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Research Article

Risk assessment and uncertainty of the shrimp trawl fishery in the Gulf of California considering environmental variability

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ABSTRACT. The shrimp fishery off the Mexican Pacific coast is the country's most important fishery from the economic standpoint. However, it faces serious problems, including the fleet's overcapitalization and age, in addition to the environmental variability that affects the size of catches. Thus, this activity depends on a variety of factors that add uncertainty to the profitability of fishing vessels. This study aims to estimate the probability of success and economic risk of "type vessels" under two different environmental variability scenarios in the Gulf of California. The results from the economic simulation pointed to the vessel type used in Guaymas (Sonora) as the most efficient one under a neutral climate change scenario, showing a homogeneous behaviour in physical characteristics and mode of operation. By contrast, under a scenario of a monotonic rise in sea surface temperature, the shrimp fishery faces a greater risk of incurring economic losses. The simulated climate behaviour scenarios revealed that the activity involves a moderate economic profitability under the neutral scenario; however, under the warming scenario, profitability may be low or even nil due to the risks and uncertainty resulting from the influence of environmental phenomena.

Keywords: shrimp, sensitivity analysis, risk, uncertainty, Gulf of California, México.

Evaluación de riesgo e incertidumbre de la pesquería de camarón de alta mar del golfo de California considerando la variabilidad ambiental

RESUMEN. La pesquería de camarón del litoral del Pacífico es la más importante del país desde el punto de vista económico. Sin embargo, afronta serios problemas como la sobre-capitalización y antigüedad de la flota, además está presente la variabilidad ambiental que influye en la abundancia de las capturas. Así esta actividad depende de varios factores que generan incertidumbre en la rentabilidad económica de las embarcaciones. El objetivo del trabajo fue estimar la probabilidad del éxito y riesgo económico de embarcaciones "tipo" considerando dos escenarios de variabilidad ambiental en el golfo de California. Los resultados de la simulación económica indicaron que el barco más eficiente es el de Guaymas (Sonora) bajo el escenario de cambio climático neutral, mostrando un comportamiento homogéneo en sus características físicas y forma de operar. Por el contrario, bajo condiciones de calentamiento monótono de la temperatura superficial del mar, la actividad presenta mayor riesgo de incurrir en pérdidas económicas. Los escenarios simulados de comportamiento climático mostraron que la actividad tiene una rentabilidad económica moderada para el escenario neutral. En condiciones de calentamiento la rentabilidad llega a ser baja o inclusive nula, debido al factor de riesgo e incertidumbre provocado por la influencia de los fenómenos ambientales.

Palabras clave: camarón, análisis de sensibilidad, riesgo, incertidumbre, golfo de California, México.

INTRODUCTION

Overview of the Mexican shrimp fishery

The shrimp fishery is not only the most complex activity of this kind in Mexico for its broad geographic distribution, multi-species composition and sequentiality of captures, which altogether involve a number of fisheries, fishing gear, social sectors and fishing strategies; it is also the most important fishery in Mexico as a source of foreign income. The price of shrimp

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shrimp in the international market is high, ranging from 5 to US$9 per pound, with the United States as the largest buyer.

The volume of wild shrimp catches reported for the Mexican Pacific coast ranks third countrywide; with just over 42.000 ton live weight, 92% of which come from the Gulf of California (CONAPESCA, 2012). The importance of this fishery is also evident from the social standpoint, as it generates over 37,000 jobs in the Pacific coast alone (INP, 2006).

Shrimp are exploited by both offshore and artisanal fisheries; the latter is conducted in protected waters (bays and lagoons). In 2012, the industrial shrimp fleet was comprised by 906 shrimp vessels that share common features as defined in the National Fishing Chart for large fishing units or vessels (DOF, 2012), and represents 70% of the total large fleet in Mexico (CONAPESCA, 2011). These vessels have been continuously improved both to increase their autonomy and to enable them to operate in depths ranging from 9 to 90 m (INP, 2006). This study focused only on the industrial fleet, which concentrates the greatest investment and has been operating the shrimp fishery for a longer time.

Artisanal fishing is conducted in small boats (locally named “pangas”), with approximately 56,412 units recorded, 85% of which are estimated to be devoted to shrimp fishing (INP, 2006). Artisanal fishing provides most jobs, whereas the shrimp trawl fishery generates more economic value by catching larger specimens, which amount to 53% of the sea catch in the Pacific coast, while the rest comes from bays and lagoons (CONAPESCA, 2012).

The shrimp fishery relies on four different penaeid species, known locally as white (*Litopenaeus vannamei*), blue (*L. stylirostris*), brown (*Farfantepenaeus californiensis*) and red or crystal (*Farfantepenaeus brevirostris*) shrimp. The brown shrimp is the most abundant species in the Pacific Ocean fishing grounds, followed by the blue and white shrimps and, with the lowest abundance, by the red or crystal shrimp (Lluch-Cota *et al*., 2006).

The states of Sinaloa and Sonora are the top producers along the Mexican Pacific coast. Their high production is determined by factors such as vessels concentration, port infrastructure and the presence of processing plants (CONAPESCA, 2011).

The issues

The Mexican shrimp trawl fishery, particularly the one that operates inside the Gulf of California, faces significant problems, including over-capitalization (a surplus of vessels in relation to those required to optimize yield per vessel) and fleet senescence (Lluch-Belda, 1974; Quimbar, 2004; García-Caudillo & Gómez-Palafox, 2005). These problems are the result of poor management practices as well as organizational and structural limitations arising from failed or absent public policies to promote a proper performance of the activity (Medina-Neri, 1982; Quimbar, 2004; INP, 2006; Almendarez-Hernández, 2008).

In addition, the fishery’s historical statistical records show variations not entirely accounted for by the fishing effort alone, likely because shrimp catch is a multifactor phenomenon in which interrelationships between biological, environmental, economic and social factors can be expected.

This multifactor phenomenon leads to uncertainty in terms of the fleet’s economic profitability, as the shrimp fishery is a high-risk activity due to catch variability. The aim of this study is to conduct a probabilistic estimation of the economic success and risk of shrimp trawler vessels under different scenarios of environmental variability in the Gulf of California.

MATERIALS AND METHODS

Stochastic simulation models are commonly used for analyzing capital expenditure and generating management scenarios under uncertainty conditions (Richardson & Mapp, 1976; Richardson *et al*., 2000). The model used in this study works on a number of Microsoft® Excel spreadsheets and utilizes a companion program named Simulation and Econometrics of Risk Analysis, SIMETAR©, developed at Texas A&M University (Richardson *et al*., 2004, 2008). For this study we used data from the fishing fleet operating along the Gulf of California, particularly in the states of Sinaloa and Sonora (Fig. 1).

Representative shrimp trawler vessels

The Representative Production Units (RPU) method is based on a panel technique. A panel includes groups of producers who characterize a production system; all production units within a given production system are similar to each other. Producers are grouped through a consensus-building process, by identifying the main characteristics (scale, production and marketing) that define the region’s most representative production unit (SAGARPA, 2010).

To define a RPU, groups of shrimp trawler vessels sharing common characteristics were first identified based on official information issued by the fisheries authorities. These groups were called Representative Shrimp Trawler Vessels (RSV) in this study. This information was supplemented and corroborated through

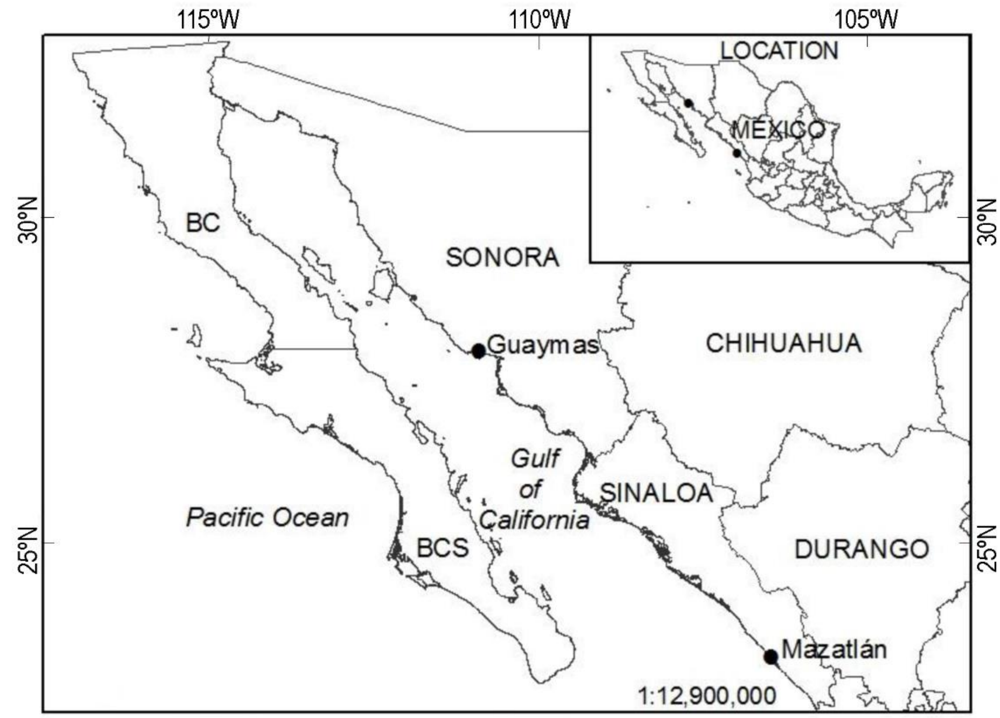

Figure 1. Map of the Gulf of California, bordered by the states of Baja California Sur (BCS), Baja California (BC), Sonora and Sinaloa. Guaymas (Sonora) and Mazatlán (Sinaloa) ports are the main shrimp producers and concentrate most of the industrial fleet.

meetings and interviews with shrimp trawl fishermen (owners) held in Mazatlán and Guaymas.

In order to gather representative information on the fishery's activity, data on the major costs incurred by producers during the shrimp trawler vessels operation, shrimp sale (export and domestic) prices, taxes, subsidies, etc. were collected directly from producers during the meetings (SAGARPA, 2010).

Two meetings with producers of offshore shrimp fishery from the Gulf of California (Almendarez-Hernández, 2013) were also held. The first meeting aimed to gather information on the activity's economic aspects. These meetings were held in January 2010 in Guaymas and Mazatlán. The second meeting was meant to validate the data that would afterwards feed the economic simulation model, as well as to make adjustments according to the producers' perspective. These meetings were held in August 2010 in Mazatlán and in December 2010 in Guaymas.

Economic analysis and environmental variability

Data supplied by producers were used for analyzing and simulating the economic and financial performance of previously characterized RSVs from analysing Guaymas and Mazatlán. The simulation model used is based on the analysis of Net Cash Income (NCI), as defined by the following equation:

$$Y_N = Y_T - C_T$$

where: Y_N = net cash income, Y_T = total income, and C_T = total costs.

NCI represents the average figure obtained from subtracting total cash outflows from total income over the 2010-2019 period. Total Income (TI) is the average cash income from all possible sources, including sales, subsidies and other income related to the activity. Finally, total costs (TC) correspond to the total cash outflow resulting from each vessel operation; *i.e.*, the sum of variable plus fixed costs.

The model used is based on an iterative, stochastic, Monte Carlo simulation process that relies on empirical probability distributions to generate random outputs. The larger the number of iterations (*i.e.*, the more simulations are run), the more statistically reliable the result (Richardson & Outlaw, 2008; Baca-Urbina, 2010). For this study, the model was set to run 500 iterations, each producing outputs for a 10-year planning horizon.

The model used empirical probability distributions of projected price and income for the analysis, under different assumptions:

Base year information:
Total costs
Income generated by the activity
30-year historical data series of production volumes
30-year historical data series of product prices

Climate greatly influences shrimp populations, as these species are favoured by mild El Niño events (Lluch-Cota *et al*., 1995), probably due to the increase in temperature and rainfall, rise in mean sea level, and decreasing salinity. The input of continental fresh water increases productivity and promotes shrimp growth (Soto, 1969; INP, 2000; Rodríguez de la Cruz, 2000).

For the above, warm periods foster higher shrimp productivity and increased fishery yield, thus making the shrimp fleet more likely to obtain economic benefits. However, severe environmental conditions affect biological shrimp productivity (Castro-Ortiz & Lluch-Belda, 2008), and extreme warming conditions were considered in this investigation in order to simulate a potential negative effect on the fishery. In order to include environmental factors into the simulation model and examine two output scenarios, the projected future behaviour of two different estimates of future shrimp catch functions-named neutral climate change and monotonic increase of sea surface temperature (SST) scenarios-was included.

The neutral climate change scenario portrays the historical fishery behaviour. The monotonic warming scenario includes potential future SST conditions as predicted by the Japanese Atmospheric General Circulation Model (AGCM/MRI), which is used by the Intergovernmental Panel on Climate Change (IPCC) to build the A1B or intermediate scenario (moderate CO_2 emissions).

Catch forecasts were obtained by means of a Generalized Additive Model (GAM). GAMs are semi-parametric versions of generalized linear models that have proved useful in identifying numerical relationships between variations in the abundance of marine organisms and fluctuations in their environment (Murase *et al*., 2009). GAMs are characterized by their flexibility for describing complex relationships (Hastie & Tibshirani, 1990).

The determination coefficient and the percentage of deviance explained (DE) for by the models were used to assess, firstly, the explanatory power of climate variables on shrimp abundance. Subsequently, the best-fit models were chosen to exchange atmospheric for oceanic variables in an attempt to further improve the models' goodness of fit. The lowest Generalized Cross-Validation (GCV) figures were used as the criterion to identify the model with the best balance between goodness of fit and complexity (Wood, 2006). Given the numerical discrete nature of the response variable, a quasipoisson error distribution with a log link function was chosen to build the model, while the scale parameter was set to 0, denoting that the parameter was known. GAMs were fitted using the *mgcv* library (Wood, 2006) in R (R Core Team, 2013).

The GAMs chosen were built including the following input variables: 1) the first component (PC) of rainfall in Sonora, Sinaloa, Baja California and Baja California Sur; 2) the cumulative sum of SST anomalies as represented by the Pacific Decadal Oscillation (PDO) index; and 3) the common pattern of change in upwelling indices (NOAA, 2013), as obtained from a minimum/maximum autocorrelation factor (MAF) analysis that sought to isolate a common variation pattern among time series from different localities (Shapiro & Switzer, 1989; Solow, 1994; Zuur *et al*., 2007). The output variable was the size of the shrimp catch.

The two climate change scenarios (neutral and monotonic warming) were incorporated into the simulation model in terms of Catch per Unit Effort (CPUE) figures predicted by the GAM as an indicator of production per vessel (Csirke, 1989), assuming a normal probability distribution for each year's catch. Resource variability and future availability were analyzed by building scenarios to explore situations that might pose a risk to the activity. To this end, a random component was added to the outputs from the Monte Carlo simulation model analyzed.

RESULTS

Vessels characterization and information provided by producers

First, relevant information on the main features of the shrimp trawler fleet in Sinaloa and Sonora was obtained from official sources. This information allowed the discussion of these aspects in meetings held with representatives from the production sector, to reach an agreement on the criteria to use for defining each RSV.

The main physical features of each RSV are shown in Table 1, where differences such as vessel length, width, engine power, number of trips, crew size and the composition of species caught are evident. The characteristics are homogeneous in both cases. Large-sized blue and brown shrimp are meant for the export market, whereas medium and small shrimp are allocated to the domestic market.

The operating range of the two RSVs stretches across the coasts of Sinaloa, Sonora and Baja California. The Sinaloa RSV conducts four fishing trips during the catch season (September to February), where

Table 1. Comparison of physical, operating, and catch features of the two RSV.

Feature/Port	RSV Sinaloa	RSV Sonora
Physical characteristics		
Length (m)	22	24
Width (m)	6	6.3
Gross weight (m^3)	100	100
Net weight (m^3)	56	60
Storage capacity (m^3)	50	50
Engine power (HP)	450	425
Operating characteristics		
Base port	Mazatlán	Guaymas
Daily diesel consumption (L)	1,300	1,280
Number of trips	4	5
Crew size	7	6
Catch		
Blue shrimp (%)	17	59
Brown shrimp (%)	40	26
White shrimp (%)	-	-
Medium and small-sized shrimp (%)	43	15

as the Sonora RSV conducts five fishing trips (September to March). Each trip lasts about 30 days at sea plus a five-day in-port stay to download the product. Each RSV is older than 30 years.

The base year data used as input for the simulation model are summarized in Table 2. This table shows the income obtained and the expenses incurred (both in 2009 US$) by each RSV in 2009. Revenues include shrimp sales as the main income, as well as the marine diesel subsidy and the Value Added Tax (VAT) refund, as these two items derive from government policies set out in the Mexican law for supporting the primary sector. In both cases, a favourable income was earned.

Costs incurred include, firstly, the expenditure on fuel and lubricants; second, crew wages; then, expenses related to catch processing, packaging and marketing. Maintenance costs include those related to the vessel itself, plus those of the vehicles used to haul the product at landing, using only one truck for each RSV. Finally, there are other expenses such as payment for accounting services, telephone and electricity bills, ground staff (secretary, fleet manager, etc.), taxes, vessel insurance, etc.

Catch figures were expressed as CPUE for each RSV, and were validated in meetings with producers. The Sinaloa RSV had a historical maximum CPUE of 35 ton in 1987, and a minimum of 10 ton in 2004 (Fig. 2). The highest CPUE for the Sonora RSV was achieved in 1986 with 25 ton, and the minimum was only 8 ton in 1992 (Fig. 2). Figures shown in Fig. 2 for 2010 onwards are the outputs projected by GAMs under the two environmental variability scenarios.

Table 3 summarizes the results of fitting shrimp catch data in Sonora and Sinaloa to GAM, using the long-term pattern in the PDO, upwelling events and the first component of rainfall records in the region as predicting variables. For both regions, the fitness parameters were similar, with $R^2 > 0.7$ and deviance explained >80%; both models were selected based on the value of the GCV.

As for price, the historical trend (1980-2009) of nominal price was obtained from fisheries and aquaculture statistical yearbooks. Projected shrimp prices for 2010-2019 were estimated using official inflation rate projections (BANXICO, 2013).

Simulation for 2010-2019

A Minimum Acceptable Rate of Return (MARR) of 10.67% was used for calculating the Net Present Value (NPV). MARR was calculated as the sum of the inflation rate (3.57%; BANXICO, 2013) and the asset interest rate (7.1%; World Bank, 2013) in Mexico in 2009.

The mean NCI reveals a positive balance under the neutral climate change scenario, and a negative one under warming conditions. The other key financial indicators used for assessing economic risk are also shown in Table 4. Over the study period, the mean Cost/Benefit (C/B) ratio was greater than the decision criterion for this indicator only under the neutral scenario in both cases.

Table 2. Operating costs and revenue generated in 2009 (thousand US$) by producers from Sinaloa and Sonora. These data were used as the base year information to feed the simulation model and as baseline for the simulation runs.

Item	Sinaloa		Sonora	
	Income	Expenditures	Income	Expenditures
Shrimp	164.61		239.65	
Refund of Value Added Tax (VAT)	22.60		23.94	
Subsidy to marine diesel	41.18		38.92	
Fuel and lubricants		72.63		98.79
Workmanship		44.42		62.57
Processing, packaging and marketing		30.92		30.60
Maintenance		26.16		21.89
Other		26.56		24.31
Total	228.39	200.70	302.51	238.17
Net Cash Income (NCI)	27.69		64.33	

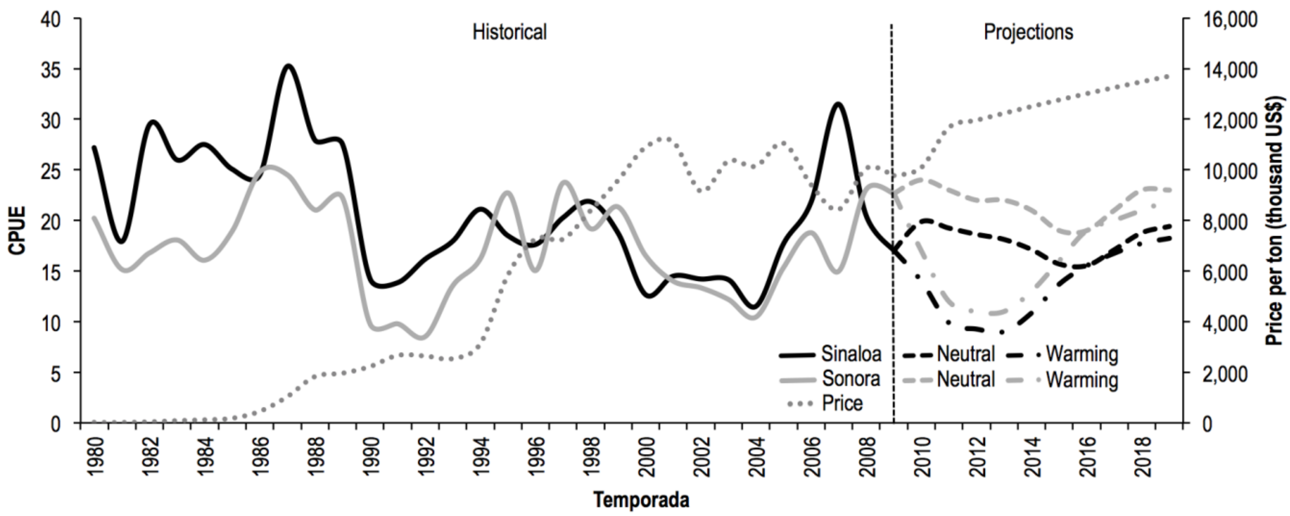

Figure 2. Catch per unit effort (CPUE) in Sinaloa (solid black line) and Sonora (solid gray line). Dashed lines are CPUE figures projected by GAMs under two scenarios: neutral climate change and monotonic warming. The gray dotted line depicts the historical trend of shrimp price up to 2009 and, from this year onward, the projected price.

The rate of return on assets was positive for both RSVs over the ten-year period analyzed, with lower figures under the monotonic warming scenario, noting that the only asset considered is the value of each vessel. NPV was positive under the neutral scenario, with a lower percentage of economic success for the Sinaloa RSV, and negative for both warming scenarios. This indicates that the established rate of return turned out to be lower than the required one, and generates no value over time. The Internal Rate of Return (IRR) was higher than MARR only under the neutral scenario for both RSVs.

The Sinaloa RSV displays a favourable behaviour under the neutral scenario, since the probability of NCI being lower than zero ranges between 13 and 18%. Meanwhile, under the warming scenario, NCI has a higher probability (between 46 and 95%) of falling below zero (Fig. 3). Mean NCI over the simulation period remained positive under the neutral scenario; under the warming scenario, however, it was negative from 2010 to 2017, and then it became positive again, thus generating losses in seven out of the ten years of simulation.

Figure 3 shows NCI values for each simulated year under both scenarios, displaying the mean and 25th and 75th percentiles, with a 90% confidence interval. Under the neutral climate change scenario, and assuming that fishing is only conducted by the Sinaloa RSV, the cumulative probability distribution of NCI shows a probability lower than 8% of incurring losses; under the monotonic warming scenario, the probability of yielding a positive NCI is 23%.

Table 3. Fitness of shrimp catches data in Sonora and Sinaloa to GAM. Environmental variables where used to approximate the curve of the response variable. Below each predictor are shown the effective degrees of freedom (edf), F-statistic and significance *P*-values.

Site	Environmental variables	R^2	DE (%)	n	GCV
Sonora	te(Upwelling + PDO_{CumSum}) + Rain(PC1) edf = 13.2; F = 4.9; $P = 1.45^{-5}$; edf = 1.3; F = 3.6; $P = 0.05$	0.73	84	44	502
Sinaloa	te(Upwelling + PDO_{CumSum}) + Rain(PC1) edf = 17.9; F = 4.1; $P = 1.78^{4}$; edf = 1.5; F = 0.73; $P = 0.04$	0.72	83	44	960

Table 4. Projected values for the key financial indicators of shrimp trawler vessels (average 2010-2019).

Indicator	Sinaloa RSV		Sonora RSV	
	Neutral	Warming	Neutral	Warming
Total Revenue (thousand US$)	286.48	235.81	354.08	286.91
Cash Expenses (thousand US$)	240.03	258.41	284.82	309.86
Net Cash Income (thousand US$)	46.45	-22.60	69.26	-22.95
C/B ratio	1.20	0.90	1.25	0.91
Return on Assets (%)	11.83	4.90	12.46	6.15
Net Present Value (thousand US$)	56.71	-174.04	142.10	-167.40
P (positive NPV or economic success) (%)	74.73	3.20	86.99	10.61
Internal Rate of Return (%)	16.74	-	22.46	-
Final Cash Reserves (thousand US$)	38.30	-205.58	330.39	-259.25

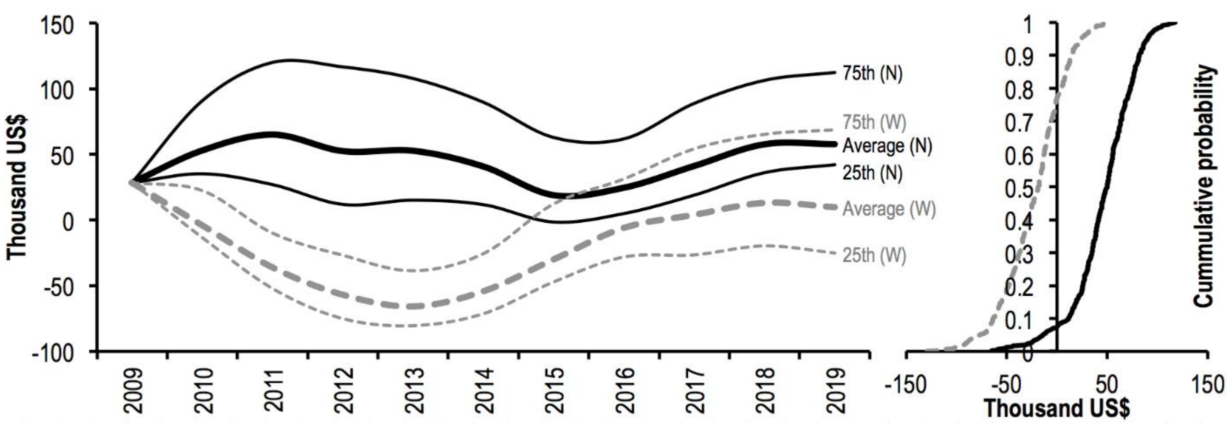

Figure 3. Simulated Average Net Cash Income for the Sinaloa RSV, considering the 25th and 75th percentiles of the NCI, under two different climate change scenarios, neutral (N) solid black line and monotonic warming (W) discontinued gray line, and using the cumulative probability distributions of the net present value of the average NCI for each scenario.

The Sonora RSV also displayed favourable conditions under the neutral scenario, with a 12-19% probability of the NCI falling below zero; under the warming scenario, this probability increased to 30-95% (Fig. 4). Mean NCI was positive under the neutral scenario; by contrast, under the warming scenario it became negative from 2010 to 2016, then shifting to positive figures until the end of the simulated period.

Under the neutral environmental variability scenario, the cumulative probability distribution of NCI showed a probability lower than 5% of incurring losses; under the monotonic warming scenario, the probability of achieving a positive NCI was 31%.

DISCUSSION

Slight physical differences between RSVs were observed, including length, width and engine power. The latter is the most important feature, as it defines the main operating cost and the consumption of marine

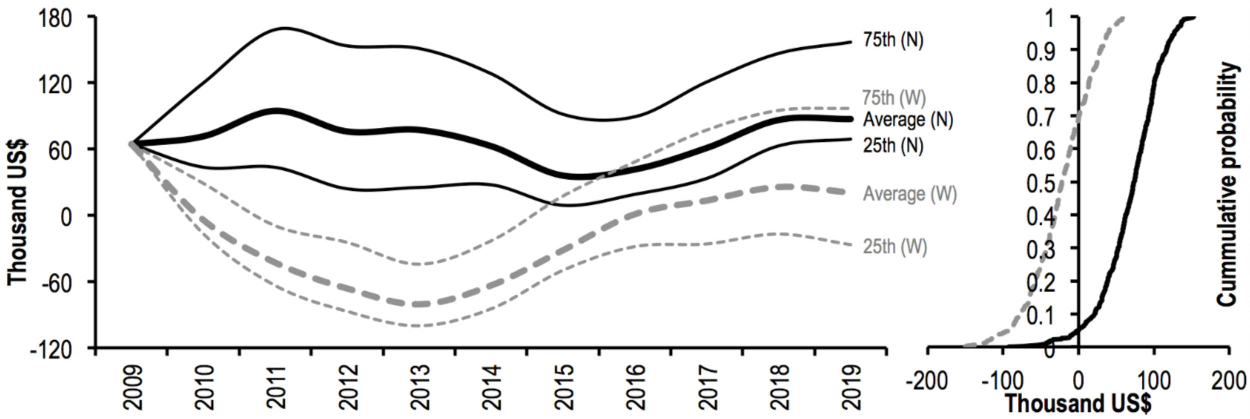

Figure 4. Simulated Average Net Cash Income for the Sonora RSV, considering the 25th and 75th percentiles of the NCI, under two different climate change scenarios, neutral (N) solid black line and monotonic warming (W) discontinued gray line, and using the cumulative probability distributions of the net present value of the average NCI for each scenario.

diesel, which, in turn, determine the main government subsidy, *i.e.*, the volume of marine diesel to subsidize. The Sinaloa RSV displays higher diesel consumption per day, just above the figure for the Sonora RSV.

Differences in crew size and number of trips, which also affect each vessel's operating costs, were also noted. However, although the Sinaloa RSV has an additional crew member, the Sonora RSV devotes a larger proportion to pay crew salaries, which are proportionally related to catch volume. The Sonora RSV also makes an additional trip, hence determining the higher profitability of this RSV in the present simulation.

In general, any extractive activity poses a risk to investment, and the analysis of the fishing activity is particularly challenging. Under the neutral scenario, both RSVs showed a high probability of making profit. By contrast, under warming conditions, such as a strong El Niño event that negatively affects production (López-Martínez, 2000), there is a higher probability of incurring losses in the planning horizon for both RSVs.

Moreover, these penaeid shrimp are considered stenothermic, with an optimum growth temperature between 24 and 28°C (Rodríguez de la Cruz, 1981); temperatures outside this range negatively affect their growth and spawning (Rodríguez de la Cruz & Juárez-Rosales, 1976). The low tolerance of these shrimp species to variations in temperature was confirmed in the warming scenario, which was built based on the GAM model by including a temperature increase from 28 to 32.6ºC, resulting in a negative effect on production and, therefore, on profitability.

In this sense, under the neutral scenario IRR figures for both vessels suggest that the shrimp fishery generates attractive returns, particularly considering that this is a high-risk extractive activity due to catch variability and the range of factors affecting it. IRR exceeded MARR for both vessels; however, the Sonora vessels showed a higher profitability and also a higher NPV, with a greater capital growth than the Sinaloa vessels.

Under the warming scenario, both RSVs showed losses due to a decline in production, thus increasing the risk and uncertainty related to obtaining no profits. However, the simulation in this analysis did not include factors such as changes in public policy, variations in the number of trips, etc., since the simulation was based on the base year conditions projected over a planning horizon.

Another indicator that does not take into account the value of money over time is the C/B ratio. Under the neutral scenario, C/B figures were higher than the decision criterion for both vessel types. This means that operating costs are covered and positive economic returns are generated: for every dollar spent or invested, 0.20 ¢ are recovered by the Sinaloa RSV and 0.25 ¢ by the Sonora RSV. Opposite results were obtained under the warming scenario for both RSVs.

The analysis reported here, which considers scenarios of environmental variability as alternatives, provides a tool to support decision makers involved in the shrimp fishery management, but does not imply that the fishery will necessarily behave as described herein.

In this regard, Ramírez-Rodríguez & Almendarez-Hernández (2013) suggested reducing the number of fishing trips of a unit composed of a vessel that fishes shrimp and squid, for NCI not to become negative. The idea was to represent the producer behaviour in an attempt to preserve his income or reduce his losses. This agrees with the producers' point of view, given that the first fishing trip is essential to determine the course of the shrimp fishing season (Quimbar, 2004; FIRA, 2009).

Under environmental conditions unfavourable for the resource, such as an anomalous and sustained rise in temperature, the offshore shrimp fishery becomes an unprofitable and unattractive activity. However, as in any economic activity, the operation of each RSV will be driven by the availability and size of catches, market conditions, policies for vessels withdrawal, etc.

CONCLUSIONS

Type vessels of Guaymas and Mazatlán are similar in terms of physical features; however, they differ in the way they operate and their economic performance, and are largely representative of the industrial shrimp fleet operating in these two ports.

The shrimp fishery, as any marine resource, is affected by fluctuating environmental processes which, in turn, impose variations in catch volume and, thus, in the expected economic return. Therefore, the climatic behaviour scenarios simulated here provided a sensitivity analysis of the activity for the two vessel types, showing an activity with moderate profitability under the neutral scenario, but with a low or nil profitability under the warming scenario. Which of these scenarios could be used for management and planning purposes will depend on a more profound understanding of past and present climatic conditions in the Gulf of California.

While the shrimp fishery always involves certain risk and uncertainty arising from climate fluctuations and associated biological processes, this study contributes to the identification of relevant factors that should be considered in planning and management to achieve a better performance of this activity.

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