TOPIC AREA:
CLIMATE CHANGE ADAPTATION: INDIGENOUS SPECIES DEVELOPMENT

❖

Two Small Indigenous Species to Improve Sustainability in Typical Polyculture Systems in Nepal

Climate Change Adaptation: Indigenous Species/Experiment/13IND04UM

Bailey Keeler[1], James Diana[1], Narayan P. Pandit[2], and Madhav K. Shrestha[2]

[1]*University of Michigan, USA*
[2]*Agriculture and Forestry University, Nepal*

Abstract

Small indigenous species (SIS) grown in polyculture ponds in Nepal have been shown to increase economic and nutritional sustainability for farmers. However, there has been little research determining optimal stocking density of SIS, the resulting production of carp and SIS, effects on water quality, and economic feasibility of purposely stocking SIS. Thus, the overall goal of this research was to identify an optimal stocking density of the SIS punti (*Puntius sophore*) and dedhuwa (*Esomus danricus*) within a typical six-species production system including common carp (*Cyprinus carpio)*, bighead carp (*Hypophthalmichthys nobilis)*, silver carp (*Hypophthalmichthys moltrix)*, grass carp (*Ctenopharyngodon idella)*, rohu (*Labeo rohita)*, and mrigal (*Cirrhinus cirrhosis)*. We hypothesize this could be done without significant negative impacts on the system itself and with the rationale that these additions will allow farmers to more efficiently use their pond space and will increase economic, nutritional, and environmental sustainability of carp culture. Objectives were evaluated using a controlled production experiment with four stocking densities of SIS: 0/ha, 25,000/ ha, 50,000/ha, and 75,000/ha. SIS stocking density had no significant effect on carp production, water quality, or SIS production, indicating that carp production was not influenced by SIS stocking, but also that there was no advantage to stocking SIS. SIS naturally recruited to all experimental ponds from canal water. Instead of stocking density, isolation and average size of SIS at stocking were strongly correlated to overall fish production. Dedhuwa proved particularly difficult to harvest and contain within ponds and should not be considered for SIS production in ponds. Overall, the high variability of SIS production in this experiment and high harvest of SIS when none were stocked indicate purposeful stocking of the SIS punti and dedhuwa appear to be an additional system cost without increasing profits or SIS production from the system.

Introduction

Pond culture is the dominant aquaculture system in Nepal and accounts for 90% of aquaculture production (FAO 2013). Similarly, carp are the dominant species used in aquaculture and comprise 90% of the yield. Aquaculture production is fairly new to the country: it began in the 1940s, but did not develop significantly until the 1980s with the creation of the Aquaculture Production Program in 1981 (FAO 2013). Since then, production has increased dramatically from 2,041 tons in 1982 to 36,020 tons in 2013 (FAO 2015). Aquaculture systems, particularly polyculture including SIS, are well received and accepted among rural families and can improve the nutritional and economic well-being of farmers and their families, with special emphasis on improved welfare for women and children (Kawarazuka 2010, Rai et al. 2014).

SIS may be added to carp polyculture systems to increase pond production, as well as improve household consumption and nutrition. Since SIS are most commonly earmarked for household consumption rather than market sales (Kadir et al. 2006, Roos et al. 2007), SIS production in ponds can directly affect household nutrition. Also, SIS have a higher reproductive rate than carp species and have been known to breed in culture ponds (Kadir et al. 2006). SIS-carp production systems raised production above the national average, doubled consumption rate of household members, and provided $34 USD income per household in 270 days of culture (Rai et al. 2014). Moreover, when compared to carp species, the eyes, head, organs, and viscera of SIS are found to contain higher levels of vitamin A, calcium, zinc, and iron (Roos et al. 2007). This is significant, as SIS are typically consumed whole, whereas carp are gutted and the internal organs discarded. SIS are also a plentiful schooling fish, commonly found in rivers of Nepal, and they are plentiful in the Terai region. Their inclusion in culture should not require additional pond inputs, since they can utilize naturally occurring food sources within the pond, such as plant material, algae, and small insects.

This research focuses on best practices for carp polyculture systems in southern rural Nepal (Terai), with the goal of improving systems to better serve rural farmers and families, without negatively impacting the environment. Given previous evidence for SIS to improve the livelihoods and health of farmers and their families without negative environmental impacts, identifying an optimal stocking density is an important research need. Punti (*Puntius sophore)* and dedhuwa (*Esomus danricus*) were chosen as the focus of this research because they are two SIS commonly found in southern Nepal, they are preferred for consumption in the region, and their inclusion in a carp-SIS culture has shown favorable results in previous studies on improvement of livelihood, income, and nutrition (Rahman 2005, Morales and Little 2007, Rai et al. 2014). The six carp species used in polyculture include common carp (*Cyprinus carpio)*, bighead carp (*Hypophthalmichthys nobilis)*, silver carp (*Hypophthalmichthys moltrix)*, grass carp (*Ctenopharyngodon idella)*, rohu (*Labeo rohita)*, and mrigal (*Cirrhinus cirrhosis)*.

Inclusion of periphyton substrate in ponds has been shown to increase primary production and reduce the need for input of feed, which can lower production costs and increase income for farmers. Rohu is an established periphyton feeder (Wahab et al. 1999, Azim et al. 2002, Rai and Yi 2012), common carp consume periphyton (Rai and Yi 2012) and production of common carp has been shown to increase in ponds with periphyton substrates installed (Wahab et al. 1999, Azim et al. 2002, Rai et al. 2008). Bamboo substrate has been shown to promote the growth of periphyton and can increase carp production (Azim et al. 2002). Because of these results, we used bamboo in ponds to enhance periphyton production in the SIS-carp polyculture system.

The main objective of this study was to compare different SIS stocking densities and their effects on carp production and survival, SIS production, and water quality, in order to identify an optimal stocking density to promote overall pond production, as well as nutritional and economic returns of a typical carp polyculture system in Nepal. We hypothesized that stocking SIS at any density would not negatively impact carp production or survival, or water quality and that inclusion of SIS would provide means to improve economic returns. Moreover, we hypothesized that a density could be identified where pond production and economic return was increased the most by natural reproduction of SIS within the ponds. These objectives were evaluated by investigating carp production and survival, SIS production, and water quality at four different SIS stocking densities.

OBJECTIVES

The overall goal of this research was to identify an optimal stocking density of the SIS punti and dedhuwa within a typical polyculture system, including common carp, bighead carp, silver carp, grass carp, rohu, and mrigal. Specific objectives were:

- To evaluate the impact of adding different densities of two small indigenous fish species (punti and deduwa) to the yield and economic performance of the carp polyculture system in Nepal; and
- To determine the impacts of adding new species on water quality and primary production in these polyculture ponds.

MATERIALS AND METHODS

We used a replicated design with four stocking treatments of SIS to evaluate optimal stocking density of SIS in the carp polyculture system. For all treatments, carp densities, feed composition, and fertilization rate were chosen based on the typical practices in the area, which incorporated six species of carp. Carp density was 15,000/ha and resulted in 300 total carp in each 200 m^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%. Four treatments with different stocking densities of SIS were evaluated in triplicate ponds. The treatments were: 1) Control, 0 SIS/ha; 2) 25,000 SIS/ha; 3) 50,000 SIS/ha; and 4) 75,000 SIS/ha. Both punti and dedhuwa were stocked at 250 of each species per pond in Treatment 1, 500 in Treatment 2, and 750 in Treatment 3. These are referred to as T250, T500, and T750, respectively.

Ponds were drained, dried, and limed several months prior to stocking. The 12 ponds were stocked in late July and August 2013, with 3 ponds randomly assigned to each of the treatments. Pond depths were maintained at ~1.5m. The 12 ponds were completely harvested in mid-January 2014, giving a 5.5 month grow-out period.

Carp were fed with rice bran and mustard oil cake six days per week at 3% carp body weight per day (excluding grass, bighead, and silver carp). Diammonia phosphate (DAP) was added as fertilizer once a week at 700g per pond, along with urea at 950 g per pond. Bamboo poles were installed as a substrate for periphyton production in all ponds at ~8.64% of the pond surface area. Fertilization was not done on weeks when algae cover became high and morning DO levels were less than three mg/L.

Monthly carp sampling was conducted by seining one to two times to collect fish. All fish caught were identified, counted, and weighed (in g). This sampling was used to estimate carp growth and to recalculate feeding rate based on carp body weight. A few SIS were caught during partial harvests in October; they were counted, measured for length (in cm), and removed from ponds to simulate consumption by the owner. Carp were all returned to ponds after being counted and weighed. During final harvest in January 2014, ponds were drained and all fish identified, counted, weighed, and measured for total length. Survival (%) was estimated using total number of each species at final harvest compared to number stocked. We also determined total number of SIS stocked and harvested in each pond at draining.

Water temperature, DO, pH, and Secchi disk depth were measured weekly in each pond. Diurnal oxygen measurements were made bi-monthly to estimate primary productivity. Weekly water quality measurements were all taken between 6:00–8:00 h (as close to dawn as possible). 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 or at 25 cm and 75 cm and then averaged. Diurnal oxygen measurements were taken at 6:00 h (dawn1 DO) and 18:00 h (dusk DO) on the first day, and then again at 6:00 h (dawn2 DO) the following day at 10, 25, 50, and 75 cm. These DO measurements were then used to estimate primary productivity with the 3-point diel method (Boyd and Tucker 1992). Respiration (RSP: dusk DO – dawn2 DO), net primary production (NPP: dusk DO – dawn1 DO), and gross primary productivity (GPP= RSP + NPP) were calculated ($gC * m^{-2} * d^{-1}$) at all four depths and then averaged.

Substrate was installed in all ponds to add a natural food source of periphyton. Bamboo was sourced from stands growing around the experimental site, and split in half lengthwise. One set of four split poles with a length of eight m and an average diameter of 30 cm were installed in each pond for surface area coverage of 6.4 m^2. A second set of four split poles eight 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 facing up, to two small split bamboo poles, which were pushed into the sediment and anchored at 25 cm depth. The total bamboo surface area coverage in each pond was ~17.28 m^2 or ~8.64% of the total pond surface area.

To estimate periphyton growth in ponds, ceramic tiles were installed in ponds during August 2013 and January 2014. One pond per treatment was randomly chosen (Ponds 3, 5, 8, and 10) and three tiles were installed in each of these ponds 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 four to five 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 two hours, and dry weight of periphyton (g) was then determined.

Analysis of variance (ANOVA) was used to determine significant differences in carp production, carp survival, SIS production, and water quality variables between treatments. Carp production was evaluated in grams (g harvested – g stocked) and survival (%). SIS production was examined using counts, or number harvested – number stocked. Alpha was set at 0.05 for all analyses. Any significant ANOVA results were further analyzed using Tukey's HSD post hoc test. In addition to initial ANOVA analysis using pond production data, correlation matrixes, backward stepping multiple regression, and ANOVA on yield residuals created from regression model results were analyzed to further assess and determine variables affecting variation in pond production.

Correlation matrixes were created to explore significant relationships between the independent variables and carp production or SIS production by pond. These variables included number of days DO fell below five mg/L (DO<5mg/L), average Secchi disk depth, average primary productivity, weight of carp stocked, and isolation from disturbance. For weight of carp stocked, both average individual weights of each species and total weight of carp stocked were examined. Isolation — distance from disturbance from a bordering house, road, and footpath — was determined by assigning ponds a score (1-6) based on how far the ponds were from each of the three sources of disturbance. This was done because disturbances caused birds to flee ponds, and bird predation appeared to affect fish survival and production. The scores for each source of disturbance (house, road, and footpath) were weighted at 60%, 25%, and 15%, respectively. These weighted scores were then added together and used as an index of isolation for each pond (Figure 1) with higher numbers indicating more isolation.

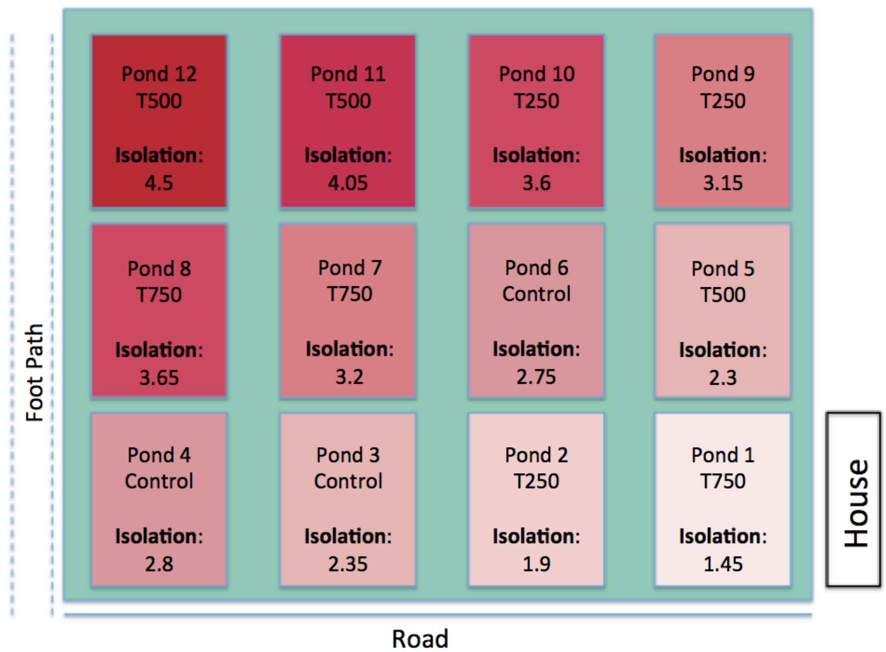

Figure 1. Numbers, treatments, and pond isolation scores based on distance from disturbance. Higher Pond scores indicate higher isolation.

In order to identify which physical variables were associated with the variation between ponds in total carp and punti production, backward stepwise multiple regressions were performed. Results from correlation matrixes, Pearson's correlation tests, standard deviations, and inter-quartile ranges (IQRs) were used to help select variables to include in the regression model and to find any correlation between independent variables to avoid issues with co-linearity. Independent variables used for each pond included isolation, number of days DO fell below five mg/L, average Secchi disk depth, average carp stocking size, and SIS stocking density. Four models were produced in each analysis. After analyzing residuals for normality and variance, and using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) tests for estimating the relative quality of models compared to each other, final models were chosen. Residuals of carp and punti yield (expected – actual yield) were analyzed using ANOVA to explore possible treatment effects on production after accounting for predictive variables identified in regression analysis.

Additionally, average periphyton growth ($g*m^{-2}*d^{-1}$) in test ponds was compared to average primary productivity ($g*m^{-2}*d^{-1}$) using the Pearson's Correlation Test to assess whether periphyton growth promoted higher primary productivity.

The economic feasibility of purposely stocking punti and dedhuwa, and the variance in economic returns resulting from differences in polyculture system design and management in the region were also evaluated using data gathered from this experiment and surveys with local farmers, hatcheries, and market vendors. 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. Information was gathered by interviewing three individual farmers, the Kathar Women's Aquaculture Cooperative, a private hatchery, a government hatchery, and a vendor at a local fish market in Bharatpur, Chitwan. Questions included SIS prevalence and interest, carp, and SIS market price and production, sources of aquaculture information and training, fish production, and pond preparation costs, including purchase of fingerlings, feed, and fertilizer (Appendix Table 1). The partial enterprise budget evaluated potential changes in income and expenses resulting from stocking of SIS. Reported SIS harvest and costs from all three farmers interviewed were averaged and then corrected to kg/ha. Two results were created: one based on production data gathered in interviews, and the other based on production data collected in this experiment. Additionally, overall production strategies and the resulting variations in costs, production, and profits of various farmers and the experiment were also compared. These comparisons were created assuming 100% sale of carp produced, and all results were adjusted to one hectare of pond area.

RESULTS

As hypothesized, changes in SIS stocking density did not result in significant variations in carp production or survival between treatments (ANOVA, $p>0.05$). Furthermore, total carp production in ponds showed more within treatment than between treatment variation (p-value = 0.823, F-value = 0.302; Figure 2).

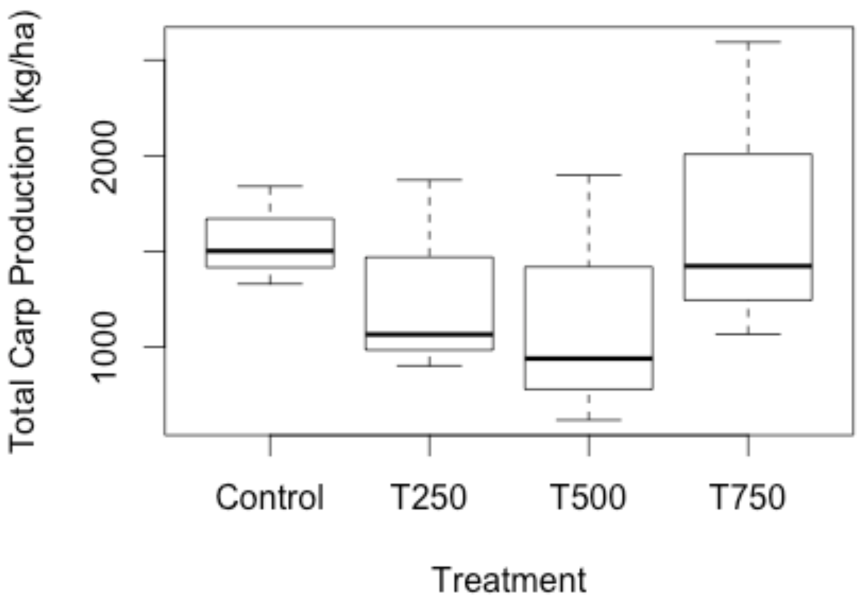

Figure 2. Boxplot of carp production in each treatment. Upper horizontal line: maximum of range, lowest horizontal line: minimum of range, bold horizontal line: median, box: interquartile range, upper and lower limits of box: third and first quartile.

Correlation matrices showed significant correlations between total carp production and isolation, primary productivity, Secchi disk depth, DO, and size at stocking. There was also a significant correlation between isolation index and production of bighead, common, mrigal, rohu, silver carp, and punti ($p < 0.05$), but not grass carp production. Average primary productivity was positively correlated to production of all carp species except grass carp. Secchi disk depth had a negative correlation to production of these same species and with average primary productivity. Average DO showed no significant correlation to production of most species, but a positive correlation to production of grass carp (p = 0.0225). Size at stocking was significantly correlated with common carp production (p = 0.0024).

Regression analysis for total carp production showed isolation was the major factor correlated to pond production, with average carp size at stocking explaining less variance but still significantly correlated ($F_{(2, 9)} = 27.88$, $p < 0.0005$, $R^2 = 0.83$).

Stocking density did not significantly affect punti production. Higher production of punti came from control ponds through natural colonization, and these ponds had higher punti production than T250 or T500 ponds. One-way ANOVA results for production showed more within treatment variation in production than between treatments ($p = 0.177$, Figure 3). Punti were harvested at fairly high numbers in control ponds where none were stocked. Regression analysis for punti production showed only isolation was significantly correlated to production ($F_{(1, 10)} = 14.86$, $p < 0.005$, $R^2 = 0.5575$).

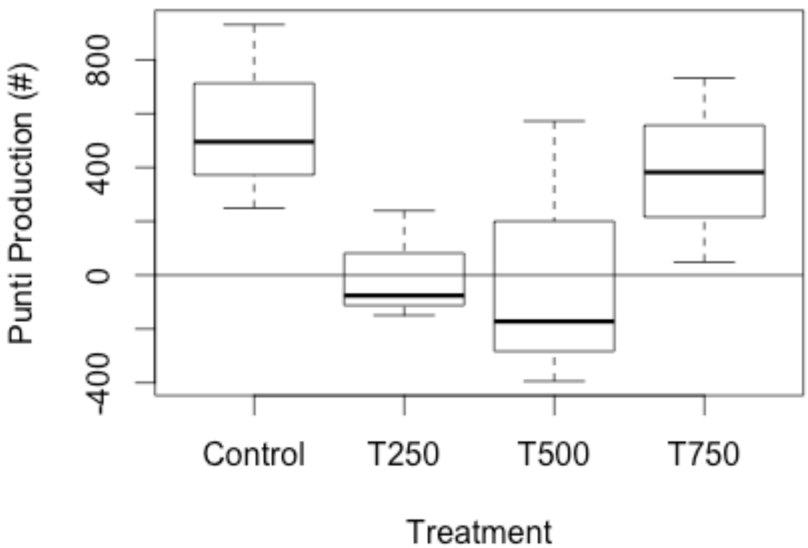

Figure 3. Boxplot of punti production by treatment; notation as in Figure 2.

Stocking density had a significant effect on production of dedhuwa, but this effect was often negative. These negative production values indicated that dedhuwa numbers declined from stocking to harvest. Once again, there was significantly higher production in control ponds than in stocking treatments, while the T750 treatment had the lowest production (Figure 4, $p = .00173$).

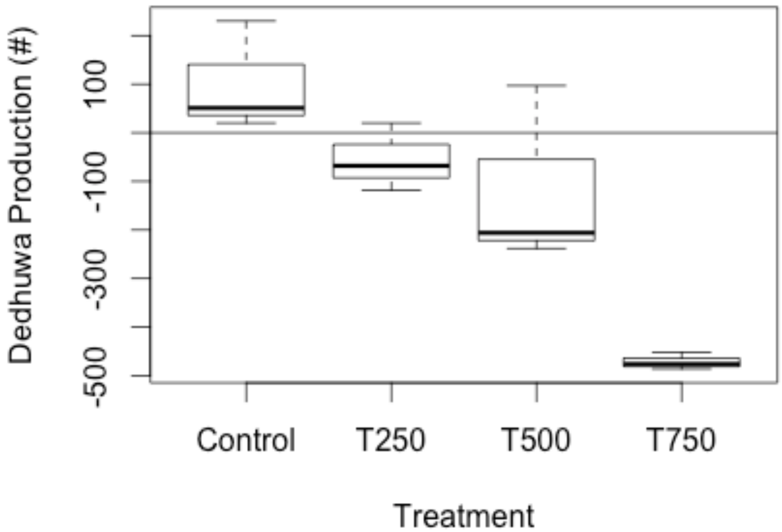

Figure 4. Boxplot of dedhuwa production by treatment; notation as in Figure 2.

There were no adverse effects of SIS stocking density on water quality. For all water quality parameters tested, including primary productivity, average pH, average Secchi disk depth, and DO (days<5 mg/L) there was more within treatment variation than between treatments ($p > 0.05$), and water quality parameters remained within acceptable ranges for carp and SIS survival. Temperature declined over the course of the experiment and reached levels that likely reduced production (T < 20 C) over the last six weeks of grow-out.

Periphyton growth was variable between ponds, at depths, and over time. Neither periphyton growth in August or January were significantly correlated to primary productivity (p = 0.704 and 0.9964, respectively), total carp production, or common carp production. However, a significant correlation was found between periphyton growth in August and rohu production (p = 0.012). Periphyton growth was higher in control, T250, and T750 ponds sampled in January than in August. For primary productivity, ponds showed fair uniformity with productivity oscillating over time and no overall increasing or decreasing trend.

All farmers interviewed reported harvesting SIS, although they did not purposely stock them, and they were all aware of their higher nutritional content and market price compared to carp. Farmers reported harvesting between 180-800 kg/ha. In comparison, the experiment had an average SIS harvest of only 86 kg/ha, but with a wide range from 21 to 202 kg/ha. SIS are not often sold in markets but consumed at home. When they are sold, however, prices are higher/kg than that for carp; (USD $4.00/kg for SIS, $2.00- $3.60 for carp). All farmers interviewed reported selling their carp for Rs 200 ($2.00). Interestingly, farmers with larger ponds did not necessarily report larger harvests of SIS, and when corrected to kg/ha, smaller ponds yielded more SIS per unit area.

Maximum profit was achieved for SIS when no stocking occurred ($1,840 per ha annually), assuming all SIS were sold at market (Table 1). They are usually consumed in the family and not sold, but the value of the produced SIS would be the same. Using average experimental values or maximum values resulted in far less profits ($116–$582). This was partially due to the cost of stocking SIS, but also to higher yields achieved in farmer ponds. Stocked SIS can either be collected from the wild or purchased from fishermen. Daily collection labor cost was estimated at ~ \$3.00/person to collect 1kg SIS, and purchase cost was also ~ \$3.00/kg. Purchase and labor costs assumed an average SIS size of 1.5g for this analysis. Thus, when acquiring SIS from either method, \$3.00 would equal ~667 SIS. No other costs were increased to include SIS in ponds for experiments or farmers. Our estimates of the costs and benefits of carp production by these same farmers indicated about \$3,400 to \$4,800 profit per ha annually, indicating that SIS production in their ponds was valued at about 25%–35% of the total value of production, even though SIS were not intentionally stocked or provided any inputs for their added production.

Table 1. Comparison of costs and benefits concerning addition of SIS, dedhuwa and punti, to carp polyculture systems. Values in US dollars.

	Farmers Average	Experiment (Avg. SIS Harvest)	Experiment (Max SIS Harvest)
Purchase/labor Cost	\$0	\$224	\$224
SIS Production (kg/ha)	460	85	201.5
Market price (\$/kg)	\$4	\$4	\$4
Total SIS Sales (\$)	\$1,840	\$340	\$806
SIS Profit (\$/ha)	\$1,840	\$116	\$582

DISCUSSION

The two main objectives in this study were to determine optimal stocking density of SIS and to evaluate the impact of added SIS production on water quality and production. In contrast to our initial hypotheses, stocking SIS into ponds did not increase their production, but rather natural recruitment of SIS into ponds yielded the best production results. Economically, this was also shown by much higher yields and lower costs for farmers who were surveyed from SIS production compared to our experiment. Also, stocking SIS had no impact on water quality or primary production of ponds, and SIS production in the ponds was not correlated with any decline in water quality.

Punti production was not driven by stocking density, and extra effort spent to stock them did not correlate with increased production over ponds with natural recruitment. Movement of SIS between ponds and the connecting canal was evidenced by presence and harvest of punti in control ponds where no punti were originally stocked. Punti production was also highly variable between ponds. Initial ANOVA results on punti production showed that production varied more between ponds of the same treatment than between different treatments. Similar results were seen with dedhuwa. Although at times there were significant differences between treatments, most of the production values for both dedhuwa and many for punti were negative, indicating a loss of stocked fish. Moreover, due to their small size and narrow body structure, dedhuwa were very difficult to harvest and contain within ponds. Based on this, we believe our numbers of dedhuwa harvested are quite biased, so dedhuwa production numbers were not evaluated by treatment or by pond in relation to variation in carp production, punti production, or water quality variables.

SIS stocking density did not significantly affect carp production between treatments. Rather, other variables seemed to be driving variation in carp production, especially isolation and, to a lesser degree, average size of carp at stocking. Similar to punti results, the multiple regression model indicated a strong relationship between carp production and isolation, as well as size of carp at stocking.

Periphyton production was correlated with rohu production, which matched with findings in previous studies showing rohu consumed periphyton (Azim et al. 2004). Thus, addition of periphyton substrate could be beneficial if farmers are especially interested in promoting growth of this species. There was considerable variability in periphyton growth between ponds, at different depths, and between months (August vs. January).

It would be useful to gain a better understanding of what drives natural recruitment of SIS into ponds. Since most ponds in Nepal are filled with canal water, characteristics of the canals and their fish communities are important in setting potential SIS recruitment into ponds. It would benefit farmers to provide means for more SIS to colonize ponds, as long as other damaging fish species do not enter at the same time through natural pathways.

QUANTIFIED ANTICIPATED BENEFITS

The target end users of this system are small-scale rural farmers and their families in the Terai region of Nepal. We anticipated that the addition of SIS to this culture system would increase yield by at least 20%, without reducing carp production, but this was not the case. Natural recruitment of SIS into these ponds was sufficient to seed a population of SIS for household consumption. In fact, average SIS production in farmers' ponds resulted in an added value of about $1,600/ha annually to total fish production. The large carp species are commonly considered cash crops and are sold in local markets, as well as consumed in the home. SIS serve principally as a regular food source for farmers. We believe SIS produced in the ponds will increase household fish consumption by women and children by at least two-fold.

ACKNOWLEDGMENTS

University of Michigan Rackham Graduate Program, The School of Natural Resources and Environment, and the Agriculture and Forestry University of Nepal provided funding, support, and lab space. We particularly thank Mohammad Saddam Hussain field assistance, and Dr. Sunila Rai for her advice and expertise with periphyton and SIS. Also, Joe Krieger, Ellen Spooner, Ryan Young, Whitney Conrad, Andrew Layman, and Alexis Sakas assisted with research design, statistics, and editing.

LITERATURE CITED

Azim, M.E., M.M. Rahaman, M.A. Wahab, T. Asaeda, D.C. Little, and M.C.J. Verdegem. 2004. Periphyton-based pond polyculture system: a bioeconomic comparison of on-farm and on-station trials. Aquaculture 242: 381–396.

Azim, M.E., M.C.J. Verdegem, H. Khatoon, M.A Wahab, A.A van Dam, and M.C.M. Beveridge. 2002. A comparison of fertilization, feeding and three periphyton substrates for increasing fish production in freshwater pond aquaculture in Bangladesh. Aquaculture 212: 227–243.

Boyd, C.E. and C.S. Tucker. 1992. Water quality and pond soil analyses for aquaculture. Auburn University, Auburn, Alabama.

FAO (Food and Agriculture Organization). 2013. National Aquaculture Sector Overview Nepal. National Aquaculture Sector Overview Fact Sheets. Text by G. Pradhan. *In*: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 10 October 2005. [Cited 30 May 2013]. http://www.fao.org/fishery/countrysector/naso_nepal/en.

FAO. 2015. Fishery and aquaculture statistics. Global aquaculture production 1950-2013. Rome. http://www.fao.org/fishery/statistics/software/fishstatj/en.

Kadir, A., R.S. Kundu, A. Milstein, and M.A. Wahab. 2006. Effects of silver carp and small indigenous species on pond ecology and carp polycultures in Bangladesh, Aquaculture 261: 1065–1076.

Kawarazuka N. 2010. The contribution of fish intake, aquaculture, and small-scale fisheries to improving nutrition: A literature review. The WorldFish Center Working Paper No.2106. The WorldFish Center, Penang, Malaysia. 51 pp.

Morales, E.J. and D.C Little. 2007. Self-recruiting species (SRS) from farmer-managed aquatic systems – the contribution of non-stocked species to household livelihoods, 603–616. In: M.G. Bondad-

Reantaso (ed.). Assessment of freshwater fish seed resources for sustainable aquaculture. FAO Fisheries Technical Paper. No. 501.Rome, FAO. 628 pp.
Rahman, A.K.A. 2005. Freshwater fishes of Bangladesh. Dhaka, Bangladesh: Zoological Society of Bangladesh, 133pp.
Rai, S., S.H. Thilsted, M.K. Shrestha, M.D. Wahab, and M.C. Gupta. 2014. Carp-SIS polyculture: a new intervention to improve women's livelihoods, income and nutrition in Terai, Nepal. Asian Fisheries Science. Gender in Aquaculture and Fisheries: Navigating Change 27S: 165–74.
Rai, S., and Y. Yi. 2012. Nibbling frequency of carps in Periphyton-Based Aquaculture Systems with and without Supplemental Feed. Israeli Journal of Aquaculture 64: 818–822.
Rai, S., Y. Yi, M.A. Wahab, A. Bart, and J.S. Diana. 2008. Comparison of rice straw and bamboo sticks substrates in periphyton-based carp polyculture systems. Aquaculture Research 39: 464-–73.
Roos, N., M.A. Wahab, M.A.R. Hossain, and S.H. Thilsted. 2007. Linking human nutrition and fisheries: incorporating micronutrient dense, small indigenous fish species in carp polyculture in Bangladesh. Food and Nutrition Bulletin.
Wahab, M.A., M.A. Mannan, M.A. Huda, M.E. Azim, A.G. Tollervey, and M.C.M. Beveridge. 1999. Effects of periphyton grown on bamboo substrates on growth and production of Indian major carp, rohu (Labeo rohita Ham.). Bangladesh Journal of Fisheries Research 3: 1–10.

APPENDIX

Appendix 1. Survey questions and possible responses used for economic evaluation.

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?						