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Trophic functioning of integrated rice-fish farming in Madagascar: insights from stable isotopes ($\delta^{13}C$ & $\delta^{15}N$)

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Abstract

Trophic dynamics of integrated rice and fish farming (IRF) systems were studied in irrigated rice plots stocked with common carp in Madagascar. Fish feeding behavior was assessed by analyzing stable carbon and nitrogen isotopes of fish and natural feed sources. Stable isotope signatures of 45-day-old carp fry introduced into rice plots ($\delta^{13}C$ = -18.8‰ ± 0.5‰, $\delta^{15}N$ = 9.3‰ ± 0.6‰) revealed that they had been fed chicken egg yolk and corn meal, in accordance with local practices. However, after a 100-day growing period in experimental rice plots, ^{13}C and ^{15}N depletion was observed for 145-day-old carp, indicating a change in feeding sources. Under extensive conditions, common carp that fed on rice roots, sediments and suspended particulate organic matter (i.e. plant debris and detritus) had a larger trophic niche (3‰^{2}) than 45-day-old carp (1.2‰^{2}). Overall, common carp feeding behavior and the trophic food web in the IRF system suggest that increasing natural productivity through organic fertilization will enhance ecological intensification of both rice and fish production.

Keywords: Rice-fish farming, Common carp, Food web, Stable isotopes, Trophic niche partitioning

1. Introduction

Integrated rice and fish farming (IRF) with aquatic animal aquaculture (i.e. rice-fish farming; Lu and Li, 2006) is described as an ingenious agricultural system that produces fish and rice within the same plot using the same amount of water, while benefitting from synergistic effects. IRF systems decrease farmers' dependence on external inputs and increase the efficiency of the entire system by optimizing the use of nutrients, energy and water. Fish such as common carp (*Cyprinus carpio* L.) influence nutrient dynamics through consumption, excretion and bioturbation (Shin-ichiro et al., 2007), which ultimately benefit the rice. Conversely, rice provides a shelter and nursery for fish (Little et al., 2001; Noble, 2001) and is a source of food (invertebrates, and periphyton that develop on its stems; Saikia and Das, 2009). Overall, IRF with common carp can be considered as a symbiosis between rice and fish whose mutual benefits provide ecosystem services (Willot et al., 2019).

From an economic viewpoint, IRF systems diversify farm production and generate a more resilient source of income that depends less on market fluctuations than that of single-product farms. In Madagascar, IRF has been promoted by the FAO since 1985 and by the non-governmental organization APDRA since 2006 (Dabbadie and Mikolasek, 2017). Recent on-farm experiments with local IRF in Madagascar indicated that their net rice yields were more than 10% larger than traditional rice yields, in the absence of fertilizers or feed inputs (Mortillaro and Dabbadie, 2019). Despite these obvious benefits, however, the potential of IRF to address challenges related to food security and to alleviate poverty is constrained by the small fish yields obtained in improved Madagascar systems (i.e. common carp + channel and higher bunds; from 50 kg ha^{-1} cycle^{-1} to 350 kg ha^{-1} year^{-1}, on average; Mortillaro and Dabbadie, 2019; APDRA, 2018, respectively). However, the literature reports that fish yields in IRF could reach 906-1 282 kg ha^{-1} (i.e. fish and prawn) by increasing natural productivity through application of 5 000 kg ha^{-1} of cow dung (Mohanty et al., 2004). Similarly, when fish are fed and/or rice fields fertilized, fish yields can reach up to 2.5 t ha^{-1} in China, 2.0 t ha^{-1} in India, 805 kg ha^{-1} in Indonesia, 980 kg ha^{-1} in Bangladesh, 2.2 t ha^{-1} in Vietnam and 900 kg ha^{-1} in Thailand (Lu and Li, 2006).

Rice-based ecosystems are a large source of animal and plant diversity (Halwart, 2008). Bambaradeniya et al. (2003) described the biodiversity associated with an irrigated rice system in Sri Lanka; besides microbiodiversity, they found 494 species of invertebrates, 103 species of vertebrates and 89 species of macrophytes. Similarly, a total of 147 species were reported from Cambodian rice field fisheries, comprised of 126 finfish species, 13 other aquatic animal species (four species of snake; two species of frogs, snails, and bivalves; one species of crab, prawn, and turtle), and eight aquatic plant species (Freed et al., 2020). These species play a major role in feeding and providing nutrition to local communities, as a source of self-recruiting species and in supporting the production of farmed fish in association with rice (Halwart, 2006). However, the high biodiversity also suggests complex trophic interactions. Characterizing the trophic food web in IRF systems may thus improve knowledge about ecosystem functioning as well as ecological intensification of aquatic food production. Indeed, ecosystem functioning provide information on the relationships among organisms in order to guide the use of trophic resources and energy and maximize natural processes to produce fish.

Stable carbon and nitrogen isotopes (δ^{13}C and δ^{15}N) are often used to characterize trophic food webs. The basic principle is that the isotopic composition of a consumer's tissues reflects that of its food (DeNiro and Epstein, 1978, 1981; Minagawa and Wada, 1984). Unlike analysis of stomach contents, which provides information about the type of prey ingested, the isotopic method provides an integrated measure of the food consumed over time, based on the assimilation and metabolization of nutrients ingested (Hesslein et al., 1993; MacAvoy et al., 2001). The stable nitrogen isotope ratio (^{15}N:^{14}N) estimates the trophic levels of species in an ecosystem and characterizes predator-prey relationships. The stable carbon isotope ratio (^{13}C:^{12}C) traces the origin of organic matter ingested by organisms, since each food source, whether terrestrial or aquatic, has its own range of $\delta^{13}C$, which is strongly conserved along trophic chains (Pinnegar and Polunin, 2000). Therefore, studying stable carbon and nitrogen isotopes provides different but complementary types of information to characterize a food web. In our study, we expected that stable carbon and nitrogen isotopes would characterize the feeding behavior of common carp in a Madagascar IRF agriculture to aquaculture system.

2. Materials and methods

2.1. IRF system management

The experiment was conducted on-farm using experimental rice plots located near the village of Tsiafahy (19°03'41.8"S, 47°36'36.3"E; 1 344 m.a.s.l.), Antananarivo Atsimondrano district (Analamanga region, Madagascar). The experimental design and yields of the system were previously described in Mortillaro and Dabbadie (2019) presenting the Malagasy rice-fish farming study case. Briefly, three plots (P2: 863 m^2, P3: 713 m^2 and P5: 467 m^2) with a total area of 2 043 m^2 were selected. In accordance with traditional farming practices, rice was sown on 1 October 2016 using a local rice strain (i.e. “Vary Botry”). Rice seedlings 61 days old were transplanted on 1 December 2016. The experiment was then conducted for 100 days, from 11 January to 24 April 2017, with the concurrent production of fish and rice starting 41 days after rice was transplanted. Fish were introduced somewhat later than usual due to low rainfall in December 2016 and early January 2017. As recommended by the FAO and APDRA (Dabbadie and Mikolasek, 2017), the traditional practices were improved: stocking common carp, building larger and higher plot bunds, and increasing the water level in the rice plots. Bunds improve and secure production by preventing fish from escaping during flood events. Rice plots were completed by digging a channel through it (40-60 cm deep; 8.6% ±

1.5% of cultivated area), which served as a refuge for fish, especially during climatic hazards (e.g. tropical cyclone Enawo, March 2017) or when the rice plots are drained during harvest of the rice crop (Halwart and Gupta, 2004). The objective of these developments in Madagascar was to guarantee an acceptable survival rate for the common carp and thus increase fish production. The 45-day-old carp fry used in the experiment, with a mean weight (± SD) of 2.5 g ± 1 g and a mean length of 39 mm ± 6 mm, were sourced from a fish farmer near the experimental farm. The number of fry stocked in the three experimental rice plots was 216 (P2), 178 (P3) and 116 (P5), which corresponded to a density of 0.25 fish m^{-2}.

2.2. Sampling procedures

2.2.1. Fish

Five 45-day-old carp were sampled at the beginning of the experiment prior to stocking. At harvest, three 145-day-old carp from each rice plot were sampled (Table 1). All fish were euthanized and dissected, and white muscle was sampled for stable isotope analysis.

2.2.2. Macroinvertebrates

Macroinvertebrates were monitored during the experiment prior to harvest. Despite frequent sampling (every two weeks), only aquatic insects were found (i.e. adults or larvae; mainly Hemiptera, Odonata and Diptera; Table 2). They were collected from the water column using a 500 µm mesh landing net (50 cm × 30 cm) within rice straw, the refuge channel and along the bunds. Three locations in the rice plots were sampled, which provided a composite sample that was transferred into a labelled polypropylene tube and kept in a cooler until being taken to the laboratory. Insect samples were then sorted and identified to the lowest taxonomic level.

2.2.3. Zooplankton

Zooplankton were sampled at harvest using a plankton net (63 µm mesh, 40 cm diameter) towed in the refuge channel before emptying the rice plot. Three plankton transects were sampled in each plot (Table 1). For each sample, the plankton net was shaken to remove water until the volume of the sample decreased below 40 mL. The collected material was then transferred into polypropylene tubes (one per plankton transect and rice plot) and kept in a cooler until being taken to the laboratory.

2.2.4. Suspended particulate organic matter

Suspended particulate organic matter (SPOM) was sampled at harvest using glass fiber filters (Whatman GF/F, porosity 0.7 µm, 47 mm diam.) and a vacuum system under low pressure. The filters were pre-combusted at 450°C for 12 h. Three water samples of 1.5 L each were collected in bottles in the three rice plots (Table 1) and filtered until particulate material saturated the filter (after 500 mL, on average). Each filter was then transferred into a labelled polypropylene tube and kept in a cooler until being taken to the laboratory.

2.2.5. Sediments

Sediments were sampled at harvest at 15 locations in each rice plot, transferred into polypropylene tubes and kept in a cooler until being taken to the laboratory. For each rice plot, sediments from five locations were thoroughly mixed into a composite sample before preparing the stable isotope sample (Table 1).

2.2.6. Weeds

Prior to harvest and during monitoring of the experiment, weeds were collected when observed in rice plots (Table 2). Samples were transferred into single-use plastic storage bags and kept in a cooler until being taken to the laboratory. Weed samples were then sorted and identified to the lowest taxonomic level.

2.2.7. Rice

At harvest, three composite samples of rice compartments (i.e. leaves, roots and seeds) were collected from each plot (Table 1). Quarter-meter squares (50 cm × 50 cm) made of polypropylene tubes were thrown randomly into each rice plot three times. All rice plants within the square were subsequently sampled, sorted by compartment (Table 1), transferred into single-use plastic storage bags and kept in a cooler until being taken to the laboratory.

2.3. Sample preparation

Fish white muscle, aquatic insects, zooplankton, SPOM, sediments, weeds and rice were dried at 45°C for 24-48 h, manually ground into a fine homogeneous powder and transferred into Eppendorf Tubes®. Then, 1-50 mg of each dried sample was weighed and packed into a tin capsule to analyze stable carbon and nitrogen isotopes simultaneously. Sample preparation was realized in FOFIFA DRZVP laboratory in Antananarivo, Madagascar.

2.4. Stable isotopes

Stable carbon and nitrogen isotopes ($\delta^{13}C$ and $\delta^{15}N$) were analyzed by subcontracting to the stable isotope laboratory of UMR B&PMP in Montpellier (France). For each compartment of the rice plots, ^{13}C and ^{15}N in the same sample was analyzed using an automated on-line system, including an Elementar Isoprime mass spectrometer coupled with a Eurovector Euroflash 3000 elemental analyzer, thus characterizing the trophic functioning of the IRF via isotope ratio mass spectrometry analysis. Results were expressed in δ unit notation as deviations from standards (Vienna Pee Dee Belemnite for $\delta^{13}C$ and atmospheric N_2 for $\delta^{15}N$; Peterson and Fry, 1987) following the formula:

$$\delta^{13}C \text{ or } \delta^{15}N = \frac{R_{sample}}{R_{standard}}\, 10^3$$

where R is the ratio of heavy to light isotopes (^{13}C:^{12}C or ^{15}N:^{14}N).

2.5. Comparison of common carp isotopic niches

A standard ellipse area (SEA) was calculated for 45- and 145-day-old carp using the *Stable Isotope Bayesian Ellipses in R* package (SIBER, version 2.1.4; Jackson et al., 2011). The SEA Bayesian metric is a bivariate equivalent of the standard deviation that contains the mean core population isotopic niche (ca. 40% of the data). SEA metrics were chosen prior to the convex hull metric (TA: total area of the convex hull that encompasses the data points; Layman et al., 2007), which includes outlier individuals. SEA metrics are more robust to differences in sample size. The corrected version (SEAc) was then used to circumvent the bias caused by small sample sizes. SEAc sizes were then compared using a Bayesian approach based on Markov-chain Monte Carlo methods (Jackson et al., 2011). TA was compared to SEAc (Table 3), but data analysis focused on the latter.

2.6. Statistical analysis

One-way analysis of variance (ANOVA) was used to compare $\delta^{13}C$ and $\delta^{15}N$ values among 145-day-old carp. Tukey's post-hoc tests were used to examine pairwise differences. Assumptions of normality and homoscedasticity of residuals were tested using Shapiro-Wilk and Bartlett tests, respectively. A two-sample Student's t-test was used to compare $\delta^{13}C$ and $\delta^{15}N$ values between 45- and 145-day-old carp. Assumptions of normality and homoscedasticity of residuals were tested using Shapiro-Wilk and Fisher tests, respectively. Statistical analyses were performed using R software version 3.6.3, with a significance level α of 0.05.

2.7. Data analysis

The theoretical sources of a trophic group were calculated using the graphic coordinates of the consumer compartment's centroid as a reference point and adding a theoretical trophic enrichment factor (TEF: 3.4‰ and 0.8‰ for $\delta^{15}N$ and $\delta^{13}C$, respectively; Zanden and Rasmusen, 2001) to it (Fig. 1). The closer a compartment lies to this point, the more it contributes to feeding the consumer compartment. The theoretical signatures of fish meal (13.6‰ ± 0.1‰ and -19.9‰ ± 0.3‰ for $\delta^{15}N$ and $\delta^{13}C$, respectively; Kusche et al., 2018), chicken egg yolk (6.3‰ ± 1.4‰ and -25.0‰ ± 3.4‰ for $\delta^{15}N$ and $\delta^{13}C$, respectively; Rogers, 2009) and corn meal (4.9‰ ± 0.6‰ and -12.7‰ ± 1.0‰ for $\delta^{15}N$ and $\delta^{13}C$, respectively; Yamada et al., 2003; Enyidi et al., 2013) were included in the analysis to consider 45-day-old carp feed, which was not sampled in the current study. Mixing models (e.g. MixSIR, SIAR; Moore and Semmens, 2008; Parnell et al., 2010) were not used to estimate contributions of sources to consumers' diets, because we assumed that (i) not all sources ingested could be sampled and (ii) fish opportunism would create underdetermined systems (i.e. with more sources than tracers), which increases the inaccuracy of models, even though they are Bayesian (Brett, 2014; Stock et al., 2016). Thus, we focused on bulk data to avoid biased estimates of source contributions.

3. Results & discussion

At the beginning of the experiment, the stable isotope signature of the 45-day-old carp was -18.8‰ ± 0.5‰ and 9.3‰ ± 0.6‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively. Assuming a TEF of 3.4‰ and 0.8‰ for $\delta^{15}N$ and $\delta^{13}C$, respectively, between a prey and its predator (Zanden and Rasmusen, 2001), the theoretical food source of 45-day-old carp had a mean signature of -19.6‰ and 5.9‰ (Fig. 1) for $\delta^{13}C$ and $\delta^{15}N$, respectively. Fry of 10-20 days old can feed on cladocerans, copepods and the small larvae and pupae of insects such as chironomids and mosquitoes. Fry of 21-45 days old can also consume larger insect larvae, worms and small shellfish (Colman et al., 1992). Although these sources were not sampled in the nursery ponds, the stable isotope signatures of zooplankton and insects suggested that they contributed little to young carp diets (Fig. 1, Table 3). On the contrary, the theoretical food source signature of 45-day-old carp suggested that their food was composed mainly of animal protein (chicken egg yolk; Fig. 1, Table 3) and carbohydrates from C_4 plants (corn meal; Fig. 1, Table 3). Local farmers have used both ingredients as the first artificial feed for common carp since the FAO introduced them to Madagascar in the 1980s (Woynarovich, 1980, 1982; Colman et al., 1992).

After 100 days of extensive farming in the rice plot, the signature of 145-day-old carp became depleted compared to that of the 45-day-old carp, decreasing to -24.9‰ ± 1.0‰ and 5.7‰ ± 0.9‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively (Fig. 1). They remained, however, in the range of signatures found in rice plot ecosystems (Fig. 1, Table 3), which confirmed that feeding had switched from external sources to natural resources. No differences among the three experimental plots were measured at the end of the experiment (Table 3, ANOVA, $p > 0.05$). The plots were thus considered to have similar signatures and availability of natural food sources.

The theoretical food source of 145-day-old carp had a mean signature of -25.7‰ and 2.3‰ (Fig. 1) for $\delta^{13}C$ and $\delta^{15}N$, respectively. The latter lay exactly in between the signatures of rice roots, sediments and SPOM, which suggests that these three sources were consumed (as plant debris and detritus). However, zooplankton, rice leaves and weeds had little to no contribution to the carp diet (Fig. 1). Common carp has been described as consuming mainly detritus and plants (more than 60%), followed by invertebrates associated with plant debris (Fig. 3, Matsuzaki et al., 2007; Kanaya et al., 2009; Ramírez-Herrejón et al., 2014). Similarly, gut contents analyses from common carp in rice-field of the Apatani plateau revealed a total of 60 food items of which 22 belonged to the Chlorophycea, 12 to the Cyanobacteria, 10 to the Bacillariophycea and 16 to several zooplankton taxa, while selectively feeding on periphyton (Saikia and Das, 2009). It confirms that common carp can forage on a large variety of food items, including invertebrates through bottom feeding (Fig. 3), although all of them won't be assimilated in their tissues, as revealed by stables isotopes. However, C_4 weeds (i.e. *Echinochloa colona*, *Fimbristylis ferruginea* and *Pycreus mundtii*; Table 2) displayed a highly enriched carbon signature (Fig. 1; $\delta^{13}C$ = -11.3‰ ± 0.4‰) suggesting no contribution to the common carp diet. These weeds had either little to no contribution to the food web unless through decomposition as suggested for other aquatic C_4 macrophytes in Amazon floodplains (Mortillaro et al., 2016).

Although few insects had a signature similar to that of the theoretical food source, the mean signature displayed a large heterogeneity (-27.1‰ ± 2.6‰ and 5.9‰ ± 2.9‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively), which suggests the need for further investigation. For instance, Dadebo et al. (2015) found 39.8% detritus and 26.7% Diptera (by volume) in common carp guts from Lake Koka (Ethiopia). Frei et al. (2007) found that stocking common carp and tilapia in rice fields had a significant influence on controlling weeds and dipterous insects. In our study, in Madagascar, only Culicidae larvae (mosquitoes, Table 2; δ^{13}C = -24.1‰ and δ^{15}N = 3.1‰, Fig. 1) belonged to Diptera, while the other insects collected belonged mainly to Hemiptera and Odonata, which contribute less than 3% to the common carp diet according to the literature (Dadebo et al., 2015). However, the insects sampling effort in this study was the main limitation for a deeper assessment on their contribution to carp diet.

IRF is believed to provide ecosystem services, such as weed and pest control, via integrated pest management (Frei et al., 2007; Kathiresan, 2007; Sinhababu et al., 2013). However, although similar assumption was made in Madagascar by farmers and technicians, weeds and insects did not contribute to the diet of 145-day-old carp. Common carp in our IRF system fed mainly on detritus but also increased rice yields by more than 10% for improved IRF systems (i.e. common carp + channel and higher bunds) as described in Mortillaro and Dabbadie (2019), which is a major improvement considering the Madagascar needs for rice. Thus, while feeding on natural resources, carp recycled organic matter as fertilizer for rice providing a way for sustainable intensification of rice culture given the low incomes and available inputs for farmers in Madagascar (Fig. 3). Fish excretion, which increases the nutrients available for plants such as rice (Boyd et al., 2020), has been described as the main driver of larger rice yields (Lu and Li, 2006; Shin-ichiro et al., 2007). Bioturbation caused by common carp may also increase soil quality since oxygen supply (Ritvo et al., 2004) influences water transparency and community composition, such as that of plankton and submerged macrophytes (Shin-ichiro et al., 2007).

The SEAc based on δ^{13}C and δ^{15}N values of the 45- and 145-day-old carp did not overlap and were significantly smaller for the younger carp (Fig. 2, Table 3). In polyculture rice-fish systems (i.e. *Barbonymus gonionotus, Oreochromis niloticus* and *Macrobrachium rosenbergii*), similar results were found for common carp (1.36‰^{2} to 2.04‰^{2}; Saowakoon et al., 2021). Thus, each group had different feeding habits, as the older carps appeared to have more trophic plasticity (i.e. being able to forage on a large range of food items) than the younger carps. The biodiversity available in Madagascar rice fields (Fig. 3) as food sources for carp during the 100 days of the experiment was probably higher than that in nursery ponds. The ability of older carp in using different resources was also confirmed by their preferential consumption and retention of high-quality dietary sources such as formulated feeds, which have been observed to contribute up to 76.5% of the carp diet (Schultz et al., 2012). The small trophic niche of 45-day-old carp (Fig. 2, Table 3) was due to preferential consumption of exogenous feeds (i.e. corn meal and chicken egg yolk), as observed in semi-intensive in temperate fish polyculture, according to trophic niche partitioning (Nahon et al., 2020). Indeed, after the onset of the juvenile period (20-25 mm; 20-30 days old) functional morphology, feeding behavior and differential growth capacity of common carp change little (Vilizzi and Walker, 1999).

In our study, sampling didn't permit to have a larger number of samples for sources during the experiment. The experiment was done in farmers conditions where exhaustive sampling is often an issue. However, as related to sources and as mixing models were not used, the sample size was not a major issue for comparison with consumers (i.e. common carps).

4. Conclusion

Our study explains the trophic behavior of common carp in Madagascar IRF, which forage mainly on detritus under extensive conditions. Preferential consumption of feeds was also confirmed for fry, as previously observed for adults. Thus, although common carp are opportunistic, when reared under extensive conditions, they are also ecosystem engineers that influence ecosystem functioning and biodiversity through bioturbation, improving IRF systems. This suggests that ecological intensification of Madagascar IRF using organic fertilizers (e.g. rich in nitrogen, carbon and phosphorus), instead of synthetic fertilizers should help increase natural productivity, particularly in a context of low incomes and available inputs in Madagascar rural areas. Such ecological intensification through natural productivity improvement and/or low feed inputs should be further assessed, as the integration with lombricompost and earthworm culture to optimize the recycling of crop waste to feed the fish and fertilize the rice. However, the little contribution of insects, weeds (e.g. C_4) and zooplankton to the common carp diet, suggest that further studies integrating species from multiple trophic levels, including Madagascar native fish and freshwater prawn, can increase overall productivity.

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Figure captions

Figure 1. Dual stable isotope plot of $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) showing the mean (± standard deviation (SD)) isotopic signature of common carp, theoretical feed source and trophic compartments collected from rice plots. The signatures of fish meal (FM), chicken egg yolk (EY) and corn meal (CM) came from the literature. SPOM: suspended particulate organic matter

Figure 2. a) Standard ellipse areas (SEAc) and b) density plots showing confidence intervals of 45-day-old carp and 145-day-old carp in the rice-field experiment. Red crosses indicate maximum-likelihood-estimated SEAc values obtained after 10 000 bootstrap iterations. Gray shades from dark to light represent 50%, 75% and 95% credibility intervals.

Figure 3. Illustration of the trophic functioning of the IRF system in Madagascar from Mortillaro and Dabbadie (2019)

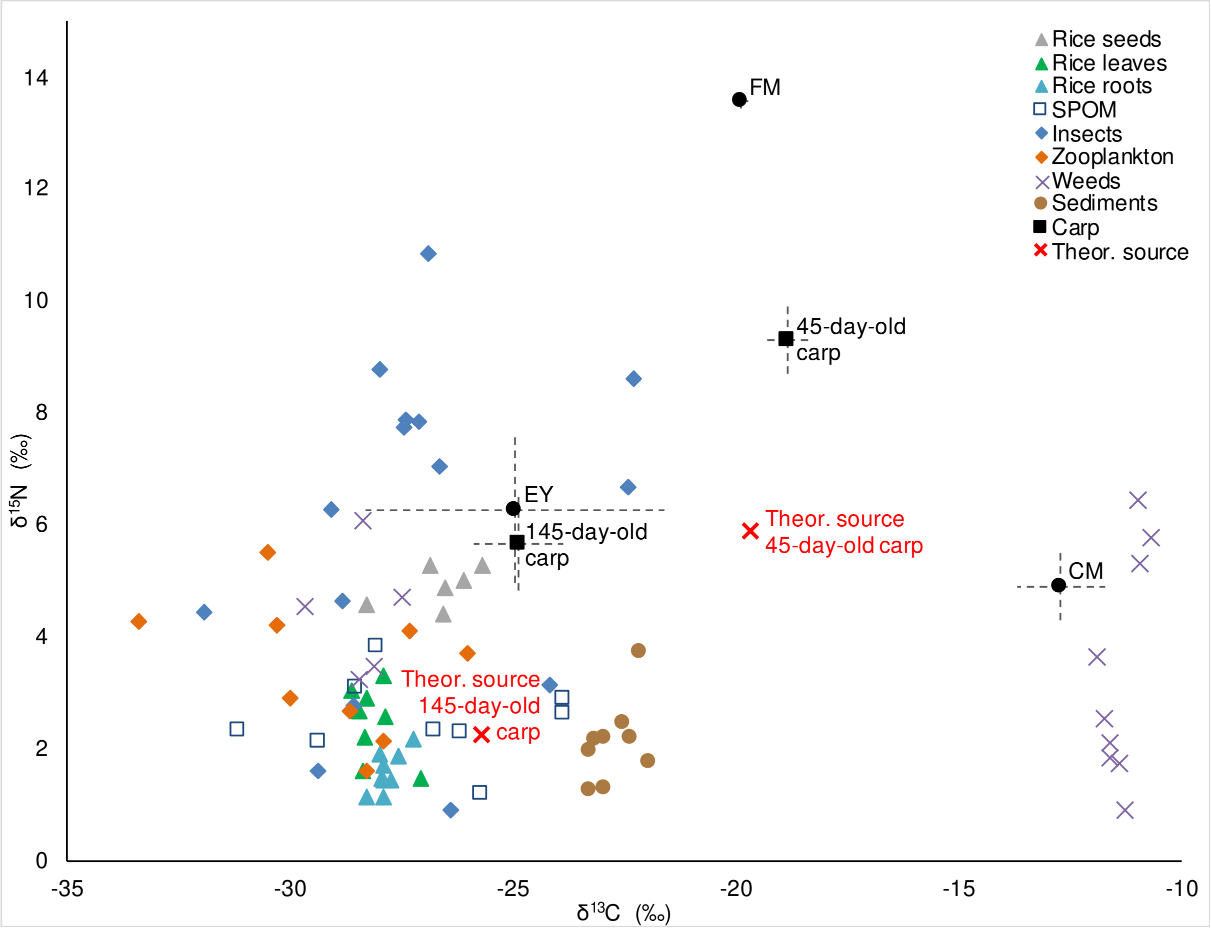

Rice seeds
Rice leaves
Rice roots
SPOM
Insects
Zooplankton
Weeds
Sediments
Carp
Theor. source
FM
45-day-old carp
EY
145-day-old carp
Theor. source 45-day-old carp
CM
Theor. source 145-day-old carp
δ15N (‰)
δ13C (‰)
0
2
4
6
8
10
12
14
-35
-30
-25
-20
-15
-10

Figure 1

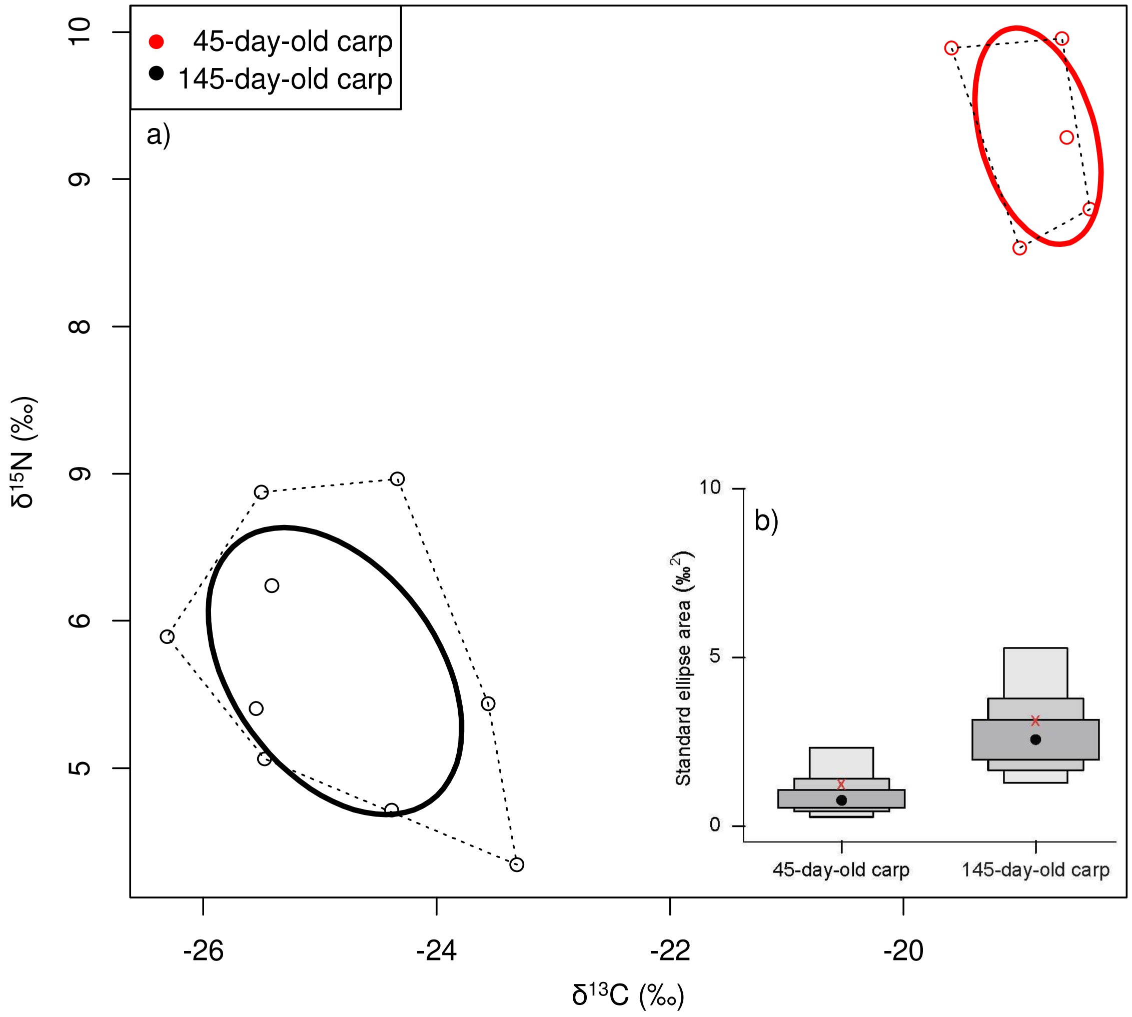
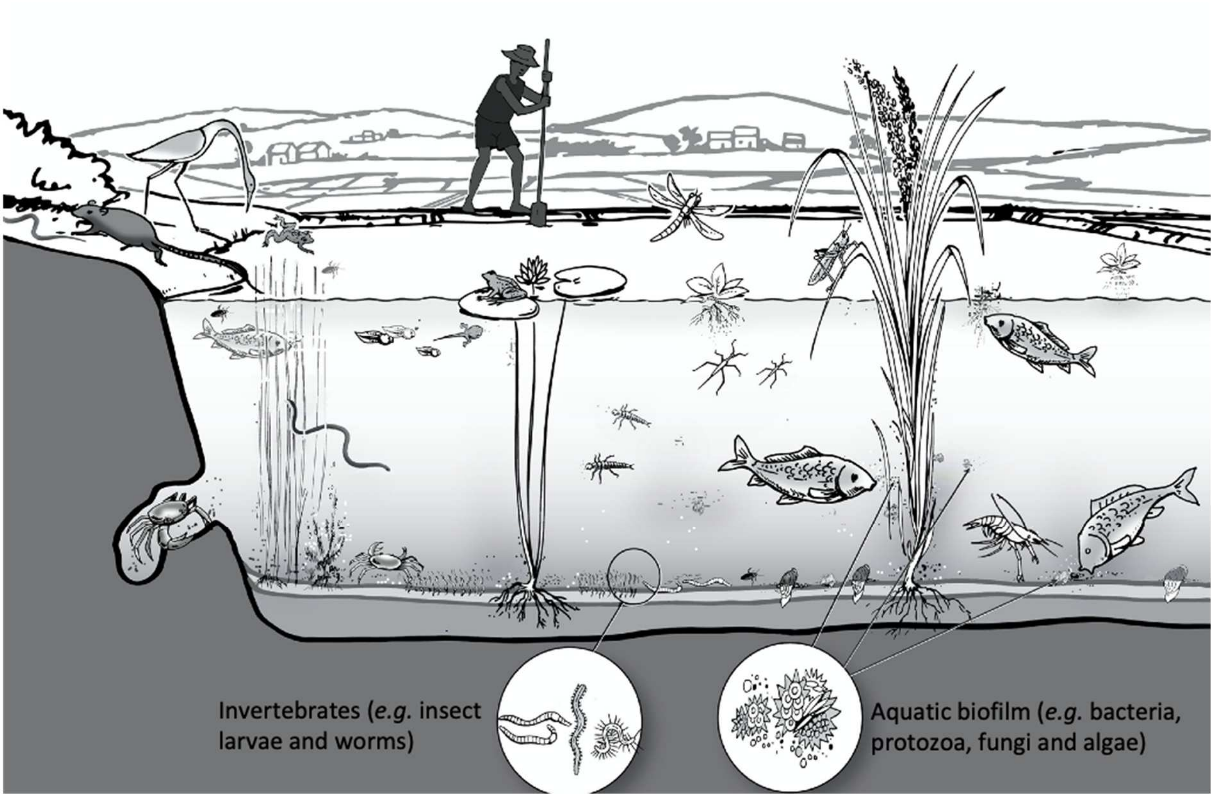

45-day-old carp
145-day-old carp
a)
10
9
8
9
6
5
δ15N (‰)
-26
-24
-22
-20
δ13C (‰)
b)
10
5
0
Standard ellipse area (‰2)
45-day-old carp
145-day-old carp

Figure 2

522



523 **Figure 3**

Table 1. Number of samples per compartment collected at harvest from the three experimental rice plots (P2, P3 and P5). SPOM: suspended particulate organic matter

Compartment	P2	P3	P5	Weight (g)	Length (mm)
Cyprinus carpio	3	3	3	48 ± 22	142 ± 24
Rice leaves	3	3	3	-	-
Rice roots	3	3	3	-	-
Rice seeds	1	2	3	-	-
Zooplankton	3	3	3	-	-
SPOM	3	3	3	-	-
Sediments	3	3	3	-	-

Table 2. Insects and weed species (C_3 and C_4) collected in the experimental rice plots when observed. Insects were identified to the lowest taxonomic level (family, subfamily or infraorder).

Insect species	Order	n	Weed species	n	Type
Anisoptera larvae	Odonata	2	*Courtoisina cyperoides*	2	C_3
Baetidae larvae	Ephemeroptera	2	*Schoenoplectus juncoides*	3	
Corixidae	Hemiptera	1	*Echinochloa colona*	3	C_4
Culicidae larvae	Diptera	1	*Fimbristylis ferruginea*	3	
Dytiscidae larvae	Coleoptera	1	*Pycreus mundtii*	3	
Naucoridae	Hemiptera	2	-	-	
Notonectidae	Hemiptera	2	-	-	
Ranatrinae	Hemiptera	2	-	-	
Zygoptera larvae	Odonata	2	-	-	
Total		15		14	

Table 3. The $\delta^{13}C$ and $\delta^{15}N$ values (mean ± standard deviation) of sampled compartments and, for common carp, corrected standard ellipse area (SEAc, ‰^{2}) and total area of the convex hull encompassing the data points (TA, ‰^{2}). Letters indicate significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between 45- and 145-day-old carp (Student's t-test, $p < 0.001$). No differences among 145-day-old carp in the three experimental rice plots were observed (ANOVA, $p > 0.05$).

Compartment	n	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	SEAc (‰^{2})	TA (‰^{2})
45-day-old carp	5	-18.8 ± 0.5^b	9.3 ± 0.6^b	1.2	1.0
145-day-old carp	9	-24.9 ± 1.0^a	5.7 ± 0.9^a	3.0	4.5
Plot P2	3	-24.4 ± 0.9	6.2 ± 0.8	-	-
Plot P3	3	-24.4 ± 1.1	4.7 ± 0.4	-	-
Plot P5	3	-25.8 ± 0.5	6.1 ± 0.7	-	-
Rice seeds	6	-26.6 ± 0.9	4.9 ± 0.4	-	-
Rice leaves	8	-28.1 ± 0.5	2.5 ± 0.7	-	-
Rice roots	9	-27.8 ± 0.3	1.6 ± 0.3	-	-
C_3 weeds	5	-28.4 ± 0.8	4.4 ± 1.1	-	-
C_4 weeds	9	-11.3 ± 0.4	3.4 ± 2.0	-	-
Sediments	9	-22.7 ± 0.5	2.1 ± 0.7	-	-
Zooplankton	9	-29.1 ± 2.2	3.5 ± 1.2	-	-
Insects	15	-27.1 ± 2.6	5.9 ± 2.9	-	-