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# **The Economics of Aquaculture with respect to Fisheries**

95th EAAE Seminar  
Civitavecchia (Rome), 9-11 December 2005

Edited by  
Kenneth J. Thomson and Lorenzo Venzi



# ECONOMIC VIABILITY OF POLYCULTURE OF NILE TILAPIA AND AUSTRALIAN REDCLAW CRAYFISH IN YUCATAN STATE, MEXICO

Donny Ponce-Marbán<sup>1</sup>, Juan Hernández<sup>2</sup>, Eucario Gasca-Leyva<sup>3</sup>

## Abstract

*Tilapia culture in rural communities of the state of Yucatan, Mexico, has been increasing in recent decades. Polyculture of tilapia with other more commercially valuable species is an opportunity to substantially improve the economic yields of rural producers. The economic viability of implementing a Nile tilapia with Australian redclaw crayfish polyculture was analyzed using profitability indicators such as internal rate of return (IRR) and net present value of the investment (NPV). A bioeconomic model was developed to simulate three production densities (33/0, 33/10 and 33/20, tilapia and crayfish, respectively), accounting for investment recuperation in time horizons of 5, 10 and 15 years. The model includes a biological sub-model describing the growth of both organisms, a management sub-model that influences organism development and an economic sub-model describing the main input and output variables of the economic setting of tilapia producers in the state of Yucatan. The biological sub-model was parametrized using published experimental polyculture data from Israel. A thermal correction function was integrated into Von Bertalanffy's growth model to include the effect of temperature of Yucatán on growth in both organisms. The simulations showed a notable improvement in profitability when farms adopt the polyculture strategy, particularly over the 5-year horizon. The NPV of this horizon was -\$4,855.06, \$7,923.33 and \$1,519.88, Mexican pesos, to the tilapia monoculture, medium crayfish density polyculture and high crayfish density polyculture, respectively. The Nile tilapia with Australian redclaw crayfish polyculture shortens investment recuperation time and it inhibits the risk related to changes in tilapia sale price. The best of the three studied combinations was the medium crayfish density polyculture (33/10) in all time horizons.*

**Keywords:** Economic Viability; Polyculture; Nile Tilapia; Australian Redclaw Crayfish; Yucatán, Mexico.

**JEL classification:** O13, Q22.

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<sup>1</sup> Center of Research and Advanced Studies of IPN, Mérida, Apdo. Postal 73-CORDEMEX, 97310 Mérida, Yucatán, Mexico: email donnyp@mda.cinvestav.mx

<sup>2</sup> Department of Quantitative Methods for Economics and Management, University of Las Palmas de Gran Canarias, Edificio Departamental Modulo D-4, 35017 Las Palmas de Gran Canaria, Spain.

<sup>3</sup> Center of Research and Advanced Studies of IPN, Mérida, Apdo. Postal 73-CORDEMEX, 97310 Mérida, Yucatán, Mexico.

## Introduction

The Yucatan state is one of the Mexican regions with the greatest economic limitations. Rural economy communities are based on small family farms that produce vegetables, citric products and farmyard birds. The Mexican government has considered Yucatan for high-priority programs of economic support and aquaculture has been implemented as an alternative productive activity. Due to the topographical characteristics of the peninsula of Yucatan (lack of superficial rivers and calcareous floor), the federal government since the beginning of the 1980s has tried to introduce intensive culture of tilapia in concrete tanks. This had the double purpose to implement agricultural watering systems and to introduce the tilapia culture in the region (Flores Nava, 1998).

However, technical, social and cultural problems to implement the technology, plus the sexennial (presidential) duration of the development programs did not allow the consolidation of these systems. With each government change in Mexico, there is a great uncertainty in the continuity of these programs, and because of that the necessity to look new production strategies that allow the fast consolidation of the rural culture companies or that cooperate to diminish the negative effects for the lack of continuity in these programs. In the current sexennium, aquaculture has had a great impulse in rural areas of Yucatan to the??, particularly to the tilapia culture. However, it still has not reached its full consolidation, because the curve of the farmers' learning to assimilate these systems seems to require more time than the duration of the development programs.

Polyculture consists of adding one or more subordinate species to the culture system of a "main species" (De la Lanza-Espino et al., 1991), and is a management strategy that considerably improves production yields per unit area because it better exploits a system's available resources (Bardach et al., 1972, Landau, 1992). Nile tilapia (*Oreochromis niloticus*) is produced throughout the tropics due to its resistance and fast growth in a wide variety of production systems (Brummett and Alon, 1994). As in many states in Mexico (e.g. Morelos, Tabasco, Veracruz), tilapia culture in the state of Yucatan is seen as a subsistence activity that complements agricultural or fishing activities. Any surplus production is sold at the production site, in the local market or is occasionally integrated into the tourist industry (on-site fishing and consumption).

A number of studies have focused on determining the technical viability of polyculture of tilapia with other freshwater organisms such as carp, other cichlids (Hulata et al., 1993; Vromant et al., 2002), crustaceans like the giant freshwater prawn (*Macrobrachium rosenbergii*) (Cohen et al., 1983<sup>a</sup> ; Cohen et al., 1983b; Tidwell et al., 2000) and more recently the Australian redclaw crayfish (*Cherax quadricarinatus*) (Brummett and Alone, 1994; Karplus et al., 1995; Rourse and Kahan 1998; Barki et al., 2001, Karplus et al., 2001). Australian redclaw crayfish is also produced in rural zones in Mexico (in the states of Morelos, Tamaulipas, Yucatan and Veracruz) using semi-intensive monoculture systems. Research has shown that polyculture of Nile tilapia with Australian redclaw crayfish is technically possible if certain factors are accounted for, such as addition of enough shelters for the crayfish population (Karplus et al., 2001) and spatial and temporal separation of feed rations (Barki et al., 2001).

However, the success or failure of management strategies does not depend solely on technical possibility, but must include the social and economic factors implicit in the setting where they are implemented (Stewart and Seijo, 1994). The economic viability of the polyculture management strategy using Nile tilapia and Australian redclaw crayfish has not yet been determined. In response, the present study analyzes the economic feasibility of Nile tilapia and Australian redclaw crayfish polyculture as a production strategy in the state of Yucatan, Mexico. Results are compared between monoculture and polyculture, at two species densities and considering investment recuperation on three time horizons (5, 10 and 15 years).

A dynamic biological model is used to evaluate this system. These models involve development of mathematical models that consider biological, technical and economic aspects of production in a given social setting (Cacho, 1997). The strength of this kind of analysis lays in its thorough abstraction of the real setting before making any decision with implicit risk. Originally developed for fisheries analysis, these models have been successfully adapted to aquaculture in a number of ways. The work of Allen et al., 1984; Bjorndal 1988; Leung and Shang, 1989; Cacho et al., 1990; Springborn et al., 1992; and Cacho 1997, among others, demonstrate the utility of these bioeconomic models as an evaluative tool.

Very little research has been done on the economic evaluation of polyculture using aquatic organisms. Boll and Lanzer (1995) evaluated polyculture of tilapia with Chinese carp using a bioeconomic analysis, and Sadek and Moreau (1996, 1998) studied the cost-benefit of tilapia culture with high commercial value species like prawns (*Macrobrachium rosenbergii*). More recently, Irz and McKenzie (2003) analyzed the economic feasibility and efficiency of shrimp culture with marine fish species. All these studies have addressed economic analysis of polyculture in semi-intensive systems as a way of fomenting future research in intensive systems. In this paper, using a bioeconomic model, we demonstrate the economic viability of implementing polyculture of Nile tilapia and redclaw crayfish.

## Materials and Methods

The bioeconomic model developed to analyze this polyculture system is conceptually based on Systems Dynamics theory. A dynamic system is defined as a group of elements the internal organization of which produces a common behavior that evolves over time. Applying this approach, the model was built by extracting the most important elements from the Nile tilapia/Australian redclaw crayfish production system. The model includes a biological sub-model describing the growth of both organisms, a management sub-model that influences organism development and an economic sub-model describing the main input and output variables of the economic setting of tilapia producers in the state of Yucatan.

Polyculture data for these species were taken from Karplus et al. (2001) to create the parameters for the biological sub-model<sup>4</sup>. The environmental and management conditions

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<sup>4</sup> Use of the experimental database was done directly with the co-author of the study (A. Barki) via electronic mail.

from which these authors obtained their data are similar to those present in tilapia culture in Yucatan<sup>5</sup>. Model parameters were created in Excel 2000 (Microsoft Corporation 1995-1999) and built using Powersim 2.51 (Academic, Powersim AS) for scenario simulation. A goodness-of-fit test was done for the growth functions of both species, contrasting the modeled results with real data using the Theil statistic (Barlas, 1988)<sup>6</sup>. A sensitivity analysis was also carried out to determine which variables had more economic influence on the economic dynamic of the simulated scenarios.

A Von Bertalanffy-type growth function was incorporated into this sub-model to describe development in both species. A thermal correction function was integrated into this to include the effect of temperature on growth in both organisms. A similar model was used by Martínez and Seijo (2001) to describe shrimp growth in La Paz Bay, Mexico. Growth was adjusted according to the annual water temperature cycle for Yucatan, but is possible to adjust the model an other regions. The average daily temperature (1950-2002) were obtained from the National Water Commission of Yucatan, Mexico (personal communication with Rojas-Morales Carlos).

This management sub-model contains the main culture control variables, such as density, feed quantity and quality, etc., which are closely linked to organism growth and consequently to farm economic results. It considers 10 m diameter x 1.8 m high circular tanks with a 1.5 m water depth. These are supplied with subterranean water from community pumps<sup>7</sup>, with partial (50%) changes every third day and one total change per week. Production cycles were assumed to be continuous throughout each time horizon, that is, when a tank is harvested it is seeded again to start another production cycle. Mortality was estimated based on data in Karplus et al. (2001) for each culture combination. The feed regime was based on commercial pellet feed with 30% protein content and a 3% biomass feed rate for both organisms. Harvest was treated as simultaneous for the biomass of both species, based on a fish harvest weight of 400g, meaning individual weight of the crustaceans varied from 25g to >35g.

The economic sub-model included those variables with the greatest impact on the economic results by using profitability indicators like internal rate of return and present net investment value. The model input variables included on-site market price for both species<sup>8</sup>, costs of tilapia fingerlings and crayfish juveniles, feed, electricity (for pumping) and labor (man hours), as well as initial investment value for a culture tank<sup>9</sup> (Table 1). Depreciation was calculated using the straight line method for the three time horizons (5, 10 and 15 years) over the value of the concrete tanks. Output variables included the economic-financial indicators of net present value (NPV) and internal rate of return (IRR). The discount rate, or

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<sup>5</sup> Tilapia culture conditions in Yucatan are generally semi-intensive, with densities of from 25 to 35 fingerlings seeded per m<sup>3</sup>. There are fewer than 100 rural aquaculture farms in the state of Yucatan.

<sup>6</sup> Both growth models were adjusted to the available experimental data and have not been validated with commercial culture data.

<sup>7</sup> The municipal government provides the pump service, mainly for irrigation of small agricultural parcels.

<sup>8</sup> Given that Australian crayfish is not currently cultivated in Yucatan, the market price used was that of producers in the state of Morelos.

<sup>9</sup> Value of the concrete tank was estimated based on the cost of acquiring construction materials and information from producers in Yucatan collected in interviews in 2004.



minimum acceptable yield rate (MAYR), was assumed to be the interest paid on 28-day federal Treasury Certificates (Certificado de la Tesorería - CETES) in Mexico.

Because the final culture cycle did not conclude at the same time as the time horizon, it was decided not to reseed during this last cycle if tilapia weight did not exceed 250g. For sale of both species, market price was determined considering the size attained. Keeping tilapia density constant, the growth of both species was simulated in three scenarios: 1) tilapia monoculture; 2) low density polyculture; and 3) high density polyculture. The simulation began on day one, corresponding to the first of January, and was run for 5-, 10- and 15-year periods.

**Table 1. Summary of Economic Sub-Model main variables and initial values.**

Concept	Description	Value	Unit
<b>Price</b>			
Tilapia	> 400 g	30	\$/Kg
	350 - 400 g	25	\$/Kg
	250 - 350 g	20	\$/Kg
Redclaw crayfish	> 35 g	180	\$/Kg
	25 - 35 g	150	\$/Kg
<b>Costs</b>			
Tilapia fingerlings	20 g	2	\$/p/u
Crayfish juveniles	7 g	2.5	\$/p/u
Tilapia feed	Purina (Tilapia chow 30%)	6.4	\$/Kg
Crayfish feed	Purina (Camaronina 30%)	8.4	\$/Kg
Labor	(Man hours/day)	27.4	\$/Day
Depreciation	5 years	20	%(annual)
	10 years	10	%(annual)
	15 years	6.67	%(annual)
<b>Investment</b>			
Tank	Circular concrete tank (10 m diameter x 1.8 m high)	\$19,000	Unit
Discount rate (MAYR)	28-day CETES	7.27	%

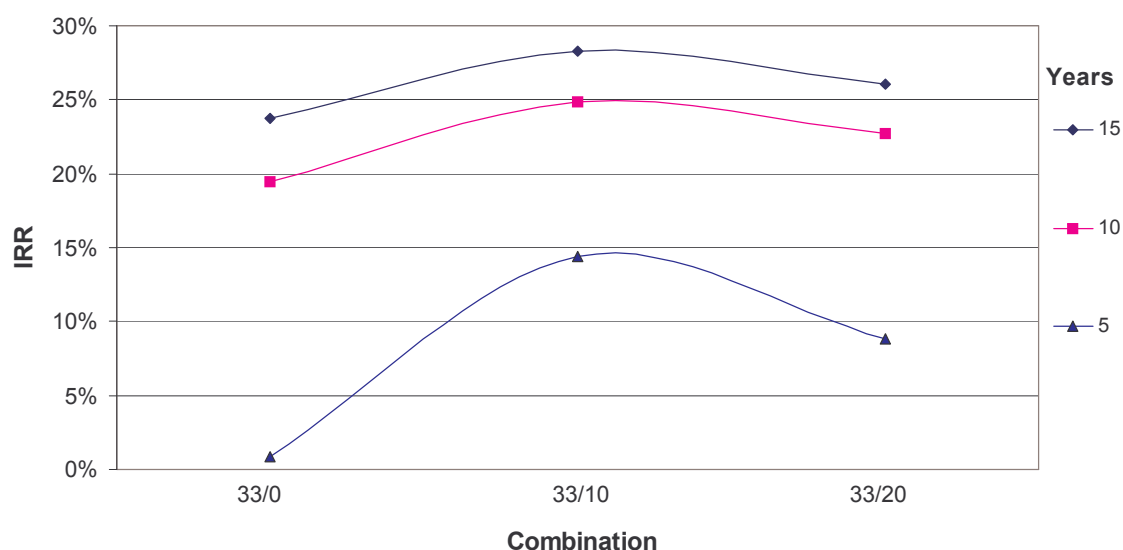
## Results and Discussion

When the monoculture results are compared to the two polyculture combinations using the studied assumptions, profitability indicators exhibit notable improvement with the polyculture management strategy, which is more evident in the shortest time horizon (Table 2). This was so marked that when using the five-year capital recuperation period, only the polyculture combinations attained a NPV greater than zero (Mexican pesos). This was because the yield on investment in these scenarios was higher than the discount rate (MAYR). In contrast, though the monoculture IRR was positive, it was so low that it did not cover the MAYR (see Table 2). This means that under the monoculture system the tilapia farms in Yucatan do not recover all of the investment in this period. This is an extremely important indicator as the creation of rural aquaculture companies in Yucatan is generally the result of six-year state government plans, and thus have very short periods in which to consolidate.

**Table 2: Financial Results for Tilapia Monoculture and Polyculture with Australian Redclaw Crayfish**

Period Years	in Density Tilapia/Crayfish	IRR	NPV (Mexican pesos \$)
5	33/0	0.84%	-\$4,855.06
	33/10	14.43%	\$7,923.33
	33/20	8.82%	\$1,519.88
10	33/0	19.44%	\$17,646.84
	33/10	24.84%	\$35,029.91
	33/20	22.68%	\$32,164.33
15	33/0	23.71%	\$32,948.54
	33/10	28.26%	\$57,464.20
	33/20	26.07%	\$54,104.55

The best yields in all three time horizons were obtained with the 33/10 combination (Table 2). This organism combination results in greater daily weight gain in both species, leading to slightly shorter culture cycles, a consequent reduction in production costs, an increase in the number of harvests per year and thus higher annual income. The IRR shows a clear difference between the monoculture and the polyculture combinations in the five-year horizon, though it varies less and is more uniform when moving from ten to fifteen years (Figure 1). This suggests that for all time horizons polyculture increase profitability over tilapia monoculture, but profitability decreases as crayfish density rises from 33/10 to 33/20.

**Figure 1. Variation in internal rate of return (IRR) by culture combination and investment recuperation time horizon**



When comparing results by cycle, gross income from tilapia sales were notably lower in both polyculture combinations (Table 3), a drop attributed to the decrease in tilapia biomass resulting from higher mortality under polyculture conditions. This mortality is probably not due to presence of the redclaw crayfish as it is not aggressive towards this cichlid (Rouse and Kahan 1998). However, this drop in tilapia income was compensated for by income from the redclaw crayfish. Indeed, gross income for the 33/10 combination was 1.67% higher than for monoculture and that for the 33/20 combination was 7.4% higher.

In addition, despite 25 to 50% increases in seed costs from purchase of juvenile crayfish, production costs dropped substantially in both polyculture combinations for feed ration (8.5% for 33/10; 7% for 33/20) and fixed costs (6.7% for 33/10; 5% for 33/20). This is attributed to the shorter culture period since tilapia can eat part of the feed and excrement of the subordinate species in a polyculture scenario, which produces better growth performance. As a consequence, net income would improve greatly in the polyculture versus the monoculture, from 21.8% for the 33/10 to 23% for the 33/20.

This highlights the trends shown in Figure 1 because it shows how the cost of including the redclaw crayfish in tilapia culture is marginally lower than the benefit at a crayfish stocking density of 33/10. However, when this density is raised to 33/20, it begins to decrease, suggesting that densities higher than 33/10 may have marginal costs greater than the resulting economic yield.

**Table 3: Pro forma average results by culture cycle (Mexican pesos \$)**

	Unit measure	33/0	33/10		33/20	
Income		Tilapia	Tilapia	Crayfish	Tilapia	Crayfish
Biomass per species	Kg	1,456.72	1,363.55	19.59	1,371.57	32.17
Sale price	\$/Kg	30	30	180	30	180
Gross income	\$	43,701.60	40,906.50	3,526.20	41,147.10	5,790.60
Total gross income	\$	43,701.60	44,432.70		46,937.70	
<b>Variable costs</b>						
Fingerlings-Juveniles	Number	3,888	3,888	785	3,888	1,571
Fingerling-Juvenile cost	\$	2.0	2.0	2.5	2.0	2.5
Fingerling -Juvenile total cost	\$	7,776.00	7,776.00	1,962.50	7,776.00	3,927.50
Feed Intake	Kg	3,854.95	3,434.04	71.89	3,425.57	122.91
Feed cost	\$	6.40	6.40	8.40	6.40	8.40
Total feed cost	\$	24,671.68	21,977.86	603.88	21,923.65	1,032.44
Cycle	Days	179	167		170	
Cycles / year	Years	2.04	2.19		2.14	
<b>Fixed Costs *</b>						
Electricity	\$	716.00	668.00		680.80	
Labor	\$	4,886.16	4,558.60		4,645.95	
<b>Total cost</b>	\$	38,049.84	37,546.83		39,986.34	
<b>Net Income per cycle **</b>	\$	5,651.76	6,885.87		6,951.36	
<b>Net Annual Income **</b>	\$	11,529.59	15,080.05		14,875.90	

\* Electricity and labor costs were calculated as fixed by day and the value in the table depends on culture cycle duration.

\*\* Net income before depreciation, taxes and subsidies.

The sensitivity analysis (Table 4) measured the percentage rise in IRR ( $((IRR_i - IRR_0)/IRR_0)/0.01$ ) given a percentage unit change in sales price and the main production costs for each species. This showed that under the simulated conditions the IRR maintains a direct and more than proportional link to changes in tilapia price. It also showed that the degree of sensitivity is greater when the investment recuperation period is shortest.

Tilapia price had a strong effect on IRR in the monoculture scenario. In the five-year period a unit percentage change represents a change of more than 600% in this profitability indicator. This effect is much less pronounced in the polyculture scenarios, with 22.97% for the 33/10 and 56.68% for the 33/20. Changes in redclaw crayfish price caused minor changes, modifying IRR 1.97% for the 33/10 and 5.93% for the 33/20. However, when crayfish density was increased sensitivity increased more than proportionally.

Sensitivity to tilapia price changes was considerably less in the 10- and 15-year horizons, especially in the monoculture, where it dropped from 616.92% in the five-year horizon to 22.89% in the 10-year and then to 17.73% in the 15-year. Sensitivity in the polyculture also improved over time, though it was always lower than with the monoculture and was not significantly different between the 10- and 15-year horizons (12.84% for the 33/10 and 13.59% for the 33/20 at 10 years; 10.83% for the 33/10 and 11.45% for the 33/20 at 15 years).

**Table 4: Sensitivity Analysis: Percentage Change in IRR versus percentage unit increase in Sale Price and Main Production Costs**

	33/0	33/10		33/20	
Year	Tilapia	Tilapia	Crayfish	Tilapia	Crayfish
Sale price					
5	616.92	22.97	1.97	56.68	5.93
10	22.89	12.84	1.07	13.59	1.83
15	17.73	10.83	0.89	11.45	1.54
Feed Cost					
5	-346.45	-13.05	-0.36	-23.87	-1.12
10	-23.69	-7.28	-0.20	-7.78	-0.36
15	-9.87	-6.13	-0.17	-6.55	-0.31
Seed Cost					
5	-106.88	-4.78	-1.21	-8.61	-4.35
10	-4.23	-2.70	-0.68	-2.79	-1.41
15	-3.33	-2.28	-0.58	-2.37	-1.19

This suggests that inclusion of the Australian redclaw crayfish in Nile tilapia culture had a buffering effect on profitability versus the risk of changes in tilapia market price. This effect is more pronounced over short recuperation periods, making it even more attractive given the uncertainty in which tilapia producers operate.

The IRR also had a minor, though no less important, effect versus changes in tilapia feed and fingerling costs. It exhibited an inverse relationship to these costs, and, like sale price, was more pronounced in the short-term monoculture scenarios. This reemphasizes the importance of time horizon in the consolidation of rural aquaculture companies in Yucatan.

In all of the sensitivity tests this risk absorbing effect was most notable in the 33/10 polyculture combination versus the 33/20 combination and the tilapia monoculture. Again, this indicates that this organism combination was the optimum under the simulated culture conditions.

No significant changes in profitability were observed in IRR sensitivity to changes in feed and juvenile crayfish costs, suggesting a certain stability in crayfish production versus changes in market prices and costs. However, when redclaw crayfish culture

density were increased, profitability indicators experienced a more than proportional marginal increase.

## Conclusions

Using the simulated scenarios with the studied assumptions, inclusion of Australian redclaw crayfish in tilapia culture had positive economic effects. This strategy can help to increase profitability, shorten investment recuperation time and attenuate risk from changes in tilapia sale price and production costs, especially in relatively short recuperation periods.

The polyculture strategy substantially improved profitability at the three studied time horizons in comparison with tilapia monoculture. Tilapia monoculture at the 5-year time horizon was not profitable, because only the simulated polyculture scenarios attained a yield rate higher than the discount rate.

Production costs decreased in the polyculture scenarios because culture cycles were shorter as a result of greater tilapia weight gain over a shorter period. Gross income increased from the crayfish's commercial value, which is comparable to the price of langoustine and some shrimp species.

Due to the uncertainty in the continuity of the programs of the Mexican government's support with each presidential change, the time horizon plays a determinant role in the consolidation of rural aquaculture companies. The polyculture scenarios show that this management strategy allows a rapid recovery of investment capital, that which is essential for the consolidation of the rural aquaculture companies of Yucatan. Furthermore, the sensitivity analysis suggests that diversifying Nile tilapia culture with high commercial value species like Australian redclaw crayfish attenuates the risk implicit in the market.

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