AQUACULTURE CRSP 21ST
ANNUAL TECHNICAL REPORT

DEVELOPMENT OF A TROPHIC BOX MODEL TO ASSESS POTENTIAL OF ECOLOGICALLY SOUND MANAGEMENT FOR COVE AQUACULTURE SYSTEMS IN TRI AN RESERVOIR, VIETNAM

Tenth Work Plan, Aquaculture System Modeling Research 1 (10ASMR1)
Final Report

Vu Cam Luong and Yang Yi
Aquaculture and Aquatic Resources Management
School of Environment, Resources and Development
Asian Institute of Technology
Pathumthani, Thailand

Le Thanh Hung
Faculty of Fisheries
University of Agriculture and Forest
Ho Chi Minh City, Vietnam

C. Kwei Lin and James S. Diana
School of Natural Resources and Environment
The University of Michigan
Ann Arbor, Michigan, USA

ABSTRACT

This study was conducted at Truong Dang Cove of Tri An Reservoir from June 2002 to March 2003 to determine biomass production of various trophic levels in the fish culture cove, to construct a trophic box model for the selected cove, and to recommend ecologically sound stocking and management strategies for cove aquaculture. From June to July 2002, ground vegetation in the selected plots was harvested biweekly four times to estimate terrestrial vegetation biomass before flooding. Water quality parameters including pH, dissolved oxygen, temperature, and Secchi disk depth were measured in situ. Monthly water samples were taken for analyses of total alkalinity and chlorophyll a and to determine the biomass of phytoplankton and zooplankton. Biomass of benthic organisms and detritus were estimated monthly, while fish biomass was determined at stocking and harvest.

A trophic box model of cove aquaculture in Truong Dang Cove of Tri An Reservoir was constructed using Ecopath 3.0 approach and software. The energy flows through the system, which included five cultured fish species (Cyprinus carpio, Aristichthys nobilis, Hypophthalmichthys molitrix, Ctenopharyngodon idella, and Oxyeleotris marmorata) were quantified. Fish stocking density ranged from 0.018 to 0.107 fish m^{-2}, and there was no addition of feed or fertilizer. In terms of natural food sources, the mean biomass [g dry weight (DW) m^{-2}] and mean production (g DW m^{-2} per season) were 1.21 and 191.25 for phytoplankton, 0.34 and 2.22 for zooplankton, 1.88 and 4.00 for benthos, 257.30 and 264.29 for terrestrial vegetation, and 1.41 and 0.92 for small wild fish, respectively. Detritus biomass was determined to be 1,066.90 g DW m^{-2}.

The trophic model shows that the system had rather few trophic levels, and the bulk of flows were at trophic level II (herbivores and detritivores). Although marble goby, the main cultured species, had an average trophic level of 3.24, its chain linked directly to trophic level II. Phytoplankton and zooplankton became important limiting factors affecting productivity of trophic level II, while their biomasses were rather low. Effective use of natural plankton sources is the best strategy to achieve greater economic return from cove culture.

Species selection for stocking was developed to make full use of food resources and ecological niches in the cove aquaculture. Some high-value predatory fish, climbing perch (Anabas testudineus), and bronze featherback (Notopterus notopterus), which produce minimal predation on other stocked fish could be introduced into the system. Freshwater prawns (Macrobrachium spp.) should also be considered as potential species to be stocked in coves for better utilization of all food resources there.

INTRODUCTION

A large number of reservoirs have been built in Indochina, mostly for irrigation, electrical generation, and domestic water supply. With few exceptions the fish of these reservoirs provide an important source of animal protein and livelihood for people residing nearby. However, most reservoirs in the region are relatively unproductive with catch ranging from less than 10 to 65 kg ha^{-1} yr^{-1} (Anon., 1998). In Vietnam, many reservoirs exist in the central highland and some are used for fish production by enhancement of stocking and cage culture. In large reservoirs, catch per unit effort of wild fisheries is quite low due to low productivity of pelagic water. Cage culture in large reservoirs often suffers from heavy mortality and usually requires protein-rich feed, such as small fish caught from the reservoir itself. An alternative means to enhance fish production would be to pen semi-enclosed shoreline areas with barrier nets to isolate them from the main reservoir. Such a system is termed cove culture. Dendroid coves are a prominent feature of most mountain reservoirs. The ideal cove for aquaculture is one that contains mainly a littoral zone at 1 to 2 m depth with flooding during the wet season and exposure during the dry season. Cove culture has been widely used in Chinese reservoirs (Sifa and Senlin, 1995). Some advantages of cove culture are ease of access from shoreline (compared to pelagic cage culture), more available food sources in the littoral zone, ease of harvest during the dry season, and low cost.

Tri An Reservoir, located 75 km from Ho Chi Minh City, contains 50 coves of various sizes within its surface area of 324 km2. At least a dozen cove culture systems already exist in this area. However, fisheries development of Tri An Reservoir is threatened by water pollution from runoff, organic matter input from surrounding vegetation, and wastes from cage culture (Luu, 1998). Development of cove culture relying on natural foods within the reservoir is ecologically sound and most likely more sustainable than systems using extensive food inputs.

Locally, the most common method of cove culture is to stock mainly herbivorous and detritivorous species such as common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), Nile tilapia (*Oreochromis niloticus*), and grass carp (*Ctenopharyngodon idella*). Stocking densities and species ratios are based on those practiced for pond culture (Yang et al., 1990). As Tri An Reservoir is rich in benthic invertebrates, small fishes (such as clupeids), and freshwater shrimp, stocking of carnivorous species with high food value, such as marble goby (*Oxyeleotris marmorata*) and snakehead (*Channa striata*), could enhance production and economic gain from cove culture. Many efforts have been made to collect marble goby fingerlings from the reservoir for use in cage culture, but these efforts have failed due to mass mortality after stocking marble goby in cages. An alternative method may be to stock marble goby in coves.

So far, little information is available on natural food productivity of a cove. Such information could enable us to estimate productivity of natural food at various trophic levels, predict carrying capacity of stocked fish species of different trophic levels, and thus determine the quantity and combination of fish to be stocked based on food availability. An ecosystem model could be constructed to assess trophic status for a cove. An average system can be described with a steady-state model (Christensen and Pauly, 1993). Such static models can give important information on energy flow and biomass storage, which should be measured to validate such a model. However, coves within a reservoir are often not in a steady state, so information gained from such an analysis is most likely a rough approximation of the fishery potential for the cove.

The purposes of this study were to:

1) Determine biomass production of various trophic levels in the fish culture cove;
2) Construct a trophic box model for the cove; and
3) Recommend ecologically sound stocking and management strategies for cove aquaculture.

METHODS AND MATERIALS

This study was conducted at Truong Dang Cove of Tri An Reservoir from June 2002 to March 2003. Truong Dang Cove is located at 17°05′ N and 11°13′ E and has many characteristics that facilitate cove aquaculture. The cove's shape is long with a tortuous shoreline and narrow mouth. The surface area of the cove is 56,800 m^2 with a mean water level of 5.4 m. Monthly water level in the cove varied from 0 to 10 m. The fish culture season in the cove ranges from 6 to 8 months per year, depending upon the annual hydrological regime of the reservoir. The cove is usually flooded from August or September and empty in June. The season with the highest water level spans from October to January.

This study consisted of two components: field measurements and model development using the collected data.

Field Measurements

From the middle of June to the end of July 2002, when the cove was empty of water, ten plots (1 m^2 quadrat) were randomly selected. Ground vegetation in the selected plots was harvested biweekly four times and was identified to species. Subsamples of terrestrial vegetation were taken for the analyses of moisture, and changes in dry weight of terrestrial vegetation were used to assess growth (Winberg, 1971; Whittaker and Marks, 1975).

Nine stations were selected in the cove for monthly sampling of water and sediment from August 2002 to March 2003. A Global Positioning System navigator (MLR SP24) was used to record the location of selected sample sites.

Water quality parameters including pH, dissolved oxygen (DO), temperature, and Secchi disk depth were measured in situ. Water samples were taken for analyses of total alkalinity and chlorophyll a (APHA et al., 1985). Gross primary productivity (GPP) and net primary productivity (NPP) were estimated monthly by three-point DO curve method (Hall and Moll, 1975).

Phytoplankton dry weight was estimated using measured concentrations of chlorophyll a (APHA et al., 1985). Zooplankton were sampled monthly by filtering 50-l of water from each of the nine sampling stations using a 25-micron net. Counts were taken of each species, size-frequency was estimated, and then dry weight of zooplankton was determined by converting average length to biomass using length-dry weight regression equations (Dumont et al., 1975; McCauley, 1984). The size-frequency method was used to assess the zooplankton productivity (Hamilton, 1969).

Benthic organisms were sampled monthly using an Ekman dredge with an area of 0.0225 m^2. Benthic organisms were separated from sediments using a soil sieve with 500 μm mesh. Benthos biomass was dried at 105°C. Due to the large amount of inorganic material included in some benthic organisms, the dried samples were ignited at 550°C for 4 h to estimate ash-free dry weight (Lin, 1974).

Biomass of detritus in the bottom sediment was estimated by the organic matter content of sediment (g DW m^{-2}). Bottom sediment was collected monthly from the 5-cm top layer of bottom material. The air-dried bottom sediment was used for the determination of organic matter content using the dry ash method (Boyd, 1995).

The biomass of different fish species (marble goby, common carp, silver carp, grass carp, bighead carp, and small fish) was calculated as average biomass at stocking and at harvest, not taking into account changes in growth (or consumption) rates throughout the culture period (Ruddle and Christensen, 1993). Production to biomass ratios (P/B) for each fish species were determined as the ratio between net biomass harvested divided by mean biomass.

The area and volume of the cove were calculated using SURFER 6.0 software (Keckler, 1997), with three-dimensional data recorded by an Echo Sounder in October 2002 at maximum water depth.

Model Development

A trophic box model of Truong Dang Cove in Tri An Reservoir was constructed using the modeling software Ecopath 3.0 (Christensen and Pauly, 1992a, 1992b, 1993; Dalsgaard and Oficial, 1998). All flows, rate coefficients, and steady-state values for state variables are normally not known for an ecosystem. Ecopath software includes a routine for balancing the flows in a steady-state ecosystem without data on all flows and rate coefficients. Missing parameters are estimated either by general ecological knowledge about the parameters or as "unknowns" in a set of linear equations based upon data from the ecosystem. Equations in the software are based on mass conservation principles in a steady-state situation. This means that all inputs and outputs must balance. The first Ecopath equation describes how the production term of each group (i) can be split into components.

$$P_i = Y_i + B_i \hat{I}\, M2_i + E_i + BA_i + P_i \hat{I}\, (1 - EE_i) \tag{1}$$

Where, P_i = total production rate of group i,
Y_i = total harvest rate of group i,
$M2_i$ = predation mortality of group i,
B_i = biomass of group i;
E_i = net migration rate (emigration – immigration),
BA_i = biomass accumulation rate for group i; and
EE_i = ecotrophic efficiency of group i.
$P_i \hat{I} (1 - EE_i)$ is the non-predation mortality or other mortality rate for group i.

Equation 1 can be re-written as:

$$B_i \hat{I}\, (P/B)_i - \sum B_j \hat{I}\, (Q/B)_j \hat{I}\, DC_{ji} - (P/B)_i \hat{I}\, B_i \hat{I}\, (1 - EE_i) - Y_i - E_i - BA_i = 0 \tag{2}$$

or

$$B_i \hat{I}\, (P/B)_i \hat{I}\, EE_i - \sum B_j \hat{I}\, (Q/B)_j \hat{I}\, DC_{ji} - Y_i - E_i - BA_i = 0 \tag{3}$$

where $(P/B)_i$ = production/biomass ratio, $(Q/B)_j$ = consumption/biomass ratio, and DC_{ji} is the fraction of prey (i) in the diet of predator (j).

Equation 3 can be developed for all state variables. With n state variables, there are n linear equations of the same form as Equation 3. Additional n equations can be estimated for the mass conservation principle applied to consumption. The consumption is used for either production, respiration, or unassimilated food. This can be expressed as:

$$(1 - U_i) \hat{I}\, B_i \hat{I}\, (Q/B)_i - B_i\, (P/B)_i - B_i R_i = 0 \tag{4}$$

where U_i = fraction of food not assimilated, and
R_i = respiration coefficient (the respiration expressed in biomass units per biomass ratio).

The gross conversion efficiency, g_i, is estimated using:

$$g_i = (P_i/B_i) \,/\, (Q_i/B_i) \tag{5}$$

while (Pi/Bi) and (Qi/Bi) are attempted to be solved by inverting the same equation. The (P/B) ratio is then estimated (if possible) from:

$$P_i/B_i = (Y_i + E_i + BA_i + \sum Q_j \hat{I}\, DC_{ji}) \,/\, (B_i \hat{I}\, EE_i) \tag{6}$$

EE is estimated from:

$$EE_i = (Y_i + E_i + BA_i + M2_i \hat{I}\, B_i) \,/\, P_i \tag{7}$$

where the predation mortality M2 is estimated from:

$$M2_i = \sum EE_i \hat{I}\, DC_{ji} \tag{8}$$

A box (group) in an Ecopath model is a group of ecologically related species. In a model the energy input and output of all living groups must balance. The basic Ecopath Equation 1 includes only production of a box. When balancing the energy of a box, other flows will be considered. After other missing parameters have been estimated, mass balance is ensured within each group using the equation:

$$\text{Consumption} = \text{production} + \text{respiration} + \text{unassimilated food} \tag{9}$$

At least three parameters are needed for the Ecopath model: 1) biomass of food organisms and ratio of production to biomass of a particular food organism; 2) utilization rate of food organisms; and 3) food coefficient. Biomass and production data were collected in this study and supplemented with parameters estimated from the literature or assumed values of utilization rates of food organisms and food coefficients where needed.

Results

Physicochemical Characteristics of Truong Dang Cove

The difference in water temperature between the upper and lower layers was small in Truong Dang Cove (± 1.1 to 2.3 °C). Vertical variation of water temperature from August to September (27 to 28.3 °C) was smaller than from October to March (27.7 to 30.2 °C) (Table 1). Variation in DO from top to bottom from August to September (5.1 to 7.5 mg l^{-1}) was smaller than that from October to March (4.5 to 7.8 mg l^{-1}) (Table 2).

Secchi disk depth in Truong Dang Cove was generally high during high water levels in the reservoir (120, 160, 160, 200, 105, and 98 cm in October, November, December, January, Feb-

Table 1. Vertical distribution of water temperature in Truong Dang Cove from August 2002 to March 2003.

Depth (m)	**Water Temperature** (C)							
	Aug.	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*
0.1	28.2	28.3	29.6	30.2	29.8	30.0	30.0	30.2
1.0	28.0	28.1	29.5	30.1	29.7	29.9	29.8	30.0
2.0	27.9	28.0	29.4	30.0	29.3	29.4	29.6	29.8
4.0	27.4	27.6	28.5	28.7	28.3	28.7	28.7	28.9
6.0	27.0	27.2	27.7	27.9	27.9	28.1	28.0	28.2

Table 2. Vertical distribution of dissolved oxygen in Truong Dang Cove from August 2002 to March 2003.

Depth (m)	**Dissolved Oxygen** (mg l^{-1})							
	Aug.	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*
0.1	7.5	7.4	7.5	7.7	7.7	7.2	7.8	7.3
1.0	7.3	7.3	7.5	7.7	7.6	7.2	7.7	7.2
2.0	6.9	7.2	7.4	7.7	7.4	6.6	7.6	6.6
3.0	6.4	7.1	6.9	6.6	7.0	6.2	6.6	5.8
4.0	5.9	6.9	6.4	6.5	6.4	5.9	6.5	5.6
5.0	5.7	6.7	5.6	5.5	5.6	5.2	5.7	5.3
6.0	5.2	6.2	5.1	5.2	5.0	4.8	5.3	5.0
7.0	5.1	5.5	4.8	4.5	4.8	4.6	4.9	4.7

ruary, and March, respectively) and low at the start of the rainy season (29 and 80 cm in August and September, respectively) due to runoff. Values of pH in Truong Dang Cove varied over a small range (7.06 to 7.12) from August to March, and the vertical difference was also small (± 0.30 to 0.44). Mean concentration of total alkalinity was 18 mg l^{-1} as $CaCO_3$.

Biomass and Productivity of Natural Food Sources in Truong Dang Cove

Phytoplankton

Common phytoplankton species in Truong Dang Cove included Melosira (Bacillariophyta), Staurastrum (Chlorophyta), Microcystis (Cyanophyta), and Ceratium (Pyrrophyta). Phytoplankton biomass was lowest from August to September (0.14 to 0.20 g DW m^{-2}), reached a peak from November and December (2.30 and 2.13 g DW m^{-2}, respectively), and then declined gradually to 0.46 and 0.35 g DW m^{-2} from February to March, respectively (Figure 1). Mean phytoplankton biomass during the fish culture period was 1.21 g DW m^{-2}, and the mean phytoplankton productivity was 191.25 g DW m^{-2} per month.

Zooplankton

Common species of zooplankton found in Truong Dang Cove belonged to the genera Diaphanosoma, Bosmina, Ceriodaphnia (all Cladocera); Mesocyclops (Copepoda); Brachionus, Asplanchna, Lecane (all Rotatoria); and Difflugia (Protozoa).

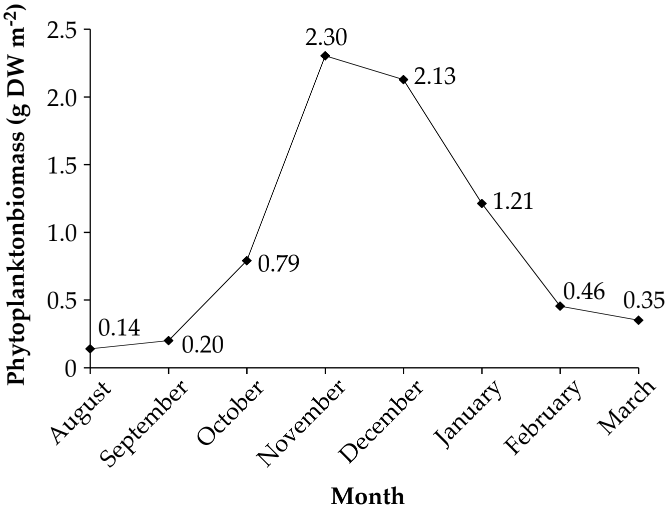

Figure 1. Phytoplankton biomass (g DW m^{-2}) in Truong Dang Cove from August 2002 to March 2003.

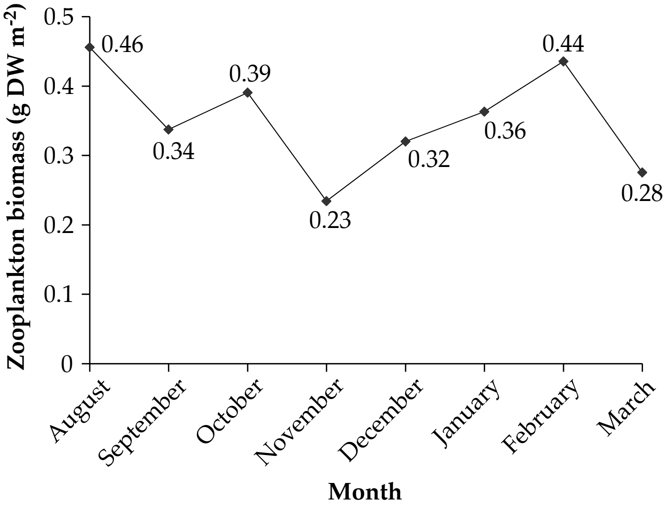

Figure 2. Zooplankton biomass (g DW m^{-2}) in Truong Dang Cove from August 2002 to March 2003.

In terms of species and biomass of zooplankton, Cladocera and Copepoda were dominant. Zooplankton biomass was highest in August and February (0.46 and 0.44 g DW m^{-2}, respectively) and lowest in November and March (0.23 and 0.28 g DW m^{-2}, respectively) (Figure 2). Monthly zooplankton biomass did not change much over time. Mean zooplankton biomass during the fish culture season (October to March) was 0.34 g DW m^{-2}, and the mean zooplankton productivity was 2.22 g DW m^{-2} per month.

Benthos

Limnoperna siamensis (Bivalvia) was the most abundant benthic species but had low biomass. In terms of biomass, Macrobrachium pilimanus (Crustacea) was the dominant species. Chironomus spp. (Insecta) was next to Bivalvia in abundance. Both abundance and biomass of benthos were zero in August and increased gradually until December or January when peaks were reached (395 to 620 m^{-2} and 2.16 to 3.14 g DW m^{-2}, respectively) (Figure 3). The mean benthic biomass during the

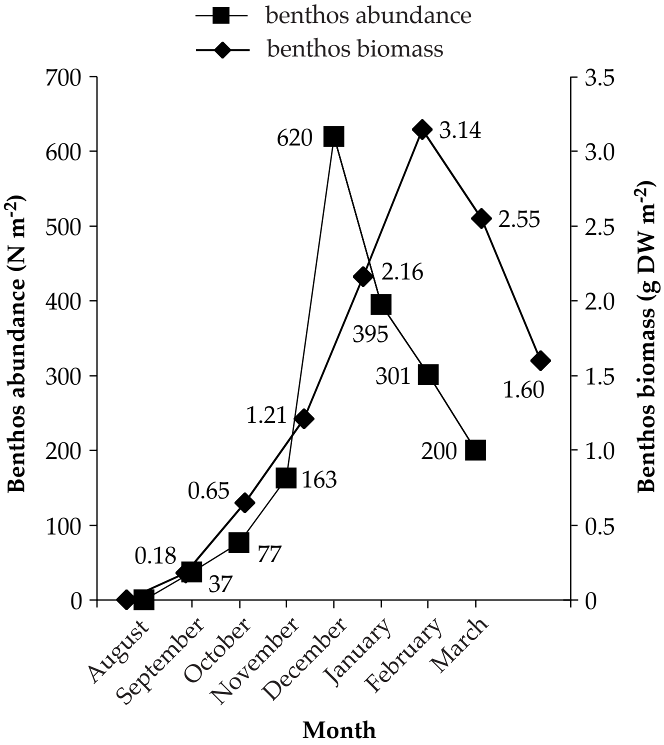

Figure 3. Benthos abundance and biomass in Truong Dang Cove from August 2002 to March 2003.

fish culture period (October to March) was 1.88 g DW m^{-2}.

Terrestrial Plants

There were 12 terrestrial vegetation species found in the submerged area of Truong Dang Cove, including Phyllantus ninuri, Eragrostis japonica, Scorparia dulcis, Indigofera trifoliata, Cynodon datylon, Panicum repens, Chrysopogon aciculatus, Imperata cylindrica, Setaria pallidefusca, Eleocharis dulcis, Ipomea triloba and Mimosa pigra. Among the 12 species, M. pigra was the dominant species in terms of biomass. The mean terrestrial vegetation biomass was 257.30 g DW m^{-2}, and the mean productivity of terrestrial vegetation was 264.29 g DW m^{-2} over the June to July time period.

Detritus

The approximate biomass of detritus in Truong Dang Cove was estimated to be about 1,066.90 g DW m^{-2}. The terrestrial vegetation that grew in the system during the dry season was treated as an import to the detritus box (Ruddle and Christensen, 1993).

Fish Resources

The major cultured fish species in Truong Dang Cove was marble goby with a stocking density of 0.107 fish m^{-2} and mean biomass of 4.542 g DW m^{-2} (Table 3). Common carp, silver carp, and bighead carp were stocked at 0.049 fish m^{-2} with mean biomass of 1 to 1.45 g DW m^{-2}, while grass carp was stocked at 0.018 fish m^{-2} with mean biomass of 0.467 g DW m^{-2}. It was assumed that there was no other predatory fish naturally entering the cove. The most abundant small wild fish species in the cove were river sprat (Corica spp.), Dangila spilopleura, and glassy perchlet (Chanda spp.), accounting for 60, 31, and 9% of total number of small wild fish, respectively. These three species had mean biomass and production of 1.411 g DW m^{-2} and 0.92 g DW m^{-2} per season, respectively.

Trophic Model of Truong Dang Cove

The ecosystem model consisted of 11 groups, of which four were carp species, one marble goby, and one small wild fish. Three different species of small wild fish were grouped together because they have a similar trophic level and serve as main food sources for marble goby. The basic inputs and estimated parameters for Ecopath 3.0 are presented in Table 4. The main point of the model was to estimate production/biomass ratios (P/B) for benthos and consumption/biomass ratios (Q/B) for all groups. This was, however, of little importance in this application, as the parameters directly related to the remainder of the system—biomass and P/B ratios—were measured directly. Qualitative and quantitative statements of diet were found in the literature (Sifa and Senlin, 1995; Billard, 1999), or were estimated by the authors (Table 5). Some rather long food chains seem to exist in the system, e.g., detritus/phytoplankton → zooplankton→ benthos/small fish → marble goby.

Figure 4 gives the trophic flows (g DW m^{-2} per season) in a trophic box model of Truong Dang Cove in Tri An Reser-

Table 3. Density, biomass, and production values for fish in Truong Dang Cove at stocking and harvest.

Species	**Stocking**		**Harvesting**		**Mean Biomass** (g DW m^{-2})	**Mean Production** (g DW m^{-2} per season)
	Density (N m^{-2})	*Biomass* (g DW[1] m^{-2})	*Survival* (%)	*Biomass* (g DW m^{-2})		
Marble Goby	0.107	1.740	95	7.345	4.542	5.605
Common Carp	0.049	0.082	65	1.922	1.002	1.840
Silver Carp	0.049	0.123	65	2.243	1.183	2.119
Bighead Carp	0.049	0.131	70	2.760	1.446	2.629
Grass Carp	0.018	0.071	70	0.863	0.467	0.792
Small Fish[2]	1.548	0.951	50	1.870	1.411	0.920

1) DW: dry weight
2) Small fish includes wild fish entering from the reservoir to the cove.

Table 4. Input values used in the trophic box model of Truong Dang Cove. The consumption to biomass ratio (Q/B) is estimated using the empirical model of Palomares and Pauly (1989) modified to take the proportion of food derived from herbivory/detritivory (PHD) into account (Ruddle and Christensen, 1993).

Group Name	Mean Biomass (g DW[1] m^{-2})	Annual P/B [2]	Annual Q/B[3]
Phytoplankton	1.207	158.451	0
Terrestrial Plants	257.300	1.027	0
Zooplankton	0.336	36.303	133.3 [a]
Benthos	1.885	4.000 [b]	133.3 [a]
Small Fish	1.411	0.652	14.0
Common Carp	1.002	1.836	8.3
Silver Carp	1.183	1.791	12.1
Bighead Carp	1.446	1.818	8.0
Grass Carp	0.467	1.696	12.0
Marble Goby	4.540	1.235	9.5
Detritus	1,066.900 [c]	--	--

[a] Ruddle and Christensen, 1993

[b] Sifa and Senlin, 1995

[c] Ruddle and Christensen, 1993

[1]DW: dry weight

[2]P/B: Production to biomass ratio

[3]Q/B: Consumption to biomass ratio

voir for the six-month culture season. The main harvest was marble goby at 7.3 g DW m^{-2}. Using the trophic aggregation routine of Ecopath (Christensen and Pauly, 1992a), flows in the system can be aggregated on discrete trophic levels (Table 6). The overall system had rather few trophic levels, and the bulk of the flow is at trophic level II (herbivore). Common carp and bighead carp nearly reached trophic level III (predatory level), i.e., 2.87 and 2.78, respectively. Only marble goby had a trophic level exceeding 3. The flows were predominantly of phytoplankton, zooplankton, and detrital sources. The biomass of detritus was very high. Plankton biomass, however, was limited. In terms of biomass, terrestrial vegetation was also abundant, but its direct contribution to the ecosystem occurred only for a short period after flooding. Therefore, most of the terrestrial vegetation went directly to the detritus box.

DISCUSSION

There are several advantages of fish culture in coves in terms of physicochemical conditions. Coves usually have good water quality and are rich in nutrients. The variation in water temperature and DO between the upper and lower water layers was small in Truong Dang Cove, and due to mixing of water in the cove, there was no thermal stratification. Compared to fish ponds, DO in coves is higher, thus the high DO concentration can fully meet physical demands of the fish. In coves, there is little vertical change of DO and in this case with a depth of 7 m, ranged from 4.5 to 7.8 mg l^{-1}. Water depth in ponds on the other hand is generally 1.5 to 3 m, and coupled with very high inputs, vertical variation of DO is so great that fish at the bottom often suffer serious DO depletion.

Secchi disk depth is low in the rainy season due to floodwater and runoff, but of other times, Secchi disk depth in coves was high (0.98 to 2 m). Compared to the water in the main reservoir and rivers, coves have slower water flow, shallower depth, greater transparency, and richer nutrients, thus greater potential for high fish production. In the cove, pH vales were 6.64-7.12, within the optimal range for fish farming.

Fish culture in coves depends on availability of natural foods. The species composition and biomass of fauna and flora in coves influences fish productivity. Therefore, it is necessary to determine sources of natural foods and assess fish productivity before suitable stocking strategies can be made for fish culture in coves.

Unlike rapid growth in the phytoplankton community, zooplankton develops slowly in reservoirs that have strong fluctuations in water level. In general, density of phytoplankton is much higher than that of zooplankton in coves. In Truong Dang Cove, biomass of phytoplankton was about 3.5 times greater than that of zooplankton. When the cove had just been flooded, the phytoplankton biomass was very low while the zooplankton biomass was high. These zooplankton might come from river water input, but zooplankton biomass decreased rapidly after flooding due to initial low biomass of phytoplankton from August to September. Thus, farmers sometimes prefer not to stock fish during that period.

Table 5. Diet composition (%) of species/groups considered in the trophic box model of Truong Dang Cove.

Prey	Diet Composition (%)							
	Predator							
	Zooplankton	Benthos	Small Fish	Common Carp	Silver Carp	Bighead Carp	Grass Carp	Marble Goby
Phytoplankton	65	25	40	0	60	10	20	5
Terrestrial Plants	0	0	0	0	0	0	70	0
Zooplankton	10	15	40	20	30	70	0	10
Benthos	0	10	0	50	0	0	0	70
Small Fish	0	0	0	0	0	0	0	15
Detritus	25	50	20	30	10	20	10	0

Table 6. Trophic transformation matrix for the Truong Dang cove aquaculture ecosystem showing how flows (%) for each group in the system are distributed on discrete trophic levels.

Group	**Distributed Flows** (%)					
	Trophic Level					*Average Trophic Level*
	I	II	III	IV	V	
Phytoplankton	100	-	-	-	-	1.00
Terrestrial Plants	100	-	-	-	-	1.00
Zooplankton	-	95	5	0	-	2.11
Benthos	-	82	17	1	-	2.30
Small Fish	-	60	38	2	-	2.44
Common Carp	-	30	60	9	-	2.87
Silver Carp	-	70	28	1	-	2.33
Bighead Carp	-	30	66	3	-	2.78
Grass Carp	-	100	-	-	-	2.00
Marble Goby	-	5	76	18	1	3.24
Detritus	100	-	-	-	-	1.00

Compared to plankton, the development of benthos in the cove is a longer process that varies with hydrological conditions, light intensity, water depth, siltation, and bottom conditions. Water level fluctuation should cause a quantitative reduction of bottom fauna in the drawdown zone and the remaining area of reservoirs, and this seemed to be the case in Truong Dang Cove from August to September when the cove had just been flooded. Benthic biomass significantly increased for four to six months after flooding. One important reason is the migration of some benthic fauna such as freshwater prawns (Macrobrachium spp.) from the main reservoir into the cove during the period from November to January. The benthos sources in the cove showed a high potential for fish production.

Fluctuating water levels produce large drawdown areas where terrestrial vegetation grows. The large amount of terrestrial vegetation provides additional biomass to the cove every year. Only a very small fraction of this vegetation is fed upon directly by grass carp, while most undergoes microbial decomposition. For that reason the stocking density of grass carp in the cove must be kept low.

Next to plankton, detritus is the second most important natural food source in reservoirs (Sifa and Senlin, 1995). Detritus plays an important role in trophic dynamics and also serves as a nutrient source and important link in the food chain of reservoirs. Such roles are particularly important in coves when water level fluctuations are very strong and water is easily mixed. When terrestrial vegetation was imported to the detritus box, detritus could support much higher fish productivity in coves (Ruddle and Christensen, 1993).

Most farmers try to eliminate wild fish entering coves, but many fail due to a delay in installing the barrier net at the beginning of water flooding. Predatory fish such as snakehead may enter coves, but it is difficult to catch them. Fortunately, the density of such predatory fish was low in Tri An Reservoir. In this study it was assumed that there were no wild predatory fish in Truong Dang Cove. Fish resources in the cove included stocked fish and small wild fish. Since small wild fish and freshwater prawns easily enter the cove through the barrier net, their abundance becomes a potential food source for marble goby in the cove. Farmers also stock Chinese carp to utilize plankton and detritus in the cove. The stocking density of such species, however, is quite low due to limited plankton biomass in the cove.

Modified from farmers' practices, the trophic box model of Truong Dang Cove was constructed using the Ecopath 3.0 approach and software (Dalsgaard and Oficial, 1998). The trophic box model of Truong Dang Cove gave a qualitative representation of the energy and material linkages. Knowledge of the complete food web of a cove ecosystem can assist limnologists and fish specialists to assess the role that each organism plays in biomass production in an inundated area of the reservoir.

This model demonstrated the farmers' technical knowledge of the cove culture system. With much trial and error, stocking density of Chinese carp seemed to have been adjusted to natural food sources in the cove, requiring no additional fertilizers or supplemental feeds. In the present study, with only a six-month period for fish culture, farmers stocked large fingerlings to achieve reasonable sizes at harvest.

The results showed that the system had rather few trophic levels, and the bulk of flows were at trophic level II (herbivores and detritivores). The stocking density of fish at trophic level II was 0.049 fish m^{-2} per species. Considering the limitation of plankton as food and that most of the food chains in the cove that depend on plankton are also limited, such low stocking density was reasonable.

Marble goby may be considered as one of the most suitable species to be stocked in coves of Tri An Reservoir due to high survival rate, good growth rate, lack of harm to other cultured fish species, and high economic value. Marble goby also has a rather flexible food chain, e.g. detritus/phytoplankton → zooplankton → benthos/small fish → marble goby. Marble goby generally prefer freshwater prawns (Macrobrachium spp.), the dominant component of benthos biomass of Truong Dang Cove, and abundant in the reservoir and cove. Small wild fish were secondarily preferred by marble goby because marble goby has bottom-feeding habits. Prawns and small wild fish, however, are at a similar trophic level to carp species. The market price of marble goby is usually five to six times higher than that of carp species, so increasing harvest of marble goby would dramatically increase profit.

Cove aquaculture in Tri An Reservoir has been practiced well in terms of technical aspects, including cove selection, design, and construction and fish production and harvest. The main technical problem is how to identify the most suitable fish species composition for cove aquaculture. In this study the main consideration for species selection was to make full use of all food resources and ecological niches. To improve cove aquaculture efficiency, some high-valued predatory fish species that are less harmful to other stocked fish could be introduced into the cove system. Marbled sleeper (Oxyeleotris marmorata), climbing perch (Anabas testudineus), and bronze featherback (Notopterus notopterus) are potential candidates. Also, freshwater prawns could be considered as a potential species to be stocked in coves for a better utilization of food resources and to provide another target crop.

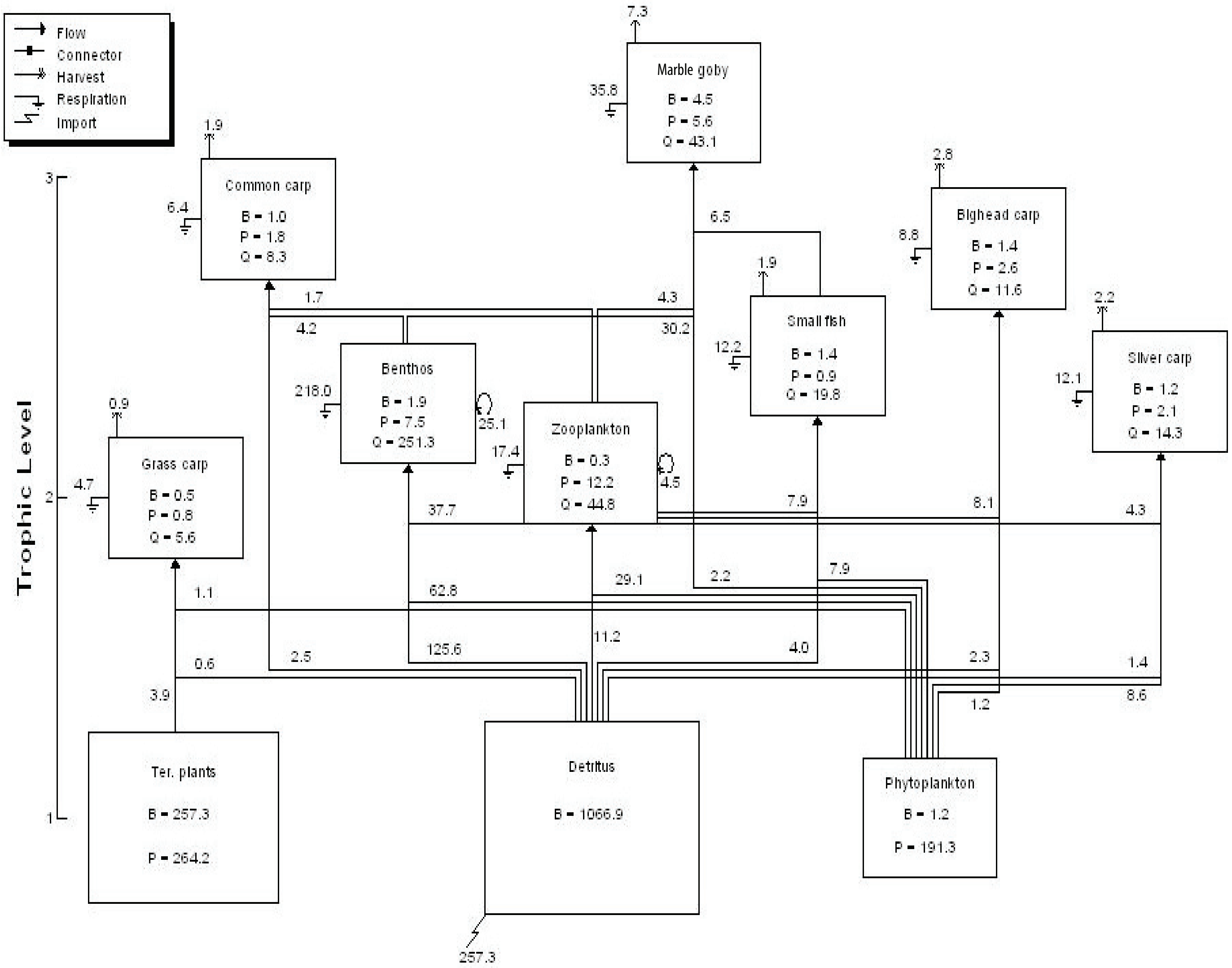

Figure 4. Trophic flows (g DW m^{-2} per season) in trophic box model of Truong Dang Cove in Tri An Reservoir. Biomass (B) (g DW m^{-2}), production (P) (g DW m^{-2} season), and consumption (Q) (g DW m^{-2} season), rates are given inside the boxes.

ANTICIPATED BENEFITS

The results of this study could be used to enhance fish production with greater economic return from cove culture. The study will also establish a case for sound management of fish culture in reservoirs that is more ecologically sustainable than current cage culture systems. The development of realistic ecological models provides a new strategy for development and management of reservoir systems and facilitates extension of cove culture systems throughout the region. Use of Ecopath and a steady-state analysis is only the first step in the development of realistic models, but it is a necessary first step.

ACKNOWLEDGMENTS

The authors wish to acknowledge the University of Agriculture and Forestry (UAF) of Vietnam and the Asian Institute of Technology (AIT) of Thailand for providing the research, field, and laboratory facilities. T. Thuy, P.N. Tam, H.H. Tinh, T.H. Thuy, L.T.T. Truc, and N.T. Vy of UAF are greatly appreciated for their field and lab assistance.

LITERATURE CITED

Anonymous, 1998. Workshop on reservoir fisheries in Indochina region. Mekong River Commission, Bangkok, Thailand.

APHA, AWWA, and WPCF, 1985. Standard Methods for the Examination of Water and Wastewater, 16th Edition. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC, 1,268 pp.

Billard, R., 1999. Carp: Biology and Culture. Praxis Publishing, Chichester, England, 335 pp.

Boyd, C.E., 1995. Bottom Soils, Sediment and Pond Aquaculture. Chapman and Hall, New York, 348 pp.

Christensen, V. and D. Pauly, 1992a. Ecopath II – A software for balancing steady-state ecosystem models and calculating network characteristics. Ecological Modeling, 61:169–185.

Christensen, V. and D. Pauly, 1992b. A guide to the Ecopath II software system (version 2.1). ICLARM Software 6, 72 pp.

Christensen, V. and D. Pauly, 1993. On steady-state modelling of ecosystems. In: V. Christensen and D. Pauly (Editors), Trophic Models of Aquatic Ecosystems. ICLARM/DANIDA, Manila, Philippines, 14–19.

Dalsgaard, J.P.T. and R.T. Official, 1998. Modeling and analyzing the agroecological performance of farms with ECOPATH. ICLARM Tech. Rep. 53, 54 pp.

Dumont, H.J., I. Van de Velde, and S. Dumont, 1975. The dry weight estimate of biomass in a selection of Cladocera, Copepoda and Rotifera from the plankton, periphyton and benthos of continental waters. Oecologia, 19:75–97.

Hall, C.A.S. and R. Moll, 1975. Methods of assessing aquatic primary productivity. In: H. Lieth and R.H. Whittaker (Editors), Primary Productivity of the Biosphere. Springer-Verlag, New York, 1,953 pp.

Hamilton, A.L., 1969. On estimating annual production. Limnol. and Oceanogr., 14:771–782.

Keckler, D., 1997. SURFER for Windows, Version 6.0 – User's Guide: Contouring and 3D Surface Mapping. Golden Software Inc., USA, 483 pp.

Lind, O.T., 1974. Handbook of Common Methods in Limnology. C.V. Mosby Company, St. Louis, Missouri, 154 pp.

Luu, T.T., 1998. The survey of pollution of cage aquaculture in Tri An Reservoir in 1997–1998. Department of Technology and Environment of Dong Nai Province, HCMC, 42 pp. (in Vietnamese)

McCauley, E., 1984. The estimation of the abundance and biomass of zooplankton in samples. In: J.A. Downing and F.H. Rigler (Editors), A manual on methods for the assessment of secondary productivity in fresh waters, Blackwell Scientific Publishers, Oxford, pp. 228–265.

Palomares, M.L. and D. Pauly. 1989. A multiple regression model for predicting the food consumption of marine fish populations. Aust. J. Mar. Freshwat. Res. 40:259-273.

Ruddle, K. and V. Christensen, 1993. An energy flow model of the mulberry dike-carp pond farming system of the Zhujiang delta, Guangdong province, China. In: V. Christensen and D. Pauly (Editors), Trophic models of aquatic ecosystems. ICLARM/DANIDA, Manila, Philippines, pp. 48–55.

Sifa, L. and X Senlin, 1995. Culture and capture of fish in Chinese reservoirs. Southbound, Penang, Malaysia and International Development Research Centre, Ottawa, Canada, 128 pp.

Whittaker, R.H. and P.L. Marks, 1975. Methods of assessing terrestrial productivity. In: H. Lieth and R.H. Whittaker (Editors), Primary productivity of the biosphere, Ecological Study 14. Springer-Verlag, New York, pp. 55–118.

Winberg, G.G., 1971. Methods for the estimation of production of aquatic animals. Academic Press, London, 167 pp.

Yang, H.Z., Y.X. Fang, and Z.Y. Liu, 1990. The biological effects of grass carp (Ctenopharyngodon idella) on filter-feeding and omnivorous fish in polyculture. In: R. Hirano and I. Hanyu (Editors), The Second Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines, pp. 197–200.

Cite as: [Author(s), 2004. Title.] In: R. Harris, I. Courter, and H. Egna (Editors), Twenty-First Annual Technical Report. Aquaculture CRSP, Oregon State University, Corvallis, Oregon, [pp. ___.]