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Short Communication

Characterization of rural small-scale rainbow trout (*Oncorhynchus mykiss*) farms in Mexico

David García-Mondragón[1], Iván Gallego-Alarcón[1], Daury García Pulido[1] Carlos R. Fonseca[1] & Iván Cervantes-Zepeda[1]
[1]Instituto Interamericano de Tecnología y Ciencias del Agua (IITCA)
Universidad Autónoma del Estado de México, Toluca, México
Corresponding author: Iván Gallego-Alarcón (iga@uaemex.mx)

ABSTRACT. Rainbow trout (*Oncorhynchus mykiss*) production has developed rapidly, particularly in the highlands of central Mexico. The objective of this study was to characterize rainbow trout production systems based on factor and cluster analysis. Data were collected for 21 variables from 71 trout production units (TPU) through semi-structured interviews. Four groups were obtained. Group 1: rural entrepreneurs, and Group 3: organized family TPU, are business-oriented operations developed with government support schemes with incorporated internal procedures enabling higher production and sales either to wholesalers or final consumers as fresh trout. These groups have the potential to scale up their operations. Group 2: small-scale family TPU, and Group 4: small-scale artisan TPU, are less organized, based on family labor, have lower yields, and sell their products at the farm gate or to small restaurants. These groups represent the role of aquaculture for social development in rural areas. Public policies, government support schemes, growth of markets, and high demand for trout have favored all four groups. Based on the results, development strategies and applied research must be directed differentially to each group of rainbow trout producers.

Keywords: *Oncorhynchus mykiss*; rainbow trout farming; smallholder producers; rural production; aquaculture

Aquaculture has become an important activity around the world, identified both as an area for investment and a significant factor for social development, given its contribution to food production, rural development, human nutrition, generation of income, employment opportunities, and environmental management (Lazard et al. 2010, Belton 2013, Ortega & Valladares 2017). Most of this activity is carried out in developing countries (more than 80%), with 75% in rural areas (Halwart et al. 2003), potentially contributing towards improving the quality of life in rural communities (Irz et al. 2007, Sheriff et al. 2008). The success and rapid growth of aquaculture are greatly due to the perception of public and private sectors as a good and profitable source for economic development (Subasinghe et al. 2001, Belton et al. 2012). Also, changes in macro-economic policies, institutional structures, legal matters, and domestic and international markets have allowed an environment that has a positive tendency in aquaculture (Morales & Morales 2005).

Rainbow trout (*Oncorhynchus mykiss*) is one of the 12 most cultivated fish globally (FAO 2018). In 2017, Mexico produced 404,551 t of rainbow trout, representing 18% of the national fish production and average growth of 25% from 1989 to 2016. Rainbow trout production generates more than 14,000 jobs in the country (CONAPESCA 2017). The volume share of aquaculture in national trout production is 66.91%. From 1983 to 2017, production increased from 97 to 9499 t, representing an average annual growth of 230% (CONAPESCA, 2009, 2017). Mexico, Brazil, Ecuador, and Chile are the four top countries in aquaculture in Latin America (FAO 2018).

The state of Mexico has favorable ecosystems for rainbow trout production. It is the first producer of rainbow trout, with 46% of the national production (average annual yield of 4055.5 t in the last 10 years; SAGARPA 2017). The statistics evidence the accelerated growth. However, no published information documents the processes and factors involved in

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developing rainbow trout production in central Mexico. Proper knowledge of production conditions, characteristics, and needs of the different systems are essential to any subsequent actions for development strategies, applied research, and technological transfer, as well as for the design of effective public policies (Michielsens et al. 2002) for the development of the activity (Belton et al. 2012).

Before carrying out any study, researchers must establish interacting factors, type of interactions, and their impacts on territories (Lazard et al. 2010, Belton 2013), such as technical resources, infrastructure, family management, family administration, socio-economic level, and marketing objective (Lazard et al. 1991). The core idea of Stevenson et al. (2007) is that aquaculture systems of one particular type are similar and different from other types; this enables the identification of characteristics and needs of each production unit for the design of public policies that promote the development of both aquaculture and individual producers. Belton & Little (2011) advocate a typology of aquaculture that uses relations of production as a heuristic with greater explanatory power than scale regarding the likely developmental outcomes associated with the different forms of aquaculture.

This work aimed to characterize the aquaculture production units from the point of view of smallholders' rainbow trout farms in Mexico. This study was carried out in trout production units (TPU) located in the state of Mexico, which surrounds Mexico City and is in the transverse neovolcanic axis of the Mexican highlands (18º29'N, 98º35'W and 20º17'N, 100º37'W). With an average temperature of 10-16ºC, three major rivers originate in the state of Mexico (INEGI 2019): Lerma, in the central-west region; Panuco, in the northeast; and Balsas, in the southern region. TPUs studied are located at altitudes from 2400 to 2900 m above sea level, with temperatures under 15ºC and annual precipitation of approximately 1000 mm.

The study was conducted during the production cycle of 2017-2018; 83 TPUs were initially selected. All TPUs smallholders are members of the non-governmental organization "Mexiquense A.C. Trout Product System" (Trout Production System of the State of Mexico, A.C.). Seventy-one TPUs (15% of the TPUs registered in the state of Mexico in 2018) agreed to participate in the study.

Semi-structured interviews were applied (Cea D'Ancona 2001) to participating TPU operators/ owners to identify factors for the descriptions of the people in charge (Stevenson et al. 2007, Yildiz et al. 2010). Through factorial analysis of main components, new orthogonal variables were extracted and generated (Michielsens et al. 2002) using a linear combination of original variables that explain the major part of the total variation (Stevenson et al. 2007). Based on their nature, these variables were categorized as geographic, socio-economic, legal, administrative, technological, and environmental (Table 1).

Based on the resulting main components, a cluster analysis was performed (Michielsens et al. 2002, Stevenson et al. 2007) through the Ward method (Hair et al. 2009), thus allowing the grouping of TPUs by the degree of association (maximum association degree within groups or minimum association degree among groups; Stevenson et al. 2007). All statistical analyses were carried out with the SPSS 15.0 statistical software for Windows.

Ten variables explain the 68.1% of the total variation (Table 2); of these, four components were identified as determining factors for the development of production characterization for smallholders' TPUs:

1. Production management: efficient production management and logbook-keeping of biological and economic parameters. As previously reported, good management of the aquaculture system directly impacts production (Michielsens et al. 2002, Yildiz et al. 2010). The positive load of this component may be an indication of the transition. From almost empirical and disjointed beginnings of trout farming as supplementary economic activity, towards a market-oriented economic activity through organized management which involves recording biological parameters (growth, mortality, feeding), financial records (incomes and expenses), and marketing.

2. Legal and productive certainty: this factor may be considered the main principle for developing trout production; the acquirement of a legal identity that defines the rights and obligations related to the activity through creating a legal firm or cooperative registered at the Treasury Department. This factor may be considered the main principle for the development of trout production. Legal identity, which defines the rights and obligations related to the activity, is acquired by creating a legal firm or registering the cooperative at the Treasury Department. In addition, having salaried full-time employees instead of unpaid family labor ensures a successful operation of TPUs, thus reducing the risk of production loss due to lack of supervision.

However, there are no reports on including this type of variable in the characterization of productive systems. Mexico is enforcing farmers and aquaculture producers to formalize their operations, something seldom done in the past. Legally formalized operations have three advantages: a) the possibility of accessing governmental financial aid programs, b) the possibility to offer an invoice/tax receipt proof of purchase of the

Table 1. Categories of quantified variables at the trout production units.

Category	Variable
Geographic	Hydrological region
Socio-economic	Paid employees
	Sales of product
	Invoice/legal receipt of sales
	Main economic activity
	External government support/financial aid
Legal	Registration at the Mexican Treasury Department
	National Water Commission (CNA) award of rights for water use
	Land ownership
	Established as a firm or cooperative
Administrative	Logbook for growth and mortality
	Record of income and expenditures
	Feeding records
	Accounting
Technological	Tons of trout produced
	Kilograms produced per cubic meter
	Farm areas
	Number of growth stages and size selection
	Harvesting frequency
Environmental	Participation in an environmental improvement program
	Actions to improve the environment

Table 2. Matrix of components rotated with the VARIMAX method. *Variables with the highest percentage of variation in each component that allowed to compose the orthogonal components.

Variables	Component			
	1	2	3	4
Hydrological region	0.288	0.021	0.076	0.769*
Paid work	0.030	0.816*	0.085	0.322
Product sales	-0.369	0.175	-0.113	0.756*
Main income activity	-0.154	0.087	0.513*	0.363
Prosecutor registry	-0.415	0.727*	-0.053	-0.034
Legal entity	0.114	0.593*	0.570*	-0.147
Kg trout m^{-3}	0.764*	0.010	0.062	0.209
Tons produced	0.695*	-0.334	-0.249	-0.247
Administration processes	0.688*	-0.031	-0.449	-0.165
Government support	-0.113	0.001	0.826*	-0.098
% Explained variance by component	29.2	15.2	12.9	10.6

product, required by formal markets, c) the certainty of having full-time operators, thus reducing the risk of production loss due to lack of supervision.

3. Social development: Mexico's public policies have prioritized the rural population for a long time. The elements of this component help establish how trout production has become the main economic activity for producers, thanks to the financial support it receives from governmental schemes. As described in the previous component, organization and registration as a formalized firm or registered cooperative allow access to diverse financial aid programs to improve the activity. Financial supports are crucial in the development of trout production. In less than 30 years, producers changed their main economic activity, from farming/forestry to trout production, which has become their primary source of income.

4. Marketing region: The state of Mexico's location (central region of the central Mexican highlands) has expanded trout production throughout (across) the

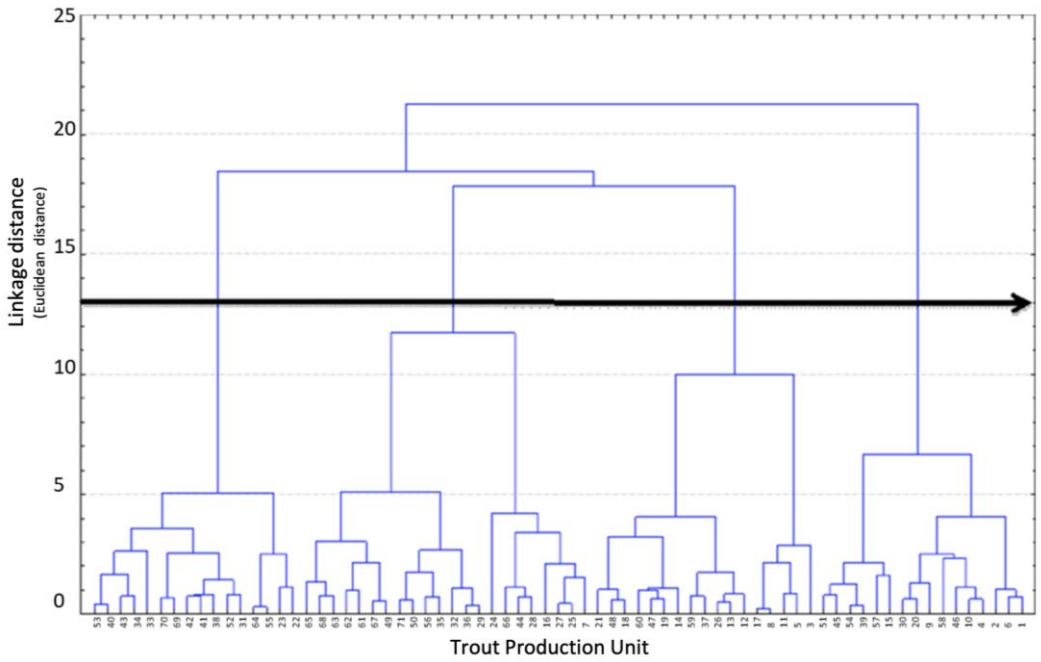

Figure 1. Dendrogram obtained from the hierarchical cluster analysis of the trout production units in the state of Mexico. Tree diagram for 71 cases, Ward method.

Table 3. Specific characteristics of identified clusters. EXW: Ex Works; seller places the goods at the buyer's disposal at the seller's premises (trout farm). SHCP: Secretariat of Finance and Public Credit. LLRPS: limited responsibility of rural production society.

	Rural business	Individual family member	Organized family	Small artisan
UPT number.	16	17	22	16
Efficiency (kg m^{-3})	19	12	15.7	10.4
Production (t)	18	4.8	5.3	2.1
Administration level	High	Middle	Middle	Under
Workforce and remuneration	Non-family with remuneration	Unpaid family member	Family 37% with remuneration	Unpaid family member
Registration with SHCP	With registration	No registration	19% with registration	75% with registration
Main economic activity	Trout-farming	Trout-farming	Trout-farming	Trout-farming
Legal figure	LLRPS	LLRPS	LLRPS	No legal figure
Hydrological basin	Balsas and Lerma rivers	Balsas and Lerma rivers	Panuco and Lerma rivers	Panuco and Lerma rivers
Sale	Wholesalers	Wholesalers	Restaurants and EXW	Restaurants and EXW

state. TPUs have settled in all three hydrological regions (Lerma, Panuco and Balsas; INEGI 2019). Each region has its market characteristics and different sales options for the product.

Based on their particular characteristics, four groups were identified (Fig. 1, Table 3).

Group 1: rural entrepreneurs

These producers have an average productive efficiency of 19 kg m^{-3} of water and a mean production of 18 t per year. This type of TPU has the largest number of administrative processes compared to other groups. TPUs of this type are registered at the Treasury Department and have paid employees. These TPUs are organized in limited liability rural production societies (LLRPS), whose facility improvement has been favored by governmental financial support schemes. Most of these production units are located throughout the high basin of the Balsas River. The product is sold mainly to wholesalers.

Group 2: small-scale family TPU

The average productive efficiency of this type of TPU is 12 kg m^{-3}; the mean production is 4.8 t per year. Small-scale family TPUs are not registered at the

Ministry of Finance and rely on unpaid family labor. There is no organizational structure, although producers may have some knowledge about administrative management. Trout production is the main activity, and they are recipients of government financing for facility improvement. They are located throughout the high basin of the Balsas River. The product is sold mainly to wholesalers.

Group 3: organized family TPU

The average productive efficiency of this type of TPU is 15.7 kg m^{-3}, and the average production is 5.3 t per year. Regarding administrative processes, this group is more knowledgeable than the last group. However, only 19% of these TPUs are registered at the Ministry of Finance, and only 37% have paid employees (the remaining 63% rely on unpaid family labor). However, these TPUs are organized as SPRRL and have received government financing. They are located mainly throughout the high basin of the Panuco River, and the product is sold to final consumers in restaurants or directly at the farm gate as whole fresh trout.

Group 4: small-scale artisan TPU

With an average productive efficiency of 10.4 kg m^{-3} and an annual production of 2.1 t, small-scale artisan TPUs carry out the lowest size operations with a minimum of administration. These TPUs rely on unpaid family labor and lack an organizational structure. Although 75% of these TPUs are registered at the Ministry of Finance, and trout production is their main activity, only 28% have received government financial support. They are located throughout the high basin of the Panuco River, and the product is sold mainly to final consumers in restaurants or at the farm.

Traditionally in aquaculture, the most frequently used criteria are agronomical (Lazard et al. 2010) or technological (Stevenson et al. 2007). The inclusion of functional processes (administrative, legal, and socio-economic) in the principal components analysis (PCA) allows a more realistic description of TPU groups, with intangible but fundamental elements in trout production. This heuristic analysis of productive relationships of the TPU at different levels (Belton & Little 2011) will allow a better understanding of the development of the activity, its functionality, and trajectories, and the establishment of a classification method for small-scale aquaculture production systems in rural communities.

The Food and Agriculture Organization of the United Nations assessed the small-scale aquaculture in Latin America (FAO 2010). They considered factors like technology, natural resources, administration, market, capital, profitability, inputs, compliance with the regulatory framework, access to bank loans, and services for a productive aquaculture chain. Such factors (production management, legal and productive certainty, social development, and regionalized markets) determine the interactions among variables evaluated and their effects on production units. Based on this assessment, FAO proposes two large groups of aquaculture producers: those performing with limited resources and those similar to micro and small enterprises.

Historically, the classifications for small-scale rural aquaculture were based on the integration with other production systems, such as agriculture or stockbreeding (WCED 1987, Edwards & Demaine 1998), mainly in Asian and African countries (Shrestha & Pant 2012). Other authors propose that, in European countries like Turkey (Sener 2002), Denmark, Faroe Islands, Finland, Iceland, and Sweden (Paisley et al. 2010), the classification must include marketing (Lazard 1991) and technological development (Edwards & Demaine 1998).

The most frequently used classification of aquaculture systems worldwide (WCED 1987, Edwards & Demaine 1998) relies on productive technology, particularly the stock density variable. Thus, farming systems are categorized as extensive, semi-intensive, and intensive. Even though this terminology is the most commonly used, the definitions are usually inaccurate and ambiguous (Edwards & Demaine 1998). This scenario allows creating an approved diagnostic instrument for smallholder producers in Latin America and the Caribbean region, involving administrative, legal, socio-economic, and productive variables, whose purpose is to identify groups not represented by traditional characterizations.

The regional diagnosis may provide the basis to define a strategy to support the development of aquaculture producers with features of any of the groups in every other country (FAO 2010). This fact formed the groups with a common origin, support, and programs from the federal and state governments to obtain rainbow trout under similar production schemes. However, how each producer approached the daily activities of the production units differentiated them, generating four groups based on the four factors (production management; legal and productive certainty; social development and regionalized markets) that have the greatest variability among them. These factors, which determined the clusters encountered, are present in other aquaculture systems in the world. Pemsl et al. (2006) report in Bangladesh and Malawi that the small-scale operations are based fundamentally on family labor, geared towards home consumption with sales of surplus production in local markets. In Latin American countries such as Argentina (FAO 2005) and Peru

(Flores & Yapuchura 2016), their production is marketed in local and interprovincial markets. The main objective of the activity is to contribute to social development, poverty alleviation, and diversification of regional business activities.

Similar characteristics were found in Group 2 and Group 4. Although the main difference is that rainbow trout production is a source of food for families. Oriented to the sale of a basic high-value product that allows them to base their livelihood on trout farming that, given their small size and location in forest areas, is not suitable for agriculture, otherwise cannot be sustained by other activities. In both situations, either for domestic consumption as reported by Pemsl et al. (2006) or in groups reported in this work inclined to produce and sell high-value food to satisfy urban consumers demand. Aquaculture plays a fundamental role in the social development of rural inhabitants, such as have concluded Sheriff et al. (2008) in terms of the role that aquaculture can play in the development of rural communities.

Correspondingly, to findings in Nepal (Rai et al. 2005, Gurung 2008), Turkey (Bozoğlu et al. 2007, Yildiz et al. 2010), Peru (Flores-Mamani & Yapuchura-Sayco 2016) or Venezuela (Ablan & Rosales 2016), producers in this study rely on the rainbow trout production as their main economic activity and source of income so much that the original farming activities from these families have now become a much lesser part of their incomes.

A trend found in Groups 1 and 3 had not been described before, representing farmers with higher trout yields that have formalized their operations, enabling them to attract government financial support. These two groups represent those producers that are moving towards a business-oriented paradigm in their trout operations.

According to the definitions of Micro and Small Aquaculture Business (AMYPE) and Limited Resources Aquaculture (AREL), proposed in 2010 in the "Diagnostic and monitoring workshop on small-scale aquaculture and limited resources in Latin America," it is observed that the present classification has subgroups. Therefore, it is impossible to manage only those two categories, although two trends are observed among the four groups defined here.

Firstly, Group 1: rural entrepreneurs, and Group 3: organized family TPU, have larger production and the legal formalization of their operation, which has enabled them access to government support schemes. These two groups have evolved into organizing their production activities within their TPU. The latter's characteristics are like AMYPES, with aquaculture practiced with a commercial orientation, which generates paid employment, some level of technical expertise, and does not exceed the limits defined for the AMYPES of each country. These types of companies are just above the AREL producers. It is recognized that this activity is limited in its development by one or more resources, so it requires instruments to improve its competitiveness and ensured sustainability (FAO 2010).

The second trend is Group 2: small-scale family TPU, and Group 4: small-scale artisan TPU, with deficient production processes regarding the other two groups. However, trout production meets the objective of being an alternative to enhance the social development of rural families. Being small, they must rely on unpaid family labor such as these family operations.

Regardless of the trends found in these four groups, the functional classifications realistically describe the groups. Working with conceptual categories, such as the traditional ones, in which the production intensity is the only variable, many characteristics certainly occur but do not apply to all aquaculture production units listed under these classifications in line with the concept of rural aquaculture with limited resources (AREL). It includes producers who carry out aquaculture as product diversification to complement the needs of the basic family basket, hence having unpaid family labor. Resources that may limit activity are referred to technology, natural resources, administration, market, capital, inputs, and services for the aquaculture production chain (FAO 2010).

In conclusion, functional and structural variables have made it possible to establish an integral characterization of the trout smallholder production unit, standardizing the criteria for grouping small-scale rural aquaculture in the region, which has been accepted for the Latin American Caribbean region.

Above all, they are identifying producers as "hidden populations" not included in the traditional classification and drawing away those classifications that traditionally only considered variables of a productive nature. In this sense, the characterization obtained from small-scale rural rainbow trout production units in Mexico, the variables used, and the proposed concepts can serve as an example to classify other aquaculture activities in Latin America and the Caribbean, whose systems and conditions of production are similar.

Finally, the four identified groups have similar characteristics to the AREL and AMYPE groups. However, subgroups that share some intermediate features continue to emerge. The instrument must be

tested and refined in other regions, with production units of other species, where social, economic, commercial, and legal conditions resemble small-scale rural areas aquaculture.

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