Latin American Journal of Aquatic Research, 54(5): 728-734, 2026
DOI: 10.3856/vol54-issue5-fulltext-3521

Research Article

Effects of environmental conditions on the size-at-maturity of blue spiny lobster females of *Panulirus inflatus* (Decapoda: Palinuridae) at the southern coast of Sinaloa, Mexico

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ABSTRACT. An artisanal fleet has operated a small-scale spiny lobster fishery targeting *Panulirus gracilis* and *P. inflatus* since the 1980s south of Sinaloa, within the Gulf of California, Mexico. This study analyzed how environmental conditions affected female maturation and size-at-maturity in blue spiny lobster (*P. inflatus*) females from southern Sinaloa. We sampled the wild population in 1997 (El Niño), 2008 (La Niña), and 2013 (neutral conditions). For each specimen, we recorded carapace length (CL), total weight, sex, and maturity; for each environmental condition, we fitted a logistic model to size-at-maturity data. We compared the resulting curves using a coincident curves test. A total of 2,230 lobster females of *P. inflatus* were analyzed, with CLs ranging from 35.2 to 107.5 mm. The size structure differed significantly among environmental conditions; under El Niño conditions, we observed the highest proportion of mature females and the smallest CL at female maturity. We detected significant differences between the coincident curves for El Niño and those for La Niña and neutral conditions. These results suggest that blue spiny lobster females (*P. inflatus*) exhibit environmentally driven variability in maturation and size-at-maturity, reflecting prevailing habitat conditions, with important implications for fisheries management.

Keywords: *Panulirus inflatus*; breeding; carapace length; lobster; maturity; spawn

INTRODUCTION

An artisanal fleet has operated a small-scale spiny lobster fishery targeting *Panulirus gracilis* and *P. inflatus* south of Sinaloa, within the Gulf of California, Mexico, since the 1980s (Pérez-González 2011). Although commercial catches are relatively low (less than 200 t), they are highly relevant to the livelihoods and local economies of fishers in coastal communities (CONAPESCA 2024).

Management measures include a closed season from July to October and a legal-size catch (LSC) of 82.5 mm of carapace length (CL) for both species (DOF 2016) (review NOM-006-SAG/PESC-2016). The proportion of both species in the catch varies and depends on prevailing environmental conditions and each species' specific habitat (Pérez-González 2011).

The blue spiny lobster, *P. inflatus*, is native to the Pacific coast of Mexico, with a distribution ranging from Magdalena Bay in Baja California South to the

Associate Editor: Ingo Wehrtmann

Gulf of Tehuantepec on the Oaxaca coast, including the Gulf of California. Despite its economic importance (Pérez-González 2011), knowledge of the blue spiny lobster's biological features remains limited. In general, the environmental effects on the population dynamics of spiny lobster species are unknown; however, rising summer temperatures could trigger maturation and spawning (Pérez-González et al. 2009).

For *P. inflatus*, multiple spawning events throughout the year have been reported (Briones-Fourzán & Lozano-Álvarez 1992, Pérez-González et al. 1992, Hendrickx 1995). In the congeneric species *P. interruptus*, warmer temperatures during El Niño conditions accelerate breeding, whereas colder waters associated with La Niña have the opposite effect (Vega-Velázquez 2003). Similarly, Pollock et al. (1997) reported reduced growth rate in El Niño conditions (CEN) in the lobster *Jasus lalandii*.

A key parameter for assessing the effect of environmental conditions on maturity is the size-at-maturity (CL_{50}), defined as the length at which 50% of individuals in a population are sexually mature. In this study, we analyzed environmental conditions affecting maturation and CL_{50} in female blue spiny lobster (*P. inflatus*) from southern Sinaloa.

MATERIALS AND METHODS

The study was conducted along the southern coast of Sinaloa, from Mazatlán lighthouse to Piaxtla Point (Fig. 1). We collected female *P. inflatus* from commercial catches in 1997, 2008, and 2013, representing El Niño, La Niña, and neutral environmental conditions, respectively. Lobsters were classified as immature (stage 1) or mature (stage 2-6) according to a morphochromatic scale proposed by Briones-Fourzán et al. (1981). We measured the CL with a caliper from the base of the rostral spines to the back of the carapace. We used the two-sample Kolmogorov-Smirnov test ($\alpha = 0.05$) to compare the overall shape of CL size data between year-environmental conditions. We carried out all statistical analyses in R. We grouped the CL data into 5 mm intervals and estimated the proportion of mature females for each year analyzed. We then fitted a logistic model (Beverton & Holt 1957, Lysack 1980) to the maturity data.

$$P_i = \frac{1}{1 + e^{-b(CL_i - CL_{50})}}$$

where CLi is carapace length, *b* is the rate of maturity, and CL_{50} is size-at-maturity. Model parameters were estimated by minimizing the negative log-likelihood

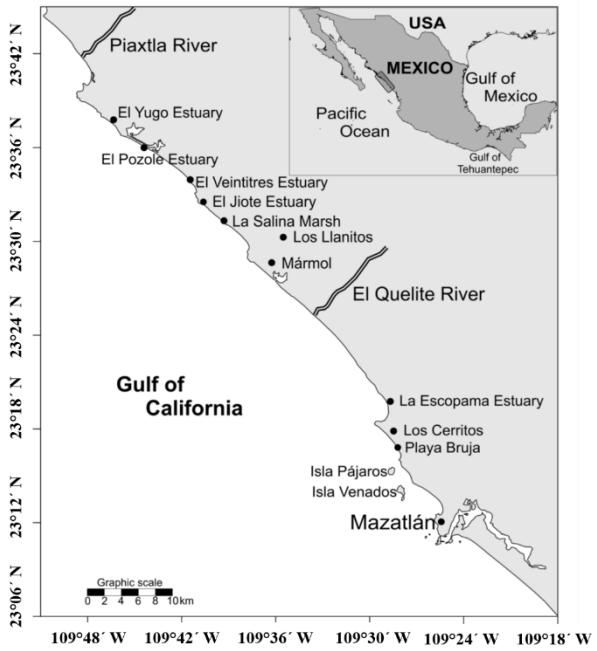


Figure 1. Location of the study area along the southern coast of Sinaloa, from Mazatlán lighthouse to Piaxtla Point, Mexico.

function, assuming a binomial distribution (Brouwer & Griffiths 2005):

$$-LL(\emptyset|data) = -\sum_{i=1}^{n}\left[mi \times Ln\left(\frac{p}{1-p}\right) + n \times Ln(1-p) + Ln\binom{n_i}{m_i}\right]$$

where LL represents the negative log-likelihood, p is the proportion of individuals in length class LCi, n_i is the total number in length class LCi, and m_i is the number of mature individuals in class LCi.

We used a bootstrap procedure to generate 1,000 random samples with replacement. We fitted each dataset independently and estimated parameter uncertainty using a nonparametric confidence interval (95%) based on the bias-corrected percentile method (Haddon 2011).

We compared maturity ogives between environmental conditions using a likelihood ratio test (Kimura 1980, Haddon 2011) to evaluate the coincidence curves.

$$X^2_{gl} = -N \times Ln(RSSa/SSi)$$

where N is the sample size in both curves, RSSa is the LL sum for the null model, and RSSi is the LL sum for the full model. We fitted models, ran bootstrap procedures, and performed statistical analyses in R (Posit Team 2025).

RESULTS

We analyzed 2,230 *P. inflatus* females across the three years under different environmental conditions. CL in the pooled dataset ranged from 35.2 to 107.5 mm. The smallest and largest CL were observed in 2008 and 2013, respectively, whereas the 1997 sample exhibited a narrower size range (Table 1).

Figure 2 shows the CL frequency for each environmental condition; the normality test was rejected in all datasets ($P < 0.05$; Table 1). The two-sample Kolmogorov-Smirnov test detected significant differences in CL among environmental conditions: 1997-2013 (D = 0.52671, *P*-value < 2.2e-16), 1997-2008 (D = 0.23898, *P*-value < 2.2e-16), and 2008-2013 (D = 0.41977, *P*-value < 2.2e-16).

Monthly maturity patterns suggest that female lobsters of *P. inflatus* reproduce year-round, independently of environmental conditions. However, the proportion of mature females was highest during El Niño and lowest during La Niña. Under El Niño conditions, maturity exceeded 50% in most months (except March and May); under La Niña, this occurred only in November; and under neutral conditions, maturity was 50% from February to May (Fig. 3).

Table 2 summarizes ogive parameters by environmental condition. *P. inflatus* showed thermal plasticity in CL_{50}, with the smallest CL_{50} during El Niño and the largest under neutral conditions. The La Niña CL_{50} was similar to the neutral condition estimate but showed a higher maturity rate.

Comparisons of maturity ogives between environmental conditions revealed significant statistical differences between El Niño and the other environmental conditions, whereas La Niña and neutral years did not differ significantly (Table 3, Fig. 4).

DISCUSSION

The proportion of mature females shows a monthly dynamic associated with environmental conditions. Although year-round maturation has already been reported in *P. inflatus* (Hendrickx 1995, Torres-Zepeda et al. 2008), the influence of environmental conditions on the proportion of mature females had not previously been evaluated. Differences in the duration of the reproductive season of *P. inflatus*, at least at the northern end of its distribution range, are likely related to differences in environmental conditions (Villalejo-Fuerte & Velázquez-Abunader 2007).

Under neutral conditions, two breeding peaks were observed in *P. inflatus* females: the first occurred in April and the second during the closed season, from July to October. This pattern of reproductive activity has been previously reported (Briones-Fourzán & Lozano-Álvarez 1992, Pérez-González et al. 1992).

Under El Niño conditions, a high proportion of mature females (>50%) were recorded throughout the year. Warmer seawater temperatures may accelerate ovarian maturation in *P. inflatus* females and shorten spawning intervals (Pérez-González et al. 2009), which is consistent with the continuous breeding previously reported for this species (Briones-Fourzán & Lozano-Álvarez 1992, Pérez-González et al. 1992, Hendrickx 1995, Torres-Zepeda et al. 2008).

Under La Niña conditions, mature females were observed year-round; however, their proportion remained below 30% from January to May. No information was available for July to October due to the closed season. Nevertheless, a high proportion of mature females were present in November, suggesting a single main breeding peak during the closed season. When we contrasted these results with those reported by Puga-López et al. (2015) for the same year in an area adjacent to our study site, an increasing trend in the proportion of mature females from May to November became evident. These results suggest that the warm waters associated with El Niño events stimulate reproductive activity throughout the year, resulting in several multiple spawning peaks. In contrast, the colder waters characteristic of La Niña events appear to inhibit breeding, limiting spawning to a single peak between July and November. Similar results have been reported for the spiny lobster *P. interruptus* in Baja California, where El Niño and La Niña conditions affected not only the onset and duration of the breeding season, but also oviposition and hatching processes (Vega-Velázquez 2003).

The dynamic variation in the proportion of mature females has important implications for fisheries management, because female size and maturity are key parameters for estimating CL_{50}. In this study, mature females were observed at CLs of 52.0, 53.1, and 54.0 mm under El Niño, neutral, and La Niña conditions, respectively. Pérez-González et al. (1992) found mature females of *P. inflatus* at 49.4 mm CL in wild populations from the same study area, while Gracia (1985) and Briones-Fourzán et al. (1981) recorded mature females between 54 and 56 mm CL in Zihuatanejo, Guerrero, Mexico.

Table 1. Size of *Panulirus inflatus* and normality test results for each environmental condition: El Niño, La Niña, and neutral (N: sample size, DE: deviance, and *P*: probability).

Condition (year)	N	Range (mm)	Mean	DE	*P*
El Niño (1997)	295	44.7-97	66.2	6.6	0.019
La Niña (2008)	1316	35.2-98.8	69.9	8.3	0.0002
Neutral (2013)	619	43.3-107.5	75.2	8.7	0.0005
Pooled data	2230	35.2-107.5	70.5	7.9	0.001

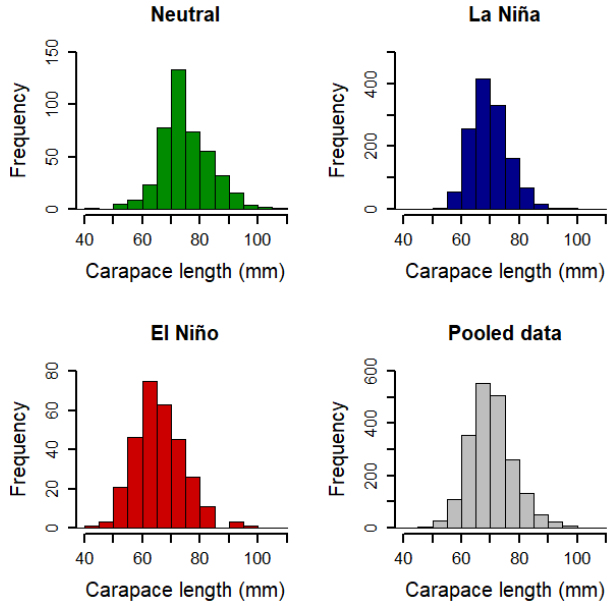


Figure 2. Size structure of *Panulirus inflatus* females under different environmental conditions along the southern coast of Sinaloa, Mexico.

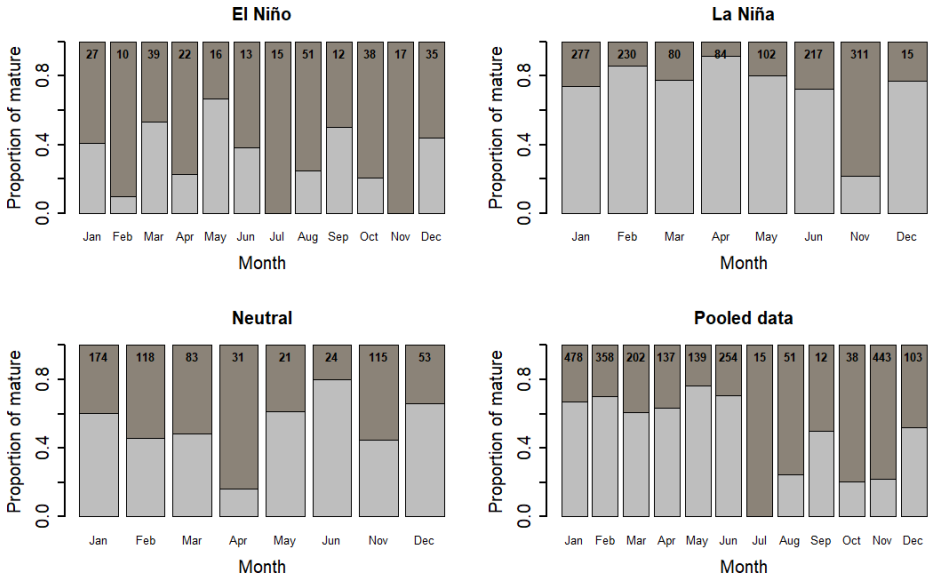


Figure 3. Maturity composition of *Panulirus inflatus* females across environmental conditions along the southern coast of Sinaloa, Mexico. Immature: light gray; mature: dark gray (the number on the bar top is the sample size).

Table 2. *Panulirus inflatus*. Parameters of the Lysack model under different environmental conditions (El Niño, La Niña, and neutral). CL_{50}: size-at-maturity, b: slope, and CI: confidence intervals (CI).

Environmental condition (year)	CL_{50} (CI)	b (CI)
El Niño (1997)	64.45 (62.56-65.78)	0.215 (0.086-0.261)
La Niña (2008)	69.63 (68.69-70.32)	0.262 (0.199-0.305)
Neutral (2013)	70.98 (69.62-71.99)	0.213 (0.159-0.261)
Pooled data	68.94 (68.36-69.49)	0.227 (0.193-0.252)

Table 3. Likelihood ratio test comparing maturity ogives of *Panulirus inflatus* among environmental conditions, El Niño-neutral (1997-2013), El Niño-La Niña (1997-2008) and La Niña-neutral (2008-2013). X^2: squared chi, and P: probability.

Comparison	Coincident test	X^2	P
1997-2013	Rejected	12.461	0.002
1997-2008	Rejected	9.332	0.009
2008-2013	Acepted	5.752	0.06

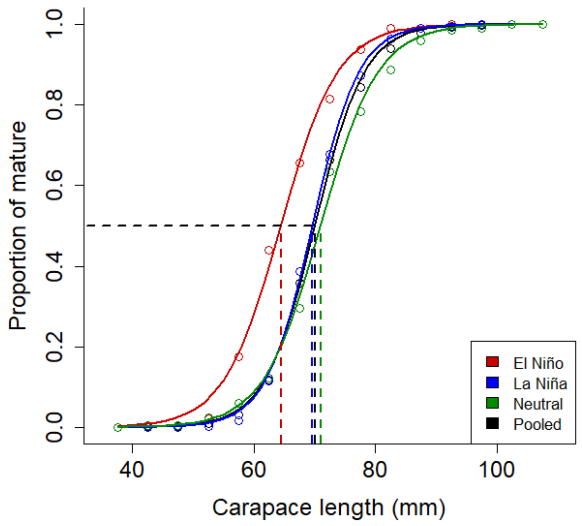


Figure 4. Maturity ogives of *Panulirus inflatus* females under different environmental conditions at the southern coast of Sinaloa, Mexico.

The variability of CL_{50} across environmental conditions provides clear evidence of an environmental effect on this population parameter. The comparison of maturity ogives showed that curve coincidence was rejected for El Niño relative to neutral and La Niña conditions, indicating that the female lobsters reach sexual maturity at a smaller CL under El Niño conditions. This pattern likely reflects warmer seawater temperatures, which stimulate gonadic development and accelerate maturation (Juinio 1987, Vega-Velázquez 2003, Pérez-González et al. 2009). The confidence intervals for CL_{50} under El Niño conditions did not overlap with those estimated for either La Niña or neutral conditions. In contrast, the LC_{50} intervals for La Niña and neutral years overlapped. This pattern confirms that CL_{50} is smaller under El Niño than under neutral conditions. In contrast, during La Niña events, size at maturity tends to be reduced, but values remain within the range of variation observed under neutral conditions. Future studies should explicitly test these patterns by incorporating both strong and moderate El Niño and La Niña events.

Although no studies have evaluated the effects of El Niño, La Niña, and neutral conditions on population parameters for *P. inflatus*, Briones-Fourzan & Lozano-Álvarez (2003) reported significantly higher growth rates in this species during winter than in summer. In addition, evidence from congeneric species and other crustaceans suggests similar responses. For example, Pollock et al. (1997) reported reduced growth rates in the lobster *J. lalandii* associated with El Niño conditions.

The former may help explain the occurrence of mature females at smaller CLs during El Niño conditions observed in this study. Warmer seawater temperatures likely stimulate maturation and reproductive activity (Pérez-González et al. 2009), promoting greater energy allocation to gonadic development; as a consequence, females may reach sexual maturity at smaller CLs. These findings provide clear evidence of environmental influence on biometric traits fundamental to biological understanding and fishery science. These results suggest that blue spiny lobster females, *P. inflatus*, exhibit dynamic patterns of maturation and size-at-maturity associated with prevailing environmental conditions in their habitats, with important implications for fisheries management.

Credit author contribution

J.Z. Borrego-Durán: writing and preparation of the manuscript; J. Payán-Alejo & G. Rodríguez-Domínguez: analysis and interpretation of results; Y. Gutiérrez-Rubio: conception and design of the study; R. Pérez González: data collection and interpretation of results; J.A. Félix-Ortiz: conception and design of the study and preparation of the manuscript.

Conflict of interest

The authors declare no conflict of interest in this manuscript.

ACKNOWLEDGMENTS

We acknowledge SECIHTI for the scholarship awarded to the first author (CVU 415832). We thank the Cooperative Societies of C.V. Punta Tiburón, José María Canizales and Rafael Buelna Tenorio for the facilities provided to carry out the sampling. Martín Ignacio Borrego and Luis Miguel Valadez-Manzano, staff of the lobster laboratory FACIMAR-UAS.

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Received: September 4, 2025; Accepted: August 12, 2026

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