Aquaculture 285 (2008) 47–55

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Accounting for genotype by environment interaction in economic appraisal of genetic improvement programs in common carp *Cyprinus carpio*

Raul W. Ponzoni [a,*], Nguyen Hong Nguyen [a], Hooi Ling Khaw [a], Nguyen Huu Ninh [b]

[a] WorldFish Center, Jalan Batu Maung, 11960 Batu Maung, Bayan Lepas, Penang, Malaysia
[b] Research Institute for Aquaculture No. 1, Dinh Bang, Tu Son, Bac Ninh, Vietnam

ARTICLE INFO

Article history:
Received 9 May 2008
Received in revised form 11 August 2008
Accepted 16 August 2008

Keywords:
Common carp
Cyprinus carpio
Genetic improvement
Selective breeding
Economic benefit
Genotype by environment interaction

ABSTRACT

In this study we examine effects of genotype by environment (G × E) interaction due to re-ranking and scaling effects on economic benefit (EB) and benefit to cost ratio (BCR) from a genetic improvement program in common carp at a national level in Vietnam. A discount approach was used for the economic evaluation over a 10 year time horizon. G × E interaction resulting from scaling effects generally had a negligible impact on EB and BCR. However, both EB and BCR decreased with the magnitude of the G × E (i.e. with the decrease in the genetic correlations between homologous traits in the selection and production environments). Furthermore, both EB and BCR from the genetic improvement program depend on other factors, which can be categorized in three groups: i) biological (heritability and feed intake), ii) economic (initial investment, annual recurrent cost, discount rate, price of fish and feed cost) and iii) operational (year when first return is realized, adoption rates of the improved fish by the production sector). The level of heritability affected EB and BCR, with greater heritability being associated with greater EB and BCR. Accounting for feed intake in breeding objectives avoided an overestimation of EB and BCR. Generally, the economic efficiency of the breeding program was almost insensitive to initial investment and annual cost. Increasing the discount rate by three times reduced EB and BCR by a factor of only 1.4 and 2.0, respectively. The price of fish and feed costs had a substantial effect on EB and BCR. However, the greatest contribution to variations in EB and BCR came from increases in adoption rates of the improved fish by the industry. The risk program failure due to technical reasons was extremely low. We conclude that even under the most conservative assumptions, and in the presence of G × E interaction, genetic improvement programs are highly beneficial from an economic viewpoint, and that for the situations studied they could result in EBs ranging from 11 to 226 million US$, and corresponding BCRs of 22 to 420.

1. Introduction

Investment in breeding programs can provide a high rate of economic return since genetic gain is cumulative, permanent and sustainable. Nearly all the genetic gain is contributed to the national economy, especially in countries where a pyramid breeding structure is well established to disseminate improved genotypes from the nucleus either directly or indirectly to commercial production. Although genetic gain is never lost if the population is well maintained, its value needs to be discounted to express all returns and costs in terms of net present value (Hill, 1971). The benefits of improved breeds or varieties (strains) through genetic selection have been widely demonstrated in terrestrial animal and plant species. For example, the wheat breeding program at CIMMYT yielded returns of greater than US$ 50 for every dollar invested (Lantican et al., 2005). Mitchell et al. (1982) also demonstrated that the genetic improvement carried out for economically important traits in pigs brought about 101×10^6 lb, with a benefit to cost ratio of 50 for Great Britain. Many other studies reported substantial economic benefits in livestock such as dairy cattle (Wickham et al., 1977) and beef cattle in New Zealand (Morris, 1980), Merino sheep in Australia (Atkins, 1993; Greeff, 1997).

Recently, Ponzoni et al. (2007) evaluated investment in a genetic improvement program in tilapia and reported that the economic benefit (EB) ranged from 4 to 32 million US$, and corresponding benefit to cost ratio (BCR) of 8.5 to 60. The substantial returns clearly indicate that it is wise for government institutions to invest in breeding programs. In order to gain further confidence in such benefits for other aquaculture species, we conducted an economic assessment of the investment in breeding programs in carp species, with particular reference to common carp (*Cyprinus carpio*) in Vietnam.

A selection program for common carp at Research Institute for Aquaculture No. 1 (RIA1), Vietnam, has been conducted over the past 22 years (Thien et al., 2001). Initially, a synthetic population was assembled from three base stocks: Vietnamese white carp, Hungarian scale carp and Indonesian yellow carp. Mass selection for high body weight was carried out over five generations (1985 to 1991). Growth

* Corresponding author. Tel.: +60 4 620 2159; fax: +60 4 626 5530.
E-mail address: r.ponzoni@cgiar.org (R.W. Ponzoni).

0044-8486/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.aquaculture.2008.08.012

rate of the selected fish increased by 33% relative to the base population, but the genetic gain declined in the fifth generation. Family selection was then followed with a genetic gain of approximately 7% during the period of 1998 to 2001. Since 2004, the breeding program has been strengthened by incorporating six carp populations available at RIA1, and a combined within and between family selection using best linear unbiased prediction (BLUP) method was applied. The program is in the second generation of selection. Genetic gain per generation ranged from 7 to 21% (Ninh et al., unpublished results).

Based on parameters estimated from this program in common carp, we derived the economic benefit and benefit to cost ratio under different biological, economic and operational scenarios, following the approach used by Ponzoni et al. (2007). The approach was extended to account for different adoption rates of the improved fish by the production sector and for the effects of genotype by environment (G×E) interaction. We concluded that even under the most conservative assumptions, the genetic improvement program in carps was highly beneficial from an economic viewpoint.

2. Materials and methods

2.1. Breeding structure

A typical breeding structure for any given aquaculture species consists of three main tiers: the nucleus, the multiplication, and the production populations. Research institutions or government agencies usually take the lead in establishing and running the genetic improvement programs to develop the nucleus populations at the top of the pyramid. The improved fish from the nucleus are then transferred to hatcheries in lower tiers to be multiplied and distributed to farmers for commercial production as food fish. In this study, we assumed that after each generation of selection, all brooders in hatcheries were replaced by fish from the latest generation in order to obtain the greatest expression of genetic gain in the production tier.

It was further assumed that surplus brood stock (after selection and replacement requirements were satisfied) in the nucleus were made available to be utilized by the hatcheries, and that only a portion of the fish produced by hatcheries were grown out for sale.

2.2. Reproductive efficiency

Assume that the nucleus consists of N females. The number of progeny ($\mathrm{Prg_{Nu}}$) produced in the nucleus is a function of

$$\mathrm{Prg_{Nu}} = N \times F_{\mathrm{Nu}} \times \mathrm{Spw_{Nu}} \times (1-\mathrm{Wst_{Nu}})$$

where F_{Nu} is the number of fry produced per spawning per female, $\mathrm{Spw_{Nu}}$ is number of spawnings per year, and $\mathrm{Wst_{Nu}}$ is the wastage of fry from spawning to sexual maturity.

Table 1
Reproductive rate of common carp with different spawning systems

Spawning systems	N	F_{Nu}	$\mathrm{Spw_{Nu}}$	$\mathrm{Wst_{Nu}}$	0.5 $\mathrm{Prg_{Ha}}$	$\mathrm{Prg_{Pot}}$
1. Natural spawning (low efficiency)	100	14,000	1	0.65	245,000	1,200,500,000
2. Induced spawning in pools or tanks	100	21,000	1	0.50	525,000	5,512,500,000
3. Induced breeding and artificial incubation in the nucleus only, pools in hatcheries	100	28,000	1	0.50	700,000	7,350,000,000
4. In vitro fertilization in both nucleus and hatcheries	100	28,000	1	0.50	700,000	9,800,000,000

N = number of females in the nucleus; F_{Nu} = number of fry produced per spawning per female; $\mathrm{Spw_{Nu}}$ = number of spawnings per year; $\mathrm{Wst_{Nu}}$ = wastage of fry from spawning to harvest; 0.5 $\mathrm{Prg_{Ha}}$ = number of progeny produced by hatcheries with 50% females; $\mathrm{Prg_{Pot}}$ = total potential fish produced by hatcheries.

Table 2
Number of marketable fish annually (Nmkt) with different adoption rates by the industry

Adoption rate (%)[a]	Nmkt
10 (base)	60,658,280
30	181,974,840
60	363,949,680
100	606,582,800

[a] Percentage of improved fish cultured by the commercial sector.

It is also assumed that 50% of the progeny (0.5 $\mathrm{Prg_{Nu}}$) are females. Then, the number of progeny produced by hatcheries ($\mathrm{Prg_{Ha}}$) can be calculated as:

$$\mathrm{Prg_{Ha}} = 0.5\mathrm{Prg_{Nu}} \times F_{\mathrm{Ha}} \times \mathrm{Spw_{Ha}} \times (1-\mathrm{Wst_{Ha}})$$

where F_{Ha}, $\mathrm{Spw_{Ha}}$, and $\mathrm{Wst_{Ha}}$ are as defined above, but for hatcheries (not nucleus). $\mathrm{Prg_{Ha}}$ is the total potential fish produced by hatcheries which can be grown out for sale by the production sector. It is also denoted as $\mathrm{Prg_{Pot}}$ (potential number of progeny).

In order to calculate $\mathrm{Prg_{Pot}}$, we considered four different systems of reproduction in common carp: 1) representing a very low reproduction rate of females spawned in natural environments, 2) induced breeding using hypophysation technique, followed by the release of the injected fish into pools for natural spawning, 3) induced breeding followed by collection of fertilized eggs for artificial incubation, and 4) in vitro fertilization (strip eggs and sperm, then mix to fertilize and transfer the fertilized eggs to incubators) (Table 1). In all cases, we used $N=100$, a normal size of a nucleus herd in carps. Calculations of fry number for different systems of reproduction were based on a very conservative fecundity of females. Systems of reproduction 1, 2, 3 and 4 correspond to 50,000, 75,000, 100,000 and 100,000 eggs per kg body weight of female, respectively. System 1 (natural spawning) represents poor management and low reproduction efficiency. System 2 (induced spawning in pools) is commonly practiced by carp hatcheries. System 3 combines both induced breeding and artificial incubation in the nucleus, but spawning in pools still occurs in hatcheries. System 4 (in vitro fertilization and artificial incubation) is applied in both the nucleus and hatcheries.

Results reported in the literature indicate that the fertility rate in carps averages 80%, and that 70% of the fertilized eggs are hatched. Survival of larvae to fry stage is 50%. In addition, we assumed that females spawn only once per breeding season and are on average 1 kg at spawning.

Based on the above values, the potential number of progeny ($\mathrm{Prg_{Pot}}$) that could be produced by hatcheries is presented in Table 1.

Even under the most conservative reproduction scenarios, there is an abundant quantity of fish to supply to the production sector. Total common carp production in Vietnam was of the order of 303,291.4 tons in 2005. If we assume that the market weight of the fish is 0.5 kg (actual range 0.3 to 0.7 kg), then the total production population consists of 606,582,800 fish heads. This is the maximum number of marketable fish annually (Nmkt), if the industry cultured 100% improved fish from the breeding program. In reality, the common carp genetic improvement program at Research Institute for Aquaculture No. 1 (RIA1) supplies about 10% of the market requirements for production in the form of larvae, fry, fingerlings and brood stock. Hence, the number of market fish was considered to be 10% of the total current carp population in the country, and used as the base value in all analyses. In addition, we tested different adoption rates by the production sector, ranging from 10% (the actual level of dissemination) to 30, 60 and 100% adoption, which would be expected to increase in later years as the program unfolds (Table 2).

2.3. Breeding objective

Defining the breeding objective in common carp involves two main steps: i) choice of traits of economic importance, and ii) derivation of their economic values.