Emergy accounting of fish aquaculture chains in Brazil

O. Cavalett*, J. Ferraz de Queiroz, E. Ortega***
**LEIA - Departamento de Engenharia de Alimentos / FEA (College of Food Eng) – UNICAMP, Campinas, SP, Brasil*
***Embrapa Meio Ambiente (CNPMA), Jaguariúna, SP, Brasil*

Abstract

The aim of this study is to evaluate and compare the use of resources and the environmental sustainability of the main aquaculture fish chains in Brazil and, also, quantitatively demonstrate how the reduction of the fish chain environmental impacts is linked to the decreased use of non-renewable external inputs. The fish chains evaluated were: (A) polyculture, transport and processing industry and (B) polyculture, transport and fee-fishing establishment. The emergy accounting methodology was used in this evaluation to provide scientific information in support to public policy and sustain the development of more sustainable aquaculture fish chains. The main findings of this study indicated that the fish production stage is the most important step of fish chain because it uses the higher amount of resources. Therefore, environmental public policies should be orientated in order to provide guidelines for fish producers to reduce the impacts caused by their aquaculture systems. The emergy indicators calculated for the investigated fish polyculture production systems suggest a better performance than those found in literature for other aquaculture systems. Also, the results obtained for fish chains showed that the fish processing chain (A) is less intensive in use of non-renewable resources, produces less pressure on the environment and has a higher degree of long-term sustainability than fee-fishing chain (B).

Key words: Ecology; Environmental accounting; Sustainability; Aquaculture; Fee-fishing establishment; Fish industrialization processing.

1. Introduction

Overfishing reduced world stocks so that the yield from the fisheries is the first of the renewable resources that seems to have reached its limit (Odum and Odum, 2001). The high prices practiced on the global market for most species of fish are the major cause of the expansion of aquaculture systems around the world. Brazil has a big potential to increase fish production by aquaculture due the abundance of fresh water, favorable climate conditions, availability of fish feed ingredients (corn and soybean), and increasing market to industrialized fish products. Also, the expansion of the fee-fishing systems around big cities mostly at the Southeast region in recent years has contributed to the demand of fish produced by aquaculture. Aquaculture fish production in Brazil has increased from 20.5 thousands of tons in 1990 to 210 thousands of tons in 2001. This is an increase of 925% while the world fish aquaculture has increased 187% in the same period (FAO, 2003). Therefore, the expansion of aquaculture systems in Brazil and the industrialization process of the fish chain is becoming an issue of public interest.

Natural and human inputs contribute to the economic growth of different aquaculture production systems, but economics analyses are not able to quantify the use of natural resources. Therefore, the emergy accounting methodology developed by Odum (1996) was choose to evaluate the aquaculture fish chains in Brazil, because it offers a means of quantifying all the economy resources and the direct and indirect environmental contribution involved in generating a product or service. The aim of this study is to evaluate and compare the use of resources and the environmental sustainability of the two main aquaculture fish chains in Brazil: (A) polyculture, transport and processing industry and (B) polyculture, transport and fee-fishing establishment. Also, this study quantitatively demonstrate that decreasing the use of external inputs can lead to a reduction of environmental impacts caused by fish systems and contribute to the development of more sustainable fish chains in Brazil.

Emergy analysis has been already applied to several fish farming systems (Queiroz *et al.*, 2000; Cavalett *et al.*, 2006; Brown and Bardi, 2001; Brown et al, 1992; Odum, 2001; Zuoa *et al.*, 2004; Kang and Park, 2002). However, this paper evaluates the main fish aquaculture production system in Brazil, as well the subsequent two main fish chains.

2. Material and Methods

2.1 Description of the aquaculture fish chain

The Figure 1 shows the energy system diagram the main fish aquaculture chain in Brazil. The energy diagram is important to organize the relationships between the main components and process of a system of interest, and also to depict the ecosystem environmental basis and its connection to the larger economy. The diagrams are constructed using the energy systems language, which is a symbolic modeling language. This language presents network properties of systems, holistically using symbols with specific meanings (Odum, 1996).

The diagram shows that the fish is produced in polyculture system located mainly at the West region of Santa Catarina State in Brazil. Then, the production is forward to two main chains: (A) transported to industrial plants to be processed, packed and shipped to the domestic market or (B) transport to fee-fishing establishments. According the recent estimative of Brazilian government, around 80% of the aquaculture fishes are consumed by the fee-fishing establishments located mainly at the Southeast region and the other part, 20% are processed by local industries in the South region.

2.1.1 The Polyculture fish production system

The polyculture production system evaluated is based on the production of different species of fish integrated with livestock production (mainly pig and poultry). It represents the most important extensive fish aquaculture production system in Brazil. Normally, most of the polyculture systems are associated with swine production in the West region of Santa Catarina State, where the fish production depends directly on the input of manure into the ponds. The most common fish species cultured are: pacú (*Piractus mesopotamicus*), tilápia *(Oreochomis sp.),* bighead carp (*Aristichtys nobilis*), silver carp (*Hypophthalmichthys molitrix*), mirror carp (*Cyprinus carpio*) and african catfish (*Clarias sp.*).

The row data of polyculture fish production used in this evaluation were first published by Cavalett *et al.* (2005) that also provides detailed information about the characteristics of such system. In order to conduct that study, Cavalett *et al.* (2005) used the emergy methodology to

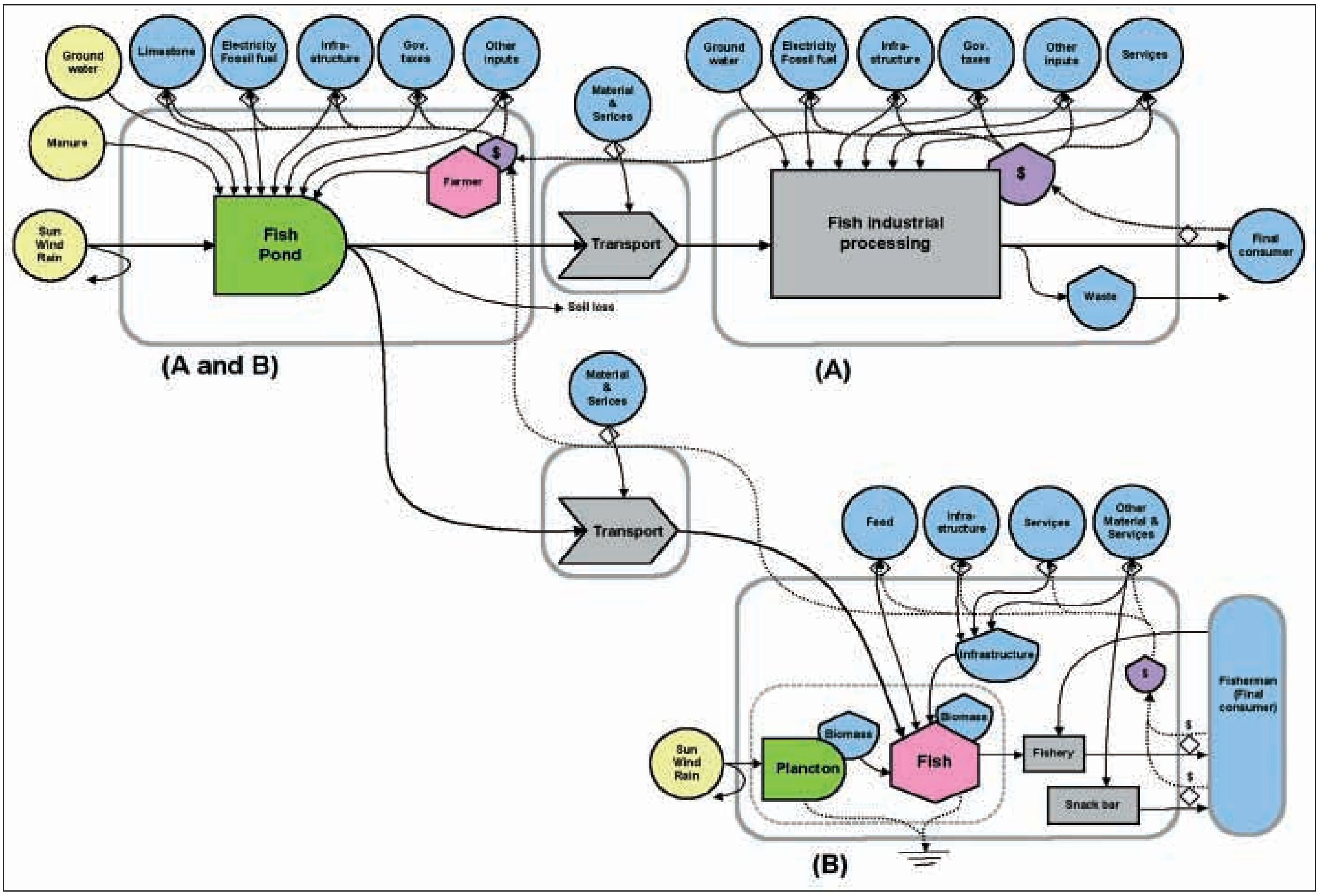

Fig. 1 - Energy system diagram of the main aquaculture fish chains in Brazil (chain A and B).

evaluate the referred fish production system with another scope, quantifying the emergy flows of fish production inside a complex integrated system with agriculture, pig production and fish rearing. The row data from literature used to do the present study were revised, updated and also confronted with those collected thought personal visits and interviews made on site.

2.1.2 The fee-fishing system

Fee-fishing establishment is considered a new rural activity and it has showed a huge expansion during the last years in Brazil. Sites that previously had been used only for traditional agriculture nowadays support many non-agricultural activities such as industries and commerce, as well as, fish culture and fee-fishing establishments. It was also realized by different governmental authorities and environmentalists that intensive agriculture, industry and commerce all require high inputs from economy, human services, technology and natural resources and may stress the environment (Kitamura *et al.*, 2002). Fee-fishing systems are mainly characterized as a recreation site on the country side, where the customers can relax, enjoy the nature and pay a fixed amount for the fish captured on the ponds.

The row data of fee-fishing establishments used in this evaluation were first published by Kitamura *et al.* (2002), that also provides a detailed information about this activity. Kitamura *et al.* (2002) provides an environmental and economic assessment of fee-fishing establishments located in São Paulo State. The row data from literature used to performed the present study were revised, updated and also confronted with those collected thought personal visits and interviews made on site.

2.1.3 Fish processing industry

The fish industrialization process depends on the use of specialized machinery, goods, services and labor. This process is not specific and it can be used for more than one specie of fish. The main product of the industrialization process is the packaged frozen fish filet that is sold at the local or regional market. The processing system is intensive in the use of external non renewable resources such as fuels, electricity, labor and services.

The row data of fish industrialization process used in this evaluation were first published by Shirota *et al.* (2000). Further information about the fish industrialization processes characteristics can be found on this work. Shirota *et al.* (2000) provides a complete economic evaluation of aquaculture fish processing industries. The row data from literature used to do the present study were revised, updated and also confronted with those collected thought personal visits and interviews made on site.

2.2 Emergy methodology

Solar emergy is defined as the sum of all inputs of energy directly or indirectly required by a process to provide a given product or service. Emergy analysis considers all the inputs of a process, including the contributions from nature (rain, water, soil, sediments) and inputs from the economy (goods, machinery, fossil fuels, services, taxes) in terms of embodied solar energy (emergy). Emergy accounting methodology has been developed over the last three decades as a tool for environmental policy to evaluate quality of resources based on the dynamics of complex systems (Brown and Ulgiati, 2004; Odum, 1996; Ulgiati and Brown, 1998).

2.2.1 Emergy accounting procedure

At the core of an emergy evaluation of a given production system or process is the mass and energy flow analysis in which the flows are adjusted for energy quality using it's specific transformation factor (called transformity). Emergy evaluation procedure is accomplished in four main stages: (1) preparation of system diagram; (2) analysis of input and output energy flows of the system; (3) calculation of emergy indices and (4) interpretation of these indicators. Odum (1996) gives a detailed explanation of the application of emergy accounting procedures for a variety of systems. Also, a collection of papers have been published that describe in details the emergy accounting procedure and the meaning of the various emergy indicators (Brown and Ulgiati, 2002; 2004; Ulgiati and Brown, 1998).

2.2.2 Emergy indicators

Discussions and definitions of terms and indicators can be found in Odum (1996) and Brown and Ulgiati (2002; 2004). What follows is a brief description of some emergy indicators used in performing the specific analysis specific used for this study. The system's transformity (Tr) is obtained dividing the total emergy flow of the system by the available energy of the outputs, in Joules. Transformity measures how much emergy is taken to generate one unit of output, regardless of whether or not the input is renewable. It indicates the hierarchical position of an item in the thermodynamic scale of the biosphere and can be regarded as a quality factor from the point of view of biosphere dynamics (Brown and Ulgiati, 2004). The renewability ratio (%R), or degree of sustainability, is the percentage of renewable emergy used by the system. In the long run, production systems with a high percentage of renewable emergy are likely to be more sustainable and prevail (they are more able to survive to the economical stress) than those that use a high portion of non-renewable emergy (Brown and Ulgiati, 2004; Lefroy and Rydberg, 2003).

The environmental loading ratio (ELR) is given by the ratio emergy from purchased and nonrenewable local inputs, to the emergy from renewable resources. It is an indicator of the pressure of a transformation process on the environment and can be considered a measure of ecosystem stress due to a particular production system (transformation activity). The ELR is clearly able to make a difference between nonrenewable and renewable resources, thus complementing the information that is provided by the transformity. ELRs around two or less are indicative of relatively low environmental impacts (or processes that can use large areas of a local environment to "dilute impacts"). ELRs between three and ten are indicative of moderate environmental impacts, while ELRs ranging from ten up to extremely high values indicate much higher environmental impacts due to large flows of concentrated nonrenewable emergy in a relatively small local environment (Brown and Ulgiati, 2004).

The emergy yield ratio (EYR) is the ratio of the total solar emergy, divided by the emergy value of purchased inputs. Primary energy sources (crude oil, coal, natural gas, uranium) usually show EYR greater than 5. Secondary energy sources and primary materials, like cement and steel, show EYR in the range from 2 to 5, indicating moderate contribution to the economy (Brown and Ulgiati, 2004).

The emergy investment ratio (EIR) is the ratio of purchased resources to renewable and nonrenewable local inputs. However, EYR = (N+R+F)/F = 1+(N+R)/F = 1+1/[F/(N+R)] = 1+1/EIR. Therefore EIR and EYR are both the same index written in a different way. Nevertheless, the utilization of EIR in an emergy assessment, sometimes, makes discussion easier and facilitates the understanding. EIR evaluates if a process is a good user of the emergy that is invested, in comparison with alternatives (Brown and Ulgiati, 2004). This index can help to evaluate alternatives for development. In this paper we used this index to enrich the discussion about the different fish chains alternatives. Evaluating EIR provides an a priori method of determining if some economic-environmental use will be economical. It will trend to be economical if its ratio is less or equal to the one prevailing in the region (Odum, 1996).

3. Results and discussion

The results obtained by this study allow the conduction of an emergy evaluation of the main fish aquaculture chains in Brazil. The functional unit used was 4,300 kg of fish, because this is the average productivity of 1.0 hectare of polyculture fish pond during a period of one year.

Tab. 1 - Emergy evaluation of fish production, transport, processing and fee-fishing establishment stages.

Note	Description of the flow	Units	Amount ($ha^{-1} yr^{-1}$)	Emergy per unit ($seJ unit^{-1}$)	Reference	Emergy flow ($x10^{13} seJ ha^{-1} yr^{-1}$)
Fish production stage						
Renewable inputs						
1	Sunlight	J	1,39E+11	1,00E+00	1	<1
2	Rain	J	9,66E+10	3,06E+04	2	296
3	Deep heat	J	3,00E+10	1,01E+04	3	30
Nonrenewable inputs						
4	Ground water	J	7,41E+09	4,28E+05	4	317
5	Loss of topsoil	J	4,61E+09	1,24E+05	2	57
6	Manure	kg	6,48E+04	1,27E+11	5	823
7	Limestone	J	1,83E+09	2,72E+06	2	499
8	Fingerlings	J	4,39E+09	3,31E+05	8	145
9	Diesel	J	4,33E+09	1,10E+05	2	48
10	Electricity	J	1,30E+08	2,77E+05	3	4
11	Labor	yrs	1,25E-01	1,07E+16	6	134
12	Annual services	USD	7,01E+02	3,70E+12	7	259
Output						
13	Fish	kg	4,30E+03	6,92,E+12	8	2975
		J	8,99E+10	3,31,E+05	8	2975
Fish transport to industrial processing						
Nonrenewable inputs						
14	Steel	kg	4,01E+00	1,13E+13	2	5
15	Diesel	J	7,65E+08	1,10E+05	2	8
16	Labor	yrs	1,34E-03	1,07E+16	6	1
17	Annual services	USD	8,38E+01	3,70E+12	7	31
Output						
18	Fish transported	kg	4,30E+03	7,02,E+12	8	3020
		J	8,99E+10	3,36,E+05	8	3020
Fish industrial processing stage						
Nonrenewable inputs						
19	Water	J	2,12E+08	4,28E+05	4	9
20	Diesel	J	9,62E+08	1,10E+05	2	11
21	Electricity	J	1,39E+09	2,77E+05	3	39
22	Labor	yrs	7,52E-02	1,07E+16	6	81
23	Annual services	USD	8,20E+02	3,70E+12	7	303
Output						
24	Fish processed	kg	4,30E+03	8,06,E+12	8	3462
		J	8,98E+10	3,86,E+05	8	3462
	Fish filet	kg	1,42E+03	2,44,E+13	8	3462
		J	2,96E+10	1,17,E+06	8	3462
Fish transport to fee-fishing						
Nonrenewable inputs						
25	Steel	kg	2,01E+01	1,13E+13	2	23
26	Diesel	J	3,82E+09	1,10E+05	2	42
27	Labor	yrs	7,17E-03	1,07E+16	6	8
28	Annual services	USD	4,23E+02	3,70E+12	7	157
Output						
29	Fish transported	kg	4,30E+03	7,45,E+12	8	3203
		J	8,99E+10	3,56,E+05	8	3203
Fee-fishing establishment stage						
Renewable inputs						
30	Sunlight	J	1,39E+11	1,00E+00	1	<1
31	Rain water	J	8,04E+10	3,06E+04	2	246
32	Deep heat	J	3,00E+10	1,01E+04	3	30
Nonrenewable inputs						
33	Ground water	J	1,48E+09	4,28E+05	4	63
34	Loss of topsoil	J	9,22E+08	1,24E+05	2	11
35	Limestone	J	4,89E+08	2,72E+06	2	133
36	Diesel	J	6,72E+08	1,10E+05	2	7
37	Electricity	J	1,04E+08	2,77E+05	3	3
38	Labor	yrs	1,04E+00	1,07E+16	6	1116
39	Annual services	USD	5,81E+03	3,70E+12	7	2149
Output						
40	Fish	kg	4,18E+03	1,66,E+13	8	6932
		J	8,74E+10	7,93,E+05	8	6932

1: Definition; 2: Brown and Ulgiati, 2004; 3: Odum, 1996; 4: Bastianoni and Marchettini, 2000; 5: Bastianoni *et al.*, 2001; 6: Brown, 2003; 7: Coelho *et al.*, 2003; 8: This study.

Table 1 presents the emergy evaluation of fish production, transport, industrial processing and fee-fishing establishment stages. First, the fish chains emergy indicators were calculated and compared in order to provide insights about the more sustainable and environmentally sound fish chain alternative. Further, the fish polyculture production system results obtained were compare to with other aquaculture systems evaluations found in literature.

All the energy, matter and money inputs were converted into solar emergy using the proper seJ unit^{-1} values from literature. The results obtained for emergy flows are presented in Table 2.

Tab. 2 - Emergy flows (seJ) obtained to each stage of the fish chains.

Stage	Renewable	Non renewable	Materials	Labor & Services	Total emergy
(A and B) Fish production	2,96E+15	3,75E+15	1,91E+16	3,93E+15	2,97E+16
(A) Transport	0,00E+00	0,00E+00	1,29E+14	3,25E+14	4,54E+14
(A) Processing	0,00E+00	0,00E+00	5,83E+14	3,84E+15	4,42E+15
(B) Transport	0,00E+00	0,00E+00	6,47E+14	1,64E+15	2,29E+15
(B) Fee fishing	2,46E+15	7,49E+14	1,43E+15	3,26E+16	3,73E+16

The contribution of fish production stage is added to booth chains (A and B). The systems that compound the fish chain evaluated by this study, such as, fish polyculture associated with swine production and fee-fishing establishments depend on external and internal sources of energy that may be regarded as renewable and non renewable. An appropriate measurement of energy flows in ecosystems as proposed by Odum (1996) has allowed the measurement of their sustainability.

The renewable emergy flow (R), the local non renewable emergy flow (N), the materials and services (M) and labor & services (S) of fish production stages were 2.96x10^{15}, 3.75x10^{15}, 1.91x10^{16} and 3.93x10^{15} seJ year^{-1}, respectively. The total emergy inflow of the fish production system was 2.97x10^{16} seJ year^{-1}, what also corresponds to the system's emergy embodied in the output (Y). The manure used to fertilize the fish ponds was the most important contribution in terms of total emergy related to fish polyculture production system, followed by limestone, ground water, rain and annual services. The transport from the fish farm at the West region of Santa Catarina State until the processing industry located in the same region was done by special trucks equipped with tanks and it consumed 4.54x10^{14} seJ year^{-1} of materials, labor and services. The emergy involved in the fish industrialization process consumed 4.42x10^{15} seJ year^{-1} of material, labor and services.

On the other side, the transport of fish by special trucks from the fish farms located at the West region of Santa Catarina State to the fee-fishing establishments located at São Paulo State, takes two days to overcame a distance of almost 1500 km consumed 1.09x10^{18} seJ year^{-1} of material, labor and services. The fee-fishing establishments consumed 2.46x10^{15} of renewable resources, 7.49x10^{14} seJ year^{-1} of local non renewable resources, 1.43x10^{15} seJ year^{-1} of material and 3,26x10^{16} seJ year^{-1} of labor and services. The annual services were the most important contributions in terms of total emergy consumed by the fee-fishing establishments, followed by labor, rain and limestone.

It was observed that the environmental emergy flows, such as, rain and ground water are important contributions necessary to the fish chains stages evaluated. The use of emergy analysis allowed the measurement of the relative importance of these environmental flows.

3.1 Comparison between the fish chains

The emergy flows related to fish production system, transport, industrial processing and fee-fishing establishment stages provided all the information and data necessary to calculated the emergy indicators. Further discussions and definitions of terms and indicators can be found in Odum (1996) and Brown and Ulgiati (2004). A summary of the emergy indicators calculated for each stage of the fish chain is presented in Table 3.

Table 3. Emergy indicators obtained for each stage of the fish chains.

Stage	Tr (seJ J^{-1})	%R (%)	EYR	EIR	ELR
(A and B) Fish production	3,31E+05	9,9%	1,29	3,44	9,1
(A) Transport	3,36E+05	9,8%	1,29	3,51	9,2
(A) Processing	3,86E+05	8,5%	1,24	4,17	10,7
(B) Transport	3,56E+05	9,2%	1,26	3,78	9,8
(B) Fee fishing	7,93E+05	7,8%	1,17	5,99	11,8

Emergy indicators calculated showed negative sustainability trends in the fish chains evaluated (A and B). Therefore, the analysis of the emergy indicators presented at Table 3 allows the conclusion that both fish chains evaluated were not sustainable. Additional inputs of emergy from fuels, electricity, goods and services are necessary to complete all the stages since the fish culture until their delivered at the fee fishing establishments or processing industries. The Figure 2 illustrates the complete process and also presents all the connections between the two fish chains evaluated. This figure also presents the emergy indicators obtained for the fish chains.

Figure 2 also shows that each stage had its value added, and the value added by human services is often expressed by the money flow paid for the added services as indicated by Odum (1996). However, since there are other emergy inflows (such as materials and labor) besides services added, the emergy evaluation required to be complete as proposed by this study.

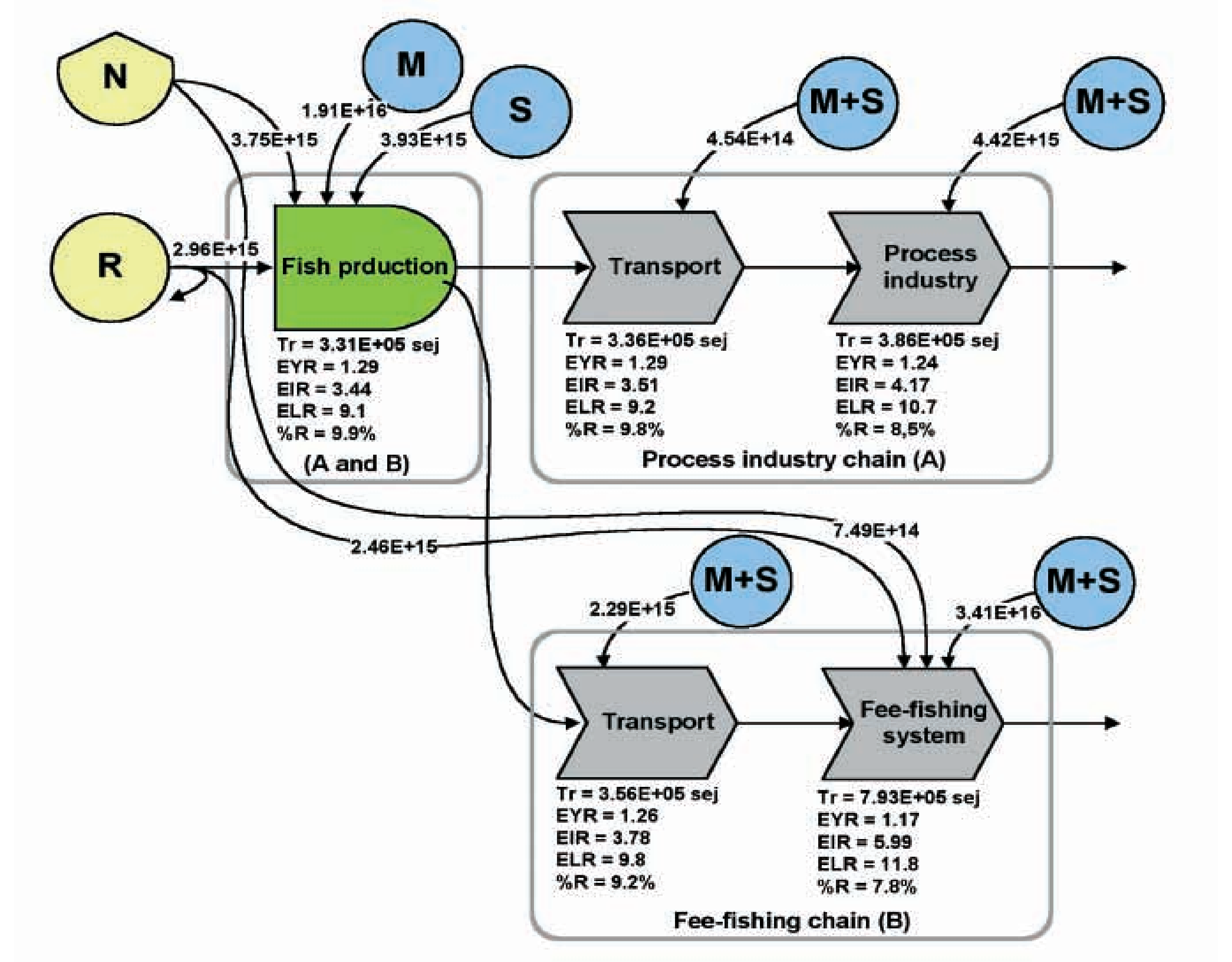

Fig. 2 - Energy system diagram of the fish chains in Brazil with the aggregated summary of emergy flows (seJ year^{-1}) and emergy indicators. R = Renewable emergy flows; N = Local non renewable emergy flows; M = Material emergy flows from economy; S = Labor and services emergy flows from economy.

It is important to consider that each transformation used the energy available to produce a smaller amount of energy into another form, what means that the emergy increases and the energy decreases, and therefore the emergy per unit of energy (transformity) increases sharply. The emergy indicators showed in Table 3 indicate that the fish processed at the industrialization process chain (A) are more efficient in the use of all the resources necessary to produce one joule of fish (lower transformity value of the final product) than fee-fishing chain (B).

In general, the emergy indicators turn worse in each stage because more materials and services are necessary. However, it is also noticed that the fish chain A is less intensive than the fee-fishing chain (B), because it required minor inputs in the different chain stages. This is demonstrated in Table 3 which shows that the fish industrialization process chain (A) produced a less negative trend for the emergy indicators than the fee-fishing chain (B). It occurs because more amounts of non renewable resources are used in the transport and fee-fishing establishments stages (in chain B).

For the fish industrialization process chain (A), the fish production system, the transport and the industrialization process uses, respectively, 86%, 1% and 13% of the total emergy of the chain. And for the fee-fishing chain (B), the fish production system the transport and the fee-fishing establishments uses, respectively, 43%, 3% and 54% of the total emergy of the chain. The fish polyculture production system stage is the same in both chains. The transport to the fee-fishing establishments is more intensive in use of fuel, services, labor and goods due to higher distances (normally above 1500 km). In addiction, it was observed that more non-renewable resources were necessary in the fee-fishing establishments stage instead the industrialization process stage.

It is important to consider that this study compares to fish chains completely different. Fee-fishing establishment is not a fish production system, it is mainly a recreation site where the maximum fish output from ponds are not the main objective. Instead, the fish processing industries should provide maximum rationalization of labor and goods used (but also without concerns about environmental resources used).

The proportion of renewable emergy used in relation to the total emergy consumed is the indicator that measures the sustainability of the system. The fish industrialization process chain (A) is more sustainable (higher renewability indicator) than the fee-fishing chain (B). In addiction, the fish industrialization process chain (A) produce less pressure on the environment (lower ELR value), and it also has a better capability to exploit the natural resources by unit of imported input applied (higher EYR value) than the fee-fishing chain (B).

The EIR is an important indicator to be used by decision makers to compare and choose between different fish chains which one is more sustainable and it also helps to evaluate distinct alternatives for development. The EIR provides an a priori method to determine between different systems which one is more economic-environmental efficient. It will also shows a trend to indicate what economical ratio is less efficient or equal to the one prevailing in the region (Odum, 1996). A lower EIR value indicates that a particular system is more effective, and also makes a better use of renewable internal emergy sources, considering that the renewable energy can be replenished in order to continually feed the system. The EIR obtained for the fish industrialization process chain (A) is lower that the EIR calculated for the fee-fishing chain (B). This indicates that fish industrialization process chain (A) is characterized by lower economic investment (F) and bigger nature contribution (R+N) in relation to fee-fishing chain (B), what means that such systems has more advantages to compete in a coming future when the availability of energy all over the world will less at high costs. In this new scenario the use of technical designs combined with regional planning associated with fair trade rules must be considered in order to evaluate and conduct development strategies for systems that presently require higher nonrenewable inputs.

The fish industrialization process chain (A) is less intensive in the use of resources and produced less pressure on the environment and have a higher degree of long-term sustainability than fee-fishing chain (B). These results were quite unexpected because the industrialization chain is an intensive industrial activity (with high use of energy, fuels, labor), and the fee-fishing establishments are mainly a recreation site on the country side. Results showed that fee-fishing establishments are more dependent on the use of human labor and infra structure, and also have a high appropriation of the local non renewable resources (high soil loss and water use). In this regard the industrialization fish chain (A) should be put in evidence by the public policy because it is more environmentally sound and more efficient in the use of emergy available.

3.2 Comparison between the fish polyculture and other aquaculture production systems

The most important stage for the fish chains evaluated is the fish polyculture production system, what comprises the fish culture in the ponds associated with swine production. This step uses the major part of the resources involved in the industrialization chain (86%) and almost half in fee-fishing chain (43%). Thus, public policies to promote actions to optimize the environmental sustainability of different fish chains should be mainly oriented to more sustainable fish production systems. Therefore, the polyculture fish production results obtained by this study are compared with some results found in literature for intensive aquaculture farming systems (Table 4). The intensive fish cultured systems used for such comparison are the following: channel catfish (Ictalurus punctatus) in the Alabama, USA (Queiroz *et al.*, 2000); tilapia (*Tilapia mariae*) in the Nayarit, Mexico (Brown *et al.*, 1992); salmons (*Salmo salar*) in the Umpqua river estuary (Odum. 2001) and shrimp pond mariculture in Ecuador (Brown and Bardi, 2001).

As showed in Table 4, the emergy indicators calculated for the polyculture production system were: Transformity (Tr) = 3.3x10^5 seJ J^{-1}; Emergy Yield Ratio (EYR) = 1.29; Emergy Investment Ratio (EIR) = 3.44; Environmental Loading Ratio (ELR) = 9.1; Renewability (%R) = 9.9%. The comparison between the emergy indicators obtained for the polyculture systems and those from others studies become quite difficult to do because the considerations about the resources used by the different systems are not the same. However, the values obtained for the emergy indicators related to fish polyculture production system

Table 4. Comparison of emergy indicators calculated for polyculture and previous studies of fish production systems obtained from international literature**.**

	Polyculture[a]	Catfish[b]	Tilapia[c]	Salmon[d]	Shrimp[e]
Tr (seJ J^{-1})	3.3E+05	4.8E+05	1.2E+06	9.7E+06	1.9E+07
%R	9.9	33.2	0.3	-	2.3%
EYR	1.29	1.50	1.98	1.23	1.38
EIR	3.44	2.01	1.02	-	2.60
ELR	9.1	2.01	357.3	4.24	42.1

[a] (present study)
[b] (Queiroz *et al.*, 2000)
[c] (Brown *et al.*, 1992)
[d] (Odum, 2001)
[e] (Brown and Bardi, 2001)

are similar to those found in literature for other intensive fish production systems (mainly catfish and tilapia rearing). And, these results also demonstrate the reliability of the emergy methodology, because tilapia is one of the main fish used in the polyculture system, and catfish is also used in the polyculture.

The transformity values showed that polyculture is more efficient regarding the use of resources to produce one joule of fish (emergy efficiency of production) than channel catfish, salmon, shrimp and tilapia production. The transformity of salmon and shrimp really should be higher because they are in a higher position in the hierarchy of the biosphere. These results demonstrate that transformity is properly measures the hierarchical position of these species in the biosphere thermodynamics.

The polyculture production system is more sustainable than tilapia and shrimp production, but less sustainable than catfish production. The polyculture presents a good level of sustainability in relation with other aquaculture production systems, and in the long run, it is likely to prevail (i.e. it has a better capability to survive to the economical stress).

The EYR values obtained for the fish polyculture production system are quite low in comparison with other aquaculture systems. This is an indication of the prevalent dependence of the analyzed system from economy and human control. This kind of result is typical for systems which are unable to exploit natural resources on a sustainable basis, and directly dependent on the import of inputs characterized by high emergy. This is true also for the other intensive systems evaluated, especially for salmon and shrimp, because the indicators obtained resulted in a higher needs for expensive external non-renewable resources. However, tilapia production has a higher EYR value due higher contribution of local non-renewable resources, such as, groundwater water and fish fingerlings, the high EYR for Tilapia culture reflects the system's ability to exploit local natural resources. These resources are mainly non renewable, and this is also demonstrated by the extremely higher ELR value for the tilapia culture. Because a lower EIR value represents more effective systems with better use of renewable internal emergy sources, the EIR value calculated for polyculture production system shows that this system is the less effective in the use of internal resources. This value indicates that purchased inputs used in the integrated production system were 340% larger than locally available (R+N) emergy sources. The EIR calculated for polyculture production system is higher than other aquaculture systems, and this means that the polyculture system has a lower possibility to prevail in comparison with other aquaculture system that uses more internal resources. However, as already explained for the EYR indicator, the other aquaculture systems presented a lower EIR values due the higher use of local non renewable resources.

The ELR values showed that fish reared in the polyculture system produced less pressure on the environment than shrimp and tilapia production but higher pressure than salmon and catfish. According Brown and Ulgiati (2004) the ELR value for the polyculture production system (9.1) is an indicative of moderate environmental impact, while shrimp and tilapia production systems presented extremely higher values, which indicates much higher environmental stress due to the large flows of non renewable emergy concentrated in a relatively small portion of the natural environment .

The emergy evaluation showed that fish production under polyculture system imposes a moderate stress on the environment. The higher emergy contribution to polyculture system is the manure used to fertilize the fish ponds, that is an external non renewable input. The high dependence of external contributions and the relative inability for exploiting local natural renewable resources strongly affect the level of environmental sustainability of the polyculture production system. However, in the general way the fish polyculture production system presents a good level of environmental sustainability in relation to others aquaculture production systems.

The manure used to fertilize the fish ponds could be considered as a internal recycling resource instead a local non renewable resource, because the fish production is integrated to pig or poultry production on the major part of farms located at the West region of Santa Catarina State (Cavalett *et al.*, 2006). However, the approach of analysis and their considerations should be different because the inputs and outputs should be relative to the fish production together with the pig (or poultry) production. Another evaluation approach considers the swine manure with it's partial renewability, because it is the most important input for the fish polyculture production (represents approximately 28% of the total inputs). However, such considerations turn inconsistent the comparison of the results achieved with those found in literature, because they do not accounted the partial renewability of the inputs.

4. Conclusion

The results obtained by this study indicated that the fish production system used the highest amount of resources in the fish chains. Therefore, any improvement in the management of such systems can result in a direct improvement of sustainability for the whole fish chain. In this regard, public policies for aquaculture should be orientated to promote more sustainable fish production systems. The adoption of more sustainable fish production systems becomes fundamental for the sustainability of different fish chains on a long term basis. The integration of distinct technologies and management processes could be used in order to optimize the sustainability indicators of the fish chains because it will decrease the dependence of imported non renewable resources by the fish production systems. The emergy indicators obtained for the fish polyculture production system are better than those found for other aquaculture systems described by the international literature.

The emergy indicators showed a negative sustainability trend because both fish chains are important keys to identify critical problems that will require more urgent attention by researchers and government authorities. The emergy indicators obtained by this study showed that the industrialization chain (A) is less intensive in the use of resources, and produces less pressure on the environment, as well as, they have a higher degree of long-term sustainability in comparison to the fee-fishing chain (B). Therefore, the industrialization chain (A) should be putted in evidence by the governmental authorities involved with environmental protection because they are more environmentally friendly and more efficient in the emergy use.

Finally, the emergy accounting methodology provided a comprehensive tool to complement other approaches used to evaluate the consumption and demands of energy, economical and social resources related to the systems analyzed by this study. Also, the emergy accounting allowed to measure the relative importance of the environmental flows used to evaluate both fish chains. However, for the further analyses it is necessary to do more efforts to incorporate other issues, such as, social aspects, entertainment options and welfare impacts (important outputs of the fee-fishing system), as well as, other negative externalities. The biggest challenge for the fish chains evaluated will be the development and adoption of culture systems and management techniques less dependent on non-renewable resources. The emergy methodology could be used as an excellent strategy to provide insights and information to help answering some of these questions.

Acknowledgements

We are grateful to Dr. Pier Paolo Franzese and Dr. Sergio Ulgiati for the suggestions in the preparation of this paper. Otávio Cavalett is grateful to CNPq and Capes for the financial support.

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