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RECRUITMENT AND POPULATION DYNAMICS OF THE SPINY LOBSTER (*Panulirus argus*) IN THE GULF OF BATABANÓ, CUBA

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ABSTRACT

Caribbean spiny lobster *Panulirus argus* supports the most valuable fishery in Cuba. Despite the improvement of the management system catches have not recovered. Studies of factors outside the fishery that may be affecting lobster populations, mainly the recruitment process are of importance. Therefore, the first objective of this project was to evaluate the effect of tropical storms on recruitment in the Gulf of Batabanó and the second was evaluate the suitability of the Gadget model for the stock assessment of spiny lobster, and compare the results with the age-structured assessment model applied. Simple correlations were first explored between the recruitment indices for the three different life-stages (puerulus, juveniles and preadults) and the power dissipation index of tropical cyclones. Followed by cross-correlation analysis for the time series. A generalized linear model approach was applied to combine the effects. These models were compared using the second order Akaike information criterion and the Akaike weights. Moreover using the catch available, together with the survey abundance index and the catch per unit effort, a Gadget model was applied. The recruitment process has a high interannual variability, with some seasonality. There was not a strong correlation between the recruitment indices and the tropical cyclones index, the majority showed a slight positive effect of the tropical cyclones on the recruitment. The best relationship on the preadults index were found by combining the effect of the puerulus settlement with 17 months of time lag, the juvenile index with 5 months of time lag and the tropical cyclones index with 18 months of time lag. The Gadget model fit to the survey abundance index and the catch per unit effort was poor but with length distributions was better. The growth parameter used in the Gadget model resulted in lower growth than is estimated for the species. The population estimates, recruitment and biomass, for the spiny lobster by Gadget model are lower than those estimated by the VPA model. While the fishing mortality rate is higher by the Gadget model. Further development of the Gadget model for the spiny lobster is warranted.

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1 INTRODUCTION

The Cuban Archipelago is located in the tropical western region of the Atlantic Ocean, including the Caribbean Sea, as well as the waters of the Gulf of Mexico. The Cuban shelf has an approximate area of 69,881km². Almost 25% of this area is marine protected areas and is subject to different protection regimes (CNAP, 2013). The shelf is divided into four major fishing areas: Zone A (southeastern), B (southwestern), C (northwestern) and D (northeastern).

Marine fisheries are an important source of foreign currency, animal protein and employment. The Ministry of the Fishing Industry¹ of Cuba estimate that the sector provide 42,000 jobs, which include fishers, officials, technicians, administrative and support staff (Valle *et al.*, 2011). Fishing is done by 11 state enterprises, distributed throughout the country. They include 767 vessels of different types and 3,500 fishermen. Also associated with these companies are 3,600 small private boats with about 9,000 fishermen. They are only allowed to catch fin-fish.

Catches in Cuba, by weight, currently consist of: 62% fish, 21% lobster (*Panulirus argus*), 10% molluscs, 3% shrimp (*Farfantepenaeus notialis*) and 4% other species. According to Claro and Parenti (2001), around 140 fish species have some commercial value and many of them are exploited in a multispecies fishery. The main molluscs harvested in Cuban waters are mangrove oyster and queen conch. Other resources include sea cucumber (*Isostichopus badionotus*), sponges (*Hippospongia lachne*, *Spongia obscura*, *S. barbara*, y *S. graminea*), blue crab (*Callinectes sapidus*), stone crab (*Menippe mercenaria*), and all bycatch of the shrimp fishery. In terms of boat length, gross tonnage of boats, fishing gear, target species and technology efficiency, most fisheries operating on the Cuban shelf, with the exception of the shrimp fishery, can be considered to be artisanal/small-scale fisheries (Valle *et al.*, 2011).

The Caribbean spiny lobster *P. argus* supports the most valuable fishery in Cuba, and generates a net income of around US\$70 million per year, it provides direct employment to 1,110 fishers and indirect employment to approximately 7,800 people (Puga *et al.*, 2006). The fishery is conducted by 8 state companies, with 14 fishing ports (6 in the north and 8 in the south). There are nine processing plants that produce precooked entire lobster and packs of frozen lobster tails, which are the principal products exported to Europe, Japan and Canada (Puga and de León, 2003). This fishery takes place in all shallow waters around the Cuban shelf, but it is most common around the south shelf, especially in the Gulf of Batabanó (southwestern) where 70% of the total national catch is harvested. The total catch of spiny lobster grew until the early-mid 80s, when reached about 12,000 tons. In the early 90s, landings decreased along with the Cuban economy, but by the middle of the 90s it began to recover, but without reaching the previous maximum, then fell again. Currently the landings appear to be stabilizing, the average catches in the last 5 years are 4,500 tons of lobster.

The management system of this fishery has been improved over time. This has led to a significant decrease in fishing effort by a reduction in the number of boats (from 364 in the 70s to 176 in 2010) and in the number of fishing days (over 50,000 in the 70s to less than 20,000 in 2009), the increase in the minimum legal size of 69 mm CL to 76 mm CL (Puga *et al.*, 2010). Despite these improvements, catches have not recovered. Current assessment shows that recruitment has been

¹ The Ministry of the Fishing Industry was merged with another ministry, currently called Ministry of Food Industry (MINAL), in 2009.

below average level since 1996 with the lowest values during 2006-2011. Fishing effort and the fishing mortality rate (F) have declined sharply and stabilized at low levels during the current period 2008-2011 (Puga *et al.*, 2013). The landings have been slightly below the annual Total Allowable Catch (TAC), which was based on the rather conservative reference point $F_{0.1}$. Therefore, it is important continue to study factors outside the fishery, both environmental and anthropogenic, that may be affecting lobster populations, mainly the recruitment process. Further new stock assessment models might bring new aspect on recent changes.

Caribbean spiny lobster nursery habitat is characterized by shallow waters and the presence of mangroves roots, seagrass beds and sponges (Acosta and Butler, 1997). In the Gulf of Batabanó evidence suggests benthic habitat loss due to the occurrence of numerous environmental and anthropogenic factors (Areces *et al.*, 2006). This loss of habitat could affect recruitment success and therefore the subsequent abundance of fishable population due to the great importance of post-settlement processes in the population dynamics of lobsters (Butler and Herrnkind, 2000).

Recruitment variations have been observed in other populations of spiny lobsters, becoming up to 50% in cases of *P. argus* in Florida (Muller *et al.*, 2000) and Brazil (Ehrhardt and Sobreira, 2003), *P. cygnus* in Western Australia (Caputi *et al.*, 2001) and *P. marginatus* in Hawaii (Polovina *et al.*, 1995). In general, the authors suggest that these variations can not only be attributed to the effect of fishing operations, but are also determined by the influence of environmental conditions.

Among the environmental factors that could affect recruitment are meteorological events such as tropical cyclones that can possibly impact on both the ocean habitats and on the shelf. The passage of cyclones can cause changes in sediment dynamics, reef biota, seagrasses and mangroves, which may or may not recover according to the severity, duration and frequency of these events (Salazar-Vallejo, 2002). In addition, damages to the habitat by increasing frequency and intensity of tropical cyclones and socioeconomic development, have been suggested (FAO, 2007; Piñeiro *et al.*, 2006; Puga *et al.*, 2010).

1.1 Objectives

- Evaluate the effect of tropical storms on recruitment of the Caribbean spiny lobster, *Panulirus argus*, in the Gulf of Batabanó, Cuba.
- Evaluate the suitability of the Gadget model for the stock assessment of spiny lobster, and compare the results to the current age-structured assessment model of spiny lobster fishery.

2 LITERATURE REVIEW

2.1 Biology of *Panulirus argus*

The Caribbean spiny lobster is distributed from Bermuda and North Carolina in the United States in the north, to Rio de Janeiro in Brazil in the south, across the Yucatan and Central America and the Antilles (Cruz *et al.*, 1995). The life cycle of the species is complex and requires different habitats: oceanic (larvae) and shelf areas with abundant underwater vegetation and coral reefs for the juvenile and adult phases (Butler *et al.*, 1997).

The first life-history stage of the spiny lobster is a 5-12 months oceanic planktonic phase with 11 larval stages (*phyllosoma*) (Briones-Fourzán *et al.*, 2008). Given the strong ocean currents in the Caribbean Sea where these larvae are found, it is plausible that they may colonize regions downstream, thus the Pan-Caribbean theory of spiny lobster population structure (Lyons, 1980). This theory is supported by genetic studies (Silberman *et al.*, 1994; Naro-Maciel *et al.*, 2011). Although there is likely a high degree of larval connectivity in the Caribbean, some *P. argus* populations are located in strongly retentive oceanographic environments and probably experience significant self-recruitment because they are retained in offshore gyres and counter-currents that are persistent enough to constrain their long-lived larvae contributing to some of the most productive fisheries in the Caribbean (Ehrhardt *et al.*, 2011).

After developing in offshore waters, *phyllosoma* return towards the continental shelf where the final stage larvae metamorphose into the *puerulus*, a non-feeding stage, which then swims towards the coast, where it moults after a few days or weeks into a benthic juvenile stage (Phillips and Melville-Smith, 2006). Small juveniles are usually found in shallow coastal reefs and larger juveniles and adults in deeper water offshore. It is in these depths that they reach maturity, mating takes place, and the life cycle is completed (Butler and Herrnkind, 2000; Phillips and Melville-Smith, 2006).

2.2 Lobster fishery

2.2.1 Fleet and gear for spiny lobster fishery

Around 170 boats currently operate in the lobster fishery. The fleet includes boats made of different materials. Fiberglass boats are most common although still some ferrocement. The size of boats ranges between 10 to 18 m in length. One special feature of the lobster boats is a fish-well constructed in the hull of the boat which allows water circulation through holes and keeps lobsters alive for transportation to the collection center where it is landed daily (Valle *et al.*, 2011). These centers have been constructed at sea, close to the fishing zones (Baisre, 2000). There the lobster are kept in cages until a transporting boat (called *enviada*) that takes them alive in boxes to the processing plants on land.

Many types of fishing gear are used in the lobster fishery varying with the zone and with the season of the year. The most common is the artificial shelter (called *pesquero*), that is used mostly in the opening season (from July to September). Fishing by this gear is done by diving and using a lobster net or a bully net. A type modified of *pesquero*, or a liftable artificial shelter that is elevated on

board the boat using a winch is also used. A trap-like net (called *jaulón de corrida*) is used during the migratory season from October to February. Unbaited traps are also used in some areas, like on the northeastern shelf where it is very common. Here it is used together with the artificial shelters, the fishermen do not touch the shelters, they only fish with the surrounding traps.

2.2.2 *Spiny lobster fishery management*

The fisheries policy in Cuba is based on the Decree-law 164 “Rules of fishing” from 1996. This law constituted a significant shift in fisheries management, focusing on sustainability and profitability. In that year, resolution 456 “Methodology for policy granting of fishing authorizations” was approved. According to Baisre-Hernandez (2006) the most relevant aspects of this legislation were the creation of a system of fishing licenses, by which any fisherman or fishing boat must have a proper license or permit and the creation of the system of fines and penalties to be applied to lawbreakers. Monitoring, control and surveillance is implemented by the National Office for Fishery Inspection (ONIP). An advisory and consulting body (Fisheries Consulting Commission), which includes all parties involved in the use and exploitation of fishery resources and the coastal zone were established. Furthermore, there exist other 68 ministerial regulations for the fishery management. These sometimes can have temporary laws such as moratoriums, and others are renewed annually.

Adapting the model described by Puga and de León (2003), the fishery management workflow based on this legal framework is as follows. The Fisheries Research Center (CIP) and Bureaus of Capture (BC) do research and recommendations, providing scientific and technical support. Science and Fishing Regulations Division of MINAL (Ministry of food industry) prepares and proposes a management strategy based on these recommendations. The strategy is presented to the Fisheries consulting commission, where stakeholders, producers, management, researchers and inspectors analyse and discuss the proposal. When they come to an agreement it is presented to the Minister of the MINAL for approval and confirmed as a state law. Then, the state enterprises and private sector have to adhere the established regulations in the fisheries.

In the case of spiny lobster fishery, the CIP and BC collect, process, and analyse biological data (size composition, maturity, etc.), fishery independent abundance indexes and environmental data. The fishing sector contributes daily catch and effort statistics, GPS data on position of fishing gears and fishery operation, commercial weight categories from processing plants and economic data (costs and price) on fishery, processing and exporting. Workshop on stock assessment and fisheries management is conducted annually during the lobster closed season. Participants include the stock assessment group of CIP (organizers), representatives from managers of all enterprises, the ONIP, National Center for Protected Areas (CNAP) and Science and Fishing Regulations Division of MINAL. After discussing the results and proposals, agreements are signed and the process continues as previously explained.

The lobster fishery main regulations are: a state property limited entry regime; territorial rights by fishing enterprises; catch quotas and effort licenses by fishing areas (renewed every year); minimum legal size (76 mm carapace length); maximum legal size of females (140 mm carapace length); main nursery areas permanently closed; closed seasons to protect reproduction,

recruitment and growth (February to July, depends of the fishery zone); prohibition on taking berried females; prohibition to use lacerating fishing gears.

2.3 Gadget model

The Gadget (Globally applicable Area Dis-aggregated General Ecosystem Toolbox) is a statistical model of marine ecosystems that can utilise many different types of fisheries data, using appropriate assumptions on each dataset (Begley, 2012; Taylor *et al.*, 2007) (Figure 1). Gadget is an age-length structured forward-simulation model, coupled with an extensive set of data comparison and optimization routines. Processes are generally modelled as dependent on length, but age is tracked in the models, and data can be compared on either a length and/or age scale. (Thordarson and Elvarsson, 2014).

Gadget works by running an internal model based on many parameters, and then comparing the data from the output of this model to observed data to get a goodness-of-fit likelihood score, the parameters can then be adjusted, and the model re-run, until an optimum is found, which correspond with the model with the lowest likelihood score (Begley and Howell, 2004). A detail user guide, as well as worked examples can be found on www.hafro.is/gadget.

Gadget has successfully been used to evaluate the population dynamics of stock complexes in Iceland waters, the Barents Sea, the North Sea, the Irish and Celtic Seas and the Sofala Bank fishery of Mozambique (Begley and Howell, 2004). Also the Nile perch, *Lates niloticus*, in Lake Victoria (Nyamweya, 2013).

3 METHODS

3.1 Study area

The Gulf of Batabanó is a large semi-enclosed water body in southwest of Cuba approximate 21,305 km² in area (Cerdeira-Estrada *et al.*, 2008) with an average depth of 6 m (Emilsson and Tapanes, 1971) (Figure 2). The coastal area is predominantly fringed by mangrove forests and the bottom is covered by seagrass beds, with varying densities of *Thalassia testudinum* and other phanerogams and algae (Guerra-Garcia *et al.*, 2001). Living coral reefs are found all along the shelf (Alcolado, 1990). The southern border of this platform is fully covered by coastal coral reefs that in certain sectors emerge as reef crests (Gonzalez-Ferrer *et al.*, 2004).

This region is important for lobsters, coral reef fish, demersal fish such as red snappers and grunts, and some pelagic-neritic species such as sardines and crevalle jacks (Claro and Reshetnikov, 1994). It also represents an important tourism zone. Biological studies have indicated environmental degradation in the Gulf, resulting in loss of biodiversity and shift of benthic communities (Baisre *et al.*, 2003; Cruz *et al.*, 2001; Hernandez-Zanuy & Carballa, 2001) and reduction in size and capture levels of the spiny lobster (Puga *et al.*, 2005).

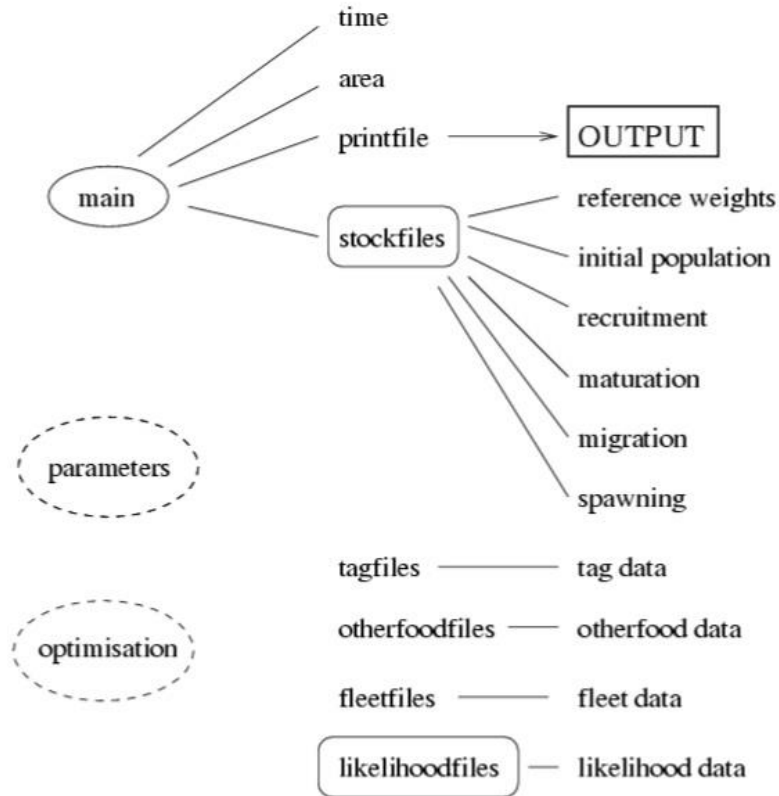


Figure 1: Schematic description of a Gadget model adapted from Begley (2012).

3.2 Data

3.2.1 *Puerulus settlement index*

For sampling the *puerulus* stage a modified floating collector, originally developed and used in Western Australia, was employed. The modifications were described by Cruz (2000) (Figure 3a). The collectors are situated in Matias cay (Figure 2). The samples were collected monthly for the years 1988-1996 and 2002-2012. In the first period there were 10 collectors, and were reduced to 5 collectors when the samples were retaken in 2002. *Puerulus* settlement index (PSI) was calculated as the average number of *puerulus* per collector per month.

3.2.2 *Juvenile abundance index*

For sampling juvenile stages of spiny lobster, an artificial shelter constructed with concrete blocks as described by Cruz (2000) was used (Figure 3b). The concrete blocks were placed in the nursery area of Bocas de Alonso (Figure 2). The samples were conducted monthly for the years 1989-1995 and 2002-2013. In the first period there were 60 collectors, and were reduced to 10 collectors when the samples were retaken in 2002. Juvenile abundance index (JI) was calculated as the average number of juveniles per artificial shelter per month.

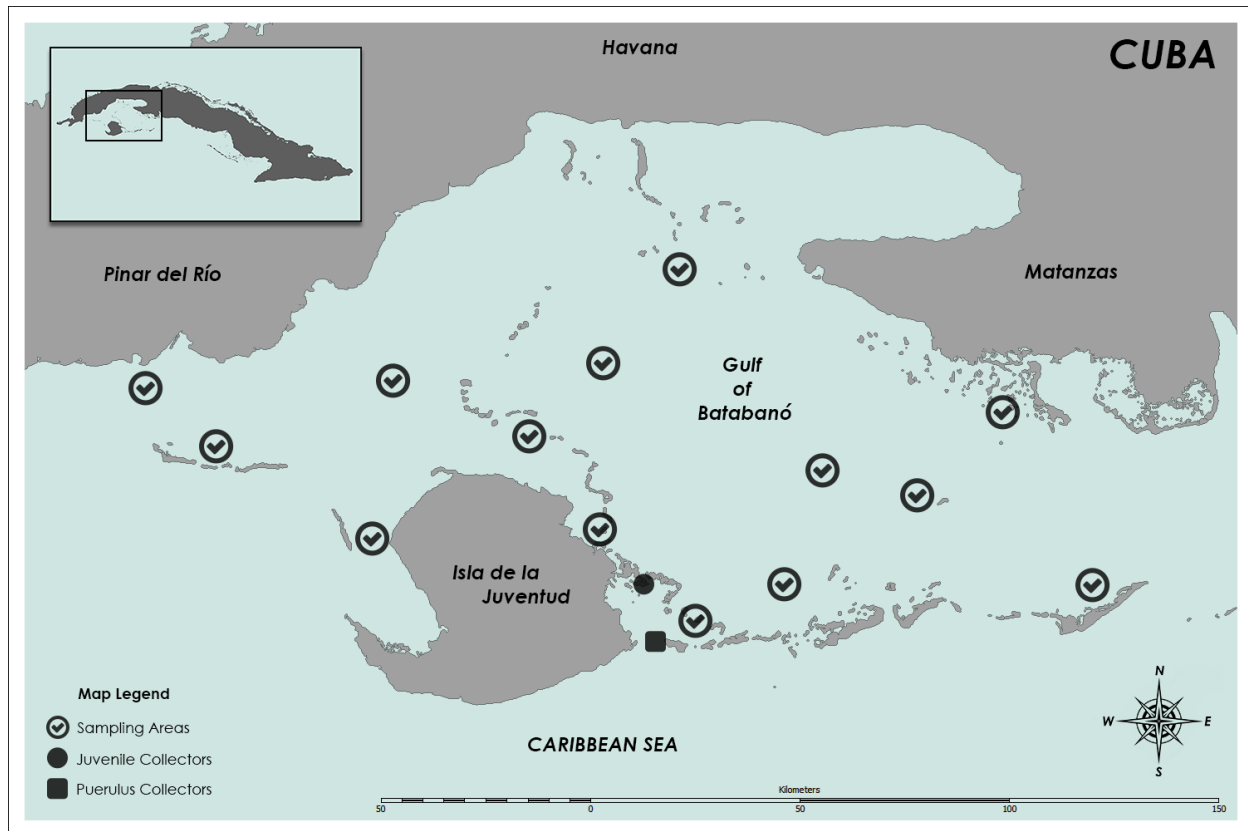


Figure 2: The Gulf of Batabanó, south-western region of Cuba. In the map is indicated the sampling areas (checkmark), the puerulus collectors in Matias cay (square) and the juvenile collectors in Bocas de Alonso (dot).

3.2.3 Survey abundance index

The samples were taken from unsorted catch on board commercial boats. At each sampling area (16 areas distributed around the Gulf of Batabanó), 200 individuals were randomly measured from the artificial shelter or “*pesquero*” used for commercial fishing (Figure 3). The lobsters were sexed and the carapace length (CL) was measured with a Vernier caliper of 200 mm and an accuracy of 1 mm, and the number of fishing gears deployed was recorded. The sampling was conducted monthly for the years 2002-2013. Survey abundance index was calculated as the average number of lobster per artificial shelter per month. The monthly preadults abundance index (PAI) was calculated as the average number of small lobster (CL < 70 mm) per artificial shelter.

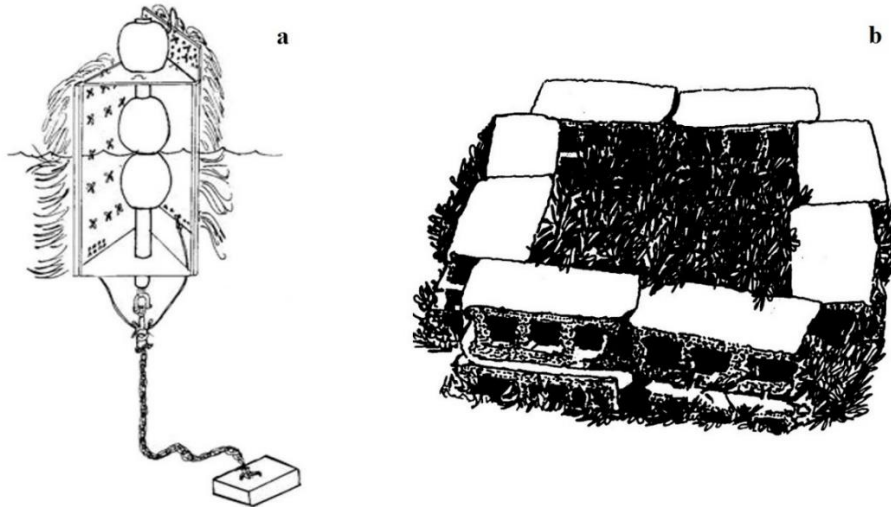


Figure 3: Collectors schemes used for sampling. a) Puerulus collector. b) Juvenile artificial shelter (Cruz, 2000).

3.2.4 Power Dissipation Index

The monthly activity of tropical cyclones on Cuban marine area was quantified by the Power Dissipation Index (PDI) from Emanuel (2005):

$$PDI = \sum v^3$$

Where v is the maximum sustained wind speed measured each 6 hours while the cyclones remain in the area. Only the tropical cyclones passing over the platform and/or surrounding seas of the Gulf of Batabanó were taken into account (approximately 100 nmi). The data were obtained from the database published in: <http://weather.unisys.com/hurricane/atlantic/index.php>.

3.2.5 Fishery data

Annual catches in tonnes from 1962 to 2013, fishing effort in boat-days from 1972 to 2013 and commercial weight categories from 1971 to 2013 were obtained from official compulsory records of the fishing enterprises to the Cuban Ministry of Food.

The commercial weight categories were converted into length composition and later to age structures of total catch, using the growth parameters for the von Bertalanffy growth equation obtained by de León *et al.* (1995), considered by Arce and de León (2001) to be the most consistent parameters for the species in the area (Table 1), and the length-weight relationship from Cruz *et al.* (1981):

$$W = 0.00243 * CL^{2.764}$$

Where W is the lobster weight (g) and CL is the carapace length (mm).

Table 1: The von Bertalanffy growth parameters for *Panulirus argus* estimated by de León *et al.* (1995). L_∞ is the asymptotic carapace length (mm), K is the growth coefficient, and t_0 is the age (years) when length would have been zero.

Parameter	Females	Males
L_∞	155	185
K	0.19	0.23
t_0	0.37	0.44

3.3 Recruitment analysis

In order to find out whether the different recruitment indices show a specific pattern of linkage between them and with the PDI, simple correlations were first explored including time lags of up to 18 months between the variables. Followed by cross-correlation analysis for the time series. The same original series were cross-correlated and the resulting cross-correlation functions (CCF) were plotted against the lags and tested for significance using confidence bounds, which are independent of any time lag and thus constant. CCF spikes outside of these confidence bounds are considered to be significant and determinate those lags at which one variable depends on the delayed variable.

It should be noted that the CCF procedure correlates the effects separately thereby ignoring any kind of interactions or co-variation between these indices, whereas a generalized linear model (GLM) approach applied would combine the effects. The GLM models were built that related the preadults (PAI) as the dependent variable combined the effects of the other indices (puerulus (PSI), juveniles (JI) and tropical cyclones (PDI)) varying the model according to the significant time lags found in the CCF:

$$\ln(\text{PAI}_{y_i, m_j} + 1) \sim \beta_1 * \ln(\text{PSI}_{y_i, m_j} + 1) + \beta_2 * \ln(\text{JI}_{y_i, m_j} + 1) + \beta_3 * \ln(\text{PDI}_{y_{i-1}, m_j} + 1)$$

Where PAI_{y_i, m_j} is the preadults abundance index in the year i , month j ; PSI_{y_i, m_j} is the puerulus settlement index in the year i , month j ; JI_{y_i, m_j} is the juveniles abundance index in the year i , month j ; PDI_{y_i, m_j} is the power dissipation index of tropical cyclones in the year i , month j ; and β is the estimated parameters for each independent variable.

The fit of the GLM models was examined using the second order Akaike information criterion (AICc) and the Akaike weights as the weight of evidence for each model given all the tested models (Burnham and Anderson, 2002). All the analysis were conducted using R studio and the libraries suggested by Crawley (2007).

3.4 Gadget model

A detailed description of the Gadget model is given in (Begley, 2012). In short it is a length-age based model with separable selection (as opposed to VPA-type models). It was originally developed as a multispecies- multiarea model but can just as well be used in a single stock context.

3.4.1 Model files

There is a separation of model and data within Gadget. The ‘main’ file was the first and it contains links to the all principal files to start working Gadget. In the ‘time’ file the time period to be modeled was defined from 1962-2015, with 4 steps of 3 months per year.

The ‘stock’ file was the most important and complicated, and it contains all the information on the stock. The age was defined between 1-14 years and length (CL) was 1.5-23.0 cm. The parameters of the length-weight relationship from Cruz *et al.* (1981) (see equation in section 3.2.5) was used to reference weight for each length group for the stock (other file contained a list of the reference mean weight for each length group). The next section of this file cover the parameters required for the growth of the stock. The growth function used in this example is an expanded form of the Von Bertalanffy growth function, split so that the increase in weight is calculated first, and then the change in weight is used to calculate a change in length (Begley, 2012). The natural mortality (M) was assumed to be constant with age at 0.34, derived from the empirical equation proposed by Cruz *et al.* (1981), this estimate has been used in previous stock assessment analysis. The stock was defined as a prey that is ‘eaten’ by the commercial fleet. The minimum/maximum length for the initial conditions was the same group that at the beginning for the stock. Like recruitment was defined CL between 1.5-6.0 cm.

In the ‘fleet’ file one commercial fleet and one survey fleet were defined. The selection curve was described as an exponential suitability function (ExpsuitfuncL50) which means it has an S-shaped form. The monthly landings, available from 1962, were grouped into the 4 time steps per year. The length distribution available for commercial catch was 0.5 cm basis.

The survey abundance index, as well as the length distribution (0.5 cm), was grouped into the 4 time steps per year. Catch per unit effort (CPUE) available on a monthly basis since 1981 was used as an index of relative abundance grouped into the 4 time steps per years.

3.4.2 Aggregations files

There are two age aggregation files - one that lists the possible ages individually and one that groups all the ages together into one age group. There are 3 length aggregation files. The first aggregates all the length declared for the stock in 0.5 cm length groups. A second file for the CPUE aggregates all the length groups together into one length group. The thirds corresponding to the survey index, aggregates the stock into 4 length groups. Although there is only one area it is still necessary to define an area aggregation file.

3.4.3 Optimization

The Rgadget package in R (Elvarsson *et al.* 2011) was used iteratively reweight each component separately. This was done in order to determine the lowest possible value for each likelihood component. Optimization in the iterative reweighting scheme involved use of Simulated Annealing and Hooke and Jeeves to estimate the weights. The determined likelihood weights were then fine-tuned using expert knowledge for the final run (Table 2).

Table 2: Likelihood components in the re-iterative process for the spiny lobster modelling in Gadget framework.

Type	Likelihood	
	Component	Weight
Catch distribution	ldist.catch	0.0241
	ldist.survey	0.0434
Survey indices	CPUE	7.8725
	si.all	4.0387
Understocking	understocking	1
Penalty	bounds	10

The results from the length based Gadget model were then compared to the results from the currently used VPA-type model employed in Cuba.

4 RESULTS

4.1 Recruitment indices and the power dissipation energy of tropical cyclones

4.1.1 Description of the recruitment and tropical cyclones series

The spiny lobster recruitment indices of different life stages showed high interannual variability, while tropical storms are occasional and produce strong disturbances (Figure 4). The *puerulus* settlement index (PSI) has an average value of 11.01 puerulus/collector, with a minimum of 2.18 puerulus/collector and a maximum of 60.14 puerulus/collector (Figure 4a). The juvenile abundance index (JI) has an average value of 9.62 juvenile/collector, with a minimum of 0.59 and a maximum of 35.3 (Figure 4b). The preadults abundance index (PAI) has an average value of 0.87 preadults/pesquero, with a minimum of 0.05 preadults/pesquero and a maximum of 2.99 preadults/pesquero (Figure 4c). The power dissipation index (PDI) of tropical cyclones has an average value of $0.21 \cdot 10^6$ m/s, reaching maximum of $8.62 \cdot 10^6$ m/s (Figure 4d).

Although recruitment occurred throughout the year some seasonality was observed in the indices, in some more pronounced than in other (Figure 5). The PSI is higher in the last months of the year, from September to December (Figure 5a). The JI does not show a marked seasonal pattern, but two peaks are observed, one between September - October and another in April (Figure 5b). The PAI shows a marked seasonal pattern, the main recruitment to the fishing areas occurred in the months of March to May (Figure 5c). While the PDI, shows practically the typical seasonal pattern for tropical cyclones, reaching highest values between August - October (Figure 5d).

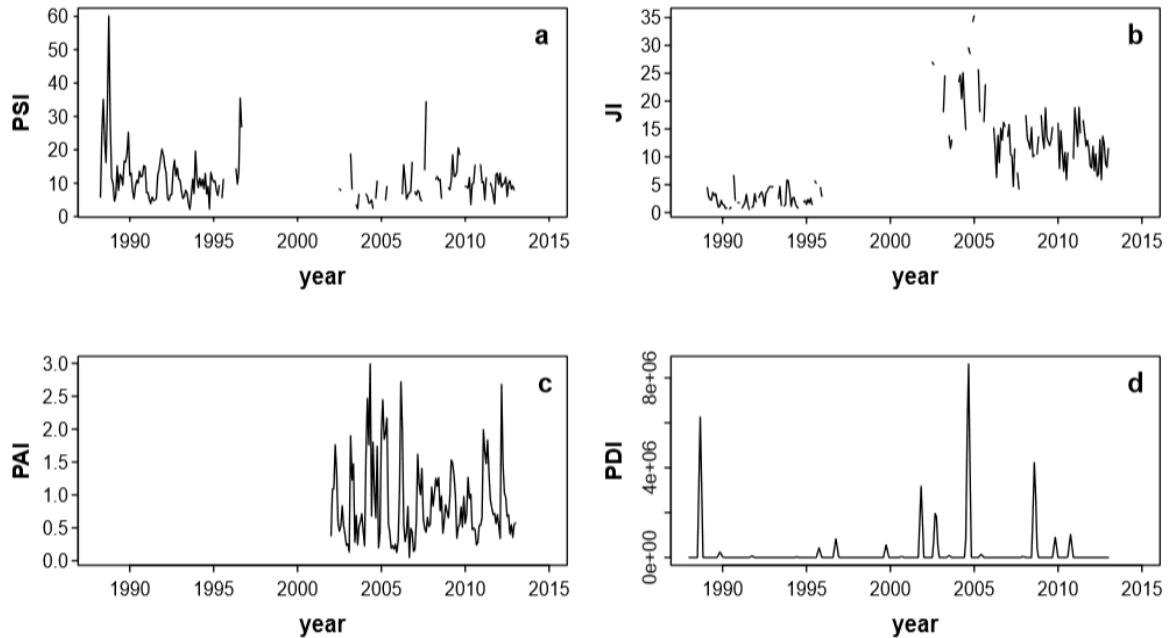


Figure 4: Time series of recruitment indices of *Panulirus argus* and power dissipation index of tropical cyclones, in the Gulf of Batabanó, Cuba. a) *Puerulus* settlement index (PSI). b) Juveniles abundance index (JI). c) Preadults abundance index (PAI). d) Power dissipation index of tropical cyclones (PDI).

In the first sampled period (1988-1996), PSI reached maximum values in 1988, which subsequently decreased, showing a second but lower peak in 1996. During the second period 2002-2012, the trend was to increase slightly, with a peak in 2009 (Figure 6a). The JI showed low values during the first period 1989-1995, increasing significantly in the early 2000s, declining again in 2006, and shows some stabilization in more recent years, with higher values than the early 90s (Figure 6b). The PAI shows a slight decreasing trend in the period (2002-2013), and has two peaks, the first higher in 2004 and another in 2011 (Figure 6c).

The annual PDI showed a high activity of tropical cyclones in the first decade of the 2000s, with a maximum value in the year 2004 (Figure 6d). In the last years, these phenomena did not impact on the Gulf of Batabanó.

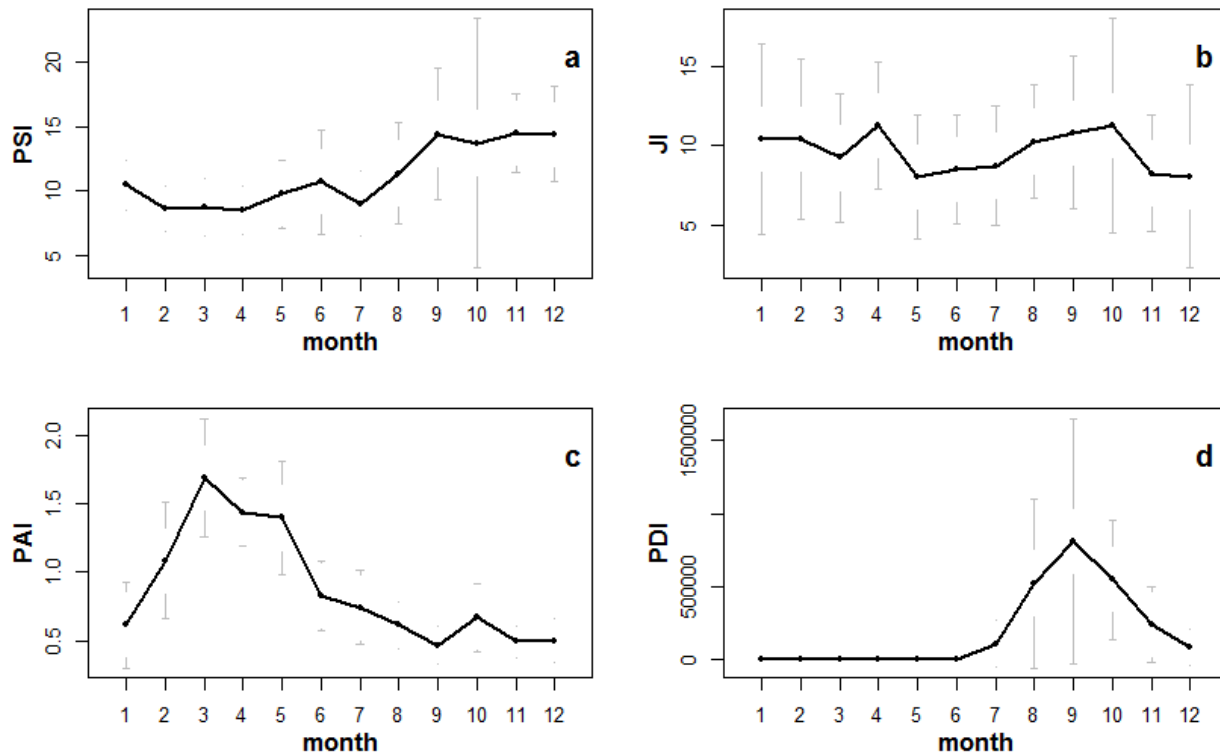


Figure 5: Seasonality of the recruitment indices of *Panulirus argus* and power dissipation index of tropical cyclones in the Gulf of Batabanó, Cuba, with 95% confidence interval. a) *Puerulus* settlement index (PSI). b) Juveniles abundance index (JI). c) Preadults abundance index (PAI). d) Power dissipation index of tropical cyclones (PDI).

4.1.2 Correlations

Monthly recruitment indices were correlated with each other with lags up to 18 months (Table 3). Only weak correlations were found between the indices. The PSI was correlated with the JI and PAI, and the JI with the PAI. Between the PSI and the JI only negative correlations were found. While between the PSI and the PAI the highest correlation was observed with a lag of 4 months ($r = 0.20$). Moreover, between the JI and the PAI, significant correlations were found for the first lags, the most high with one month of lag ($r = 0.36$) followed by 4-5 months of lag ($r = 0.34$).

By correlating the monthly PDI with different indices of recruitment weak positive correlations were mainly found (Table 4). With the PSI, the highest correlation was found with one month of lag ($r = 0.32$). While with the JI, between 3-4 months of time lag ($r = 0.35$) and with the PAI the highest correlations were found with 6 months of lag ($r = 0.33$) and 18 months ($r = 0.35$), although it should be noted that between 11-14 months, negative correlation ($r = -0.24$) was found.

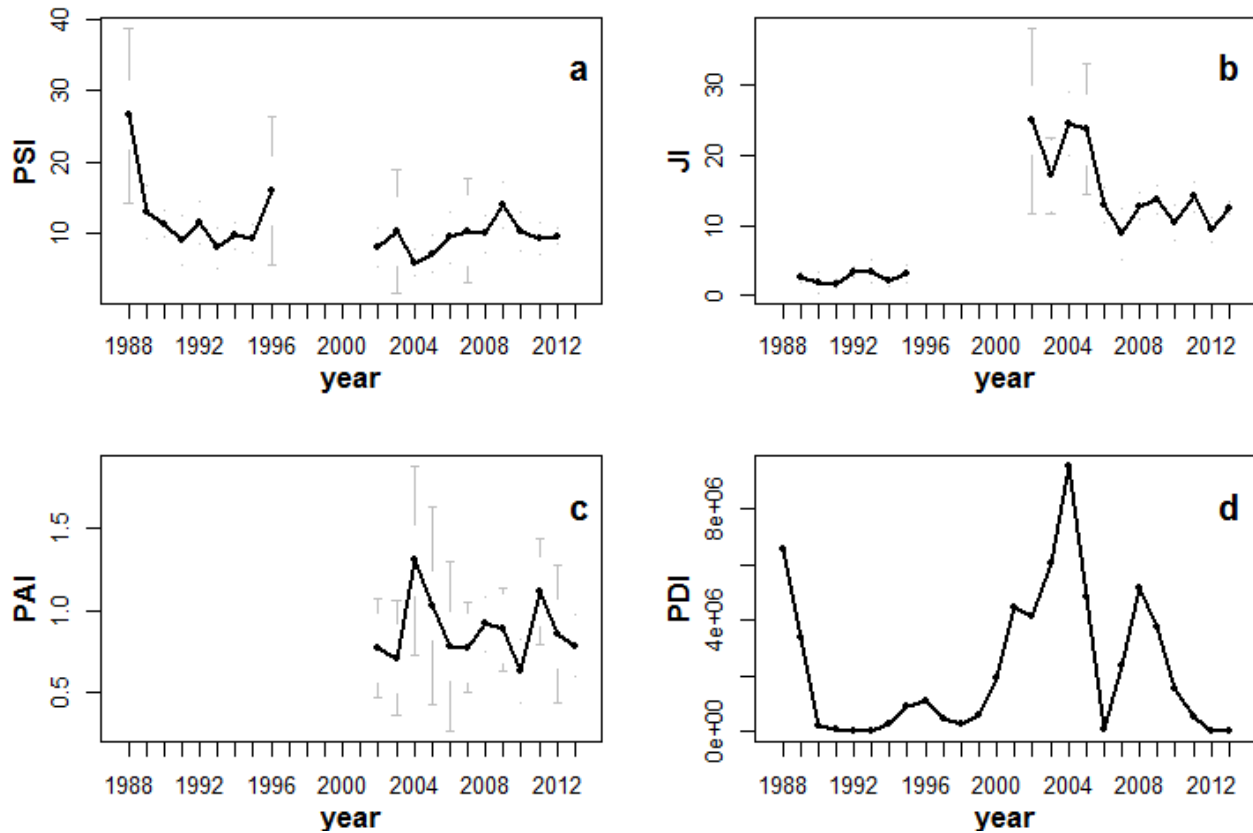


Figure 6: Annual average of the recruitment indices of *Panulirus argus* and power dissipation index of tropical cyclones in the Gulf of Batabanó, Cuba, with 95 % confidence interval. A: *Puerulus* settlement index (PSI). B: Juveniles abundance index (JI). C: Preadults abundance index (PAI). D: Power dissipation index of tropical cyclones (PDI).

Table 3: Simple correlations with monthly lags between the recruitment indices of *Panulirus argus* in the Gulf of Batabanó, Cuba. The first variable leads the second. *Puerulus* settlement index (PSI), juvenile abundance index (JI) and preadults abundance index (PAI). * $p < 0.05$, ** $p < 0.01$

Lag	PSI & JI	PSI & PAI	JI & PAI
0	-0.161	-0.184	0.236*
1	-0.164	-0.190	0.359**
2	-0.176	-0.110	0.243*
3	-0.132	-0.066	0.259*
4	-0.117	0.203	0.339**
5	-0.084	0.077	0.341**
6	-0.151	0.134	0.089
7	-0.172	-0.116	0.034
8	-0.164	-0.099	-0.057
9	-0.180	-0.179	-0.221
10	-0.159	-0.255*	-0.157
11	-0.146	-0.124	0.005
12	-0.219*	-0.231	-0.100
13	-0.153	-0.147	-0.053
14	-0.129	0.059	0.130
15	-0.209*	0.098	0.142
16	-0.189	0.169	0.082
17	-0.205*	0.187	-0.007
18	-0.187	0.182	0.053

Table 4: Simple correlations with monthly lags between the power dissipation index (PDI) of tropical storms and the recruitment indices of *Panulirus argus* in the Gulf of Batabanó, Cuba. The first variable leads the second. *Puerulus* settlement index (PSI), juvenile abundance index (JI) and preadults abundance index (PAI). * $p < 0.05$, ** $p < 0.01$

Lag	PDI & PSI	PDI & JI	PDI & PAI
0	0.194**	0.285**	-0.008
1	0.317**	0.295**	-0.032
2	0.252**	0.296**	-0.115
3	0.025	0.345**	-0.078
4	-0.068	0.353**	0.139
5	-0.093	0.183*	0.309**
6	-0.087	0.096	0.334**
7	-0.077	0.218**	0.308**
8	-0.072	0.161	0.220**
9	-0.009	0.107	0.036
10	-0.008	0.067	-0.129
11	0.006	0.108	-0.218**
12	0.062	0.108	-0.243**
13	-0.028	0.033	-0.234**
14	0.195**	-0.057	-0.230**
15	0.178*	-0.064	-0.191*
16	0.071	0.008	-0.059
17	-0.036	0.066	0.163
18	-0.107	0.045	0.349**

The cross-correlations of original time series of recruitment indices and PDI showed similar patterns to those detected in the simple correlations with time lags. For the relationship between the PSI and the JI, negative correlations were observed (Figure 7A). Between the PSI and the PAI, peaks are perceived at different time intervals, alternating between positive and negative values, which should be influenced by the seasonality of the both series (Figure 7B). While the JI and the PAI slightly more robust relationship were found (Figure 7C).

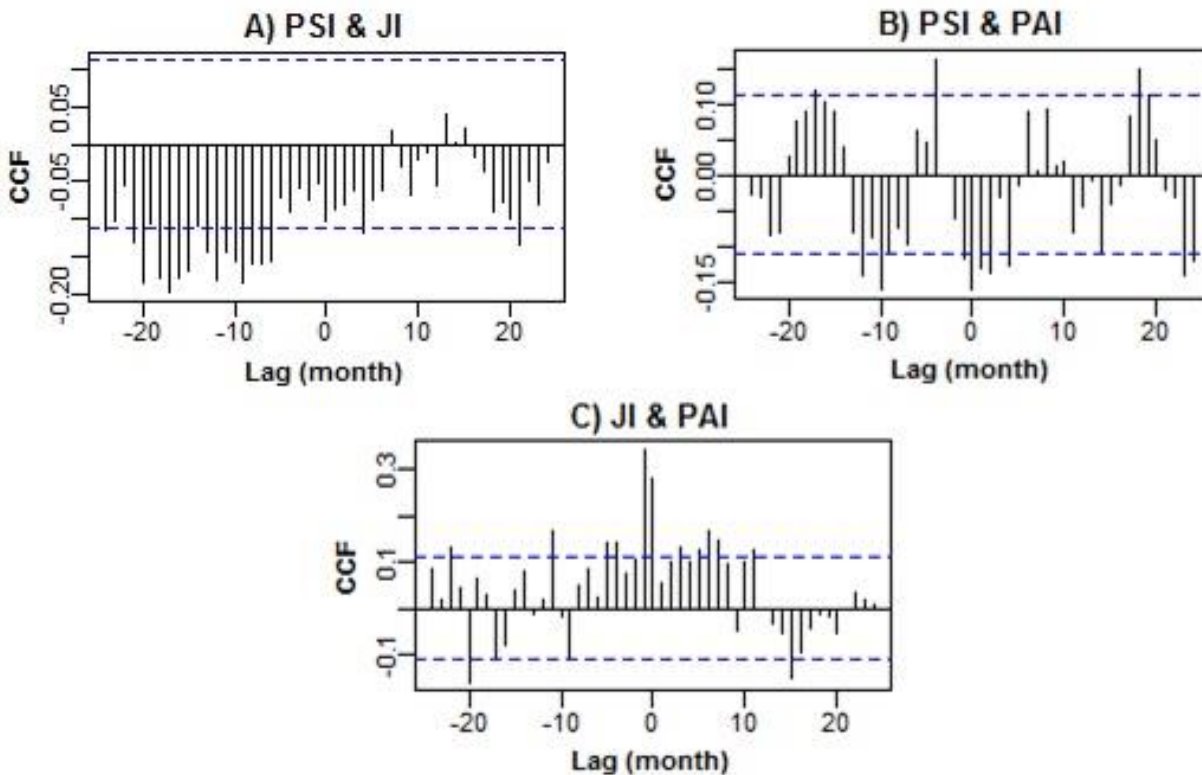


Figure 7: Cross-correlation function (CCF) of the recruitment indices of *Panulirus argus* in the Gulf of Batabanó, Cuba; negative lags indicate that the first index leads the second. The blue lines indicated bounds for statistical significance A: Between the *puerulus* settlement index (PSI) and the juvenile abundance index (JI). B: Between the *puerulus* settlement index (PSI) and the preadults abundance index (PAI). C: Between the juvenile abundance index (JI) and the preadults abundance index (PAI).

The cross-correlations between the PDI and the PSI showed seasonal trend, varying periodically among positive and negative cycles, although the first are slightly stronger and significant (Figure 8A). Between the PDI and the JI was observed a positive relationship between each of the first five months of time lags (Figure 8B). While with the PAI, the relationship with seasonal trend is more marked, showing slightly stronger positive values, but both, negative and positive spike appears was significant (Figure 8C).

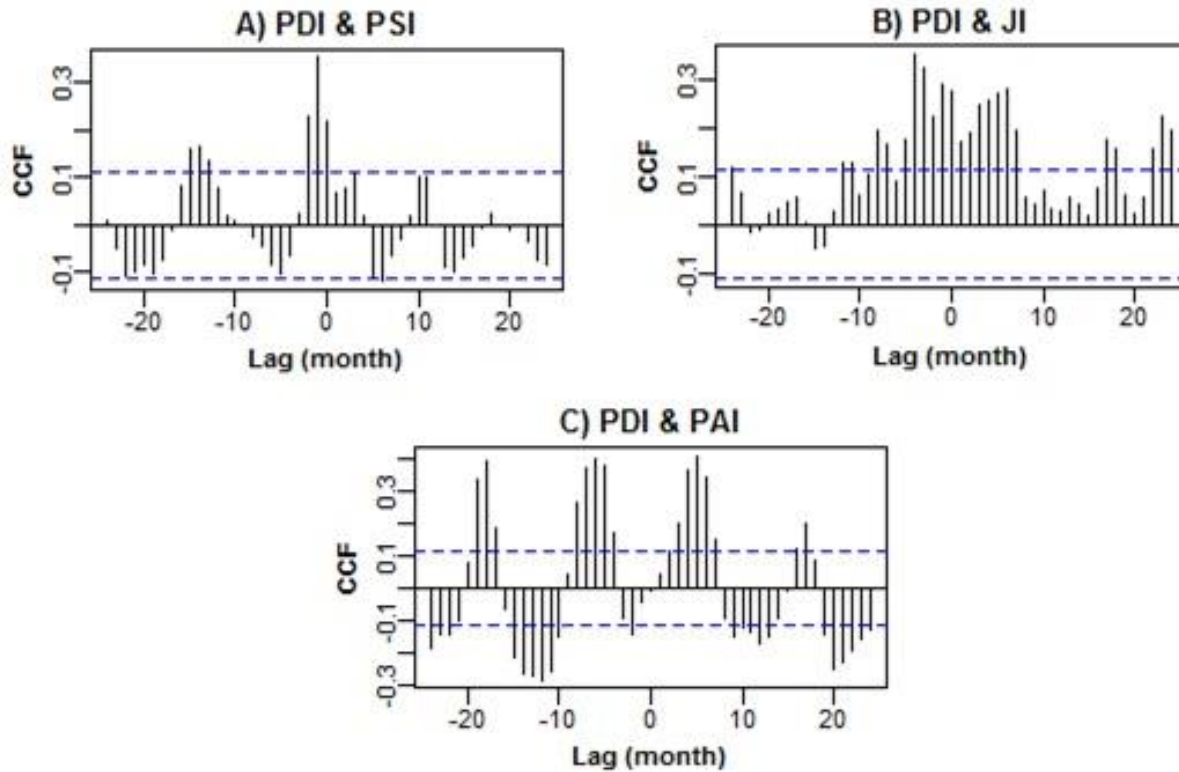


Figure 8: Cross-correlation function (CCF) of the power dissipation index (PDI) of tropical storms and the recruitment indices of *Panulirus argus* in the Gulf of Batabanó, Cuba; negative lags indicate that the first index leads the second. The blue lines indicated bounds for statistical significance A: With the *puerulus* settlement index (PSI). B: With the juvenile abundance index (JI). C: With the preadults abundance index (PAI).

4.1.3 GLM models

According to the correlations found between the different indices of recruitment, and between them and the PDI, diverse variants of possible models to predict recruitment to the fishing area (PAI) were studied, considering time lags between variables. The five models with lower AICc values were chosen as the “best” predictors (Table 5). When comparing these models, it was found that Model 5 was the best fit to the data, with support of 65% according to the Akaike weights (Table 6). This model predicts the PAI in the year i , month j considering the PSI with 17 months of time lag, the JI with 5 months and the PDI with 18 months, all index influencing positively on the dependent variable.

Table 5: Models that related the recruitment indices of *Panulirus argus* and the power dissipation index (PDI) of tropical storms, in the Gulf of Batabanó, Cuba. PAI_{yi,mj}: preadults abundance index in the year i, month j. PSI: *puerulus* settlement index, JI: juveniles abundance index. β: estimated parameters for each independent variable.

Model	Equation
1	$\ln(\text{PAI}_{y_i,m_j}+1) = \beta_1 * \ln(\text{PSI}_{y_{i-1},m_{j-5}}+1) + \beta_2 * \ln(\text{JI}_{y_i,m_{j-1}}+1) + \beta_3 * \ln(\text{PDI}_{y_{i-1},m_{j-6}}+1)$
2	$\ln(\text{PAI}_{y_i,m_j}+1) = \beta_1 * \ln(\text{PSI}_{y_{i-1},m_{j-5}}+1) + \beta_2 * \ln(\text{JI}_{y_i,m_{j-4}}+1) + \beta_3 * \ln(\text{PDI}_{y_{i-1},m_{j-6}}+1)$
3	$\ln(\text{PAI}_{y_i,m_j}+1) = \beta_1 * \ln(\text{PSI}_{y_{i-1},m_{j-5}}+1) + \beta_2 * \ln(\text{JI}_{y_i,m_{j-5}}+1) + \beta_3 * \ln(\text{PDI}_{y_i,m_{j-6}}+1)$
4	$\ln(\text{PAI}_{y_i,m_j}+1) = \beta_1 * \ln(\text{PSI}_{y_{i-1},m_{j-5}}+1) + \beta_2 * \ln(\text{JI}_{y_i,m_{j-5}}+1) + \beta_3 * \ln(\text{PDI}_{y_{i-1},m_j}+1)$
5	$\ln(\text{PAI}_{y_i,m_j}+1) = \beta_1 * \ln(\text{PSI}_{y_{i-1},m_{j-5}}+1) + \beta_2 * \ln(\text{JI}_{y_i,m_{j-5}}+1) + \beta_3 * \ln(\text{PDI}_{y_{i-1},m_{j-6}}+1)$

Table 6: Comparison between different models that related the recruitment indices of *Panulirus argus* and of the power dissipation index (PDI) of tropical storms, in the Gulf of Batabanó, Cuba. β is the estimated parameters for each independent variable. AICc is the second order Akaike information criterion.

Model		β ± SE	T	p	AICc	AICc weight
1	β ₁	0.0966 ± 0.0646	1.495	0.1406	-12.89	0.0033
	β ₂	0.1537 ± 0.0714	2.151	0.0359		
	β ₃	0.0249 ± 0.0067	3.715	0.0005		
2	β ₁	0.1183 ± 0.0618	1.913	0.0606	-14.85	0.0089
	β ₂	0.1172 ± 0.0615	1.906	0.0615		
	β ₃	0.0273 ± 0.0063	4.321	0.00006		
3	β ₁	0.0662 ± 0.0686	0.964	0.3389	-20.56	0.1539
	β ₂	0.0097 ± 0.0637	0.153	0.8793		
	β ₃	0.0108 ± 0.0059	1.842	0.0706		
4	β ₁	0.0756 ± 0.0685	1.103	0.2745	-20.85	0.1779
	β ₂	0.0624 ± 0.0649	0.960	0.3411		
	β ₃	-0.0087 ± 0.0045	-1.918	0.0599		
5	β ₁	0.0853 ± 0.0673	1.267	0.2102	-23.46	0.6559
	β ₂	0.0034 ± 0.0622	0.054	0.9567		
	β ₃	0.0147 ± 0.0058	2.516	0.0146		

4.2 Gadget model

4.2.1 Fit to data

The model fit to the abundance indices, survey and CPUE, was not too good (Figure 9). The best fit was found for the survey abundance index in the length group len10-13 ($r = 0.532$) and len1-6 ($r = 0.479$).

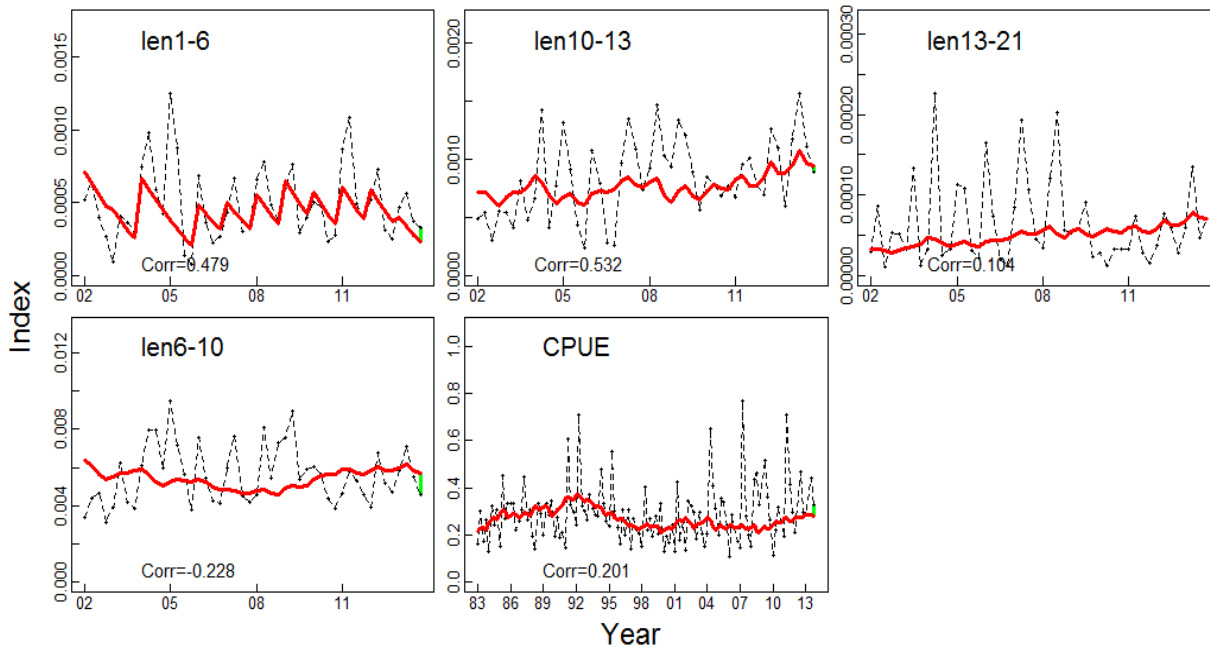


Figure 9: Length aggregated survey abundance indices and CPUE for *Panulirus argus* in the Gulf of Batabanó, Cuba. Dotted line is the observed values and the red line is the predicted indices from the model.

4.2.2 Length distributions

In general, the model fit to the length distributions from the survey and commercial catches was fairly well (Figure 10 and 11).

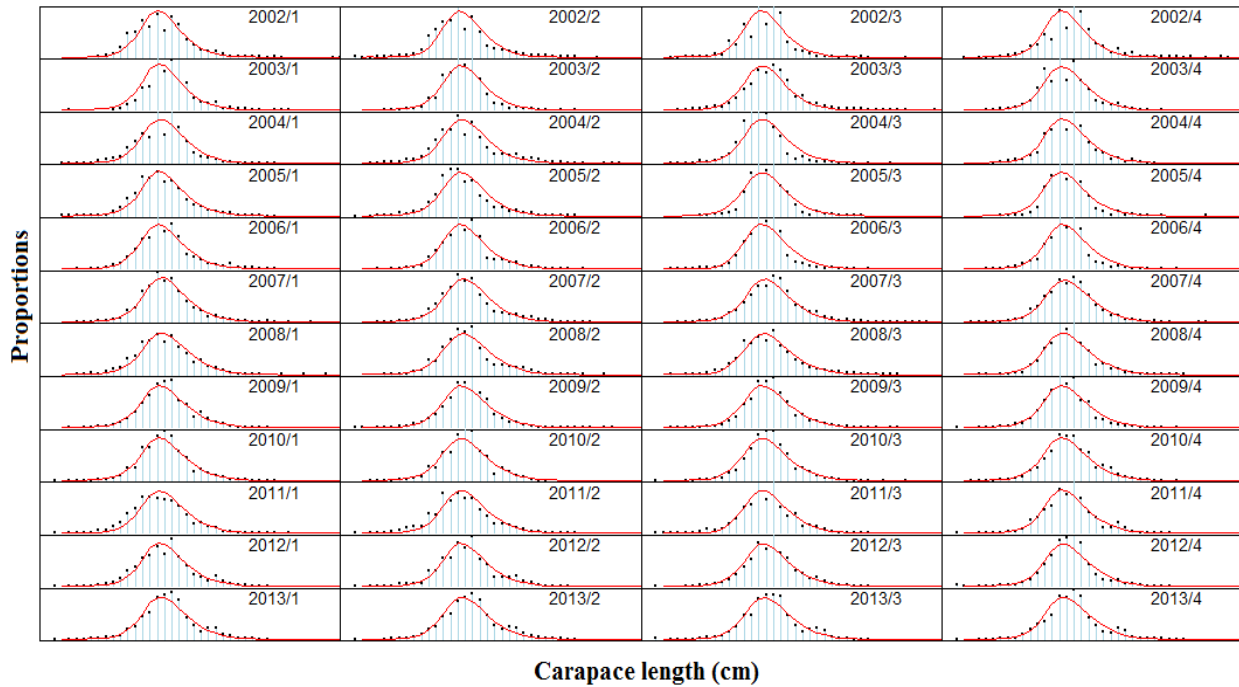


Figure 10: Survey length distribution of *Panulirus argus* in the Gulf of Batabanó, Cuba. Points and blue bars denote the observed values and the solid red line the predictions by the base model.

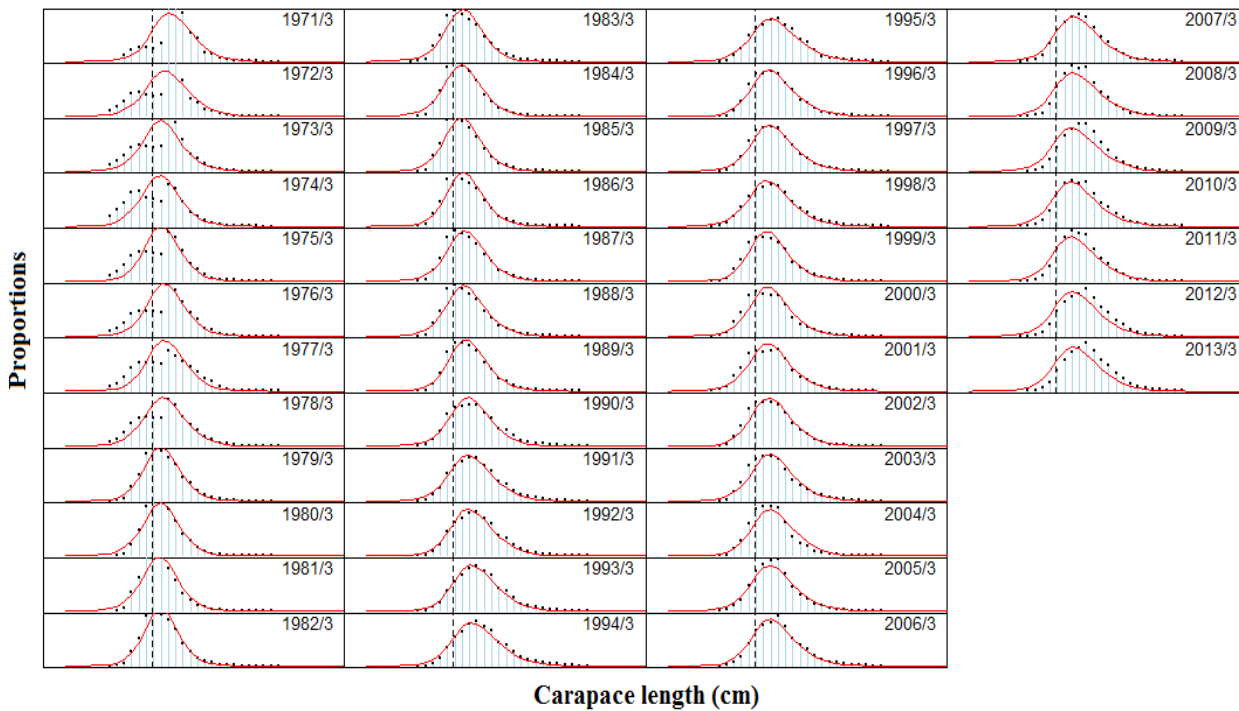


Figure 11: Catch length distribution of *Panulirus argus* in the Gulf of Batabanó, Cuba. Points and blue bars denote the observed values and the solid red line the predictions by the base model.

4.2.3 Growth

The predicted mean growth curve for commercial fleet and survey (Figure 12a). Although with a lower asymptotic length, this curve shows a similar pattern to the curves with the estimated parameters for the specie by de León *et al.* (1995) (Figure 12b).

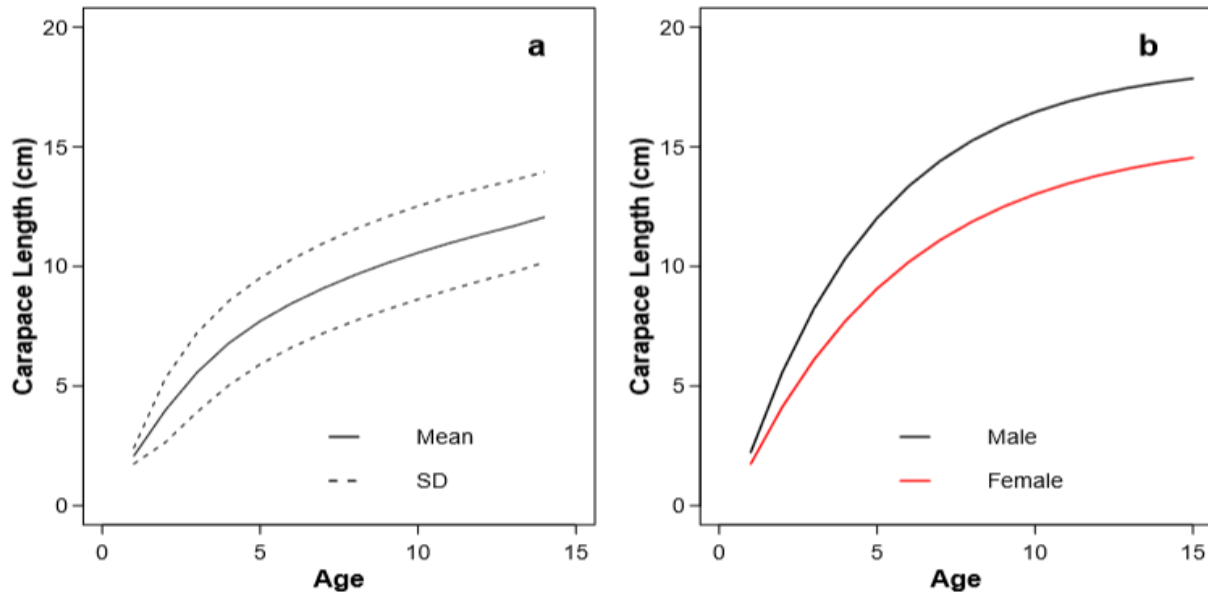


Figure 12: Growth curves for *Panulirus argus* in the Gulf of Batabanó, Cuba. a) Estimate of growth for both sexes from the Gadget model. b) Estimates of growth for each sex with the parameters for the von Bertalanffy equation obtained by de León *et al.* (1995).

4.2.4 Selectivity

The predicted selection curves for the commercial fleet and the survey was practically the same (Figure 13a). These curves show that lobsters above 7 cm CL have the higher probability of being caught. While as a result of VPA, the pattern of exploitation, expressed as the proportion of F at age respect to the F maximum shows that lobsters receiving the largest fishing mortalities are between 3 and 6 years old (Figure 13b).

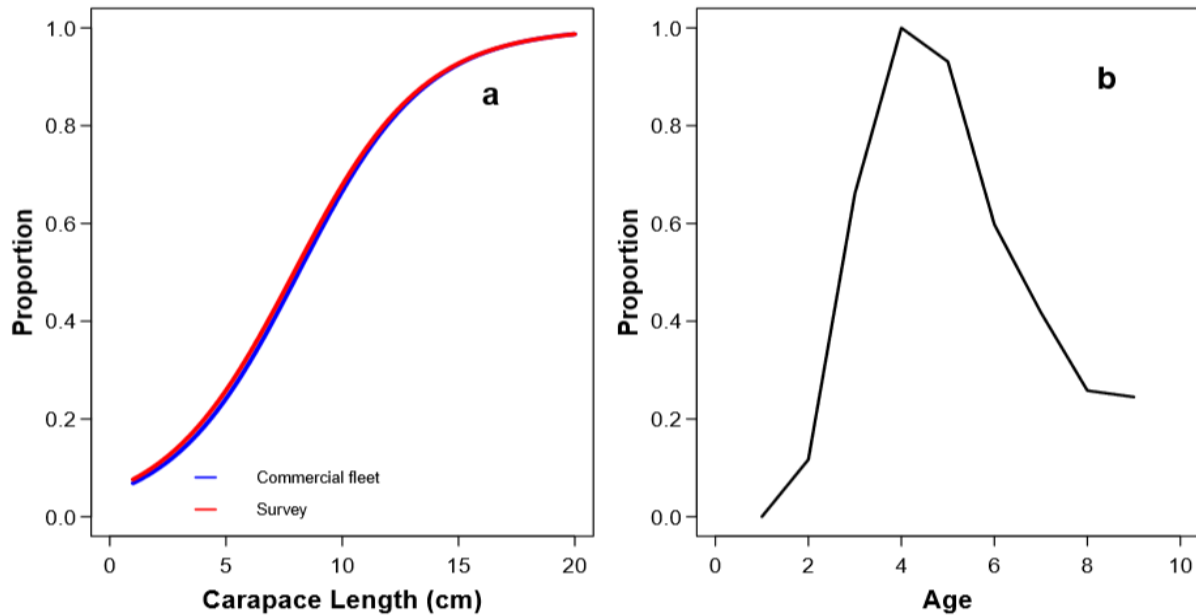


Figure 13: Estimated selection curves for *Panulirus argus* in the Gulf of Batabanó, Cuba. a) Estimate from the commercial fleet and survey in the Gadget model. b) Estimate from VPA model (Puga and Alzugaray, unpublished data).

4.2.5 Population estimates

The recruitment predicted by the Gadget model showed a decreasing trend from the 80s to the present (Figure 14a). The maximum values estimated was around 37 million. In some years, the model seems to underestimate the recruitment, giving very low or even null values. While in the recruitment estimated by the VPA model, the decreasing trend is more pronounced, with less annual variability, and reached maximum values of about 50 million, with minimal about 23 million recruits (Figure 14a).

The estimated total biomass had a more stable behavior, reaching maximum values of around 21,000 tons at the beginning of the 90s, decreasing later, while maintaining some stability in recent years (Figure 14b). But in the total biomass estimated by the VPA model reached higher values, the maximum was around 26,000 tons (Figure 14b).

The fishing mortality rate estimated by the Gadget model showed a decreasing trend (Figure 14c). The maximum values reached was around 0.5 and the minimum was around 0.2. The estimates of F by both models, Gadget and VPA, show a similar historical behavior, but the VPA estimate is slightly lower. The maximum values were around 0.4, and the minimum was 0.12 (Figure 14c).

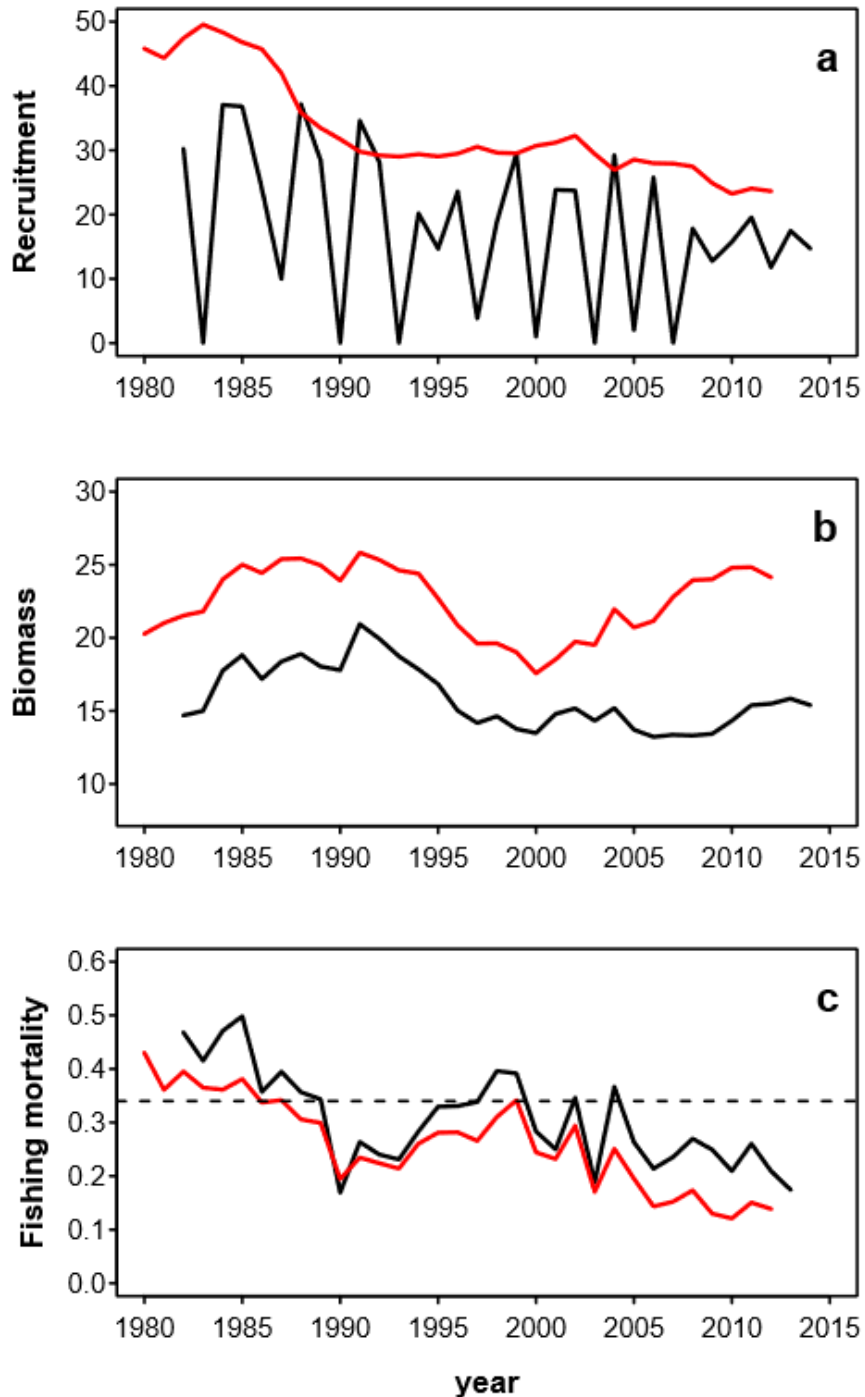


Figure 14: Annual series of estimated variables according to the Gadget and the VPA models for *Panulirus argus* population in the Gulf of Batabanó, Cuba. a) Recruitment in millions, the black line in the Gadget estimated and the red line is the VPA estimated. b) Biomass in thousand tonnes, the black line is the Gadget estimated and the red line is the VPA estimated. c) Fishing mortality rate for ages 1 to 9, the black line in the Gadget estimated, the red line is the VPA estimated and the dotted line is the natural mortality rate. All the the VPA results are from Puga and Alzugaray, unpublished data.

5 DISCUSSION

5.1 Recruitment indices and tropical cyclones

On annual scale the recruitment indices did not showed a significant decrease in the lobster population, although high interannual variability was observed. Furthermore, it should be noted that the presence of missing values in the series of puerulus and juveniles can significantly bias the results, especially if this lack of data occurs in the most important recruitment process for months. However, understanding the cause(s) of recruitment variability and identifying any potential long-term trends has important implications in the stock assessment and management of the fishery (de Lestang *et al.*, 2014).

In general, the relationships between the recruitment indices of different stages of the life cycle of *P. argus* was not strong. In previous studies conducted in Cuba, the relationship between the catch of puerulus caught on collectors and the abundance of juvenile lobsters dwelling in artificial structures several months later was inconsistent (Cruz *et al.*, 2001). The most successful of these types of studies is that for *P. cygnus* in Western Australia. Where, puerulus settlement is strongly correlated with juvenile abundance on nearby reefs (Jernakoff *et al.*, 1994) and with the commercial fishery catch four years later (Caputi *et al.*, 2003). Anyway, the lack of a strong, consistent correlation between postlarval supply and recruitment to later juvenile or adult stages is probably real, reflecting the additional importance of post-settlement processes in regulating recruitment (Butler *et al.*, 2006). However, it should be noted that the preadults are sampled over the whole bay whereas the puerulus and juveniles come from single station. Improve sampling of those indices could strengthen the weak relationship found.

The “best” model obtained is about the average times it requires to pass from one stage to the next, 18 months from settlement to recruitment to the fishing area, and 8 months from recruitment to nursery area to recruitment to fishing area (Arce and de León, 2001). The difference with the juvenile index could be due to the possibility that most of the animals counted are mainly of larger sizes, losing perhaps the smaller size groups, so the relationship with preadults could in fact be in a shorter time period. On the other hand, the 18-month lag in the model with a positive effect of cyclones may indicate that the greatest effect could relate to allow more input puerulus to the shelf to the next month the passage of these phenomena, and therefore increased recruitment time after the fishing area. Although the model itself, is not suitable for predicting recruitment, set bases in the possible relationships between these indices, but above shows that the combined effect of indices is better that each one separately.

Among other factors, that the effect of tropical cyclones on the entrance of puerulus may be related to, is increased Ekman transport due to the passage of these events (Piñeiro and Cobas, 2010). This has been reported as an essential mechanism in the larval movements and their entrance to shelf areas for many marine species in different regions (Alfonso *et al.*, 2000; Caputi *et al.*, 2001). Other authors have been found correlations between wind stress and the fluctuations of settlement rates in various crustaceans: *Carcinus maenas* (Queiroga *et al.*, 2006), *Cancer magister* (Miller and Shanks, 2004), *Callinectes sapidus* (Rabalais *et al.*, 1995) and *P. argus* (Eggleston *et al.*, 1998).

Although a significant negative impact of tropical cyclones on recruitment is not observed, it is difficult to establish how great effect, the passage of these have on post-settlement processes, because while it is possible that it may facilitate the entrance of puerulus, the damage caused to the nursery habitat can counter effect the success of this process. Considering that these events during its passage cause changes in sediment dynamics, reef biota, seagrass beds and mangroves, which may or may not recover according to the severity, duration and frequency of the tropical cyclones (Salazar-Vallejo, 2002).

Therefore, the fact that other authors have found negative relationships between recruitment index dependent on the fishery, resulting from stock-assessment models may be sound, first, these analyses have been to annual levels, to compare longer series and allow a better long-term relationships. Puga *et al.* (2013) relating the PDI and an anthropogenic activity index with the recruitment success found that the reduction of recruitment and catches in the Cuban spiny lobster fishery could be a result of synergistic cumulative effects because of the anthropogenic reduction of fresh water and nutrients supplies to the coastal zone and the increase of the potential destructiveness of tropical cyclones (PDI).

Also climate impacts on recruitment may occur through a number of different physical and biological processes, mainly related to the effects of temperature, salinity, oxygen, turbulence and advection (Ottersen *et al.*, 2004). Furthermore, it is necessary to link to other abiotic factors, because the combined effect of the PDI with these factors can be higher and show a major cause-effect relationship between these and the recruitment process.

5.2 Gadget model

Generally, Gadget obtained a good fit to the data. But in the case of the survey abundance index and CPUE the fit was not very good, which should significantly influence the results. However, it is worth mentioning that both the survey index and CPUE have high seasonal variability which results in high coefficient of variation and thus making it difficult for the model fit individual data points. Considering that the selection of an optimum explanatory model requires a trade-off between improving the quality of fit between the model and the data, keeping the model as simple as possible, and having the model reflect reality as closely as possible (Haddon, 2011).

On the other hand, the growth curve obtained is lower than the estimated growth for the spiny lobster, considered the best for this specie throughout the Caribbean area (Arce and de León, 2001). In the current setup the growth parameters are fixed as there is no available data on age structure. In order to get closer to the estimates of de León *et al.* (1995) these parameters would have to be tweaked manually. It should be noted that in Gadget fishing mortality has an effect on observed growth. So if fishing mortality is high, estimated population growth will be lower as the fastest growing individuals are removed from the population at a faster rate than the slow growing individuals. This estimate directly influences the estimated population and this may be one reason that this is lower for modeling with Gadget that with the VPA. Considering that the assessments based on size (length)-structured population dynamics models require information on the probability of animals growing from one size-class to each of other size-classes at each time-step and staying in the same size class. Furthermore, age-structured models fitted to reliable data on fishery or survey age-composition should be able to estimate year-class strength, in contrast, the ability to estimate year-class strength from size-composition data depends critically on being able

to adequately characterize growth (Punt et al, 2013). Consequently, these models are sensitive to growth estimates (Punt *et al.*, 2014).

While the selectivity curve with sigmoid form may not be the most appropriate selection pattern for the spiny lobster. This curve suggests that virtually all sizes above 70 mm CL have the same probability of being captured, which by the life cycle of the species is very difficult. The lobsters with larger sizes, usually are found in the deeper reef areas, inaccessible regions for fishing, from where difficult to return (González *et al.*, 1991). Also, this is reflected in the composition of sizes of catches, where more than 70 % of landings are below 100 mm CL, which has been report for the different fisheries of *P. argus*, like in Florida (Muller *et al.*, 1997), Turks and Caicos (Clerveaux *et al.*, 2003) and in the Gulf of Batabanó (Puga, 2005). However, the Gadget model predicts very high values of F for the oldest age groups (not shown). In terms of assessment and advice it may be more prudent to assume a sigmoid selectivity rather than a bell-shaped selection as in the form of the latter selection pattern there is a real danger of estimating a huge large/old biomass that is unavailable to the fishery. This estimated biomass could then in turn be used for setting to high TAC, resulting in very high fishing mortality for the smaller individuals.

Despite these observations, estimates for the lobster population were achieved. Of these, less consistent is the recruitment, because it has extremely high variability reaching values near zero at times. This is a modelling issue related to the fact that no age-structured data is included in the model. Therefore, it may be easier to find a minima in the likelihood surface by vastly varying recruitment from year to year. And although it is known that recruitment processes are variable, we have samples of various phases of the life cycle of the species in the Gulf of Batabanó that evidence has indeed been recruiting every year, and variability was not so radical. Compared with the results of VPA, this gives superior estimated recruitment, although both models generally show a tendency to decrease in this process.

The historical performance of the biomass was similar between both models, although the estimated values from Gadget were lower in the order of about 5,000 tons of difference. But the models in terms of estimated fishing mortality were consistent, since the Gadget with lower abundance estimate a fishing mortality greater than VPA, but following a very similar pattern, with a marked descending trend. Which is related to the decrease in fishing effort resulting from the management of this fishery in Cuba (Puga *et al.*, 2013).

Although it is difficult to know which model is best suited, the most important consideration is that the models used should be consistent with the available data (Butterworth and Rademeyer, 2008). Be noted that the Gadget used to adjust the model both indices of abundance, survey and CPUE, while the VPA only CPUE was used. This work should be considered a preliminary study using Gadget framework, therefore it is appropriate to continue working on improve the Gadget model in terms of settings and data. In this respect improving the estimates of growth and explore the effects of a changed selection pattern to a dome-shaped are the obvious first steps. Also, can be to include the survey index to adjust the estimates from the VPA model. And then, deepening in the differences between both models, compare their predictions and assess what would be the most appropriate for the spiny lobster population.

Given that all models are only approximations of reality; it is necessary to choose the best models after applied because they provide different perspectives on the same problem. Although the main advantage is to maintain the same methodology over time that allows maintaining the *status quo* (Butterworth and Rademeyer, 2008). Which is not discards exploring new alternatives searching to improve our understanding of exploited populations, allowing us to contribute to a better management of them.

6 CONCLUSIONS AND RECOMMENDATIONS

- The recruitment process of the spiny lobster *Panulirus argus* in the Gulf of Batabanó has a high interannual variability. There was not a strong correlation between the recruitment indices for the three different life-stages analysed: puerulus, juveniles and pre-adults.
- The correlation between the monthly recruitment indices and the tropical cyclones index was weak. The majority of the correlations showed a slight positive effect of the tropical cyclones on the recruitment.
- The best relationship on the preadults index were found by combining the effect of the puerulus settlement with 17 months of time lag, the juvenile index with 5 months of time lag and the tropical cyclones index with 18 months of time lag. In future studies it is recommended to include other abiotic variables related to the tropical cyclones, as well as establish relationships between the independent recruitment indices, the tropical cyclones index with the recruitment by the stock assessment models.
- The Gadget model fit to the survey abundance index and the catch per unit effort (CPUE), was not good. However fit to length distributions was good.
- The preliminary growth parameter used in the Gadget model resulted in lower growth than is estimated for the species. This need to be addressed in future work on the model.
- The population estimates, recruitment and biomass, for the spiny lobster by Gadget model are lower than those estimated by the VPA model. While the fishing mortality rate is higher by the Gadget model.
- Further development of the Gadget model for the spiny lobster is warranted.

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LIST OF REFERENCES

- Acosta, C. A. & Butler, M. J. (1997). Role of mangrove habitat as a nursery for juvenile spiny lobster, *Panulirus argus*, in Belize. *Marine and Freshwater Research* 48:721-727.
- Alcolado, P. M. (1990). Aspectos ecológicos de la macrolaguna del Golfo de Batabanó con especial referencia al bentos. In P. M. Alcolado (Ed.) *El Bentos de la Macrolaguna del Golfo de Batabanó* (pp. 129-161). La Habana: Editorial Academia.
- Alfonso, I., Frías M. del P., & Baisre, J. A. (2000). Distribución larval de la langosta comercial *Panulirus argus*, en relación con algunos factores hidrometeorológicos, al Sur de Cuba, Síntesis de la Tesis de Maestría, 1998. *Revista de Investigaciones Marinas* 21(1-3): 23-32.
- Arce, A. M. & de León, M. E. (2001). Biology. In: Report on the FAO/DANIDA/CFRAMP/WECAFC Regional Workshop on the Assessment of the Caribbean Spiny Lobster (*Panulirus argus*). *FAO Fisheries Report*. 619:17-25.
- Areces, A.J., García, A., Martínez, C., Hidalgo, G., Castellanos, S., Cantelar, K., Martínez, J.C., del Valle, R., Abreu, M., Marcos, Z. & Pérez, D. (2006). *Hacia el uso sostenible del Golfo de Batabanó: Análisis de sistemas y modelación de escenarios. Informe final de proyecto. Programa Ramal Protección del Medio Ambiente y Desarrollo Sostenible Cubano*. La Habana: Instituto de Oceanología.
- Baisre, J. A. (2000). The Cuban Spiny Lobster Fishery. In B. F. Phillips, J.S. Cobb, & J. Kittaka (Eds.), *Spiny Lobsters Fisheries and Culture* (pp. 135-152). London: Fishing News Books.
- Baisre, J., Booth, S., & Zeller, D. (2003). *Cuban fisheries catches within FAO area 31: 1950-1999*. La Habana: Fisheries Research Center.
- Baisre-Hernández, J. A. (2006). Cuban fisheries management regime: current state and future prospects. Reykjavik: United Nations University Fisheries Training Programme (Final Project).
- Begley, J. & Howell, D. (2004). An overview of Gadget, the globally applicable area disaggregated general ecosystem toolbox. ICES CM, 1–15.
- Begley, J. (2012). *Gadget user guide*. Reykjavik: Marine Research Institute Report Series. [December 2014] <<http://www.hafro.is/gadget/userguide/userguide.html>.>
- Briones-Fourzán, P., J. Candela and E. Lozano-Álvarez (2008). Postlarval settlement of the spiny lobster *Panulirus argus* along the Caribbean coast of Mexico: Patterns, influence of physical factors, and possible of origin. *Limnology and Oceanography* 53(3):970-985.
- Burnham K.P., & Anderson D.R. (2002). *Model selection and multimodel inference: a practical information-theoretic approach*. New York: Springer.
- Butler M. J. IV, Herrnkind W.F. & Hunt, J.H. (1997). Factors affecting the recruitment of juvenile Caribbean spiny lobsters dwelling in macroalgae. *Bulletin of Marine Science* 61(1):3–19.

Butler, M. J., & Herrnkind, W. F. (2000). Puerulus and juvenile ecology. In B. F. Phillips, J.S. Cobb, & J. Kittaka (Eds.), *Spiny Lobsters Fisheries and Culture* (pp. 276-301). London: Fishing News Books.

Butler, M. J., Steneck, R. S., & Herrnkind, W. F. (2006). Juvenile and adult ecology. In B. F. Phillips (Ed.), *Lobsters: biology, management, aquaculture and fisheries* (pp 263-309). London: Blackwell Publishing Ltd.

Butterworth, D. S. & Rademeyer, R. A. (2008). Statistical catch-at-age analysis vs ADAPT-VPA: the case of Gulf of Maine cod. *ICES Journal of Marine Science*, 65(9):1717-1732.

Caputi, N., Chubb & A. Pearce (2001). Environmental effects on recruitment of the western rock lobster, *Panulirus cygnus*. *Marine and Freshwater Research* 52(8):1167-1174.

Caputi, N., Chubb, C., Melville-Smith, R., Pearce, A. & Griffin, D. (2003) Review of relationships between life history stages of the western rock lobster, *Panulirus cygnus*, in Western Australia. *Fisheries Research* 65:47–61.

Cerdeira-Estrada, S., Lorenzo-Sanchez, S., Areces, A., & Martinez-Bayon, C. (2008). Cartografía de la distribución espacial de los habitats bentónicos en el Golfo de Batabanó utilizando imágenes LANDSAT-7. *Ciencias Marinas* 34(002):213-222.

Claro, R. & Parenti, L.R. (2001). The marine ichthyofauna of Cuba. In R. Claro, K.C. Lindeman & L.R. Parenti (Eds.) *Ecology of the marine fishes of Cuba* (pp. 21-57). Washington: Smithsonian Institution Press.

Claro, R. and Y. S. Reshetnikov (1994). Condiciones de habitat. In R. Claro (Ed.) *Ecología de los peces marinos de Cuba* (pp. 13-54). Instituto de Oceanología, La Habana & Centro de Investigaciones de Quintana Roo, Mexico.

Clerveaux, W., Puga, R., & Medley, P. (2003). National report on the spiny lobster fishery of The Turks and Caicos Islands. *FAO Fisheries Report* 715:135-143.

CNAP (2013). *Plan del Sistema Nacional de Áreas Protegidas 2014-2020*. La Habana: Ministerio de Ciencias Tecnología y Medio Ambiente.

Crawley, M. J. (2007). *The R Book*. Chichester: Wiley.

Cruz, R. (2000). *Variabilidad del reclutamiento y pronóstico a la pesquería de langosta (Panulirus argus Latreille, 1804) en Cuba*. (Doctoral dissertation, Centro de Investigaciones Marinas. Universidad de la Habana. <<http://www.cervantesvirtual.com>>).

Cruz, R., E. Díaz, M. Báez & R. Adriano (2001). Variability in recruitment of multiple life stages of the Caribbean spiny lobster, *Panulirus argus*, in the Gulf of Batabanó, Cuba. *Marine and Freshwater Research* 52(8):1263 – 1270

- Cruz, R., J. González, M. E. de León, & R. Puga (1995). La pesquería de la langosta espinosa (*Panulirus argus*) en el Gran Caribe. Evaluación y pronóstico. *Revista Cubana de Investigaciones Pesqueras* 19(2):63-76.
- Cruz, R., R. Coyula & A. T. Ramirez (1981). Crecimiento y mortalidad de la langosta espinosa (*Panulirus argus*) en la plataforma suroccidental de Cuba. *Revista Cubana de Investigaciones Pesqueras* 6(4):89–119.
- de León, M. E., Cruz, R. & Puga, R. (1995). Actualización de la edad y el crecimiento de la langosta espinosa *Panulirus argus*. *Revista Cubana de Investigaciones Pesqueras* 19(2):3-8.
- de Lestang, S., Caputi, N., Feng, M. Denham, A., Penn, J., Slawinski, D., Pearce, A., & How, J. (2014). What caused seven consecutive years of low puerulus settlement in the western rock lobster fishery of Western Australia? *ICES Journal of Marine Science* 72(1):i49-i58.
- Eggleston, D.B., R.N. Lipcius, L.S. Marshall & S.G. Ratchford. 1998. Spatio-temporal variation in postlarval recruitment of the Caribbean spiny lobster in the central Bahamas: lunar and seasonal periodicity, spatial coherence, and wind forcing. *Marine Ecology Progress Series* 174:33-49.
- Ehrhardt N., Puga R., & Butler M.J. IV (2011). Implications of the ecosystem approach to fisheries management in large ecosystems. The case of the Caribbean spiny lobster. In L. Fanning, R. Mahon & P. McConney (Eds.) *Towards Marine Ecosystem-Based Management in the Wider Caribbean* (pp. 157-175). Amsterdam University Press.
- Ehrhardt, N.M., Sobreira, C.A. (2003). An assessment of the Brazilian spiny lobster, *P. argus*, fishery. *FAO Fisheries Report* 715:68-74.
- Elvarsson, B., Sigurdardóttir, Á. J., Ólafasdóttir, E. I., Taylor, L., & Stefánsson, G. (2011). *Rgadget: A marine multispecies simulator*. Unpublished manuscript.
- Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436:686-688.
- Emilsson, I., & Tapanes, J. J. (1971). Contribucion a la hidrologia de la plataforma sur de Cuba. *Serie Oceanologica* 9:1-31.
- FAO (2007). *Informe del Quinto Taller Regional sobre la Evaluación y la Ordenación de la Langosta Común del Caribe. Mérida, Yucatán, México, 16-29 de septiembre de 2006*. FAO Informe de Pesca No. 826.
- González, G., Herrera, A., Díaz, E., Brito, R., Gotera, G., Arrinda, C., & Ibarzábal, D. (1991). Biología y conducta de la langosta (*Panulirus argus*, Lat.) en las zonas profundas del borde de la plataforma en la región suroccidental de Cuba. *Revista de Investigaciones Marinas* 12(1-3):140-153.

- Gonzalez-Ferrer, S., S. Lorenzo-Sanchez, S. Cerdeira-Estrada (2004). Arrecifes coralinos. In S. Gonzalez-Ferrer (Ed.) *Corales petreos, jardines sumergidos de Cuba* (pp. 45-64). La Habana: Editorial Academia. Instituto de Oceanologia-Caja Madrid.
- Guerra-Garcia, R., Chavez-Marrero, C. M., Hernandez-Valdes, K., & Trista-Barreras, E. (2000). Cambios sedimentarios en la cuenca sur de la provincia de La Habana. *Revista Ciencias de la Tierra y el Espacio*, 1.
- Haddon, M. (2011). *Modelling and Quantitative Methods in Fisheries*. London: CRC Press.
- Hernandez-Zanuy, A. C., & Carballa, J. L. (2001). Distribution and abundance of ascidian assemblages in Caribbean reef zones of the Golfo de Batabanó (Cuba). *Coral Reefs* 20:159-162.
- Jernakoff, P., Phillips, B. F., & DeBoer, E. (1994) Density and growth in populations of juvenile western rock lobster, *Panulirus cignus* (George). *Australian Journal of Marine and Freshwater Research* 45:69-81.
- Lyons W. G. (1980). Possible sources of Florida's spiny lobster population. *Proceedings of the Gulf and Caribbean Fisheries Institute* 33:253-266.
- Miller, J.A. & A. Shanks. 2004. Ocean-estuary coupling in the Oregon upwelling region: abundance and transport of juvenile fish and of crab megalopae. *Marine Ecology Progress Series* 271:267-279.
- Muller, R.G., Hunt, J.H., Matthews, T.R., Sharp, W.C., 1997. Evaluation of effort reduction in the Florida Keys spiny lobster, *Panulirus argus*, fishery using an age-structured population analysis. *Marine and Freshwater Research*. 48:1131-1136.
- Muller, R.G., Sharp, W.C., Matthews, T.R., Bertelsen, R., & Hunt, J.H. (2000). The 2000 update of the stock assessment for spiny lobster, *Panulirus argus*, in the Florida Keys. <http://www.floridamarine.org/publications/>
- Naro-Maciel, E., Reid, B. Holmes, K. E., Brumbaugh, D. R., Martin, M. & DeSalle, R. (2011). Mitochondrial DNA sequence variation in spiny lobster: population expansion, panmixia, and divergence. *Marine Biology* 158:2027-2041.
- Nyamweya. C.S. (2013). Modelling and forward projection of Nile perch, *Lates niloticus*, stock in Lake Victoria using GADGET framework. Reykjavik: United Nations University Fisheries Training Programme, Iceland (Final Project).
- Ottersen G, Alheit J, Drinkwater K, Friedland K, Hagen E, & Stenseth NC (2004) The responses of fish populations to ocean climate fluctuations. In: Stenseth NC, Ottersen G, Hurrell J, Belgrano A (Eds.) *Marine ecosystems and climate variation: the North Atlantic* (pp. 73–94). Oxford: Oxford University Press.

- Phillips, B. F., and R. Melville-Smith (2006). *Panulirus* species. In: B. F. Phillips (Ed). *Lobsters: biology, management, aquaculture and fisheries* (pp. 359-384). London: Blackwell Publishing Ltd.
- Piñeiro R., Puga, R. & Gonzáles-Sansón, G. (2006). Bases para el manejo integrado del recurso langosta (*Panulirus argus*) en la zona costera sur de Pinar del Río. I. Factores ambientales. *Revista de Investigaciones Marinas* 27(3):245-251.
- Piñeiro, R., & Cobas, S. (2010). Dinámica del océano y mares de la plataforma suroccidental de Cuba: variabilidad interanual. *Revista Cubana de Investigaciones Pesqueras* 27(1):33-40.
- Polovina, J.J., Haight, W.R., Moffitt, R.B., & Parrish, F.A. (1995). The role of benthic habitat, oceanography, and fishing on the population dynamics of the spiny lobster, *Panulirus marginatus* (Decapoda, Palinuridae), in the Hawaiian Archipelago. *Crustaceana* 68(2):203-212.
- Puga R., R. Piñeiro, S. Cobas, M.E. de León, N. Capetillo, and R. Alzugaray (2010). La pesquería de la langosta espinosa, conectividad y cambio climático en Cuba. In Hernández- Zanuy A. & Alcolado P.M. (Eds.) *La Biodiversidad en ecosistemas marinos y costeros del litoral de iberoamérica y el cambio climático: I. Memorias del Primer Taller de la Red CYTED BIODIVMAR, La Habana*. La Habana: Instituto de Oceanología.
- Puga, R. (2005). *Modelacion bioeconomica y analisis de riesgo de la pesqueria de langosta Espinosa Panulirus argus (Latreille, 1804) en el Golfo de Batabano, Cuba* (Doctoral dissertation, Centro de Investigaciones Biologicas del Noroeste, La Paz, B. C. S. Retrieved from <http://www.oceandocs.org/handle/1834/1543>).
- Puga, R. and M.E. de León (2003). Informe de la reunión científica del 2do Taller sobre el manejo de las pesquerías de langosta espinosa del Caribe del área de la COPACO. *FAO Fisheries Report* 715: 201-204.
- Puga, R., de León M. E., Capetillo N., Piñeiro R., Morales O. (2006). Evaluación de la pesquería de langosta en Cuba. Taller Regional de la FAO sobre la evaluación y la ordenación de la langosta espinosa del Caribe, Mérida – México, del 19 al 29 de septiembre de 2006.
- Puga, R., R. Piñeiro, R. Alzugaray, L. S. Cobas, M. E. de León and O. Morales (2013). Integrating Anthropogenic and Climatic Factors in the Assessment of the Caribbean Spiny Lobster (*Panulirus argus*) in Cuba: Implications for Fishery Management. *International Journal of Marine Science* 3(6):36-45.
- Puga, R., S. Hernández-Vázquez, J. López-Martínez, M.E. de León (2005). Bioeconomic modelling and risk assessment of the Cuban fishery for spiny lobster *Panulirus argus*. *Fisheries Research* 75(1-3):149-163.
- Punt, A. E., Huang, T. C., & Maunder, M. N. (2013). Review of integrated size-structured models for stock assessment of hard-to-age crustacean and mollusk species. *ICES Journal of Marine Science* 70:16-33.

Punt, A. E., M. Haddon and R. McGarvey (2014). Estimating growth within size-structured fishery stock assessments: What is the state of the art and what does the future look like? Fisheries Research in Press, 14pp.

Queiroga, H., M.J. Almeida, A. Alpuim, A.A.V. Flores, S. Francisco, I. González-Gordillo, A.I. Miranda, I. Silva & J. Paula. 2006. Tide and wind control of megalopal supply to estuarine crab populations on the Portuguese west coast. *Marine Ecology Progress Series* 307:21-36.

Rabalais, N.N., F.R. Burditt Jr., L.D. Coen, B.E. Cole, C. Eleuterius, K.L. Heck Jr., T.A. McTigue, S.G. Morgan, H.M. Perry, F.M. Truesdale, R.K. Zimmer-Faust & R.J. Zimmerman. 1995. Settlement of *Callinectes sapidus* megalopae on artificial collectors in four Gulf of Mexico estuaries. *Bulletin of Marine Science* 57:855-876.

Salazar-Vallejo, S. (2002). Huracanes y biodiversidad costera tropical. *Revista de Biología Tropical* 50(2).

Silberman, J. D., S. K. Sarver and P. J. Walsh (1994). Mitochondrial DNA variation and population structure in the spiny lobster *Panulirus argus*. *Marine Biology* 120:601-608.

Taylor, L., Begley, J., Kupca, V., and Stefansson, G. (2007). A simple implementation of the statistical modelling framework Gadget for cod in Icelandic waters. *African Journal of Marine Science* 29(2):223–245.

Thordarson, G. and B. Elvarsson (2014). A Gadget assessment of Ling in Va. WKDEEP-2014: WD-01, 29 pp.

Valle, S. V., M. Sosa, R. Puga, L. Font and R. Duthit (2011). Coastal fisheries of Cuba. In S. Salas, R. Chuenpagdee, A. Charles, & J.C. Seijo, J.C. (Eds.) *Coastal fisheries of Latin America and the Caribbean* (pp. 155-174). Rome: FAO Fisheries and Aquaculture Technical Paper. No. 544.