The Impact of Fish Stocking on Wild Fish Populations, Fish Production and Aquatic Environment in Irrigation Reservoirs in South Vietnam

Mitigating Negative Environmental Impacts/Study/09MNE05UM

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ABSTRACT

The southeast of Vietnam is characterized by uphill geography with hundreds of small and medium reservoirs (10-400 ha) built for irrigation. This study aimed to assess the impact of fish stocking on wild fish populations, fish production, and aquatic environments in 8 irrigation reservoirs. These reservoirs included 3 without stocked fish (Bau Um, Suoi Lai and Hung Phu reservoirs in Binh Phuoc Province) and 5 with aquaculture practices (Dong Xoai, Sa Cat Reservoirs in Binh Phuoc Province and Cau Moi, Da Ton and Gia Ui Reservoirs in Dong Nai Province). The areas of Bau Um, Suoi Lai, Hung Phu, Dong Xoai, Xa Cat, Cau Moi, Da Ton and Gia Ui are 60, 30, 18, 450, 45, 273, 350 and 320 ha, respectively. Bimonthly surveys were carried out in Dong Nai Province since July 2010 and Binh Phuoc Province since August 2010 to estimate the total catch and fish species composition. In addition, bimonthly field sampling was also done at Cau Moi stocked reservoir since July 2010 and Bau Um non-stocked reservoir since August 2010 to measuring water quality and to estimate the biomass (in dry weight) of natural food webs including phytoplankton, zooplankton, benthos, detritus, terrestrial plants and main fish species groups. At the end of the sampling year in August 2011, Ecopath 5.0 models were constructed to evaluate the stocking rate and fisheries carrying capacity for each reservoir. The results indicated the necessity to manage fish stocking and wild fish populations in reservoirs for better utilization of aquatic resources, thus enhance sustainable development. In stocked reservoirs, fish production was higher and at times water quality was lower. Increased stocking rates must be controlled to maintain adequate water quality, and the utilization of land surrounding the reservoirs may also affect water quality in reservoirs. Specific information on the impacts of cultured fish species on fisheries and natural food resources allow governmental agencies and local communities to establish policies, plans and mechanisms for management of stocking of cultured fish species.

INTRODUCTION

Exotic species are defined as species or subspecies introduced outside their natural past or present distribution. These introductions include any materials, such as gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce (Bartley and Fleischer, 2005). Among reasons for introduction of exotic aquatic animals, aquaculture development is a major motive (Welcomme, 1998). The introduction of exotic aquatic species into a new region may cause not only environmental and socio-economic effects, but also be associated with “genetic pollution” (Cripps and Kumar, 2003). Invading exotic species in the United States cause major environmental damages and losses adding up to almost $120 billion per year (Pimentel et al., 2005). The introduction of exotic species into a new region will risk damage to native fish communities through predation, competition for habitats and food, disease, hybridization and other adverse environmental impacts (Welcomme, 2001; Cripps and Kumar, 2003), and can also produce imbalances in the fish community, disrupting food chains, and threatening the survival of non-target species (Welcomme, 2001).

The southeast of Vietnam is characterized by uphill geography. To support agriculture in this area, more than 50 small reservoirs (from 10 to 50 ha) and about 10 medium reservoirs (200 – 400 ha) were built for irrigation. In Binh Phuoc and Dong Nai provinces, many surrounding communities make use of the large water area (<50 ha) by stocking cultured fish species into reservoirs. This has been hypothesized as damage to natural fish populations, but there are no formal analyses about that and no evidence on reasons for these changes. Moreover, there has been no evaluation of the impact of water quality from reservoirs used for fish culture on the use of that water for irrigation.

Tilapia, bighead carp, silver barb, common carp and grass carp (all scientific names of fishes are in Appendix 2) are non-indigenous species stocked into big reservoirs like Tri An Reservoir (Luong et al., 2004) in south east Viet Nam. These species may compete for food and habitat but also serve as prey of native existing species (Luong et al., 2004). Previous CRSP project results have shown that the interaction among aquatic flora and fauna in Tri An Reservoir is very complicated, due to the varying fishery harvest, the continual input of new species, and the large size of the reservoir. However, using methodologies from Tri An studies, especially Ecopath modeling, it should be feasible to estimate carrying capacity, stocking rate and species composition of smaller reservoirs. These studies will estimate the degree and extent of damages on fisheries and biodiversity of indigenous fish species due to the introduction of cultured fish species in small reservoirs.

MATERIALS AND METHODS

The study was carried out at 8 small reservoirs in South Vietnam. These reservoirs include 3 without stocked fish (Bau Um, Suoi Lai and Hung Phu reservoirs in Binh Phuoc Province) and 5 with aquaculture practices (Dong Xoai and Sa Cat reservoirs in Binh Phuoc Province and Cau Moi, Da Ton and Gia Ui reservoirs in Dong Nai Province). The areas of Bau Um, Suoi Lai, Hung Phu, Dong Xoai, Sa Cat, Cau Moi, Da Ton and Gia Ui reservoirs are 60, 30, 18, 450, 45, 273, 350, and 320 ha, respectively. Bimonthly surveys have been carried out in Dong Nai Province since July 2010 and Binh Phuoc Province since August 2010 to estimate total catch and fish species composition at studied reservoirs.

For field sampling, one stocked reservoir and one un-stocked reservoir were selected. Bimonthly field sampling was conducted at Cau Moi reservoir (stocked) since July 2010 and Bau Um Reservoir (un-stocked) since August 2010 to measure water quality and to estimate biomass (in dry weight) of natural organisms including phytoplankton, zooplankton, benthos, detritus, terrestrial plants and the main fish species.

To determine biomass for phytoplankton and zooplankton, water samples were collected at 09:00-10:00h at nine stations in each reservoir. Concentration of chlorophyll *a* was measured using the spectrophotometric method (APHA et al., 1985), and the dry weight (DW) of phytoplankton was calculated by multiplying the content of chlorophyll a by a factor of 67 (Creitz and Richards, 1955). Zooplankton was concentrated from 50-L water sample by filtering through a 25-μm net, and fixed by 4% formalin solution. The zooplankton within 125 selected grids of a Sedgewick-Rafter counting cell were counted, and their size measured. The frequency of zooplankton size distribution was then calculated. The dry weight of zooplankton was determined by converting estimated length of zooplankton to biomass using length-weight relationship (Dumont et al., 1975; McCauley, 1984).

In Ecopath models, phytoplankton biomasses were converted from g DW/m^3 to g DW/m^2 by multiplying total volume of the photic zone, and then dividing for total area of the reservoir. Zooplankton biomasses was converted from g DW/m^3 to g DW/m^2 by multiplying total volume of the reservoirs, and then dividing for total area of the reservoir. The volume of the photic zone was estimated as the area of the reservoir within the depth range of twice the Secchi disk value.

Benthos was sampled at nine stations in each reservoir, with seven replications at each station, using an Ekman dredge with an area of 225 cm^2. Species abundance and biomass of benthos were quantified. The biomass was measured in ash-free dry weight. Due to the large amount of inorganic material included in some benthic organisms, benthos was dried at 105 C for dry weight determination, then it was ignited at 550 C for 4 hrs to estimate ash-free dry weight (Wetzel and Likens, 1979).

Sediment and bottom soil samples were collected from the top 5-cm layer of sediments at the nine stations in each reservoir for detritus biomass determination in terms of organic matter content (g DW/m^2). Benthos was separated from the sediment by a sieve. There was no periphyton growing on the sediments. Air-dried sediment samples were analyzed for the determination of organic matter content using the dry ash method (Boyd, 1995).

Terrestrial vegetation was surveyed at ten randomly selected plots (1x1m quadrats) in the littoral drawdown area when the reservoirs were at low levels from July to August 2010. Vegetation was categorized into three groups according to the trunk size and height of vegetation. Calculation of relative abundance (%) of species groups within a given area was carried out along 60-m long transects. Ground vegetation was harvested twice monthly for identifying species and estimating biomass on dry weight basis, done by drying in an oven at 105 C for 24-48 hours (Whittaker and Marks, 1975). The net production was equal to the observed change in biomass (Westlake, 1963).

The biomass of different fish groups (stocked fish, carnivorous wild fish, and herbivorous wild fish) was assessed. The stocked fish biomasses were calculated as the mean of the biomasses at stocking and at harvest, while the wild fish biomass was estimated from the survey of fish harvest and the availability of natural food. The biomass estimate was made on a dry weight basis obtained at temperatures at 103^0C (Winberg, 1971).

At the end of the sampling year in August 2011, Ecopath 5.0 models were constructed to evaluate stocking rate and fisheries carrying capacity for each reservoir (Christensen et al., 2000). In the models, energy flows of terrestrial plant, detritus, phytoplankton, zooplankton, benthos, and main fish species (stocked fish, carnivorous wild fish, and herbivorous wild fish) were quantified. The foundation of Ecopath is to create a static mass-balance snapshot of the resources in an ecosystem and their interactions, represented by trophically linked biomass boxes. An average model to represent the one year period was constructed for each reservoir. To construct the models, main input values included: (1) The average biomass in habitat area (B); (2) Production/biomass ratio (P/B); (3) Consumption/biomass ratio (Q/B); (4) Production/consumption ratio (P/Q); (5) Diet composition (DC). While the biomass (B) was measured directly in this study, other input values were referenced and calculated from the Ecopath model.

Ecotrophic efficiency (EE) is the proportion of production that is used in the system (i.e. either passed up the food web, used for biomass accumulation, migration, predation mortality, or export). This value varies between 0 and 1, and can be expected to approach 1 for groups with considerable predation pressure. According to Ricker (1971), the EE value is often assumed to range from 0.65 to 0.95. In this study, this parameter was calculated by the Ecopath program and then it was considered as one of the most important diagnostics for balancing the model and for predicting fish stock composition at the studied reservoirs.

RESULTS

1. Water quality and biomass at Bau Um and Cau Moi reservoirs

At Cau Moi reservoir (stocked), water quality parameters were collected from Upstream, Midstream and Downstream stations in the reservoir (Appendix 1). The results showed that total NH_3 concentration ranged from 0.037-0.742 mg/L, NO_2 from 0.002-0.006 mg/L, total phosphorus from 0.007 – 0.212 mg/L, DO from 4.4 – 5.5 mg/L, pH from 7.2 – 7.7, total alkalinity from 46.67 – 63.67 mg $CaCO_3$/L, temperature from 29 – 29.8^0C, and transparency from 75 - 85 cm.

At Bau Um Reservoir (not stocked), water quality parameters were also collected from Upstream, Midstream and Downstream stations and analyzed (Appendix 1). The results showed that total NH_3 concentration ranged from 0.00-0.27 mg/L, NO_2 from 0.000-0.003 mg/L, TP from 0.003- 0.059 mg/L, DO from 3.9-5.2 mg/L, pH from 6.80-7.16, total alkalinity from 19.33–31.67 mg $CaCO_3$/L, temperature from 28–29^0C, and transparency from 90-110 cm.

Phytoplankton biomass ranged from 1.17-1.97 g DW/m^3 during July-May at Cau Moi (Table 1), and from 0.21-1.47 g DW/m^3 during August-June at Bau Um Reservoir (Table 2). Phytoplankton biomass at the downstream station was significantly lower than at the upstream and midstream stations for both Cau Moi and Bau Um reservoirs ($P<0.05$). In general, phytoplankton biomass of Cau Moi Reservoir was more abundant than Bau Um Reservoir. The average phytoplankton biomass at Cau Moi was 1.53 gDW/m^3 or 3.37 gDW/m^2, while the average phytoplankton biomass at Bau Um was 0.73 gDW/m^3 or 2.05 gDW/m^2.

Table 1. Fluctuations of phytoplankton biomass at Cau Moi stocked reservoir.

Months	Phytoplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Jul	1.69 ± 0.04	1.57 ± 0.21	1.51 ± 0.12
Sep	1.45 ± 0.06	1.91 ± 0.26	1.29 ± 0.06
Nov	1.59 ± 0.19	1.63 ± 0.04	1.23 ± 0.12
Jan	1.43 ± 0.07	1.39 ± 0.06	1.17 ± 0.04
Mar	1.53 ± 0.07	1.47 ± 0.07	1.21 ± 0.08
May	1.91 ± 0.09	1.97 ± 0.09	1.59 ± 0.09

[ab] Values in the columns under the headers with different superscript letters were significantly different ($P<0.05$)

Table 2. Fluctuations of phytoplankton biomass at Bau Um non-stocked reservoir.

Months	Phytoplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Aug	0.56 ± 0.11	0.48 ± 0.05	0.46 ± 0.12
Oct	0.32 ± 0.10	0.29 ± 0.04	0.24 ± 0.05
Dec	0.74 ± 0.05	0.82 ± 0.09	0.56 ± 0.04
Feb	0.79 ± 0.08	0.54 ± 0.07	0.48 ± 0.08
Apr	1.47 ± 0.13	1.35 ± 0.08	1.21 ± 0.05
Jun	0.98 ± 0.09	1.01 ± 0.07	0.91 ± 0.08

[ab] Values in the columns under the headers with different superscript letters were significantly different ($P<0.05$)

Zooplankton biomass ranged from 0.05-0.83 g DW/m^3 during July-May at Cau Moi (Table 3), and from 0.11-1.27 g DW/m^3 during August-June at Bau Um (Table 4). Zooplankton biomass at the downstream stations were significant lower than the upstream and midstream stations of both Cau Moi and Bau Um reservoir ($P<0.05$). In general, zooplankton biomass of Bau Um was somewhat more abundant than that of Cau Moi. The average zooplankton biomass at Cau Moi was 0.31 gDW/m^3 or 1.86 gDW/m^2, while the average zooplankton biomass at Bau Um was 0.35 gDW/m^3 or 1.41 gDW/m^2.

Table 3. Fluctuations of zooplankton biomass at Cau Moi stocked reservoir.

Months	Zooplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Jul	0.22 ± 0.02	0.35 ± 0.03	0.2 ± 0.02
Sep	0.81 ± 0.04	0.83 ± 0.05	0.32 ± 0.03
Nov	0.50 ± 0.04	0.24 ± 0.02	0.26 ± 0.03
Jan	0.33 ± 0.04	0.14 ± 0.01	0.05 ± 0.01
Mar	0.24 ± 0.02	0.21 ± 0.02	0.17 ± 0.02
May	0.32 ± 0.03	0.24 ± 0.02	0.15 ± 0.01

[b] Values in the columns under the headers with different superscript letters were significantly different ($P<0.05$)

Table 4. Fluctuations of zooplankton biomass at Bau Um non-stocked reservoir.

Months	Zooplankton biomass (gDW/m^3)		
	Upstream [a]	Midstream [a]	Downstream [b]
Aug	0.25 ± 0.03	0.29 ± 0.03	0.20 ± 0.02
Oct	0.60 ± 0.07	0.33 ± 0.05	0.18 ± 0.03
Dec	1.27 ± 0.22	0.81 ± 0.13	0.68 ± 0.10
Feb	0.18 ± 0.02	0.22 ± 0.03	0.11 ± 0.01
Apr	0.22 ± 0.03	0.21 ± 0.03	0.20 ± 0.02
Jun	0.20 ± 0.02	0.20 ± 0.02	0.19 ± 0.02

[ab] Values in the columns under the headers with different superscript letters were significantly different ($P<0.05$)

Table 5. Fluctuations of benthos biomass at Cau Moi stocked reservoir.

Months	Benthos biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Jul	0.12	0.15	0.05
Sep	0.01	7.40	9.05
Nov	0.13	8.34	1.98
Jan	2.73	7.08	7.29
Mar	5.18	6.09	9.43
May	0.05	0.13	0.11

Benthos biomass ranged from 0.01-9.43 g DW/m^2 during July-May at Cau Moi Reservoir (Table 5), and from 0.08-0.64 g DW/m^2 during August-June at Bau Um Reservoir (Table 6). Benthic biomass was very poor at Bau Um (average was 0.41 gDW/m^2), while it was higher and exhibited more fluctuations at Cau Moi (averaging 3.63 gDW/m^2).

Table 6. Fluctuations of benthos biomass at Bau Um non-stocked reservoir.

Months	Benthos biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Aug	0.64	0.72	0.16
Oct	0.48	0.32	0.40
Dec	0.56	0.64	0.16
Feb	0.32	0.16	0.16
Apr	0.64	0.56	0.08
Jun	0.32	0.32	0.16

Table 7. Fluctuations of detritus biomass at Cau Moi stocked reservoir.

Months	Detritus biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Jul	469.9	496.8	546.8
Sep	307.7	406	251
Nov	352	627.6	458.7
Jan	5600.4	10245.8	6019.3
Mar	6014.4	7009.3	5184.4
May	5188.4	6791.4	8500.9

Table 8. Fluctuations of detritus biomass at Bau Um non-stocked reservoir.

Months	Detritus biomass (gDW/m^2)		
	Upstream	Midstream	Downstream
Aug	91.1	26.2	22.8
Oct	103.5	121.7	41.5
Dec	2931.6	3820.9	3670.9
Feb	4341.5	4122.6	2867.9
Apr	1393.2	3320.2	2906.3
Jun	4847.6	2360.4	1779.8

Detritus biomass ranged from 251-10,245 gDW/m^2 during July-May at Cau Moi Reservoir (Table 7), and ranged from 22.8-4,847 gDW/m^2 during August-June at Bau Um Reservoir (Table 8). In general, detritus biomass was more abundant at Cau Moi. The average detritus biomass at Cau Moi and Bau Um were 3581 gDW/m^2 and 2153 gDW/m^2, respectively.

Terrestrial vegetation biomass in the drawdown areas of the reservoirs (Table 9) was categorized into three groups according to the height of vegetation. The mean biomass of terrestrial plants for whole year was about 292 gDW/m^2 and 766 gDW/m^2 for Cau Moi and Bau Um reservoirs, respectively.

Table 9. Terrestrial vegetation biomass during July-August.

Reservoir	Vegetation height (cm)	The ratio (%)	Biomass (gDW/m^2)
Cau Moi	< 30	30	160.2
	30 - 70	55.	280.1
	> 70	15	603.3
	All size	100	292.6
Bau Um	< 30	10	326.7
	30 - 70	50	546.7
	> 70	40	1150.1
	All size	100	766.1

2. Fisheries at the 8 reservoirs

There were 63 fish species (Appendix 2) belonging to 23 families in the 8 reservoirs. Relative abundance by family was dominated by Cyprinidae (30%), and Bagridae (14%, Figure 1). Cyprinidae dominated distribution in all reservoirs with 19 species, then Bagridae with 9 species, Mastacembelidae with 4, the other families only had 1-3 species.

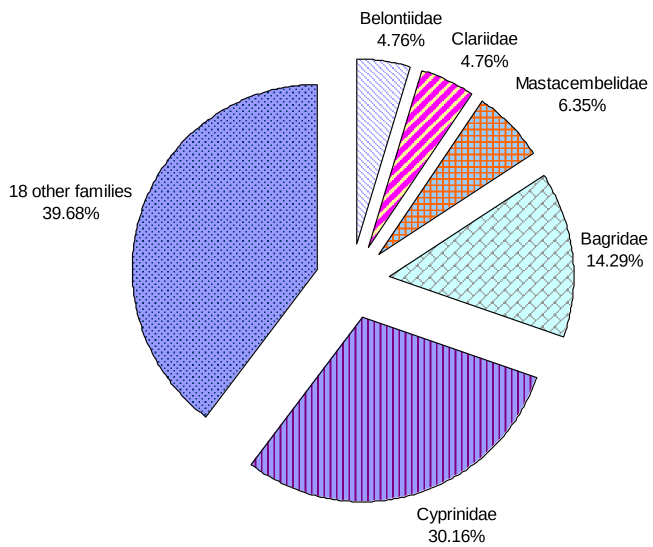

Figure 1. Fish family composition averaged for all 8 reservoirs.

Stocked reservoirs included Cau Moi (CM), Da Ton (DT), Gia Ui (GU), Dong xoai (DX), and Xa Cat (XC). Reservoirs without stocking included Bau Um (BU), Hung Phu (HP), Minh Hung, and Suoi Lai (SL). Dong Xoai had highest numbers of fish species (53 species belongs to 21 families) and accounted for 84% of all species observed, then Cau Moi with 45 species in 17 families, Gia Ui with 36 species in 19 families. Suoi Lai and Hung Phu had less species than the others; Suoi Lai with 25 species in 11 families and Hung Phu with 27 species in 15 families (Figure 2).

Fish in reservoirs without stocking included species from former rivers, escaped fish from culture ponds, and released fish from surrounding communities so the number of species and families in those reservoirs was lower than the stocked reservoirs. The difference depended mainly on the natural fish composition in the former rivers. Moreover, the number of species collected depended on the gears of people who fish in these reservoirs (Table 10).

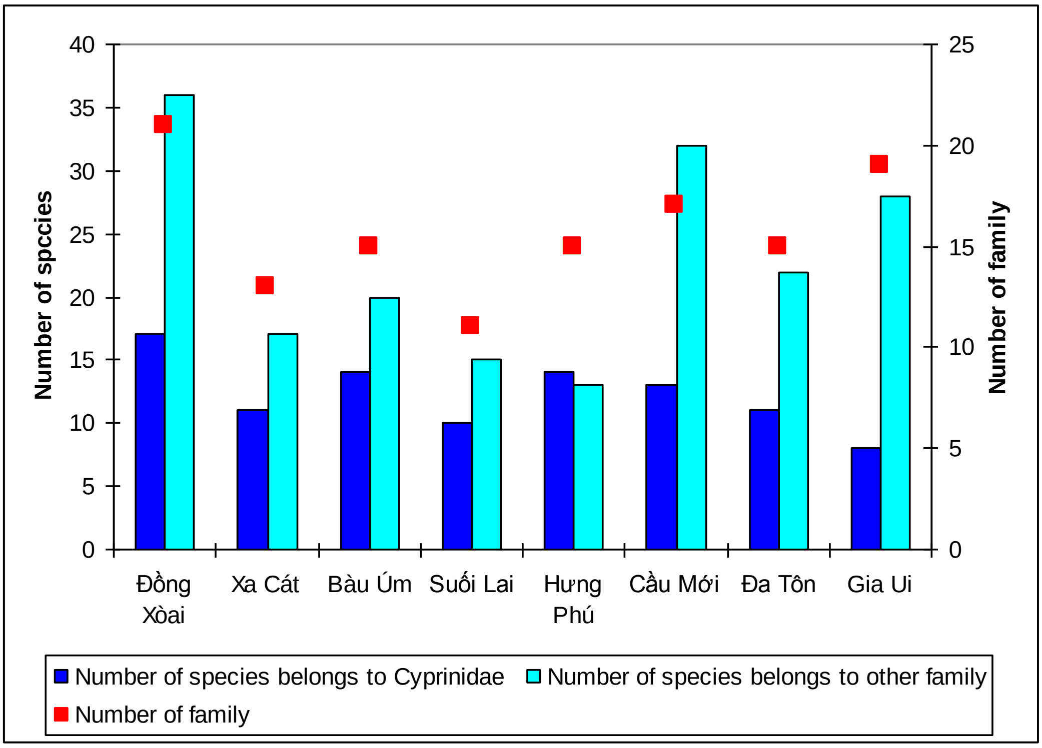

Figure 2. Number of fish species and families collected in each reservoir.

Table 10. Fishing gears used in the 8 reservoirs.

No.	Fishing gears	BU	SL	HP	DX	XC	CM	ĐT	GU
1	Hook	x	x	x	x	x	x	x	X
2	Line-hook				x	x		x	
3	Cast net	x	x		x	x			
4	Standing net	x			x				
5	Reef				x				
6	Bow net		x		x				
7	Prawn net	x	x	x		x			
8	Snake head net				x				
9	Trail net	x	x	x	x	x	x	x	X
10	Trammel net	x	x	x	x	x			
11	Floating lift net					x			
12	Improved bottom set net	x	x				x		X
13	Circle net						x	x	X
14	Improved set net							x	
Total		7	7	4	9	7	4	5	4

CPUE results of trail net and trammel net at different reservoirs (Tables 11 and 12) showed that CPUE at reservoirs without stocked fish was much lower than at reservoirs with stocked fish. This might be due to the number of fishermen as well as the production at each reservoir.

Table 11. CPUE (g/person/day) of trail nets at each reservoir.

Reservoir	CPUE (g/person/day)	
	Dry season	Rainy season
Bau Um	1.000 ± 816	2.785 ± 2.047
Suoi Lai	2.354 ± 1.078	3.758 ± 2.451
Hưng Phu	2.088 ± 712	2.488 ± 872
Đong Xoai	8.384 ± 7.594	5.277 ± 3.582
Xa Cat	4.744 ± 2.837	5.791 ± 2.232
Cau Moi	105.772 ± 39.837	45.541 ± 24.142
Đa Ton	75.754 ± 12.361	31.458 ± 9.467
Gia Ui	68.547 ± 38.245	20.457 ± 17.541

Table 12. CPUE (g/person/day) of trammel nets at each reservoir.

Reservoir	CPUE (g/person/day)	
	Dry season	Dry season
Bau Um	2.019±1.414	1.045±261
Suoi Lai	1.954±945	2.151±680
Hung Phu	2.105±814	2.287±744
Đong Xoai	5.345±2.361	6.670±3.300
Xa Cat	3.633±1.797	4.000±00

Mostly carp species were stocked in the reservoirs in 2010 (Table 13). There were 3 kinds of reservoir management; private, cooperative, and community group (Table 14). These kinds of management also affected the fish yields and fishing gears used.

Table 13. Number of fish stocked at 5 reservoirs.

Species	Cau Moi	Đa Ton	Gia Ui	Đong Xoai	Xa Cat
Silver carp	2,250 kg	1,840 kg	1,000 kg	55 kg	45 kg
Big head carp	2,250 kg			25 kg	15 kg
Indian carp	400 kg	200 kg			
Common carp	400 kg	1,400 kg	500 kg	30 kg	30 kg
Grass carp	400 kg			40 kg	30 kg
Silver barb			150 kg		
Total (kg)	**5,700**	**3,340**	**1,650**	**150**	**120**
Stocking density fish/m^2	0.4	0.2	0.1	0.007	0.062
Stocking density fish/ha	4,193.8	2,240.2	1,113.5	70.2	628.6

Table 14. Fisheries management at 5 reservoirs.

Reservoir	Management type	Established year	Re-established year
Cau Moi	Private	2008	
DaTon	Cooperative	2000	2010
Gia Ui	Cooperative	2001	2010
Xa Cat	Community group	2006	2010
Dong Xoai	Community group	2007	

Table 15. Fish yields at 5 reservoirs with stocking during 2010-2011.

Reservoir	Cultured fish yield kg/ha	% of total fish yield	Wild fish yield kg/ha	% of total fish yield	Productivity kg/ha
Cau Moi	640.9	95.7	29	4.3	670.0
Đa Ton	472.6	90.0	53	10.0	525.1
Gia Ui	422.5	93.0	32	7.0	454.3
Đong Xoai	81.7	71.8	32	28.2	113.7
Xa Cat	3 3.3	81.8	83	18.2	456.5

Fish yields at each reservoir were recorded (Table 15). The harvest from wild fish at reservoirs with stocking ranged from 29-83 kg/ha and was lower than harvest of wild fish at reservoirs without stocking (ranging from 36-89 kg/ha, Table 17). Stocked fish affected wild fish yield after reservoirs were established.

Table 16. Culturing efficiency (%) of stocked and wild fish in stocked reservoirs.

Reservoir	Area Ha	Stocked fish kg/ha	Yield kg/ha	Culturing efficiency %
Cau Moi	320	17.81	640.9	36.0
Đa Ton	328	10.18	472.6	46.4
Gia Ui	326	5.06	422.5	83.5
Đong Xoai	470	0.32	81.7	255.9
Xa Cat	42	2.86	373.3	130.7

Table 17. Yield of cultured and wild fish at reservoirs without stocking.

Reservoir	Yield of cultured fish kg/ha	% of total fish yield	Wild fish yield kg/ha	% of total fish yield
Bau Um	38	51.2	36	48.8
Hung Phu	110	55.3	89	44.7
Suoi Lai	87	66.6	44	33.4

Table 18. Aquatic species that disappeared (*) or had decreased yield (**) after reservoir establishment.

Local name	Scientific name	Cau moi	Đa Ton	Dong xoai	Xa Cat	Gia Ui
Cá chạch lấu	*Mastacembelus armatus*	**		**	**	
Cá ch nh	*Anguilla marmorata*	*		*		*
Cá đỏ mang	*Systomus orphoides*		**			**
Cá lìm kìm	*Hyporhamphus limbatus*			**		
Cá lăng nha	*Hemibagrus nemurus*	**	**	**	**	**
Cá lăng vàng	*Hemibagrus filamentus*				**	
Cá ngựa nam	*Hampala macrolepidota*	**		**	**	
Cá nhái	*Xenetodon cancila*			**	**	
Cá thát lát cư m	*Chitala ornata*			**		
Cá trê trắng	*Clarias batrachus*			**		
Cá Sặc rằn	*Trichogaster pectoralis*			**	**	
Tôm càng xanh	*Macrobrachium rosenbergii*	*		*		
		5	2	10	6	3

Higher rates of stocking did not necessarily result in a larger harvest of stocked fish in all reservoirs (Table 16). This will be discussed more detail when we analyze the relationship between the food web and fish yield.

The results from interview and group discussions with fishermen showed that eel and giant freshwater prawn disappeared after the reservoirs were established, while 4-8 other fish species (Table 18) had decreasing yield after reservoir establishment.

Table 19. Aquatic species with increasing yield after reservoir establishment.

No.	Local name	Scientific name	BU	CM	ĐT	DX	GU	HP	SL	XC
1	Cá bống tượng	*Oxyeleotris marmoratus*	x	x	x	x			x	
2	Cá chốt	*Mystus mysticetus*		x	x	x	x			
3	Cá lăng vàng	*Hemibagrus filamentus*				x				
4	Cá lóc đồng	*Channa striata*			x	x	x			
5	Cá mè vinh	*Barbodes gonionotus*			x					x
6	Cá ngựa nam	*Hampala macrolepidota*			x					
7	Cá rô biển	*Pristolepis fasciatus*	x			x			x	x
8	Cá rô đồng	*Anabas testudineus*		x		x	x			
9	Cá rô phi	*Oreochromis niloticus*	x	x	x	x	x	x	x	x
10	Cá đỏ mang	*Systomus orphoides*				x				
11	Cá sặc	*Trichogaster sp*		x		x	x			x
12	Cá sơn	*Parambassis sp.*		x		x			x	
13	Cá trê vàng	*Clarias macrocephalus*	x		x	x		x		x
14	Cá tr n	*Kryptopterus moorei*			x					
15	Lòng tong	*Rasbora sp.*		x		x	x	x	x	x
16	T p	*Macrobrachium sp.*	x	x	x	x	x	x	x	x

Depending on the origin of fish composition and fisheries management type, some aquatic species in the 8 reservoirs had increasing yield after the reservoir was established. Most of reservoirs with stocked fish had more fish species with increasing yields after reservoir establishment (Table 19).

3. Fish and food chains

Based on feeding habits and economic value, the fish found in Cau Moi and Bau Um reservoirs could be categorized as economically important, predatory, or small low-value fish. The diet matrix in Table 20 was obtained from results of stomach content analyses available in the literature.

The economically important fish were all high-value non-predatory fishes that grew quickly and reached large size. The major cultured and wild fish species included common carp, bighead carp, silver carp, grass carp, tilapia, mrigal, and rohu. The predatory fishes also grew quickly and reached a large size. They have good quality flesh and a high economic value. The main predatory fishes include Chevron snakehead, giant snakehead, *Wallago attu*, *Mystus wycki*, marbled sleeper, and bronze featherback. The small, low-value fishes grew slowly, remained small, and were generally of low economic value. They may compete for food with the economically important fish. The main low-value fishes in coves are: *Dangila spilopleura*, *Mystus spp*., *Osteochilus hasselti*, *Chanda gymnocephala*, and river sprat.

4. Trophic model at Cau Moi Reservoir

The input parameters of Ecopath modeling are given in Table 21 for the study period. The ecotrophic efficiency (EE) of cultured fish and carnivorous fish was set at 0.99, indicating total harvest at late stages of the culture period. The EE values for small wild fish, benthos, zooplankton, phytoplankton, vegetation, and detritus were set at 0.919, 0.325, 0.719, 0.738, 0.026, and 0.320, respectively (Table

21). There were very high EE values for small wild fish, phytoplankton, and zooplankton, ranging from 0.719 to 0.919.

A quantitative representation of the trophic interaction at Cau Moi Reservoir for the entire culture period is presented in Figure 3. Discrete trophic levels of the system are shown in Table 22. The average trophic levels of bighead carp, silver carp, mrigal, common carp, grass carp, tilapia, carnivorous fish, and small wild fish were 2.25, 2.0, 2.0, 2.58, 2.0, 2.11, 3.13, and 2.26, respectively. The bulk of the flows were at trophic level I and II, with total flow of 1829.9 and 1131.3 g DW/m^2, respectively. The flows at trophic level III and IV were 85.6, and 4.5 g DW/m^2, respectively.

Table 20. Diet composition of various species in Truong Dang Cove (% by weight).

Predator	Prey						Sources
	8	9	10	11	12	13	
1. Bighead carp	-	-	24	7	-	69	(a)
2. Silver carp	-	-	-	84	-	16	(a)
3. Mrigal	-	-	-	30	20	50	(b)
4. Common carp	-	50	-	-	-	50	(b), (c)
5. Grass carp	-	-	-	-	85	15	(d)
6. Tilapia	-	-	10	25	10	55	(b)
7. Carnivorous fish	85	5	-	-	-	10	(e), (f)
8. Small wild fish	-	-	25	40	-	35	(e), (f)
9. Benthos	-	5	10	20	-	65	(g), (h)
10. Zooplankton	-	-	5	95	-	-	(i)
11. Phytoplankton	-	-	-	-	-	-	
12. Vegetation	-	-	-	-	-	-	
13. Detritus	-	-	-	-	-	-	

Sources: (a) Cremer and Smitherman (1980); (b) Jørgensen (1979); (c) Specziár et al. (1997); (d) Colle et al. (1978); (e) Luong (2004); (f) Rainboth (1996); (g) Moreau et al. (1993); (h) Leveque et al. (1983); (i) Moriarty et al. (1973).

Table 21. Input and Ecopath estimated (values in parentheses) parameters for the study period at Cau Moi Reservoir.

Group	Biomass gDW/m^2	P/B (/crop)	Q/B (/crop)	P/Q (/crop)	EE (/crop)	Trophic level
Bighead carp	2.94	1.79	12.60	(0.142)	0.99	(2.25)
Silver carp	3.01	1.75	18.38	(0.95)	0.99	(2.00)
Mrigal	0.39	1.75	12.00	(0.46)	0.99	(2.00)
Common carp	0.21	1.79	11.17	(0.60)	0.99	(2.58)
Grass carp	0.34	1.65	27.12	(0.61)	0.99	(2.00)
Tilapia	0.17	1.70	15.30	(0.11)	0.99	(2.11)
Carnivorous fish	3.04	1.01	6.70	(0.15)	0.99	(3.13)
Small wild fish	12.16	1.55	15.50	(0.1)	(0.919)	(2.26)
Benthos	3.63	8.05	40.25	(0.2)	(0.325)	(2.16)
Zooplankton	1.86	81.32	406.6	(0.2)	(0.719)	(2.05)
Phytoplankton	3.37	351.67	-	-	(0.738)	(1.00)
Vegetation	292.6	1.19	-	-	(0.026)	(1.00)
Detritus	3581.7	-	-	-	(0.320)	(1.00)

P/B and Q/B rations are from Luong (2004)

Table 22. Trophic transformation matrix for the study period at Cau Moi Reservoir presenting trophic flows (gDW/m^2/crop) for each group at discrete trophic levels.

Group	Trophic level	Absolute flows by trophic level			
		I	II	III	IV
Bighead carp	2.25	-	28.2	8.9	-
Silver carp	2.00	-	55.3	-	-
Mrigal	2.00	-	4.7	-	-
Common carp	2.58	-	1.2	1.0	0.1
Grass carp	2.00	-	9.2	-	-
Tilapia	2.11	-	2.3	0.3	-
Carnivorous fish	3.13	-	2.0	13.9	4.4
Small wild fish	2.26	-	141.4	47.1	-
Benthos	2.16	-	130.7	15.4	-
Zooplankton	2.05	-	756.3	-	-
Phytoplankton	1.00	1185.1	-	-	-
Vegetation	1.00	9.0	-	-	-
Detritus	1.00	635.8	-	-	-
Total	-	1829.9	1131.3	85.6	4.5

5. Predicted ecological efficiencies from different simulated management scenarios using Ecopath model

Using Ecopath modeling, various options for manipulation of Cau Moi reservoir's food web are presented in Table 23. Manipulation focused first on the objective to reduce ecological efficiencies (EE) of small wild fish by increasing small wild fish biomass 30%, resulting in the small wild fish's EE value changing to 0.706.

In step II, biomass of herbivorous and small wild fish were increased by 50%, resulting in EE values of 0.919, 0.874, and 0.769 for small wild fish, zooplankton, and phytoplankton, respectively. In step III, biomass of small wild fish was increased by 100%, resulting in EE for zooplankton over 1, indicating not enough zooplankton food to support the system. In step IV, biomass of silver carp was increased by 400% to utilize phytoplankton in the system, changing the EE for phytoplankton to 0.894.

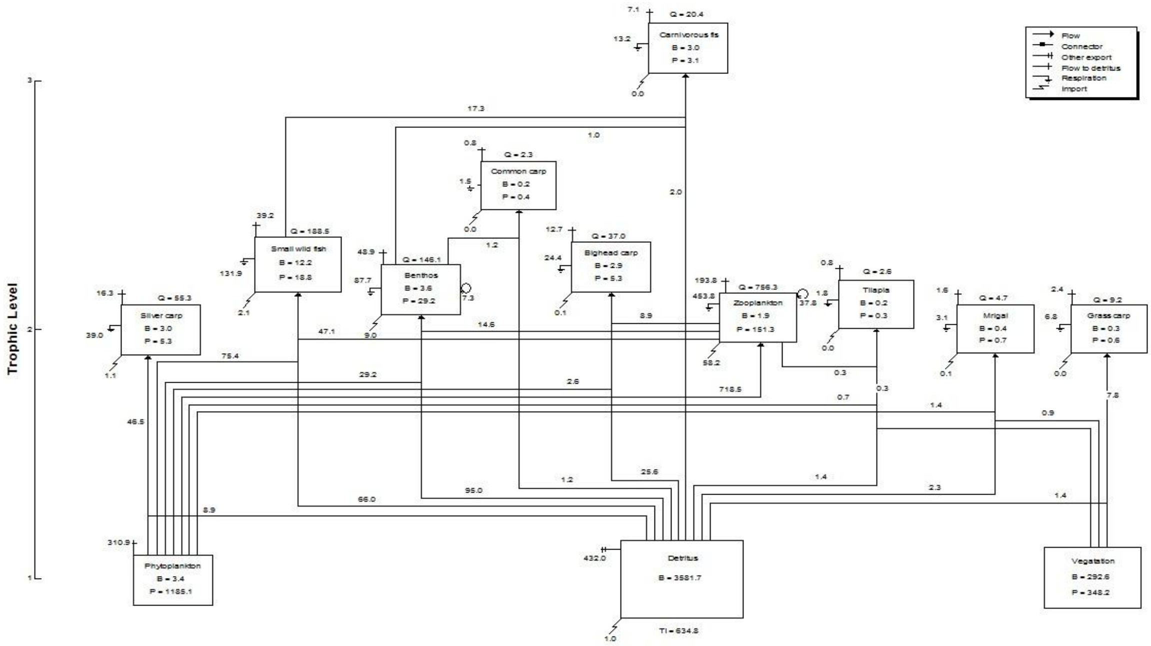

Figure 3. A quantitative representation of the trophic interaction for the study period at Cau Moi Reservoir. All flows are expressed in g DW/m^2/crop, while biomass (B) is in g DW/m^2.

Table 23. Predicted ecological efficiencies (EE) from different simulated management scenarios using Ecopath model.

Steps	Objectives	Adjustments	Affected factors	Results
I	To reduce EE of small wild fish	B = 15.81 gDW/m^2 for small wild fish (30% increasing)	EE = 0.812 for zooplankton and 0.757 for phytoplankton	EE = 0.706 for small wild fish
II	To increase biomass of carnivorous and small wild fish	B = 4.56 and 18.24 gDW/m^2 for carnivorous and small wild fish, respectively (50% increasing)	EE = 0.874 for zooplankton and 0.769 for phytoplankton	EE = 0.919 for small wild fish
III	To increase biomass of small wild fish	B = 24.32 gDW/m^2 for small wild fish (100% increasing)	EE = 0.801 for phytoplankton	EE = 1.03 for zooplankton
IV	To increase biomass of silver carp	B = 15.05 gDW/m^2 for silver carp (400% increasing)	EE = 0.499 for detritus	EE = 0.894 for phytoplankton

Table 24. Input and estimated parameters for the yearly period at Bau Um Reservoir (as in Table 21).

Group	Biomass gDW/m^2	P/B (/crop)	Q/B (/crop)	P/Q (/crop)	EE (/crop)	Trophic level
Bighead carp	2.0	1.79	12.60	(0.142)	0.99	(2.25)
Silver carp	1.0	1.75	18.38	(0.95)	0.99	(2.00)
Common carp	0.4	1.79	11.17	(0.60)	0.99	(2.58)
Grass carp	10.0	1.65	27.12	(0.61)	0.99	(2.00)
Carnivorous fish	2.4	1.01	6.70	(0.15)	0.99	(3.13)
Small wild fish	10.0	1.55	15.50	(0.1)	(0.882)	(2.26)
Benthos	0.41	8.05	40.25	(0.2)	(0.927)	(2.16)
Zooplankton	1.41	81.32	406.6	(0.2)	(0.655)	(2.05)
Phytoplankton	2.05	351.67	-	-	(0.870)	(1.00)
Vegetation	766.1	1.19	-	-	(0.253)	(1.00)
Detritus	2153.9	-	-	-	(0.124)	(1.00)

6. Trophic model for the yearly period at Bau Um Reservoir

The input parameters for Ecopath modeling are given in Table 24 for the study year in Bau Um Reservoir. The ecotrophic efficiency of harvested fish was set at 0.99, indicating total harvest at the late stage of the culture period. The EE values for small wild fish, benthos, zooplankton, phytoplankton, vegetation, and detritus were 0.882, 0.927, 0.655, 0.870, 0.253, and 0.124, respectively (Table 24). There were very high EE values for benthos, phytoplankton, and small wild fish, ranging from 0.870 to 0.927.

A quantitative representation of the trophic interaction at Bau Um Reservoir for the study year is presented in Figure 4. The average trophic levels of bighead carp, silver carp, common carp, grass carp, carnivorous fish, and small wild fish were 2.25, 2.0, 2.58, 2.0, 3.13, and 2.26, respectively. In the system, the bulk of flows were at trophic level I and II, with total flow of 2690 and 1017 gDW/m^2, respectively. The flows at trophic level III and IV were only 58.8 and 3.7 gDW/m^2, respectively.

Table 25. Trophic transformation matrix for the yearly period at Bau Um Reservoir presenting trophic flows (gDW/m^2/crop) for each group in the system on discrete trophic levels.

Groups	Trophic level	Absolute flows by trophic level			
		I	II	III	IV
Bighead carp	2.25	-	19.2	6.1	-
Silver carp	2.00	-	18.4	-	-
Common carp	2.58	-	2.2	2.0	0.2
Grass carp	2.00	-	271.2	-	-
Carnivorous fish	3.13	-	2.4	10.3	3.4
Small wild fish	2.26	-	116.3	38.8	-
Benthos	2.16	-	14.8	1.7	-
Zooplankton	2.05	-	573.3	-	-
Phytoplankton	1.00	720.9	-	-	-
Vegetation	1.00	911.7	-	-	-
Detritus	1.00	1057.5	-	-	-
Total	-	2690.1	1017.7	58.8	3.7

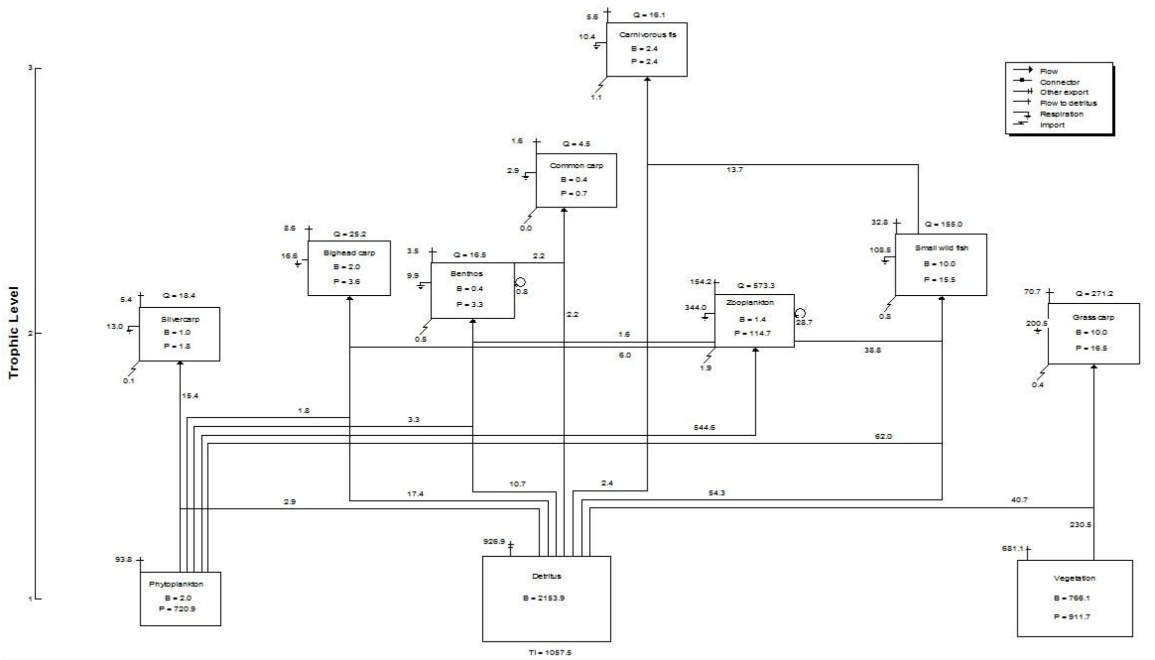

Figure 4. A quantitative representation of the trophic interaction for the yearly period at Bau Um non-stock reservoir. All flows are expressed in g DW/m^2/crop, while biomass (B) is in g DW/m^2.

DISCUSSION

The reservoir without stocked fish had higher transparency and lower toxic substance concentrations than the reservoir with stocking. However, water quality in both reservoirs was suitable for fish survival. Water quality in Cau Moi Reservoir, with stocked fish, still met the quality for irrigation (standard of Vietnamese Ministry of Environment and Natural Resources, 2005). Water quality in Bau Um reservoir was even cleaner water but had poor natural food.

Huang D. and et al. (2001), Li Sifa (2001) and Tuantong Jutagate (2009) reported that dam construction affected on the indeginous fish composition in reservoirs, especially fish has migration for spawning, prey for food or suitable habitat for each life stage. Those species tend to be excluded their life environment. It is obviuos that giant fresh water prawn (*Macrobrachium rosenbergii*) and fresh water eel (*Anguilla marmorata*) disappear in most of investigated reservoirs, or *Systomus orphoides* never present in Da Ton reservoir after it is established. Moreover, the wide fluctuation of water level in reservoirs also causing the lost of spawning ground of some fish species that laying sticky eggs. In the year of 2010, the low precipitation and the low water level in reservoirs due to supplying more water for crop lead the spawning grown drying. Therefore, the yield of some species decrease in the next year. However, the storing water in reservoirs also stimulate the growing and propagation of some indeginous and exotic species inside theirs such as marble goby, silver barb, tilapia, snake head, etc. Beam (1983) and De Silva (1985) also reported that the periodic increasing water level created the active affect on the increasing yield of some fish species in reservoirs.

The transparency and low nutrient in Bau Um reservoir lead to less phytoplankton biomass comparing to the richer nutrient in Cau Moi reservoir with abundant plankton. These results explain the yield of herbivorous fish in Bau Um reservoir is lower than in Cau Moi reservoir although the fishing in those reservoirs is different.

According to Russell-Hunter (1970), fluctuations in the aquatic food web are controlled by the interaction of several factors, which are usually divided into three groups: (1) physical factors such as light intensity, temperature, mixing and turbulence caused by wind action; (2) content of nutrients in the water body; and (3) interaction of organisms present in the aquatic community which may promote or hamper production of certain species. In this study, fluctuations of the food web in studied reservoirs were affected greatly by wide fluctuation of water level and severe drawdown.

Fluctuations by phytoplankton in reservoirs are one of the most interesting areas of study to aquatic biologists. Algae can be utilized indirectly through secondary trophic levels (zooplankton, benthos, invertebrates, etc.) or directly through grazing by fish. Average plankton biomass (0.73-1.53 g DW/m^3) in the reservoirs measured in this study was higher than the average value (0.3 g DW/m^3) in lakes and reservoirs in South Vietnam reported by Shirota (1966). Phytoplankton biomass of Cau Moi stocked reservoir was more abundant than that of Bau Um non-stocked reservoir, indicating better culture potential for herbivorous fish at Cau Moi Reservoir.

The development of zooplankton in reservoirs depends on phytoplankton biomass and environmental factors such as location and physicochemical characteristics (Bhukaswan, 1973). At Cau Moi stocked reservoir, phytoplankton and zooplankton biomass were 1.53 and 0.31 gDW/m^3, respectively. At Bau Um non-stocked reservoir, phytoplankton and zooplankton biomass were 0.73 and 0.35 gDW/m^3, respectively. Bau Um reservoir may have more favorable environment conditions for zooplankton development. In the present study, the fluctuations of zooplankton biomass were very large, ranging from 0.05-0.83 gDW/m^3 during July-May at Cau Moi, and from 0.11-1.27 gDW/m^3 during August-June at Bau Um, indicating an unstable food source of zooplankton.

Compared with plankton, development of benthos in reservoirs is a long process that varies depending on bottom conditions, water level fluctuations, water depth, siltation, hypolimnetic oxygen deficiency, hydrostatic pressure, light intensity, and other impoundment associated conditions (Isom, 1971). Grimas (1961) stated that water level fluctuations caused a quantitative reduction of the bottom fauna up to 70% in the drawdown zone of Swedish reservoirs, and 25% for the remaining area. In the present study, there were strong fluctuations in benthic biomass in both reservoirs, indicating strong effects of water level fluctuations on benthic fauna. Benthos therefore became one of limited food sources in these reservoirs.

Terrestrial vegetation that grows in the drawdown area during dry season is another unique feature of reservoirs. The terrestrial vegetation becomes sources of food and nutrients for aquatic ecosystems after inundation. Only a small part of flooded and surrounding-shore grasses were consumed directly by grass carp, and most terrestrial plants were decomposed to detritus after flooding. Terrestrial vegetation plays an important role in releasing nutrients through decomposition for natural food production in coves. Although there was no measurement of nutrient releases from terrestrial plant decomposition, such results directly affect the development of phytoplankton biomass in the system. Abundant terrestrial plant biomass resulted in good development of phytoplankton biomass in studied reservoirs.

To assess the role of natural food sources in our reservoirs, the Ecopath model combined an approach for estimating biomass and food consumption of various species in the aquatic ecosystem. In this study, trophic models for the system were constructed following a "bottom up" approach by estimating most of the actions and processes involving all individuals in the ecosystem. The modeling procedure therefore reduced assumptions. As the main objective for food web manipulation is to assess and manage trophic chains within reasonable EE values, steady-state models can be used to describe ecosystems (Christensen and Pauly, 1993).

During the entire culture period at Cau Moi stocked reservoir, EE values estimated by Ecopath for detritus, terrestrial vegetation, and benthos were very low, ranging from 0.026 to 0.325. The low EE values implied that most production of detritus, terrestrial vegetation, and benthos was not consumed by any trophic group in the system. This suggests that there is still room for additional stocking of fish species to utilize such foods.
The EE values of phytoplankton and zooplankton (0.719–0.738) at Cau Moi stocked reservoir indicated that both phytoplankton and zooplankton may still be available for additional stocking of herbivorous fish. The very high EE values for small wild fish (0.919) at Cau Moi stocked reservoir indicated that prey fish were fully utilized by higher trophic levels. However, because there was no harvest data for small wild fish, their biomass could be more abundant at Cau Moi than we estimated.

Trophic levels for all components were similar in the models for stocked and non-stocked reservoirs, in which the trophic levels were highest for carnivorous fish (3.13). There were seven species and groups of species occupying trophic levels from 2 to 2.58, including bighead carp, silver carp, mrigal, common carp, grass carp, tilapia, and small wild fish. Such a high quantity of species in this trophic group resulted in the bulk of the trophic flows at levels I and II, and increased potential for food competition. Therefore, appropriate manipulation strategies should be implemented to reduce the number of species at the same trophic level. The trophic flows, however, were very low at trophic levels III and IV, mostly from carnivorous fish. To increase the flows in these higher trophic levels, utilization of small wild fish by predatory fish should be enhanced.

Manipulation of food webs at Cau Moi stocked reservoir was done in three directions: (1) to utilize the small wild fish source; (2) to enhance stocking of carnivorous fish; and (3) to utilize phytoplankton as a food source. According to Christensen et al. (2000), EE values of the food web components can be rationalized by adjustments in fish stocking densities. In this study, as wild fish consumption by carnivorous fish was limited, step I of manipulation was to increase biomass of small wild fish by 30%, which the models showed had more potential to enhance both carnivorous and small wild fish biomass. In step II, biomass of herbivorous and small wild fish was increased by 50%, and the balance of the system indicated this could be applied to manage fish stocked. However, when biomass of small wild fish was increased by 100%, the EE value of zooplankton indicated that plankton abundance was the limiting factor for the system. Another management solution would be to increase biomass of silver carp to utilize the phytoplankton food source.

While the Cau Moi stocked-reservoir was managed well with good harvest data, the Bau Um non-stocked reservoir did not have good harvest information. Based on the balance of all trophic flows in the models, we evaluated the manipulation process for Bau Um non-stocked reservoir in order to estimate a suitable stocking strategy. For Bau Um non-stocked reservoir, stocked fish biomass was set to fit the EE values of natural food sources in the reservoir. In this reservoir, several factors were important: (1) benthos abundance was very low, reducing common carp stocking; (2) abundance of terrestrial vegetation could allow more grass carp to be stocked; (3) suitable biomass of carnivorous and small wild fish was present; and (4) there was still an abundant zooplankton food source but the limitation of phytoplankton may occur in the future.

ANTICIPATED BENEFITS

The major impact of this study will allow managing the stocking strategy of indigenous and exotic species into small irrigation reservoirs. Specific information on the impacts of cultured fish species on fisheries and natural food resources will allow governmental agencies and local communities to establish policies, plans and mechanisms for stocking of cultured fish species.

Specifically, this study estimated the impact of stocking cultured fish species on fish production in small irrigation reservoirs. The studied food webs in reservoirs with and without cultured fish species indicated diet overlap and potential competition between some cultured and wild species. Additionally, the management of water in reservoir for irrigation and other uses affect on the inundated spawning ground of some fish species and the abundant of plankton – natural food for herbivorous indeginoous or exotic fish in reservoirs. These reason create the concerns of local management agencies for purpose of fish culture in small and medium reservoirs.

We were able to estimate environmental carrying capacity for fish stocking in each reservoir. Moreover, physical-chemical and biological parameters provide useful information on the impact of aquaculture activities on the environment, especially in waters used for irrigation purposes.

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Appendix 1

WATER QUALITY AT BAU UM AND CAU MOI RESERVOIR

Cau Moi reservoir

Table 1. Temperature (^{0}C) at different sampling points.

Sampling points	Temperature (^{0}C)				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	29.0	29.0	29.0	29.6	
Midstream	29.0	29.0	29.0	29.8	
Downstream	29.0	29.0	29.0	29.8	
Average	29.0^a±0.0	29.0^a±0.0	29.0^a±0.0	29.7^b±0.1	29.2 ± 0.4

Table 2. Transparency (cm) at different sampling points.

Sampling points	Transparency (cm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	75.0	75.0	85.0	80.0	
Midstream	75.0	80.0	80.0	85.0	
Downstream	80.0	80.0	85.0	80.0	
Average	76.7^a ± 2.9	78.3^a ± 2.9	83.3^a ± 2.9	81.7^a ± 2.9	80.0 ± 3.0

Table 3. pH at different sampling points.

Sampling points	pH				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	7.5	7.5	7.2	7.4	
Midstream	7.7	7.3	7.4	7.5	
Downstream	7.7	7.3	7.2	7.4	
Average	7.6^b ± 0.1	7.4^a ± 0.1	7.3^{ab} ± 0.1	7.4^{ab} ± 0.1	7.4 ± 0.2

Table 4. Total alkalinity ($mgCaCO_3/l$) at different sampling points.

Sampling points	Total alkalinity ($mgCaCO_3/l$)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	51.67^a_x ± 2.89	51.67^a_x ± 2.51	59.33^b_x ± 1.15	57.67^b_x ± 0.58	
Midstream	50.00^a_x ± 0.00	53.00^a_x ± 1.00	51.67^a_y ± 1.53	57.00^b_x ± 1.73	
Downstream	46.67^a_x ± 3.21	52.67^a_x ± 4.01	63.67^b_z ± 1.53	63.33^b_z ± 1.53	
Average	49.45^a ± 2.55	52.45^a ± 0.69	58.22^a ± 6.08	58.22^a ± 3.48	54.59 ± 4.37

Table 5. Dissolved oxygen (mgO_2/l) at different sampling points.

Sampling points	Dissolved oxygen (mgO_2/l)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	4.9	4.4	5.1	4.4	
Midstream	5.0	4.4	5.5	4.5	
Downstream	5.2	4.6	5.5	4.5	
Average	$5.0^{ab} \pm 0.2$	$4.5^{c} \pm 0.1$	$5.4^{b} \pm 0.2$	$4.5^{ac} \pm 0.3$	4.8 ± 0.4

Table 6. Total ammonia concentration (ppm) at different sampling points.

Sampling points	Total ammonia concentration (ppm)			
	12/2010	02/2011	04/2011	06/2011
Upstream	$0.062^{a}\pm0.033$	$0.161^{a}\pm0.097$	$0.482^{b}\pm0.031$	$0.074^{a}\pm0.018$
Midstream	$0.076^{a}\pm0.008$	$0.225^{a}\pm0.033$	$0.516^{b}\pm0.041$	$0.037^{a}\pm0.006$
Downstream	$0.050^{a}\pm0.023$	$0.742^{a}\pm1.031$	$0.519^{a}\pm0.030$	$0.076^{a}\pm0.036$

Table 7. Nitrite concentration (ppm) at different sampling points.

Sampling points	Nitrite concentration (ppm)			
	12/2010	02/2011	04/2011	06/2011
Upstream	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$
Midstream	$0.002^{a}\pm0.000$	$0.002^{a}\pm0.000$	$0.003^{b}\pm0.000$	$0.002^{a}\pm0.000$
Downstream	$0.005^{a}\pm0.000$	$0.005^{a}\pm0.000$	$0.002^{b}\pm0.000$	$0.005^{a}\pm0.000$

Table 8. Total phosphorus concentration (ppm) at different sampling points.

Sampling points	Total phosphorus concentration (ppm)			
	12/2010	02/2011	04/2011	06/2011
Upstream	$0.024^{a}\pm0.011$	$0.008^{a}\pm0.002$	$0.034^{a}\pm0.005$	$0.212^{a}\pm0.259$
Midstream	$0.013^{a}\pm0.011$	$0.009^{a}\pm0.004$	$0.031^{a}\pm0.008$	$0.113^{b}\pm0.051$
Downstream	$0.017^{a}\pm0.006$	$0.013^{a}\pm0.002$	$0.028^{a}\pm0.006$	$0.070^{b}\pm0.029$

Bau Um reservoir

Table 9. Temperature (^{0}C) at different sampling points.

Sampling points	Temperature (^{0}C)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	28.5	28.0	29.0	28.5	
Midstream	28.0	28.0	29.0	28.5	
Downstream	28.0	28.0	29.0	29.0	
Average	$28.3^{ac} \pm 0.3$	$28.0^{c} \pm 0.0$	$29.0^{b} \pm 0.0$	$28.8^{ab} \pm 0.3$	28.5 ± 0.5

Table 10. Transparency (cm) at different sampling points.

Sampling points	Transparency (cm)				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	90	100	95	110	
Midstream	90	95	95	110	
Downstream	90	95	95	110	
Average	90.0[a]±0.0	96.7[b]±2.9	95.0[b]±0.0	110.0[c]±0.0	97.9 ± 8.5

Table 11. pH at different sampling points.

Sampling points	pH				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	6.90	6.80	6.80	7.16	
Midstream	6.80	6.80	6.80	7.12	
Downstream	6.90	6.90	6.90	7.08	
Average	6.86[a]±0.05	6.83[a]±0.05	6.83[a]±0.05	7.12[b]±0.04	6.91[a]±0.14

Table 12. Total alkalinity ($mgCaCO_3/l$) at different sampling points.

Sampling points	Total alkalinity ($mgCaCO_3/l$)			
	12/2010	02/2011	04/2011	06/2011
Upstream	19.33[a]±0.58	21.67[b]±0.58	29.00[c]±1.00	30.67[c]±1.56
Midstream	21.00[a]±1.00	22.00[a]±1.73	29.33[b]±0.58	31.00[b]±1.00
Downstream	26.67[a]±1.53	20.00[b]±1.00	28.67[a]±0.58	31.67[c]±0.58

Table 13. Total hardness ($mgCaCO_3/l$) at different sampling points.

Sampling points	Total hardness ($mgCaCO_3/l$)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	-	-	$27.36^{a}_{x} \pm 1.16$	$35.70^{b}_{x} \pm 0.58$	
Midstream	-	-	$26.69^{a}_{x} \pm 1.53$	$34.70^{b}_{x} \pm 1.16$	
Downstream	-	-	$29.03^{a}_{x} \pm 0.00$	$41.04^{b}_{y} \pm 1.73$	
Average	-	-	27.70[a] ± 1.21	37.15[b] ± 3.17	32.42 ± 6.68

Table 14. Dissolved oxygen (mgO_2/l) at different sampling points.

Sampling points	Dissolved oxygen (mgO_2/l)				Average
	12/2010	02/2011	04/2011	06/2011	
Upstream	4.2	4.6	4.4	4.3	
Midstream	4.4	5	4.5	3.9	
Downstream	4.4	5.2	4.3	3.9	
Average	4.3[ab]±0.1	4.9[a]±0.3	4.4[ab]±0.1	4.0[b]±0.2	4.4 ± 0.4

Table 15. Total ammonia concentration (ppm) at different sampling points.

Sampling points	Total ammonia concentration (ppm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	$0.148^{a}_{x} \pm 0.077$	$0.259^{a}_{x} \pm 0.043$	$0.014^{b}_{x} \pm 0.015$	$0.237^{a}_{x} \pm 0.019$	
Midstream	$0.000^{a}_{y} \pm 0.000$	$0.227^{b}_{x} \pm 0.035$	$0.000^{a}_{x} \pm 0.000$	$0.268^{b}_{x} \pm 0.012$	
Downstream	$0.148^{c}_{x} \pm 0.024$	$0.091^{ac}_{y} \pm 0.021$	$0.000^{a}_{x} \pm 0.000$	$0.270^{b}_{x} \pm 0.079$	
Average	$0.099^{ab} \pm 0.085$	$0.192^{a} \pm 0.089$	$0.005^{b} \pm 0.008$	$0.258^{a} \pm 0.019$	0.139 ± 0.11

Table 16. Nitrite concentration (ppm) at different sampling points.

Sampling points	Nitrite concentration (ppm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	$0.001^{ab}_{x} \pm 0.001$	$0.003^{bc}_{x} \pm 0.001$	$0.000^{a} \pm 0.000$	$0.003^{c}_{y} \pm 0.001$	
Midstream	$0.002^{bc}_{x} \pm 0.001$	$0.002^{b}_{x} \pm 0.001$	$0.000^{ac} \pm 0.000$	$0.001^{a}_{x} \pm 0.001$	
Downstream	$0.001^{a}_{x} \pm 0.000$	$0.001^{a}_{y} \pm 0.000$	$0.000^{b} \pm 0.000$	$0.001^{ab}_{x} \pm 0.001$	
Average	$0.0013^{a} \pm 0.001$	$0.002^{a} \pm 0.001$	$0.000^{a} \pm 0.000$	$0.0017^{a} \pm 0.001$	0.0013 ± 0.0009

Table 17. Total phosphorus concentration (ppm) at different sampling points.

Sampling points	Total phosphorus concentration (ppm)				Average
	11/2010	01/2011	03/2011	05/2011	
Upstream	$0.024^{a}_{y} \pm 0.001$	$0.038^{b}_{x} \pm 0.003$	$0.025^{a}_{x} \pm 0.004$	$0.049^{c}_{y} \pm 0.006$	
Midstream	$0.020^{b}_{xy} \pm 0.002$	$0.036^{a}_{x} \pm 0.005$	$0.030^{ab}_{x} \pm 0.006$	$0.024^{ab}_{x} \pm 0.009$	
Downstream	$0.018^{c}_{x} \pm 0.001$	$0.059^{a}_{y} \pm 0.006$	$0.036^{b}_{x} \pm 0.006$	$0.027^{bc}_{x} \pm 0.007$	
Average	$0.021^{a} \pm 0.003$	$0.044^{a} \pm 0.013$	$0.030^{a} \pm 0.006$	$0.033^{a} \pm 0.014$	0.032 ± 0.010

APPENDIX 2: Fisheries Composition at 8 Reservoirs

No.	Family	Scientific name	Local name	Đồng xoài	Xa cát	Bào Úm	Suối Lai	Cầu Mới	Đa Tôn	Gia Ui	Hung Phu
1	*Anabantidae*	*Anabas testudineus (Bloch.1792)*	Cá rô đồng	x	x	x	x	x	x	x	x
2	*Anguillidae*	*Anguilla marmorata (Quoy. 1824)*	Cá chình hoa							x	
3	*Bagridae*	*Bagriichthys obscurus (Bleeker. 1854)*	Cá lăng tối/chuột					x			
4	*Bagridae*	*Leiocassis siamensis (Regan.1913)*	Cá chốt bông	x				x	x		
5	*Bagridae*	*Mystus albolineatus (Roberts.1994)*	Cá chốt giấy	x				x			
6	*Bagridae*	*Mystus mysticetus (Roberts.1992)*	Cá chốt sọc					x	x		
7	*Bagridae*	*Mystus rhegma (Fowler.1935)*	Cá chốt vạch					x			
8	*Bagridae*	*Mystus singaringan (Bleeker. 1846)*	Cá chốt ngựa singa					x			
9	*Bagridae*	*Hemibagrus filamentus (Fang and Chaux. 1949)*	Cá lăng vàng	x				x		x	
10	*Bagridae*	*Hemibagrus wyckioides (Fang and Chaux. 1949)*	Cá lăng đỏ	x							
11	*Bagridae*	*Hemibagrus nemurus (Valenciennes. 1839)*	Cá lăng nha	x		x					
12	*Balitoridae*	*Nemacheilus platiceps (Kottelat. 1990)*	Cá chạch suối platy	x							
13	*Balitoridae*	*Nemacheilus masyae (Smith. 1933)*	Cá chạch suối nam	x							
14	*Belonidae*	*Xenetodon cancila (Hamilton. 1822)*	Cá nhái	x	x						
15	*Belontiidae*	*Trichopsis vittata (Cuvier. 1831)*	Cá bẫy trầu	x	x	x	x	x	x	x	X
16	*Chandidae*	*Parambassis apogonoides (Bleeker. 1851)*	Cá sơn giả	x			x	x	x	x	X
17	*Chandidae*	*Parambassis wolffii (Bleeker. 1851)*	Cá sơn bầu	x			x	x	x	x	X
18	*Channidae*	*Channa striata (Bloch.1795)*	Cá lóc đồng	x	x	x	x	x	x	x	X
19	*Channidae*	*Channa gachua (Hamilton. 1822)*	Cá trào chó		x	x					
20	*Characidae*	*Colosoma brachypomum (Peter. 1852)*	Cá chim trắng	x		x	x	x		x	X
21	*Cichlidae*	*Oreochromis niloticus (Linnaeus.1757)*	Cá rôphi	x	x	x	x	x	x	x	X
22	*Cichlidae*	*Oreochromis spp.*	Cá diêu hồng	x	x	x	x				X
23	*Clariidae*	*Clarias macrocephalus (Gunther.1864)*	Cá trê vàng	x	x	x	x	x	x	x	X

APPENDIX 2: Fisheries Composition at 8 Reservoirs

No.	Family	Scientific name	Local name	Đồng xoài	Xa cát	Bào Úm	Suối Lai	Cầu Mới	Đa Tôn	Gia Ui	Hung Phu
24	*Clariidae*	*Clarias batrachus (Linnaeus.1758)*	Cá trê trắng	x	x	x	x	x	x	x	X
25	*Clariidae*	*Clarias gariepinus (Burchell. 1815)*	Cá trê phi	x				x			
26	*Cobitidae*	*Botia modesta (Bleeker. 1865)*	Cá heo vạch	x							
27	*Cobitidae*	*Botia helodes (Sauvage. 1876)*	Cá heo rừng	x							
28	*Cyprinidae*	*Esomus metallicus (Ahl. 1924)*	Cá long tong sắt	x	x	x	x	x	x	x	X
29	*Cyprinidae*	*Rasbora aurotaenia (Tirant.1885)*	Cá lòng tong đá	x	x	x		x			X
30	*Cyprinidae*	*Rasbora borapetensis (Smith. 1934)*	Cá lòng tong đỏ đuôi	x	x	x	x	x	x	x	
31	*Cyprinidae*	*Rasbora paviei (Tirant.1885)*	Cá lòng tong pavi	x	x	x	x	x			
32	*Cyprinidae*	*Rasbora trilineata (Steindachner. 1870)*	Cá lòng tong sọc			x		x			
33	*Cyprinidae*	*Cyprinus carpio (Linnaeus.1758)*	Cá chép	x	x	x	x	x	x	x	X
34	*Cyprinidae*	*Cyclocheilichthys repasson (Bleeker. 1853)*	Cá ba kỳ	x							
35	*Cyprinidae*	*Barbodes gonionotus (Bleeker.1850)*	Cá mè vinh	x	x	x	x	x	x	x	X
36	*Cyprinidae*	*Hampala macrolepidota (Valenciennes.1842)*	Cá ngựa nam	x				x	x		
37	*Cyprinidae*	*Hampala dispar (Smith.1934)*	Cá ngựa chấm	x				x	x		
38	*Cyprinidae*	*Systomus orphoides (Valenciennes. 1842)*	Cá đỏ mang	x		x					
39	*Cyprinidae*	*Puntius brevis (Bleeker. 1860)*	Cá dầm đất		x	x	x		x	x	
40	*Cyprinidae*	*Cirrhinus mrigala (Hamilton.1822)*	Cá trôi trắng	x	x	x	x	x	x	x	X
41	*Cyprinidae*	*Ctenopharyngodon idellus (Cuvier & Valenciennes.1844)*	Cá trắm cỏ	x	x	x	x	x	x	x	X
42	*Cyprinidae*	*Aristichthys nobilis (Richardson. 1844)*	Cá mè hoa	x	x	x	x	x	x	x	X
43	*Cyprinidae*	*Hypophthalmichthys molitrix (Cuv & Val.1844)*	Cá mè trắng	x	x	x	x	x	x	x	X
44	*Cyprinidae*	*Osteochilus hasseltii (Valenciennes. 1842)*	Cá mè lúi	x		x			x	x	
45	*Cyprinidae*	*Osteochilus waandersii (Bleeker. 1852)*	Cá mè lúi nâu	x							

APPENDIX 2: Fisheries Composition at 8 Reservoirs

No.	Family	Scientific name	Local name	Đồng xoài	Xa cát	Bào Úm	Suối Lai	Cầu Mới	Đa Tôn	Gia Ui	Hung Phu
46	*Cyprinidae*	*Labeo rohita (Hamilton. 1822)*	Cá trôi đen (rohu)	x				x	x	x	
47	*Eleotridae*	*Oxyeleotris marmoratus (Bleeker.1852)*	Cá bống tượng	x		x	x	x	x	x	X
48	*Helostomatidae*	*Helostoma temmincki (Cuvier. 1831)*	Cá mùi		x	x			x	x	X
49	*Hemiramphidae*	*Hyporhamphus limbatus (Valenciennes. 1846)*	Cá k m dưới chậu	x	x			x			
50	*Loricariidae*	*Hypostomus plecoftomus (Linnaeus.1758)*	Cá tỳ bà/lau kiếng	x	x		x	x		x	X
51	*Mastacembelidae*	*Macrognathus siamensis (Gunther.1861)*	Cá chạch lá tre	x	x	x		x		x	
52	*Mastacembelidae*	*Mastacembelus favus (Hora.1924)*	Cá chạch bông					x		x	
53	*Mastacembelidae*	*Mastacembelus armatus (Lacepede.1800)*	Cá chạch lấu	x		x		x	x	x	
54	*Mastacembelidae*	*Mastacembelus circumcinetus (Hora. 1942)*	Cá chạch khoang	x				x			
55	*Nandidae*	*Pristolepis fasciatus (Bleeker.1851)*	Cá rô biển	x		x		x	x	x	X
56	*Notopteridae*	*Notopterus notopterus (Pallas. 1780)*	Cá thát lát	x						x	X
57	*Belontiidae*	*Trichogaster trichopterus (Pallas.1770)*	Cá sặc bướm	x	x	x	x	x	x	x	X
58	*Belontiidae*	*Trichogaster microlepis (Gunther. 1861)*	Cá sặc điệp	x	x	x	x	x	x	x	X
59	*Palaeomonidae*	*Macrobrachium sp.*	Tép	x	x	x	x	x	x	x	X
60	*Siluridae*	*Kryptopterus moorei (Smith.1945)*	Cá trèn mo	x				x	x	x	
61	*Siluridae*	*Ompok bimaculatus (Bloch.1797)*	Cá trèn bầu	x		x		x		x	
62	*Synbranchidae*	*Monopterus albus (Zuiew.1793)*	Lươn	x	x	x		x	x	x	X
63	*Synbranchidae*	*Ophisternon bengalensis (M`Clelland. 1845)*	Lịch	x					x		
Total				53	28	34	25	45	33	36	27