Quantitative estimates of ecological sustainability in integrated agriculture-aquaculture systems in the Philippines

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OUTLINE

- Introduction
  - Why we do this research
  - Sustainability
- Methodology
  - Quirino project
  - Data
  - Ecopath
- Results
  - Ecopath model
  - Diagram
  - Sustainability indicators
- Discussion and conclusions

INTRODUCTION

- Shift in research approach for new technology
  - top-down technology transfer ===> stakeholder participation
  - disciplinary ===> systems approach
  - only food production ==> also environmental and social aspects

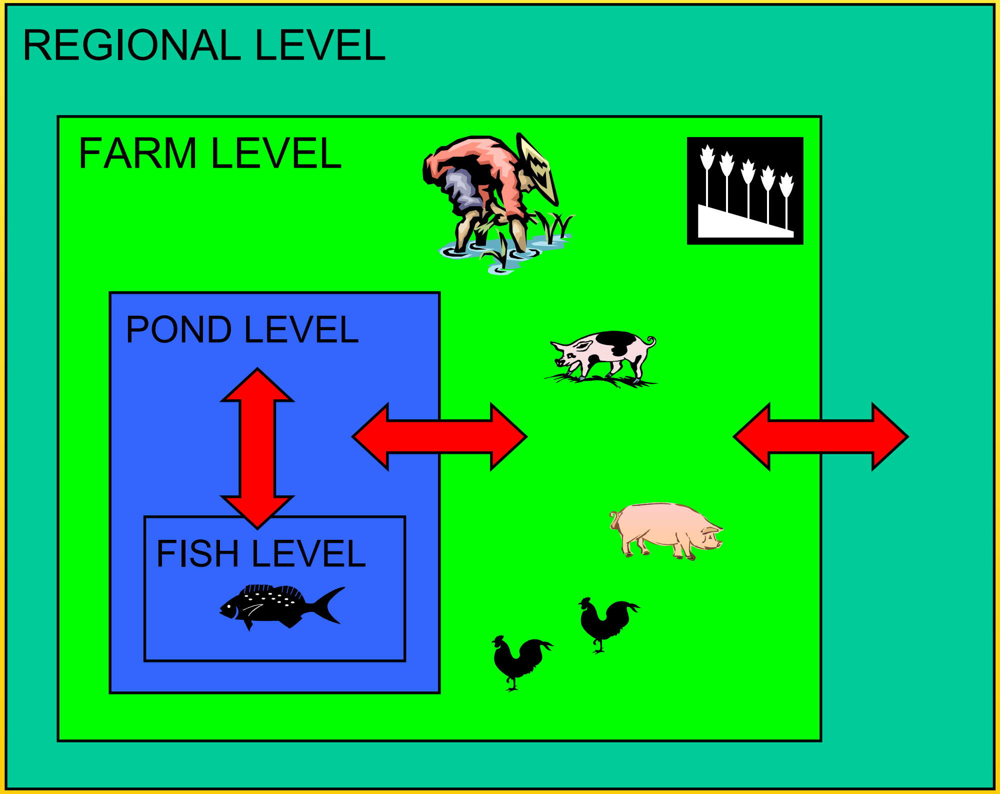
- Limitations of participatory approach
  - keep disciplinary scientists involved
  - quantitative
  - “horizontal upscaling” : how to reach large numbers of farmers with new technology
  - “vertical upscaling”: how to translate local results into regional policies

INTRODUCTION

- Aggregation levels and scale

Decision making is done at different levels:

> allocation of resources: farm level (farmer)
> prices/taxes: regional level (government)
> effects of geographical/climatic/spatial factors
> interdependent ==> complex



- Need to analyze and link different aggregation levels

INTRODUCTION

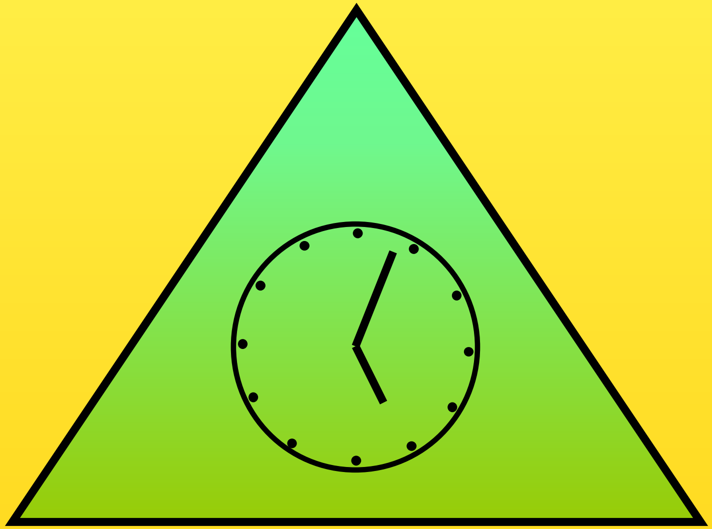
Example: Vietnam, Mekong Delta

- high-density catfish (*Pangasius* sp.) culture
- feed: trash fish
- water quality problems
- profitability (farmer) vs. environment (government)

INTRODUCTION

“Sustainability”

(no conflicts, culturally acceptable)
SOCIAL



ECOLOGICAL
(preserve natural resource base)

ECONOMIC
(food, employment, livelihoods)

INTRODUCTION

- General objectives

> Analyze farming systems quantitatively

> Analyze ecological and economic sustainability, also simultaneously

> Link farm level with watershed/regional levels

- Specific

> Recommend options for development of Ecopath as agroecosystems tool (see Dalsgaard et al.)

Dalsgaard, J.P.T. and R.T. Oficial (1997) A quantitative approach for assessing the productive performance and ecological contributions of smallholder farms. *Agricultural Systems* **55,** 503-533.

Dalsgaard, J.P.T. and R.T. Oficial (1998) Modelling and analyzing the agroecological performance of farms with ECOPATH. *ICLARM Technical Rep*. 53, 54 p.

Dalsgaard, J.P.T., C. Lightfoot and V. Christensen (1995) Towards quantification of ecological sustainability in farming systems analysis. *Ecological Engineering* **4,** 181-189.

METHODOLOGY

- Quirino project

> participatory analysis of farming systems: NRT's, enterprises
> monitoring for 3 years (1995-1998)
> Analysis: RESTORE (database software)
> sustainability indicators

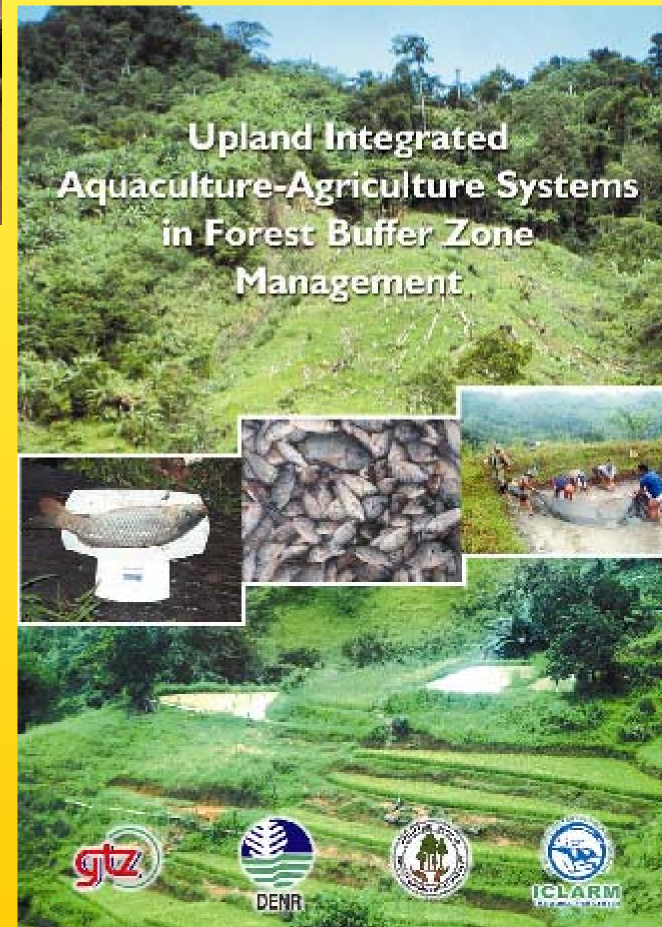
- Dataset (Prein et al.)

> 30 mixed farms
> natural resource types (NRT's)
> resource flows per NRT
> economics

Prein, M., R. Oficial, M.A. Bimbao and T.S. Lopez (2002) Aquaculture for diversification of small farms within forest buffer zone management: an example from the uplands of Quirino Province, Philippines. p. 97-109, In: P. Edwards, D.C. Little and H. Demaine (eds.) *Rural Aquaculture*. CABI Publishing, Oxon, UK.

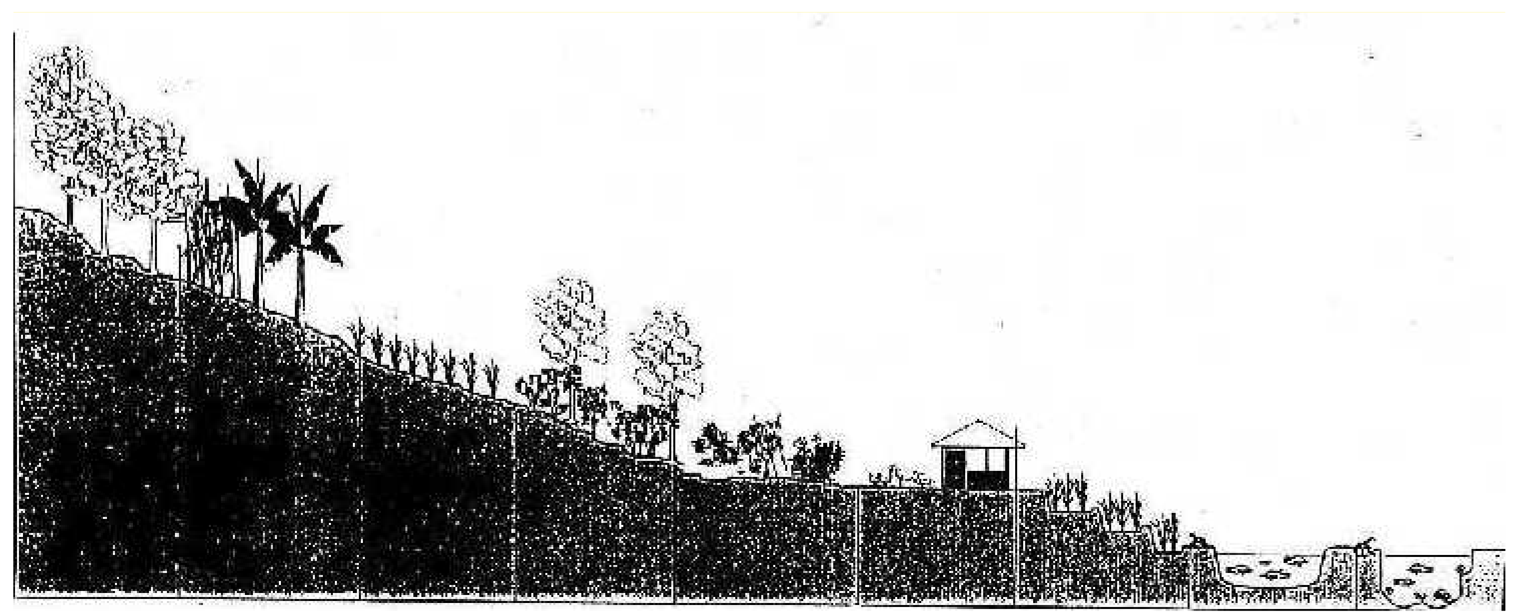
Prein, M., M.A. Bimbao, T.S. Lopez and R. Oficial (1999) *Upland integrated aquaculture-agriculture systems in forest buffer zone management*. Final Report, Philippine-German Community Forest Project Quirino. ICLARM - The World Fish Center, Penang, Malaysia.

Community Forestry Project-Quirino
DENR-Philippines / BMZ-GTZ-Germany
Don Mariano Perez and Baguio Village,
Diffun, Quirino Province, Philippines



METHODOLOGY

Farm transect: NRT - natural resource type
Enterprises - crops, animals, ponds



NRT	Forest reserve	Upland / fallow	Upland rice	Orchard	Vegetable garden	Homestead with livestock	Irrigated rice	Fish pond	Creek / stream
Enter-prises	timber trees, grass, wild animals	banana, some vegetables	rice, some other crops	fruit trees, some other crops	beans, taro, garlic, onions, etc.	livestock, poultry, some crops	rice, azolla, some fish, animals	fish, frogs, azolla, other animals	aquatic animals

METHODOLOGY

- Dataset

Area (ha), location (dmp = Don Mariano Perez, bv = Baguio Village) and natural resource types (NRT) of 30 farms in Diffun, Quirino province, Philippines (from: Prein et al. 1999).

farm no.	no.of NRTs	location	NRT area (ha)								Total farm (ha)
			forest reserve	upland rice	upland/ fallow	orchard	home-stead	fishpond	irrigated rice	veget-ables	
1	7	dmp	5.00	0.00	2.00	1.00	0.05	0.190	0.50	0.25	8.99
2	7	dmp	6.00	0.00	2.00	1.25	0.25	0.013	1.00	0.28	10.79
3	6	dmp	0.50	0.00	1.50	0.25	0.25	0.010	0.25	0.00	2.76
4	7	dmp	8.00	0.00	1.00	3.00	0.02	0.016	0.50	0.50	13.03
5	7	dmp	10.00	0.00	1.00	2.00	0.20	0.045	0.50	0.15	13.90
6	6	dmp	5.00	0.00	4.00	0.25	0.04	0.040	1.00	0.00	10.33
:	:	:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:	:	:
29	4	bv	0.50	0.00	2.50	0.00	0.05	0.000	0.00	0.25	3.30
30	6	bv	1.00	0.00	1.75	0.25	0.06	0.000	0.75	0.50	4.31
no. of farms without NRT			4	26	1	4	0	4	12	20	
overall average NRT area (ha)			1.94	0.08	1.67	0.71	0.06	0.03	0.35	0.08	4.93
average NRT area nonzeros (ha)			2.24	0.56	1.73	0.82	0.06	0.03	0.59	0.25	

METHODOLOGY

- Ecopath-equation: mass balance

Fisheries	**Agro-ecology**	
Production (of a group)	**Production (of a group)**	
=	**=**	
catches	**harvests**	sold, payments in kind, gifts
+ predation mortality	**+ bioresource flows**	on-farm usefor other crops or animals; consumption by household if household is part of the model
+ biomass accumulation	**+ biomass accumulation**	e.g., growth of trees or livestock
+ net migration	**+ (losses - imports)**	<u>losses</u>: e.g., manure produced by animals off-farm; nutrients lost in irrigation water or fishpond effluent; N-volatilization <u>imports</u>: fertilizers and manures bought outside, feeds from outside; dry and wet deposition; nutrients in irrigation water; biological N-fixing
+ other mortality	**+ other mortality**	“un-used” production = flow to detritus

METHODOLOGY

For each functional group:

Production = Harvest + Resource flows + Biomass accumulation + Losses - Imports + Flows to detritus

Or:

$$P_i - H_i + B_i RF_i + BA_i + EX_i - IM_i + P_i(1-EE_i) = 0$$

$$B_i\,(P/B)_i - H_i + \Sigma B_j\,(Q/B)_j\,RF_{ji} + BA_i + EX_i - IM_i + B_i\,(P/B)_i(1-EE_i) = 0$$

$$B_i\,(P/B)_i\,EE_i + H_i + IM_i - \Sigma B_j\,(Q/B)_j\,RF_{ji} - BA_i - EX_i = 0$$

System of simultaneous linear equations for system with n groups:

$$B_1\,(P/B)_1\,EE_1 + H_1 + IM_1 - B_1\,(Q/B)_1\,RF_{11} - B_2\,(Q/B)_2\,RF_{21} \ldots - B_n\,(Q/B)_n\,RF_{n1} - BA_1 - EX_1 = 0$$
$$B_2\,(P/B)_2\,EE_2 + H_2 + IM_2 - B_1\,(Q/B)_1\,RF_{12} - B_2\,(Q/B)_2\,RF_{22} \ldots - B_n\,(Q/B)_n\,RF_{n2} - BA_2 - EX_2 = 0$$
$$B_3\,(P/B)_3\,EE_3 + H_3 + IM_3 - B_1\,(Q/B)_1\,RF_{13} - B_2\,(Q/B)_2\,RF_{23} \ldots - B_n\,(Q/B)_n\,RF_{n3} - BA_3 - EX_3 = 0$$
:
:
:
$$B_n\,(P/B)_n\,EE_n + H_n + IM_n - B_1\,(Q/B)_1\,RF_{1n} - B_2\,(Q/B)_2\,RF_{2n} \ldots - B_n\,(Q/B)_n\,RF_{nn} - BA_n - EX_n = 0$$

METHODOLOGY

- Data needed for each enterprise group:

B : average biomass for period. Needs to be measured on-farm.
P/B : production/biomass ratio.
Q/B : consumption/biomass ratio. Crops: Q/B = P/B
RF : resource flow, or how much of each group goes where? From on-farm monitoring. If household is part of model, consumption and household wastes are also RF
BA : increase in biomass during period. From measurements.
IM : fertilization is import to detritus; feeding is import to animal group fed deposition, N-fixing need to be estimated
EX : needs to be estimated per group.
H : from farm monitoring

Remarks:

1. Ecopath estimates EE's ==> balanced model
2. Annual crops: P/B = 2
3. Model currency:nitrogen (kgN /ha /y)
4. More assumptions (see pubs. Dalsgaard)

METHODOLOGY

- Data estimation for each group:

B	: from NRT area and density estimates
RF	: measured
IM	: estimated from data on feed and fertilizer cost
	estimated based on theory of BNF
EX, H	: harvests and on-farm use measured
	estimated based on theory of N-volatilization and denitrification
P/B, Q/B,	
BA	: calculated based on different sources. Sometimes “guesstimates”

METHODOLOGY

- Ecological sustainability indicators

> Diversity : Shannon-index $H' = -\Sigma\, p_i \ln(p_i)$, with p_i group biomass proportion

> Capacity : B/E-ratio (biomass/throughput), where

B = total system biomass (kg N ha^{-1} y^{-1})

E = total system throughput (kg N ha^{-1} y^{-1})

> N balance (kg N ha^{-1} y^{-1}) :

feed + fertilizer + BNF + deposition + irrigation - harvests - other losses

> Efficiency:

apparent : harvests / (feeds + fertilizers)

actual : harvests / (feeds + fertilizers + BNF + deposition + irrigation)

METHODOLOGY

- Evaluation of sustainability

> effect of (aquaculture) integration:

compare indicators of farms with and without pond

> from one year to the next (time):

compare performance in different years

> simultaneous evaluation of ecological and economical sustainability:

what happens to ecological and economic sustainability indicators after introduction of aquaculture?

RESULTS

- Basic input: B, P/B, Q/B, BA, IM

Ecopath with Ecosim: [C:\Program Files\Ecopath with Ecosim\Database\Kassel.MDB] Quirino model 96_97 - [Input data]

File Edit Uncertainty Parametrization Network Ecosim Ecospace Utilities Window Help

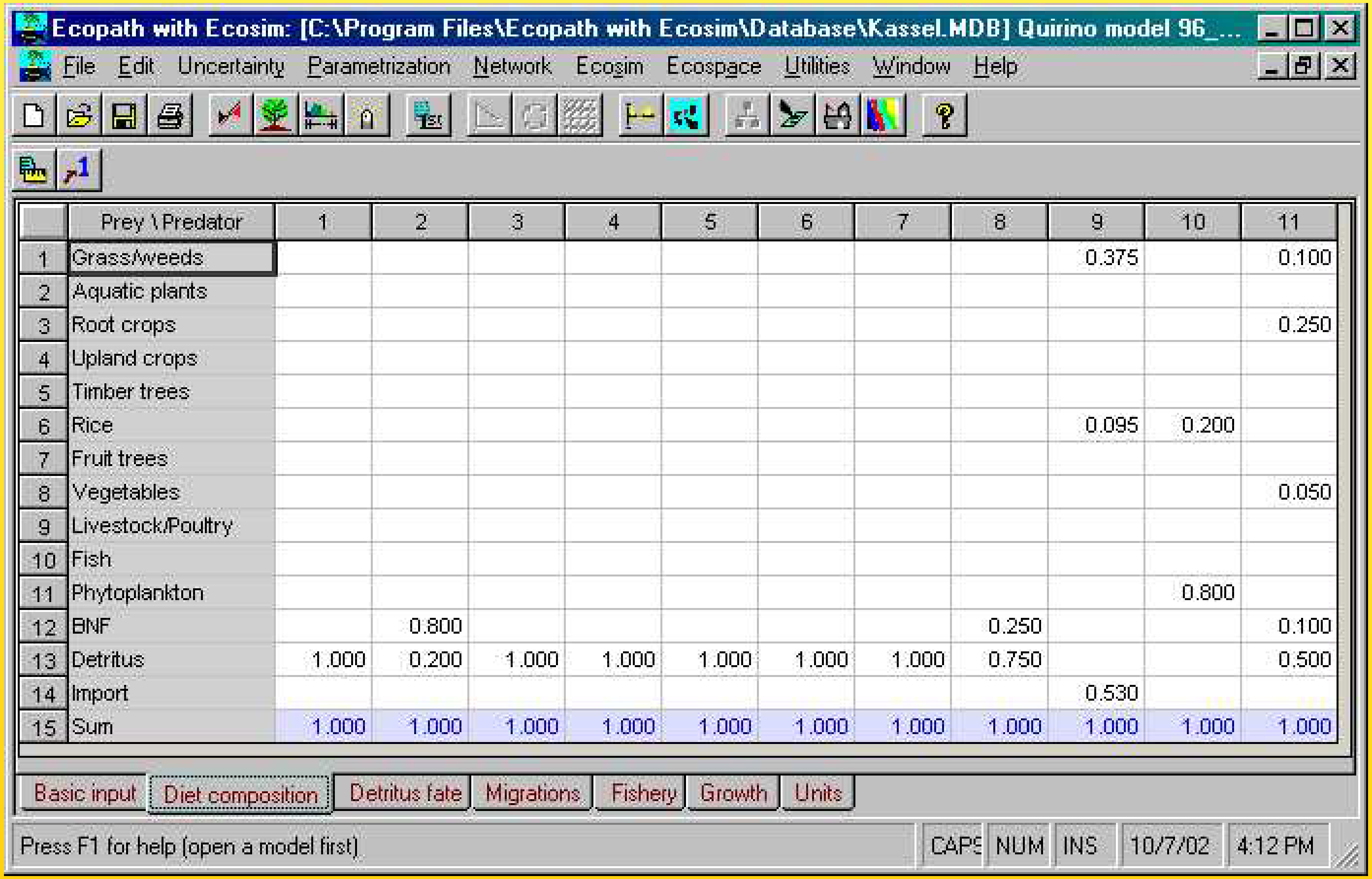
	Group name	Habitat area (fraction)	Biomass in hab. area (kgN/ha)	Production / biomass (/year)	Consumption / biomass (/year)	Ecotrophic efficiency	Production / consumption	± Biom.acc. (kgN/ha/year)	Unassimil./ consumption	Detr.import (kgN/ha/year)
1	Grass/weeds	1.000	10.600	2.500	2.500			0.000		
2	Aquatic plants	0.074	9.766	54.930	54.930			0.000		
3	Root crops	0.325	44.001	2.000	2.000			0.000		
4	Upland crops	0.325	84.481	0.091	0.091			0.000		
5	Timber trees	0.418	1000.000	0.110	0.110			20.914		
6	Rice	0.084	48.890	2.000	2.000			0.000		
7	Fruit trees	0.138	1134.000	0.110	0.110			7.832		
8	Vegetables	0.012	11.137	2.000	2.000			0.000		
9	Livestock/Poultry	0.014	1135.353	0.400	1.528			0.000		
10	Fish	0.007	14.640	1.820	15.000			0.000		
11	Phytoplankton	0.007	19.424	24.000	24.000			0.000		
12	BNF	1.000	1.000	36.000				0.000		
13	Detritus	1.000	1500.000							7.350

Basic input | Diet composition | Detritus fate | Migrations | Fishery | Growth | Units

Press F1 for help (open a model first) | Fish | CAPS | NUM | INS | 10/8/02 | 4:04 PM

RESULTS

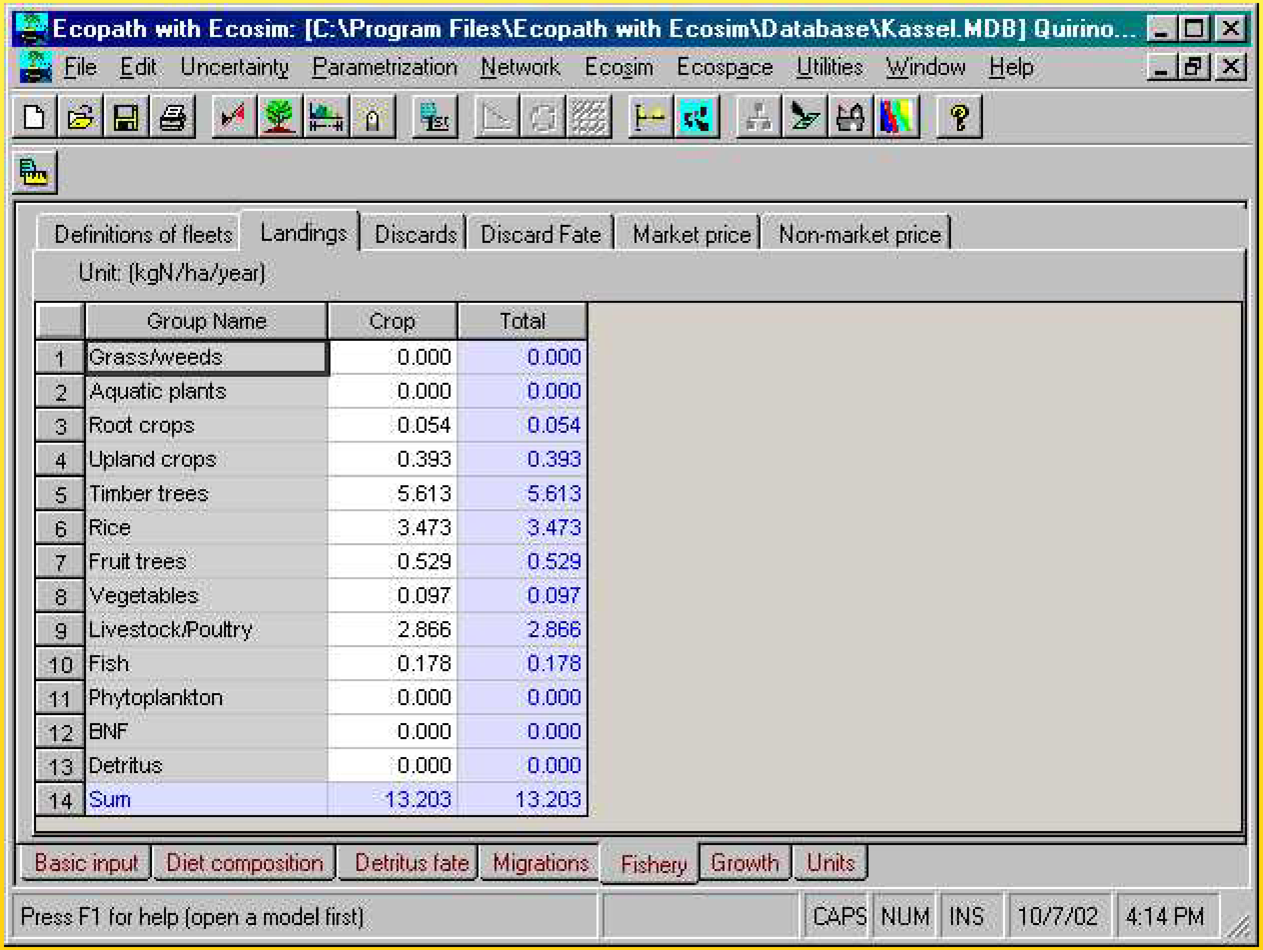
- Resource flows



	Prey \ Predator	1	2	3	4	5	6	7	8	9	10	11
1	Grass/weeds									0.375		0.100
2	Aquatic plants											
3	Root crops											0.250
4	Upland crops											
5	Timber trees											
6	Rice									0.095	0.200	
7	Fruit trees											
8	Vegetables											0.050
9	Livestock/Poultry											
10	Fish											
11	Phytoplankton										0.800	
12	BNF		0.800						0.250			0.100
13	Detritus	1.000	0.200	1.000	1.000	1.000	1.000	1.000	0.750			0.500
14	Import									0.530		
15	Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

RESULTS

- Harvests (equal to “average” farm)



	Group Name	Crop	Total
1	Grass/weeds	0.000	0.000
2	Aquatic plants	0.000	0.000
3	Root crops	0.054	0.054
4	Upland crops	0.393	0.393
5	Timber trees	5.613	5.613
6	Rice	3.473	3.473
7	Fruit trees	0.529	0.529
8	Vegetables	0.097	0.097
9	Livestock/Poultry	2.866	2.866
10	Fish	0.178	0.178
11	Phytoplankton	0.000	0.000
12	BNF	0.000	0.000
13	Detritus	0.000	0.000
14	Sum	13.203	13.203

RESULTS

- Balanced model

	Group name	TL	B (kgN ha^{-1})	P/B (y^{-1})	Q/B (y^{-1})	EE (-)
1	Grass/weeds	2	10.60	2.50	2.50	0.36
2	Aquatic plants	2	0.72	54.93	54.93	0.00
3	Root crops	2	14.30	2.00	2.00	0.03
4	Upland crops	2	27.46	0.09	0.09	0.16
5	Timber trees	2	418.00	0.11	0.11	0.58
6	Rice	2	4.11	2.00	2.00	0.74
7	Fruit trees	2	156.49	0.11	0.11	0.49
8	Vegetables	2	0.13	2.00	2.00	0.97
9	Livestock/ Poultry	3	15.90	0.40	1.53	0.45
10	Fish	3.3	0.10	1.82	15.00	0.95
11	Pond	2.4	0.14	24.00	24.00	0.38
12	BNF	1	1.00	36.00	-	0.89
13	Detritus	1	1500.00	-	-	0.88

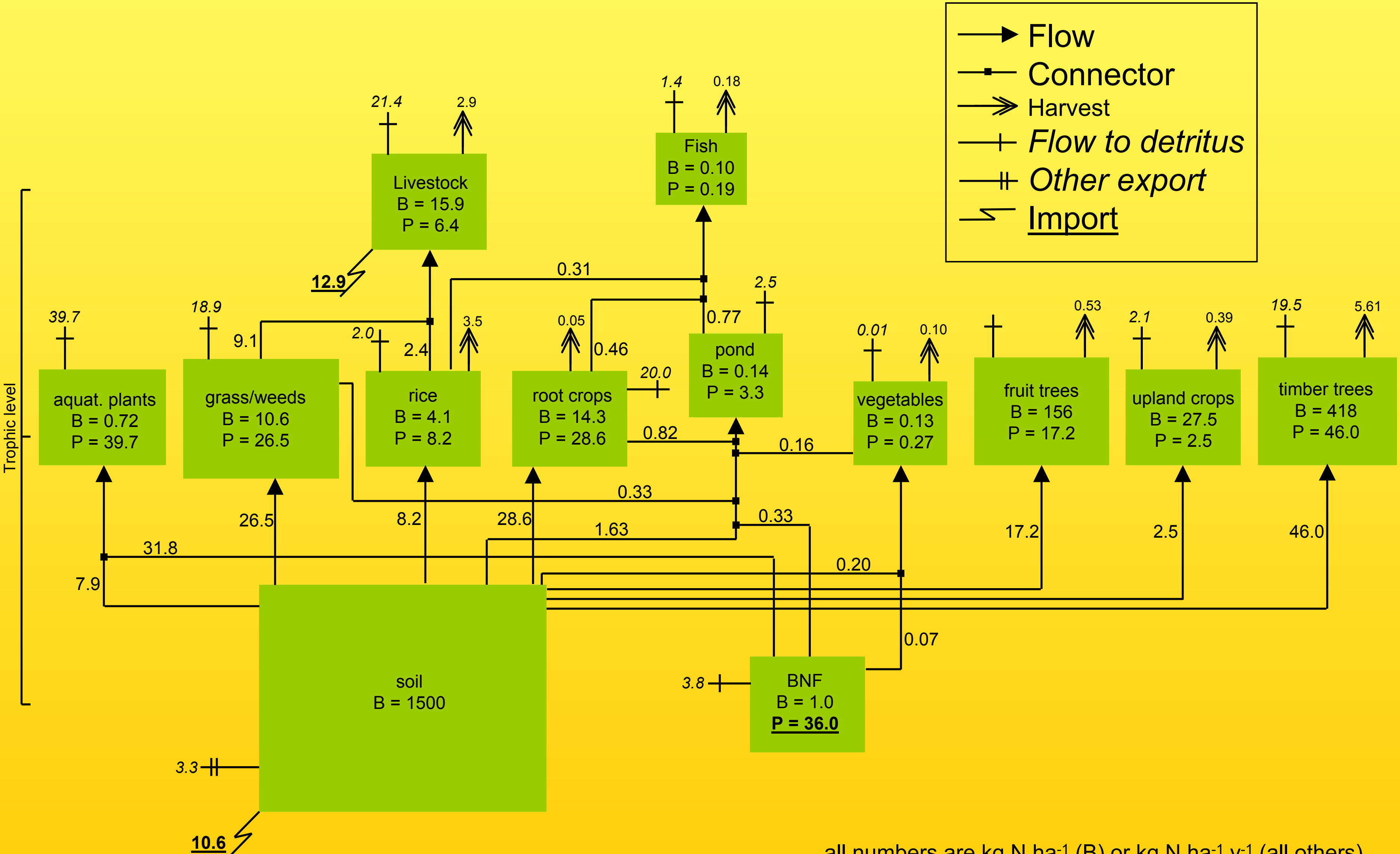
RESULTS

- Flows

TO → / FROM ↓		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Grass/weeds									9.11		0.33		17.07
2	Aquatic plants													39.70
3	Root crops											0.82		27.73
4	Upland crops													2.11
5	Timber trees													19.45
6	Rice									2.31	0.31			2.13
7	Fruit trees													8.85
8	Vegetables											0.16		0.01
9	Livestock/ Poultry													21.42
10	Fish													1.36
11	Pond										1.23			2.03
12	BNF		31.76						0.07			0.33		3.85
13	Detritus	26.50	7.94	28.60	2.50	45.98	8.21	17.21	0.20			1.63		0.00
	Import									12.87			36.00	10.60

all numbers are kg N ha^{-1} y^{-1}

RESULTS



all numbers are kg N ha^{-1} (B) or kg N ha^{-1} y^{-1} (all others)

RESULTS

- Ecological sustainability indicators

Attribute	Indicator	This study	Dalsgaard models (Dalsgaard and Oficial 1997)	
			Rice monoculture	Diversified integrated rice (incl. aquaculture)
Diversity	Shannon-index	1.06	0.70	1.56
Capacity	B/E ratio	1.60	0.12	0.46
Nutrient balance	Nitrogen	+43	-2	-9
Apparent efficiency	Nitrogen	0.74	0.33	0.77
Actual efficiency	Nitrogen	0.22	1.19	0.38

- Evaluation of sustainability indicators is problematic

> effects of time and integration: aquaculture component is small ==> overshadowed by other NRT's

RESULTS

- Economic sustainability

Average costs and returns across NRT of 30 farms in Diffun, Quirino, Philippines, 1996-1997, in Philippine peso (1 USD = appr. 27 PhP), and labour in persondays. Adapted from Table 2.6.6. in Prein et al. (1999).

NRT	Gross income	Total costs	Net income	Labour	Return to labour
forest	2873	1255	1618	22	74
upland rice	228	31	197	13	15
upland/fallow	28774	2846	25928	127	204
orchard	6216	848	5368	35	153
homestead (incl. livestock)	7672	5985	1687	123	14
fishpond	709	803	-94	14	-7
irrigated rice	11969	2108	9861	57	173[a]
vegetables	2298	649	1649	18	92

[a]Cash income negative

- Simultaneous evaluation of economic and ecological sustainability

DISCUSSION

- General objectives

☐? Analyze farming systems quantitatively

☐? Analyze ecological sustainability

☐ Analyze economic sustainability

☐ Analyze ecological and economic sustainability simultaneously

☐ Link farm level with watershed/regional levels

- Specific

☐ Recommend options for development of Ecopath as agroecosystems tool (see Dalsgaard et al.)

DISCUSSION

- Analyze farming systems quantitatively

> data collection: no problem, except biomass estimation. Time !

> need to compare approach with other methods of analysis at farm level

> separate soil types within one farm

- Ecological sustainability

> quality of nutrient balance depends a lot on accurate data on BNF and N-loss (denitrification and volatilization)

> look for good indicators

DISCUSSION

- General objectives

☑ Analyze farming systems quantitatively

☑ Analyze ecological sustainability

? Analyze economic sustainability

? Analyze ecological and economic sustainability simultaneously

☐ Link farm level with watershed/regional levels

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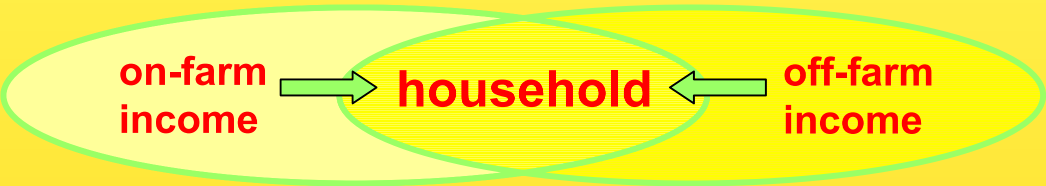
☐ Recommend options for development of Ecopath as agroecosystems tool (see Dalsgaard et al.)

DISCUSSION

- Economic sustainability

> how to value non-cash flows

> off-farm income? How to incorporate in model



- Simultaneous analysis of ecological and economic sustainability

> put money values on inflows and outflows

> not really possible in current version of Ecopath

> possible to evaluate effects of:

resource allocation	==> B
production level	==> P/B, Q/B, BA, H
integration	==> RF

DISCUSSION

- General objectives

☑ Analyze farming systems quantitatively

☑ Analyze ecological sustainability

☑ Analyze economic sustainability

☑ Analyze ecological and economic sustainability simultaneously

☐ Link farm level with watershed/regional levels

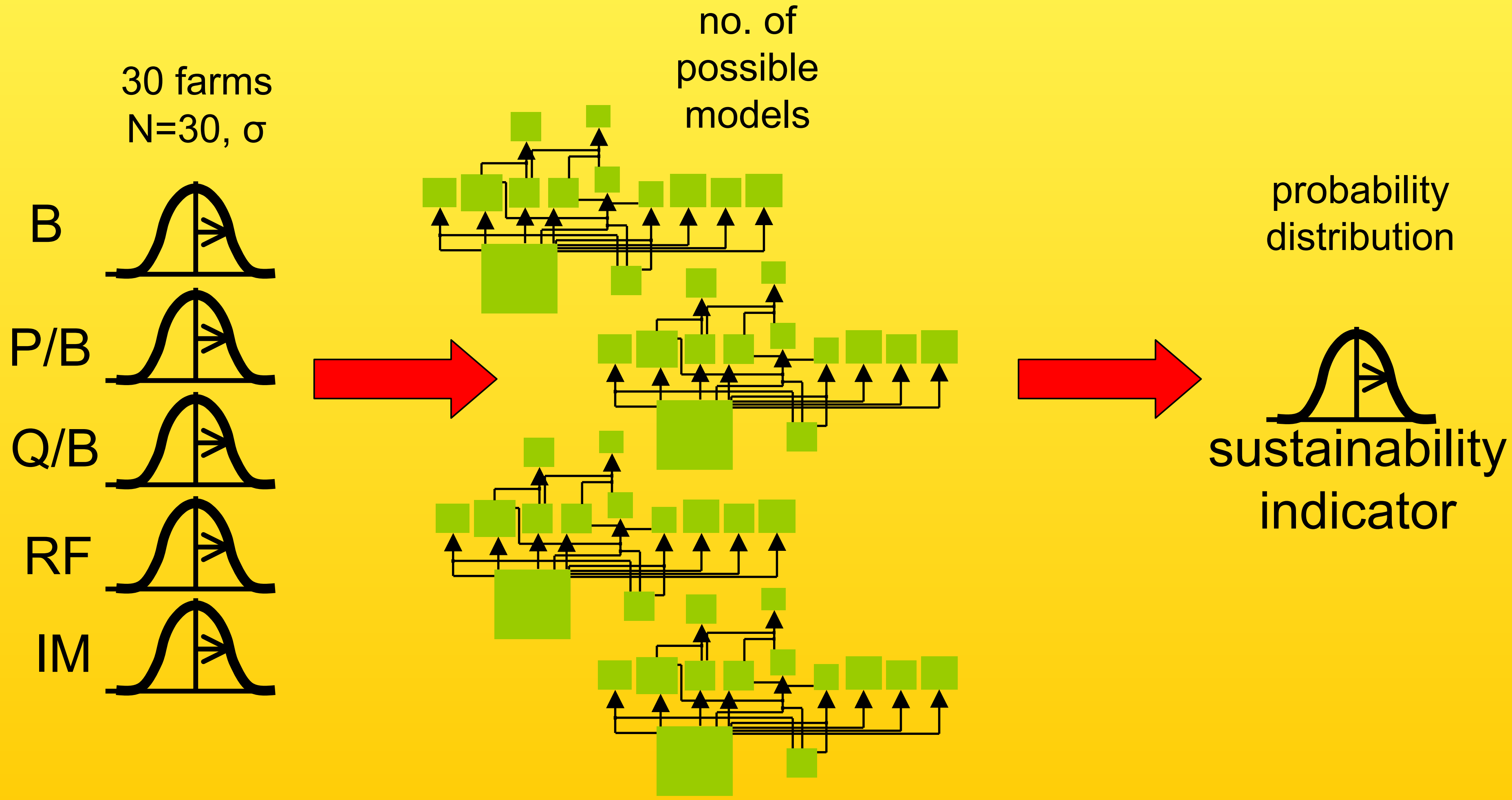
- Specific

☐ Recommend options for development of Ecopath as agroecosystems tool

(see Dalsgaard et al.)

DISCUSSION

- Regional / watershed level analysis



DISCUSSION

- General objectives

☑ Analyze farming systems quantitatively

☑ Analyze ecological sustainability

☑ Analyze economic sustainability

☑ Analyze ecological and economic sustainability simultaneously

☑ Link farm level with watershed/regional levels

- Specific

? Recommend options for development of Ecopath as agroecosystems tool

DISCUSSION

- Agro-ecopath ?

> transform Ecopath into agroecosystem tool (terminology)

incorporate economics

reduce data requirements

graphical output

> develop analysis on farm and regional scale for policy analysis

fit into existing land use analysis frameworks

Thank you for your attention