Fisheries resources management of crucian carp based on assessment of fish stock and potential yield in the mid-upper system of Seomjin River

Hui Seong Ryu[1], Sung Hyun Jang[2], Jung Ho Lee[2] and Jung Joon Lee[2,*]

[1]Nakdong River Environment Research Center, Goryeong 717-873, Korea
[2]Department of Biology Education, Daegu University, Gyeongsan 712-714, Korea

Abstract

This study was undertaken to suggest an effective fisheries resources management system by using stock assessment and potential yield analyses of crucian carp population in the mid-upper system of the Seomjin River. Fieldwork was conducted seasonally from 2008 to 2009 in the mid-upper system of the Seomjin River. The stock assessment was carried out by the swept area method and the potential yield was estimated by improved fisheries resource potential estimation system based on the Allowable Biological Catch. Also, the yield-per-recruit analysis was used to review the efficient management implication of the resource, *Carassius auratus*. As a result, the age at first capture (t_c) was estimated as 1.468 year, converted body length (BL) was 10.8 cm. Meaning the current fishing intensities, the instantaneous coefficient of fishing mortality (F) was 0.067 year^{-1}, and the yield-per-recruit analysis showed that the current yield per recruit was estimated to be 15.999 g with F and t_c. The instantaneous rate of fishing mortality that provides for Allowable Biological Catch (F_{ABC}) based on the current t_c and F was estimated as 0.618 year^{-1}. Therefore, the optimum fishing intensities could be achieved at the higher fishing intensity for *Carassius auratus*. The calculated annual stock of *C. auratus* was estimated as 7,608 kg, and the potential yield was estimated as 343 kg with t_c and F at the fixed current level. Using yield-per-recruit analysis, if F and t_c were set at 0.618 year^{-1} and 2 year, the yield per recruit and total allowable catch would be predicted to increase to 62 g and 2,531 kg by about 3.9 times and 7.3 times, respectively.

Key words: allowable biological catch, *Carassius auratus*, fisheries resources management, potential yield, stock assessment, yield per recruit

INTRODUCTION

Fish population as a top predator of the aquatic food web plays a major role in aquatic systems and is also of great economic importance (Kalff 2002). Their dynamics have a large influence on the others aquatic organisms; especially, commercial fish species have a direct bearing on the changes of fisheries resources. Therefore, it is essential to manage the fish population systematically and scientifically for efficient utilization of fisheries and ecosystem sustainability.

The fisheries resources management in freshwater of Korea had relied on technical measures. These technical measures included restriction of mesh or setting size, boat licenses, closed fishing areas/seasons, and gear limitations (Kim 2008). Recently, to manage their fisheries,

some governments, including Korea, Japan, USA, Australia, and Mexico, adopted a newer fisheries management measure (e.g., output control) based on potential yield and stock assessment in seawater (Lopez-Martinez et al. 2002, Ryu et al. 2005, Lee et al. 2009, Griffiths 2010, Lee et al. 2011). This management measure requires stock assessment methodologies for estimating potential yield (Zhang and Lee 2001). The Potential Yield (PY) will represent an appropriate harvest rate that is applied to a current fish stock size estimated. Ideally, the PY will produce a biologically average yield over the long term and avoid overfishing during periods when the stock is low. Therefore, PY is essential for sustainable utilization and effective management of the stock (Fazli et al. 2009). To properly estimate PY, it is essential to obtain accurate information of target species such as the ecological population characteristics, optimal levels of catch and fishing effort, biomass and age at first capture (Jang et al. 2010, 2011b).

Crucian carp (*Carassius auratus*) are distributed throughout North Korea, China, Japan, Africa, and Eurasia (Nakamura 1969, Choi et al. 1990, Nelson 2006). In Korea, crucian carps are widely distributed and caught in freshwater, comprising a large proportion of fisheries resources production in inland water (Seo and Byun 2004). Crucian carps are deemed an iconic species and are greatly targeted by commercial and recreational fishers as they grow to large sizes. Notwithstanding the ecological and commercial significance of crucian carp, scientific information on population ecological characteristics and stock is inadequate (Han et al. 2001, Jang et al. 2011a). Therefore, in order to suggest fisheries resource management implications in freshwater ecosystem and study applicability, crucian carps were selected in this study as one of fish that have commercial value and are distributed widely.

The specific aims of this study are as follows: (i) to assess annual the stock of crucian carp in the mid-upper system of the Seomjin River, (ii) to estimate the potential yield that is considered the Allowable Biological Catch (ABC), and (iii) to investigate and evaluate the fishing intensity at the current level using yield-per-recruit analysis.

MATERIALS AND METHODS

Stock Assessment

Sampling areas were located in the mid-upper system of the Seomjin River (Fig. 1). This area was relatively not
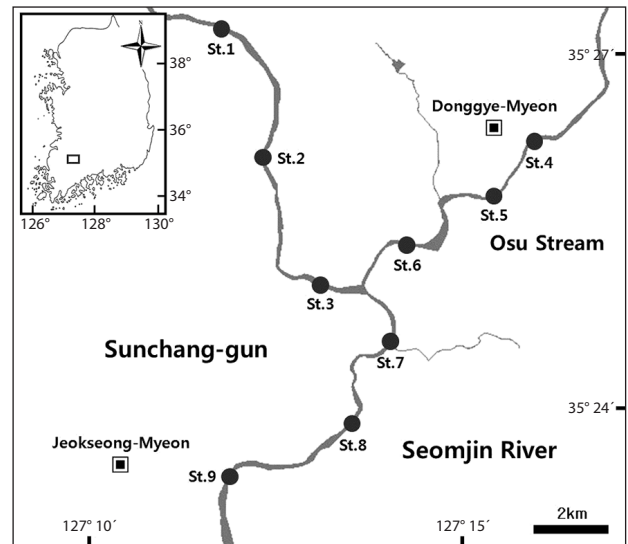

Fig. 1. Map showing the sampling sites (from St. 1 to St. 9, marked as closed circles) in the upper system of the Seomjin River.

disturbed by the artificial environmental factors, and commercial catch activities were strictly prohibited. It has been reported that there are many various species in this area (Jang et al. 2009). Sampling was carried out at 9 sites from August 2008 to April 2009 seasonally, considering fish habitat, water depth, and other factors (Fig. 1). All Sampling type were selected the random block sampling.

Study on potential yield and biomass of crucian carp could facilitate sustainable utilization of fisheries resources in the way that stock diagnosis enable the quantitative assessment and variation prediction of biomass. The method for estimating stock followed the "swept area method" (Pezzuto et al. 2008, Shin 2009). This restricts the sampling area using seine net (mesh of 10×10 mm) and specimens were collected by cast net (mesh of 7×7 mm; $\pi \times 1.2$ m^2 = 4.5 m^2), fyke net (mesh of 30×30 mm; 500 m^2), and divers. The divers were sent in to search the groundfish of deepwater. A total of 402 fish were collected and the catch was 75,233 g.

In the field, collected specimens were measured up to the nearest 1 mm (total length, TL; body length, BL) and up to the nearest 0.1 g (body weight). Date of collection, length and weight of each specimen were recorded. All specimens were identified according to Choi et al. (1990) and Kim and Park (2002). After identification of species, specimens were randomly selected and transferred to the laboratory for analysis. To analyze age determination, the scales were removed from 93 species at the interval of 10 mm body length. The catch data were applied as input data for estimating stock (Table 1).

The method for estimating stock followed the "swept area method", the following equation was used (Pezzuto et al. 2008, Shin 2009).

$$B = \frac{\overline{D} \times \overline{W} \times A}{q} \quad (1)$$

where B is the biomass, $\overline{D}$ is an average density (individuals/m²) ($\overline{D} = \sum_{i=1}^{n} D_i / n$, n = number of sites), $\overline{W}$ is the target species of average weight (g) ($\overline{W} = \sum_{i=1}^{n} W_i / n$, n = number of individuals), A is the area of investigated waters (m²), and q is a catchability. The estimated values of average density and average weight were 0.018 ± 0.001 indviduals/m² and 187.1 ± 11.2 g, respectively. The catchability was calculated by the assumption that import and export of fish in restricted area by the seine net were equal each to each and all specimens should be caught in sampling area. The area of investigated waters and fishing ground were calculated by Rural Agriculture Water Resource Information System (https://rawris.ekr.or.kr). They were calculated at approximately 22,347 m² and 2,259,900 m², respectively.

In this study, parameters of population ecological characteristics that were estimated from the prior research were applied as input data. In the previous study, age structure of crucian carp has been assessed by otolith. Biological parameters for crucian carp are summarized in Table 2 (Jang et al. 2011a).

Table 1. Catch in number at total length (TL) of crucian carp in the mid-upper system of the Seomjin River

TL class (cm)	Season				Combined means		
	1st	2nd	3rd	4th	TL (cm)	BL (cm)	BW (g)
9	5				9.7	8.4	9.4
10	2				10.2	8.8	10.8
11	3	5	4	1	11.5	9.4	14.3
12	1	2	3		12.5	10.1	16.4
13		2	3		13.4	11.1	21.0
14	1		1	8	14.6	12.1	54.6
15	3		3	5	15.5	13.1	65.6
16	3	2	3	6	16.6	13.7	84.4
17	1		1	5	17.5	14.4	98.0
18	3	4	2	1	18.7	15.5	116.6
19	3	3		3	19.6	16.4	137.3
20		5	1		20.4	17.1	151.5
21	1	3		3	21.5	18.2	180.8
22	2	3	5	2	22.5	18.9	221.9
23	2	2	2	2	23.6	19.5	249.0
24		6		2	24.9	20.7	268.8
25		2		1	25.9	21.5	315.0
26	1	1	3	2	26.3	21.8	335.2
27			2		27.3	22.8	336.0
28				1	28.8	23.4	526.0

Age at first capture (t_c)

In general, t_c of a stock was estimated directly from fishing experiments either by attaching a small-meshed cover over the cod-end or from the size composition of the catches of nets of smaller meshes caught at the same time and place (Gulland 1983). Pauly method, based on a length-converted catch curve, was used because of the lack of information on fishing experiment. The method involves the following assumption: instantaneous coefficient of total mortality (Z) is same in all age group. When Z was estimated by linearized catch curve, data under age at full recruitment was not used. Virtual catch in number under age at the full recruitment was estimated by extrapolation method. Therefore, it calculates the gap between actual catch in number and virtual catch in number, at all ages. The value of gap means compositive effect between recruitment and setting mesh size (Zhang 2010). In this study, age at first capture was estimated by Pauly method (Pauly 1983, 1984).

Optimal fishing intensity and optimal age at first capture

To determine the optimal fishing mortality and the optimal age at first capture, the following equation was used (Beverton and Holt 1957).

$$\frac{Y}{R} = F_e^{-M(t_0-t_r)} \cdot W_\infty \frac{U_n e^{[-nK(t_c-t_0)]}}{F+M+K} \cdot (1-e^{-(F+M+nK)(t_L-t_c)}) \quad (2)$$

where asymptotic weight (W_∞), growth coefficient (K), and age at zero length (t_0) are parameters of von Bertalanffy growth function; R is the number of fish alive at time t_r, the age at recruitment, which was the youngest age in the catch, the minimum length in the catch was identified as 8.0 cm. converted t_r was 0.88 age. Y is the yield and M is the instantaneous coefficient of natural mortality. U_n is a summation parameter equal to +1, -3, +3, and -1 for n = 0, 1, 2, and 3, respectively.

Potential Yield

The Potential Yield (PY) that was defined as the allowable biological catch (ABC) provides an optimal catch level about fisheries resources exploited or unexploited in specified areas. To estimate the PY, this study was undertaken using the improved Fisheries Resources Potential Estimation System (FRPES) (Zhang and Na 2006). It was composed of a five-tier-classification system, which

was modified from the six-tier-system used under the US Fisheries Management Plan for the North Pacific ground-fish fisheries (NFMS/AFSC 1998). The estimation of F_{ABC} (instantaneous rate of fishing mortality that provide for Allowable Biological Catch) of stock in Fisheries Resources Potential Estimation System must take into consideration the quantity and quality of information available and the exploitation history of fisheries resources. For tier 1-3, F_{ABC} was determined, and the following equation was used to determine PY.

$$PY = PY_r + \sum_{i=r+1}^{t_L} \frac{B_i \times F_{ABC}}{M \times F_{ABC}} \times (1 - e^{-(M+F_{ABC})}) \quad (3)$$

where F_{ABC} is the instantaneous coefficient of fishing mortality for ABC determined by the available information and the stock status, r is a recruit age, and t_L is a maximum fishing age. PY_r was computed with the following equation:

$$PY_r = \frac{B \times F_{ABC}}{M \times F_{ABC}} \times (1 - e^{-(M+F_{ABC})}) \quad (4)$$

where B is the estimate of biomass. The study was adapted to the 3rd tier classification (Zhang and Lee 2001).

$$F_{ABC} = F_{0.1} \quad (5)$$

An estimate of $F_{0.1}$, which means the fishing mortality corresponding to 10% of the slope at the origin when no fishing occurs, was based on the following equation differentiated from the yield per recruit (YPR) equation of the Beverton and Holt (1957).

$$\frac{d(Y/R)}{dF} = e^{-M(t_c-t_r)} w_\infty \cdot \sum_{n=0}^{3} \frac{U_n(M+nK)e^{-nK(t_c-t_0)}}{(F+M+nK)^2}$$
$$+ \frac{e^{-(F+M+nK)(t_L-t_c)}}{(F+M+nK)^2} \cdot [(t_L-t_c)F^2 + (M+nK)(t_L-t_c) \quad (6)$$
$$F - (M+nK)]$$

RESULTS AND DISCUSSION

Age at first capture (t_c)

The age at first capture (t_c) of crucian carp was estimated to be 1.468 year from the length converted catch curve of the Pauly method (Pauly 1984). Body length that was converted by estimating t_c was calcurated as 10.8 cm (Total length 13.1 cm). Crucian carp was known to grow to 14-16 cm in total length during whole 1 year (Son and Song 2006), but, in this study, the results were somewhat differ (Fig. 2).
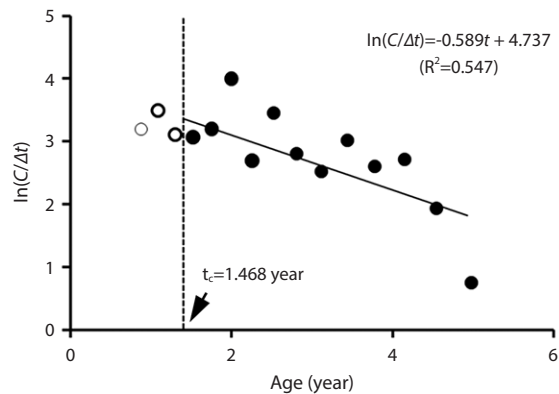

Fig. 2. E Estimation of the selection ogive of crucian carp from length-converted catch curve analysis using the method of Pauly (1984).

Optimal fishing intensity and optimal age at first capture

Fishery impact has traditionally been assessed using yield-per-recruit (YPR) analysis (Baranov 1914). YPR is estimated for different fishing mortality rates and different ages at entry to fishery (Allen 2001). Yield isopleth is developed to afford a visual representation of the influence of fishing mortality and age at entry on YPR. This analysis, which represents the tradeoff between growth and natural mortality, can be used to identify whether fish have been caught before their full growth potential (i.e., while their growth rate is still higher than natural mortality) (Wang et al. 2009). The management implications can apply the yield isopleth to help determine the relevant mesh or setting size and fishing effort.

The estimates of YPR against fishing mortalities (F) and t_c for crucian carp are summarized in Fig. 3. Yield isopleths of crucian carp were constructed to examine the response

Table 2. Parameters estimates used in yield-per recruit and Potential Yield for crucian carp in the mid-upper system of the Seomjin River

Input parameters		Values
Instantaneous coefficient of natural mortality	M	0.784 year^{-1}
Instantaneous coefficient of fishing mortality	F	0.067 year^{-1}
Instantaneous coefficient of total mortality	Z	0.851 year^{-1}
Survival rate	S	0.427 year^{-1}
Age at recruitment	t_r	0.90 age
Asymptotic length	L_∞	33.2 cm
Asymptotic weight	W_∞	1,798.4 g
Growth coefficient	K	0.20 year^{-1}
Age at zero length	t_0	-0.51 age

Note: these parameters are taken from previous study (Jang et al. 2011a).
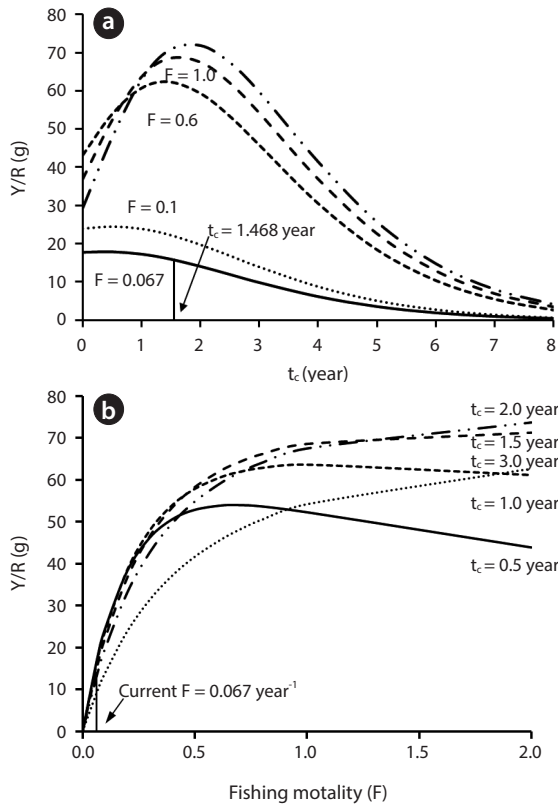
Fig. 3. Yield per recruit (Y/R) curve of the crucian carp. (a) Y/R against the age at first capture (t_c) for various fishing mortalities (F); (b) Y/R against the fishing mortalities (F) for various the age at first capture (t_c).
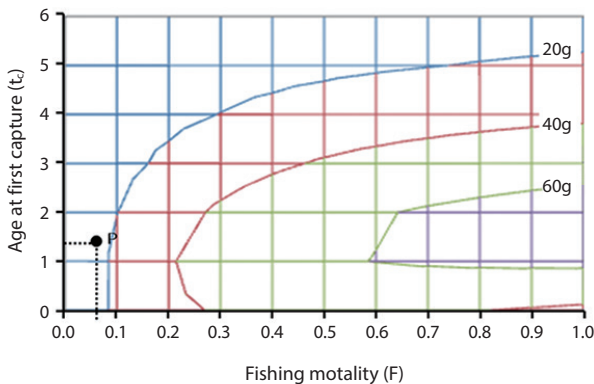

Fig. 4. Contour plot of yield per recruit of crucian carp in the mid-upper system of the Seomjin River. P indicates the current state of fishing mortality (F) and age at first capture (t_c).

of yield-per-recruit estimates to changes in t_c and F (Fig. 4). The current average yield-per-recruit (with F = 0.067 year^{-1}, and t_c = 1.468 year) was 15.999 g per recruit, indicating that the fishery was operating below the maximum-yield-per-recruit at 75.617 g, when t_c was 2.0 year. Fixing t_c at the current level, maximum-yield-per-recruit was

70.903 g when F increased more than 1.890 year^{-1}, but this F was out of range of the maximum-yield-per-recruit line. Fixing F at the current level when t_c decreased to 0.359 year, maximum-yield-per-recruit was 17.876 g which resulted in an increase of 11%, i.e., 1.88 in yield-per-recruit.

Reference points such as F_{max} and $F_{0.1}$ have often applied to evolve fisheries management implications. Table 3 delineated F_{max} and $F_{0.1}$ values from age 1 to 5 of crucian carp, which were calculated from the Beverton and Holt model. The current instantaneous coefficient of fishing mortality (F) did not exceed biological reference points. When t_c was 2 year, the yield-per-recruit was the highest at F_{max} and $F_{0.1}$ of 75.067 g and 59.346 g, respectively. F_{max} and $F_{0.1}$ decreased until 5. The yield-per-recruit corresponding to each F_{max} value increased to age 2 but the yield-per-recruit gradually declined after the age 2. Several researchers have supported designating F_{max} as target reference points and $F_{0.1}$ as a threshold reference point in order to obtain near optimal yields while guarding against stock collapse (Fazli et al. 2009). The result of the base YPR analysis in the study with t_c of 1.468 year suggests that the annual fishing intensity of crucian carp in the mid-upper system of the Seomjin River is lower than the target reference point F_{max} as well.

Stock assessment and potential yield

Study on potential yield and biomass of crucian carp could facilitate sustainable utilization of fisheries resources in the way that stock diagnosis enabled the quantitative assessment and variation prediction of biomass. This study calculated biomass using the Swept area method. The annual biomass of cruican carp was estimated as 7,608 kg and biomass per unit area was 3.37 g m^{-2}. The biomass per unit area was not relatively more plentiful

Table 3. Yield per recruit (Y/R) of crucian carp, in the mid-upper system of the Seomjin River under harvest strategies corresponding to F_{max} and $F_{0.1}$

Age at first capture	F_{max}	$F_{0.1}$	Y/R (g) at	
			F_{max}	$F_{0.1}$
1	1.076	0.505	63.702	60.703
1.46	1.890	0.618	70.903	62.339
2	>2.00	0.748	75.067	59.346
2.50	>2.00	0.865	72.617	53.347
3	>2.00	0.973	65.732	45.813
4	>2.00	1.164	46.926	30.498
5	>2.00	1.342	29.601	18.397

F_{max}, the fishing mortality rate that produces the maximum; $F_{0.1}$, the fishing mortality rate at which the slope of the yield-per-recruit curve is 10% of the slope at the origin.
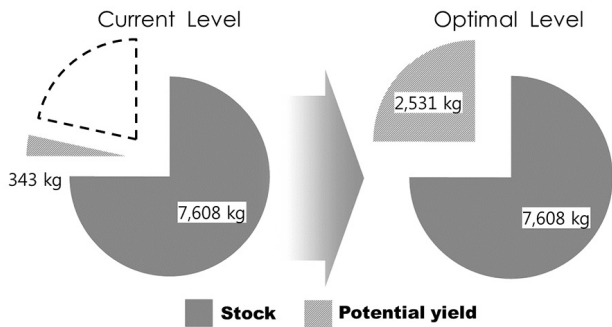
Fig. 5. Variation of potential yield for crucian carp, *Carassius auratus*, sampled in the mid-upper system of the Seomjin River.

than the result of preceded researchthat was performed in lake Namyangand estimated the result as 4.68 g m^{-2} (Jang et al. 2008). For estimating PY, information on dependable annual biomass, $F_{0.1}$, and M for crucian carp plus environmental factors affecting recruitment is required. If instantaneous coefficient of fishing mortalities (F) was set at current level, PY was estimated as 343 kg. However, in order to manage fisheries resources of crucian carp population efficiently, PY would be predicted to increase to 2,531 kg, provided that the F_{ABC} was set at 0.618 year^{-1} as derived from the estimated $F_{0.1}$ for crucian carp (Fig. 5). Also, yield per recruit would increase to 62 g. Considering the current stock status of crucian carp, we suggest the following method based on our result in order to sustain

the maximum sustainable yield of crucian carp population in the mid-upper system of the Seomjin River.

First, make a restriction on minimum fishing body length at 11 cm and over.

Second, maintain a fishing intensity of 10 times level at the current.

To establish the ecological sustainability of fish harvest, the PY estimated must be compared with actual catch figure. If total catch exceeds the PY level, fisheries resources obviously are not sustainable. Thus, Estimation of PY value must use to the threshold point, not the target reference point (Caddy and Mahom 1995). If PY values were applied to target reference level, it will occur for overfishing and collapse of fisheries.

A limited knowledge of the fisheries resources ecology of some freshwater fishes has led to overexploitation and inadequate management in freshwater (Dankel et al. 2008). Varied knowledge of the fisheries resources ecology may help establish appropriate management implication for freshwater fishes, and increasing fishery and biological information may enable a higher level evaluation to be carried out (i.e., quantitative stock assessment) (Zischke 2012). In order to suggest an effective fisheries resources management system, this study was undertaken using stock assessment and potential yield analyses of crucian carp population in the freshwater ecosystem of Korea for the first time.
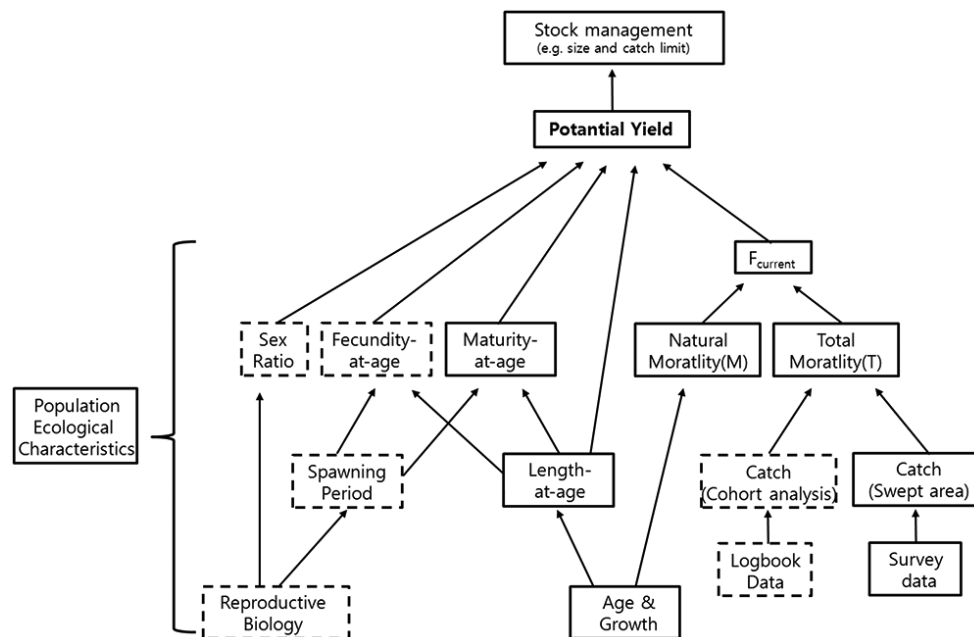

Fig. 6. A flow diagram showing key information required for stock assessment and management that is known from this research (open box), and still unknown (dashed box) for crucian carp (Griffiths et al., 2010).

CONCLUSIONS

Study on potential yield and biomass of crucian carp could facilitate sustainable utilization of fisheries resources in the way that stock diagnosis enables the quantitative assessment and variation prediction of biomass. The annual biomass of cruician carp was estimated as 7.6 t (1t = 1,000 kg) in the mid-upper system of the Seomjin River. PY would be predicted to 2.5 t, and this value can be used to establish the allowable biological catch for fisheries resources management. In order to manage fisheries resources of crucian carp population efficiently, if age at first capture (t_c) and instantaneous coefficient of fishing mortalities (F) were set at 2 year and 0.618 year^{-1}, the yield per recruit and total allowable catch would be predicted to increase to 62 g and 2,531 kg by about 3.9 times and 7.3 times, respectively.

Crucian carps (*C. auratus*) are a significant recreational and commercial species nationwide, and there will be escalating need to evaluate the stock of crucian carp more regularly to guarantee that they can be utilized sustainably. The quality of assessments will considerably depend upon accurate biological and fishery information, as well as an acceptable grasp of stock structure, if stock assessments are required. Future study should base on this information (Griffiths et al. 2010) (Fig. 6).

ACKNOWLEDGMENTS

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