

# Limiting factors for queen conch (*Lobatus gigas*) reproduction: A simulation-based evaluation

## Factores limitantes para la reproducción del caracol rosado (*Lobatus gigas*): una evaluación basada en simulación

## Facteurs limitants pour la reproduction du lambi (*Lobatus gigas*) : une évaluation basée sur la simulation

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### EXTENDED ABSTRACT

Queen conch are among the most economically, socially, and culturally important fishery resources in the Caribbean. Despite a multitude of fisheries management measures enacted across the region, populations are depleted and failing to recover. It is believed that queen conch are highly susceptible to depensatory processes, impacting reproductive success and contributing to the lack of recovery (Appeldoorn 1995). Empirical observations have suggested mating and egg laying in queen conch are directly related to the density of mature adults (Stoner and Ray-Culp 2000, Stoner et al. 2011, Stoner et al. 2012). In animals that aggregate, low population densities can make it difficult or impossible to find a mate, an issue which is likely compounded for slow-moving animals such as conch. Observations of queen conch populations also suggest an Allee effect, where little to no mating occurs below a critical density threshold (Stoner et al. 2011, Delgado and Glazer 2020).

To test whether challenges in mate finding at low densities could explain mating frequency patterns observed in the field, male and female conch movements, mating (i.e., collisions), and spawning (i.e., egg laying) were simulated in R using package ‘particles’. The simulation assumes a constant unit time step  $\Delta t = 1$  d for each step and a constant unit mass  $m = 1$  for all particles (i.e., adult conch). As a result, a force  $F$  acting on a conch is equivalent to a constant acceleration  $a$  over the time interval  $\Delta t$  and can be simulated simply by adding to the conch’s velocity, which is then added to the conch’s position.

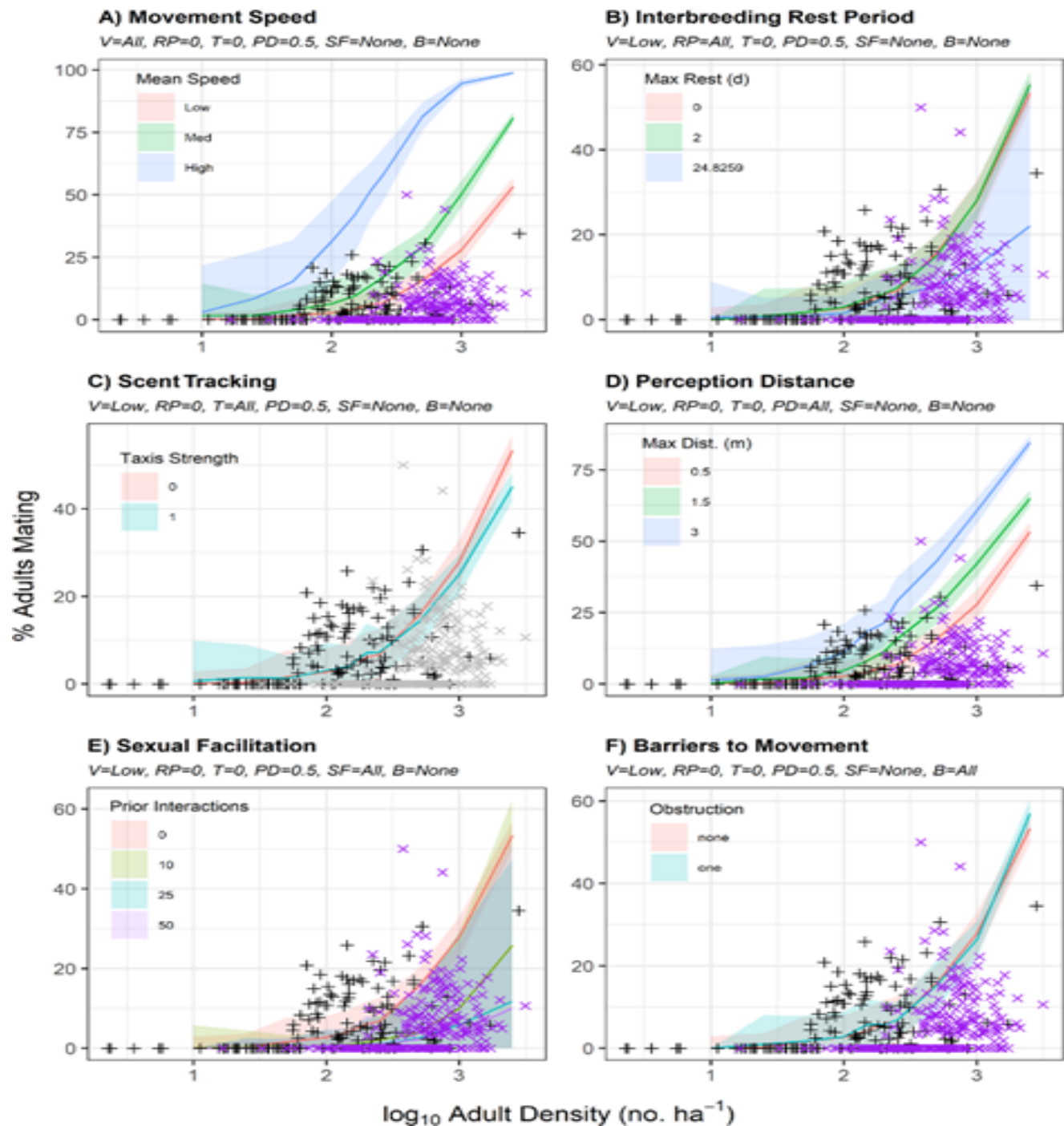
Sexually mature adult conch were randomly distributed at specified densities (i.e., 10 to 2500 adults/ha) on a 1-ha grid and tracked over one-day time steps (Fig 1). Daily reproductive dynamics were simulated across 10 days within peak spawning season, generating 10 replicates of daily random movements across a specified number of individuals per run. Movement velocities corresponded to a simple isotropic random walk model, assuming no directional persistence between daily time steps. The number and frequency of mating and spawning events was tracked and averaged across individuals over these 10 replicates. To evaluate whether mechanistic processes might provide superior fits to empirical observations over changes in density alone, simulation scenarios evaluated the additional influence of movement speed, scent tracking, interbreeding rest period, sexual facilitation, and conspecific perception distance (**Table 1**). All combinations of variables were tested using custom written R software, with 43,200 bootstrap simulation runs representing 432,000 spawning days across 20,671,200 individuals.

We compared simulation results to empirical observations of mating and spawning frequencies from conch populations in the central Bahamas and Florida Keys (**Figure 1**). Our results confirm that low probability of mate finding associated with decreased population density is the primary driver behind observed breeding behavior in the field, but is insufficient to explain observed trends. Specifically, sexual facilitation coupled with differences in movement speeds and ability to perceive conspecifics may explain the observed lack of mating at low densities and differences between mating frequencies in the central Bahamas and Florida Keys, respectively. Our simulations suggest that effective management strategies for queen conch should aim to protect high-density reproductive aggregations and critical breeding habitats.

KEYWORDS: Queen conch, *Lobatus gigas*, reproduction, simulation

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**Figure 1.** Percent mating relative to model parameters. Mean (solid lines) and 95% confidence band (shaded ribbons) for percent of simulated adult queen conch successfully mating relative to log<sub>10</sub> adult density (No./ha) relative to variation in A) movement speed (V), B) interbreeding rest period (RP), C) scent tracking (T), D) perception distance (PD), E) sexual facilitation (SF), and F) barriers to movement (B), with all other variables fixed at their lowest simulated values. Empirical observations by Stoner & Ray-Culp (2000) and Stoner et al. (2011) (black crosses) and Delgado & Glazer (2020) (purple x's) are overlaid for comparison.

**Table 1.** Queen conch reproductive parameters.

Parameter	Symbol	Units	Value	Source(s)
Adult Density	N	N ha <sup>-1</sup>	10, 25, 50, 100, 150, 200, 250, 500, 1000, 2500	Stoner et al. [34], Delgado & Glazer [38]
Movement Speed	V	M d <sup>-1</sup>	Low: N <sup>a</sup> [2.57 ± 1.57 (1.47–3.56)] Med: N <sup>a</sup> [4.17 ± 0.41 (0–5.52)] High: N <sup>a</sup> [11.36 ± 0.24 (0–21.24)]	Glazer et al. [14], Doerr & Hill [15]
Interbreeding Rest Period	RP	d	0 U <sup>b</sup> (0–2) N <sup>a</sup> [8.7 ± 4.9 (0–24.83)]	Weil & Laughlin [11]
Scent Tracking	T	n/a	0 1 (22 m max taxis distance)	Davies & Blackwell [44], Ng et al. [45], Doerr & Hill [15]
Perception Distance	PD	m	U <sup>b</sup> (0,0.5)	Informal expert elicitation from A. Stoner, G. Delgado, R. Glazer
			U <sup>b</sup> (0,1.5)	
			U <sup>b</sup> (0,3.0)	
Sexual Facilitation	SF	# prior interactions	0, 5, 10, 25, 50	Appeldoorn [35], Gascoigne & Lipcius [57], Delgado & Glazer [38]
Barriers to Movement	B	n/a	none, one	n/a

Table showing the parameters evaluated in simulation models.

<sup>a</sup>Truncated normal distribution [Mean ± SD (Min–Max)]

<sup>b</sup>Uniform distribution

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