equipped to cannibalise. During the same initial period, the frequency of lethal aggressive territorial encounters tended to peak. Following the establishment of *status quo*, deaths from this source decreased at all densities.

Both cannibalistic and non-cannibalistic deaths at this time may be associated with the onset of airbreathing (as discussed in 5.4). At 150 fish/l the initial peak in non-cannibalistic deaths was small, and of much shorter duration than that at the lower densities.

Around day 30 there was a second peak in cannibalism at all densities which was more marked at higher density and corresponded to the time of weaning fry onto 1300 µm crumbs from 790 µm particles.

Weaning represents a short period of time during which readily recognisable feed particles are substituted for different or larger feed particles, previously unassociated with feeding. It is likely that a decrease in the quantity of recognisable feed particles increases foraging for other sources of nutrients. In species exhibiting cohort cannibalism this will include siblings. Similar observations were made with larvae (as discussed in 5.4).

Food availability was considered by Hecht and Appelbaum (1988) to be the most important experimental variable determining the rate of cannibalism in *C. gariepinus* fry. It has also been suggested to increase the rate of cannibalism of other species. eg. koi carp (Van Damme *et al.* 1989), pike, *Esox lucius* L. (Hunt and Carbine 1951; Kipling and Frost 1970; Mann 1982), walleye (Li and Mathias 1982; Krise and Meade 1986; Loadman, Moodie and Mathias 1986), common carp (Von Luckowicz 1979), sea bass, *Dicentracus labrax* (L.) (Katavic, Jug-Dujakovic and Glamuzina, 1989) and sea bream, *Archosargus rhomboidalis* (L.) (Houde 1975).

From the culturist's point of view, this underlies the importance of adequate provision of fry feed to cannibalistic species, and indicates a possible role for the provision of shelter during weaning periods.

C. gariepinus fry growth is clearly negatively density dependent (Figure 6.3). At the high stocking densities used in the present trial, growth rate decreased curvilinearly in relation to increasing stocking density.

A comparison of the growth of *C. gariepinus*, over 35 days from first feeding, from a range of similar studies by various authors (Figure 6.13), reveals a curvilinear relationship over a wide range of stocking densities (5 fish/l to 150 fish/l; Log_e weight (Mg) = 9.25 - 0.803 Log_e density (Fish L^{-1}), $n = 7$, $r^2 = 0.968$). A similar relationship has been demonstrated between weight gain over 14 days from first feeding and initial larval stocking density (5.3).

An increased metabolic rate amongst densely stocked fish has been suggested to account for reduced growth at high fish density in other species (Yamagishi 1962: Li and Brocksen 1977).

Metabolic rate may be inferred from the rate of oxygen uptake, which is linearly related to surfacing to gulp air in air breathing fish (Vivekanandian and Pandian, 1977). In the present study this was demonstrated to increase significantly ($P < 0.05$) with stocking density (Table 6.2) in C. *gariepinus* fry whereby Log_e surfacing rate (Min^{-1}) = 0.83 Log_e density ($fish\ l^{-1}$) - 0.058 (r^2 = 0.86). For technical reasons, this effect was not quantified directly at high stocking density. Of interest, however, is the close agreement between the rate of decrease of weight with density (b = -0.803) and the rate of increase in surfacing rate with density (b = 0.83). The basis for density dependent growth in C. *gariepinus*, however, remains unclear.

The weight of fry produced per unit volume is clearly increased with increasing stocking density over the range studied, although individual fry weight is decreased.

6.5 SUMMARY

The growth and survival of *Clarias gariepinus* (Burchell) fry was investigated at high stocking density. Significant increases in mean fry weight, and concomitant significant decreases in specific growth rate, were recorded over successive 5-day periods. Fry growth was negatively density dependent. Fry

survival was in excess of 90% in all treatments. Increasing stocking density between 50 and 150 fish/l altered the pattern of mortality; non-cannibalistic deaths decreased significantly with increasing stocking density though cannibalism did not significantly increase. Periods of weaning fish onto larger feed particles were associated with temporarily increased rates of cannibalism.

Chapter 7: An investigation of tank design and water flow rates appropriate for *Clarias gariepinus* in hatcheries.

Our houses are such unwieldy property that we are often imprisoned rather than housed in them.
Thoreau "Economy", Walden (1854)

The information contained in Chapter 7 has been accepted for publication in Aquaculture and Fisheries Management edited by D H Mills, R J Roberts and S J De Groot, published by Blackwells.

7.1 INTRODUCTION

Optimal conditions, procedures and equipment for hatchery rearing of *Clarias gariepinus* need to be identified and the tank in which fish are housed in particular is a vital and often underestimated piece of aquaculture technology (Cripps, 1990). Its design should be the product of both biological and engineering considerations, including hydrodynamics, economics and ergonomics. In particular the specific requirements of the species to be cultured should be taken into account.

African catfish are essentially benthic, though they use much of the water column during foraging and from an early age surface regularly to breath atmospheric oxygen. As a result, tank design characteristics such as water depth and tank volume may affect their growth and/or survival.

In addition African catfish are essentially sedentary, a characteristic which may contribute to the species efficient feed conversion (Hogendoorn, Janssen, Kroops, Michiels, Ewijk and Hees; 1983). Current velocities which cause swimming in culture tanks may negate this energetic advantage and should be avoided where possible. An appropriate flow rate for fry will likely be a compromise between tank hygiene (flushing) and fish energy expenditure (current velocity). Optimal flow rates for larvae will additionally need to

supply sufficient dissolved oxygen. The current velocities which different flow rates generate will in turn depend upon tank design.

7.1.1 Tank design choice

Common tank designs may be characterised as: square, rectangular (raceways), D-ended (or Foster-Lucas raceways) and circular.

Square tanks allow a more efficient use of floor space than other designs (Klapis and Burley, 1984) but significant modifications are required of inflows and outflows in order to prevent poor water circulation. Rectangular raceways on the other hand are prone to uneven flows and fish distribution (Heskell, Davis and Reckahn, 1960) and require large flow rates to alleviate the problem (Murai, 1979). In addition, baffles may be required to generate a bottom cleaning action (Burrow and Chenoworth, 1970; Christensen and Chenoworth, 1974; Westers and Pratt, 1977 and Schlieder, 1984). In spite of this they have been recommended for African catfish fry rearing (Janssen, 1989). Foster-Lucas (D-ended) raceways are subject to turbulence in their D-ends, resulting in low velocity areas, short circuiting and poor water circulation (Burrows and Chenoworth, 1955). This can to some extent however be improved by jets, guide vanes to reduce turbulence and bottom drains in suspended solids settlement areas (Burrows and Chenoworth, 1970).

Circular tanks with a central drain in which the water inlet produces a tangential velocity component are commonly favoured for fish culture because of the even flow distribution patterns which pertain within them (Burrows and

Coombes, 1968; Brown and Gratzek, 1980) as well as the maintenance of self cleaning properties under conditions of restricted flow (Pyefinch, 1970).

From a biological and an engineering viewpoint smooth flow dynamic characteristics that produce rapid mixing of influent and tank water are important design criteria (Westers and Pratt, 1977). Potential benefits to the culturist include even distribution of inputs, of water quality and of culture organisms. In addition, flow characteristics which facilitate the clearing of solid wastes even at low flow rates are beneficial to tank hygiene.

7.1.2 The Present Study

Circular tanks were selected for further investigation with respect to their suitability for rearing the early stages of *Clarias gariepinus*.

The present study involves a series of experiments, conducted to investigate the effect of changes in circular tank dimensions and flow rates on the growth and survival of African catfish fry.

Many interconnected variables related to tank design, may affect the growth and survival of fish. These include water depth, tank volume, stocking density in terms of unit volume and unit area, depth to diameter ratio (and its effect on tank hydrodynamics), flow rate and current velocity. Separate experiments were conducted to investigate these and are described under the following headings:

7.2.1 The effect of a small increase in water depth

7.2.2 The effect of an increase in tank volume

7.2.3 The effect of an increase in diameter to depth ratio

7.2.4 The effect of flow rate on current velocity and its relation to tank dimensions and fish size

7.2 METHODS AND MATERIALS

For each experiment *Clarias gariepinus* fry were produced according to the procedure detailed in 6.2.1. On the day following the onset of airbreathing, fry were introduced into the treatment tanks. All tanks were attached to the recirculation system described in 5.2.3.

In each case feeding was *ad libitum*, three times daily between 0800 and 1800 at 4 hourly intervals, with a commercial trout starter diet (BP Nutrition No 2, 54% crude protein, 790 µm crumb).

Trials 7.2.1, 7.2.2 and 7.2.3 were conducted over 20 days from day 15 (following first feeding) to day 35. Weight and numbers surviving were measured on five occasions (on days 15, 20, 25, 30 and 35) as described in 6.2.1. Details of the tank dimensions and stocking densities are given in table 7.1.

7.2.1 The effect of a small increase in water depth

African catfish first rise to the surface to gulp air, after 12-14 days, when cultured at 30°C (see 5.4). The travel cost associated with aerial respiration will be related to the depth of water in which they are reared. This cost has

Table 7.1: *The dimensions and stocking densities of the tanks used in experiments 7.2.1, 7.2.2 and 7.2.3*

Experiment	Tank	Bottom Surface area (m^2)	Depth (m)	Volume (L)	d:D	Stocking density (m^{-2})	Stocking density (L^{-1})
7.2.1 Tank Depth	A*	0.0227	0.029	4	-	1101	6.25
	B*	0.0227	0.114	4	-	1101	6.25
7.2.2 Tank Size	C	0.035	0.114	4	1.85	2857	25
	D	0.139	0.114	16	3.69	2878	25
7.2.3 Tank diameter to depth ratio	E	0.035	0.114	4	1.85	2857	25
	F	0.062	0.065	4	4.32	1613	25
	G	0.139	0.029	4	14.51	719	25
	H	0.636	0.006	4	150.00	157	25

* see figure 7.1 for tank design

d:D diameter to depth ratio

been demonstrated to be significant in another air-breather *Colisa chuna* Hamilton in 2.2m deep aquaria (Bevan and Kramer, 1986). Tanks used to rear African catfish would typically be much shallower (Viveen *et al* 1985, Janssen, 1989). In order to see if travel cost would be significant for fry a 400% increase in travelling distance was investigated in shallow tanks. Two tanks were constructed such that the flat tank bottom area and the total water volume were constant but the distance between the tank bottom and the water surface varied (Figure 7.1). Both tanks were stocked with 25 fry at a density of 6.25 fry L^{-1} (or 1101 fry M^{-2}), growth and survival are measured. (Preliminary observations had identified a reluctance of catfish to perch on smooth sloping surfaces and a preference for deeper flat surfaces).

7.2.2 The effect of an increase in tank volume

Container volume has been suggested to affect the growth rate of fish (rainbow trout fry, *Onchorhyncus mykiss* Richardson) (Kincaid, Bridges, Thomas and Donahoo, 1976). In their experiment with rainbow trout however, container volume (12.5L and 8.8L) was not the only variable and stocking density per unit volume also varied by 42%. Since stocking density is known to affect African catfish fry growth (see 6.5), the present experiment investigated the affect of tank volume *per se* on growth and survival.

Three replicates of two different sizes of tank were used to rear fry. In each case stocking density per unit volume ($25L^{-1}$) remained constant and per unit area remained within 0.73% (2857 and 2878 M^{-2} respectively). The diameter:depth ratio remained below 3.7 (1.85 and 3.67 respectively) such that

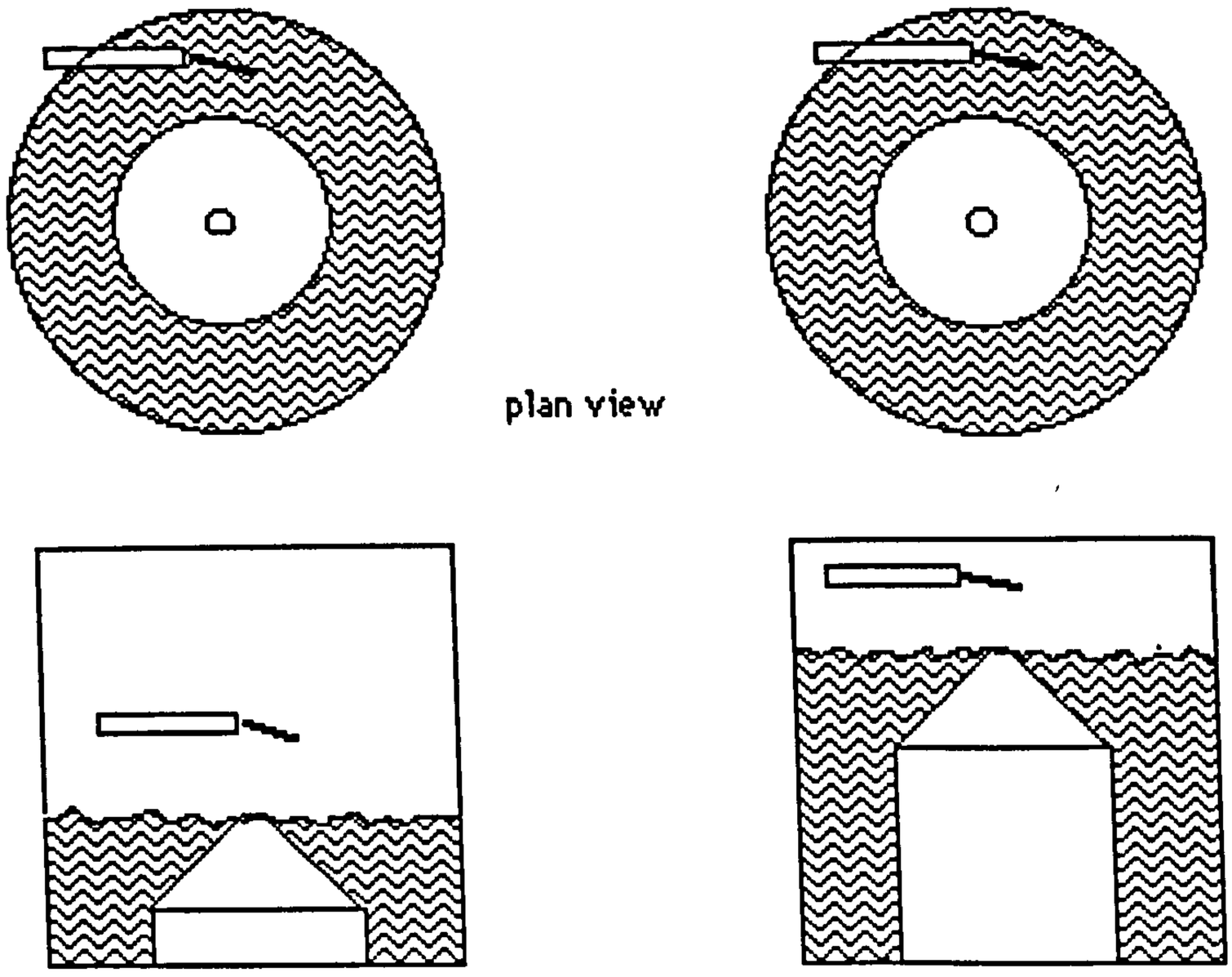


Figure 7.1 : The design of tanks A and B used to investigate the effect of water depth

hydrodynamic conditions within the tanks were essentially the same and depth was unaltered (0.114m). Volume (4L and 16L respectively) varied between the two treatments by 400%.

7.2.3 The effect of an increase in diameter to depth ratio

The hydraulic similarity rule (Larmoyeux *et al*, 1973) states that circular tanks having the same diameter to depth ratio are geometrically similar. If the inlets and outlets are also geometrically similar, the flow patterns should be identical within the range of usual peripheral current velocities (Larmoyeux, *et al*, 1973). Changing the diameter to depth ratio changes the geometric similarity of the tanks and may therefore change the flow patterns (Larmoyeux *et al, Op. Cit.*).

In order to see if diameter to depth ratio changes, affected fry growth and survival, three replicates of four treatment tanks of constant volume (4L) and with constant stocking density per unit volume (25 L^{-1}) were set up. The diameter to depth ratio of the treatment tanks were 1.85, 4.32, 14.51 and 150. The first two tanks with diameters less than five times their depth can be classified as deep tanks, whereas the two tanks with diameters more than ten times their depth can be said to be shallow (Larmoyeux *et al, Op. Cit*). 'Deep' and 'shallow' tanks would be expected to have different flow patterns (Cripps, 1990).

Varying diameter to depth ratio at constant volume and constant stocking density per unit volume results in a consequent variation in stocking density

per unit area.

7.2.4 The effect of flow rate on current velocity and its relation to tank dimensions and fish size

The effect of flow rate on current velocity may be considered independent of fry tank size *per se*, since changes in viscosity effects with tanks and flow rates suitable for fry culture are unimportant (Larmoyeux *et al* 1973).

However the velocity which a particular flow rate generates will depend upon the size and orientation of the inflow, the diameter to depth ratio of the tank and the location of interest within the tank, (Larmoyeux *et al, Op. Cit*).

In addition the maximum velocity which allows a fish to maintain station without swimming will depend on fish size.

In order therefore to provide a guide to appropriate flow rates for developing African catfish, the current velocity in different parts of deep fry tanks (diameter:depth < 2) and shallow fry tanks (diameter:depth > 14) generated by a horizontal single orifice inflow pipe set at flow rates between (0.6-4.6l/min) were recorded. The current velocity which caused sedentary catfish of varying sizes (13-100mm) to swim (in order to maintain station) was also quantified.

In addition the current velocities in different parts of a much larger (216l) shallow tank (diameter to depth = 10) were measured.

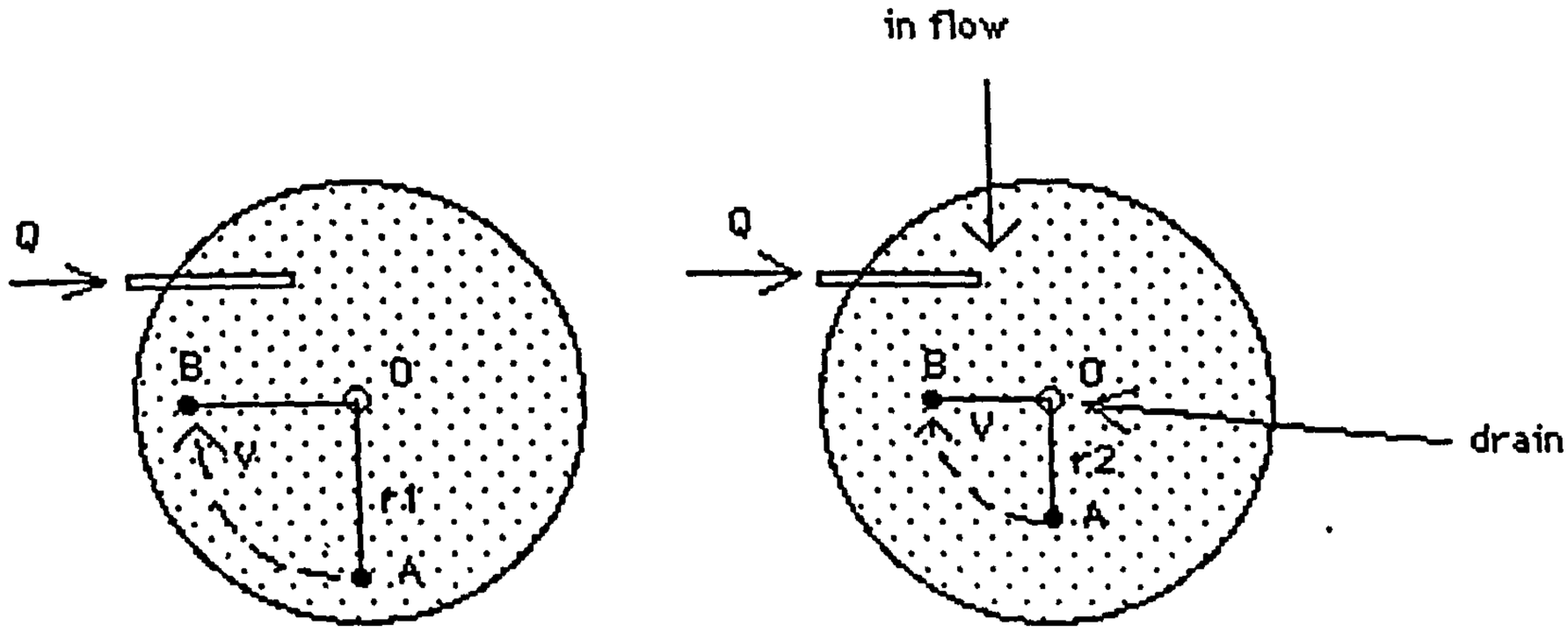
Current velocity was measured using a 2cm diameter spherical drogue with adjustable buoyancy. A stop watch was used to record the time taken for the drogue to pass between two points, marked on the tank bottom. Current velocity was measured just above the tank bottom, as shown in Figure 7.2.

7.2.5 Data Analyses

1. Because the magnitude of the variance of fry weight increases with age (as body weight increases) heteroscedasticity precludes the use of 2 way parametric analysis of variance for investigating the effects of changes in tank dimensions on fry weight over time. Therefore paired comparisons F tests were used (to examine the effect of both tank depth and of tank size) whereby each observation for one treatment is paired with one at the corresponding age for the other treatment. Homogeneity of treatment variances were confirmed using a Bartlett test.

2. A single classification analysis of variance with unequal sample size was used to investigate the effect of tank diameter to depth ratio on fry weight after 35 days. Equality of variances was confirmed using a Bartlett test and normality could be demonstrated graphically.

3. A single classification analysis of variance of two groups with equal sample sizes was used to investigate the effect of tank volume on both cannibalism and non-cannibalistic mortality following an arcsine transformation of the % mortality data. A Bartlett test was used to



Q = flow L min^-1
V = velocity cm s^-1 *
r1 =3 tank radius/4
r2 = tank radius/2
A & B = two points on the tank bottom such that angle AOB = 90'

*V=arc length AB/travel time

⟶ = drouge track

For each Q value the mean V was calculated from three drogue tracks at each position in the tank

Figure 7.2 : Diagram of the method used to investigate the effect of inflow rate on current velocity

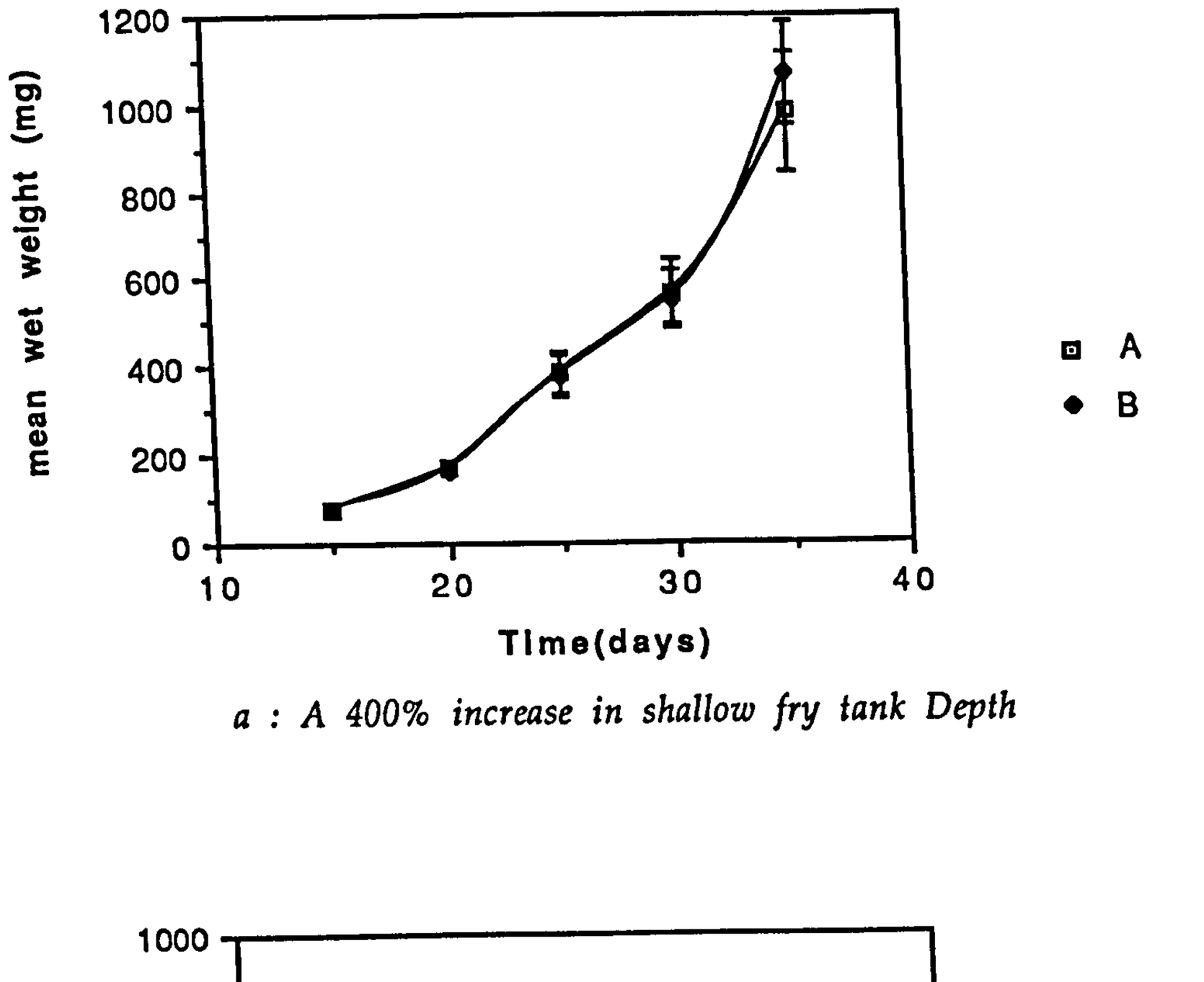
confirm homoscedasticity in each case.

4. The non-parametric Kruskal-Wallis analysis of variance was used to investigate the effect of fry tank diameter to depth ratio on both cannibalism and non-cannibalistic mortality after a Bartlett test revealed heterogeneity of variances in each case.

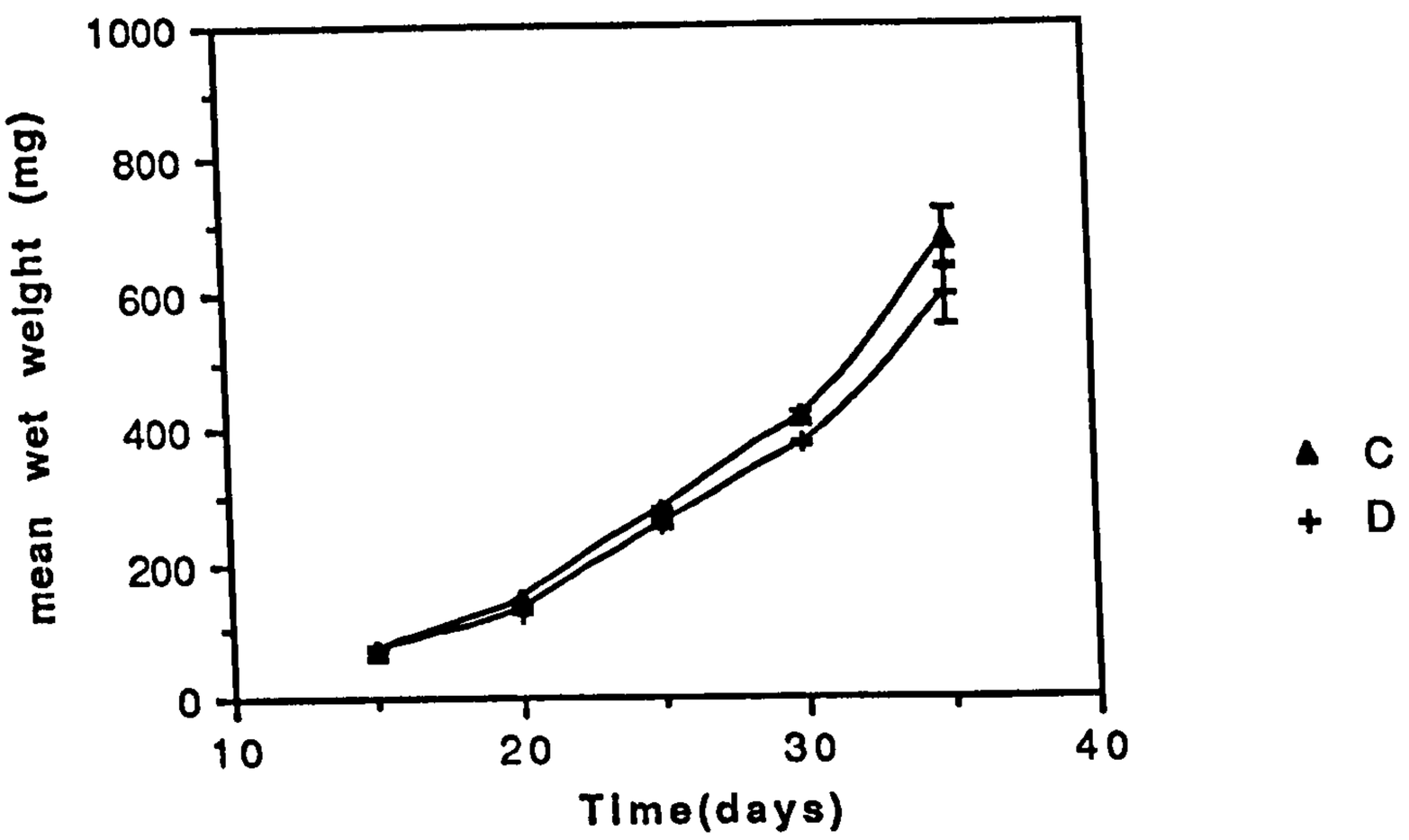
7.3 RESULTS

Increasing water depth from 0.029m to 0.114m had no discernable effect on fry growth ($F_{(1,4)} = 1.78$, $P < 0.05$). A comparison of growth in tanks of these different depths is shown in Figure 7.3a. Increasing tank volume from 4l to 16l, whilst keeping stocking density per unit volume and per unit area (of tank floor) constant also had no discernable effect on fry growth ($F_{(1,4)} = 5.44$, $P < 0.05$). A comparison of growth in 'large' and 'small' tanks is shown in Figure 7.3b. However, changing fry tank diameter to depth ratio (at constant volume and constant stocking density per unit volume) significantly affected final fry weight ($F_{(3,7)} = 24.85$, $P < 0.01$); whereby fish grew faster in shallow tanks than in deep tanks of the same volume. A comparison of growth in 'deep' and 'shallow' tanks is shown in Figure 7.3c.

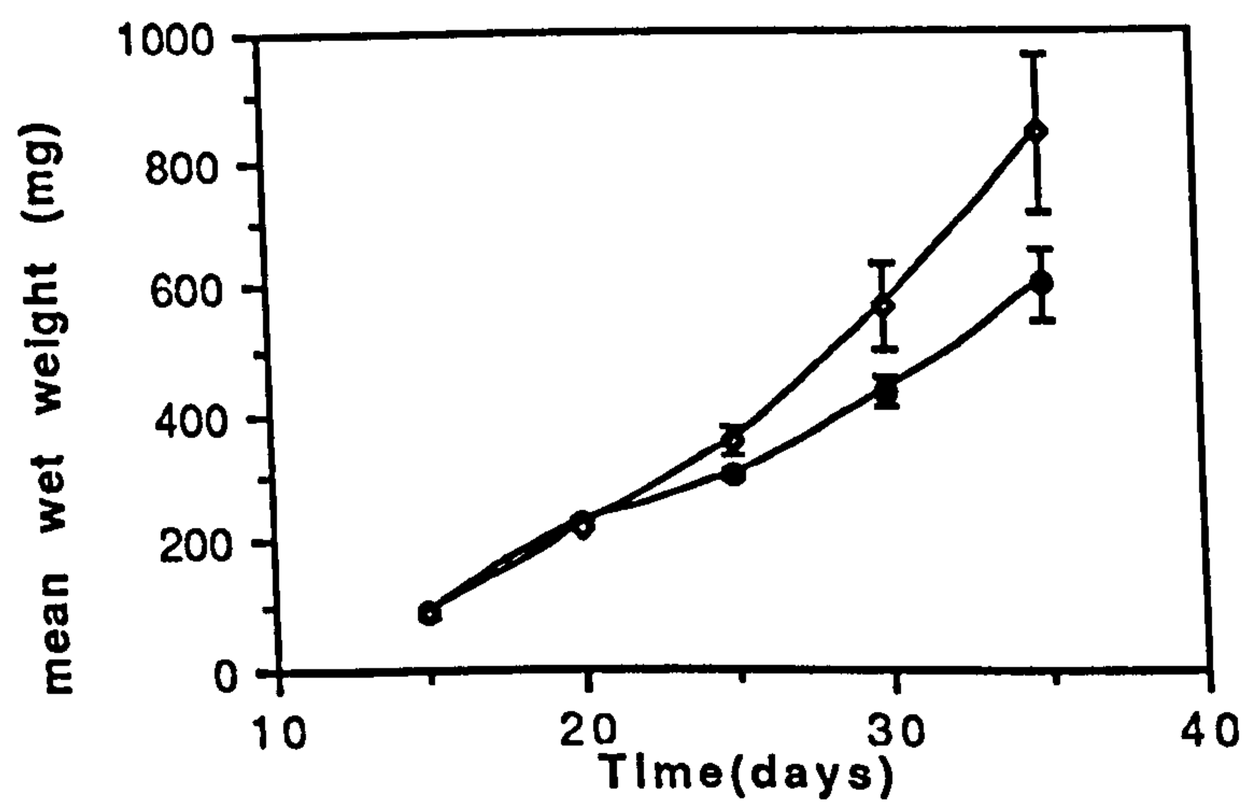
Cannibalism ($F_{(1,4)} = 2.41$, $P < 0.05$) and non-cannibalistic mortality ($F_{(1,4)} = 0.09$, $P < 0.05$) were apparently unaffected by tank volume. The tank diameter to depth ratio similarly had no discernable effect on cannibalism ($H/D = 5.32$, $P < 0.05$) or non-cannibalistic mortality ($H/D = 4.7$, $P < 0.05$).



a : A 400% increase in shallow fry tank Depth

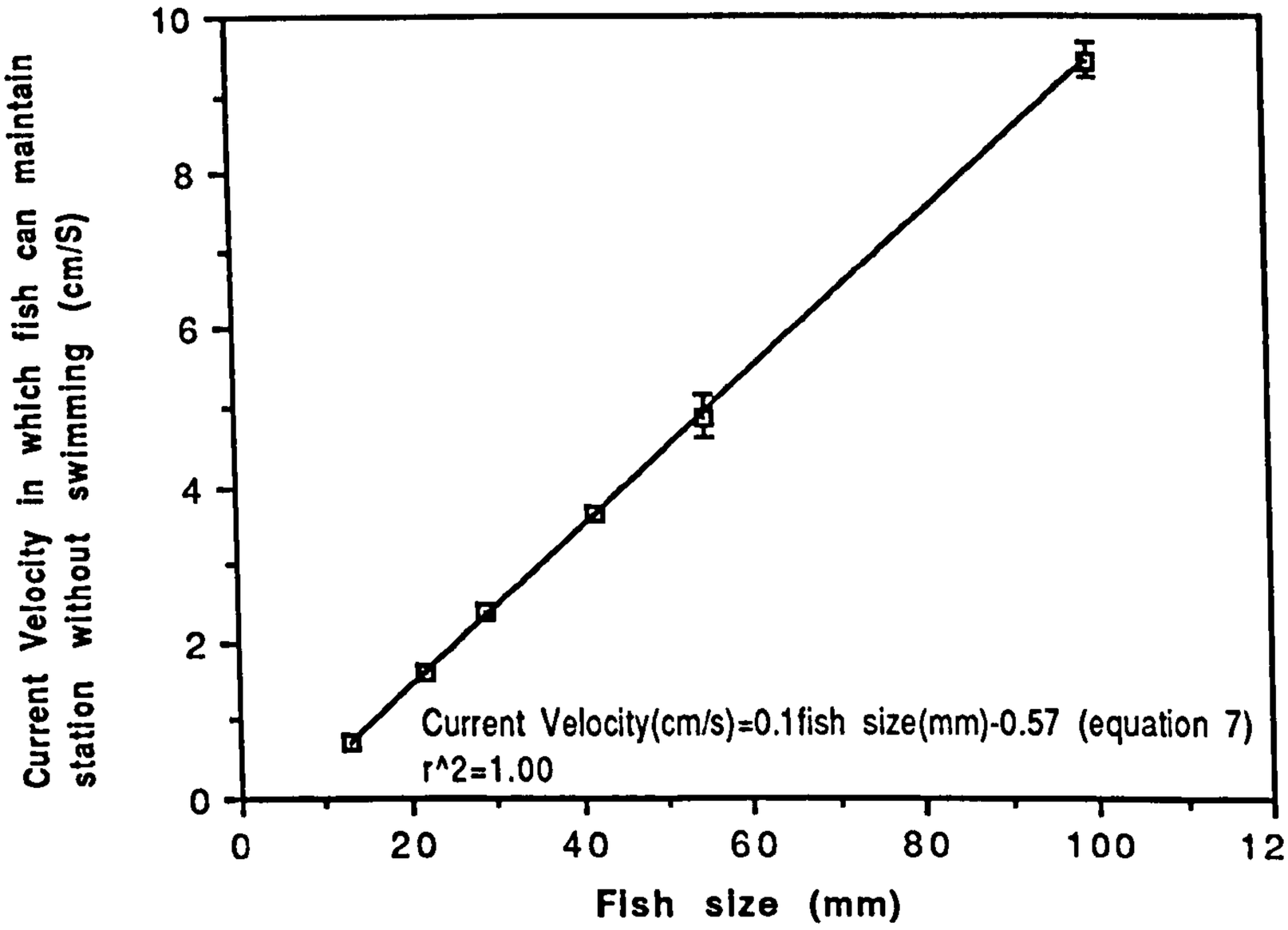


b : A 400% increase in tank Size (4 l-16 l)



c: An increse in Diameter : Depth from < 2 to >14

Figure 7.3 : The Effect of Variations in Tank Dimentions on Fry Growth



error bars are 95% C.L.

Figure 7.4 : The Maximum current velocity in which African catfish fry can maintain station without swimming

Table 7.2: *The effect of different tank designs on the survival of Clarias gariepinus (Burchell) Fry*

Experiment	Tank	% survival	% cannibalistic deaths	% non-cannibalistic deaths
i Tank Depth	A*	100	-	-
	B*	100	-	-
ii Tank Size	C	90.0	3.67	6.33
	D	87.5	5.5	7.0
iii Tank diameter to depth ratio	E	93.0	5.0	2.0
	F	93.7	4.0	2.3
	G	94.0	2.33	3.67
	H	94.5	1.0	4.5

* see Figure 7.1 for tank design

Refer to Table 7.1 for tank dimensions and stocking densities

Table 7.3: *Linear regression equations for current velocities generated by a range of flow rates in shallow and deep tanks by a single half inch horizontal inflow at a tangent to the tank radius*

Equation	Tank	Position	A	b	r	p
1	'Shallow' G *	peripheral	1.56	1.33	0.999	<0.01
2		central	0.69	0.17	0.974	<0.01
3	'Deep' E □	peripheral	3.4	1.67	0.996	<0.01
4		central	0.71	1.14	1.000	<0.01
5	'Shallow' 1.4m diameter **	peripheral	-1.12	1.67	0.993	<0.01
6		central	-0.021	0.73	0.993	<0.01

regression equation: $Y = A + b\,x$

where:

Y = current velocity in cms^{-1}

x = Flow rate in $1min^{-1}$ (between 0.6 - 4.6 $1min^{-1}$)

p = probability

* diameter to depth ratio greater than 14

□ diameter to depth ratio less than 2

** diameter to depth ratio equal to 10

There were no mortalities from either source in the tanks in which depth was varied. The relevant % data for all tanks are given in table 7.2.

The relationship between current velocity and *flow rate, centrally* and peripherally in shallow and deep tanks was in all cases linear (table 7.3). Every flow rate generated faster current velocities in deep tanks than in shallow tanks of the same volume. Peripheral current velocities were always faster than central current velocity.

In deep tanks both peripheral and central current velocity increased with increasing flow rate. In small shallow tanks the peripheral current velocity increased with flow rate but the central current velocity which was always less than $2cms^{-1}$, was relatively independent of changes in flow rate ($b = 0.173$). This was less so in the large shallow tank where both central and peripheral current velocities increased with flow rate.

The maximum current velocity in which sedentary African catfish fry can maintain station without swimming is shown in Figure 7.4. The relationship between the current velocity eliciting swimming (cms^{-1}) and fish length (mm), between 13 and 100mm, was found to be linear ($r^2 = 1.00$).

7.4 DISCUSSION

The growth of African catfish fry is clearly sensitive to the diameter to depth ratio of the tanks in which it is grown. Wide/shallow tanks are more suitable then narrower/deeper tanks of the same volume. The reasons for this are

probably manifold. Since the fish are resistant to water quality problems and independent of dissolved oxygen, the velocity of flow will have most effect on their growth rate (Cripps, 1990). Wide/shallow tanks are associated with slower current speeds (for a given flow rate) compared to narrower/deeper tanks of the same volume. They may therefore be preferable with respect to a diminished activity cost for fry. In addition, as flow rates increase, the slow moving central region of wide/shallow tanks may provide a refuge from current speeds which induce swimming.

Wide/shallow tanks also have a greater bottom surface area for settlement than narrower/deeper tanks. This maybe important in an essentially sedentary and benthic species in which increased stocking density per unit area may reduce growth.

A further potential benefit of shallow tanks is a reduction in the travelling distance required for aerial respiration, which for most air-breathing organisms has both energetic and temporal costs (Vivekanandan and Pandian, 1977; Kramer and McClure, 1981; Kramer, 1983).

Decreasing the depth of fry tanks by 400% (as in the present trial) will decrease the distance that fish must travel to gulp air by the same percentage. For example, between day 15 and day 35 (based on an example surfacing rate of 3 times per minute - from section 6.3) fry in 2.9cm deep tanks would travel 2.6km whereas fry in 11.4cm deep tanks would travel 9.8km. However the energetic cost of this additional activity in shallow fry tanks is either not large

enough to be measurable by the present study or the fry decrease their use of atmospheric oxygen in response to increased travel costs when dissolved oxygen content permits. Such a change in respiratory behaviour has been observed in another air-breather *Colisa chuna* (Bevan and Kramer, 1986) but was not quantified in the present study.

Increasing tank size apparently has little effect on African catfish fry growth and survival as long as important variables such as the diameter to depth ratio as well as stocking density per unit volume and per unit area remain relatively unchanged.

A guide to appropriate flow rates for rearing young African catfish is absent from the literature which possibly reflects the difficulties in dealing with so many inter-related variables. Hecht (1982) recommended a flow rate of 200l/h (3.33l/min) for larvae and a stocking density of 250-300 fish/l and Janssen (1989) proposed 3-5l/min for larvae stocked at 375-700 fish per l. However, neither describe an experimental or theoretical basis for their recommendations which would appear to be anecdotal.

An appropriate flow rate for larvae would need to supply sufficient dissolved oxygen without causing the fish to swim against the resultant current; a concomitant maximum tank biomass could therefore be defined in relation to mean larval weight.

ie. Maximum Tank Biomass = Maximum Oxygen Supply / Oxygen consumption per unit biomass

where maximum oxygen supply = maximum flow rate x dissolved oxygen concentration

The maximum flow rate for fry would be constrained only by the current velocity which it generates and the relationship between current velocity causing swimming and fish length. Since both of these relationships are linear and Log_e Fish weight is linearly related to Log_e Fish length (see 5.4) it follows that maximum flow rate (for larvae or fry) will be estimated by the equation:

$$\text{Maximum flow rate} = \frac{A + B\,(w/a)^{1/b} - \alpha}{\beta}$$

where A = regression constant) current velocity (cm/s) inducing
B = regression coefficient) swimming Vs. fish length (mm)

a = regression constant) Log_e fish weight (mg)
b = regression coefficient) Vs. Log_e fish length (mm)

α = regression constant) current velocity (cm/s)
β = regression coefficient) Vs. Flow rate (L/min)

w = fish weight (mg)

From equations 2 and 7

$$\text{Maximum Flow rate (L/min)} = 3.25\ W^{0.28}\text{(mg)} - 7.41 \quad \ldots 8$$

in 'shallow' tanks

From equations 4 and 7

$$\text{Maximum Flow rate (L/min)} = 0.48\ W^{0.28}\text{(mg)} - 1.12 \quad \ldots 9$$

in 'deep' tanks

From equations 6 and 7

$$\text{Maximum Flow rate (L/min)} = 0.756\ W^{0.28}\text{(mg)} - 0.549 \quad ..10$$

in a 1.4m diameter
(0.14m depth) tank

In order to calculate maximum larval biomass the maximum oxygen supply will be given by multiplying equations 8, 9 or 10 by the available dissolved oxygen concentration of the influent water (in mg/L). According to Janssen (1989) dissolved oxygen level should remain above 3mg/l or more safely 5mg/l in larval African catfish tanks. Therefore available dissolved oxygen will be equivalent to the concentration dissolved in the water in mg/l minus 5mg/l.

Oxygen consumption has not been quantified specifically for larvae, however from 3.2.6.2 an approximation of oxygen consumption in mg/kg/h is given by:

$$\text{Oxygen consumption} = \frac{649767W^{-0.25}}{1013 + 3.718(T)}$$

where W = Fish weight g
T = temperature °C

Thus by dividing maximum oxygen supply by oxygen consumption per unit biomass the predicted flow rates and maximum biomass for different types of circular tanks can be calculated. These are shown for selected larval weights in table 7.4.

Clearly the relationship between flow rate and current velocity is influenced more by diameter to depth ratio than tank size. 'Shallow' tanks which are

Table 7.4: *Predicted maximum flow rates and concomitant maximum biomass for different types of circular tanks*

Type of tank	Fish weight mg	0_2 consumption (at 30°C) mg/kg/h	Maximum flow l/minute	Maximum Biomass* kg
'Deep'	20	1537	< 0	-
(E)	30	1387	0.124	0.014
	50	1222	0.315	0.04
'Shallow'	20	1537	0.109	0.011
	30	1388	1.01	0.114
(G)	50	1222	2.31	0.29
1.4m diameter	20	1537	1.25	0.126
0.14m deep tank	30	1388	1.45	0.16
	50	1222	1.75	0.22

* assuming 100% saturation

associated with slower current velocities for a given glow rate can sustain a higher biomass per unit volume than 'deep' tanks. Scaling up however may increase the rate of change of current velocity with flow rate (see equations 1, 2,5 and 6). Thus equation 8 would tend to over-estimate tank capacity just prior to air breathing and under-estimate the tank capacity for smaller fish. The relationship between current velocity and flow rate should therefore be determined empirically for any given tank, as has been done for a 1.4m diameter tank (equation 5 and 6).

It is implied from table 7.4 that approximately 6,000 larvae (ie. c.50mg) can be accommodated in a 'shallow' tank just prior to air breathing. If stocked at 30 larvae/l a c.20l tank would be required, if diameter to depth ratio were 10 a 0.63m diameter (0.063m deep) tank would be appropriate. If stocked at 300 larvae/l a c.200l tank would be required. If diameter to depth ratio were 10 a 1.4m diameter (0.14m deep) tank would be appropriate. However, from the empirically derived flow rate/current velocity relationship its maximum capacity would be about 4,500 larvae (c.22.5 larvae/l). The relationship between maximum flow rate and fish weight would most accurately be described by equation 10.

7.5 SUMMARY

Circular tanks are appropriate for *Clarias gariepinus* culture. Wide/shallow tanks (with a diameter to depth ratio of about 10) are preferable to narrower/deeper tanks. The optimal flow rate for larvae will be one which provides sufficient oxygen yet does not generate a current velocity fast enough

to cause them to swim against it. However current velocity, for a given type and orientation of inflow, will depend particularly upon tank diameter to depth ratio and flow rate and will be related to position within the tank. Therefore for a given circular tank design a theoretical maximum flow rate and concomitant biomass can be estimated for a given mean fish size.

Once airbreathing begins the optimal flow rate for fry is simply that which does not elicit swimming.

Chapter 8: An estimate of Maximum daily Feed Intake of *Clarias gariepinus* larvae.

That all softening, overpowering knell,
The tocsin of the soul - the dinner-bell
Byron, Don Juan (1819-1824)

8.1 INTRODUCTION

Within the genetic potential of a species, biotic and abiotic factors limit maximum growth (Brown, 1957; Ivlev, 1961). The three most important factors are ration, body size and temperature (Stauffer, 1973; Elliot, 1975a, b). According to Stauffer (1973) ration can be viewed as the driving force, temperature the major rate controlling force and weight, a scaling factor that adjusts these rates to the size of the growing individual.

Since temperature affects the rate of consumption as well as the rate of metabolism, a change in temperature may increase or decrease growth rate depending on the nature of the food x metabolism x temperature relation for a species (Brett, 1979). In the case of African catfish a maximum feeding level is reached at 30°C, for the size range 0.3-70g (Hogendoorn, 1983). The temperature for fastest growth rate and the temperature preferendum of both larval and post-larval African catfish is corresponding 30°C (Hogendoorn, *op.cit.*; Britz and Hecht, 1987). Maximum larval growth rate may therefore be obtainable by maximising feed intake at this optimal temperature.

According to Brett (1979) the most important factors which bear directly on the maximum daily food intake of fishes include the duration of feeding (satiation time), individual meal size (stomach capacity), the time between meals

(feeding interval) and interactions of these. If stomach evacuation is closely related to return of appetite (Ware, 1972) the daily feed intake can be favourably adjusted by manipulating the size of ration and timing of its presentation.

The present experiment therefore attempted to quantify: satiation time, stomach capacity and return of appetite, in African catfish larvae fed decysted *Artemia* at 30°C and to estimate feed intake in relation to feeding schedule.

8.2 MATERIALS AND METHODS

8.2.1 An investigation of satiation time, stomach capacity, gastric evacuation and return of appetite

First feeding larvae were produced according to the procedure detailed in 5.2.1 and randomly allocated to fourteen 10l round tanks. Each tank received water via a single horizontal pipe and the flow was adjusted such that the larvae were not required to swim against the resulting current. The diameter depth ratio of the tanks was approximately 10.

The larval rearing, recirculation system is described in 5.2.3.

The larvae were fed, *ad libitum* three times daily at 0800, 1200 and 1600 with decysted but unhatched *Artemia* (Argentemia, 8702 152nd Ave, N.E. Redmond, WA, USA) as described in 5.2.2.

Following the first feed in the morning debris was siphoned from each tank

and on days 1, 2, 3, 4, 5, 7, 10 and 14, the following were recorded:

1. Satiation time - the time from the onset of the first morning feed, until all fish in the tank ceased to respond to continued addition of feed.

2. Stomach capacity - the mean number of cysts in the stomach of ten randomly selected larvae immediately after feeding to satiation; identified by post-mortem gastrectomy.

3. The weight of ten randomly selected larvae (as described in 5.2.4)

On day 6 or 7 of the trial (see Table 8.1a), following 24h without feed, the larvae in ten tanks (A-J) were fed to satiation with *Artemia*.

After various interfeed periods of between 0 and 24h (see Table 8.1b) the larvae were again fed to satiation. The second meal consisted of decysted unhatched *Artemia*, dyed with a vital lipid stain, Sudan black (by overnight immersion in a saturated solution followed by thorough washing in water). Following each deprivation period the satiation time and stomach capacity were recorded as before. The change in the mean number of undyed *Artemia* present in the stomach with increasing time (without subsequent feeding) was used to estimate gastric evacuation rate (G.E.R.). The change in the mean number of dyed *Artemia* consumed with increasing deprivation time was used to quantify return of appetite (R.A.).

Table 8.1 *The time of larval feeding and deprivation time (interfeed period) for each tank of larvae*

(a) Feeding schedule for larval tanks A-J with dyed and undyed *Artemia*

Time	Tanks fed to satiation with *Artemia*	Tanks fed to satiation with dyed *Artemia*
Day 6: 1600	H.I.J.	-
Day 7: 0800	A,B,C,D,E,F,G	A,H
1000	-	B
1200	-	C,I
1400	-	D
1600	-	E,J
1800	-	F
2000	-	G

(b) Deprivation time in tanks A-J

Tank	Deprivation time (interfeed period)
A	0
B	2
C	4
D	6
E	8
F	10
G	12
H	16
I	20
J	24

In a preliminary experiment to identify any larval preference for dyed or undyed *Artemia*, three tanks of larvae were offered either dyed *Artemia* or undyed *Artemia* or a 50:50 mixture of dyed and undyed. There was no significant difference in *Artemia* consumption amongst the three treatments ($P < 0.05$). In addition, no significant difference was observed between the ratio of dyed to undyed *Artemia* offered and those consumed by the group fed a mixture ($P < 0.05$) (see Appendix II).

8.2.2 Data Analyses

The following statistical analyses were carried out:

1. 95% confidence limits were calculated.

$$C.L. = \bar{Y} \pm t_{0.05[n-1]} \frac{S\bar{Y}}{\sqrt{n}}$$

2. A single classification analysis of variance with unequal sample size was carried out to investigate differences in stomach capacity at various deprivation times between 0-24h. The % body weight data was arcsine transformed and a Bartlett test established that the variances were homogeneous.

3. A Bartlett test on the satiation time data revealed heteroscedasticity; the non-parametric (Kruskal-Wallis) analysis of variance was therefore employed to investigate difference in satiation time with age.

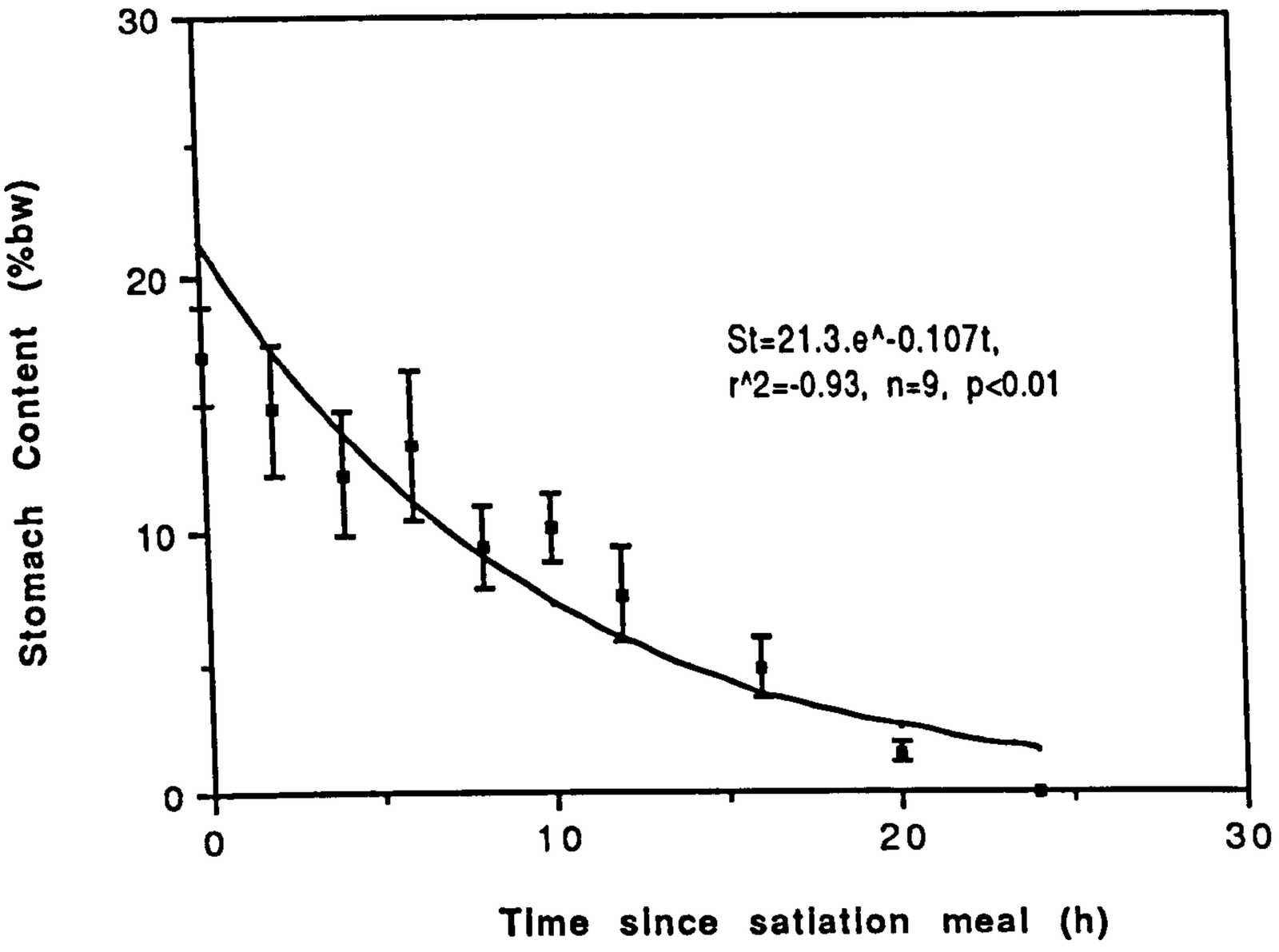
8.3 RESULTS

The evacuation of *Artemia* from the stomach of *Clarias gariepinus* larvae over time at 30°C is shown in Figure 8.1. The empirical data can be described by the exponential relationship $S_t = S_0 \cdot e^{-Rt}$ ($r^2 = -0.93$, $P<0.05$) whereby stomach content (following feeding to satiation) $S_0 = 21.3\%$ body weight, and gastric evacuation rate, $R = 0.107$. The return of appetite of the larvae is shown in Figure 8.2. The curve represents the level of consumption estimated from the gastric evacuation parameters calculated from the data in Figure 8.1 whereby consumption at time t, $C_t = S_0 (1-e^{-Rt})$.

Figure 8.3 shows the time taken for larvae to reach satiation in relation to larval age. From the fourth day of exogenous feeding to the end of the larval period, satiation time remained constant (mean = 29 mins 54 secs, $C1_{95}$ = 2 mins 24 secs) ($H = 8.246$, $P<0.05$). Satiation times recorded in relation to deprivation time (on day seven) fell close to the mean satiation time for the period regardless of deprivation time between 4h and 24h.

The mean increase in larval weight with time is shown in Figure 8.4. The data can be described by the exponential relationship $W_t = W_0 e^{kt}$ ($r^2 = 0.92$, $n = 8$, $P<0.01$) where initial weight, $W_0 = 3.4$ mg and specific growth rate for the larval period, $k = 0.24$.

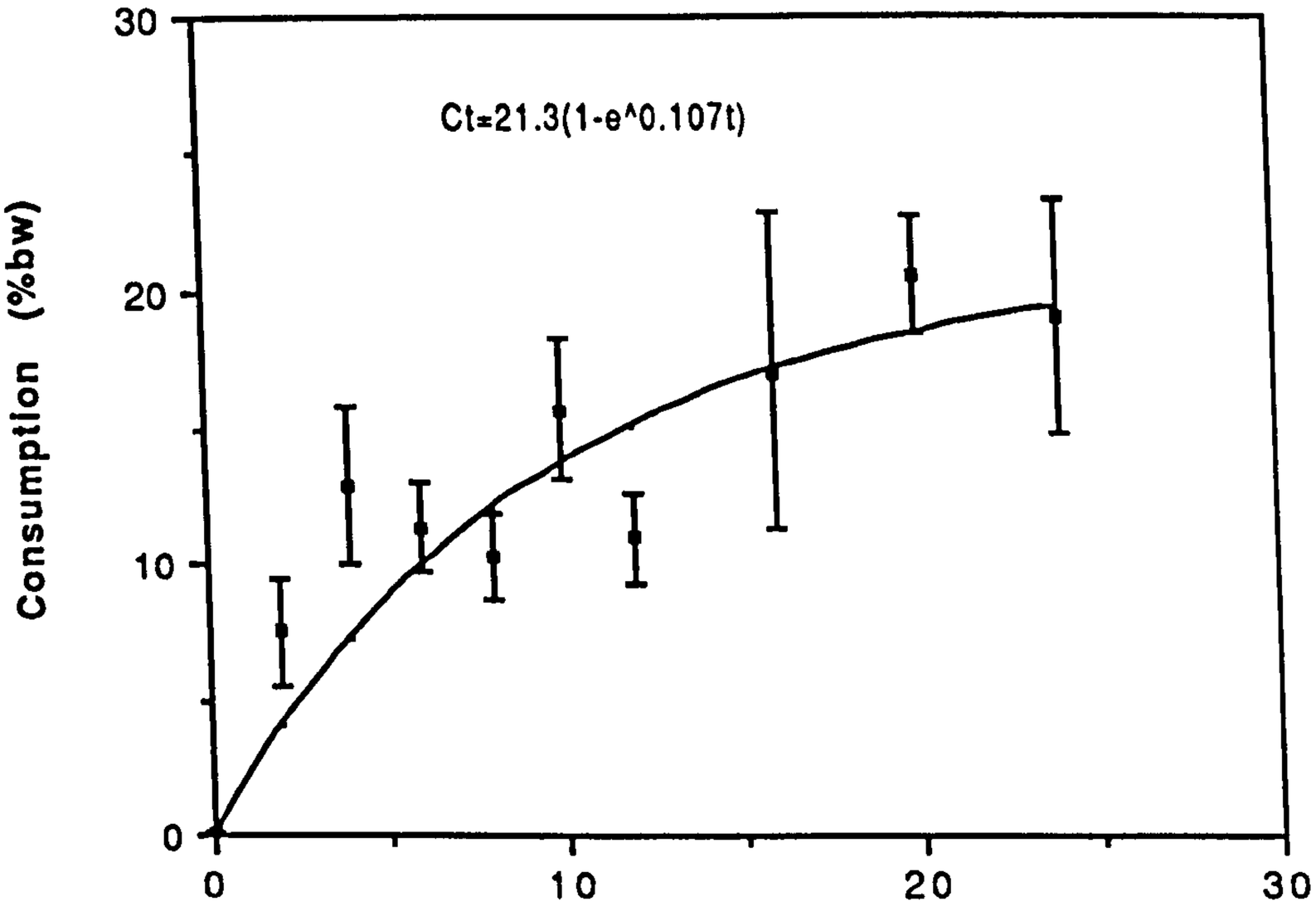
Figure 8.5 shows the increase in weight of feed ingested at a satiation meal with larval weight (which is a measure of stomach capacity). The relationship between stomach capacity (S_0) and larval weight (W) can be described by the



error bars are
95% C.L.

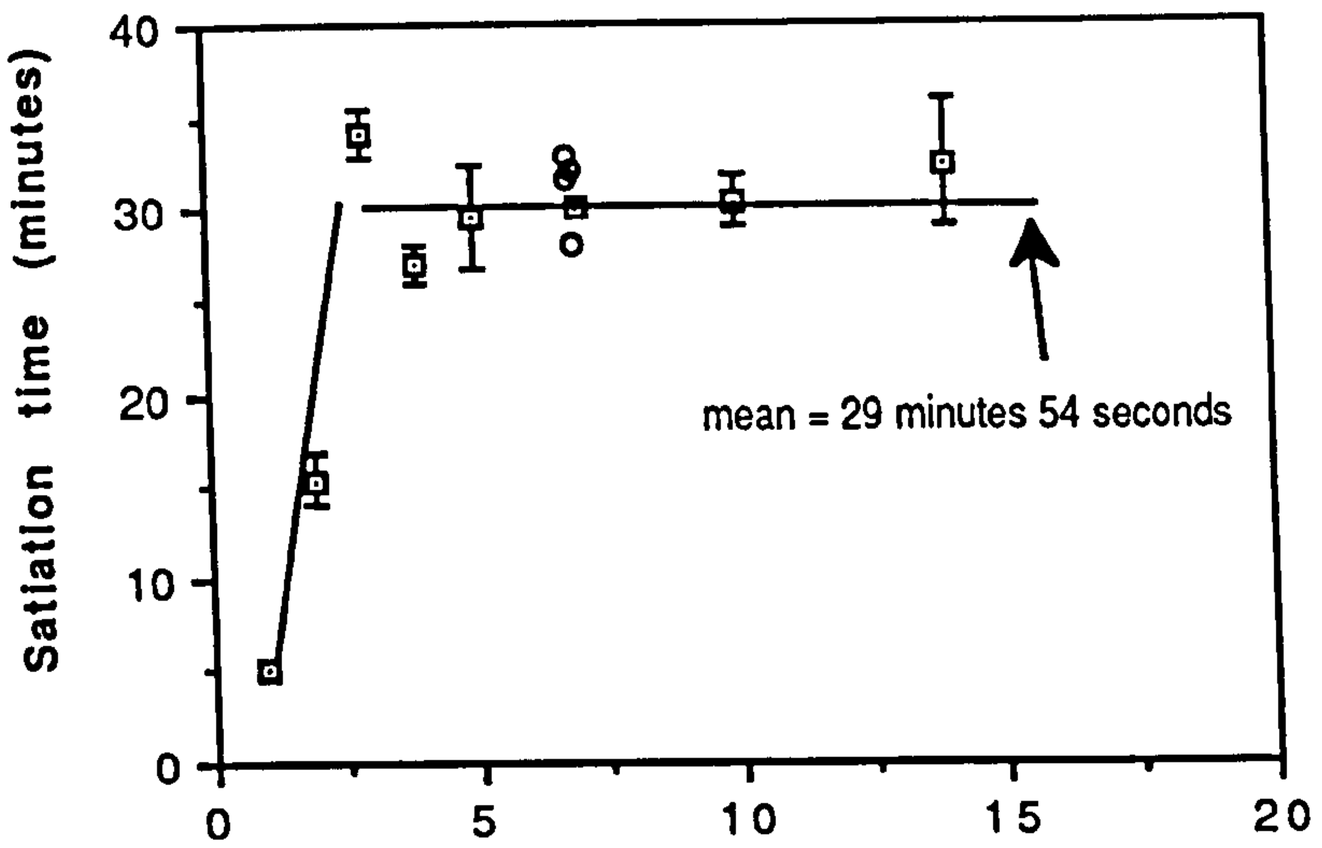
N.B. After 24 h no Artemia were found in the stomach, however since it was not known at what time complete evacuation occured this point was excluded from the G.E.R. calculation

Figure 8.1: Gastric evacuation of African catfish larvae fed Artemia at 30°C



error bars are
95% C.L.

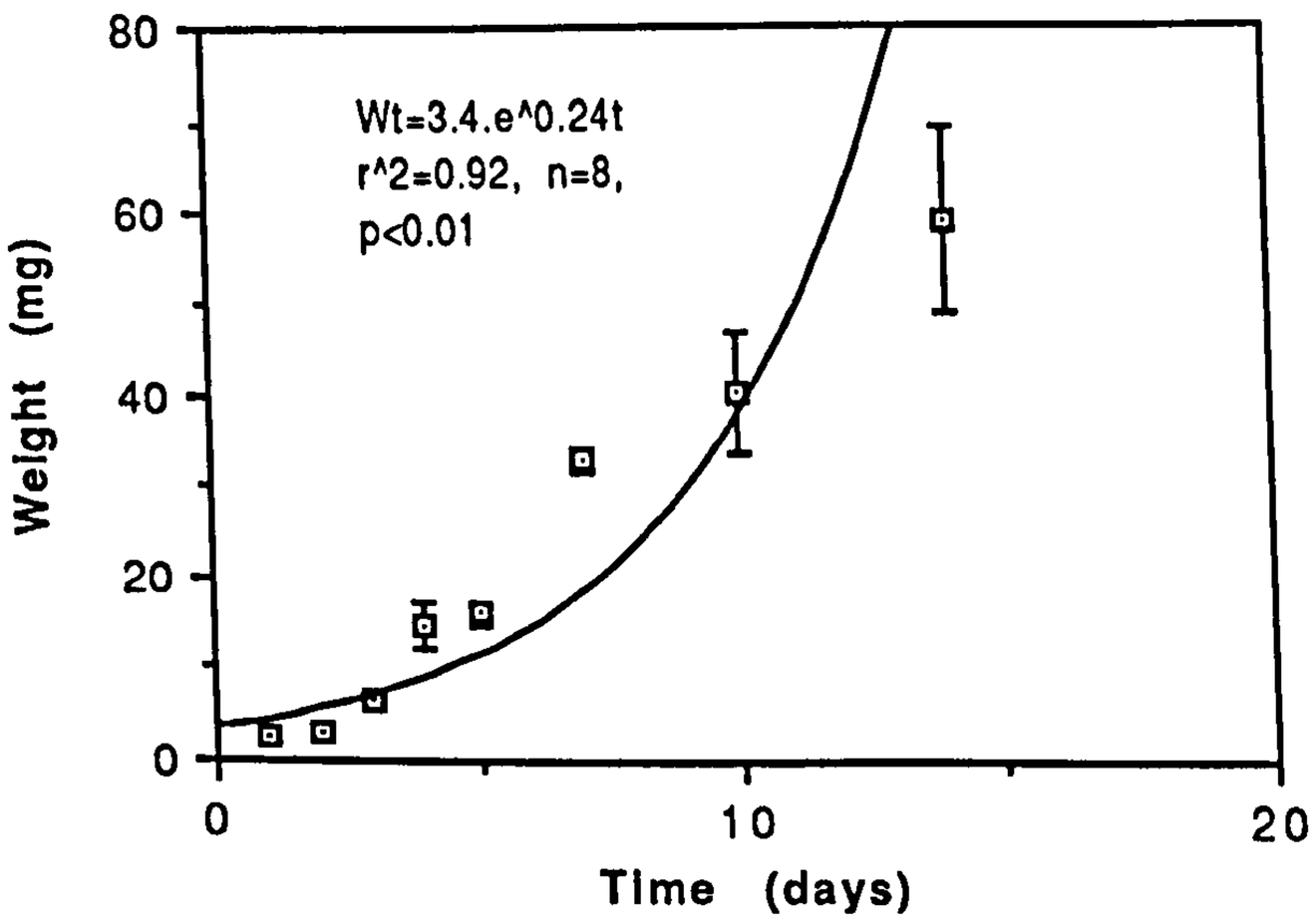
Figure 8.2: The return of appetite in African catfish larvae fed Artemia at 30°C



o represents satiation time in relation to deprivation time on day 7

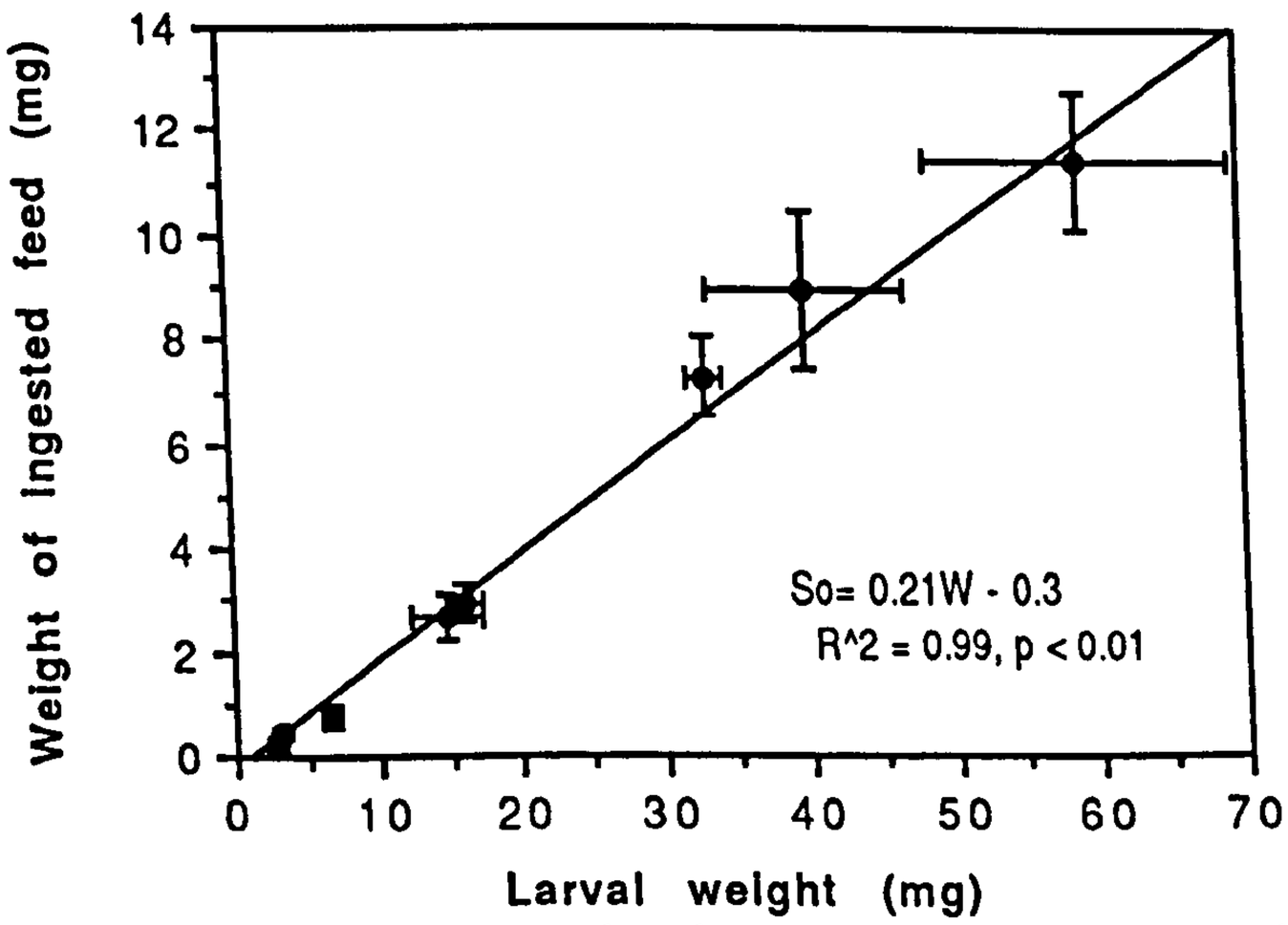
error bars are 95% C.L.

Figure 8.3: Satiation time for African catfish over the larval period



error bars are 95% C.L.

Figure 8.4: Growth of African catfish over the larval period



error bars are 95% C.L.

Figure 8.5: The change in maximum stomach capacity with larval weight

linear equation $S_{0mg} = 0.21\ W_{mg} - 0.3$ ($R^2 = 0.99$, $P<0.01$).

Stomach capacity measured in this way and expressed as a % of body weight, $S_0 = (0.21 - 0.3/W).100$, where W = larval weight (mg) increases rapidly during the first few days of exogenous feeding, as feeding becomes established, after which it represents a fairly constant proportion of body weight throughout the larval period (close to 21% bw).

During the determination of gastric evacuation rate and return of appetite, the maximum stomach capacity was measured as the weight of feed remaining in the stomach from the previous satiation meal plus the weight of feed ingested in the subsequent satiation meal at deprivation times ranging between 0 and 24h. The mean stomach capacity measured in this was 21.38% b.w. ($\pm$ 1.08 $C1_{95}$) and was unaffected by deprivation times between 0 and 24h ($F_{(9,84).05} = 1.87$, $P<0.05$); implying, therefore that regardless of time since the last meal the larvae were feeding until the space available in their stomach was filled (ie. consumption and gastric evacuation were inversely proportional).

It is interesting to note that a similar value for maximum stomach capacity of the larvae was estimated from feed intake over time, from feed intake in relation to deprivation time and from the sum of the remains of the previous satiation meal and the subsequent satiation amount.

8.4 DISCUSSION

Clearly no consensus exists with regard to the quantity to feed African catfish larvae or the frequency with which feed should be offered. Feeding to satiation has been practiced (Hogendoorn, 1980b; Hecht and Appelbaum, 1987; Appelbaum and Van Damme, 1988) as well as the provision of measured rations as a percentage of body weight (Uys and Hecht, 1985; Appelbaum and Van Damme, 1988) or of rations estimated on the basis of predicted growth rates (Verreth and Den Bieman, 1987; Verreth and Van Tongeren, 1989). Feeding frequencies used include continuous feeding over 24h (Hogendoorn, 1980b), feeding 8 times daily (Hecht and Appelbaum, 1987), 5 times daily (Hogendoorn, 1980b; Verreth and Van Tongeren, 1989), 4 times daily (Verreth and Den Bieman, 1987) and 3 times daily (Appelbaum and Van Damme, 1988).

No clear picture has so far emerged from experiments specifically designed to investigate the effect of feeding frequency. Hogendoorn (1980b) could demonstrate no significant effect on growth of doubling a 'satiation' ration or of altering feeding frequencies between 4 times daily and continuous feeding. Although Uys and Hecht (1985) found that feeding 25% bw day (on a dry weight basis) every 4h for 24h was significantly superior to feeding that ration every 2 h for 12h or every 6h for 18h. Making comparisons amongst experiments with *Clarias gariepinus* larvae, not specifically designed to investigate feeding is complex since most vary in ways likely to affect return of appetite. Comparison with other species is also limited since the frequency of feed presentation required to maximise intake is likely to vary with species (Kono and Nose, 1971).

It has long been considered, however, that feeding frequency can be scheduled according to the rate of gastric digestion (Brett and Higgs, 1970; Grove, Loizides and Nott, 1978). Indeed return of appetite is closely related to the degree of stomach emptiness in many fish species (Kariya, 1969; Kariya and Takahashi, 1969; Brett, 1971; Ware, 1972; Elliot, 1972, 1975b; Pandian, 1975; Grove, Loizides and Nott, 1978; Gwyther and Grove, 1981; Charles *et al*, 1984; Grove *et al*, 1985). This appears also to be the case with *Clarias gariepinus* larvae (Figures 8.1 and 8.2).

Although the modeling of gastric evacuation is still a contentious issue (Persson, 1986; Jobling, 1986, 1987; Macpherson *et al*, 1989) there is wide agreement (Jobling, 1986, 1987; Persson, 1986; Macpherson *et al*, 1989) that the exponential model of Elliot and Persson (1978) can be used to approximate the evacuation of small easily digestible feed organisms from the stomach (such as decysted *Artemia* used in the present trial). Where no subsequent feeding is taking place, ie. between feeds, the quantity remaining in the stomach at time t is given by:

$$S_t = S_0 e^{-Rt} \text{ ..... (1)}$$

(Elliot and Persson, 1978)

where S_0 = stomach content at satiation

S_t = stomach content at time t

R = gastric evacuation rate

Since the rate of return of appetite is inversely proportional to gastric evacuation, the maximum consumption (C) at any time after satiation (t) will

be given by

$$C_t = S_0 - S_t$$

which can also be written

$$C_t = S_0 - S_0.e^{-Rt}$$

ie.

$$C_t = S_0 (1 - e^{-Rt}) \text{ ..... } (2)$$

By expressing the maximum stomach capacity (S_0) as a % of body weight and the gastric evacuation rate (R) in terms of % body weight over time, then daily consumption (C 24h/day) as a % of body weight is given by:

$$C_{(24h\ day)} = 24/t.\ S_0 (1 - e^{-Rt}) \text{ ....(3)}$$

where S_0 = maximum stomach capacity

$1 - e^{-Rt}$ = the proportion of maximum stomach capacity that can be consumed at time t

$24/t$ = the number of meals per day at a feeding interval t.

Where it is agreeable to feed over 12h daily, the first time of feeding to satiation each day will be approximated by:

$$C_1 = S_0 (1 - e^{-12R}) \text{ ..... } (4)$$

(ie. where deprivation time = 12h)

and hence daily consumption (C 12h day) will be given by

$$C_{(12h\ day)} = S_0\ (1 - e^{-12R}) + 12/t.S_0\ (1 - e^{-Rt})\ \ldots\ (5)$$

The exponential model of Elliot and Persson (1978) fitted to the evacuation data for *Clarias gariepinus* larvae (Figure 8.1) predicts a gastric evacuation rate, R of 0.107. Where the range of fish size is small, such as over the larval period, fish size would not be expected to exert an important influence on gastric evacuation rate (Tyler, 1970; Elliot, 1972; Persson, 1981; Brodeur, 1984 and Lambert, 1985). Therefore R can be considered a constant over the larval period for the purpose of estimating daily consumption.

Maximum Stomach Capacity (S_0) for the whole of the larval period is approximately 21% of larval body weight. To correct for the reduced feed intake in young larvae, stomach capacity from Figure 8.5 can be approximated by $S_0 = (0.21 - {}^{0.3}/_{W}).100$ where W = larval weight (mg).

Equations 3 and 5 can therefore be simplied for *Clarias gariepinus* larvae as

$$C_{(24h/day)} = 24/t\ .\ 21\ (1 - e^{-0.107t})$$

$$C_{(12h/day)} = 15 + 12/t\ .\ 21\ (l - e^{-0.107t})$$

(since from equation 4 C_1 = 15%bw)

A summary of maximum daily feed (corrected for reduced feed intake in young larvae) in relation to feeding schedule is given in Table 8.2. The percentage of the daily feed intake which should be offered as the first ration each day and as subsequent rations for selected feeding intervals on a 12h/day schedule is summarised in Table 8.3. In all cases about 30 minutes is required to feed to satiation.

Feed intake is maximised by frequent feeding over 24h each day. However it is estimated that feeding every hour for 12h daily instead of every hour for 24h daily would reduce the maximum possible daily intake by only 20%; which may bring into question the economic advantage of feeding over 24h. Also of interest is the limited benefit of feeding hourly compared to every 2 h or even every 4h on a 12h daily schedule.

8.5 SUMMARY

The satiation time, stomach capacity, gastric evacuation rate and return of appetite was investigated in *Clarias gariepinus* larvae. The evacuation of food from the stomach was described by the exponential model. Gastric evacuation was found to be inversely related to return of appetite.

Both satiation time and feed intake as a % of body weight were found to increase rapidly over the first few days of larval feeding after which they remained constant.

A simple model is proposed for the estimation of maximum feed intake in relation to feeding scheduled and feeding frequency for *Clarias gariepinus* larvae.

Table 8.2: *Estimated Maximum Feed Intake (% body weight per day) for Clarias gariepinus larvae at 30°C in relation to feeding schedule*

Feeding schedule	Feeding interval (h)	Larval weight mg						
		5	10	20	30	40	50	60
24h daily	1	36.6	43.9	47.6	48.8	49.4	49.8	50.0
	2	34.7	41.6	45.1	46.2	46.8	47.1	47.4
	4	30.6	37.6	40.8	41.8	42.3	42.6	42.9
	6	28.5	34.2	37.1	38.0	38.5	38.8	39.0
	12	21.8	26.1	28.3	29.0	29.4	29.6	29.7
12h* daily	1	29.1	34.9	37.8	38.8	39.3	39.6	39.8
	2	28.2	33.8	36.7	37.6	38.1	38.4	38.5
	4	26.6	31.9	34.5	35.4	35.8	36.1	36.3
	6	25.1	30.1	32.6	33.4	33.8	34.1	34.2
	12	21.8	26.1	28.3	29.0	29.4	29.6	29.7

*When feeding 12h daily the first ration of the day should be larger than subsequent rations (see Table 8.3)

Table 8.3 *Percentage of daily ration to feed as first and subsequent rations.*

Feeding Interval	First ration (% daily ration)	No of subsequent rations	Subsequent ration (% daily ration)
1	37	12	5.25
2	38	6	10.33
4	41	3	19.67
6	43	2	28.5
12	50	1	50

Chapter 9: Controlled Hatchery Production of *Clarias gariepinus* Summary Conclusions

9.1 INTRODUCTION

The many disciplines which a heterogeneous activity like fish production draws upon are reflected in the varied facets covered in the preceeding chapters. As with every applied science the results of aquaculture research must be applicable to practical situations. The objective of this final chapter is to discuss the requirements, protocols and definitions identified for intensive primary nursing of *Clarias gariepinus* and thus to address some of the basic questions that concern farmers.

9.2 INTENSIVE PRIMARY NURSING - REQUIREMENTS, PROTOCOLS AND DEFINITIONS

9.2.1 Spawning

The wide variety of opportunities that exist for inducing spawning in African catfish are reviewed in 3.1. The administered substances which act high up the hypothalamic-pituitary-ovarian axis, such as LHRHa, are required in much smaller quantities than those, such as hormonal glycoproteins or steroids which act directly on the ovary. In situations where mature fish are available in large quantities such as on a table farm, induction of spawning by homoplastic hypophysation (Hecht *et al*, 1982) will likely be appropriate. In experimental situations where maintenance costs and space for larger fish is limiting, injection of a decapeptide, such as LHRHa, in conjunction with a dopamine inhibitor, such as pimozide, (Deleeu *et al*, 1985a) is particularly effective.

9.2.2 Incubation of Eggs

African catfish eggs are incubated successfully in a variety of ways (see 3.2.2.2), though horizontal 1mm meshes are particularly suitable. Their use avoids the need to remove the adhesive quality of the eggs (Schoonbee *et al* 1980) prior to incubation, eg. in Zoug jars. Also because African catfish eggs are negatively buoyant, a reduction in flow rate in any kind of upwelling system would predispose the eggs to deleterious clumping. Horizontal meshes can be used in incubators or set up in larval rearing tanks (see Appendix I). The dead eggs and egg cases adhering to the meshes can then be removed from the culture environment following hatching of the developed eggs. Such proteinaceous debris act as a nutrient source for ubiquitous *Saprolegnia* which once established can infect live material such as larvae (Roberts, 1989). Its separation from developing African catfish is particularly important since the concentration of therapeutic treatments such as formalin and malachite green required to control the fungi exceed the apparent tolerance of the larvae (Schoonbee *et al*, 1980; Van As *et al* 1984).

9.2.3 Hatching

The time taken for eggs to hatch is very variable, it is affected particularly by temperature (Yamagami, 1981; Pauly and Pullin, 1988) as well as other environmental conditions such as pH, oxygen level and egg size (Blaxter, 1969; Braum, 1978; Pauly and Pullin, 1988). Hatching commonly takes place between 18 and 57 hours after fertilization at between 20-30°C (see Table 3.10). It appears that the smooth inverse relationship between hatching time and

ambient temperature implied by Viveen *et al* (1985) may be oversimplistic, when viewed in relation to the empirical data of other authors (Figure 3.2), suggesting that the concept of degree-days, successfully employed with cold water species, can be less rigidly applied to the management of *Clarias gariepinus* culture.

9.2.4 Larval rearing

Following hatching, young African catfish pass through a number of developmental stages (see 4.4). The requirements of the fish change rapidly with age (Hogendoorn, 1980b; Verreth and Van Tongeren, 1989; Chapters 5, 6 and 8) so it is important that the different early life stages are recognised by the culturist and that consistent use is made of developmental terms in the literature.

The onset of the larval period commences with the transition from yolk dependent nutrition to exogenous feeding and ends with the onset of air-breathing (4.2). The first appearance of accessory breathing organs was previously believed to occur much later in fishes of about 30mm (Greenwood, 1956). However, the optimum temperature for larval rearing is 30°C (Hogendoorn, 1983b; Britz and Hecht, 1987) and at this temperature the larval period lasts approximately 10 to 12 days (5.4).

Under intensive experimental hatchery conditions larval survival is very high (eg. over 80%) (5.3) and this method of primary nursing may well prove superior to semi-intensive pond rearing (Viveen *et al* 1985) or a combination

of intensive hatchery and semi-intensive nursery pond systems (Hecht *et al* 1988) which have generally failed to provide the required numbers of fry for on-growing (Micha, 1975; Nugent, 1975; Kelleher and Vincke, 1976; Huisman, 1985; Hecht *et al* 1988). In particular intensive hatchery conditions offer the opportunity to exclude predators and competitors, to manipulate environmental conditions and to provide sufficient feed easily.

Losses of healthy larvae in good hatchery conditions will be principally due to cannibalism and handling stress (5.4). The onset of airbreathing in particular may be associated with an increase in fish deaths and a decrease in growth rate (5.4).

The appropriate provision of maximum rations is one of the most important factors limiting maximum growth (Stauffer, 1973; Elliot, 1975a,b, Brett, 1979) and has also been shown to be important in reducing the rate of cannibalism (Hecht and Appelbaum, 1988). However no consensus exists as to how much or at what frequency feed should be offered to larvae. To date no clear picture has emerged from experiments designed to investigate feeding frequency (Hogendoorn, 1980b; Uys and Hecht, 1985). In addition since growth rate in *Clarias gariepinus* larvae is both rapid and rapidly changing (5.3) daily feeding rate is difficult to quantify.

Fixing ration as a % of body weight based on periodic weighing will only poorly approximate feed requirements (Verreth and Den Biemen, 1987) and is inappropriate for such a delicate life stage.

This handling problem can be overcome by predicting daily growth increment and calculating corresponding feed requirements from the expected food conversion ratio (FCR) (Verreth and Den Bieman, 1987; Verreth and Van Tongeren, 1989, Verreth *et al*, 1991). However this method is dependent upon two erroneous assumptions: that the growth index (b) remains constant over the entire larvael period (see 5.3) and that FCR is independent of feeding rate (see Verreth and Den Bieman, 1987).

Since gastric evacuation and return of appetite are inversely proportional in *Clarias gariepinus* larvae (8.3) a simple model is proposed regarding the quantities to feed larvae and the frequency with which feed can be offered, in order to maximise intake (see Table 8.2 and 8.3). Based upon estimates of maximum stomach capacity as well as gastric evacuation rate it is predicted that feed intake (as a % of body weight per day) increases to a plateau, such that maximum intake is about 50% body weight per day. Feed intake is maximised by frequent feeding over 24h each day. However it is estimated that feeding every hour for 12h daily instead of 24h daily would only reduce maximum possible intake by 20%. This may bring into question the economic advantage of feeding over 24h. There is also only limited apparent benefit of feeding hourly over 12h compared to feeding every 2h or even every 4h over the same period (8.4). In all cases about 30 minutes is required to satiate larvae (8.3).

In addition to ration, larval growth rate will also be affected by this initial density at which they are stocked (5.4) whereby individual growth rate is

decreased curvilinearly by increasing initial stocking density.

For the purposes of comparing growth of African catfish, the mean increase in larval weight can be approximated by a cubic (Hogendoorn, 1981) or an exponential growth model (Brown, 1946) (5.3). However, contrary to the assertion of Verreth and Den Bieman (1987) both the specific growth rate and the cubic growth index vary rapidly and significantly as the larvae grow. Specific growth rate which is a measure of the % increase in body weight per day is probably a more useful indicator of growth rate than the regression coefficient of a cube root transformation of weight data which only poorly approximates an increase in body length (see 5.4 and Appendix II).

The transition from experimental primary nursing, often carried out in aquaria, to larval rearing on a commercial scale necessitates investigation of appropriate holding facilities. Similarly with increasing stocking density attention must be paid to water flow requirements.

Circular tanks possess many potential benefits for fish culture in general (see 7.1.1) and are appropriate for hatchery rearing of *Clarias gariepinus*. Wide/shallow tanks (with a diameter:depth ration of about ten) are preferable to narrower/deeper tanks. Appropriate tank design and flow rates are inextricably linked. The optimal flow rate for larvae is one which provides sufficient dissolved oxygen yet does not generate a current velocity fast enough to cause the larvae to swin against it. Current velocity for a given type and orientation of inflow depends particularly on diameter to depth ratio

and flow rate and is related to position within the tank (Larmoyeux *et al*, 1973). Therefore for a given circular tank design a theoretical maximum flow rate and concomitant biomass can be estimated for a given mean fish size (See Table 7.4). The appropriate size of tank will depend upon the desired stocking density (7.4) which in turn will affected larval growth rate (5.3).

9.2.5 Fry rearing

Fry, which are air-breathing juveniles up to 50mm or c.1g are no longer constrained by dissolved oxygen levels so that optimal flow rates for fry will be those not eliciting swimming (7.4). The density at which fry are stocked will affect their growth rate and may alter their pattern of behaviour and also the most prevalent cause of mortality (6.3). Fry are much more robust than larvae and losses of healthy fry will be principally due to two main causes both of which are behavioural (6.3). Young catfish are both cannibalistic and territorial (Hecht and Appelbaum, 1988), if uncontrolled, losses from these two sources can devastate a population. If fry are well fed, increasing stocking density (eg. from 50 fry/l to 150 fry/l) may help to decrease territorial aggressive exchanges without significantly increasing cannibalism (6.3).

9.2.6 End Piece

It has been an objective of this thesis to address some of the deficiences and inconsistencies in available information pertaining to intensive primary nursing of *Clarias gariepinus*, to attempt to answer basic questions about requirements, protocols and definitions. There is much art involved in larval and fry rearing, the science of which will go on developing. It is hoped that some of

the information herein may one day be considered to have helped with that development.

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APPENDIX I

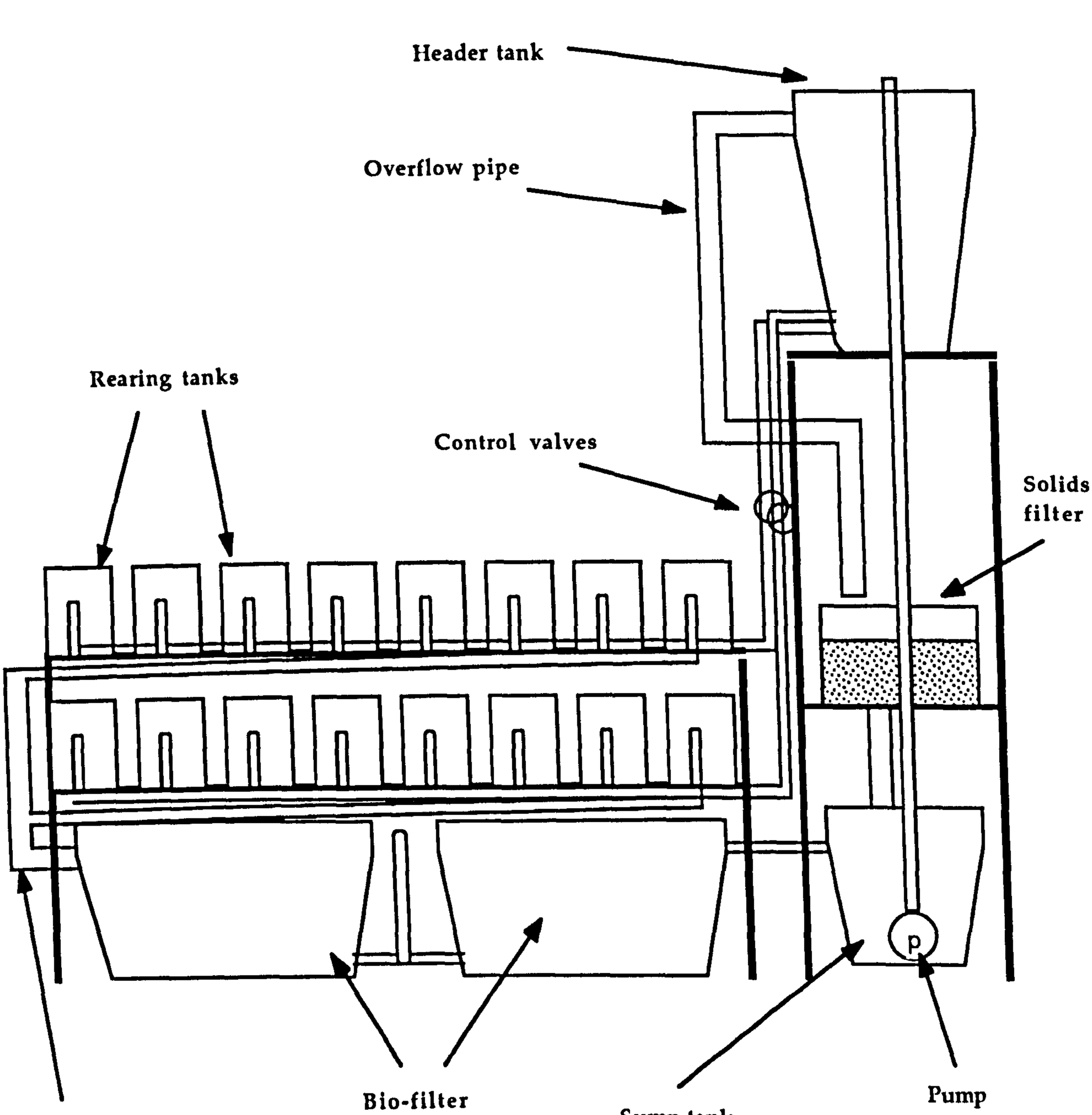

Diagram of experimental larval/fry rearing system (see 5.2.3 & plate s 1&2)

Plate 1: Experimental larval rearing recirculation system (as described in 5.2.3) (tank d:D<2)

Plate 2: Wider/shallower larval rearing tanks (tanks d:D>10)

Plate 3a: Experimental egg incubation system

Plate 3b: Horizontal egg meshes

Plate 4: In-tank horizontal egg meshes

Plate 5: Intraperitonal injection of homoplastic hypophysis

Plate 6 : Stripping eggs

Plate 7 : Adding milt

APPENDIX II

APPENDIX II

Morphometric data

Fish were raised in a 1 m diameter circular tank c.12cm deep. They were removed for sampling with a dip net at a rate of 25 per day (from a population of c.10,000). A total of 375 over 24 days. Feeding was *ad libitum* with *Artemia* (decysted, unhatched) and crushed trout fry feed.

Weights were measured, after drying for 5s on absorbent paper, with an Oertling R series balance R51 (readable to 0.01mg). Lengths were measured under a binocular microscope with a graduated eye piece to 0.01mm.

Morphometric data

Time (Days)	Number	Head Width (mm)		Mouth Width (mm)		Total Length (mm)		Body Weight (mg)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	25	1.48	.10	.	.	6.70	.71	2.37	.69
2	25	1.50	0	.97	.05	7.28	.29	2.55	.52
3	25	1.45	.05	.96	.07	7.33	.37	2.65	.15
4	25	1.56	.13	1.08	.10	7.96	.58	3.52	1.54
5	25	1.57	.16	1.17	.14	8.13	.88	3.46	1.48
7	25	2.31	.25	1.54	.16	10.92	.09	11.94	3.54
9	25	2.16	.19	1.50	.13	10.66	1.03	10.12	3.00
11	25	2.36	.27	1.66	.17	11.40	1.49	13.35	4.60
12	25	2.88	.43	1.86	.18	13.31	1.74	22.13	7.94
15	25	3.25	.39	2.09	.23	15.24	1.81	24.43	11.16
17	25	3.65	.45	2.20	.24	16.81	2.01	50.73	19.79
19	25	3.85	.44	2.28	.25	17.59	1.91	55.03	20.13
21	25	4.00	.57	2.41	.35	17.34	2.15	64.37	24.19
23	25	4.26	.61	2.60	.33	18.87	2.34	83.51	29.23
24	25	4.40	.77	2.58	.47	19.43	3.35	90.48	39.47

Larval Growth Data (Chapter 5)

Density (fish/l)	Replicate	Time (days from first feeding)						
		0	3	6	10	14	5	20
25	1	2.1	4.1	10.47	45.5	63.12	73.95	143.2
	2	2.07	4.45	11.02	38.83	53.32	69.6	121.48
	3	1.98	3.99	9.56	36.16	56.78	69.75	126.7
	mean	2.05	4.18	10.35	40.16	57.74	71.1	130.46
		0	5	10	15	20	25	30
	1	2.24	5.22	23.38	52.74	110.3	230.0	380.22
	2	2.24	6.54	22.7	57.54	127.1	250.79	421.51
	3	2.28	4.71	17.46	42.30	98.72	179.36	306.2
	mean	2.25	5.49	21.18	50.86	112.04	220.05	369.31
		0	3	6	10	14		
30	1	2.21	3.37	7.55	18.24	35.18		
	2	2.29	4.81	10.39	24.12	51.20		
	mean	2.25	4.09	8.97	21.18	43.19		
		1	3	4	7	11	14	16
50	1	2.85	4.51	6.33	13.92	25.01	31.92	42.95
	2	2.87	4.38	6.71	17.85	29.03	43.18	59.89
	3	2.94	4.44	6.27	16.23	25.52	34.49	47.46
	mean	2.89	4.40	6.40	16.0	26.53	36.53	50.10
		0	3	6	10	14		
100	1	2.51	3.48	7.04	14.83	17.98		
	2	2.47	3.66	9.28	17.93	19.10		
	mean	2.49	3.57	8.16	16.38	18.54		
		0	3	6	10	14		
150	1	2.39	3.41	8.63	14.76	22.8		
	2	2.45	3.57	7.55	13.38	17.92		
	mean	2.42	3.49	8.09	14.07	20.36		

Density (fish/l)	Replicate	Time (days from first feeding)						
250		0	3	6	10	14		
	1	2.48	3.27	6.91	10.01	15.22		
	2	2.48	2.55	9.19	14.37	19.58		
	mean	2.48	2.41	8.05	12.19	17.40		

Anova Tables

Effect of time period after first feeding and stocking density on specific growth rate (k) or larvae.

Source of variation	df	ss	ms	F
A. Time after first feeding	3	0.2603	0.087	87
B. Density	5	0.0797	0.016	16
A x B interactions	15	0.0998	0.007	7
within groups (error)	32	0.0453	0.001	
Total	55	0.4851		

$F_{A(3,32)0.05}$ = 2.9
$F_{B(5,32)0.05}$ = 2.5
$F_{A \times B(15,32)0.05}$ = 1.9

Effect of time period after first feeding and stocking density on the cubic growth index (b)

Source of variation	df	ss	ms	F
A. Time after first feeding	3	0.0939	0.0313	28.46
B. Density	5	0.0645	0.013	11.82
A x B interactions	15	0.0579	0.004	3.55
within groups	32	0.03506		
Total	55	0.25136		

$F_{A(3,32)0.05}$ = 2.9
$F_{B(5,32)0.05}$ = 2.5
$F_{A \times B(15,32)0.05}$ = 1.9

Fry growth and survival (chapter 6)

Fry weight (mg)

Fry stocking Density						
Age (Days)	50 (n = 8)		100 (n = 9)		150 (n = 9)	
	Mean	SD	Mean	SD	Mean	SD
15	58.45	16.55	47.58	6.07	40.46	9.23
20	95.30	12.1	63.27	6.07	52.60	5.04
25	146.10	10.54	105.47	7.37	92.90	9.07
30	236.06	29.44	184.47	18.55	150.42	13.66
35	355.70	50.55	238.40	38.96	198.87	19.15

Fry not cannibalised (%)

Fry stocking Density						
Age (Days)	50 (n = 8)		100 (n = 9)		150 (n = 9)	
	Mean	SD	Mean	SD	Mean	SD
13	100	-	100	-	100	-
14	100	-	100	-	100	-
15	99.5	0.93	100	-	99.94	0.09
16	99.25	1.04	99.67	0.71	99.50	0.71
17	99.25	1.04	99.56	0.73	98.99	1.37
18	99.0	1.51	99.56	0.73	98.66	1.90
19	99.0	1.51	99.11	0.78	98.58	1.86
20	98.75	1.49	99.0	0.71	98.43	1.90
21	98.75	1.49	99.0	0.71	98.21	1.92
22	98.75	1.49	98.67	1.00	98.14	1.98
23	98.75	1.49	98.67	1.00	98.06	2.00
24	98.75	1.49	98.56	1.13	98.06	2.00
25	98.75	1.49	98.56	1.13	97.99	2.18
26	98.5	1.77	98.44	1.13	97.97	2.17
27	98.5	1.77	98.33	1.32	97.97	2.17
28	98.5	1.77	98.33	1.32	97.89	2.36
29	98.5	1.77	98.00	1.41	97.75	2.52
30	98.25	1.67	97.89	1.62	97.67	2.50
31	98.0	1.51	97.44	2.01	97.30	2.65
32	98.0	1.51	96.89	2.09	96.70	2.72
33	98.0	1.51	96.78	2.11	96.55	2.69
34	98	1.51	96.44	2.01	96.48	2.64
35	98	1.51	96.33	2.00	96.41	2.58

Survival (%)

Fry stocking Density						
Age (Days)	50 (n = 8)		100 (n = 9)		150 (n = 9)	
	Mean	SD	Mean	SD	Mean	SD
13	100	-	100	-	100	-
14	99	2.14	100	-	99.44	1.39
15	98.25	2.25	99.75	0.44	99.27	1.38
16	97.5	2.78	99.11	1.05	98.14	1.76
17	97	3.21	98.78	0.97	97.60	1.92
18	96.25	4.59	98.67	1.12	97.15	2.32
19	95.75	4.59	98.11	1.45	96.93	2.22
20	95.5	4.9	98.0	1.32	96.78	2.15
21	95.25	4.53	98.0	1.32	96.48	2.01
22	94.25	4.95	97.0	1.50	96.18	2.01
23	93.25	6.23	96.44	2.19	95.81	1.98
24	93.25	6.23	95.78	3.23	95.74	1.94
25	93.25	6.23	95.53	3.67	95.51	1.96
26	92.75	6.76	95.22	3.60	95.44	1.84
27	92.75	6.76	94.78	4.29	95.44	1.84
28	92.5	6.82	94.78	4.29	95.36	1.98
29	91.75	6.88	94.33	4.39	95.14	2.12
30	91.5	6.57	94.22	4.63	95.07	2.16
31	90.75	5.75	93.56	5.00	94.62	2.36
32	90.75	5.75	92.89	5.3	94.02	2.46
33	90.75	5.75	92.86	5.17	93.8	2.39
34	90.75	5.75	92.0	5.10	93.73	2.33
35	90.5	5.73	91.67	5.17	93.65	2.41

Fry length after 35 days (mm)

Fry Stocking Density									
	50			100			150		
Replicate	a	b	c	a	b	c	a	b	c
n	33	41	45	95	90	85	146	131	118
mean length (mm)	34.4	25.02	33.04	28.36	30.49	32.75	26.62	28.99	27.79
S	5.45	5.35	5.94	3.38	4.59	5.31	3.03	4.37	3.65
CV	15.8	15.3	18.0	11.9	15	16.2	11.38	15.07	13.13
GD		5.6			4.5			3.7	

Tank design data (Chapter 7)

The effect of tank size on cannibalism

Replicate	% cannibalism (arcsine)	
	Small tank	Large tank
1	8.13	13.18
2	9.97	13.56
3	14.18	13.94

Single classification ANOVA (two groups with equal sample size)

Source of variation	df	ss	ms	F
between large/small tanks	1	11.75	11.75	2.41
within treatments (error)	4	19.5	4.875	
Total	5	31.25		

$F_{(1,4)0.05} = 7.71$

The effect of tank size on non-cannibalistic mortality

Replicate	% non-cannibalistic mortality (arcsine)	
	Small tanks	Large tanks
1	9.97	14.18
2	20.27	19.14
3	11.54	11.90

Single classification ANOVA (two groups with equal sample sizes)

Source of variation	df	ss	ms	F
between large/small tanks	1	1.97	1.97	0.09
within treatments (error)	4	88.997	22.25	
Total	5	90.967		

$F_{(1,4)0.05} = 7.71$

The effect of tank size and fish age on Fry weight

Because the magnitude of the variance increases with increasing age as body weight increases heteroscadesticity precludes the use of 2 way ANOVA with replication in order to test the significance of differences in tank size.

Therefore paired comparisons were used whereby each observation for large tanks is paired with the observation at the corresponding age for the small tanks.

Paired Fry weight comparisons

Age	Large tanks	Small tanks	Σ	Difference
15	71.1	71.9	143	0.8
20	130.5	147.1	277.6	16.6
25	259.2	283.1	542.3	23.9
30	379.3	419.2	798.5	39.9
35	595.9	684.3	1280.2	88.4
	1436	1605.6	3041.6	

Source of error	df	ss	ms	Fs
Tank size	1	2876.414	2876.414	5.44
Age	4	408924.114	102231.03	193.46
error	4	2113.726	528.43	
Total	9	413914.254		

$F_{(1,4)0.05} = 7.71$

The effect of diameter to depth ration on fry weight after 35 days

Fry weight after 35 days (mg)

Replicate	Tanks	E	F	G	H*
1		621	674.5	898	832
2		576	724	819.5	926
3		602	658.5	804	

*See table 7.1 for tank dimensions

Single classification ANOVA with unequal sample size

Source of variation	d.f	ss	ms	F
Tank diameter: depth	3	136877.58	45625.86	24.85
within treatments (error)	7	12850.33	1835.76	
Total	10	149727.91		

$F_{(3,7)0.05} = 8.45$

The effect of tank depth on Fry weight

An ANOVA of pair comparisons

	Paired Fry weight comparisons			
Day	Shallow Tank	Deep Tank	Σ	Difference
15	70	82.6	162.6	2.6
20	165.2	149.5	314.7	15.7
25	385.8	382.07	767.87	3.73
30	553.3	623.08	1176.38	69.78
35	981.3	1067.3	2048.6	86
	2165.6	2304.55	4470.15	

Source of error	df	ss	ms	Fs
Tank depth	1	1930.712	1930.712	1.78
Age	4	1149641.426	287410.356	256.17
error	4	4335.492	1083.87	
Total	9	1155907.63		

$F_{(1,4)0.05} = 7.71$

Gastric evacuation, return of appetite and satiation time (Chapter 8)

Gastric Evacuation

Time Post Satiation (h)	Stomach Content (% bw)			
	Mean	SD	SE	CL
0	16.9	2.64	0.84	1.89
2	14.8	3.5	1.11	2.5
4	12.3	3.3	1.04	2.36
6	13.4	3.8	1.27	2.91
8	9.36	2.19	0.69	1.57
10	10.16	1.8	0.57	1.29
12	7.62	2.45	0.77	1.75
16	4.84	1.0	0.45	1.24
20	1.47	0.57	0.18	0.41

$$\text{Stomach content at time t} = \frac{\text{number of orange cysts} \times 0.0189}{\text{Body weight}} \times 100$$

where : one hydrated (decysted) *Artemia* cyst weighs 0.0189 mg.

Return of Appetite

Time Post Satiation (h)	Consumption (% bw)			
	Mean	SD	SE	CL
0	0.105	0.167	0.053	0.119
2	7.48	2.71	0.86	1.94
4	12.98	4.09	1.29	2.93
6	11.4	2.21	0.74	1.7
8	10.4	2.17	0.69	1.55
10	18.81	3.58	1.13	2.56
12	11.0	2.4	0.76	1.72
16	17.1	4.7	2.15	5.8
20	20.6	2.97	0.94	2.12
24	19.14	5.9	1.87	4.2

$$\text{consumption at time t} = \frac{\text{number of black cyst} \times 0.0189}{\text{Body weight}} \times 100$$

Change in body weight and Stomach Capacity with age

Time	Number	Weight(mg)				No	Stomach Capacity (%bw)				Satiation $\pm CL_{95}$	
Days		Mean	SD	SE	CL_{95}		Mean	SD	SE	CL_{95}	time	(mm)
1	10	2.67		0.092	0.212	10	8.3	6.8	2.3	5.2	5	-
2	10	3.27	0.276	0.12	0.27	10	14.5	4.4	1.4	3.1	15.4	1.4
3	10	6.7	0.38	0.25	0.57	10	11.5	5.2	1.6	3.72	34.1	1.25
4	10	14.9	0.79	1.1	2.46	10	17.9	4.4	1.4	3.2	27.04	0.88
5	10	16.2	3.3	0.54	1.2	10	17.98	3.0	0.95	2.15	29.5	2.8
7	100	32.99	1.7	0.66	1.3	10	21.97	3.36	1.06	2.4	*	
10	10	40.2	6.56	3.0	6.8	10	22.2	5.1	1.6	3.7	20.4	1.36
14	10	59.12	9.5	4.6	10.4	10	19.33	3.18	1.01	2.28	32.4	3.38
			14.6									

on day 7*	Deprivation time (h)	Satiation time (mm)
	0	0
	2	19
	4	28
	6	32
	8	30
	10	32
	12	34
	16	30
	20	33
	24	33

Maximum stomach capacity after 0-24h deprivation of feed.

A single classification ANOVA with unequal sample sizes

Source of Variation	df	ss	ms	F
amongst deprivation times	9	493.47	54.84	1.87
within groups (error)	84	2457.66	29.26	
Total	93	2951.13		

$1.96 < F_{0.05\,(9,84)} < 1.99$

The effect of dying of *Artemia* with Sudan black on cyst consumption by larval African catfish, figures are % body weight (Arcsine transformed)

Treatments					
Replicate	Dyed	Undyed	50:50 mixture		
			Dyed	Undyed	Total
1	22.0	28.3	20.1	18.9	28.2
2	24.4	23.7	17.6	16.7	24.7
3	27.3	27.4	17.4	18.1	25.4
4	24.2	25.3	13.9	18.0	23.0
5	26.1	28.2	17.6	12.3	25.0
6	23.8	23.0	21.6	23.0	32.5
7	23.4	26.4	19.6	19.1	27.9
8	25.3	27.2	19.6	20.4	28.9
9	26.9	22.4	18.0	19.7	27.2
10	32.4	26.6	19.0	19.9	28.0

(Variance homogeneity confirmed by Bartlett tests)

Source of Variation	df	SS	MS	FS
Among groups	1	2.24	2.24	0.59
Within groups	18	68.197	3.79	
Total	19	70.437		

$F_{0.05(1,18)} = 4.41$

The difference in the consumed quantity of dyed, undyed or a 50:50 mixture of *Artemia* cysts when offered as a single satiation meal.

Source of Variation	df	SS	MS	FS
Among groups	2	12.786	6.393	0.948
Within groups	27	182.094	6.744	
Total	29	194.88		

$F_{0.05(2,27)} = 3.35$

(Therefore in nutritional trials sequential meals can be identified by staining *Artemia* cysts with the vital lipid stain, Sudan black, without any apparent effect on *Artemia* cyst consumption by African catfish larvae).