Impacts of irrigation development on capture fisheries in the rice-based farming systems of southern Laos

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Summary

Fish populations inhabiting the rivers, streams, natural wetlands and paddy fields of rice-based farming systems support capture fisheries of major importance to local livelihoods. Water resources development for irrigation has the potential to impact significantly on these fisheries by modifying habitats and their connectivity, as well as patterns of exploitation. We conducted a field survey to establish the impacts of small to medium sized weir and dam irrigation schemes on local fisheries in the rice-based farming systems of southern Laos. The survey was replicated at the irrigation scheme level. Impacted sites were paired with non-impacted controls within the same watershed. Weir schemes were associated with a significant decline in households and per-area catches which as not fully explained by a concomitant change in fishing effort. Dam schemes caused no significant overall decline in catches, but a very significant re-distribution of catches and effort into the newly created reservoirs. In both weir and dam schemes, changes catch were largely explained by changes in fishing effort. No significant impacts on fish species richness were detected. Small-to-medium sized irrigation schemes have only moderate impacts on local fisheries in rice-based farming systems. Net impacts of weirs may be more pronounced than impacts of dams. Rather than being fundamentally degraded as often assumed, fish populations and the fisheries they support can remain productive and diverse within irrigated rice systems. Protecting and enhancing wild fish stocks in such systems is likely to generate social and ecological benefits.

Key words: irrigation development, tropical inland fisheries, impact assessment

Introduction

Inland fisheries play an important role in rural livelihoods in many developing countries, in particular within the most resource-poor sections of the population (ADB, 2002). The productivity and diversity of the aquatic resources upon which these fisheries depend is closely linked to the functioning of aquatic ecosystems, hence inland fisheries link environmental and food security issues in a unique way.

The productivity and diversity of inland aquatic resources are strongly affected by the development of water resources for irrigation, hydropower generation, and urban and industrial uses. In rural areas of the developing world, irrigation is widely seen as the single most important intervention impacting on fisheries. Irrigation systems may abstract and deplete (through evapotranspiration) a large proportion of the annual flow from tropical river basins, and reduce the overall availability and ecological connectivity of aquatic habitats. In addition to direct physical and ecological impacts, irrigation development may affect fishing practices, use rules and the opportunity costs of fishing. Hence the overall impacts of irrigation development on fisheries are multiple and varied.

It is now recognized that fisheries impacts should be considered in the planning and management of irrigation development, but there is a lack of reliable quantitative impact assessments to inform this process (WCD, 2000). Although substantial qualitative knowledge has been generated in recent years (mainly through detailed descriptions of impacts on fish ecology), to date and to our knowledge, no quantitative assessment of the impacts on fishing activities and their consequences for rural livelihoods has substantiated the qualitative information. As a result impacts on fisheries are often effectively ignored in performance analyses of irrigation schemes. Despite growing awareness, aquatic ecosystems continue to be degraded by unsound forms of utilization (ADB, 2002).

The aim of our study is to assess quantitatively the fisheries impacts of irrigation development within rice-based farming systems. Rice-based farming systems support a large share of the rural population in South, Southeast and East Asia, and in parts of West Africa. Rainfed rice paddies are designed to store water for extended periods, creating aquatic ecosystems with many similarities to natural floodplains (Heckmann 1979). Like floodplain habitats paddies are colonized by fish during the wet season and contribute substantially to the overall fisheries production of the river-floodplain system. Fishing, often carried out on an occasional or part-time basis, makes a significant contribution to livelihoods in many rice-based farming systems.

Irrigation development in rice-based systems aims to allow cultivation of a second crop of rice or another field crop, or at the very least to secure a single crop in dry years. The present study is concerned with small to medium scale irrigation schemes, irrigating command areas of up to about 500 ha. The schemes considered in this study use gravity to supply water to fields via canals, but differ in the diversion structures used abstract water from rivers. Weirs are relatively low structures that divert water without creating a significant storage reservoir. Dams involve significant storage of water in reservoirs.

Weir irrigation schemes have the effect of exacerbating the natural seasonality of river flows, abstracting water mostly during the dry season when irrigation demand is highest. Dam schemes on the other hand tend to attenuate natural flow patterns, retaining a large share of peak flows in the reservoir but increasing dry season flows due to drainage and seepage.

We carried out a quantitative assessment of irrigation impacts on artisanal fisheries in Southern Laos. The study was designed as a paired comparison of household fishing effort and yield as well as local fish stock diversity between irrigated and non-irrigated sites.

Material and methods

STUDY AREA

In Laos, the climate is tropical with an average daily temperature of 31°C and an average annual precipitation of 1500 mm, about 75% of which occurs in the monsoon season (May to October). Rice is the single most important crop in Lao agriculture, accounting for about 80% of the cultivated area. More than 85% of rice produced is of traditional varieties of the glutinous type, and annual yields are in the range of 1.5 to 2.8 t/ha. Only 3% of the paddy area is irrigated, and the dependence on rainfed systems is seen as the major constraint to the expansion of rice production (Suan 1989; IRRI 1999). Agricultural production in the rainfed areas tends to be subsistence-oriented.

Field studies were carried out in three provinces of Southern Laos: Khammouane, Savannakhet and Champassak. The lowlands of Savannakhet and Champassak provinces are among the major rice producing areas in Laos, together accounting for over a third of national rice production. Much of Khammouane is mountainous, making the province a less important, but still significant area for rice production.

The study covered weir and dam irrigation schemes with command areas ranging from 17-515 ha (average 155 ha) and associated paddy areas varying from 3 to 346 ha (average 93 ha). Weir schemes and the respective control sites were located mostly in the upper reaches of watersheds, while dam sites and controls were located in lower reaches. Consequently both irrigation command and overall aquatic habitat areas were smaller in weir sites and controls than in dam sites and controls. Within all irrigation schemes, the wet season rice crop was cultivated as a largely rainfed crop and there was little land engineering.

STUDY DESIGN

The study was replicated at the irrigation scheme level based on the paired comparison of catch, effort and species richness at sites impacted by irrigation and non-impacted control sites. Control sites were located within the same watershed and on a river of the same order as the impacted site. A paired design was chosen to minimize environmental variation and maximize the statistical power of the comparisons. Preliminary investigations suggested that 50% reduction in fish catches would be sufficient to offset the net benefits of many irrigation schemes. Hence the survey was designed to detect a 50% reduction in catch at a level of significance of ? = 0.1 and power of 1-? = 0.9. Based on estimates of within and between-village variance in fish catches (Garaway 1999), power analysis suggested that ten paired sites with samples of ten households in each would be sufficient to meet the design criteria. Hence the weir and dam studies were designed with ten paired sites each.

SURVEY METHODS

At each site, we carried out a site survey, a household fishing survey, and a fish biodiversity survey. The household fishing and biodiversity surveys were carried out twice, in the dry season and the period of receding floods.

The site survey was designed to provide general information on the village (population, paddy area, irrigated area), and to quantify habitat availability. Villagers were asked to draw water body maps for the local area. Surveyors then measured area, depth, and some other characteristics of the water bodies.

The household fishing survey covered ten households selected at random from the village list. Surveyors carried out a detailed interview in each selected household, collecting data on fishing events (person fishing, time fished, and catch in weight) with a one-week recall. The interview method was adapted from a previous survey (Garaway, 1999) and involved the use of aids such as bowls of different size and sticks of different length to help the villagers in quantifying their catches. Catches were recorded separately by habitat type. To assess whether irrigation development impacted on the fisheries productivity of floodplain habitats (including paddies), catch and effort per unit habitat area were calculated by multiplying average household catch with the number of households, and dividing by the average (wet and dry season) aquatic habitat area in the village proper.

For the fish diversity survey, large groups of villagers fished in all local aquatic habitats for a fixed period of about two hours. All fish caught were preserved and identified to species level in the laboratory. The number of specimens obtained differed between sampling locations, and species richness was positively correlated with the total number of specimens obtained. To correct for this sampling effect, average richness of computer generated re-samples of 30 fish (the lowest number of specimens obtained for a site) was used in the analysis of species richness.

DATA ANALYSIS

All survey data were stored in a relational database. Exploratory analyses showed that the paired differences in catch, effort and species richness were slightly skewed and leptokurtic. A non-parametric bootstrap was used to generate confidence limits for effects. Regression analysis of logarithmically transformed catch and effort per unit area was used to assess whether observed variation in catches could be explained by variation in effort.

Results

BASELINE DATA

Participation in natural aquatic resource use was near universal in all sites, with 83% of households fishing during the survey period. In the non-impacted sites, average household fishing effort was consistently about 5 h/week, but household catches were lower in weir controls (0.77 kg/week) than in dam controls (2.07 kg/week). This difference in catches is likely to reflect differences in the hydrology of weir and dam controls related to their different locations within watersheds. On a per-area basis, fishing effort was much higher in weir than in dam controls (6.6 vs. 2.9 h/ha/week) while catches were similar. Species richness was similar between weir and dam sites.

EFFECTS OF IRRIGATION SCHEMES ON OVERALL HOUSEHOLD FISHING EFFORT AND CATCHES

Average household catch and effort in the paired sites are shown in Fig. 1. A strong pair effect is noticeable, i.e. overall household catch and effort are far more variable among than within pairs. Pairing of impacted and control sites within watersheds has effectively reduced environmental variation.

Weir schemes were associated with and a significant 36% decline in household catch and a smaller, non-significant decline of 14% in household effort (Table 1). Overall this indicates a moderately negative effect of weir irrigation schemes on fish catches, partly but not fully explained by a decline in fishing effort. Declining fishing effort may in itself be the result of increased demand for labour in other activities (such as irrigated agriculture), and/or a reduction in the actual or perceived opportunity for fishing due to changes in fishable habitat or fish abundance.

No significant overall impact on household catch or effort was detected for dam schemes, although a tendency towards reduced household catch and effort was noticeable (-17% and –13% respectively). However, the lack of a significant overall effect hides very substantial changes that emerged when analyzing the data separately between floodplain habitats and the newly created reservoirs. Dam schemes were associated with drastic and statistically significant reductions in floodplain catch (-51%) and effort (-58%) on a household and unit area basis. Increases in reservoir catch and effort partially compensated for the reduction in floodplain fishing, so that overall effects were not significant.

Relationships of catch per unit area (CPUA) and CPUE to effort per unit area are given in Fig. 2, aggregated over all habitats other than reservoirs. Catch-effort relationships for weir an dam sites (impacted and controls) had a similar slope but the intercept was significantly higher in dam sites and the associated controls than in weirs and controls. This reflects underlying differences in physical and hydrological site characteristics. Impact status (impacted/control) had not significant effect on the relationship between CPUA or CPUE and EPUA in either weir or dam sites.

Discussion

The overall impacts of irrigation development on household catches in weir and dam irrigation schemes have been assessed as moderately negative. These impacts are largely but not fully (in the case of weirs) explained by differences in fishing effort. A slight reduction in fishing effort observed within irrigation schemes in general is likely to reflect increased opportunity costs of fishing. In the case of dam schemes, it is difficult to ascertain to what extend the observed shift in fishing activities from river-floodplain to reservoir habitats reflects a positive response to new fishing opportunities in the reservoir, and to what extent this change is forced by degradation of the river-floodplain habitat. The fact that no significant impact of irrigation schemes on per-area catch-effort relationships could be detected suggests that impacts on activities and catches reflect predominantly responses to opportunities. Impacts on fish stock productivity and diversity appear to be limited overall.

The low overall level of irrigation impacts on fisheries productivity and stock diversity in the rice-based farming systems of southern Laos may be surprising, given the substantial impacts of weirs and dams on river flows and longitudinal connectivity of river habitats (WCD 2000; Welcomme 2001). Two likely contributing factors are the nature of the rice-based farming systems, and the fact that the schemes assessed were embedded into largely intact river-floodplain systems. Rainfed rice farming systems constitute extensive quasi-floodplain habitats, the hydrology of which is driven by runoff and direct precipitation rather than river flow and level. Hence the hydrology of rice fields which represent the largest aquatic habitat in the systems studied is insensitive to modifications of river flow. Their fisheries productivity is likely to be maintained as long as ecological connectivity with perennial habitats is sufficient to allow colonization by fish. As colonization is linked to seasonal migrations significant colonization is unlikely to occur in the second, irrigated production cycle. Hence, unless water is maintained in the paddy between production cycles, the irrigated crop is unlikely to add significantly to annual fisheries production. A crucial factor in rice field fish production is the maintenance of a sufficient water level, at least in the initial stages of cultivation. This was the case in all sites assessed, where the wet season crop was cultivated in the traditional rain fed way even in irrigated sites. Elsewhere in Asia, there has been a tendency to use irrigation water even during the wet season and to drastically reduce storage within the rice field. This modification in farming practice may well have a more dramatic impact on local fisheries production than the development of irrigation infrastructure as assessed in the present study.

A second factor likely to contribute to the moderate level of impacts detected is the fact that impacted sites were embedded within largely intact river systems. This configuration allowed us to adopt a rigorous comparative methodology in the first place, but it also meant that colonization of irrigated sites from the surrounding area could raise local productivity and diversity. Cumulative and synergistic impacts are likely to occur as a result of increasing density of small-to-medium schemes, and consecutive repeated interruptions of longitudinal connectivity in rivers and streams. Hence further studies at catchment level are warranted to assess these issues.

There are several important implications of these results for the assessment and mitigation of irrigation development impacts on fisheries. Firstly, impact assessments must consider responses in exploitation patterns as well as ecological effects in retrospective and predictive assessments. Secondly, ecological attributes of rice-based farming systems are such that they may support productive fisheries even within irrigated areas. Irrigation water management and farming practices within irrigated rice systems may have a greater impact on their fisheries productivity than irrigation infrastructure per se. Thirdly, cumulative and synergistic impacts of irrigation schemes should be considered even where the individual scheme has appears to have only a limited impact.

Adequate guidelines and tools for the assessment of irrigation development impacts on fisheries should be developed and integrated into the commonly used Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) frameworks.

Even within irrigated rice farming systems, natural aquatic resources can be productive and diverse. Thy may continue to play an important role in rural livelihoods, and add considerable value to the use of water in agricultural areas. This value should be quantified particularly in the estimation of water productivity and considered in water allocation decisions. Measures should be taken to conserve and enhance natural fisheries productivity and diversity in irrigated rice systems for social and ecological benefits. In the face of increasing pressure on water resources, this will make an important contribution to the conservation of inland aquatic resources in the tropics.

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Table 1 Results of the paired comparisons of average household fishing effort (HH effort) and catch (HH catch), catch per unit of effort (CPUE), effort (EPUA) and catch (CPUA) per unit area (average of wet and dry season area including paddies), and species richness.

	Weir sites		**Dam sites (overall)**		**Dams (outside reservoir)**	
	NI	**Effect**	**NI**	**Effect**	**NI**	**Effect**
HH catch (kg/week)	0.77	**-0.28 [-0.50, -0.10]** **- 36 %**	2.07	-0.36 [-1.18, 0.27] - 17 %	1.80	**-0.91 [-1.89, -0.12]** **-51 %**
HH effort (h/week)	4.84	-0.69 [-1.64, 0.21] - 14 %	5.55	-0.72 [-1.91, 0.62] - 13 %	4.48	**-2.58 [-4.04, -1.13]** **-58 %**
CPUE (kg/h)	0.15	+0.01 [-0.04, 0.07] + 7 %	0.38	0.29 [-0.05, 0.82] + 76 %	0.37	-0.04 [-0.17, 0.10] - 11 %
CPUA (kg/ha/week)	1.01 0.52	**-0.63 [-1.73, -0.01]** **- 62 %** **-0.07 [-0.14, -0.01]*** **- 13 %**			1.26	**-0.75 [-1.49, -0.13]** **-69 %**
EPUA (h/ha/week)	6.62 4.78	-1.20 [-3.04, 0.39] - 18 % -0.45 [-2.00, 0.90]* - 9 %			2.85	**-1.76 [-2.94, -0.66]** **-61 %**
Richness	9.05	-0.50 [-1.80, 0.60] - 6 %	8.94	+0.40 [-1.65, 2.21] + 4 %		

* Excluding the influential pair W1.

Figure legends

Fig. 1. Average household catch and fishing effort in the paired weir (a, b) and dam (c-f) sites. Non-impacted controls (open bars) and impacted sites (solid bars). For the dam sites, catch and effort are shown overall for all aquatic habitats (c, d) and for habitats other than reservoirs only (e, f).

Fig. 2. Relationships between fishing effort (EPUA) and catch (CPUA) per unit area in weir sites (a, b) and in the non-reservoir habitats of the dam sites (c, d). Non-impacted controls (open squares) and impacted sites (solid squares).

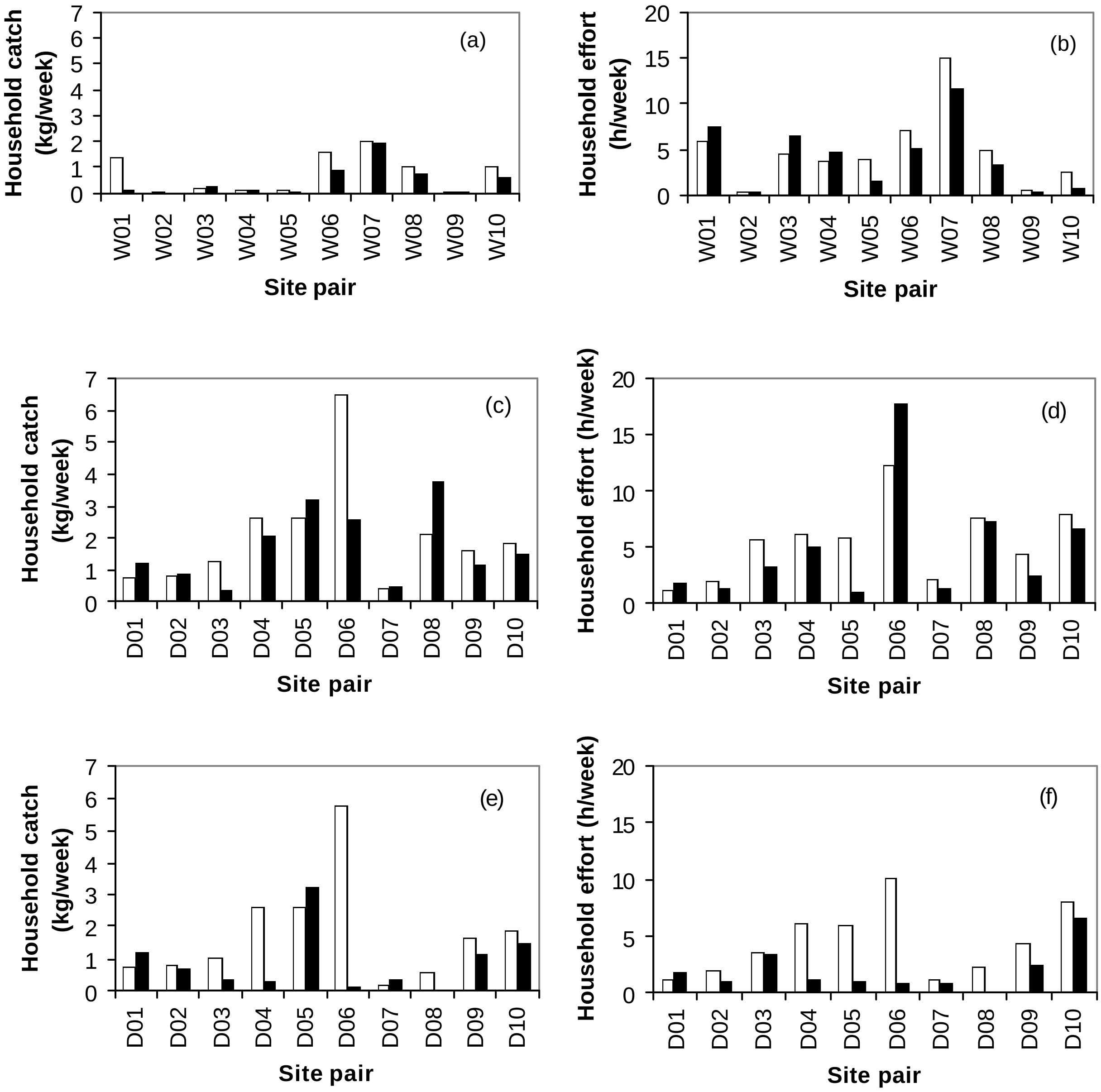
(a)
Household catch (kg/week)
0
1
2
3
4
5
6
7
W01
W02
W03
W04
W05
W06
W07
W08
W09
W10
Site pair
(b)
Household effort (h/week)
0
5
10
15
20
W01
W02
W03
W04
W05
W06
W07
W08
W09
W10
Site pair
(c)
Household catch (kg/week)
0
1
2
3
4
5
6
7
D01
D02
D03
D04
D05
D06
D07
D08
D09
D10
Site pair
(d)
Household effort (h/week)
0
5
10
15
20
D01
D02
D03
D04
D05
D06
D07
D08
D09
D10
Site pair
(e)
Household catch (kg/week)
0
1
2
3
4
5
6
7
D01
D02
D03
D04
D05
D06
D07
D08
D09
D10
Site pair
(f)
Household effort (h/week)
0
5
10
15
20
D01
D02
D03
D04
D05
D06
D07
D08
D09
D10
Site pair

Fig. 1.

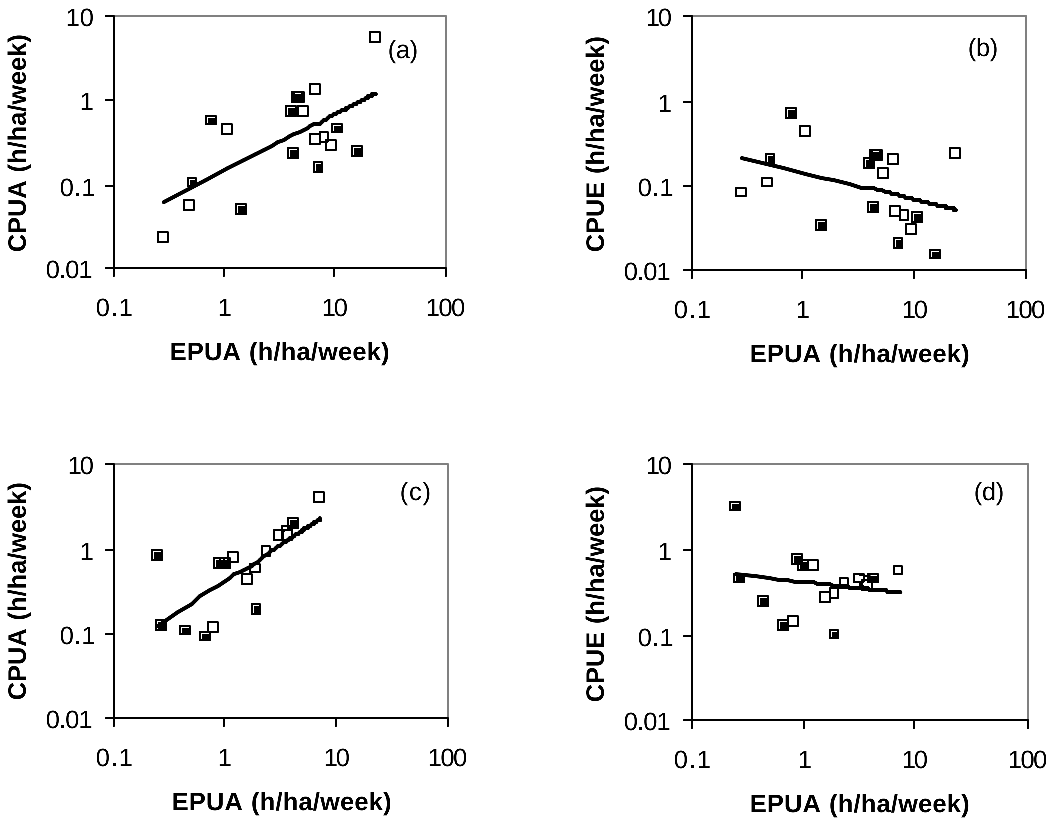
(a)
CPUA (h/ha/week)
10
1
0.1
0.01
0.1
1
10
100
EPUA (h/ha/week)
(b)
CPUE (h/ha/week)
10
1
0.1
0.01
0.1
1
10
100
EPUA (h/ha/week)
(c)
CPUA (h/ha/week)
10
1
0.1
0.01
0.1
1
10
100
EPUA (h/ha/week)
(d)
CPUE (h/ha/week)
10
1
0.1
0.01
0.1
1
10
100
EPUA (h/ha/week)

Fig. 2.