Ecological spillover from a marine protected area replenishes an over-exploited population across an island chain

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Quantifying successful ecological spillover from marine protected areas (MPAs) is challenging yet crucial for conservation planning. The queen conch (Lobatus gigas) supports an iconic Bahamian fishery, but populations are declining. Here we provide evidence for MPAs as a solution: showing that a well-enforced MPA supplies ecological spillover through larval supply. Dive surveys throughout the Exuma Cays, including a centrally-located MPA, provided information on abundance, size, and age. Data showed higher-adult abundance within the MPA and positive associations between enforcement and conch size and age. A biophysical model estimated that MPA larvae settled in unprotected areas, and that MPA larval sources included unprotected sites with densities too low for reproduction. The MPA is currently sustaining nearby populations, yet its future is in jeopardy without upstream larval sources. Our results and consultations with stakeholders regarding management of the Bahamian conch fishery support creating a network of MPAs that exchange larvae for a sustainable future.

KEYWORDS
biophysical model, connectivity, larval transport, Lobatus gigas, queen conch, SCUBA survey

1 | INTRODUCTION

Marine protected areas (MPAs) are conservation tools that enhance ecosystems and fisheries by providing larval and adult spillover (Di Lorenzo, Claudet, & Guidetti, 2016). Socio-economic factors, such as enforcement level and fisher engagement, also alter MPA success (Di Franco et al., 2016). Although examples of ecological spillover from MPAs to unmanaged adjacent areas by harvested and unharvested species abound (Barrett, Buxton, & Edgar, 2009; Bonin et al., 2016; Harrison et al., 2012) these studies required specialized tools, expertise and research time. Indeed, studies evaluating MPA impacts often require multi-year monitoring programs, and tend to focus on large, mobile, fished species (Babcock et al., 2010). However, short-term studies of threatened and relatively immobile species should provide data on MPA function, if they are designed and given context using a well-studied species' life-history.

Queen conch (Lobatus gigas) is a valuable, iconic, and threatened denizen of the wider Caribbean region. This
herbivorous marine snail typically inhabits shallow (<30 m) vegetated habitats (Randall, 1964), making it an easy target for fishers. Heavy harvest results in reductions in density that can impact reproductive success since L. gigas are vulnerable to Allee effects (Stoner & Ray-Culp, 2000). A reproductive threshold is estimated at between 56 and 100 mature adults per hectare (Stoner, Davis, & Booker, 2012a; UNEP, 2012). In an effort to curtail widespread population collapse as demand for export has increased exploitation, a CITES Appendix II listing for the species has tracked and restricted trade since 1992 (CITES, 2012). Caribbean populations of L. gigas are isolated by larval dispersal (Truelove et al., 2017) and once local populations become depleted they are slow to rebound (Glazer & Delgado, 2003; Glazer, unpublished). Other than their larval phase, L. gigas are relatively sedentary, with home ranges on the scale of 10,000 m² (Doerr & Hill, 2013; Stieglitz & Dujon, 2017), thus MPA-associated replenishment of outside areas is directly through the ecological process of larval spillover.

Commercially, L. gigas is the second-largest fishery in The Bahamas valued at US $3 to 5 million per year (Sherman et al., 2018). However, increases in fishing effort and concurrent declines in abundance of L. gigas in fished areas in The Bahamas over short timescales highlight an urgent need for in-country conservation action and fishery regulation (Stoner, Davis, & Kough, 2018). Growth in L. gigas reaches a maximum size after about 3.5 years but shell thickness continues to grow over an animal's life, which approaches 20 years (Appeldoorn, 1988). Histological work demonstrates that lip thickness reliably estimates sexual maturity (Stoner, Mueller, Brown-Peterson, Davis, & Booker, 2012) and recent Caribbean-wide work suggests that a 15 mm lip thickness indicates 50% maturity (Boman et al., 2018), which we use in this study as the division between immature and adult individuals. Current Bahamian regulations restrict harvest to animals with a flared lip, yet the presence of a flared lip is not a reliable indicator of sexual maturity (Boman et al., 2018; Stoner, Mueller, et al., 2012). It is therefore legal to harvest some juveniles, and it is not surprising that populations are decreasing. The decline has not gone unnoticed. During 2015, The Nature Conservancy undertook a telephone survey throughout The Bahamas, aimed at gauging opinions about how Bahamians feel about L. gigas and their suggestions for L. gigas preservation. Their results (respondents = 1,001) demonstrated that L. gigas is thought to be in decline (73% of respondents) and that a clear majority of citizens (96% of respondents) support government regulatory action to protect L. gigas and the L. gigas fishery (TNC, 2015).

Given the overwhelming evidence of a population driven into decline by fishing and popular demand for action, our aim was to investigate MPAs as a conservation tool for L. gigas. Our study considers two critical and interlinked questions: (1) does a MPA replenish adjacent populations, and (2) how are populations connected through larval exchange?

2 | METHODS

2.1 | Surveys of tidal channels

In the summer of 2017, we conducted surveys of tidal channels in the Exuma Cays, The Bahamas, for L. gigas. The area surveyed included a central MPA, the Exuma Cays Land and Sea Park (ECLSP). Tidal channels naturally consolidate L. gigas as they move from nursery habitat on the banks, towards deeper shelf habitat which adults can exploit and forage on (Stoner, 2003). The abundance, distribution, and shell measurements of L. gigas in tidal channels (N = 25) within a ca 90 km stretch of the Exumas were assessed using SCUBA surveys. A pair of divers counted and measured the length and shell lip thickness of L. gigas within a 6 m wide transect during a 30 min drift dive. Each channel was surveyed using at least four dives (mean = 10 dives ± SD 3 dives) that encompassed a minimum of 19,700 m² (mean = 35,100 m² ± SD 13,000 m²). Dive start points were haphazardly distributed within a polygon that encompassed habitat from the mouth of a channel between any two islands to ca 3 km up the bank. Powerful currents and diver safety considerations prevented the exact prehoc allocation of survey distance, but a GPS (eTrex 10; Garmin) enabled the posthoc reconstruction of each dive. The locations of individual L. gigas were calculated from measurement time along the dive track. Direct observations by the authors of active copulation or egg-laying were also recorded as breeding activity.

2.2 | Survey statistics

Generalized linear mixed-effect models (GLMM) were used to describe associations between variable L. gigas abundance, and dive-, channel-, and MPA-specific factors. Separate models were run for adult (shell lip thickness > = 15 mm; Boman et al., 2018; Stoner, Mueller, et al., 2012) and immature (shell lip thickness < 15 mm) L. gigas. The best-fit combination of factors for each statistical model was evaluated using Akaike’s Information Criterion (AIC). A negative binomial model (“glm.nb”; package MASS; R Core Team 2016) was used for variable abundance because L. gigas is a rare species with over-dispersed and zero-inflated counts. We examined variable abundance (counts of immature or adult L. gigas) associated with the fixed-effects of Dive Length (DL; m), the longest segment of a dive with No Conch (NC; m), interactions between DL and NC, max depth (MD; m), and the categorical factor “park” along with the random effect of channel. The random effect accounted for the unique environmental and physical characteristics of each channel. All factors were centered and scaled.
(i.e., units of SD) to facilitate model convergence. The factor NC accounted for detection effort and was calculated by dividing each dive path into segments between individuals; the largest segment in each dive was NC. Shell measurements (length or shell lip thickness in mm) taken from individuals during the dive survey were assessed relative to the continuous factors distance to channel mouth (CM; m) and distance to park headquarters (HQ; m) using a generalized linear model with a Poisson link.

### 2.3 Biophysical model of larval transport

We used a coupled biophysical Lagrangian stochastic model, the open-source Connectivity Modeling System (CMS; Paris, Helgers, Van Sebille, & Srinivasan, 2013), to simulate larval transport and expected connections between *L. gigas* habitat throughout the Exuma Sound. The CMS is an individual-based probabilistic model where each particle takes a value at random from a distribution of traits (e.g., competency period). The model then uses a tricubic interpolation of ocean currents and a fourth-order Runge-Kutta temporal and spatial integration scheme to advect particles offline with high fidelity. The CMS was coupled offline to a high temporal (3-hourly) and spatial (1/50°C14) resolution ocean model using the 3D (u,v,w velocities) Hybrid Coordinate Ocean Model (HYCOM; Bleck, 2002), specifically run to resolve the circulation over the complex topography of the Bahamian Archipelago (BAH-HYCOM; Paris, unpublished). Surface forcing for the BAH-HYCOM model was provided by the 0.5° Navy Operational Global Atmospheric Prediction System and open boundaries were resolved by nesting BAH-HYCOM within the ATL-HYCOM (1/25°, daily resolution; Androulidakis et al., 2016; Kourafalou et al., 2016) simulation. The bathymetry for BAH-HYCOM was interpolated from the high-resolution General Bathymetric Chart of the Oceans (GEBCO_2014, version 20150318, www.gebco.net; Weatherall et al., 2015) and resolves many of the cays and shallow shelf areas that are missed by global ocean models yet prevalent through the Bahamian archipelago.

Potential spawning and settlement areas for the CMS habitat module were identified based on a reduced likelihood of encountering *L. gigas*, including recent recruits, moving away from deep water in the Exumas (Kough, Cronin, Skubel, Belak, & Stoner, 2017). Importantly, we took a theoretic approach and all potential habitat was treated equally in the simulation, despite large disparities in breeding stock and nursery habitat. We applied a 3 km buffer towards shallow water over a line placed across the sound-side border of the island chain to create habitat. We then split the habitat approximately every 5 km into 119 sites. Sites were further grouped into 7 regions of between 20 and 80 km. These region groups followed logical breaks created by park boundaries (e.g., the ECLSP is one region), deep-water passages (e.g., isolated Cat Island is one region) and landmarks (e.g., ~20 km long Great Guana Cay and ~40 km long Great Exuma Cay divide regions) that kept region size relatively consistent with the size of the ECLSP. Each site was assigned a virtual larval release location towards its center or in the center of a channel which it contained. On a biweekly basis during the *L. gigas* spawning season in The Bahamas, April through September, (Aldana Aranda et al., 2014) for the years 2010 thru 2013 we released 200 passive larvae (moved by 3D velocities and turbulence) from each release location at 1 m depth. This yielded 952,000 probabilistic trajectories (i.e., 200 particles from 119 sites during 10 biweekly releases for 4 years) to estimate Exuma *L. gigas* larval connectivity. The release frequency and magnitude were based on ranges from previous research (Kough & Paris, 2015) and the exact CMS simulation parameters are given in Table S1, Supporting Information.

### 2.4 Stakeholder perceptions

An important stakeholder in conservation, yet challenging to engage, is the fishers themselves (Barclay et al., 2017). The Bahamas National Trust directly opened dialog with fishers throughout the archipelago in a series of townhall style meetings during 2016 and 2017. These meeting were advertised to fishers, open to the public, and facilitated by the Bahamas National Trust. Meetings included a presentation on *L. gigas* life history and current regulations followed by a group conversation. This enabled adaptive question and answer opportunities to reflect each community’s needs. Meeting notes from the lead organizer (A. Lundy) were assessed to determine if the room reached consensus (i.e., majority) on implied questions relevant to *L. gigas* decline and conservation action. To increase coverage on more remote islands, the Bahamas National Trust’s Discovery Club, a group of youth learning about the environment, replicated the questions used in The Nature Conservancy’s 2015 phone survey (TNC, 2015) for one-on-one conversations with fishers.

The authors have not published the data elsewhere, have meet COPE authorship criteria, have injured no animals, have informed consent to report on townhall meetings and have disclosed funding sources.

### 3 RESULTS

Dive surveys (*n* = 250; Figure 1) show depth associations and an MPA effect associated with the relative abundance of adult and immature *L. gigas*. The best-fit statistical model for counts of adult and of immature *L. gigas* includes a random-effect of channel (*n* = 25) and fixed-effects DL (m), NC (m), interactions between DL and NC, max depth (m), and categorical factor “Park” (Table 1; Tables S2 and S3). Adults were associated with deeper habitat and had a threefold increase in abundance in the park versus outside the
Immature abundances were nominally associated with shallower depths and nominally associated with park protection (Table 1; Figure 1). As expected, both adult and immature abundances were positively influenced by DL (i.e., the longer the dive, the more animals you count), negatively associated with NC (i.e., if it is hard to find animals, you count fewer) and a positive interaction between the two (Table 1).

Measurements of 2,340 geolocated-individuals reveal the effects of position within a channel and proximity to effective enforcement on size and lip thickness (i.e., relative age; Table 2; Figure 2d,e,f). The best-fit model used a Poisson link to describe how variable shell length and lip thickness (mm) varied relative to continuous factors distance to channel mouth (m), and distance from park headquarters (HQ; m) for flared-lip \((n = 1,291)\) and unflared \((n = 1,049)\) \textit{L. gigas}. The size of unflared individuals was negatively associated with distance, both from the park HQ and from the mouth of a channel (Figure 2d,e). The size of flared animals was nominally positively-associated with distance from HQ and negatively associated with distance from a channel mouth (Figure 2d,e). Lip thickness was negatively associated with distance from HQ (Figure 2f) and negatively associated with distance to channel mouth (Table 2).

Larval transport simulations described the probabilities that potential \textit{L. gigas} habitat throughout the sound was connected through modeled particle exchange over 4 years (Figure 3). Although connectivity between all potential \textit{L. gigas} habitat in the Exuma sound was estimated and presented (Figure 3), we focus on exchanges involving the ECLSP region for brevity and as the location of our population surveys. Modeled larvae that successfully reached settlement habitat in the ECLSP from anywhere around the sound describe import (i.e., ECLSP as a destination) and export (i.e., ECLSP as the source) probabilities at a regional (30–90 km) scale. The model estimated that export from the ECLSP would go 12% south, 57% north, 5% across to Cat Island and 25% back into the park. Imports into the ECLSP were estimated to come from 57% south, 19% north, 3% across, and 20% from the park. Away from the ECLSP, two areas relatively devoid of \textit{L. gigas}, Cat Island and south of Great Exuma, were estimated to be largely self-recruiting, with more than 80% of their imported larvae coming from within the same region. The cays on the western side of the

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**TABLE 1** Measured effects on adult and immature \textit{L. gigas} abundance

| Factor     | Coefficient, adults | Coefficient, immature |
|------------|---------------------|-----------------------|
| Intercept  | -0.656 ± 0.168      | 0.534 ± 0.197         |
| MD         | 0.322 ± 0.079       | 0.007 ± 0.102 NS      |
| DL         | 1.344 ± 0.181       | 1.107 ± 0.207         |
| NC         | -2.744 ± 0.215      | -2.673 ± 0.241        |
| Park (yes) | 1.103 ± 0.187       | -0.653 ± 0.276 NS     |
| NC: DL     | 0.456 ± 0.065       | 0.458 ± 0.068         |

*Note.* The coefficients of fixed-effect factors from the best-fit GLMM models (negative binomial link with channel as the random effect) predicting the counts of adult and immature \textit{L. gigas} during dive surveys \((n = 250)\). Factors considered include dive length (DL; m), the longest segment of a dive with No Conch (NC; m), interactions between DL and NC, max depth (MD; m), and the categorical factor “park”. NS Denotes not significant \((p > 0.05)\), suggesting a nominal effect despite inclusion in best-fit model.

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**FIGURE 1** Abundance, breeding, and age of \textit{L. gigas} through an island chain including a MPA. Surveys in the Exuma cays (a) of the Bahamas. The surveyed channels (b) included the centrally located Exuma cays land and Sea Park, a well-enforced no-take MPA. The relative abundance of adult (c) and immature (d) \textit{L. gigas} per hectare surveyed during 6 m wide drift dives \((n = 250); total distance 146.5 km\). Divers noted reproductive activity, presented here as a proportion of the total observed activity (e), such as egg laying and copulation. Most of the observed breeding was within the park (86%). Mean (±SD) lip thickness (i.e., relative age) in flared-lip animals was also measured (f).
Exuma Sound are interlinked but the general flow of larvae is estimated to be from the south towards the northwest (Figure 3; Video S1).

Townhall meetings revealed general trends in perceptions of how _L. gigas_ is faring and what strategies should be employed (Table 3). The Bahamas National Trust reached a
total of 295 (9 minimum, 48 maximum, 25 average) Bahamians during 13 townhall meetings and in one-on-one meetings with fishers on two family islands (17 respondents). Each island had a consensus perception of *L. gigas* population decline and was aware of protected areas as a conservation strategy. Concerns about foreign poachers and livelihoods were also common, as was the false notion that park rules were only applied to Bahamians and not foreigners. Three meetings supported a ban on *L. gigas* export as a conservation strategy. While fishers are aware of MPAs as a conservation tool, they also see them as only having “fairytale benefits” (Table 3), in part due to a lack of successful local examples.

### 4 | DISCUSSION

We show that a well-enforced MPA supplies ecological spillover through larval supply. The ECLSP contains an

| Island        | Community         | People | Consensus population decline? | Aware of MPA as a conservation tool? | Believe in MPA benefits? | Supported management action                                                                 | Relevant comment                                                                 |
|---------------|-------------------|--------|-------------------------------|-------------------------------------|--------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Andros        | Nicholls town*    | 12     | Yes                           | Yes                                 | n/a                      | Closed season; heavy penalties for undersize conch; create sea parks                        | “Do not wait until the cows come home—establish these parks”                      |
| South Andros  |                   | 13     | Yes                           | Yes                                 | No                       | Stop poaching; stop exports                                                                  | “You cannot stop Bahamians and then let the foreigners do everything they want.” |
| Long Island   | North Long Island*| 5      | Yes                           | Yes                                 | n/a                      | Stop poaching; closed season; harsh penalties for breaking regulation                       | “...put strict regulations in place to protect the queen conch population”         |
|               | Clarence Town     | 26     | Yes                           | Yes                                 | Yes                      | Stop exporting conch                                                                         |                                                                                  |
|               |                   |        |                               |                                      |                          | Stop poaching                                                                                |                                                                                  |
|               | South Andros      | 11     | Yes                           | Yes                                 | Yes                      | Stop exporting conch                                                                         |                                                                                  |
|               |                   |        |                               |                                      |                          | Stop poaching                                                                                |                                                                                  |
| Inagua        | Matthew Town      | 48     | Yes                           | Yes                                 | No                       | Create a conch season                                                                        |                                                                                  |
| Cat Island    | New Bight         | 35     | Yes                           | Yes                                 | No                       | No change                                                                                   | “Do not come here to make us criminals.”                                        |
|               | Arthur’s Town     | 35     | Yes                           | Yes                                 | No                       | No change                                                                                   | “Parks with fairytale benefits”                                                   |
|               |                   | 12     |                               |                                      |                          |                                                                                             |                                                                                  |
|               | Sandy Point       | 21     | Yes                           | Yes                                 | Yes                      | Send a fisheries officer to Sandy Point to enforce laws                                       | “The room would like a park where baby conch are safe, even if it is a small area. It will start a trend of protecting babies in the country” |
|               |                   |        |                               |                                      |                          |                                                                                             |                                                                                  |
|               | Marsh Harbour     | 9      | Yes                           | Yes                                 | Yes                      | Stop exporting conch                                                                         |                                                                                  |
|               | Fox Town          | 39     | Yes                           | Yes                                 | Yes                      | Educate immigrants to stop them from fishing juveniles                                        |                                                                                  |
|               | Coopers Town      | 12     | Yes                           | Yes                                 | Yes                      | No change                                                                                    |                                                                                  |
| Grand Bahama  | Freeport          | 37     | Yes                           | Yes                                 | No                       | Educate fishermen and vendors on current laws                                                | “Create businesses and other opportunities for fishermen because conching is hard work and you cannot make enough money from it anymore” |
|               | West End          | 33     | Yes                           | Yes                                 | Yes                      | Current penalties need to be better enforced                                                 |                                                                                  |
|               |                   |        |                               |                                      |                          |                                                                                             |                                                                                  |
|               | East End          | 11     | Yes                           | Yes                                 | No                       | Protect juveniles in Parks                                                                   |                                                                                  |

Note. The Bahamas National Trust facilitated community meetings with fishers to give a voice to local stakeholders at the out islands around the archipelago. Meeting notes were assessed to determine if the room reached consensus (i.e., majority) on implied questions relevant to conch decline and conservation action. If the fishers themselves brought up or acknowledged the potential roll of a park, reserve, or protected area for sustaining stocks their belief in MPA benefits is noted as yes.

*Denotes results one-on-one surveys by students.
abundant, large, old, and well-protected population of adult *L. gigas* that is ecologically and oceanographically placed to export larvae to unprotected and fished areas around the Exuma Sound. We found that *L. gigas* had both smaller shells and thinner lip thickness (i.e., younger) with increasing distance from the park headquarters. In addition, the factor “park” (i.e., inside the ECLSP) was associated with finding adult *L. gigas*. Taken together, this evidence suggests that the well-enforced implementation of a strict no-take fisheries policy protects *L. gigas* and allows animals to reach older ages and larger sizes relative to the surrounding harvested areas. We conclude that the breeding animals in the park are a source of *L. gigas* larvae - ecological spillover - that are replenishing adjacent populations in the Exumas as demonstrated by immature populations in areas with limited breeding stock (Figure 1) and no change in the likelihood of encountering immature animals with respect to the park.

Repeated surveys within the ECLSP have shown decreasing adult abundances and increasing lip thickness over the past three decades (Kough et al., 2017; Stoner, Davis, & Booker, 2012c). These studies concluded that the ECLSP *L. gigas* population was slowly dying of old age and hypothesized that an interruption in upstream larval supply could be a factor. The advancing age of the population, with the thickest shells in The Bahamas (Souza & Kough, unpublished), is troubling because even though elderly *L. gigas* remain capable of reproduction throughout their life, gonadosomatic indexes follow a bell-curved relationship with lip thickness (Stoner, Mueller, et al., 2012). Senescence combined with a reliance on exogenous larval sources, reinforced here by our larval transport model that estimated only 25% local retention, imply that the park cannot maintain an Exuma Sound *L. gigas* population in isolation. Protecting upstream larval sources by strategically establishing other well-enforced MPAs will ensure that the *L. gigas* population endures in both the Exumas and the ECLSP.

Our biophysical model suggests that candidate MPA locations to supply the ECLSP, and the rest of the Exuma Sound with larvae, are located south of the park and north of Great Exuma. Establishing and protecting a breeding *L. gigas* population here (region 3, Figure 3) would supplement the output of the ECLSP and supply much of the Exuma Sound with larvae, while re-establishing a larval source for the ECLSP and should be a priority. In an optimal scenario, a network of reserves could be established that includes breeding populations to the north (i.e., region 5) and further south (i.e., region 2) to add redundancy and stability to larval exchange. In our idealized simulation, with equal larval release throughout the Exuma Sound, the ECLSP did not receive more larvae per habitat site than anywhere else, concurrent with previous larval connectivity studies (Mumby et al., 2007). However, even if a location is well-situated oceanographically for connectivity, it does not alone guarantee a functional MPA, especially over shorter timescales (Babcock et al., 2010). Furthermore, establishing an MPA may have unintended ecological consequences such as changes in habitat which pose a barrier to connectivity (Sato et al., 2017). Protecting the proper habitat is essential as *L. gigas* nurseries are constrained by more than larval transport (Stoner, 2003). In addition, to act as a larval source for *L. gigas* a new MPA must contain enough adults to enable density-dependent breeding (Stoner & Ray-Culp, 2000). Specific to our recommended range for candidate MPAs, we must note that these populations are largely extirpated (Stoner, Davis, & Booker, 2012c; Figure 1) complicating effective park placement and demanding creative solutions. Translocation, aquaculture and ranching (i.e., growing juveniles thru maturity in at-sea pens with reduced predation) have yet to be successfully applied strategies for increasing wild *L. gigas* abundances (Stoner, unpublished), thus protecting remaining natural stocks must be part of the solution.

Our results confirmed that *L. gigas*, like many other relatively sessile invertebrates, are associated with currents and, in the Exuma Cays, traverse tidal channels and move towards higher flow through ontogeny. Surveys should be focused within these natural chokepoints when evaluating abundance. Indeed, shell length was associated with CM distance (i.e., a channel’s interface with the shelf, where shallow bank populations can reach deep water). Survey via SCUBA in channels could locate a remnant *L. gigas* population to protect or an optimal location for experimental population enhancement in the southern Exumas, where oceanography predicts ideal connectivity for larval export.

While some MPA networks function effectively (Abesamis et al., 2017), nearly a third of the MPAs around the globe are not seeded by any protected larval sources, putting their long-term efficacy as productive conservation and fisheries management tools into doubt (Andrello et al., 2017). Our multidisciplinary approach provides a roadmap forward for protecting a species at a 200 km scale by demonstrating MPA ecological spillover and mapping probabilistic larval exchange pathways. Expanded surveys and modeling efforts can plan effective MPA networks on regional (Bahamas) and wider Caribbean metapopulation scales for *L. gigas* and other heavily-exploited species. This is an urgent need, not only for *L. gigas* but for other species with emergent fisheries in The Bahamas, such as stone crabs (*Menippe mercenaria*) and sea cucumbers (*Holothuroidea*). We provide a concrete Bahamian example of how an MPA can replenish harvested populations to dispel the local notion that parks only provide “fairytale benefits” for fishers (Table 3). Our results, paired with the general Bahamian consensus for government action to protect *L. gigas* (TNC, 2015), support establishing a network of interconnected and well-enforced MPAs as part of the Bahamian conservation plan for *L. gigas*. 
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CONFLICTS OF INTEREST
The authors declare no conflict of interest.

DATA ACCESSIBILITY
The dive survey data and analysis code that support the findings of this study are included in the supplemental data.

Author contributions
A.S.K., C.A.B., A.W.S. conceived the study; A.S.K., C.B.P. biophysical models; A.L. townhall surveys; A.S.K., C.A.B., A.L., H.C., G.G., S.H., R.S., A.C.W. dive surveys and dataset assembly; A.S.K. analysis; A.S.K. wrote the paper with contributions from all authors.

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Additional supporting information may be found online in the Supporting Information section at the end of this article.

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