*J. Fish. Soc. Taiwan*, **30**(1): 29-41

# Effects of Stocking Density on Growth, Survival, Production, and Size Variation of the Common Carp *Cyprinus carpio* Linnaeus (1758) Fry within Aquariums

Wen-Bin Huang[1], Yu-Chun Lin[2] and Tai-Sheng Chiu[2]*

*(Received, October 15, 2002; Revised, November 25, 2002; Accepted, December 24, 2002)*

## ABSTRACTS

The density at which a fish species can be stocked is an important factor in determining the economic viability of a production system in intensive aquaculture. Producing fishes of more-or-less uniform size in the process is one of the primary goals of aquaculture, as well as maximizing production efficiency. In this study, common carp fry were stocked at the densities of 0.2, 0.4, 0.8, 1.6, 3.2 and 6.4 fry/l for an experimental period of 10 weeks to examine the effects of stocking densities on growth, survival, production, and size variation of the fish within aquariums. The standard length, length-weight relationship, percent survival, relative production, and size variation were found to be significantly affected by stocking density. At the end of the experiment, a negative relationship between the logarithms of length and the logarithms of stocking density was found. The percent survivals at all stocking densities ranged between 44.5 % at the stocking density of 6.4 fry/l and 100% at the stocking density of 0.8 fry/l and less. At the higher densities, percent survival and experimental periods were anti-logistically related. In addition to the length, a negative relationship was found between the logarithms of relative production and the logarithms of stocking density. The highest size variations is presented at the median stocking density, 1.6 fry/l.

***Key words**: stocking density, growth, relative production, size variation, common carp*

## INTRODUCTION

Growth of fishes is affected potentially by a number of biotic factors, including population density of the cohort and its potential competitors, food availability, and predation pressure (Fox and Flowers, 1990). The density of a fish population plays a predominant role in influencing the growth of the fish (Smith *et al.*, 1978). Changes of population densities of fishes may lead to changes in growth and survival rate (Miao, 1992). Fish larvae grow slowly and have a low survival rate at high stocking density (Huang and Chiu, 1997). The density at which a fish species can be stocked is an important factor in determining the economic viability of a production system in intensive aquaculture (Papst *et al.*, 1992). Both growth and survival of young brown trout *Salmon trutta* were density-dependent and related to competition for food and space in a screened natural brook (Le Cren, 1965). Rubenstein (1981) also showed that the survival rate of Everglands pygmy sunfish *Elassima evergladei* was density-depen-

---

[1] Department of Science Education, National Hualien Teachers College, Hualien 970, Taiwan. (E-mail: bruce@sparc2.nhltc.edu.tw)

[2] Department of Zoology, National Taiwan University, Taipei 106, Taiwan.

* Corresponding author

dent. The caged dace in high density have death rates an order of magnitude higher than those in low density over the first 10-12 weeks post-hatching (Mills, 1982). It seems that growth and survival of fishes is widely held to be density-dependent. However, there were several studies reported density-independent effect on growth (Li and Ayles, 1981; Ross and Almeida, 1986; Martin and Wertheimer, 1989; Miao, 1990) and survival of fishes (Carlander and Payne, 1977; Li and Ayles, 1981; Martin and Wertheimer, 1989; Fox and Flowers, 1990; Cruz and Ridha, 1995).

In aquaculture, the price of fish is determined by the market demand of supply which includes size and production. Two primary goals of aquaculture are to maximize production efficiency and, in the process, to produce animals of more-or-less uniform size (Huang and Chiu, 1997). The production is a summation of individual weights of all reared fish, or a cross-product of the number of surviving fish and their mean weight. It is very important to control the survival and growth rates and individual size difference of fish in a commercial production system. The high stocking rate may result in high size variation in culture of tilapias (Watanabe *et al*., 1990; Huang and Chiu, 1997), but Papst *et al*. (1992) stated that density had no effect on the size variation in juvenile Arctic charr, *Salvelinus alpinus* (L.). It is appears that there is no general agreement regarding the effects of stocking density on growth, survival, production, and size variation of fish.

The common carp, *Cyprinus carpio* Linnaeus (1758), is a eurythermic species (Al-Habib, 1981), and is especially tolerant of low dissolved oxygen concentrations (Lin and Peter, 1991). The mass production of egg, early and advanced fry, and fingerlings of the common carp was documented (Horvath *et al*., 1985). Intensive common carp culture is practiced in China and some other Asian countries (Lin and Peter, 1991). It is also one of the most frequently stocked fish, usually introduced as fry or yearlings, in the lakes and dam reservoirs of Central and East Europe (Bnińska, 1991). The aim of the present study was to examine the effects of various stocking densities on growth, survival, production, and size variation of the common carp fry within aquariums.

## MATERIALS AND METHODS

About 500 fry of the common carp, which were 45 day-old with a mean length of 26.77 ± 0.24 mm (mean ± standard error) and a mean weight of 0.559 ± 0.025 g, originating from the same brood were obtained from the fish hatchery in the Kaohsiung County, Taiwan. The fry were randomly selected and stocked in six aquariums (49 cm × 29 cm × 24.6 cm) at densities of 6, 12, 24, 48, 96 and 192 fry per tank, equivalent to the six density trials of 0.2, 0.4, 0.8, 1.6, 3.2 and 6.4 fry per litre, due to the water volume kept 30 litre in the aquariums. A flowing system that consisted of one 100 litre water reservoir, one 20 litre filtration tank with biofilters and the said six aquariums was designed to maintain the same water quality between the aquariums to reduce the interference of water quality on analysis of the density effects. Water in the reservoir was pumped up to the filtration tank that was placed above the aquariums at flow rate of 9 litre per min, and then distributed to the six aquariums by gravity. The water reservoir was then received the water from the aquariums. There were air-stones in each of the aquariums and reservoir to aerate the water.

The fry were fed with auto-feeders that control time, frequency and quantity of food. They were overfed with daily quantity of food equivalent to 4% of fish biomass in each aquarium to reduce the intraspecies competition for food. The crude protein and fat contents in the feed were 32% and 3.5%, respectively. Water quality, including water temperature, dissolved oxygen, pH, ammonia, nitrite, nitrate, total nitrogen, and phosphate, were measured at intervals of two weeks in each aquarium. The experimental period was 10 weeks during which natural photoperiod was adopted. Six individuals of fry were randomly sampled and measured at 7-d intervals at 10:00-12:00 AM for standard length (L) to the nearest 0.1 mm and body weight (W) to 0.01 g in every aquarium with replacement. Dead fry in each aquarium were counted and removed daily.

Two-way analysis of variance (ANOVA) was used to determine the significant level in difference of the water quality and biological variables, including standard length, survival, production and size variation, among the stocking densities by randomized complete block design (RCBD). Least square means in the density treatments were used to distinguish homogeneous groups. The relationships between stocking density and each of the biological variables were established at the end of the experiment by using the linear regression models after semi-logarithmical or logarithmical transformation, if necessary (Kleinbaum *et al.*, 1988). Stepwise regression analysis was used to select a proper model, confirmed by type III sum of square, for describing the relationship between the biological variable (dependent variable) and stocking density and experimental period (independent variables). The difference of the length-weight relationships among the stocking densities was examined by the analysis of covariance (ANCOVA). The survival rate ($S_t$, %) was calculated as $S_t = N_t / N_0 \times 100$ (%), where $N_t$ is the survival number of fry at Week t and $N_0$ is the number of fry at Week 0. The relationship between St and the experimental period was determined using the anti-logistic model (Goh, 1980) expressed as: $S_t = 1 - M_t$, and $M_t = M_\infty / \{1+[(M_\infty - M_0)/M_0]e^{-zt}\}$, where $M_t$ is the cumulative mortality rate (%) at the experimental period t; $M_\infty$ is the theoretical asymptotic cumulative mortality rate; $M_0$ is the hypothetical cumulative mortality rate at Week 0; and z is the mortality coefficient. The production in this study was shown by the relative production ($PR_t$, %) caculated by $PR_t = B_t/B_0 \times 100$ (%), where $B_t$ was the fish biomass at Week t calculated by $B_t = W_t N_t$ and t = 0-10. The size variation of fry was defined by the coefficient of variation of standard length (CL, %) and body weight (CW, %), and was calculated as: (standard deviation / mean) × 100 (%). The software of the statistics calculation and model was SAS (Strategic Application Software, SAS Institute Inc.), and all statistics tests were considered significant when $p < 0.05$.

## RESULTS

Changes of water quality variables, including water temperature, dissolved oxygen, pH, ammonia, nitrite, nitrate, total nitrogen and phosphate, during the experiment period of 10 weeks were shown in Table 1. These variables were not significantly different among the aquariums of the stocking densities (ANOVA: $p > 0.05$).

### Length and length-weight relationship

The mean standard length and mean body weight of the common carp fry stocking at six densities at the beginning and end of the experiment (Week 0 and Week 10) are shown in Table 2. At Week 0, the mean length was not significant different among the six densities (ANOVA: $p = 0.987$, $n = 36$). At Week 10, the largest mean length (36.73 ± 1.24 mm) was found at the lowest density, while the smaller mean length (30.28 ± 1.48 mm) was found at the highest density. The mean length in aquariums was significantly affected by the stocking densities during the period of the experiment (ANOVA: $p < 0.001$, $n = 396$). Length of fry at the six densities were arranged into five homogenous groups: 0.2, 0.4/0.8, 0.8/1.6, 1.6/3.2, and 3.2/6.4 fry/l. The relationship between stocking density (D) and length (L) at Week 10 is expressed by the following

**Table 1**. Changes of water qualities (mean±SE, n=6) in the flowing system during the period of the experiment.

| Variable | Week | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 2 | 4 | 6 | 8 | 10 |
| Water temperature (℃) | 26.9±0.05 | 30.1±0.05 | 25.2±0.04 | 25.1±0.02 | 28.1±0.03 | 28.5±0.03 |
| Dissolved oxygen (mg/l) | 6.95±0.05 | 5.65±0.06 | 5.85±0.06 | 5.93±0.06 | 5.96±0.04 | 6.00±0.05 |
| PH | 7.17±0.02 | 7.15±0.02 | 7.66±0.01 | 7.31±0.03 | 7.13±0.05 | 7.02±0.03 |
| Ammonia (mg N/l) | 0.14±0.01 | 0.38±0.01 | 0.40±0.00 | 0.25±0.01 | 0.28±0.00 | 0.32±0.00 |
| Nitrite (mg N/l) | 0.01±0.00 | 0.12±0.00 | 0.02±0.00 | 0.04±0.00 | 0.04±0.00 | 0.03±0.00 |
| Nitrate (mg N/l) | 0.80±0.02 | 4.30±0.03 | 6.60±0.03 | 4.80±0.02 | 4.90±0.04 | 5.50±0.02 |
| Total nitrogen (mg N/l) | 0.99±0.02 | 4.48±0.04 | 7.05±0.04 | 5.03±0.02 | 5.20±0.04 | 5.88±0.02 |
| Phosphate (mg/l) | 0.12±0.00 | 0.78±0.01 | 1.25±0.01 | 1.34±0.01 | 1.05±0.01 | 1.30±0.01 |

**Table 2**. Standard length (mean±SE, n=6) and body weight of the common carp fry at six stocking densities in the beginning (Week 0) and at the end (Week 10) of the experiment.

| Stocking Density | Week 0 | | Week 10 | |
|---|---|---|---|---|
| (fry/l) | length (mm) | weight (g) | length (mm) | weight (g) |
| 0.2 | 26.92±0.78 | 0.56±0.08 | 36.73±1.24 | 1.93±0.24 |
| 0.4 | 26.77±0.70 | 0.57±0.07 | 34.60±1.38 | 1.53±0.26 |
| 0.8 | 27.08±0.30 | 0.57±0.06 | 33.17±1.67 | 1.38±0.25 |
| 1.6 | 26.58±0.55 | 0.55±0.05 | 32.50±2.09 | 1.34±0.32 |
| 3.2 | 26.78±0.60 | 0.55±0.07 | 31.37±1.78 | 1.01±0.23 |
| 6.4 | 26.50±0.63 | 0.55±0.07 | 30.28±1.48 | 0.90±0.19 |

equation:

$\ln L = 3.498 - 0.054 \ln D$ ($r^2 = 0.254$, $n = 36$, $p = 0.002$) (Fig. 1)

Also, the regression models for the relationships between length (Lt, dependent variable), and stocking density and experimental period (D and t, independent variables) are:

$\ln Lt = 3.286 + 0.022\, t - 0.016 \ln D - 0.005\, t \times \ln D$ ($r^2 = 0.468$, $n = 396$, $p < 0.001$)

The length-weight relationships at the six stocking densities were shown in Table 3. The intercepts and slops of the regressions were significantly different among the stocking densities (ANCOVA: both $p < 0.05$, $n = 396$).

## Survival rate

Survival rates ranged between 44.5% and 100% at all stocking densities (Fig. 2). The survival rate was significantly affected by stocking densities (ANOVA: $p < 0.001$, $n = 60$). The survival rates of fry at the six densities were divided into three homogenous group: 0.2/0.4/0.8, 1.6, and 3.2/6.4 fry/l. The first group had no mortality during the experimental period. At the stocking densities of 1.6, 3.2, and 6.4 fry/l, the parameters of anti-logistic models of the relationship between percent survival and experimental periods are shown in Table 4. The relationship between survival (St, dependent variable) and the two independent variables, D and t, at the stocking density of 1.6 fry/l and higher is expressed by the following equation:

**Table 3**. Regression equations for the relationships between the standard lengths (L) and body weights (W) of the common carp fry at six stocking densities.

| Stocking Density (fry/l) | Regression Equation | $r^2$ | n | *p* |
|---|---|---|---|---|
| 0.2 | $\ln W = -13.408 + 3.910 \ln L$ | 0.931 | 66 | <0.001 |
| 0.4 | $\ln W = -12.535 + 3.651 \ln L$ | 0.938 | 66 | <0.001 |
| 0.8 | $\ln W = -12.032 + 3.507 \ln L$ | 0.933 | 66 | <0.001 |
| 1.6 | $\ln W = -14.098 + 4.100 \ln L$ | 0.913 | 66 | <0.001 |
| 3.2 | $\ln W = -13.674 + 3.959 \ln L$ | 0.862 | 66 | <0.001 |
| 6.4 | $\ln W = -13.344 + 3.865 \ln L$ | 0.839 | 66 | <0.001 |

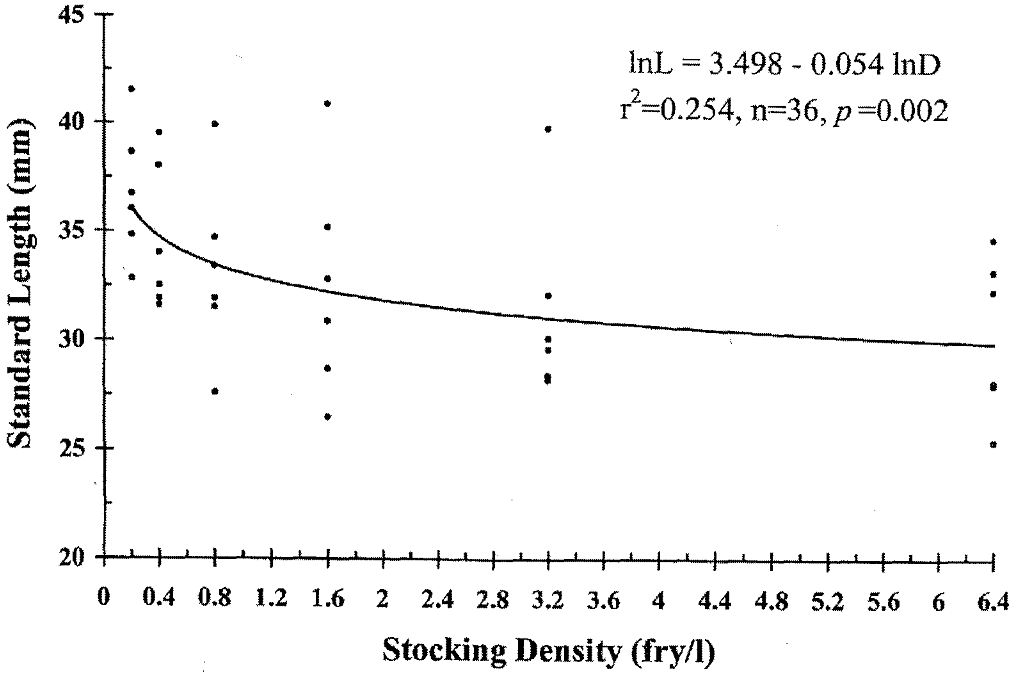

**Fig. 1**. Plot of the standard lengths at six stocking densities and the relationship between the length and stocking density for the common carp fry at week 10.

$St = 102.794 - 2.996\,t - 2.097\,t \times \ln D$ ($r^2 = 0.962$, $n = 33$, $p < 0.001$)

### Relative production

Relative productions of fry at Week 10 at the six stocking densities are shown in Figure 3. Relative production was significantly affected by stock densities (ANOVA: $p < 0.001$, $n = 60$). The relative productions at the stocking densities of 3.2 and 6.4 fry/l at Week 10 (end of the experiment) are lower than 100%, indicating that the net productions are negative at these stocking densities. A significantly negative relationship was found between the logarithms of relative production (ln RP) and the logarithms of stocking density (ln D) at the end of experiment, expressed by the following equation:

$\ln RP = 5.172 - 0.490 \ln D$ ($r^2 = 0.959$, $n = 6$, $p < 0.001$) (Fig. 3)

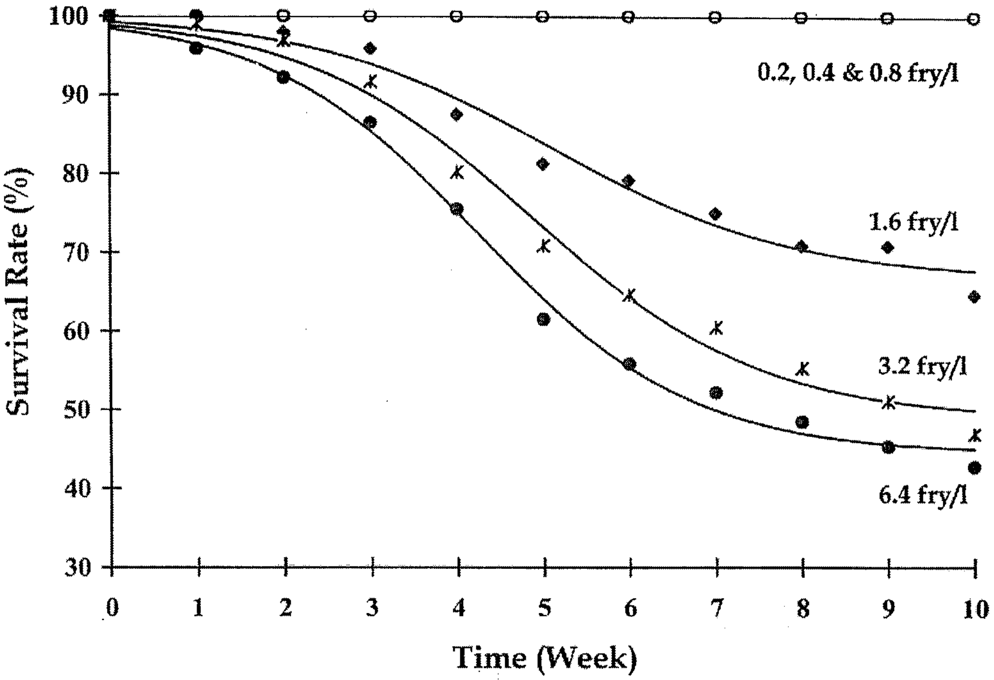

Fig. 2. Relationship between percent survival and experimental period for the common carp fry at six stocking densities.

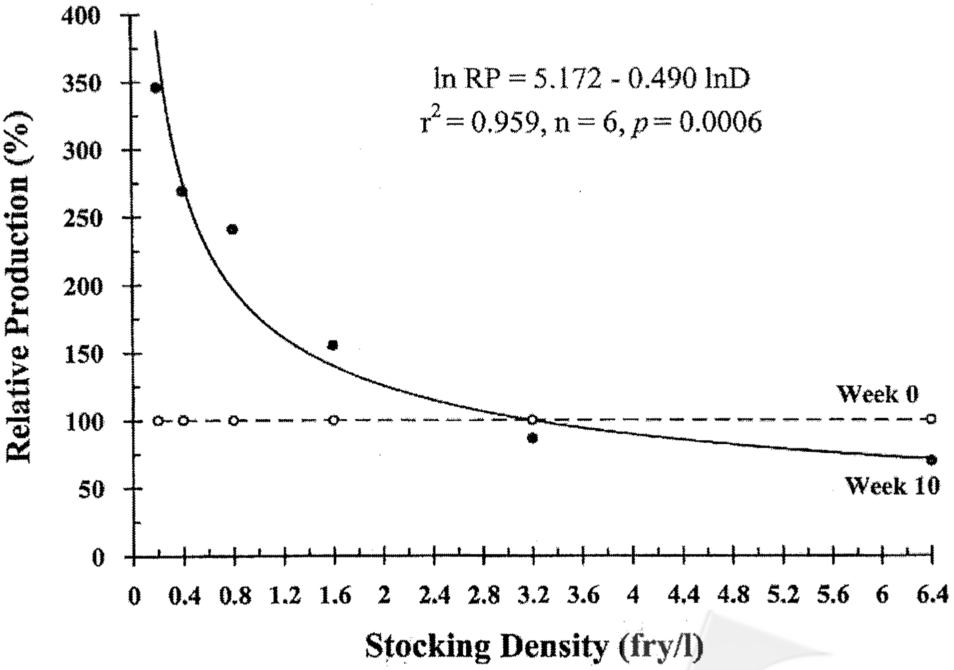

Fig. 3. Relationship between relative production of the common carp fry and stocking density at Week 10 (solid circles) and Week 0 (open circles).

**Table 4**. The parameters of anti-logistic models for the relationships between percentage cumulative survival and experimental period at the stocking densities of 1.6, 3.2, and 6.4 fry per litre.

| Parameter | Stocking Density (fry/l) | | |
|---|---|---|---|
| | 1.6 | 3.2 | 6.4 |
| z | 0.717 | 0.755 | 0.818 |
| $M_\infty$ | 33.23 | 51.12 | 55.52 |
| $M_0$ | 0.848 | 1.258 | 1.653 |
| n | 11 | 11 | 11 |
| p | <0.001 | <0.001 | <0.001 |

$M(t) = M_\infty/\{1+ M_\infty-M_0/M_0\}[\exp(-z\times t)]\}$

M(t) = Cumulative mortality rate (%) at time t (t=week)

$M_\infty$ = The theoretical asymptotic cumulative death rate

$M_0$ = The hypothetical cumulative mortality rate at initial time

Z = Mortality coefficient

## Size variation

The coefficients of variation of standard length and body weight differed significantly among stocking densities (ANOVA: both $p < 0.05$, $n = 66$). The mean size variation of length ranged between 11.02% at the density of 1.6 fry/l and 6.75% at 0.2 fry/l at Week 10, and mean size variation of weight ranged 47.05% at 1.6 fry/l and 29.12% at 0.2 fry/l at Week 10 (Fig. 4). The highest size variation is presented at the median stocking density, 1.6 fry/l. The mean size variations of length and weight were divided into two and three homogeneous groups shown in Figure 4, respectively. The mean size variation of length at all stocking densities was minimum (5.49%) at Week 0 and maximum of 12.27% at Week 10. The mean size variation of weight showed the same pattern with minimum of 23.95% at Week 1 and maximum of 46.24% at Week 10.

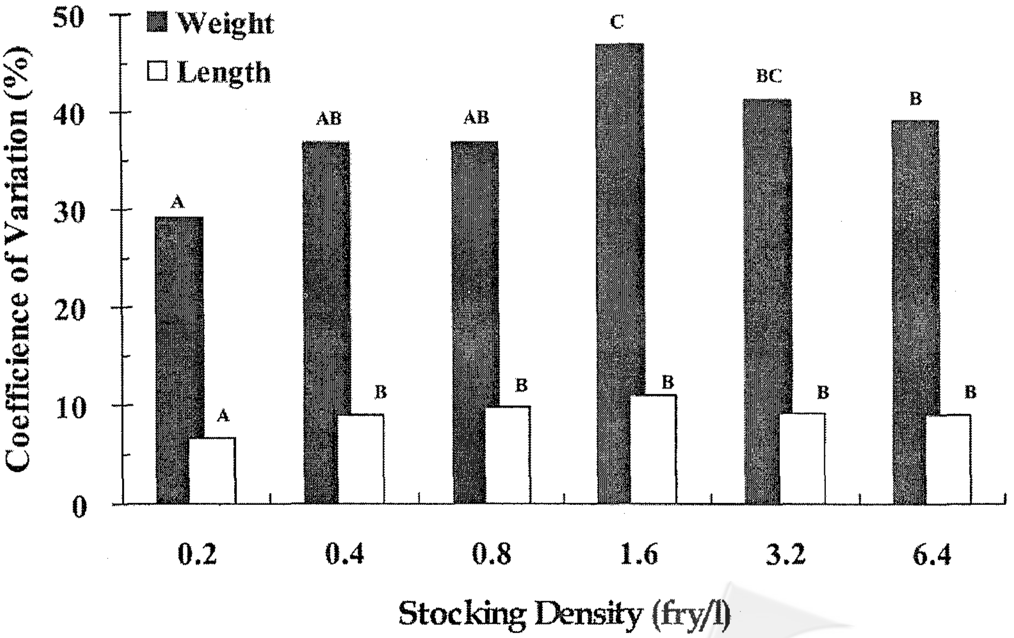

**Fig. 4**. Coefficients of variation of standard length and body weight of common carp fry at six stocking densities at Week 10 (same letters, insignificantly different, multiple range tests by least square means, $p < 0.05$)

## DISCUSSION

Environmental perturbation is one of the important factors that affect the growth and survival of fry, physiologically (Wootton, 1990). Water quality has a complex side effect on high stocking density. Metabolic wastes that are directly proportional to stocking densities have been implicated to inhibit the growth of fish, and to be toxic to fish (Yu and Perlmutter, 1970). In high stocking density, there would be accompanied by lower pH and DO, and Miao (1992) suggested that the resulting changes in water quality might play an important role in affecting growth and survival of fishes. Even when the fish were fed to satiation, decrease in the growth rate of *Ctenopharyngodon idella* was found at very high densities if the oxygen level was less than 4 mg/l (Shireman *et al.*, 1977). In our study, the water flow system supplied water in sufficiency for maintaining fairly good water quality consistently throughout the experimental period in all density trials (Table 1). There were no evidences of large physiochemical fluctuations, occurrence of disease and handling stress, and deterioration of water quality in the experimental aquariums during the course of the experiment.

### Density effects on growth and survival

Population density is an important factor affecting growth of wild and laboratory fish, as well as genetics, food supply, and environmental conditions (Smith *et al.*, 1978). Density dependence means that some life history parameters of animals are dependent on the density of that species (Diana, 1995). The growth rate of fish that is density-dependent was documented for several species, such as bluegill *Lepomis macrochirus* (Wiener and Hanneman, 1982), chinook salmon *Oncorhynchus tshawytscha* (Martin and Wertheimer, 1989), and Nile tilapia *Oreochromis niloticus* (Siddiqui *et al.*, 1989). Also, the survival rate of fish have been reported to be density-dependent, negatively related to the density, for bluegill *Lepomis macrochirus* (Wiener and Hanneman, 1982), Everglades pygmy sunfish *Elassoma evergladei* (Rubenstein, 1981), and walleye *Sitzostedion vitreum vitreum* (Li and Mathias, 1982). On the contrary, density independence that the density does not significantly affect growth and survival rates of fish was also founded by many authors, such as walleye (Carlander and Payne, 1977; Li and Ayles, 1981; Fox and Flowers, 1990), Chinook salmon (Martin and Wertheimer, 1989), gold shiner (Miao, 1990), and tilapia *Oreochromis spilurus* Günther (Cruz and Ridha, 1995). The same controversy also exists in the Cyprindae. Both growth and mortality rates of *Leuciscus leuciscus* varied with the initial stocking density (Mills, 1982), but no density-dependent relationship was founded for *Phoxinus phoxinus* (Jacobsen, 1979) and the common carp *Cyprinus carpio* (Wolny, 1962). However, the low stocking densities and short duration in experiments could result in the conclusion of the density independent (Pivnicka, 1982; Mann, 1991). For instance, size of silver hakes is correlated with density only when stock density is high (Ross and Almeida, 1986). In addition, the effects of stocking density are to be expected after a time lag, the length of which depends on the age of the fish stocked (Bnińska, 1991).

The phenomenon of density-dependent growth was demonstrated in 3-year-old common carp (Backiel and Le Cren, 1978). In our study, the similar phenomenon as well as a negative curvilinear relationship were found between stocking density and growth of the common carp fry (Fig. 1). The linear or curvilinear relationships for the roach *Rutilus rutilus* and the chub *Leuciscus cephalus* (Pivnicka, 1982), the Nile tilapia *Oreochromis niloticus* (Rosa *et al.*, 1990), the tiger prawn *Penaeus monodon* (Fong *et al.*, 1991), the Africa catfish *Clarias gariepinus* (Haylor, 1991), and the redtail shrimp *Penaens penicillatus* (Miao, 1992) were also documented. Besides, the phenomenon of density-dependent survival would be found when the density of fish suppressed a threshold in aquarium experiments (Smith *et al*., 1978), and linear relationships were found between survival rate and stocking density for the walleye *Sitzostedion vitreum vitreum* (Li and Mathias, 1982) and the redtail shrimp *P. penicillatus* (Miao, 1992). The similar result was found in our founding that the effects of the stocking densities on the survival rate of the common carp fry was occurred at the density of 1.6 fry/l and high.

As population density increases, competition for food and living space usually intensifies, providing one of the most effective controls on animal population (Odum 1959). Low levels of food availability in the water of high densities may result in decreased food consumption rates of fish (Mann, 1991). Therefore, decrease in food availability was thought to be an important factor to limit the growth at high stocking density. Pfuderer and Francis (1972) suggested that density-dependent growth in the Cyprindae is most often associated with food availability, and Hulata *et al*. (1982) suggested that the initial growth of the common carp after hatching was affected by severe crowding because the amount of food available to an individual fish was decreased. However, changes in trophic state of aquatic habitats that make more food available per individual fish do not always result in increased growth rates for *Rutilus rutilus* in Lake Sarnen, Switzerland (Müller and Meng, 1986). In our study, the density-dependent effect on growth of common carp fry was shown, even though the food was given over satisfication.

Under crowded conditions, the common carp and the goldfish, *Carassius auratus*, would liberate a hormone to depress the heart rate and to inhibit growth and production (Pfuderer and Francis, 1972). Low food conversion was also found at the high stocking densities of the chinook salmon (Martin and Wertheimer, 1989). On the contrary, high metabolism was detected for space of intraspecific competition at the high density of the rainbow trout (Li and Brocksen, 1977). Therefore, low heart rate, low food conversion and high metabolism could be the reasons why given extra food is unable to enhance the growth in high density levels for the common carp and other density-dependent species. In short, the stress of fish caused by the crowdness may be one of the important factors to induce the effects of stocking density. When the population density is above a certain level (threshold), a lack of sufficient space acts as an independent stress that reduces growth (Woiwode and Adelman, 1989). It is reasonable to assume that the potential for limiting growth is greater when stock density is higher and vice versa.

## Density effects on production

The production capabilities of ponds will vary, depending upon the species, stocking densities and management (Lin and Peter, 1991). In general, high stocking density is necessary for high yield. On the contrary, living space and dissolved oxygen are the two limiting factors of stocking density increased. If the stocking density exceeds a reasonable limit, the yield will be reduced and the fish will be stunted and unmarketable (Lin and Peter, 1991). The relationship between the production and density has been expressed by a dome-shaped for the redspot masu-trout *Oncorhynchus rhodurus* (Nagoshi and Kurita, 1986), a negative quadratic equation for tiger prawn (Fong *et al*., 1991), and a positive regression equation after logarithmic transformation for tilapia (Huang and Chiu, 1997). A curvilinear relationship between stocking density and catch of the common carp was found (Bnińska, 1991). However, in our study the relationship between the density and relative production was expressed by a negative regression equation after logarithmic transformation (Fig. 3), supporting the results of Fong *et al.* (1991). In addition, the net productions were negative at the stocking densityiesof 3.2 and 6.4 fry/l at the end of the experiment, indicating that these two stocking densities exceeds a reasonable limit for stocking common carp fry in aquariums.

### Density effects on individual difference

In the meddle stocking densities, high size variation of the common carp was found in this study (Fig. 4). This finding is different from the results that positive relationships were found between the stocking density and size variation in Everglades pygmy sunfish (Rubenstein, 1981), red tilapia (Watanabe *et al.*, 1990) and tilapia (Huang and Chiu, 1997), negative in Arctic charr (Wallace *et al.*, 1988), and negligible in walleye (Fox and Flowers, 1990) and Arctic charr (Papst *et al.*, 1992). Huang and Chiu (1997) suggested that under crowding condition the fish which is bigger and maintain a domain position grow faster, and, therefore, the high stocking rate may result in high size variation. However, size variation in fish population is related to the social interaction of the fish. The change of intraspecies relationship that the defend behavior for territoriality is reduced would be occurred and decrease the size variation in high stocking density of the Artic charr population (Jobling, 1985). This also could explain the findings that the negative relationship between the stocking density and size variation in the Arctic charr (Wallace *et al.*, 1988) and the highest size variation does not occur in the high stocking densities of the common carp in this study (Fig. 4).

In utility, stocking the common carp in a small reservoir at a high density might reduce the problem of land shortage and the cost of the production. However, at the high stocking densities the growth and survival of the common carp is low (Figs. 1 and 2) and the net production is negative (Fig. 3), indicating that stocking the common carp at the high densities is unsuitable and disadvantage for economic aquaculture. By contrast, the growth and survival of the fish is reasonable in the median stocking densities, though the size variation is high. The problem of high size variation can be resolved by the screen method that removes large fish by using large mesh nets and to allow small fish to grow (Erkoyuncu and Ozdamar, 1989). The technique takes advantage of the maximum growth potential of the fish, and the yield increase. In short, stocking common carp fry in median density with the screen method is one of the optimal options for aquaculture.

## ACKNOWLEDGMENTS

The authors would like to express his hearty appreciation to Prof. C.-t. Shih of Taiwan Fisheries Research Institute, Council of Agriculture for his comments and suggestions on the manuscript, and Prof. Sun-Chio Fong of the Institute of Marine Biology, National Sun Yat-Sen University for his comments and suggestions on the statistical methods. The authors also wish to thank anonymous reviews for reading and commenting on the manuscript.

## REFERENCES

Al-Habib, O. A. M. (1981). Acclimation to temperature and death at changing lethal temperature in the freshwater fish *Chalcalburnus chalcoides*. *J. Therm. Biol.*, **6**: 365-71.

Backiel, T. and E. D. Le Cren (1978). Some density relationships for fish population parameters. In *Ecology of Freshwater Fish Production* (S. D. Gerking, ed.), Blackwell, Oxford, 279-302.

Bnińska, M. (1991). Fisheries. In *Cyprinid Fishes: Systematics, biology and exploitation*, Chap. 21 (I. J. Winfield and J. S. Nelson, eds.), Chapman and Hall, London, 572-589.

Carlander, K. D. and P. M. Payne (1977). Year-class abundance, population, and production of walleye (*Sitzostedion vitreum vitreum*) in Clear Lake, Iowa, 1948-74 with varied fry stocking rates. *J. Fish. Res. Bd Can.*, **34**: 1792-1799.

Cruz, E. M. and M. T. Ridha (1995). Survival rates of tilapia, *Oreochromis spilurus* (Günther) fingerlings reared at high densities during winter using warm underground sea water. *Aquac. Res.*, **26**: 307-309.

Diana, J. S. (1995). Biology and Ecology of Fishes. Cooper Publishing Group LLC, Carmel, 441 pp.

Erkoyuncu, I. and E. Ozdamar (1989). Estimation of the age, size and sex composition and growth parameter of anchovy, *Engraulis encrasicolus* (L.) in the Black Sea. *Fish. Res.*, **7**: 241-247.

Fong, S. C., H. Y. Chen, Y. Y. Ting and M. H. Chang (1991). Effects of paddlewheel and stocking density on the production of tiger prawn, *Penaeus monodon*, in saline ponds. *J. Fish. Soc. Taiwan*, **18**: 279-286.

Fox, M. G. and D. D. Flowers (1990). Effect of fish density on growth, survival and food consumption by juvenile walleyes in rearing ponds. *Trans. Amer. Fish. Soc.*, **119**: 112-121.

Goh, B. S. (1980). Management and Analysis of Biological Populations. Elsevier Scientific Publishing Company, Amsterdam, Oxford, New York, 288 pp.

Haylor, G. S. (1991). Controlled hatchery production of *Clarias gariepinus* (Burchell 1822): growth and survival of fry at high stocking density. *Aquac. Fish. Manag.*, **22**: 405-422.

Horvath, L., G. Tamas and A. G. Coche (1985). Common Carp. Parts. 1 and 2: 1. Mass production of eggs and early fry. F.A.O. Training Series, No. 8, 87 pp.; 2. Mass production of advanced fry and fingerlings in ponds. F.A.O. Training Series, No. 9, 85 pp.

Huang, W. B. and T. S. Chiu (1997). Effects of stocking density on survival, growth, size variation, and production of Tilapia fry. *Aquac. Res.*, **28**: 165-173.

Hulata, G., R. Moav and G. Wohlfarth (1982). Effects of crowding and availability of food on growth rates of fry in the European and Chinese races of the common carp. *J. Fish Biol.*, **20**: 323-327.

Jacobson, O. J. (1979). On density-dependent growth in a cyprinid, *Phoxinus phoxinus* L.. *Folia boil., Kraków*, **27**: 225-9.

Jobling, M. (1985). Physiology and social constraints on growth of fish with special reference to Arctic charr, *Savelinus alpinus* L. *Aquacuture*, **44**: 83-90.

Kleinbaum, D. G., L. L. Kupper and K. E. Muller (1988). Applied Regression Analysis and other Multivariable Methods. PWS-kent Publising Company, Boston, 718 pp.

Le Cren E. D. (1965). Some factors regulating the size of populations of freshwaters fish. *Mitt. Inst. Verein. Theor. Angew. Limnol.*, **13**: 88-105.

Li, H. W. and R. W. Brocksen (1977). Approaches to the analysis of energetic costs of intraspecific competition for space by rainbow trout (*Salmo gairdneri*). *J. Fish Biol.*, **11**: 329-341.

Li, S. and G. B. Ayles (1981). Preliminary experiments on growth, survival, production and interspecific interactions of walleye (*Stizostedion vitreum*) fingerlings in constructed earthen ponds in the Canadian prairies. *Can. Techn. Rep. Fish. Aquat. Sci.* 1041.

Li, S. and J. A. Mathias (1982). Causes of high mortality among cultured larval walleyes. *Trans. Amer. Fish. Soc.*, **111**: 710-721.

Lin, H. R. and R. E. Peter (1991). Aquaculture. In *Cyprinid Fishes: Systematics, biology and exploitation*, Chap. 22 (I. J. Winfield and J. S. Nelson, eds.), Chapman and Hall, London, 590-622.

Mann, R. H. K. (1991). Growth and production. In *Cyprinid Fishes: Systematics, biology and exploitation*, Chap. 16 (I. J. Winfield and J. S. Nelson, eds.), Chapman and Hall, London, 456-482.

Martin, R. M. and A. Wertheimer (1989). Adult production of chinook salmon reared at different densities and released as two smolt sizes. *Progr. Fish-Cult.*, **51**: 194-200.

Miao, S. (1990). Growth and production control of golden shiner (*Notemigonus crysoleucas*) (Mitchill) by manipulating temperature and density. *Bull. Inst. Zool., Academia Sinica*, **29**: 223 -232.

Miao, S. (1992). Growth and survival model of redtail shrimp *Penaens penicillatus* (Alock) according to manipulating stocking density. *Bull. Inst. Zool., Academia Sinica*, **31**: 1-8.

Mills, C. A. (1982). Factors affecting the survival of dance, *Leuciscus leuciscus* (L.), in the early post-hatching period. *J. Fish. Biol.*, **20**: 645-655.

Müller, R. and H. J. Meng (1986). Factors governing the growth rate of roach *Rutilus rutilus* (L.) in pre-Alpine Lake Sarnen. *Schweiz. Z. Hydrol.*, **48**: 135-144.

Nagoshi, M. and H. Kurita (1986). Relationship between population density and production of the redspot masu-trout (*Oncorhynchus rhodurus*) in Japanese mountain stream. *Bull. Jap. Soc. Sci. Fish.*, **52**: 1875-1879.

Odum, E. P. (1959). Fundamental of Ecology. 2nd ed. W. B. Saunders Company, Philadelphia and London, 546 pp.

Papst, M. H., T. A. Dick, A. N. Arnason and C. E. Engel (1992). Effect of rearing density on the early growth and variation in growth of juvenile Arctic charr, *Salvelinus alpinus* (L.). *Aquac. Fish. Manag.*, **23**: 41-47.

Pfuderer, P. and A. A. Francis (1972). Isolation of a new heart rate depressing pheromone from the water of crowded fish. *Fedn Proc. Fedn Am. Socs Exp. Biol.*, **31**: 486.

Pivnicka, K. (1982). Long-termed studies of fish populations in the Klicava reservoir. *Acta Sci. Nat. Acad. Sci. Bohemoslov., Brno*, **10**: 149-51.

Rosa, P. V., P. M. A. Costa, J. D. R. Souza, J. A. A. Pereira and C. L. S. Costa (1990). Performance and determination of the ideal Nile tilapia density, fed swine excrements. *Revista Da Sociedae Brasileira De Zooltecnia*, **19**: 530-541.

Ross, M. R. and F. P. Almeida (1986). Density-dependent growth of silver hakes. *Trans. Amer. Fish. Soc.*, **115**: 548-554.

Rubenstein D. I. (1981). Individual variation and competition in the Everglades pygmy sunfish. *J. Animal Ecol.*, **50**: 337-350.

Shireman, J. B., D. E. Colle and R. W. Rottmann (1977). Intensive culture of grass carp, *Ctenopharyngdon idella*, in circular tanks. *J. Fish Biol.*, **11**: 267-72.

Smith, H. T., C. B. Schreck and O. E. Maughan (1978). Effect of population density and feeding rate on the fathead minnow (*Pimephales promelas*). *J. Fish Biol.*, **12**: 449-455.

Siddiqui, A. Q., M. S. Howlader and A.B. Adam (1989). Culture of Nile tilapia, *Oreochromis niloticus* (L.), at three stocking densities in outdoor concrete tanks using drainage water. *Aquac. Fish. Manag.*, **20**: 49-58.

Wallace, J. C., A. G. Kolbeinshavn and T. G. Reinsnes (1988). The effects of stocking density on the early growth in Arctic charr, *Salvelinus alpinus* (L.). *Aquaculture,* **73**: 101-110.

Watanabe, W. O., J. H. Clark, J. B. Dunhkam, R. I. Wicklund and B. L. Olla (1990). Culture of Florida red tilapia in marine cages: The effect of stocking density and dietary and dietary protein on growth. *Aquaculture*, **90**: 123-134.

Wiener, J. G. and W. R. Hanneman (1982). Growth and condition of bluegills in Wisconsin Lakes: Effects of population density and lake pH. *Trans. Amer. Fish. Soc.*, **111**: 761-767.

Woiwode, J. G. and I. R. Adelman (1989). Influence of density and multipass water use on channel catfish performance in raceways. *Progr. Fish-Cult.*, **51**: 183-187.

Wolny, P. (1962). The influence of increasing the density of stocked fish populations on the growth and survival of carp fry. *Roczniki Nauk Rolniczych Seria B, Zootechniczna*, **86**: 195-214.

Wootton, R. J. (1990). Ecology of Teleost Fishes. Chapman & Hall, London, 404 pp.

Yu, M. and A. Perlmutter (1970). Growth inhibiting factors in the zebrafish (*Brachydanio rerio*) and the blue gourami (*Trichogaster richopyerus*). *Growth*, **34**: 153-175.

# 魚缸放養密度對鯉 *Cyprinus carpio* Linnaeus (1758) 魚苗成長、存活、生產量及體型差異之影響

黃文彬 [1]．林育儁 [2]．丘臺生 [2*]

(2002 年 10 月 15 日收件；2002 年 11 月 25 日修正；2002 年 12 月 24 日接受)

魚類可放養密度之大小是決定集約式水產養殖生產系統經濟可行性的重要因子，同時在養殖過程中生產均一大小的魚體，與達成最大的生產量效率，均是水產養殖主要目標之一。在本研究中，鯉魚苗被試驗在六種不同的放養密度中試驗十個星期，以分析魚缸放養密度對魚苗成長、存活、生產量及體型差異之影響。這六種放養密度分別為 0.2、0.4、0.8、1.6、3.2 和 6.4 尾/升。研究結果顯示，鯉魚苗魚體標準體長、體長-體重關係、存活率、相對生產量及體型差異，均顯著受到放養密度之影響。在本實驗期結束時，魚體體長與放養密度間關係，呈現負相關的雙對數線性模式。鯉魚苗的最低存活率為 44.5%，發生在最高放養密度組(6.4 尾/升)。當放養密度等於和低於 0.8 尾/升時，無魚苗死亡發生。放養密度等於及高於 1.6 尾/升之三密度組在本試驗期間的魚苗存活情形，可用反邏輯曲線來描述。除體長外，放養魚苗之相對生產量與放養密度間關係，亦呈現負相關的雙對數線性模式。放養魚苗之最大體型差異，發生於中度放養密度組(1.6 尾/升)。

**關鍵詞**：放養密度，成長，相對生產量，體型差異，鯉。

---

1 國立花蓮師範學院自然科學教育學系，花蓮 970，臺灣 (E-mail: bruce@sparc2.nhltc.edu.tw)
2 國立臺灣大學動物學系，臺北 970，臺灣
* 通訊作者