Stocking Density Effects of Small Indigenous Species (SIS) on Carp Polyculture Systems in Nepal

by

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ABSTRACT

Small indigenous species (SIS) added to carp polyculture ponds in Nepal have increased production, economic returns, and nutritional well being for farmers. However, there has been little research to determine an optimal stocking density of SIS. Thus, the main objective of this experiment was to identify an optimal stocking density to promote overall pond production and profits of a typical six-species carp polyculture system in Nepal. This was accomplished by comparing the effects of three different stocking densities of punti (*Puntius sophore*) and dedhuwa (*Esomus danricus*) on carp production, SIS net gain, SIS harvest, water quality, and economic returns. As expected SIS stocking density had no significant effect on carp production or water quality. Stocking density negatively affected dedhuwa net gain, which was the product of reproduction, survival, and immigration or emigration from ponds, but did not affect harvest. Conversely, stocking density did not affect punti net gain, but did positively affect harvest. Although stocked ponds experienced variable net gain of punti, they had higher harvests than ponds with no stocking. For dedhuwa and carp, isolation and average size at stocking best predicted net gain. Budget analysis showed stocking of SIS could increase profit by an average of $536/yr. Although farmers often reported higher net gain without stocking SIS, stocking could create a more reliable harvest of punti and thus a more reliable source for household consumption or sales.

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INTRODUCTION

Pond-based aquaculture is the dominant culture system in Nepal and accounts for 90% of aquaculture production (FAO NASO, 2014); carp are the dominant species used and comprise 90% of pond production yield. Aquaculture production is fairly new to Nepal; it began in the 1940s, but did not develop significantly until the 1980s with the creation of the Aquaculture Production Program in 1981 (FAO NASO, 2014). Since then, production has increased dramatically from 2,041 tonnes in 1982 to 36,020 tonnes in 2013 (FAO, 2015).

Aquaculture systems, including polyculture of carp and small indigenous species (SIS), are well received and accepted among rural farmers and can improve nutritional and economic well-being of farmers and their families (Kawarazuka, 2010; Kawarazuka and Bene, 2011; Morales and Little, 2007; Rai et al., 2014; Thilsted, 2012). Evaluations of carp-SIS aquaculture systems have been conducted by in-field and on-station comparisons of different stocking strategies (Alim et al., 2004; Gupta and Rai, 2011; Jena et al., 2002; Milstein et al., 2006; Milstein et al., 2008; Wahab et al., 2003). Carp-SIS systems used by farmers in Chitwan raised total production above the national average, doubled consumption rate of household members, and provided USD $34 or NRs 3,400 (Nepali rupees) income per household in 270 days of culture (Rai et al., 2014).

Several biological characteristics of SIS provide inherent advantages concerning their inclusion in aquaculture systems. Many SIS contain high levels of vitamin A, calcium, iron, and zinc per 100 grams of raw, cleaned fish (Roos et al., 2007). Compared to carp species, both dedhuwa (*Esomus danricus*) and punti (*Puntius sophore*) contain higher amounts of vitamin A and zinc per gram, and dedhuwa contains more iron (Roos et al., 2007). When corrected for table waste, calcium content in SIS, including dedhuwa and punti, is much higher than that for carp (Gupta and Rai, 2011; Roos et al., 2007), because the bones, eyes, head, organs, and viscera of SIS are major sources of these nutrients, and SIS are typically consumed whole whereas carp are gutted and cleaned (Gupta and Rai, 2011; Roos et al., 2003; Roos et al., 2007). Furthermore, since SIS are most commonly earmarked for household consumption rather than market sales (Kadir et al., 2006; Roos et al., 2003; Roos et al., 2007), SIS production can directly improve household nutrition. SIS also have a higher reproductive rate than carp species and spawn in culture ponds (Alim et al., 2004; Kadir et al., 2006; Milstein et al., 2006; Milstein et al., 2008; Wahab et al., 2003). SIS are also a plentiful fish in the cyprinid family commonly found in rivers of Nepal including the Terai region (Gupta and Rai, 2011; Gupta, 2015; Husain, 2015; Rai et al., 2014). Furthermore, their inclusion does not require additional pond inputs since they feed on naturally occurring food sources within the pond, such as plant material, algae, phytoplankton, zooplankton, and small insects (Das et al., 2013; Gupta, 2015; Husain, 2015; Mustafa, 1976).

Inclusion of artificial substrates to boost periphyton production in ponds can increase both primary and secondary production and reduce need for input of feed, which lowers production costs and increases income for farmers (Verdegem and Ekram-Ul-Azim, 2001). Periphyton is a substrate attached algal community, and consists of agnate, filamentous, and stalked benthic algae as well as sedimented phytoplankton. These are associated with and usually enmeshed in bacterial bio-films, detritus, and invertebrates (Verdegem and Ekram-Ul-Azim, 2001). Adding bamboo substrate to ponds has been shown to promote growth of periphyton and can increase carp production (Azim et al., 2002a; Azim et al., 2002c; Azim et al., 2005; Rai et al., 2008; van Dam et al., 2002). Rohu (*Labeo rohita)* is an established periphyton feeder (Azim et al., 2002b; Azim et al., 2005; Rai and Yi, 2012; Wahab et al., 1999), common carp (*Cyprinus carpio)* have been seen to nibble on periphyton (Rai and Yi, 2012), and production of both species has been shown to increase in ponds with periphyton substrate installed (Ramesh et al., 1999; Verdegem and Ekram-Ul-Azim, 2001; Wahab et al., 1999).

Given previous positive results from carp-SIS polyculture systems, determining if planned stocking can enhance net gain (# harvested - # stocked) of SIS over uncontrolled natural colonization is important. Punti and dedhuwa were chosen as the focus of this research because they are two SIS commonly found in southern Nepal and are preferred for consumption in the region (Morales and Little, 2007; Rai et al., 2014). Dedhuwa has been evaluated less extensively as a potential addition than punti or mola (*Amblypharyngodon mola*), another favored SIS, and thus, their inclusion will provide valuable insight. The six species of carp also included in this experiment represent a typical carp polyculture system of the region based on availability, popularity, and historic aquaculture production data (FAO, 2015).

The main objective of this study was to compare effects of different SIS stocking densities on carp production, SIS net gain, SIS harvest, and water quality in order to identify an optimal stocking density for a typical carp polyculture system in Nepal. A significant decrease in water quality, particularly dissolved oxygen (DO), would indicate overstocking SIS, while a decrease in carp production might indicate interspecific competition between SIS and carp. I expected stocking SIS would increase SIS production in one or more treatment(s) indicating that SIS were reproducing in ponds. Since the change in SIS biomass in a pond is the product of reproduction, survival, immigration, and emigration, 'net gain' will be used instead of production to indicate the gain or loss of SIS biomass during culture. I hypothesized that stocking SIS would not negatively impact carp production, or water quality at any stocking density, and that inclusion would improve net gain and harvest of SIS and overall economic return. I hypothesized a density could be identified to maximize net gain and harvest by good survival and establishment of natural reproduction of SIS within the ponds. Carp production, SIS net gain, SIS harvest, and water quality were measured at three different SIS stocking densities and a control to test these hypotheses. Economic feasibility was analyzed using a partial budget analysis based on data from this experiment and surveys of local farmers, hatcheries, and market vendors.

METHODS

Study Site

Nepal is a land-locked country in Asia situated south of China and north of India, consisting of three distinct geographical regions (Figure 1). From north to south, terrain changes from the high elevation Himalaya region to lower elevation hills and finally to the 'Terai" region, which is subtropical lowland and contains the vast majority of the country's agriculture and aquaculture production. Nepal has plentiful freshwater resources originating mainly from rivers flowing from the Himalayas. According to the Food and Agriculture Organization of the United Nations (FAO), 94% of aquaculture ponds in Nepal are located in the Terai region (FAO NASO, 2014). The Terai region's climate ranges from hot and humid summers to mild winters. This is beneficial for aquaculture production since ponds can be kept in production all year although the typical grow-out season is spring through fall. Economically, gross domestic product (GDP) per capita in Nepal is approximately USD $730 (World Bank, 2015); however, ~30% of residents live in poverty and 75% of those living below the poverty line engage in agriculture as their main source of income (Karkee, 2008).

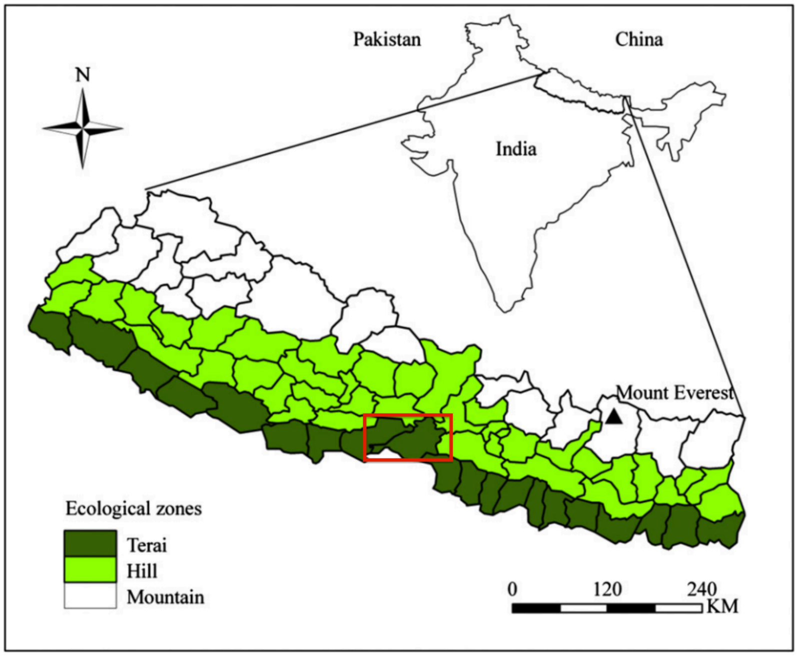

Figure 1. Ecological Regions of Nepal; Terai, Hill, and Mountain regions in dark green, light green, and white. The experimental study site was in the Chitwan District located in the Terai region within the red box. Source: Chhetri et al., 2012

The Chitwan district in the Terai region of central-southern Nepal was selected as the field site as it is the location of the Agriculture and Forestry University (AFU), which is a main contributor to aquaculture research, education, and outreach in Nepal. Carp aquaculture is also very popular in the area. This experiment was conducted in collaboration with researchers and students at AFU, and ponds used for this research were located in the village of Kathar near AFU.

Experimental Design

My experimental design included three treatments with different SIS stocking densities and a control, with each replicated in three similar ponds. For all treatments, carp density, feed composition, and fertilization rate were chosen based on typical practices in the area, which incorporated six species of carp: common carp, bighead carp (*Aristichthys nobilis)*, silver carp (*Hypophthalmichthys molitrix)*, grass carp (*Ctenopharyngodon idella)*, rohu, and mrigal (*Cirrhinus mrigala)*. Carp density was 15,000/ha, and resulted in 300 total carp in each 200m^2 pond. Surface feeders (silver and bighead carp) were stocked at 50% of total carp density, bottom feeders (common carp and mrigal) at 30%, and column feeders (rohu and grass carp) at 20%. The treatments were 1) Control - 0 SIS/ha, 2) 25,000 SIS/ha, 3) 50,000 SIS/ha, and 4) 75,000 SIS/ha. Punti and dedhuwa were stocked at 250 each per pond in treatment 1, 500 in treatment 2, and 750 in treatment 3. These will be referenced as T250, T500, and T750.

Ponds were drained, dried, and limed three months prior to stocking. Ponds were filled using underground plastic piping connecting ponds to a nearby canal (Figure 2). Pipes utilized a slight gradient to fill ponds by gravity and were sealed by tying plastic over the inlets. Pipe outlets into ponds were covered with mesh to prevent fish movement. The twelve ponds were stocked in late July and August 2013 with three ponds randomly assigned to each treatment. Pond depths were maintained at ~1.5m. The twelve ponds were completely harvested in mid-January 2014 giving the system a 5.5-month grow-out period.

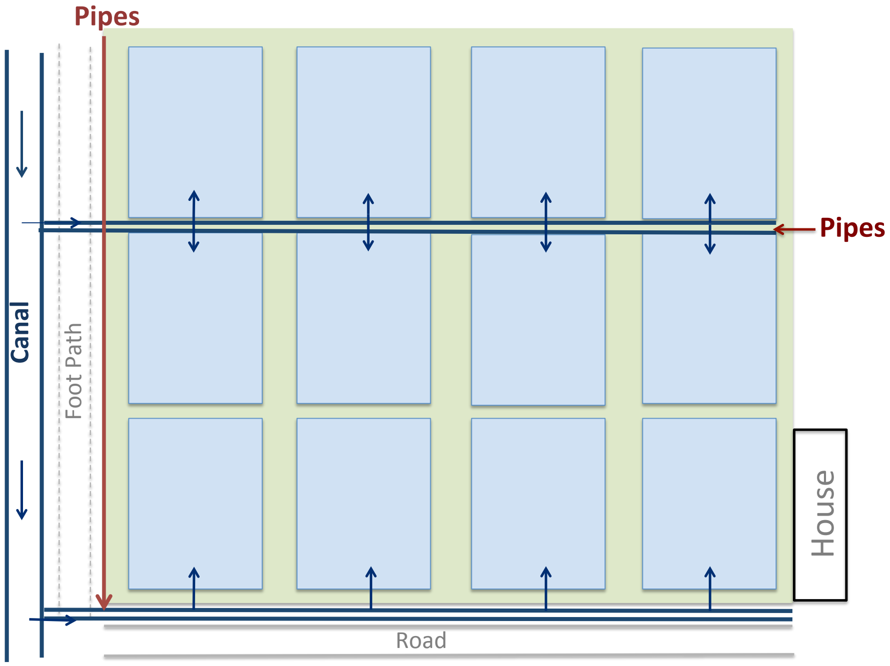

Figure 2. Canal, ponds, and pipe system for filling ponds with water.

Carp were fed with rice bran and mustard oil cake 6 days per week at 3% carp body weight per day excluding weights of grass, bighead, and silver carp. Diammonium phosphate (700 g/pond) and urea (950 g/pond) were used once a week as fertilizer to promote algae growth, and bamboo poles were installed as a substrate for periphyton production. Fertilization was not done on weeks when algae cover became high and morning DO levels were less than 3 mg/L.

Bamboo substrate was installed in all experimental ponds to promote periphyton growth. Bamboo was sourced from stands growing around the experimental site, and split in half lengthwise to provide more surface area from the hollow center of the poles. One set of four split poles with a length of 8 m and an average diameter of 30 cm was installed in each pond for surface area coverage of 6.4 m^2. A second set of four split poles 8 m long and averaging 24 cm in diameter was installed in each pond for surface area coverage of 7.68 m^2. Bamboo was installed by attaching pairs of half poles, concave side up, to two small split bamboo poles, which were pushed into the sediment and anchored the pole halves at 25 cm depth. The total bamboo surface area in each pond was ~17.28 m^2 or ~8.64% of the total pond surface area.

Sampling

Carp production parameters were collected monthly throughout the grow-out period using samples from seining all ponds 1-2 times to collect fish. Seining used a net weighted at the bottom, held above the surface, stretched across the width of the pond, and dragged over the full length of the pond. All carp caught were individually identified, counted, and weighed (g). This information was used to estimate growth of each carp species and to recalculate feeding rate based on carp body weight. A few SIS were caught during sampling in October; these were counted, weighed, and removed from ponds due to mortality during handling. Carp were all returned to ponds after being counted and weighed. During harvest in January 2014, ponds were drained and all carp individually identified, counted, weighed (g), and measured for total length (cm). SIS were also identified, counted, and weighed (g). Survival (%) was calculated using total number of each species at harvest compared to number stocked. Carp production was measured in grams, while yield of SIS (net gain and harvest) were measured using total number.

Measurements were also taken throughout the grow-out period to evaluate water quality. Water temperature, dissolved oxygen (DO), pH, and Secchi disk depth were measured weekly. Weekly water quality measurements were taken between 0600-0800. DO was measured at 25 cm and 75 cm depths, pH measurements were taken near the surface at ~5-10 cm depth, and temperature was taken at ~50 cm depth. Diurnal oxygen measurements were made bi-monthly to estimate primary productivity, and these measurements were taken at 0600 (dawn1 DO) and 1800 (dusk DO) on the first day, and then again at 0600 (dawn2 DO) the following day at 4 depths: 10, 25, 50, and 75 cm. These DO measurements were then used to estimate primary productivity with the 3-Point Free Water Diel Method (Hall and Moll, 1975; Szyper and Rosenfeld, 1992). Using diurnal oxygen measurements, respiration (RESP: dusk DO – dawn2 DO), net primary production (NPP: dusk DO – dawn1 DO), and gross primary productivity (GPP= RESP + NPP) were calculated ($gC * m^{-2} * d^{-1}$) at all four depths and then averaged.

Abundance of periphyton growth on installed substrate within ponds was investigated by sampling one pond from each treatment in August 2013 and January 2014. Three ceramic tiles (30.5 cm X 30.5 cm) were installed in randomly chosen ponds (Ponds 3, 5, 8, and 10) at 25, 50, and 75 cm depths. These were enclosed in a mesh net to prevent carp feeding on the periphyton. Tiles were left in ponds for ~5 days and then collected. Periphyton was scraped from tiles, water was strained out of the samples, samples were dried in an oven at 100 °C for 2 hours, and dry weight of periphyton (g) was determined. Production was evaluated for both months separately by averaging dry weight from tiles at all three depths to calculate average growth ($g*m^{-2}*d^{-1}$).

Statistical Analysis

Analysis of variance (ANOVA) was used to determine significant differences (alpha = 0.05) in carp production, carp survival, SIS net gain, SIS harvest, and water quality variables between treatments. Any significant ANOVA results were further analyzed using Tukey's HSD post hoc test to determine which treatments varied from the others. In addition to ANOVA using pond harvest data, correlation matrixes, multiple regression analysis, and ANOVA on yield residuals created from best–fit regression model results were analyzed to further determine variables affecting variation in carp production and SIS net gain or harvest.

Correlation matrixes were created to explore significant relationships between independent variables and carp production, SIS harvest, and SIS net gain by pond (Appendix B). These variables included number of days DO fell below 5 mg/L (DO <5 mg/L), average Secchi disk depth, average primary productivity, average size of carp stocked (g), and isolation index or distance from disturbances. Growth and survival of all carps combined and of each species were also analyzed by pond using correlation matrixes. Disturbances caused birds to flee ponds, and bird predation could affect fish survival, growth, and net gain. Thus, isolation was estimated by proximity to a bordering house, road, and footpath where human disturbances occurred. Ponds were scored (1-6) based on how far each pond was from each of the three sources of disturbance. Scores for each source of disturbance (house, road, and footpath) were weighed at 60%, 25% and 15% respectively as they did not contribute equally to disturbance. These weighted scores were then added together and used as an index of isolation for each pond (Figure 3) with higher numbers indicating more isolation.

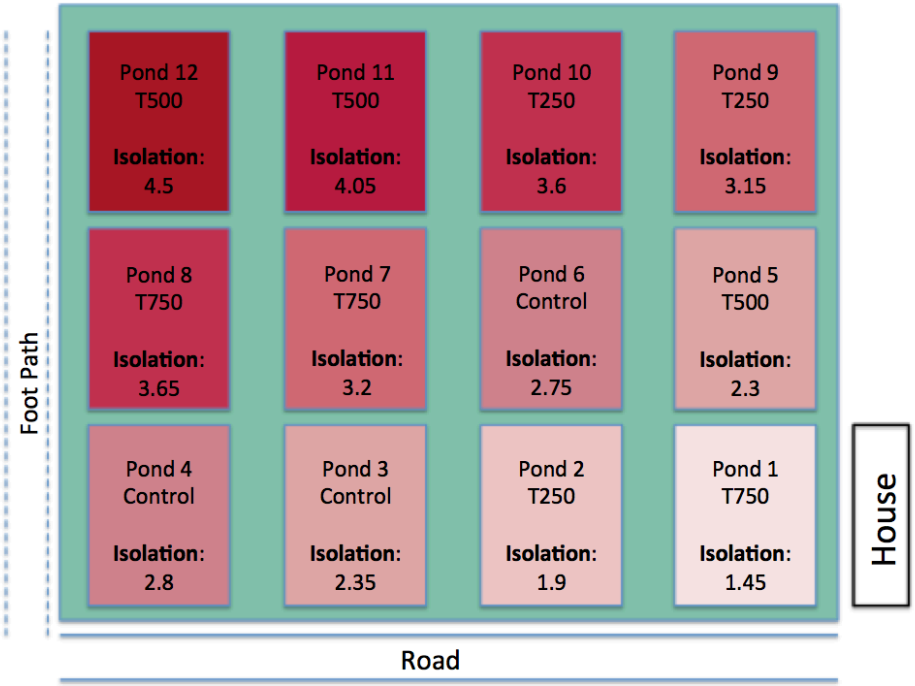

Figure 3. Distribution of experimental ponds, pond numbers, treatments, and isolation index scores for each pond based on distance from disturbances.

In order to identify which physical variables could be associated with variation between ponds in total carp production, punti net gain and punti harvest, multiple regression analyses were performed after patterns of co-variation were investigated using correlation matrixes (Appendix B). Independent variables tested in initial models included isolation, average carp stocking size, and SIS stocking density for each pond. For the best-fit models, residuals were plotted to assess for equal variance, and normality was checked using normal probability plots. Final models were chosen by comparing each model's results with Akaike Information Criterion (AIC), Akaike Information Criterion corrected for small sample size (AICc), and Bayesian Information Criterion (BIC) tests, which give each model a score. To explore possible treatment effects on carp production and punti net gain after accounting for predictive variables identified in regression analysis, residuals of carp production and punti net gain (expected - actual yield) were analyzed using ANOVA.

Due to their small size and narrow body structure, dedhuwa were very difficult to harvest and containment within ponds was difficult, which led me to believe that these data were less robust than data for punti. Based on this uncertainty, dedhuwa net gain and harvest were not evaluated in further statistical analysis by treatment or by pond in relation to variation in carp production, punti net gain, or water quality variables.

Average periphyton growth ($g*m^{-2}*d^{-1}$) in ponds was compared to average primary productivity ($g*m^{-2}*d^{-1}$), total carp production, rohu production, common carp production, and punti net gain within those ponds using Pearson's Correlation Test to assess whether periphyton growth affected them. Growth was also examined for trends by depth and season. Since periphyton growth was only analyzed in 4 out of 12 ponds, it could not be entered into the ANOVA or regression models.

Budget Analysis

Economic and market data were gathered by interviewing three farmers and one merchant, the Kathar Women's Aquaculture Cooperative, a private hatchery, a government hatchery, and a vendor at a local fish market in Bharatpur, Chitwan. Questions were designed to determine overall status of SIS and carp production, consumption, and sales as well as other economic variables associated with aquaculture systems. Questions included whether SIS were present in culture ponds, any SIS stocking, local attitudes and preferences concerning SIS culture or consumption, carp and SIS market price and production, sources of aquaculture information and training, and input costs including purchase of fingerlings, feed, and fertilizer (Table 1). A Partial Enterprise Budget was calculated using experimental and survey data to assess fiscal viability of adding SIS to carp production systems for local farmers, as well as to evaluate pond management strategies in the region. Specifically, I evaluated changes in income and expenses resulting from stocking of SIS. This assessment was chosen because it provides a simple way to analyze costs and benefits for proposed changes in agricultural activities (Roth and Hyde, 2002). Reported SIS harvest, costs, and projected profits from all three farmers interviewed were averaged and then corrected to $kg*ha^{-1}*yr^{-1}$ and $USD*ha^{-1}*yr^{-1}$. Two results were created; one based on harvest data gathered in interviews, and the other based on harvest data collected in my experiment. Additionally, overall pond management strategies and resulting variations in costs, production, net gain, and profits from farmer and the experimental carp systems were compared. Profit from carp sales was analyzed by overall profit/ha (sales-costs) as well as profit per kg produced. These comparisons were created assuming a hypothetical 100% sale of carp produced, and all results were adjusted to $kg*ha^{-1}*yr^{-1}$ and $USD*ha^{-1}*yr^{-1}$.

Economic Evaluation Survey Questions						
Question	**Answer Categories**					
Area Farmed? (m^2)						
Do you own or lease the pond(s)?	Own			Lease		
Do your ponds contain SIS species? If so, which ones?	Punti		Dedhuwa		Other	
Do you purposefully sock and riase SIS species? If so, which ones and how much(#/pond)?						
If no, are you interested in raising these species purposefully?	Yes			No		
Are you aware of any nutritional content differences between large carp and SIS?	Yes			No		
Which species do you stock?	Carp Species		Tilapia		Other	
Do you purchase hatchlings, fry, or fingerlings?						
Where do you purchase your hatchlings/fry/fingerlings?	Government Hatchery	Private Hatchery	Wild/River		Farmer's Own Production	
How much does each species cost to purchase (rs)?						
How much do you sell each species for? (rs/kg)						
How much of each species do you produce per year (kg)?						
What do you use to fertilize your pond(s)?	Organic Matter	Urea	DAP	Manure	Other	
What is the cost of the fertilizer(s) you use?						
How much fertilizer do you use per year? (kg)						
What do you feed your fish?	Mustard Oil Cake	Rice Bran	Soybean Cake	Wheat Flour	Fish Meal	Other
How much does your feed cost? (rs)						
How much feed do you use in a year? (kg)						
Where does this feed come from?						
Are there any other costs besides fry/fingerlings, feed, and fertilizer? If so, what are they?	Co-op Fees	Labor	Equipment Rental		0ther	
If so, how much do they each cost? (rs)						
What is your grow-out period to market size? (mo)						
Who do you sell your fish to?	Not Sold	Neighbors	Local Market	Wholesaler	Transporter	Other
Why do you sell to this/these buyer(s)?						
What percentage (or how much(kg)) of the fish you raise are sold to these buyers?	Consumed at home.	Neighbors	Local Market buyers/sellers	Wholesaler	Transporter	Other
What percentage (or how much(kg)) of SIS from your ponds are:	Consumed at home.	Neighbors	Local Market buyers/sellers	Wholesaler	Transporter	Other
How do you learn about new technologies?						

Table 1. Survey questions and possible answers used for the economic evaluation.

RESULTS

On-station experiment

Changes in SIS stocking density did not affect punti net gain, but stocking density did positively affect punti harvest. There was more variation in punti net gain within a treatment than between treatments (p-value = 0.177, Figure 4). Control and T750 ponds all showed positive net gain; whereas, two of three T250 and T500 ponds had negative net gains. Unlike net gain results, punti harvest generally increased with increasing stocking density. Significant differences were found between T750 and both the control and T250, with T750 having significantly higher harvest. Indeed, the 95% confidence intervals for punti harvest boxplots did not overlap although p-value was barely significant ($p < 0.05$, Figure 5). Increased isolation clearly resulted in lower net gain of punti (Correlation $p = 0.0032$). A best-fit regression model likewise showed isolation alone had a significant negative relationship with net gain ($F(1, 10) = 14.86$, $p = 0.003188$, $R^2 = 0.5575$). Further analysis of residuals for punti net gain indicated the stocking treatments had no effect on net gain even when controlling for isolation ($p = 0.076$). Punti harvest also had a negative correlation with isolation ($p = 0.0568$), and a weak but positive correlation with SIS density ($p = 0.071$). The best-fit regression model indicated SIS density had a positive effect on punti harvest, and isolation a negative effect ($F(2,9) = 11.08$, $p = 0.003746$, $R^2 = 0.6469$). The regression model equation, a summary of regression results, correlation matrixes, and a table of residuals for punti net gain and harvest can be found in Appendix B, and average SIS yield data can be found in Appendix A. Of note, punti were harvested from control ponds where none were stocked.

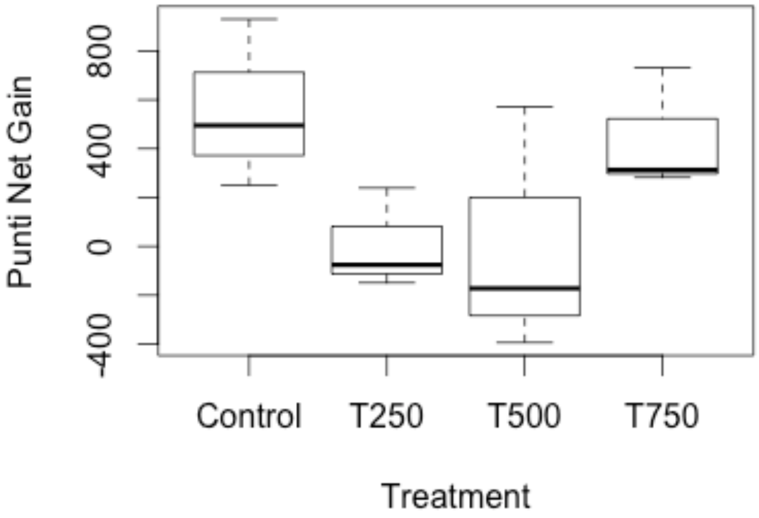

Figure 4. Boxplot of punti net gain (# harvested - # stocked) by treatment. Box = interquartile range (IQR), top and bottom of box = 1st and 3rd quartile (Q1 & Q3), dark line = mean, whiskers = min (Q1-1.5*IQR) and max (Q3+1.5*IQR) of range.

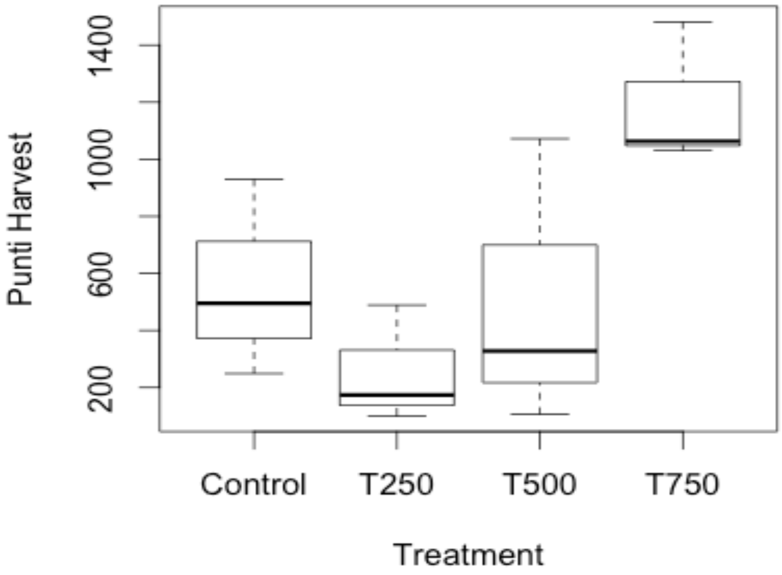

Figure 5. Boxplot of punti harvest (# harvested) by treatment. Notations as in Figure 4.

SIS stocking density had a negative effect on net gain of dedhuwa, but no effect on harvest. Control ponds had the highest average dedhuwa net gain at 100/pond with a range of 20-230, while all other treatments yielded negative net gain (Figure 6, p = 0.00173). Interestingly, there was no significant difference in net gain between the control, T250, and T500, but T750 was significantly lower than these treatments with an average loss of 471/pond (Tukey multiple comparison post-hoc test, p < 0.05). Indeed, SIS stocking density was strongly negatively correlated with dedhuwa net gain (p = 0.0003). Dedhuwa harvest for different treatments showed high variation within each treatment with a final harvest range of 20 – 597 among ponds (Figure 7, p = 0.0756). Correlation analyses for dedhuwa net gain and harvest with variables measured can be found in Appendix B. Similar to punti, dedhuwa were harvested from control ponds in which none were stocked.

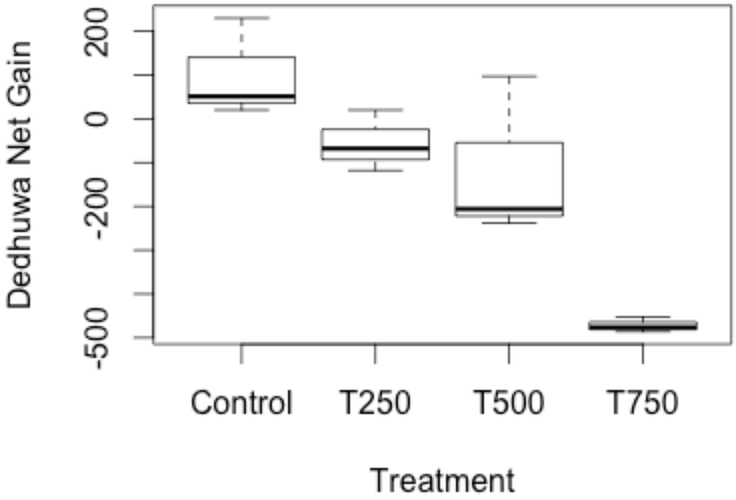

Figure 6. Boxplot of dedhuwa net gain by treatment. Notation as in Figure 4.

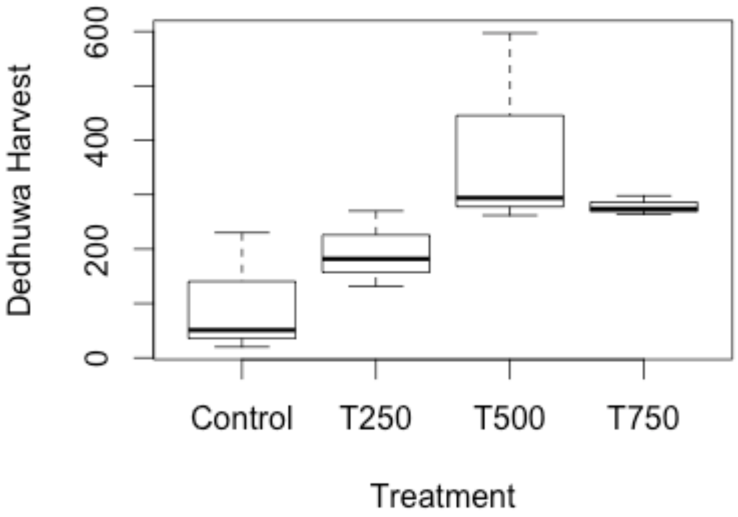

Figure 7. Boxplot of dedhuwa harvest by treatment. Notation as in Figure 4.

As hypothesized, changes in SIS stocking density did not result in variations in carp production or survival between treatments. There were no significant differences in carp production or survival for most species of carp across SIS stocking treatments ($p > 0.05$). However, grass carp survival was negatively correlated with SIS stocking density ($p = 0.046$), but grass carp growth and production were not correlated with SIS density. Total carp production and average carp survival showed more variation within than between treatments ($p = 0.823$, $F = 0.302$). Carp production decreased as pond position moved away from sources of human disturbance; ponds with higher isolation indexes had significantly lower overall carp yields (Figure 8; $p = 0.0001$). There was also considerable variation in survival of each species and overall production among ponds. Average carp survival among ponds was 74.8% with a range of 44.1 to 93.3% (Table 2). Ponds 10 and 11 experienced the lowest carp survival at 54 and 44%. By species, grass carp experienced lowest average survival at 46%, but all other species average survival ranged from 64.4 – 101.7% with an overall average of 74.8% (Table 2). Mrigal, rohu, and common carp experienced survival over 100% and up to 133% in some ponds (Table 2), indicating immigration of some carp or errors in stocking. Carp production, survival, and growth data can be found in Appendix A.

	Percent Survival							
Pond #	Grass	Silver	Mrigal	Rohu	Common	Bighead	Mean	SD
1	46.7	56.7	124.4	113.3	113.3	11.7	77.7	45.8
2	50.0	63.3	77.8	113.3	104.4	81.7	81.8	24.0
3	43.3	53.3	60.0	106.7	104.4	93.3	76.9	27.9
4	50.0	64.4	113.3	103.3	111.1	68.3	85.1	27.4
5	36.7	75.6	100.0	90.0	100.0	78.3	80.1	23.7
6	80.0	83.3	97.8	133.3	95.6	70.0	93.3	22.1
7	46.7	62.2	97.8	113.3	108.9	78.3	84.5	26.7
8	23.3	82.2	84.4	96.7	97.8	78.3	77.1	27.5
9	56.7	77.8	28.9	90.0	60.0	93.3	67.8	24.3
10	43.3	56.7	6.7	96.7	42.2	78.3	54.0	31.3
11	43.3	47.8	8.9	56.7	24.4	83.3	44.1	25.8
12	36.7	48.9	93.3	106.7	95.6	70.0	75.2	28.1
Mean	46.4	64.4	74.4	101.7	88.1	73.8	**74.8**	
SD	13.5	12.6	39.8	18.6	29.3	21.1	13.7	

Table 2. Survival (%) by species and by pond, with group means and standard deviations, (SD).

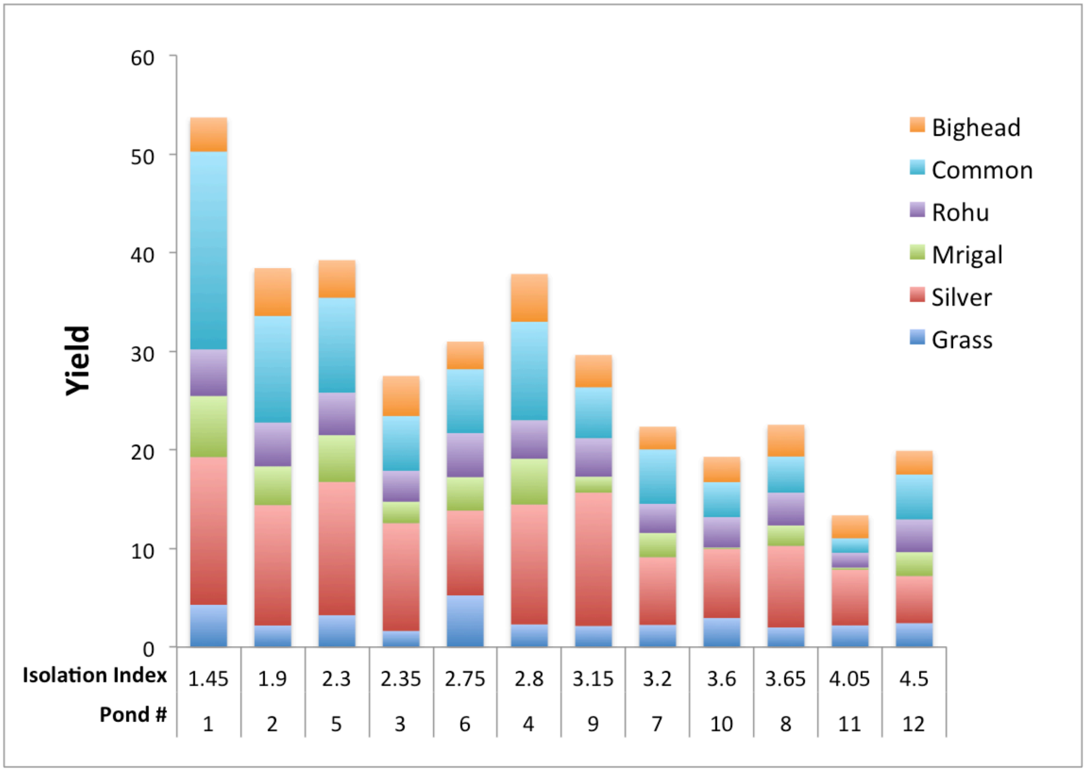

Figure 8. Carp yield (kg) by pond number and isolation index score, and proportion each species contributed to total yield for that pond.

Variation in total carp production was related to isolation and average size of carp at stocking, with increased isolation resulting in lower production and increased average size at stocking resulting in higher production. Carp production by pond was significantly correlated with isolation, primary productivity, Secchi disk depth, and average size at stocking (Table 3). When analyzed by multiple regression, isolation and, less strongly, average carp size at stocking had highest predictive ability for total pond production ($F(2, 9) = 27.88$, $p < 0.0005$, $R^2 = 0.83$). The regression model equation, a summary of regression results, and a table of residuals for carp production can be found in Appendix B. Furthermore, residuals of carp yield (expected yield - actual yield) were not affected by SIS stocking density (ANOVA, $p = 0.819$). Carp growth showed a negative correlation with isolation index with lower growth in more isolated ponds ($p = 0.0063$), and lower average growth of each individual species except grass carp and rohu (Table 4). Neither average carp survival ($p = 0.1089$) nor survival of individual carp species were significantly impacted by isolation.

As expected, average size of all carp at stocking had a positive effect on total pond production, but common carp was the only individual species to show a significant positive correlation between average size at stocking and production ($p = 0.0082$). Common carp size at stocking was particularly large in pond 1: 20.78 g compared to ~3-4 g in the other ponds. Indeed, when pond 1 data was removed and correlation and regression analysis on carp production re-run, there was no correlation between average size at stocking and overall pond production or production of individual species, and the best multivariate model predicting pond production included only isolation.

Also as expected, there were no adverse effects from stocking of SIS at any density on water quality. For all water quality parameters tested including primary productivity, average pH, average Secchi disk depth, and frequency of low DO (days DO <5 mg/L), there was more variation within treatment than between treatments, and water quality parameters remained within acceptable ranges for carp and SIS survival.

	Isolation Index		Secchi Disk Depth		Primary Productivity		Days DO <5 mg/L		Stocking Size (g)	
Species	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
Common	0.831	0.001	-0.775	0.003	0.622	0.031	0.156	0.629	0.721	0.008
Silver	-0.859	0.000	-0.652	0.022	0.576	0.050	0.093	0.774	0.457	0.136
Mrigal	-0.755	0.005	-0.658	0.020	0.549	0.064	0.274	0.388	0.504	0.095
Rohu	-0.717	0.009	-0.471	0.123	0.511	0.090	0.115	0.723	0.400	0.197
Bighead	-0.658	0.020	-0.633	0.027	0.566	0.055	-0.258	0.419	-0.062	0.849
Grass	-0.345	0.272	0.036	0.913	0.034	0.916	0.649	0.023	0.419	0.176
Total Production	-0.890	0.000	-0.729	0.007	0.626	0.029	0.190	0.554	0.599	0.039

Table 3. Pearson's correlations between water quality variables (averages for each pond) and isolation index with average net production of individual carp species and average total carp production. Significant p-values are highlighted.

	Isolation Index		Secchi Disk Depth		Primary Productivity		Days DO <5 mg/L		Stocking Size (g)	
Species	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
Common	-0.736	0.006	-0.595	0.041	0.573	0.052	0.187	0.561	0.778	0.003
Silver	-0.838	0.001	-0.860	0.000	0.667	0.018	-0.056	0.862	0.554	0.062
Mrigal	-0.733	0.007	-0.540	0.070	0.630	0.028	-0.029	0.930	0.308	0.330
Rohu	-0.561	0.058	-0.282	0.374	0.546	0.066	0.238	0.455	0.444	0.148
Bighead	-0.620	0.032	-0.709	0.010	0.426	0.167	0.164	0.610	0.899	0.000
Grass	-0.106	0.744	0.035	0.914	0.150	0.642	0.617	0.032	0.681	0.015
Average Growth	-0.737	0.006	-0.672	0.017	0.581	0.047	0.253	0.428	0.883	0.000

Table 4. Pearson's correlations between water quality parameters (averages for each pond) and isolation index with average carp growth and average growth for each carp species. Significant p-values are highlighted.

Some water quality parameters showed much variation between ponds, but all followed similar trends or patterns among ponds over time. Temperature declined from 32°C to 15°C over the course of the experiment and was uniform among ponds over time. Ponds did not vary more than 1.7°C at time of measurement, and were usually within 1 degree. Similarly, pH showed little variation between ponds with a range of ~2. Average difference of pH among ponds was small with a range of 8.01-8.63, with a maximum range at time of sampling of 7.5-9.65 except pond 12 for one measurement in November when pH was 5.5. Dissolved oxygen ranged from 2-10 mg/L with no trend over time, but all ponds followed the same overall pattern (Figure 9). Secchi disk depth showed high variation among ponds in the summer months of July and August with a range of up to 60 cm and depths between 20 to 80 cm. Starting in September and continuing through January, ponds had less variation in Secchi disk depth with a range of only 10-20 cm among ponds, with Secchi disk depths between 15 to 35 cm. Water quality data are listed in Appendix A.

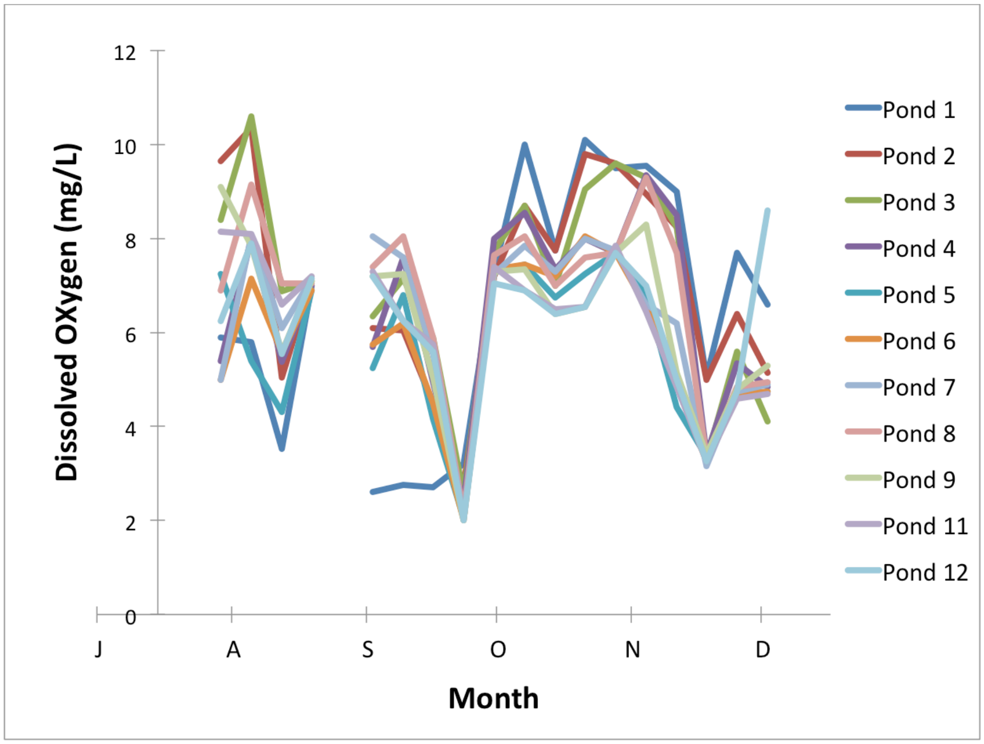

Figure 9. DO (mg/L) taken at dawn over the grow-out period. Gap signifies a week in which data were missing. X-Axis starts with July and letters coincide with first letter of each consecutive month.

Contrary to expectations, periphyton growth showed no pattern with season or depth, while primary productivity showed much variation over time, but was uniform among ponds. Periphyton growth varied between each pond sampled, as well as within each pond by depth and season. In August and January, some ponds had increased periphyton growth with depth while others had decreased growth. Average periphyton growth was higher in three out of the four ponds (control, T250, and T750) sampled in January than it was in August. However, average growth across depths in January was 42.17 g/m^2 while average growth in August was 59.44 g/m^2. August experienced highest periphyton growth with 175.58 g/m^2 in the pond sampled from the T500 treatment, but this is more than five times the growth found in the other ponds in August (Figure 10). In contrast, primary productivity in ponds showed fair uniformity with productivity oscillating almost monthly over time, showing high production in July, September, and December with declines to nearly 0 between these peaks (Figure 11).

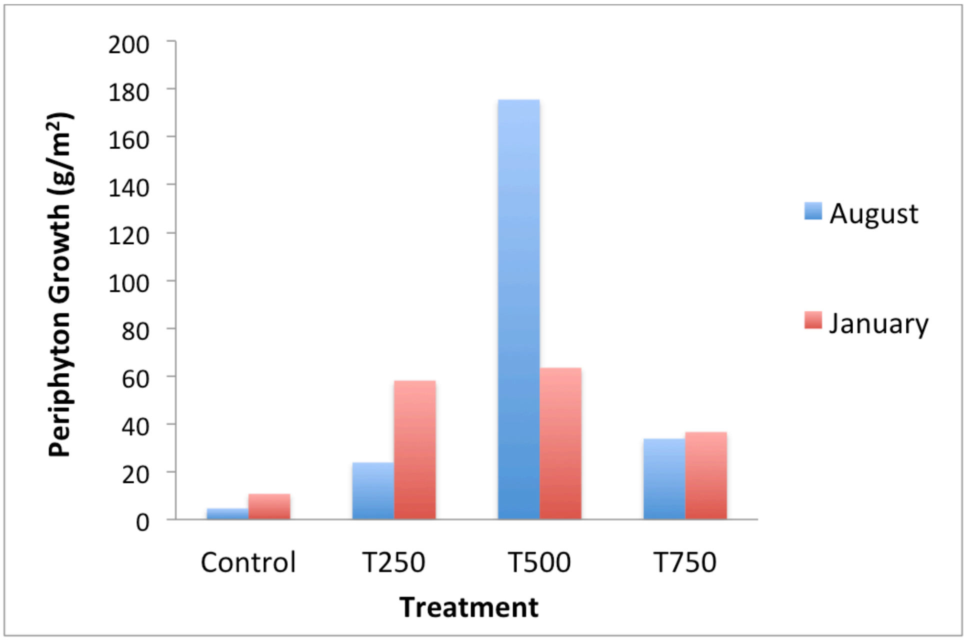

Figure 10. Average periphyton growth (g/m^2) of each treatment in August and January.

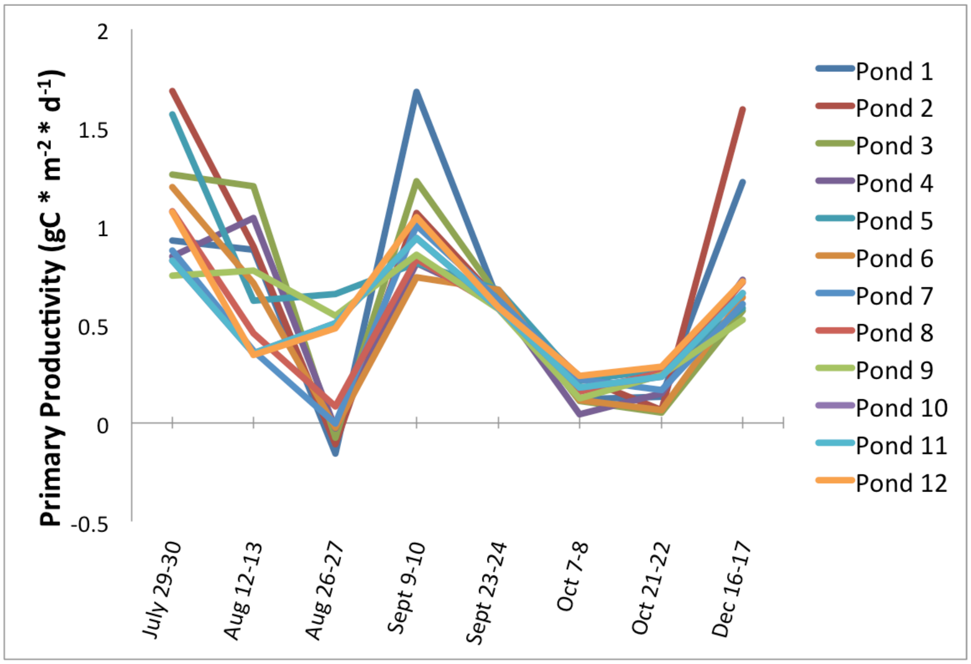

Figure 11. Primary productivity (gC*m^{-2}*d^{-1}) between ponds over the grow-out period.

Cost-benefit Analysis

SIS net gain varied between ponds, and cost varied between treatments leading to high variability in potential profits for this experiment. Average SIS harvest was 187.6 kg*ha^{-1}*yr^{-1} with a range of 46.2 to 439.64 kg*ha^{-1}*yr^{-1}. When sold, SIS prices were higher than carp (USD $4.00/kg vs. USD $2.00- $3.60/kg). Thus, potential profit from SIS net gain in this experiment was USD $526 a year per hectare on average with a maximum of $1,535. In this experiment the only cost increase to incorporate SIS was labor for collection and stocking with a range of USD $0 in control ponds to UDS $338/ha in T750 ponds, and an annual average of USD $224/ha. SIS numbers were not included in feed calculation for this experiment, nor were fertilization amounts changed based on SIS stocking densities.

Farmers reported a wide range of SIS yields, but with average yield of SIS higher than what was found in this experiment. Farmers reported harvesting between 4-12 kg of SIS for a range of 180-800 kg*ha^{-1}*yr^{-1} (Table 5) with an average harvest of 460 kg*ha^{-1}*yr^{-1}, for a potential average annual profit of USD $1,840 per hectare (Table 6). No input costs were increased to include SIS in ponds, as farmers did not purposefully stock SIS. Instead, SIS entered ponds naturally.

	Farmer 1	Farmer 2	Farmer 3	Experiment Average
Pond Size	100	100	666	200
Punti Harvest	400	200	90	165.09
Dedhuwa Harvest	400	200	90	21.82
TOTAL	800	400	180	187.61

Table 5. Pond size (m^2), and SIS harvests (kg*ha^{-1}*yr^{-1}) for each farmer and the experimental average.

Variables	Farmers Average	Experiment (Control)	Experiment (T250)	Experiment (T500)	Experiment (T750)	Experiment Average	Experiment Maximum
Feed/ Fertilizer Cost	$0	$0	$0	$0	$0	$0	$0
Purchase Cost	$0	$0	$113	$224	$338	$224	$224
SIS Net Gain	460	154	100.73	167.56	328.15	187.61	439.64
$/kg SIS	$4	$4	$4	$4	$4	$4	$4
SIS Sales (USD)	$1,840	$616	$403	$670	$1,313	$750	$1,759
Profit	$1,840	$616	$290	$446	$975	$526	$1,535

Table 6. Comparison of costs and benefits (USD) due to addition of dedhuwa and punti to carp polyculture systems. Net gain corrected to ($kg*ha^{-1}*yr^{-1}$), and cost and profit corrected to ($USD*ha^{-1}*yr^{-1}$).

Farmers also did not add more feed or fertilizer once they were aware of SIS presence. SIS were rarely sold in markets, rather they were consumed at home. Interestingly, farmers with larger ponds did not report larger harvests of SIS. When corrected to area, smaller ponds annually yielded more SIS per hectare (Table 5).

There were two ways to acquire SIS for stocking; either through collection from the wild or by purchase from fishers. Daily labor cost for collection was estimated at ~USD $3.00/person (8hr) to collect 1 kg SIS, and purchase cost was similar (Personal Communication, Dr. Madhav Shrestha, 11/28/2015). Purchase and labor costs assumed an average SIS size of 1.5 g. Thus, when acquiring SIS from either method, USD $3.00 would equal ~667 SIS.

Concerning overall pond management, the main input costs for this experiment were feed and fertilizer, followed by stocking. Annual stocking cost for this experiment was USD $245/ha, while feed and fertilizer costs were USD $2,539/ha out of total cost of USD $3,014/ha (Table 7). Average carp production from my experiment was 3,224 $kg*ha^{-1}*yr^{-1}$ (Table 7). As a result, average annual profit for carp was USD $4,117/ha. Experimental data yielded the lowest required stocking numbers per kg harvested, compared to farmers, at 10.2, but came in third for profit/kg harvested; USD $1.28 (Table 6).

	Farmer 1	Farmer 2	Farmer 3	Farmer Average	Experiment
Stocking Density	120,000	210,000	60,060	130,020	15,000
# Species Stocked	3	3	3	3	6
Carp Size at Stocking	Fry and Fingerlings	Fry	Fry and Fingerlings	Fry	Fingerlings
Pond Size (m^2)	100	100	666	1400	200
Production	3,000	3,000	3,604	3,201	3,224
Stocking Cost	$1,300	$525	$1,201	$1,009	$245
Feed Costs	$0	$500	$0	$167	$1,099
Fertilization Costs	$256	$128	$117	$167	$1,440
Other Costs	$8.00	$9.00	$8.00	$8.00	$229
Total Costs	$1,564	$1,162	$1,326	$1,351	$3,014
Total Sales	$5,000	$6,000	$7,207	$6,069	$7,131
Total Profit (sales-costs)	$3,436	$4,839	$5,881	$4,719	$4,117
# Stocked per kg Production	40	70	17	42	10.2
Profit per kg Produced	$1.15	$1.61	$1.63	$1.46	$1.28

Table 7. Comparison of carp pond production, costs, and profits between cooperative members (Farmer 1 and Farmer 2), an individual farmer (Farmer 3), and this experiment. Production, cost and profits were corrected to $kg*ha^{-1}*yr^{-1}$, costs, sales, and profits corrected to $USD*ha^{-1}*yr^{-1}$.

Variation in production and estimated profits reported by farmers was mainly due to differences in stocking density, costs, and resulting fish yield (Table 7). Annual profits for farmers averaged USD $4,719/ha. Stocking density ranged from 60,000–210,000/ha and pond size ranged from 100–666m^2, but carp production reported by farmers only ranged between 3,000-3,600 kg/ha. Farmer profit per kg of fish produced ranged from USD $1.15-$1.61 with an average of USD $1.46. Farmers 1 and 2, who stocked at 120,000 and 210,000 fish/ha, required 40 and 70 stocked fry or fingerlings to produce 1 kg compared to farmer 3 who stocked at 60,000/ha and produced 1 kg of fish per 17 fingerlings stocked.

Differences in overall pond costs and profits between farmers and this experiment were largely due to differences in stocking density, fertilization schedule and source, and feed source. The greatest input cost for farmers was for purchase of carp hatchlings, fry, and fingerlings to stock ponds. Cost for stocking varied from 0.25 – 1.5 NRs/piece (USD 0.25¢ – 1.5¢) based on size of fish stocked. Additionally, farmers reported stocking at much higher densities than what was recommended by AFU and used in this experiment. Sourcing fertilizer and feed from existing livestock and crops kept other costs low. By sourcing feed from their existing crops, two out of the three farmers spent no money on additional feed for their ponds. Also, farmers often utilized manure from livestock as a fertilizer and fertilized very infrequently (~2x/yr). Farmers interviewed did not mention lime as an extra cost when asked about other maintenance costs for the ponds, but they were also not asked specifically whether they annually dried and limed their ponds.

DISCUSSION

As expected, stocking density of SIS had a positive impact on punti harvest although it did not have the same expected effect on punti net gain. This occurred because stocked ponds experienced variable net gain, but had higher yields (kg/ha) upon harvest than ponds with no stocking, and the highest stocking density (75,000/ha) produced the highest yield of all densities explored. Initially, I hypothesized net gain would be the result of SIS survival and reproduction; however, harvest results and observations showed that immigration and emigration from outside water sources also contributed to SIS harvest. Punti net gain was highly variable between ponds, and even when isolation, the variable with strongest predictive ability for punti net gain, was controlled for, stocking density still was not correlated with SIS net gain in ponds. This indicates that effort and money spent to stock SIS did not result in increased net gain over what might enter ponds naturally from connecting waterways and reproduce there. However, stocking density did affect punti harvest, with the highest stocking density ponds (T750) having significantly higher harvests than ponds with no stocking or the lowest stocking (T250). Indeed, the best-fit regression model showed increased stocking density increased punti harvest, with lower isolation index also increasing punti harvest, so stocking at high densities is beneficial for increasing harvest of punti. Punti and dedhuwa were found in control ponds in which none were stocked, indicating there was movement of SIS among ponds or between ponds and a nearby canal via the underground pipe system.

Given high variability in harvest numbers, negative net gain in ponds with higher stocking densities, and no effect of stocking density on harvest there was no benefit to purposely stocking dedhuwa. I expected dedhuwa numbers would increase from stocking to harvest in stocked ponds due to natural reproduction. Gupta and Rai (2011) showed increased growth of dedhuwa over time and an extrapolated yield of 390 $kg*ha^{-1}*yr^{-1}$ when stocked with carp. However, in this experiment, dedhuwa net gain was negative in all stocked ponds. Due to their smaller size and narrow body shape, dedhuwa slipped through nets that were successful in catching punti, and were difficult to recover from the soft muddy bottom of drained ponds.

Reproduction of SIS was expected in this experiment, but net gain results indicate this was not the case: this is contrary to what has been found in previous work. In other studies, punti reproduction occurred in stocked ponds, produced fry and fingerlings, and increased yields (Alim et al., 2004; Kadir et al., 2006; Milstein et al., 2006; Milstein et al., 2008; Wahab et al., 2003). However, the timing of fish collection, stocking, and grow out for this experiment was at the end of the recognized spawning season for punti and dedhuwa. Stocking most likely included mostly juvenile fish that had not yet reached sexual maturity, which would limit in-pond reproduction. Collection and stocking of SIS in this experiment began in late July, but most SIS were stocked in August, and grow out occurred through January. Punti and similar floodplain fish of Southeast Asia generally reach sexual maturity by the end of their first year and can spawn at the start of the next flood season (FAO, 1996). Milstein et al. (2006) found that SIS reproduction only occurred in spring and not in winter. Most studies conclude punti spawn in summer months no later than August (Banik and Saha, 2013; Choudhury et al., 2015; Milstein et al., 2006; Tareque et al., 2009). Dedhuwa have an extended breeding season from March to mid-August, with August being the peak breeding time indicated by gonadosomatic index (GSI) (Amenla, 2014). Given the late stocking date for this experiment, spawning or reproduction of punti and dedhuwa was unlikely to occur. This is supported by size of SIS observed in this experiment; almost all SIS were <3 g in size at stocking and averaged 2.64 g at harvest, which falls in the range of smallest sizes present in another study (Milstein et al., 2008). Adult punti in Nepal have been defined as those greater than 9 g (Milstein et al., 2006), and fecund females in Bangladesh started at 5.3 g with a mean of 9.16 g (Tareque et al., 2009), which indicates that SIS collected, stocked, and harvested in this experiment were most likely juveniles.

Unexpected movement of SIS occurred between ponds and the connecting canal, and this movement further masked net gain of SIS. This movement is demonstrated by the presence and harvest of punti and dedhuwa in control ponds where no SIS were stocked. SIS entry from canal to ponds was possible due to pond connections with the nearby canal by pipes used to fill the ponds. The pipes connected to the canal were tied shut with plastic seals to stop flow, and pipe outlets to each pond were covered with fine mesh to prevent fish movement between ponds. However, the coverings were sometimes compromised and movement of fish into the pipes made possible when these pipes became submerged. Submergence was caused by periodic heavy rain during the monsoon season (June – August).

My results, high yields in other studies, and those reported by interviewed farmers indicate carp-SIS culture systems can increase SIS net gain by intentional stocking. However, total SIS yields were lower than expected in this experiment. Maximum harvest fell near the range of those seen by interviewed farmers and other studies, but averages were below. SIS can be prolific in ponds without intentional stocking, but farmer data highlights the high variability of natural SIS abundance within ponds. Farmers reported a wide range of SIS harvest (180–800 $kg*ha^{-1}*yr^{-1}$). Results from my experiment showed an average SIS harvest (188 $kg*ha^{-1}*yr^{-1}$) on the lower end of this range, with a maximum harvest of 440 kg*ha^{-1}*yr^{-1}. In a review of 126 Terai farmers who stocked SIS at 30,000/ha, average combined yield of punti and dedhuwa was 616 kg*ha^{-1}*yr^{-1} (Rai et al., 2014). When stocked at 25,000 SIS/ha, Milstein et al. (2008) found an average punti yield of 481 kg*ha^{-1}*yr^{-1}, and total average SIS yield of 983 kg*ha^{-1}*yr^{-1} (punt + mola). Gupta and Rai (2011) stocked dedhuwa and punti separately at 30,000/ha in carp polyculture, and extrapolated punti yields were ~610 kg*ha^{-1}*yr^{-1} and dedhuwa yields 390 kg*ha^{-1}*yr^{-1}.

Budget analysis of my experiment showed stocking of SIS can increase profit by an average of $536 per hectare annually, and although farmers often reported higher SIS yield without stocking, stocking can create a more reliable harvest of punti and thus more predictable profits. Average annual farmer profit based on reported harvest was $1,840/ha. However, reported harvest range was wide (180-800 kg*ha^{-1}*yr^{-1}), meaning potential profit often fell below this. Given this high variability due to natural movement into ponds, having a more reliable source of SIS could be beneficial.

Factors such as isolation and size at stocking impacted production of carp, while interspecific competition with SIS did not. This has also been supported by other studies, showing additions of SIS at similar densities resulted in no impact to carp production (Alim et al., 2004; Wahab et al., 2003) or increased carp production (Gupta and Rai, 2011). In my experiment, increased isolation, which likely coincided with increased predation by birds, had a negative impact on carp. Given carp production is a combined result of growth and survival, the negative correlation of isolation with total carp growth and individual species growth (excluding grass carp and rohu) but not carp survival indicated that bird predation did not remove a significant number of carp from ponds, but reduced production through a negative impact on growth. Bird presence and predation attempts may have forced fish to expend energy on evasive actions or drove them away from favorable areas of the pond, particularly the surface. Grass carp and rohu growth were not significantly correlated with isolation, which could be due to their ability to exploit macrophytes and periphyton (Azim et al., 2002b; FAO, 2016; Rai and Yi, 2012; Wahab et al., 1999). This provides them alternate, often submerged, sources of food compared to other carp relying on algae and feed, which are mainly at the surface of the pond and in shallow water at pond corners; locations that are more exposed to avian predators. I could find no studies on non-lethal effects of bird predators on carp, but several studies have shown that increased predator abundance resulted in reduced growth of prey fish (Fraser and Gilliam, 1992; Connell, 1998).

Common carp in pond 1 were a major contributor to the influence average size of carp at stocking had to increase production. This was expected since larger fish at stocking should take less time to grow, and common carp in pond 1 had a much larger average stocking size compared to other carp. This was due to limited availability of common carp at the time of stocking, so they were purchased from a separate location that only had larger fingerlings available. When pond 1 data was removed from analyses, size-at-stocking effects were no longer detectable. Survival greater than 100% in several ponds for mrigal, rohu, and common carp suggests movement between ponds when the carp were still fingerlings, error counting fingerlings, or error identifying species during stocking.

While there was high variation in survival for carp by pond and species, results fell within an expected range found in other studies. The average survival for this experiment was 74.8% for individual species and ponds, but the range for average species survival was between 46.4% for grass carp and 101.7% for rohu, and the range of average survival for ponds was 44.1% to 93.3%. Survival in several Bangladesh-based studies were 65.6% or higher (Gupta and Rai, 2011), 66% or higher (Wahab et al., 2003), 76% or higher (Milstein et al., 2008), and 80% or higher (Milstein et al., 2006).

Secchi disk depth is generally correlated to plankton abundance (Almazan and Boyd, 1978), and grass carp and rohu were the only species to show no correlation between production and Secchi disk depth (Table 3). Since grass carp consume primarily macrophytes, and rohu directly consume periphyton (Azim et al., 2002b; FAO, 2016; Rai and Yi, 2012; Wahab et al., 1999), they are likely not influenced by phytoplankton abundance. Average primary productivity and average Secchi disk depths were negatively correlated, because an increase in Secchi disk depth, which means increased water clarity, indicates a decrease in plankton abundance. In the four ponds in which periphyton substrate was installed and periphyton abundance measured, ponds with more periphyton growth also had increased rohu production. Thus, addition of periphyton substrate should promote growth of rohu. Alternately, there was no correlation of periphyton with growth of common carp. Although this species has been seen to nibble on periphyton substrate in other studies, they did this less than rohu (Rai and Yi, 2012). There was considerable variability in periphyton growth between ponds, at different depths, and between seasons (August vs. January). Further examination of seasonal composition of periphyton growth within culture ponds and effects on common carp production and SIS net gain are areas of possible future research. Although SIS feeding habits have been recently explored in more detail (Das et al., 2013; Gupta, 2015; Husain, 2015), whether they exploit periphyton in ponds and whether periphyton presence increases SIS growth is also a future research need (Nandi et al., 2013).

Seasonality, but not treatment, helped explain water quality trends and variation observed in this study, and seasonal changes are a driver of pond water quality (Egna and Boyd, 1997; Milstein et al., 2006; Boyd and Tucker, 1998). None of the water quality trends in this experiment were correlated with SIS stocking density. As the grow-out period progressed toward fall and winter, solar intensity and air temperature decreased, and there was less variability in cloud cover compared to the summer monsoon season. Water temperature in all ponds decreased as expected from summer to winter. During July and August, observed algal growth had high variability between ponds even though ponds were fertilized equally, and Secchi disk depth varied from 20-80 cm. As the season progressed toward winter, this variation decreased with ponds all showing ~20-30 cm Secchi disk depth between October-January.

Average carp production, survival, costs, and profits for this experiment fell within or above a normal expected range for Southeast Asia. Average carp production was 3,224 kg*ha^{-1}*yr^{-1}. Similar carp-SIS experiments in Nepal have found carp yield ranging from just over 1,500 to 2,400 kg*ha^{-1}*yr^{-1} (Kadir et al., 2006; Milstein et al., 2008; Wahab et al., 2003) with one study demonstrating yield up to 4,000 kg*ha^{-1}*yr^{-1} (Gupta and Rai, 2011). Two studies on multiple carp-SIS systems in Bangladesh found average carp yield of only 1,754 kg*ha^{-1}*yr^{-1} (Faruk-Ul-Islam, 2007) and 2,177 kg*ha^{-1}*yr^{-1} (Ahmed, 2009). Total costs for this experiment were USD $3,014/ha/yr, which exceeded average annual costs found in the Bangladesh studies: $1,044/ha (Ahmed, 2009) and $1,495/ha (Faruk-Ul-Islam, 2007). Average annual profit from carp sales for these same systems were USD $2,076/ha and $1,558/ha. Annual profit from this experiment exceeded these studies at USD $4,117/ha. While average costs for interviewed farmers were half of those for my experiment (USD $1,351/ha), reported net gain per hectare was similar at 3,201 kg leading to a higher profit of USD $4,719 for farmers. Farmers indicated much less fertilization (2x/year) than this experiment (1x/week), but reported similar production. Thus fertilizing less has potential to cut costs without impacting production.

Farmers interviewed utilized a variety of pond management strategies for carp polyculture indicating farmers tailor their systems and stocking strategies independently based on costs, availability of stocking fish, and plans for consumption and sales. All three farmers also reported taking advice from local aquaculture newsletters and training sessions at AFU. Comparison of decisions on carp system management between farmers and this experiment show farmers made their largest investment by stocking high densities of smaller fish, but avoided purchasing feed and fertilizer. Morales and Little (2007) studied culture systems in Southeast Asia and found a high proportion of investments went to purchase of seed fish while other inputs, mainly feed and fertilizer, showed underinvestment. Additionally, a factor not incorporated in this budget is cost of sourcing feed from crops, a strategy reported by farmers, which requires labor and could cut profits from agricultural production, negatively affecting a farmers' overall income.

Experimental surveys revealed motivation for many farmers choosing to partake in carp-SIS aquaculture included non-monetary incentives such as increasing nutritional well being for themselves and their families, and being able to provide fish-based meals for visitors. SIS are often earmarked for household consumption over sales (Kadir et al., 2006; Roos et al., 2003; Roos et al., 2007). Furthermore, my findings support the notion that small scale aquaculture promotes household consumption of fish (Kawarazuka, 2010), since all SIS and most carp were consumed at home, with a reported sale of only 15-30%. Thus, economic returns should not be the only factor considered when assessing aquaculture benefits to a region or group of people.

None of the farmers interviewed kept records for their aquaculture systems, and hatcheries had incomplete records on pond inputs, costs, harvest, and sales. It is not common for farmers to keep any formal records of farming practices in Nepal, and they rely on memory alone for future decisions (Gautam et al., 2011). This increased the likelihood of inaccuracies in interviews. Promotion of standardized record keeping for all levels of the aquaculture supply chain including farmers, vendors, and hatcheries is a valuable tool to improve management practices.

Based on results and observations from this study and those from the available literature, I propose that smaller ponds positioned close to human activity, stocked in early spring at high densities (75,000/ha) with punti but not dedhuwa, and carefully separated from outside water sources or otherwise managed to limit SIS emigration would increase SIS net gain. Yields reported in the literature when SIS were stocked are comparable or higher than those reported by farmers who allow SIS to enter ponds naturally instead of stocking (Gupta and Rai, 2011; Milstein et al., 2008; Rai et al., 2014), demonstrating that stocking of SIS may provide farmers a more reliable and constant source of these high-nutrient fish. Given results on timing of SIS spawning in other studies (Ahamed et al., 2012; Amenla, 2014; Banik and Saha, 2013; Choudhury et al., 2015; Milstein et al., 2006; Tareque et al., 2009), stocking in early spring would ensure a full spawning season for SIS is included in the grow-out period. Also, more isolated ponds are increasingly vulnerable to bird predation, larger ponds experience more predation, and smaller fish are particularly vulnerable (Tucker et al., 2008). If ponds cannot be placed or moved close to areas of human activity, other strategies can be employed to discourage bird predation such as installation of scarecrows or noisemakers near the pond (Tucker et al., 2008). Nets have also been used to cover ponds to prevent predation, but this strategy adds a large cost (Debnath et al., 2007). Smaller pond size would make intimidation and management of predators easier (Tucker et al., 2008), and help simplify harvest since smaller ponds are easier to navigate and use of nets with smaller mesh size is more feasible to improve catch of SIS. Moreover, I found that larger ponds from private farmers did not have higher net gain of SIS when corrected to annual harvest per hectare. This supports the idea that smaller ponds are better able to promote SIS net gain and harvest. Given unexpected impacts on production of carp and net gain of SIS from factors such as isolation and movement between connected water sources, further investigation of factors and mechanisms to promote SIS presence in ponds is an area of necessary future research.

APPENDICES

Appendix A - Additional Experimental Data

Table A1: Carp growth (g) by species and pond.

Pond #	Growth							
	Grass	Silver	Mrigal	Rohu	Common	Bighead	Mean	SD
1	302.90	289.52	110.30	136.68	372.46	486.72	283.09	142.25
2	142.34	209.10	111.96	128.76	227.00	95.55	152.45	53.49
3	122.32	223.93	80.41	96.14	114.65	68.83	117.71	55.78
4	149.16	204.63	90.76	124.30	196.28	113.93	146.51	45.88
5	288.35	192.58	105.11	157.27	210.44	75.63	171.56	76.70
6	214.80	109.99	77.05	109.21	147.58	63.30	120.32	54.81
7	157.03	117.74	55.69	84.29	109.21	45.16	94.85	41.74
8	279.79	104.43	54.14	112.48	80.63	64.63	116.02	83.29
9	121.38	186.64	124.01	142.81	187.37	55.06	136.21	49.31
10	221.59	130.89	53.11	104.21	182.69	49.89	123.73	69.17
11	166.02	126.27	57.28	86.27	129.97	42.32	101.35	47.49
12	216.45	103.36	57.40	101.75	101.81	52.96	105.62	59.02
Mean	198.51	166.59	81.44	115.35	171.67	101.16		
SD	65.24	59.61	26.31	22.89	78.91	123.21		

Table A2: Carp survival by species and pond.

Pond #	Survival							
	Grass	Silver	Mrigal	Rohu	Common	Bighead	Mean	SD
1	46.7%	56.7%	124.4%	113.3%	113.3%	11.7%	77.7%	45.8%
2	50.0%	63.3%	77.8%	113.3%	104.4%	81.7%	81.8%	24.0%
3	43.3%	53.3%	60.0%	106.7%	104.4%	93.3%	76.9%	27.9%
4	50.0%	64.4%	113.3%	103.3%	111.1%	68.3%	85.1%	27.4%
5	36.7%	75.6%	100.0%	90.0%	100.0%	78.3%	80.1%	23.7%
6	80.0%	83.3%	97.8%	133.3%	95.6%	70.0%	93.3%	22.1%
7	46.7%	62.2%	97.8%	113.3%	108.9%	78.3%	84.5%	26.7%
8	23.3%	82.2%	84.4%	96.7%	97.8%	78.3%	77.1%	27.5%
9	56.7%	77.8%	28.9%	90.0%	60.0%	93.3%	67.8%	24.3%
10	43.3%	56.7%	6.7%	96.7%	42.2%	78.3%	54.0%	31.3%
11	43.3%	47.8%	8.9%	56.7%	24.4%	83.3%	44.1%	25.8%
12	36.7%	48.9%	93.3%	106.7%	95.6%	70.0%	75.2%	28.1%
Mean	46.4%	64.4%	74.4%	101.7%	88.1%	73.8%	**74.8%**	19.1%
SD	13.5%	12.6%	39.8%	18.6%	29.3%	21.1%	13.7%	

Table A3: Production (kg harvested) for carps overall and by each species in each pond.

	Production						
	Grass	Silver	Mrigal	Rohu	Common	Bighead	**TOTAL**
1	4.29	14.98	6.20	4.72	20.06	3.45	53.67
2	2.19	12.21	3.93	4.44	10.81	4.85	38.42
3	1.64	10.93	2.18	3.13	5.55	4.06	27.48
4	2.30	12.16	4.64	3.91	9.98	4.84	37.82
5	3.23	13.52	4.74	4.31	9.63	3.81	39.22
6	5.24	8.60	3.40	4.46	6.48	2.80	30.96
7	2.25	6.87	2.46	2.95	5.52	2.30	22.34
8	1.99	8.28	2.07	3.32	3.67	3.21	22.54
9	2.14	13.52	1.62	3.91	5.16	3.27	29.61
10	2.95	6.99	0.16	3.08	3.55	2.56	19.29
11	2.20	5.64	0.23	1.50	1.47	2.32	13.35
12	2.43	4.78	2.42	3.32	4.55	2.41	19.90
Mean	2.73	9.87	2.84	3.59	7.20	3.32	29.55
SD	1.05	3.44	1.82	0.90	4.93	0.91	11.25

Table A4: Average individual weight (g) of each carp species at harvest for each pond.

		Individual Weight					
		Grass	Silver	Mrigal	Rohu	Common	Bighead
Pond 1	Mean	306.07	293.63	110.63	138.68	393.24	492.14
	SD	96.44	46.54	31.29	34.18	174.15	89.02
Pond 2	Mean	145.67	214.21	112.29	130.59	230.00	98.88
	SD	123.33	23.85	21.92	20.35	58.64	62.11
Pond 3	Mean	126.15	227.71	80.74	97.81	117.98	72.41
	SD	116.25	30.70	19.25	22.67	40.47	32.61
Pond 4	Mean	153.33	209.69	90.98	126.13	199.50	117.93
	SD	89.38	31.53	24.56	20.28	68.57	55.25
Pond 5	Mean	293.18	198.75	105.33	159.44	214.00	80.96
	SD	218.92	26.83	16.85	32.35	113.89	27.50
Pond 6	Mean	218.13	114.60	77.27	111.38	150.58	66.55
	SD	94.91	14.00	10.04	26.26	83.57	31.92
Pond 7	Mean	160.36	122.68	55.91	86.62	112.65	48.83
	SD	88.35	15.93	12.64	18.80	84.28	11.75
Pond 8	Mean	284.29	111.82	54.47	114.48	83.41	68.30
	SD	90.71	19.67	6.74	22.89	26.42	40.67
Pond 9	Mean	125.88	193.14	124.23	144.81	190.93	58.39
	SD	98.44	18.41	15.66	15.60	88.34	35.53
Pond 10	Mean	226.92	137.06	53.33	106.21	186.58	54.47
	SD	267.10	22.40	37.86	22.59	141.32	30.85
Pond 11	Mean	168.85	131.05	57.50	87.94	133.64	46.40
	SD	99.02	20.59	28.72	16.30	51.09	31.79
Pond 12	Mean	220.45	108.64	57.62	103.75	105.70	57.38
	SD	154.60	18.22	6.97	27.26	47.99	44.82

Table A5: Average SIS production (g harvested) for punti and dedhuwa in ponds. RSD (%) = relative standard deviation.

	Production		
Species	Mean	SD	RSD (%)
Punti	626.67	466.65	74.46
Dedhuwa	239.50	146.50	61.17
Total Yield	866.17	497.72	57.46

Table A6: Average production (kg harvested) for each species of carp.

	Production		
Species	Mean	SD	RSD (%)
Grass	2.735	1.052	38.46
Silver	9.871	3.436	34.80
Mrigal	2.837	1.820	64.17
Rohu	3.585	0.898	25.05
Common	7.200	4.935	68.54
Bighead	3.320	0.912	27.48
Total Yield	**29.548**	**11.245**	**38.06**

Table A7: Secchi disk depth (cm) for each pond throughout the experiment.

	Pond											
Date	1	2	3	4	5	6	7	8	9	10	11	12
07/29/13	40	40	25	60	55	75	65	55	50	55	60	65
08/05/13	25	30	25	50	45	45	45	45	50	45	40	45
08/12/13	20	25	25	30	45	45	35	40	25	45	50	35
08/19/13	20	35	35	45	80	70	70	60	60	60	55	45
09/02/13	25	35	30	30	30	35	30	35	30	40	40	30
09/09/13	30	40	30	30	35	40	30	35	30	40	35	30
09/16/13	25	30	30	30	25	25	30	35	25	25	25	30
09/23/13	20	20	25	25	25	35	30	30	35	35	40	30
09/30/13	25	30	30	20	30	30	25	35	25	30	30	25
10/07/13	25	20	30	25	25	20	20	20	25	25	20	25
10/14/13	20	20	25	20	25	25	25	30	25	25	25	25
10/21/13	20	20	25	25	20	20	25	20	25	25	25	25
10/28/13	25	20	20	25	25	20	20	20	30	25	30	30
11/11/13	25	20	15	15	20	20	20	25	25	30	30	25
11/25/13	25	25	25	20	25	25	25	25	30	25	25	25
01/09/14	30	30	35	25	20	25	30	25	30	35	25	30
01/14/14	20	30	30	30	30	30	30	25	35	30	35	30

Table A8: Temperature (°C) for each pond throughout the experiment.

	Pond											
Date	1	2	3	4	5	6	7	8	9	10	11	12
07/29/13	31.5	31.6	31.1	31.5	31.6	31.7	30.8	31.2	31.1	30.9	30.9	30.8
08/05/13	31.5	32.1	31.9	32.5	32.2	32.0	32.0	32.1	32.0	32.0	31.8	31.9
08/12/13	30.2	30.5	30.3	30.6	30.6	30.5	30.1	30.5	30.6	30.3	30.2	29.9
08/19/13	31.3	31.1	31.2	31.3	31.5	31.5	31.0	31.2	31.2	31.2	30.9	31.0
09/02/13	30.9	30.8	30.7	30.6	30.7	30.7	30.4	30.2	30.5	30.4	30.1	29.7
09/09/13	30.5	30.6	30.3	30.3	30.3	30.3	30.0	30.1	30.3	30.1	29.8	29.7
09/16/13	30.4	30.5	30.6	30.8	30.5	30.0	30.0	31.0	30.8	30.4	29.9	30.1
09/23/13	31.4	31.0	30.6	31.9	31.2	31.9	30.9	31.0	31.3	30.9	30.8	30.7
09/30/13	28.5	28.5	28.6	28.2	28.3	28.0	28.1	28.2	28.1	28.0	27.9	28.0
10/07/13	28.3	28.2	28.2	27.8	28.3	28.1	27.9	28.0	28.2	28.0	27.8	27.8
10/14/13	24.9	24.9	25.1	24.9	24.6	24.5	24.3	24.8	24.5	24.4	24.2	24.3
10/21/13	26.4	26.3	26.6	26.3	26.5	26.3	26.5	26.4	26.4	26.4	26.5	26.3
10/28/13	25.9	25.7	25.7	25.6	25.7	25.7	25.4	25.6	25.7	25.5	25.4	25.5
11/04/13	24.0	22.3	23.5	23.4	23.0	22.4	22.8	23.3	23.4	22.5	22.6	23.8
11/11/13	20.3	20.3	20.3	20.5	19.5	20.2	20.0	20.6	20.6	20.1	20.2	20.4
11/18/13	20.9	20.4	20.4	20.5	20.3	20.4	20.1	20.6	20.4	20.5	20.4	20.7
11/25/13	20.6	20.1	20.1	20.2	19.9	20.0	20.0	20.2	20.1	19.9	19.8	20.0
12/02/13	20.7	21.1	20.3	20.4	20.5	20.5	20.5	20.8	21.1	20.9	20.6	20.6
12/16/13	15.8	15.6	16.2	16.3	16.1	16.1	15.9	16.0	16.1	16.1	16.0	16.3
12/23/13	15.4	15.4	15.4	15.3	15.3	15.1	15.6	15.6	15.5	15.5	15.5	15.4
01/09/14	13.8	14.1	14.2	14.2	14.0	13.9	14.2	14.2	14.1	13.9	13.8	14.0
01/14/14	15.4	15.2	15.5	15.3	15.4	15.3	15.8	15.6	15.6	15.5	15.5	15.5

Table A9: Dissolved oxygen (mg/L) for each pond throughout the experiment.
*Suspected DO meter malfunction.

	Pond											
Date	1	2	3	4	5	6	7	8	9	10	11	12
07/29/13	5.90	9.65	8.40	5.40	7.25	5.00	5.00	6.90	9.10	6.75	8.15	6.25
08/05/13	5.80	10.35	10.60	8.00	5.40	7.15	8.05	9.15	7.85	8.05	8.10	7.90
08/12/13	3.53	5.05	6.88	5.38	4.30	5.58	6.10	7.05	5.58	5.60	6.60	5.55
08/19/13	7.00	7.10	7.10	7.00	6.90	6.90	7.15	7.05	7.10	7.10	7.20	7.15
09/02/13	2.60	6.10	6.35	5.70	5.25	5.75	8.05	7.40	7.20	7.45	7.30	7.20
09/09/13	2.75	6.05	7.15	7.60	6.80	6.20	7.60	8.05	7.25	6.55	6.25	6.25
09/16/13	2.70	4.50	5.90	4.95	4.15	4.50	5.55	5.90	5.05	6.45	5.75	5.60
09/23/13	3.20	2.75	2.55	2.35	2.05	2.00	2.00	2.15	2.00	2.10	2.05	2.00
09/30/13	7.30	7.20	7.75	8.00	7.30	7.35	7.25	7.65	7.30	7.35	7.40	7.05
10/07/13	10.00	8.70	8.70	8.55	7.45	7.45	7.85	8.05	7.35	7.45	6.90	6.90
10/14/13	7.75	7.75	7.00	7.35	6.75	7.20	7.30	7.00	6.40	6.85	6.50	6.40
10/21/13	10.10	9.80	9.05	8.00	7.25	8.05	8.00	7.60	6.55	6.55	6.55	6.55
10/28/13	9.50	9.60	9.60	7.70	7.70	7.70	7.75	7.70	7.70	7.70	7.85	7.70
11/04/13	9.55	8.95	9.30	9.35	6.80	6.55	6.60	9.30	8.30	6.70	6.45	7.00
11/11/13	9.00	8.25	8.25	8.50	4.40	4.90	6.20	7.70	5.15	4.85	4.85	5.00
11/18/13	5.05	5.00	3.30	3.40	3.35	3.25	3.15	3.35	3.40	3.35	3.25	3.25
11/25/13	7.70	6.40	5.60	5.35	4.65	4.70	4.75	4.85	4.80	4.65	4.60	4.75
12/02/13	6.60	5.15	4.10	4.85	4.75	4.75	4.90	4.95	5.30	5.05	4.70	8.60
12/16/13	5.55	3.00	9.75	8.80	10.00	9.75	9.45	9.05	10.05	9.75	9.55	8.90
12/24/13*	0.50	0.40	0.40	0.40	0.20	0.30	0.85	1.65	0.25	0.30	0.25	0.20

Table A10: pH for each pond throughout the experiment.

	Pond											
Date	1	2	3	4	5	6	7	8	9	10	11	12
07/29/13	9.10	9.53	9.63	8.90	9.18	8.35	8.35	8.80	9.20	8.86	8.83	8.60
08/05/13	8.95	9.62	9.65	9.18	9.02	8.82	8.48	8.30	8.88	8.47	8.59	8.37
08/12/13	7.63	9.33	9.64	8.80	8.11	8.63	8.20	8.55	9.10	8.30	8.50	8.20
08/19/13	7.76	9.31	9.51	8.66	7.88	8.08	8.15	8.50	8.66	8.15	8.00	8.24
09/02/13	7.50	8.50	8.70	8.20	8.00	8.50	8.70	8.20	8.90	8.50	8.40	8.60
09/09/13	7.50	8.20	8.70	8.10	8.40	8.30	8.70	8.50	8.40	8.40	8.30	8.50
09/16/13	7.70	7.90	8.20	8.10	8.00	8.00	8.20	8.50	7.90	8.10	8.20	8.40
09/23/13	7.70	8.00	8.10	8.10	7.80	8.00	8.00	8.10	7.90	7.90	8.00	8.10
09/30/13	8.10	8.30	8.70	8.60	8.60	9.60	9.80	8.90	8.70	8.80	8.90	9.00
10/07/13	7.80	8.00	8.60	8.60	8.50	8.50	8.70	8.60	8.70	8.70	8.70	8.70
10/14/13	7.50	7.80	7.80	7.80	7.70	7.80	7.90	7.90	7.90	7.90	7.90	7.90
10/21/13	7.60	8.50	8.10	8.40	8.50	8.00	8.76	8.70	8.50	8.70	8.50	8.70
10/28/13	7.40	7.80	7.80	7.80	7.70	7.90	8.10	8.00	7.90	7.90	8.00	8.10
11/04/13	7.70	8.00	8.32	8.30	8.21	8.46	8.73	8.60	8.27	8.52	8.51	8.58
11/11/13	7.80	8.20	8.20	8.40	8.30	8.60	8.70	8.50	8.50	8.60	8.50	5.50
11/18/13	7.80	8.10	8.50	8.30	8.50	8.50	8.70	8.60	8.30	8.60	8.60	8.60
11/25/13	7.80	8.10	8.20	8.20	8.00	8.30	8.50	8.40	8.20	8.30	8.30	8.40
12/02/13	7.80	8.10	8.20	8.20	8.10	8.30	8.40	8.40	7.90	8.20	8.30	8.20
12/16/13	8.30	8.60	8.90	8.80	8.90	9.00	8.80	9.00	8.90	9.10	9.10	8.80
12/23/13	8.40	8.60	8.60	8.60	8.60	8.50	8.60	8.70	8.50	8.50	8.60	8.80
01/09/14	8.53	8.80	8.70	8.83	8.70	9.50	9.30	9.20	9.10	8.90	9.00	9.10
01/14/14	8.90	9.12	8.95	8.89	8.87	9.01	9.15	9.15	9.09	8.94	8.94	8.96

Appendix B - Expanded Statistical Results

Table B1: Pearson's correlation matrix coefficients for average punti and dedhuwa harvest over all ponds and average water quality variables measured for all ponds.

	Harvest	SIS Density	Isolation	Secchi Disk Depth	pH	Primary Productivity	Days DO <5
Dedhuwa	1	0.58	0.43	0.23	-0.3	0.14	0.04
Punti	0.06	0.54	-0.56	-0.52	-0.4	0.33	0.3

Table B2: Pearson's correlation matrix p-values for average punti and dedhuwa harvest and water quality variables measured.

	Harvest	SIS Density	Isolation	Secchi Disk Depth	pH	Primary Productivity	Days DO <5
Dedhuwa	0.8477	0.0492	0.1579	0.4646	0.348	0.67	0.8915
Punti	0.8477	0.0713	0.0568	0.0842	0.1975	0.296	0.3509

Table B3: Pearson's correlation coefficients for variables considered for multiple regression analysis.

	Pearson's Correlation Coefficients											
	SIS density	Punti Net Gain	Dedhuwa Net Gain	Punti Harvest	Dedhuwa Harvest	days DO<5	Average Primary	Average Secchi Disk	Isolation	Average pH	Carp Production	Average Size at Stocking
SIS Density	1	-0.1	-0.87	0.54	0.58	0.2	0.01	0.02	0.15	-0.4	-0.03	0.51
Punti Net Gain	-0.1	1	-0.09	0.78	-0.35	0.2	0.38	-0.63	-0.8	-0.2	0.64	0.27
Dedhuwa Net Gain	-0.9	-0.09	1	-0.6	-0.09	-0.2	0.07	0.11	0.09	0.28	-0.09	-0.53
Punti Harvest	0.54	0.78	-0.62	1	0.06	0.3	0.33	-0.52	-0.6	-0.4	0.53	0.54
Dedhuwa Harvest	0.58	-0.35	-0.09	0.06	1	0	0.14	0.23	0.43	-0.3	-0.2	0.14
days DO<5	0.17	0.23	-0.18	0.3	0.04	1	-0.14	0.33	-0.1	-0.3	0.19	0.27
Average Primary Productivity	0.01	0.38	0.07	0.33	0.14	-0.1	1	-0.67	-0.6	-0.5	0.62	0.31
Average Secchi Disk Depth	0.02	-0.63	0.11	-0.5	0.23	0.3	-0.67	1	0.74	0.46	-0.73	-0.45
Isolation	0.15	-0.77	0.09	-0.6	0.43	-0.1	-0.64	0.74	1	0.43	-0.89	-0.41
Average pH	-0.4	-0.19	0.28	-0.4	-0.3	-0.3	-0.48	0.46	0.43	1	-0.69	-0.9
Carp Production	-0	0.64	-0.09	0.53	-0.2	0.2	0.62	-0.73	-0.9	-0.7	1	0.61
Average Size at Stocking	0.51	0.27	-0.53	0.54	0.14	0.3	0.31	-0.45	-0.4	-0.9	0.61	1

Table B4: Pearson's correlation p-values for variables considered for multiple regression analysis. Significant values (< 0.05) are highlighted.

	Pearson's Correlation p-values											
	SIS density	Punti Net Gain	Dedhuwa Net Gain	Punti Harvest	Dedhuwa Harvest	days DO<5	Average Primary Productivity	Average Secchi Disk Depth	Isolation	Average pH	Carp Production	Average Size at Stocking
SIS Density		0.75	0.00	0.07	0.05	0.61	0.96	0.94	0.65	0.23	0.93	0.09
Punti Net Gain	0.75		0.78	0.00	0.26	0.48	0.23	0.03	0.00	0.55	0.02	0.40
Dedhuwa Net Gain	0.00	0.78		0.03	0.78	0.58	0.84	0.72	0.79	0.38	0.78	0.08
Punti Harvest	0.07	0.00	0.03		0.85	0.35	0.30	0.08	0.06	0.20	0.08	0.07
Dedhuwa Harvest	0.05	0.26	0.78	0.85		0.89	0.67	0.46	0.16	0.35	0.53	0.66
days DO<5	0.61	0.48	0.58	0.35	0.89		0.67	0.30	0.68	0.28	0.55	0.40
Average Primary Productivity	0.96	0.23	0.84	0.30	0.67	0.67		0.02	0.02	0.11	0.03	0.33
Average Secchi Disk Depth	0.94	0.03	0.72	0.08	0.46	0.30	0.02		0.01	0.13	0.01	0.15
Isolation	0.65	0.00	0.79	0.06	0.16	0.68	0.02	0.01		0.16	0.00	0.19
Average pH	0.23	0.55	0.38	0.20	0.35	0.28	0.11	0.13	0.16		0.01	0.00
Carp Production	0.93	0.02	0.78	0.08	0.53	0.55	0.03	0.01	0.00	0.01		0.03
Average Size at Stocking	0.09	0.40	0.08	0.07	0.66	0.40	0.33	0.15	0.19	0.00	0.03	

Table B5: Pearson's correlation coefficient matrix for variables measured in this experiment.

	SIS Density	Days DO < 5	Avg Primary Productivity	Avg Secchi Disk Depth	Isolation	Avg pH	Avg Size at Stocking	Carp Production	Grass Carp Production	Silver Carp Production	Mrigal Production	Rohu Production	Common Carp Production	Bighead Carp Production	Grass Carp Survival	Siver Carp Survival	Mrigal Survival	Rohu Survival	Common Carp Survival	Bighead Carp Survival	Avg Survival	Avg Growth	Grass Carp Growth	Silver Carp Growth	Mrigal Growth	Rohu Growth	Common Carp Growth	Bighead Carp Growth
SIS Density	1	0.17	0.01	0.02	0.15	-0.38	0.51	-0.04	-0.05	-0.16	0.07	-0.17	0.13	-0.46	-0.59	-0.08	0.19	-0.22	0.05	-0.39	-0.15	0.23	0.56	-0.12	-0.23	-0.03	0.08	0.32
Days DO <5	0.17	1	-0.14	0.33	-0.13	-0.34	0.27	0.19	0.65	0.09	0.27	0.11	0.16	-0.26	0.15	0.32	0.23	-0.09	-0.04	-0.3	0.07	0.25	0.62	-0.06	-0.03	0.24	0.19	0.16
Avg Primary Productivity	0.01	-0.14	1	-0.67	-0.64	-0.48	0.31	0.63	0.03	0.58	0.55	0.51	0.62	0.57	-0.13	-0.16	0.26	0.12	0.35	-0.25	0.17	0.58	0.15	0.67	0.63	0.55	0.57	0.43
Avg Secchi Disk Depth	0.02	0.33	-0.67	1	0.74	0.46	-0.45	-0.73	0.04	-0.65	-0.66	-0.47	-0.78	-0.63	0.05	0.26	-0.48	-0.35	-0.62	0.5	-0.35	-0.67	0.04	-0.86	-0.54	-0.28	-0.59	-0.71
Isolation	0.15	-0.13	-0.64	0.74	1	0.43	-0.41	-0.89	-0.34	-0.86	-0.75	-0.72	-0.83	-0.66	-0.28	-0.2	-0.46	-0.43	-0.55	0.42	-0.49	-0.74	-0.11	-0.84	-0.73	-0.56	-0.74	-0.62
Avg pH	-0.38	-0.34	-0.48	0.46	0.43	1	-0.9	-0.68	-0.55	-0.44	-0.65	-0.47	-0.8	-0.03	0.03	0.18	-0.43	-0.1	-0.21	0.91	-0.04	-0.9	-0.65	-0.56	-0.39	-0.49	-0.84	-0.89
Avg Size at Stocking	0.51	0.27	0.31	-0.45	-0.41	-0.9	1	0.6	0.42	0.46	0.5	0.4	0.72	-0.06	-0.19	-0.1	0.32	0.07	0.17	-0.87	-0.04	0.88	0.68	0.55	0.31	0.44	0.78	0.9
Carp Production	-0.04	0.19	0.63	-0.73	-0.89	-0.68	0.6	1	0.44	0.89	0.92	0.86	0.96	0.63	0.23	0.23	0.65	0.44	0.63	-0.64	0.55	0.88	0.3	0.83	0.79	0.74	0.85	0.76
Grass Carp Production	-0.05	0.65	0.03	0.04	-0.34	-0.55	0.42	0.44	1	0.18	0.45	0.53	0.45	-0.2	0.61	0.3	0.37	0.49	0.14	-0.61	0.33	0.47	0.53	0.08	0.16	0.24	0.47	0.45
Silver Carp Production	-0.16	0.09	0.58	-0.65	-0.86	-0.44	0.46	0.89	0.18	1	0.71	0.73	0.77	0.71	0.17	0.32	0.35	0.18	0.42	-0.32	0.36	0.76	0.08	0.88	0.92	0.83	0.75	0.57
Mrigal Production	0.07	0.27	0.55	-0.66	-0.75	-0.65	0.5	0.92	0.45	0.71	1	0.8	0.91	0.55	0.14	0.21	0.87	0.51	0.79	-0.66	0.71	0.76	0.38	0.65	0.6	0.62	0.67	0.68
Rohu Production	-0.17	0.11	0.51	-0.47	-0.72	-0.47	0.4	0.86	0.53	0.73	0.8	1	0.76	0.54	0.36	0.51	0.64	0.68	0.65	-0.45	0.72	0.65	0.31	0.52	0.71	0.76	0.62	0.49
Common Carp Production	0.13	0.16	0.62	-0.78	-0.83	-0.8	0.72	0.96	0.45	0.77	0.91	0.76	1	0.49	0.14	0.02	0.67	0.43	0.61	-0.8	0.46	0.93	0.37	0.82	0.66	0.6	0.89	0.88
Bighead Carp Production	-0.46	-0.26	0.57	-0.63	-0.66	-0.03	-0.06	0.63	-0.2	0.71	0.55	0.54	0.49	1	0.04	0.18	0.33	0.2	0.5	0.02	0.42	0.34	-0.24	0.65	0.64	0.53	0.36	0.17
Grass Carp Survival	-0.59	0.15	-0.13	0.05	-0.28	0.03	-0.19	0.23	0.61	0.17	0.14	0.36	0.14	0.04	1	0.27	0.05	0.48	0	-0.05	0.32	0.03	-0.34	0.05	0.31	0.04	0.2	0.02
Siver Carp Survival	-0.08	0.32	-0.16	0.26	-0.2	0.18	-0.1	0.23	0.3	0.32	0.21	0.51	0.02	0.18	0.27	1	0.24	0.29	0.23	0.15	0.5	0	0.22	-0.15	0.29	0.49	-0.05	-0.15
Mrigal Survival	0.19	0.23	0.26	-0.48	-0.46	-0.43	0.32	0.65	0.37	0.35	0.87	0.64	0.67	0.33	0.05	0.24	1	0.64	0.92	-0.57	0.85	0.45	0.39	0.29	0.23	0.31	0.29	0.47
Rohu Survival	-0.22	-0.09	0.12	-0.35	-0.43	-0.1	0.07	0.44	0.49	0.18	0.51	0.68	0.43	0.2	0.48	0.29	0.64	1	0.73	-0.32	0.83	0.19	0.08	0.11	0.14	0.06	0.16	0.24
Common Carp Survival	0.05	-0.04	0.35	-0.62	-0.55	-0.21	0.17	0.63	0.14	0.42	0.79	0.65	0.61	0.5	0	0.23	0.92	0.73	1	-0.36	0.91	0.35	0.18	0.37	0.28	0.26	0.19	0.36
Bighead Carp Survival	-0.39	-0.3	-0.25	0.5	0.42	0.91	-0.87	-0.64	-0.61	-0.32	-0.66	-0.45	-0.8	0.02	-0.05	0.15	-0.57	-0.32	-0.36	1	-0.21	-0.83	-0.62	-0.47	-0.19	-0.25	-0.74	-0.93
Avg Survival	-0.15	0.07	0.17	-0.35	-0.49	-0.04	-0.04	0.55	0.33	0.36	0.71	0.72	0.46	0.42	0.32	0.5	0.85	0.83	0.91	-0.21	1	0.18	0.09	0.16	0.29	0.27	0.08	0.15
Avg Growth	0.23	0.25	0.58	-0.67	-0.74	-0.9	0.88	0.88	0.47	0.76	0.76	0.65	0.93	0.34	0.03	0	0.45	0.19	0.35	-0.83	0.18	1	0.51	0.81	0.64	0.65	0.94	0.94
Grass Carp Growth	0.56	0.62	0.15	0.04	-0.11	-0.65	0.68	0.3	0.53	0.08	0.38	0.31	0.37	-0.24	-0.34	0.22	0.39	0.08	0.18	-0.62	0.09	0.51	1	0.01	-0.09	0.34	0.33	0.48
Silver Carp Growth	-0.12	-0.06	0.67	-0.86	-0.84	-0.56	0.55	0.83	0.08	0.88	0.65	0.52	0.82	0.65	0.05	-0.15	0.29	0.11	0.37	-0.47	0.16	0.81	0.01	1	0.77	0.57	0.81	0.73
Mrigal Growth	-0.23	-0.03	0.63	-0.54	-0.73	-0.39	0.31	0.79	0.16	0.92	0.6	0.71	0.66	0.64	0.31	0.29	0.23	0.14	0.28	-0.19	0.29	0.64	-0.09	0.77	1	0.84	0.7	0.43
Rohu Growth	-0.03	0.24	0.55	-0.28	-0.56	-0.49	0.44	0.74	0.24	0.83	0.62	0.76	0.6	0.53	0.04	0.49	0.31	0.06	0.26	-0.25	0.27	0.65	0.34	0.57	0.84	1	0.64	0.37
Common Carp Growth	0.08	0.19	0.57	-0.59	-0.74	-0.84	0.78	0.85	0.47	0.75	0.67	0.62	0.89	0.36	0.2	-0.05	0.29	0.16	0.19	-0.74	0.08	0.94	0.33	0.81	0.7	0.64	1	0.85
Bighead Carp Growth	0.32	0.16	0.43	-0.71	-0.62	-0.89	0.9	0.76	0.45	0.57	0.68	0.49	0.88	0.17	0.02	-0.15	0.47	0.24	0.36	-0.93	0.15	0.94	0.48	0.73	0.43	0.37	0.85	1

Table B6: Pearson's correlation matrix p-values for variables measured in this experiment.

	SIS Density	Days DO < 5	Avg. Primary Productivity	Avg Secchi Disk Depth	Isolation	Avg pH	Avg. Size at Stocking	Carp Production	Grass Carp Production	Silver Carp Production	Mrigal Production	Rohu Production	Common Carp Production	Bighead Carp Production	Grass Carp Survival	Siver Carp Survival	Mrigal Survival	Rohu Survival	Common Carp Survival	Bighead Carp Survival	Avg Survival	Avg Growth	Grass Carp Growth	Silver Carp Growth	Mrigal Growth	Rohu Growth	Common Carp Growth	Bighead Carp Growth
SIS Density		0.61	0.96	0.94	0.65	0.23	0.09	0.90	0.88	0.62	0.83	0.60	0.69	0.13	0.05	0.81	0.55	0.49	0.87	0.21	0.65	0.48	0.06	0.71	0.48	0.92	0.81	0.31
Days DO < 5	0.61		0.67	0.30	0.68	0.28	0.40	0.55	0.02	0.77	0.39	0.72	0.63	0.42	0.65	0.31	0.47	0.77	0.91	0.35	0.82	0.43	0.03	0.86	0.93	0.46	0.56	0.61
Avg. Primary Productivity	0.96	0.67		0.02	0.02	0.11	0.33	0.03	0.92	0.05	0.06	0.09	0.03	0.06	0.69	0.61	0.42	0.71	0.27	0.43	0.61	0.05	0.64	0.02	0.03	0.07	0.05	0.17
Avg Secchi Disk Depth	0.94	0.30	0.02		0.01	0.13	0.15	0.01	0.91	0.02	0.02	0.12	0.00	0.03	0.88	0.41	0.12	0.27	0.03	0.10	0.26	0.02	0.91	0.00	0.07	0.37	0.04	0.01
Isolation	0.65	0.68	0.02	0.01		0.16	0.19	0.00	0.27	0.00	0.00	0.01	0.00	0.02	0.37	0.54	0.13	0.16	0.06	0.17	0.11	0.01	0.74	0.00	0.01	0.06	0.01	0.03
Avg pH	0.23	0.28	0.11	0.13	0.16		0.00	0.02	0.06	0.16	0.02	0.12	0.00	0.93	0.92	0.57	0.16	0.75	0.52	0.00	0.91	0.00	0.02	0.06	0.22	0.11	0.00	0.00
Avg. Size at Stocking	0.09	0.40	0.33	0.15	0.19	0.00		0.04	0.18	0.14	0.09	0.20	0.01	0.85	0.55	0.77	0.31	0.83	0.59	0.00	0.91	0.00	0.01	0.06	0.33	0.15	0.00	0.00
Carp Production	0.90	0.55	0.03	0.01	0.00	0.02	0.04		0.15	0.00	0.00	0.00	0.00	0.03	0.48	0.47	0.02	0.15	0.03	0.02	0.07	0.00	0.35	0.00	0.00	0.01	0.00	0.00
Grass Carp Production	0.88	0.02	0.92	0.91	0.27	0.06	0.18	0.15		0.59	0.15	0.08	0.14	0.54	0.04	0.34	0.24	0.11	0.65	0.04	0.29	0.13	0.08	0.81	0.63	0.45	0.12	0.14
Silver Carp Production	0.62	0.77	0.05	0.02	0.00	0.16	0.14	0.00	0.59		0.01	0.01	0.00	0.01	0.60	0.30	0.26	0.57	0.18	0.30	0.26	0.00	0.81	0.00	0.00	0.00	0.01	0.05
Mrigal Production	0.83	0.39	0.06	0.02	0.00	0.02	0.09	0.00	0.15	0.01		0.00	0.00	0.06	0.65	0.51	0.00	0.09	0.00	0.02	0.01	0.00	0.23	0.02	0.04	0.03	0.02	0.01
Rohu Production	0.60	0.72	0.09	0.12	0.01	0.12	0.20	0.00	0.08	0.01	0.00		0.00	0.07	0.25	0.09	0.03	0.01	0.02	0.15	0.01	0.02	0.33	0.08	0.01	0.00	0.03	0.11
Common Carp	0.69	0.63	0.03	0.00	0.00	0.00	0.01	0.00	0.14	0.00	0.00	0.00		0.10	0.67	0.95	0.02	0.17	0.04	0.00	0.14	0.00	0.24	0.00	0.02	0.04	0.00	0.00
Bighead Carp Production	0.13	0.42	0.06	0.03	0.02	0.93	0.85	0.03	0.54	0.01	0.06	0.07	0.10		0.91	0.57	0.29	0.52	0.10	0.94	0.17	0.28	0.46	0.02	0.02		0.25	0.59
Grass Carp Survival	0.05	0.65	0.69	0.88	0.37	0.92	0.55	0.48	0.04	0.60	0.65	0.25	0.67	0.91		0.39	0.88	0.12	0.99	0.88	0.31	0.93	0.28	0.87	0.32	0.91	0.53	0.95
Siver Carp Survival	0.81	0.31	0.61	0.41	0.54	0.57	0.77	0.47	0.34	0.30	0.51	0.09	0.95	0.57	0.39		0.45	0.36	0.47	0.65	0.10	0.99	0.49	0.65	0.35	0.11	0.87	0.63
Mrigal Survival	0.55	0.47	0.42	0.12	0.13	0.16	0.31	0.02	0.24	0.26	0.00	0.03	0.02	0.29	0.88	0.45		0.03	0.00	0.05	0.00	0.14	0.21	0.37	0.47	0.33	0.36	0.12
Rohu Survival	0.49	0.77	0.71	0.27	0.16	0.75	0.83	0.15	0.11	0.57	0.09	0.01	0.17	0.52	0.12	0.36	0.03		0.01	0.31	0.00	0.55	0.81	0.73	0.67	0.86	0.63	0.45
Common Carp Survival	0.87	0.91	0.27	0.03	0.06	0.52	0.59	0.03	0.65	0.18	0.00	0.02	0.04	0.10	0.99	0.47	0.00	0.01		0.25	0.00	0.26	0.58	0.24	0.39	0.41	0.55	0.25
Bighead Carp Survival	0.21	0.35	0.43	0.10	0.17	0.00	0.00	0.02	0.04	0.30	0.02	0.15	0.00	0.94	0.88	0.65	0.05	0.31	0.25		0.52	0.00	0.03	0.13	0.55	0.44	0.01	0.00
Avg Survival	0.65	0.82	0.61	0.26	0.11	0.91	0.91	0.07	0.29	0.26	0.01	0.01	0.14	0.17	0.31	0.10	0.00	0.00	0.00	0.52		0.58	0.78	0.62	0.36	0.39	0.80	0.63
Avg Growth	0.48	0.43	0.05	0.02	0.01	0.00	0.00	0.00	0.13	0.00	0.00	0.02	0.00	0.28	0.93	0.99	0.14	0.55	0.26	0.00	0.58		0.09	0.00	0.03	0.02	0.00	0.00
Grass Carp Growth	0.06	0.03	0.64	0.91	0.74	0.02	0.01	0.35	0.08	0.81	0.23	0.33	0.24	0.46	0.28	0.49	0.21	0.81	0.58	0.03	0.78	0.09		0.98	0.77	0.28	0.30	0.12
Silver Carp Growth	0.71	0.86	0.02	0.00	0.00	0.06	0.06	0.00	0.81	0.00	0.02	0.08	0.00	0.02	0.87	0.65	0.37	0.73	0.24	0.13	0.62	0.00	0.98		0.00	0.05	0.00	0.01
Mrigal Growth	0.48	0.93	0.03	0.07	0.01	0.22	0.33	0.00	0.63	0.00	0.04	0.01	0.02	0.02	0.32	0.35	0.47	0.67	0.39	0.55	0.36	0.03	0.77	0.00		0.00	0.01	0.17
Rohu Growth	0.92	0.46	0.07	0.37	0.06	0.11	0.15	0.01	0.45	0.00	0.03	0.00	0.04	0.08	0.91	0.11	0.33	0.86	0.41	0.44	0.39	0.02	0.28	0.05	0.00		0.02	0.23
Common Carp Growth	0.81	0.56	0.05	0.04	0.01	0.00	0.00	0.00	0.12	0.01	0.02	0.03	0.00	0.25	0.53	0.87	0.36	0.63	0.55	0.01	0.80	0.00	0.30	0.00	0.01	0.02		
Bighead Carp Growth	0.31	0.61	0.17	0.01	0.03	0.00	0.00	0.00	0.14	0.05	0.01	0.11	0.00	0.59	0.95	0.63	0.12	0.45	0.25	0.00	0.63	0.00	0.12	0.01	0.17	0.23	0.00	

Table B7: Tukey HSD test results for treatment effects on dedhuwa net gain.

Linear Hypotheses	Estimate	Std. Error	t value	p value
T250 - Control = 0	-155.67	93.29	-1.669	0.3974
T500 - Control = 0	-216	93.29	2.315	0.17352
T750 - Control = 0	-571.67	93.29	-6.128	0.00126
T500 - T250 = 0	-60.33	93.29	0.647	0.91378
T750 - T250 = 0	-416	93.29	-4.459	0.00887
T750 - T500 = 0	-355.67	93.29	-3.813	0.02147

Table B8: Best-fit multiple linear regression model equation for total carp production.

Total Carp Production (kg) = 44.742 + ((-9.612 * Isolation Index) + (3.612 * Average Stocking Size))

Table B9: Best-fit multiple linear regression model results for carp production.

Residuals:				
Min	1st Quartile	Median	3rd Quartile	Max
-5.5091	-3.5487	0.1415	1.8953	7.8254

Coefficients:				
	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	44.742	9.204	4.861	0.000895 ***
Isolation	-9.612	1.686	-5.699	0.000295 ***
AvgStockSize	3.612	1.718	2.102	0.064890 .

Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01‘*’, 0.05 ‘.’, 0.1 ‘ ’

Residual standard error: 4.578 on 9 degrees of freedom
Multiple R-squared: 0.861,
Adjusted R-squared: 0.8301
F-statistic: 27.88 on 2 and 9 DF
P-value: 0.0001391

Table B10: Residuals of carp yield from expected values based on multiple linear regression analysis of total carp production.

	Carp Yield		
Pond	Expected	Actual	**Residual**
1	52.361618	51.87	**0.491618**
2	36.678886	37.455	**-0.776114**
3	32.103054	26.595	**5.508054**
4	28.9654	36.792	**-7.8266**
5	36.045756	37.965	**-1.919244**
6	28.291966	30.035	**-1.743034**
7	24.785286	21.335	**3.450286**
8	22.099734	21.315	**0.784734**
9	26.571022	28.46	**-1.888978**
10	23.499588	18.05	**5.449588**
11	16.1979	12.36	**3.8379**
12	13.411212	18.795	**-5.383788**

Table B11: First alternative carp production regression model summary.

Residuals:				
Min	1Q	Median	3Q	Max
-6.7073	-1.9705	0.6353	1.7396	6.5624

Coefficients:				
	Estimate	Std. Error	T-Value	Pr(>|t|)
(Intercept)	4.12E+01	1.07E+01	3.839	0.00496**
Isolation	-8.99E+00	1.94E+00	-4.638	0.00167**
AvgStockSize	4.63E+00	2.27E+00	2.042	0.07543.
SISdensity	-4.51E-05	6.30E-05	-0.715	0.49499

Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’ 0.1 ‘ ’

Residual standard error: 4.708 on 8 degrees of freedom
Multiple R-squared: 0.8694
Adjusted R-squared: 0.8204
F-statistic: 17.75 on 3 and 8 DF
P-value: 0.0006782

Table B12: Second alternative carp production regression model summary.

Residuals:

Min	1Q	Median	3Q	Max
-8.7286	-3.6439	-0.2582	3.1767	7.2235

Coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	61.285	5.53	11.083	0.000000615***
Isolation	-11.048	1.786	-6.185	0.000103***

Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’

Residual standard error: 5.304 on 10 degrees of freedom
Multiple R-squared: 0.7928
Adjusted R-squared: 0.7721
F-statistic: 38.26 on 1 and 10 DF
P-value: 0.0001034

Table B13: Best-fit multiple linear regression model equation for punti net gain. Isolation index range: 1.45 – 4.5.

Punti Net gain (#) = 1267.76 + (-341.54 * Isolation Index)

Table B14: Best-fit multiple linear regression model results summary for punti net gain.

Residuals:

Min	1st Quartile	Median	3rd Quartile	Max
-379.82	-207.38	24.14	122.01	464.87

Coefficients:

	Estimate Std.	Error	T-Value	Pr(>|t|)
(Intercept)	1267.76	274.33	4.621	0.000949***
Isolation	-341.54	88.61	-3.855	0.003188**

Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’

Residual standard error: 263.1 on 10 degrees of freedom
Multiple R-squared: 0.5977
Adjusted R-squared: 0.5575
F-statistic: 14.86 on 1 and 10 DF
P-value: 0.003188

Table B15: Residuals of punti net gain from expected values in multiple linear regression analysis of punti net gain.

	Punti Net Gain		
Pond	Expected	Actual	**Residual**
1	772.527	731	**41.527**
2	618.834	239	**379.834**
3	465.141	930	**-464.859**
4	311.448	249	**62.448**
5	482.218	572	**-89.782**
6	328.525	495	**-166.475**
7	174.832	282	**-107.168**
8	21.139	313	**-291.861**
9	191.909	-76	**267.909**
10	38.216	-149	**187.216**
11	-115.477	-394	**278.523**
12	-269.17	-172	**-97.17**

Table B16: Alternative punti net gain regression model summary.

Residuals:				
Min	1Q	Median	3Q	Max
-378.73	-205.15	19.62	119.3	470
Coefficients:				
	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	1.26E+03	2.97E+02	4.26	0.00211**
Isolation	-3.42E+02	9.44E+01	-3.625	0.00553**
SISdensity	1.49E-04	2.90E-03	0.051	0.96011

Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’

Residual standard error: 277.3 on 9 degrees of freedom
Multiple R-squared: 0.5978,
Adjusted R-squared: 0.5085
F-statistic: 6.689 on 2 and 9 DF
P-value: 0.01659

Table B17: Best-fit multiple linear regression model equation for punti harvest.

Punti Harvest (#) = 1,260 + (-342* Isolation Index) + (.0102 * SIS Density)

Table B18: Best-fit multiple linear regression model results summary for punti harvest.

Residuals:

Min	1Q	Median	3Q	Max
-378.73	-205.15	19.62	119.3	470

Coefficients:

	Estimate	Std. Error	t - value	Pr(>|t|)
(Intercept)	1.26E+03	2.97E+02	4.26	0.00211**
Isolation	-3.42E+02	9.44E+01	-3.625	0.00553**
SISdensity	1.02E-02	2.90E-03	3.505	0.00667**

Signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’

Residual standard error: 277.3 on 9 degrees of freedom
Multiple R-squared: 0.7111
Adjusted R-squared: 0.6469
F-statistic: 11.08 on 2 and 9 DF
P-value: 0.003746

Table B19: Residuals of punti harvest based on equation created in multiple linear regression analysis of punti harvest.

	Punti Harvest		
Pond	Expected	Actual	**Residual**
1	1529.1	1481	**48.1**
2	865.2	489	**376.2**
3	456.3	930	**-473.7**
4	302.4	249	**53.4**
5	983.4	1072	**-88.6**
6	319.5	495	**-175.5**
7	930.6	1032	**-101.4**
8	776.7	1063	**-286.3**
9	437.7	174	**263.7**
10	283.8	101	**182.8**
11	384.9	106	**278.9**
12	231	328	**-97**

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