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Fisheries production in Southeast Asian Farmer Managed Aquatic Systems (FMAS) II. Diversity of aquatic resources and management impacts on catch rates

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ABSTRACT

Southeast Asian rice farmers often manage aquatic habitats and resources on their land to increase harvest of aquatic animals (Amilhat, E., Lorenzen, K., Morales, E.J., Yakupitiyage, A., Little, D.C., 2009. Fisheries production in Southeast Asian farmer-managed aquatic systems (FMAS). I. Characterisation of systems. Aquaculture 296, 219–226). We characterize the diversity of aquatic resources harvested from such Farmer Managed Aquatic Systems (FMAS) and evaluate the effectiveness of management practices within contrasting FMAS in Cambodia, Thailand and Vietnam. Farmers harvested diverse self-recruiting species (SRS) from FMAS in all study areas: 24 locally recognized species in Cambodia, 66 in Thailand and 17 in Vietnam. Fish accounted for the largest share of SRS by weight in all areas but frogs, snails, crustaceans and insects were also important. Amphibious species, well adapted to rice farming landscapes, dominated catches of both fish and non-fish SRS. Stocked cultured species (CS) comprised only fish, were less diverse and differed between countries according to aquaculture practices. SRS catch rates in FMAS were significantly higher than wild animal catch rates in open aquatic systems in Cambodia and Thailand, indicating an underlying difference in abundance. This positive effect is likely attributable to lower harvesting effort in FMAS (where access was restricted to owners), agricultural inputs, and management measures aimed specifically at increasing aquatic animal production. Various management measures were recorded, but only the construction of brush parks and fertilisation was associated with positive effects on catch rates in the SRS-dominated FMAS of Cambodia and Thailand. Ponds in Vietnamese FMAS were managed intensively as carp polyculture systems, and catch rates within them responded positively to a wide range of management inputs. FMAS support a high abundance of aquatic animals including diverse SRS and benefit nutrition and income of farming households, agro-ecosystem services, and biodiversity conservation.

1. Introduction

Rice farming landscapes constitute large man-made wetlands where aquatic resources form an important component of the agro-ecosystem and associated livelihoods, and are often actively managed by farmers (Gregory and Guttman, 2002a; Smith et al., 2005; Nguyen Khoa et al., 2005). Farmer Managed Aquatic Systems (FMAS) are seasonal or permanent aquatic habitats such as rice fields or ponds, of which farm households have private ownership or exclusive access rights (Amilhat et al., 2009). By contrast, open water bodies (OWB) are those subject to public or communal ownership or access arrangements. Typically, FMAS are smaller and more intensively managed than OWB. Aquatic animals that occur naturally in FMAS without regular stocking of hatchery-reared juveniles are referred to as 'self-recruiting-species' (SRS), while animals that are regularly stocked are referred to as 'cultured species' (CS). Amilhat et al. (2009) reported that FMAS provide more than two thirds of the total aquatic animal catch obtained by farm households in SE Asia.

Amilhat et al. (2009) characterized FMAS in Southeast Asian rice farming landscapes in three countries subject to contrasting agricultural practices and socio-economic settings. Cambodia boasted the greatest diversity of FMAS in terms of physical characteristics and the combinations of systems on a household basis. The systems were geared towards the production of SRS as well as CS and combined both traditional and modified elements (cf. Edwards et al., 1997). The Cambodian FMAS operated in a context of low population density and largely rainfed, low external input rice farming systems. Access to markets and off-farm employment was limited. Cambodian FMAS formed a flexible part of diversified semi-subsistence livelihoods geared towards making the best use of local resources and household assets (cf. Smith et al., 2005). In the Thai study area, FMAS diversity was low and dominated by the rice field-trap pond combination. Thai FMAS were carefully designed exploit ecology and movement

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behaviour of key SRS, particularly the snakehead *Channa striata* (Amilhat and Lorenzen, 2005). CS were sometimes stocked, but account for only a very small proportion of the catch. FMAS in the Thai study area operated in the context of marginal, rainfed rice farming within an advanced economy where off-farm employment was widely available and FMAS management was geared towards providing high returns to low investment of labour and capital. In addition, wild fish were preferred to cultured fish in Thailand and achieve better prices when sold. In socio-economic terms, the Thai FMAS formed a fairly well-defined part of diversified accumulation livelihoods (cf. Smith et al., 2005). In the study area in Vietnam, FMAS were limited to rice fields or intensive aquaculture ponds. Rice fields were mostly irrigated and farmed with high levels of external inputs. Aquatic animal harvests were dominated by CS and FMAS management was focused on integrated polyculture of major carps (Edwards et al., 1997; Michielsens et al., 2002). Despite this, Vietnamese FMAS supported per-area levels of SRS production even higher than those found in Cambodia or Thailand. However, due to the small land holdings and high levels of agricultural and aquaculture production, SRS made only a marginal contribution to average household income. High population density has forced the intensification of both agriculture and aquaculture to generate high levels of production from small holdings of land and FMAS. Vietnamese FMAS formed part of specialised, rural accumulation livelihoods (cf. Smith et al., 2005). For simplicity and in keeping with Amilhat et al. (2009), we refer to the study sites within countries by their respective country names. This is not meant to imply that the sites are representative of the respective countries as a whole.

In the present paper we have three aims. First, to characterise the diversity of aquatic animals harvested from FMAS and some pertinent aspects of their biology. Secondly, to assess whether FMAS increase catch rates of SRS over and above those of wild aquatic animals in open waters. Increased catch rates provide direct economic benefits to farmers (higher returns to time spent fishing) and are also indicative of higher abundance and thus, conservation benefits. Thirdly, to evaluate the effectiveness of management measures implemented by farmers in the various FMAS.

2. Methodology

A household monitoring survey covering contrasting FMAS in mainland Southeast Asia was carried out to characterize the diversity of SRS, and the effectiveness of various management measures applied to increase catch rates of aquatic animals in FMAS.

2.1. Study area

The study was carried out in rural areas of three mainland South East Asian countries: regions of Thailand and Cambodia in the Mekong basin, and a region in Vietnam in the Red River basin. A description of the site selection and study area is presented in Amilhat et al. (2009). Cambodia has the lowest population density of the three countries, about half that of Thailand and less than a quarter that of Vietnam. Cambodia is also the poorest country in terms of per capita GDP and the proportion of the population that is undernourished. Thailand boasts by far the highest per capita GDP, but a greater proportion of undernourished people than Vietnam. The countries thus offer great contrast in terms of population density and development indicators. Rice farming dominates the landscapes of all study areas. The intensity of rice farming as indicated by yields and degree of irrigation development is lowest in Cambodia, intermediate in Thailand and very high on Vietnam.

2.2. Monitoring survey

The composition of aquatic resources harvested, catch in weight, harvesting effort, and management measures implemented was quantified through a household monitoring survey. Households were selected from those included in the baseline survey (Amilhat et al., 2009). As far as possible, the proportional distribution of FMAS types found in the random sample for the baseline survey was maintained. In Vietnam, households with ponds were intentionally overrepresented in the sample, as most households only had rice fields and a random sample would have provided little information on households with other FMAS. This was accounted for in subsequent analyses. The household survey was conducted over a period of 13 months in each country from February 2002 to April 2003. Interviews were conducted monthly in 162 households (9 households per village, 3 villages per province and 2 provinces per country).

Data on aquatic animal catches (species, size, number, and location) were collected with a one-week recall. Species of fish and other animals were identified by respondents and therefore represent locally recognized species rather than strict taxonomic species identifications. Samples of SRS identified by respondents were analysed by taxonomists in order to establish correspondence between local and scientifically recognized species. In most cases, locally recognized species corresponded directly to scientifically recognized species but occasionally, local names were applied indifferently to two or more morphologically similar species. Species richness determined from household surveys thus constitutes a minimum estimate. Visual aids such as sticks and bowls of different sizes were used to aid recall (Garaway, 1999). Catch was quantified in fresh weight, based on previously established length–weight relationships for larger animals and standard weights of smaller animals collected in different sizes of bowls. Fishing location was recorded as FMAS (rice fields), FMAS (ponds), and OWB.

Fishing effort (number of fishing trips, time spent fishing, gear used, and location) was also recorded with a one-week recall (due to a survey error, time spent fishing was not quantified in the Cambodian province of Takeo). The number of fishing trips corresponds to the number of times a household member went to fish. Fishing time was defined as the time expended on fishing, i.e. the time spent fishing with an active gear (cast net, lift net, harpoon, draining, collection by hand) or the time used to set, check and retrieve passive gear (gill nets, traps, baited hooks). Quantifying effort as the time people actively spend fishing, as opposed to the time a gear is operational, provides the best estimate of labour used in fishing. Data on fishing effort and catches were used to calculate catch rates (catch per unit effort, CPUE). CPUE is directly related to labour productivity (returns to labour invested in fishing) and also provides an index of relative animal abundance (here, relative biomass).

2.3. Statistical analysis

Diversity and composition of aquatic animals harvested were characterized by study area, using descriptive analyses. In the quantitative analyses of SRS catches, effort and catch rates we used a nested general linear model (GLM) with three hierarchical levels: country, province and village (Crawley, 1993). Assessment of the effectiveness of management measures on total catch rates (combined SRS and CS) was carried out separately by country, using GLMs with management measures defined as categorical explanatory variables. Data were log-transformed where necessary to ensure homoscedasticity. All statistical analyses were carried out using the SPSS package for windows, version 12.

3. Results

3.1. Diversity of aquatic animals harvested from FMAS

Aquatic animals harvested from FMAS included fish, amphibians, crustaceans, molluscs, and insects (Table 1). The number of locally recognized aquatic animal species recorded during the monitoring

Table 1
Number of locally recognized aquatic animal species recorded per country during the monitoring survey.

Taxon	Cambodia	Thailand	Vietnam
Teleost fishes			
Cobitidae	0	1	1
Cyprinidae	4	18	6
Notopteridae	1	4	0
Anabantidae	1	1	1
Osphronemidae	3	3	0
Channidae	1	4	1
Ambassidae	0	1	0
Cichlidae	1	1	1
Eleotridae	0	1	0
Helostomatidae	0	1	0
Nandidae	1	1	0
Bagridae	1	3	0
Clariidae	3	4	1
Pangasidae	1	2	0
Siluridae	1	5	1
Mastocembelidae	1	2	0
Symbranchidae	1	1	1
Total teleost families	13	17	8
Total teleost species	20	53	13
Other aquatic animals (OAA)			
Insects	0	5	0
Crustaceans	2	2	2
Molluscs	1	3	2
Amphibians	1	3	0
Total OAA species	4	13	4
Total species	24	66	17

Table 2
Overall contributions of self-recruiting (SRS) and cultured species (CS) to catches from FMAS and composition of the two groups.

Type	Cambodia		Thailand	Vietnam
	Svay Rieng	Takeo		
Overall contributions (%)				
Self-recruiting species (SRS)	82	72	98	20
Cultured species (CS)	18	28	2	80
Composition of SRS catch (%)				
Fishes				
Channa striata (a)	31	29	29	8
Anabas testudineus (a)	8	5	17	17
Clarias spp. (a)	15	6	10	5
Esomus metallicus and *Rasbora* spp.	9	13	2	0
Carssius auratus	0	0	0	19
Puntius spp.	0	0	5	0
Squaliobarbus spp.	0	0	0	5
Other fishes	12	1	21	4
Total fishes	75	54	84	58
Other animals				
Frogs (a)	18	13	10	0
Snails (a)	0	0	2	31
Ricefield crabs (a)	2	26	1	1
Freshwater prawns and shrimps	5	7	2	10
Insects (a)	0	0	1	0
Total other animals	25	46	16	42
Total SRS	100	100	100	100
Amphibious (a) SRS	74	79	70	62
Composition of CS catch (%)				
Pangassius spp.	92	0	0	0
Cyprinus carpio	0	0	47	3
Cirrhinus molitorella	0	0	0	41
Ctenopharyngodon idella	0	0	0	22
Hypothalmichthys molitrix	0	0	0	31
Barbonymus gonionotus	0	0	20	0
Oreochromis niloticus	0	100	11	2
Clarias macrocephalus (a)	0	0	15	1
Other fishes	8	0	7	0
Total CS	100	100	100	100
Amphibious (a) CS	0	0	15	1

Amphibious species or groups are indicated by (a). All fish species and other groups contributing at least 5% to the total are listed. Results for the environmentally very different study areas in Cambodia are shown separately.

varied greatly between countries: 24 in Cambodia, 66 in Thailand and 17 in Vietnam.

In Cambodia and Thailand catches were dominated by self-recruiting species (SRS) while in Vietnam, cultured species of fish (CS) were most important (Table 2). Fishes accounted for the bulk (between 54% and 84%) of the SRS catch in all locations and were most dominant in Thailand and Svay Rieng (Cambodian lowland), areas with extensive rainfed rice fields and abundant perennial water bodies. Conversely, non-fish SRS were most important in the dry Cambodian uplands (Takeo) and in the largely irrigated farming landscapes of Vietnam.

The most important SRS fish species by weight were chevron snakehead *C. striata*, climbing perch *Anabas testudineus*, walking catfishes *Clarias* spp., gold fish *Carassius auratus*, silver barbs *Puntius* spp., barbel chub *Squaliobarbus* spp., and a lumped group of small fishes comprising the flying barb *Esomus metallicus* and *Rasbora* spp. (Table 2). Snakehead, climbing perch and walking catfish are important throughout the region, while the small fish group (*Esomus* and *Rasbora*) is important only in Cambodia and Thailand and gold fish only in Vietnam. Among the non-fish SRS, most important were frogs *Rana* spp., Snails (the pulmonate apple snail *Pomacea* spp. and prosobranch pond snail *Sinotaia* spp.), rice field crabs *Somanniathelphusa* spp., freshwater shrimps (including *Macrobrachium* spp.), and various insects. Both fishes and non-fish SRS included amphibious animals that overall accounted for between 62% and 79% of the SRS catch.

Cultured species were entirely dominated by fishes, with the most important species being river catfish *Pangasius* spp., common carp *Cyprinus carpio*, mud carp *Cirrhinus molitorella*, grass carp *Ctenopharyngodon idella*, silver carp *Hypophthalmichthys molitrix*, silver barb *Barbonymus gonionotus*, Nile tilapia *Oreochromis niloticus*, and African walking catfish *Clarias macrocephalus*. Distinctly different sets of cultured species predominated in different regions: pangasiid catfish and Nile tilapia in Cambodia; common carp, silver barb, walking catfish and Nile tilapia in Thailand; and mud, grass and silver carp in Vietnam. Amphibious species made only a small contribution to the CS catch.

3.2. SRS production in FMAS vs. open water bodies

Throughout the study regions, households divided their fishing effort equally between FMAS and open water bodies, expending on average 0.8 fishing trips and 1.3 h/week on each (GLM, no significant country effects). The only exception was the Thai province of Sisaket where frequency (1.4 vs. 0.6 trips per week) and time spent (2.3 vs. 1.9 h/week) were higher in FMAS compared to open waters (GLM, $p<0.05$). Fishing was carried out with a wide range of methods. Active methods such as cast- and lift-netting, draining, collecting by hand and harpooning accounted for 74% of catches by weight, with the remainder being passive methods such as gill netting, trapping and use of baited hooks. Catch rates (CPUE) were significantly higher (GLM, $p<0.05$) in FMAS than in OWB in Svay Rieng province in Cambodia (Takeo was not represented due to deficiencies in effort data), in Thailand and in Vietnam (Fig. 1). In most cases therefore, harvesting of SRS from FMAS provided significantly higher returns to effort than harvesting of wild aquatic animals from open water bodies.

Within FMAS, rice fields and ponds contributed about equally to SRS catches in Cambodia and Vietnam (GLM, $p>0.05$), while rice fields were the dominant source of SRS in Thailand (GLM, $p<0.05$) (Fig. 2). No significant difference was found in SRS catch rates between FMAS that included ponds and those that comprised only

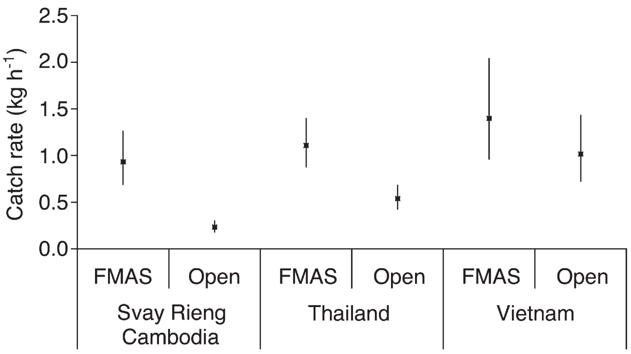

Fig. 1. Mean SRS catch rates (catch per unit of effort, CPUE) in FMAS vs. open waters (with 95% CI). (Only Svay Rieng province is shown for Cambodia because effort data were unavailable for Takeo).

rice fields. Ponds however played an important role in extending the seasonal availability of SRS in the rainfed and flood-prone FMAS of Cambodia and Thailand, where ponds were the dominant source of SRS during the dry season (Fig. 3). In the largely irrigated FMAS of Vietnam, no clear seasonality of SRS catches or their source was evident.

3.3. Within-FMAS management and its impact on total catch rates of aquatic animals

Only farmers that owned, or had exclusive access to FMAS other than rice fields practiced active management to increase aquatic animal production. Therefore only farmers that had at least one FMAS other than rice fields were included in the characterisation of management practices. A total of 12 management activities were found to be commonly practiced in FMAS (Table 3). The monitoring survey provided detailed information on FMAS management activities. Between 53 and 92% of the farmers monitored practiced at least one activity to manage their aquatic system. An overview of activities for all countries is given in Fig. 4. In Cambodia, farmers practiced on average 2.9 activities in the lowland, and 1.2 activities in the upland province, a significant difference (GLM, $p<0.05$). In the Cambodian lowland the most common activities were drying and deepening the pond, brush parks, stocking, feeding and water management. In the upland, feeding and stocking were most common. Thai farmers practiced the fewest activities (1.6 activities household^{-1} on average, GLM, $p<0.05$), and the most common were constructing brushparks, stocking and feeding. Vietnamese farmers with ponds practiced significantly more activities (GLM, $p>0.05$) than those in Cambodia or Thailand (4 activities/household), with feeding, stocking and pond preparation practiced by more than half of the households monitored.

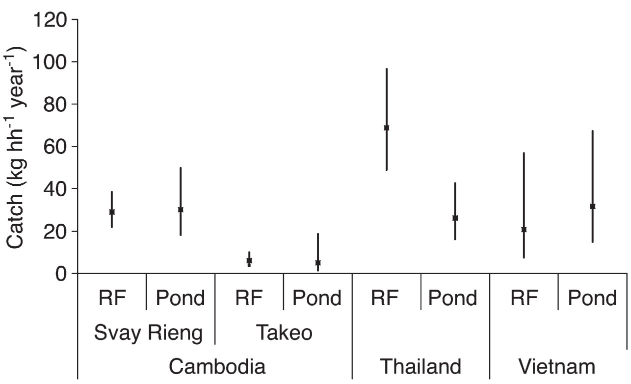

Fig. 2. Mean annual SRS catch per household from rice fields (RF) and ponds (with 95% CI).

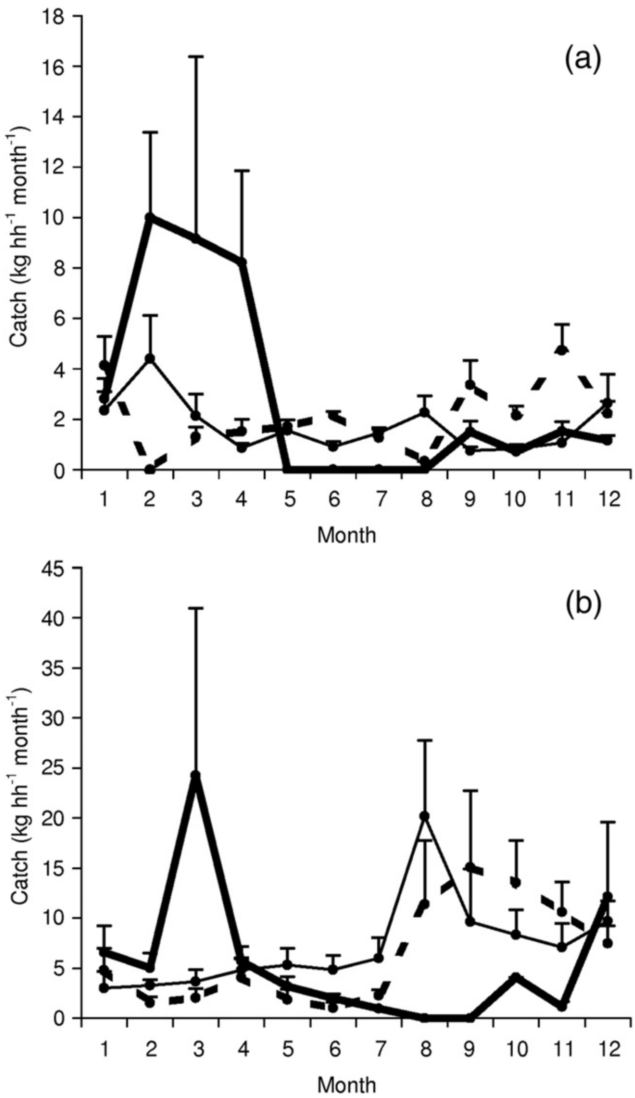

Fig. 3. Seasonality of mean SRS catches per household (with SE), from FMAS components (rice fields and ponds) and OWB (all open water bodies) in Cambodia (a) and Thailand (b). Rice fields (heavy dashed line), ponds (heavy solid line) and open waters (light solid line).

The effects of management measures on total catch rates (combined SRS and CS) are shown in Table 3. In the Cambodian FMAS, dominated by SRS, only construction of building brush parks had a significant positive effect. In the Thai FMAS, equally dominated by SRS, only fertilisation was associated with a positive effect on CPUE. By contrast, strong effects were apparent for a range of management measures (owning a pond, feeding, pond preparation and stocking) in Vietnam where ponds within FMAS were managed comprehensively as carp polyculture systems.

4. Discussion and conclusions

4.1. Diversity and characteristics of aquatic resources harvested from FMAS

A substantial diversity of SRS and CS was harvested in all study locations, consistent with earlier studies of SE Asian rice farming landscapes and aquaculture systems (Heckman, 1979; Edwards et al., 1997; Ali, 1990). The diversity of harvested SRS was highest in Cambodia and Thailand, where rainfed rice farming of low to moderate intensity predominated and SRS were not intentionally excluded or eliminated

Table 3
Effects of various management measures on the total aquatic animal catch rates in FMAS.

Management measure	Effect on catch rates (%) [95% CI]		
	Cambodia	Thailand	Vietnam
Owning a pond			
Incorporating a pond in the FMAS (as opposed to rice fields only)	–	22 [−37, 139]	**415 [86, 1324]**
Brush park			
Piles of branches or bamboo to attract wild fish, create habitat and substrate for periphyton, and prevent poaching.	**127 [22, 322]**	10 [−30, 74]	–
Dike management			
Repair or build dikes to restrict fish movement or prevent flooding.	–	–	−6 [−65, 153]
Cleaning pond			
Remove unwanted plants from the pond	−37 [−75, 57]	74 [−36, 384]	–
Draining			
Pond is drained in order to eliminate predators and improve the pond environment, or to aid harvesting.	−11 [−52, 64]	–	115 [−9, 411]
Feeding			
Feeding with any indigenous or industrial feeds, also installation of light to attract insects.	70 [−9, 217]	0 [−37, 60]	**437 [109, 1280]**
Water management			
Removing or adding water, screening inlet and outlet with fences or nets to restrict fish movements.	9 [−44, 116]	53 [−20, 196]	111 [−5, 375]
Fertilisation			
Manuring (cow, buffalo, chicken, bird), or addition of urea.	–	**90 [1, 264]**	30 [−50, 241]
Pond preparation			
Draining liming and/or pesticide use to eradicate the wild fish in the pond prior to stocking of hatchery fish.	–	–	**138 [6, 430]**
Treatment of fish disease			
Treatment of fish disease using pieces of banana tree trunk	–	–	–
Stocking			
Release of juvenile fish produced in hatcheries or caught in the wild	50 [−21, 185]	1 [−36, 62]	**194 [5, 722]**
Deepening pond			
Deepening the pond to create a deep and permanent pool of water	41 [−26, 170]	–	–

Effects shown in bold are significant (GLM, $p<0.05$). Where no effect is shown, the management measure is not or rarely practiced and so that its effectiveness could not be evaluated. For convenience of interpretation, effects are shown as proportional changes relative to the non-managed average.

from FMAS. Lower SRS diversity was found in Vietnam, most likely reflecting the predominance of irrigated rice fields which provide less habitat for truly aquatic organisms and active exclusion/elimination of SRS from ponds (Amilhat et al. al., 2009). It is interesting if unsurprising to note the predominance of amphibious species among SRS. Amphibious fish including the chevron snakehead *C. striata*, climbing perch *A. testudineus* and walking catfish *Clarias* spp. are able to breathe air (obligatory in some species), 'walk' over moist ground, and survive buried in mud for extended periods (Sayer, 2005). Amphibia, rice field crabs, snails and aquatic insects show similar or equivalent adaptations. Such adaptations allow amphibious organisms to colonize rice farming landscapes where aquatic habitats are extensive in area, but seasonally or intermittently dry and also fragmented by dikes. The ability of amphibious species to disperse across terrestrial barriers implies that connectivity of aquatic habitats is unlikely to be a major limitation to SRS production in FMAS. However, availability of truly aquatic habitat of sufficient depth is important to sustain production of primarily aquatic organisms such as fish. This is reflected in the greater contribution of fish to SRS production in the deep-water, rainfed and flood-prone rice farming landscapes of lowland Cambodia and Thailand compared to the shallow-water, irrigated landscapes of Vietnam.

The diversity and composition of CS reflect preferences for, and availability of different hatchery-bred or wild caught seed fish. In Cambodia, capture-based aquaculture of pangasiid catfish is a traditional industry, though seed is increasingly sourced from Vietnamese hatcheries (Poulsen et al., 2008). Pond and rice-fish culture of other species including the Nile tilapia is of more recent origin but expanding rapidly (Gregory and Guttman, 2002b). Cultured or captured species are thus increasingly stocked into FMAS which now produce a true mix of CS and SRS. In Thailand, flexible polyculture of silver barb, common carp, Nile tilapia and Chinese and Indian major carp is commonly practiced within extensive or semi-intensive pond aquaculture systems (Edwards et al., 1997; Demaine et al., 1999; Michielsens et al., 2002). However, use of CS remains minimal in many areas where SRS are productive, as is borne out in our study. In Vietnam, CS dominate overall catches from FMAS. Most ponds in the study area were managed through a well-developed, integrated carp polyculture technology (Edwards et al., 1997; Luu et al., 2002; Michielsens et al., 2002). The majority of CS recorded (*C. carpio*, *C. idella*, *H. molitrix*, *O. niloticus* and *C. macrocephalus*) were non-native species known to be widely used in aquaculture and fisheries enhancement in SE Asia (De Silva et al., 2006; Arthur et al., in press).

4.2. Catch rates of SRS in FMAS and open systems

Cambodian and Thai FMAS supported significantly higher catch rates of SRS than were achieved for wild aquatic animals in local open water bodies. This difference in catch rates indicates an underlying difference in aquatic animal abundance. Reasons for greater abundance of SRS in FMAS are likely multiple, including lower harvesting effort due to restricted access, rich food resources supported in part by agricultural and aquacultural inputs, and the effects of management measures. Previous studies have shown dramatic increases in aquatic animal abundance associated with access restrictions, as well as close relationships between trophic status and fish yield in communal water bodies (Lorenzen et al., 1998a,b). Vietnamese sites had the highest average catch rates of SRS, but there was no significant difference between FMAS and open water bodies. This may reflect the strong contribution of non-fish aquatic animals, high levels of nutrient inputs, and widespread use of measures to eliminate SRS from FMAS. Owning ponds as part of FMAS did not increase SRS catches or catch rates, but extended SRS availability into the dry season. Ponds account for only a small share of average FMAS area (Amilhat et al., 2009) and natural biological production is therefore likely to be dominated by the ricefield component of FMAS.

4.3. Effects of within-FMAS management measures on aquatic resource productivity

A wide range of traditional and more recent (modified) management measures were practiced in all study regions, illustrating the diverse and dynamic nature of aquaculture systems in the region (see also Edwards et al., 1997; Michielsens et al., 2002). However, in the SRS-dominated FMAS of Cambodia and Thailand, only construction of brush parks and fertilisation increased SRS catch rates. Brush parks are well known to act

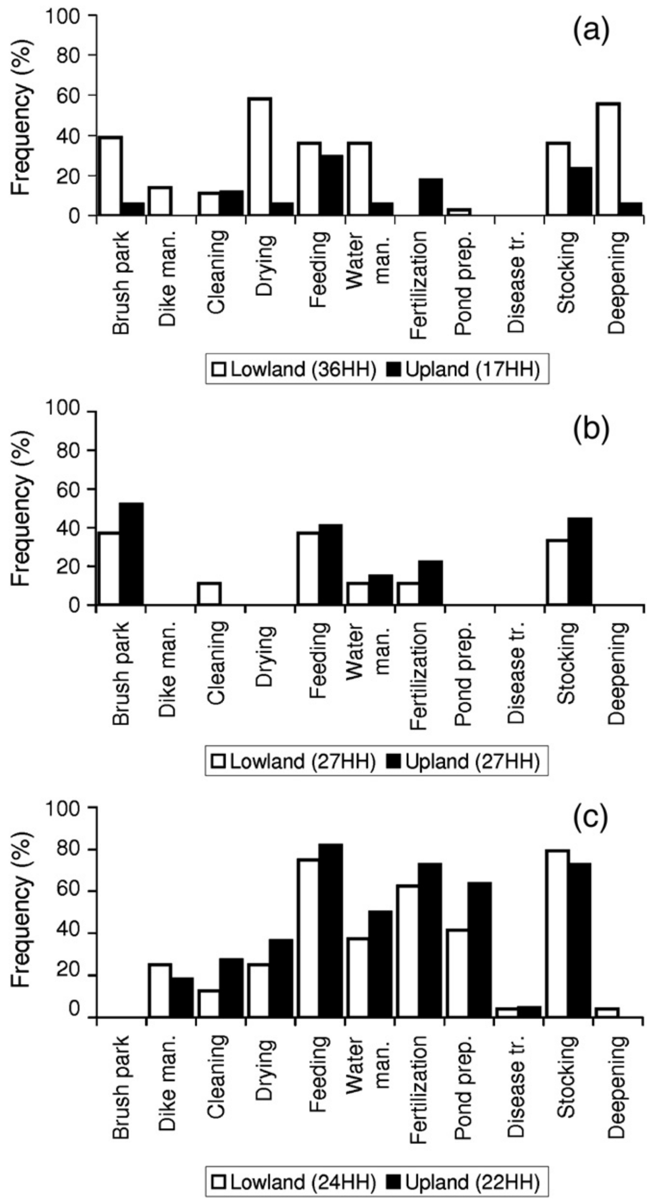

Fig. 4. Frequency of different FMAS management activities undertaken by monitored households in the three countries and lowland vs. areas.

as fish aggregation devices and to provide substrate for periphyton that can be utilised by fish (Welcomme, 2002). Likewise, fertilisation is a common measure to increase fish production in ponds and may help to sustain the high densities of fish typically aggregated in trap ponds, which are likely to suffer extreme resource limitation (Amilhat and Lorenzen, 2005). Other management measures practiced in the SRS-based systems of Cambodia and Thailand were found to be ineffective. This is likely to reflect low input levels and a continued reliance of SRS production on natural aquatic biological production. By contrast, Vietnamese FMAS operated as semi-intensive aquaculture systems with high levels of inputs, and production responded well to a wide range of management measures.

Our results show how survey-based research within an FMAS framework can be used not only to identify and characterise different farmer-managed systems at the aquaculture–fisheries interface, but also to evaluate the effectiveness of various management measures at the disposal of farmers. When interpreting results on management effectiveness however it must be borne in mind that data were collected through an analytical survey, not a designed experiment (Eberhardt and Thomas, 1991). Treatments (management activities) were allocated to experimental units (individual FMAS) by farmer decision making, not at random. This may lead to biased estimates of the effectiveness of management measures when farmers adopt measures in response to the perceived status of their FMAS, such as stocking systems of below-average SRS production, or building brush parks to restrict fishing by others in systems that are particularly productive. The possibility of such biases is difficult to avoid in on-farm studies.

4.4. Role of FMAS in aquatic resource production and conservation

The improved availability (higher catch rates) and diversity of aquatic resources, in particular SRS, harvested from FMAS improve overall food availability and nutrition in rural households, particularly with respect to micronutrients (Shams, 2007; Roos et al., 2007a,b). Aquatic resources from FMAS therefore contribute to the overall nutrition benefits derived from rice agriculture (Welch and Graham, 1999). It is also likely that SRS contribute to pest control and other ecosystem services within the rice farming system (Frei and Becker, 2005), in a way similar to the well documented role of terrestrial biodiversity (Altieri, 1999). FMAS covered a large surface area, were colonized by a substantial diversity of SRS, and supported higher levels of SRS abundance (as inferred from catch rates) than open waters. This suggests that the man-made habitat of FMAS may benefit aquatic biodiversity conservation by increasing overall aquatic habitat area and providing a high quality matrix that promotes movement of aquatic animals between natural open water bodies (Rosenzweig, 2003; Amilhat and Lorenzen, 2005; Perfecto and Vandermeer, 2008). We suggest that FMAS and the aquatic resources they support should receive greater attention in agro-ecological research and extension (Altieri, 2002).

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