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AVALIAÇÃO DO CRESCIMENTO, REPRODUÇÃO E EXPLOTAÇÃO DO ESTOQUE DAS LAGOSTAS ESPINHOSAS NO NORDESTE DO BRASIL

FORTALEZA
2020

IVO STUARDO ORELLANA SALAZAR

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Tese apresentada ao Programa de Pós-Graduação em Ciências Marinhas Tropicais da Universidade Federal do Ceará, como requisito parcial à obtenção do título de Doutor em Ciências Marinhas Tropicais.

Orientador: Prof. Dr. Raúl Cruz Izquierdo

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"O professor se liga à eternidade; ele nunca sabe onde cessa a sua influência."

- HENRY ADAMS-

RESUMO

As lagostas espinhosas *Panulirus argus* (Latreille, 1804) e *Panulirus laevicauda* (Latreille, 1817) têm sido economicamente um importante recurso pesqueiro marinho na região do Nordeste do Brasil, desde aproximadamente o ano de 1960. Naquela região, as últimas pesquisas sobre os parâmetros biológicos de crescimento e comprimento de primeira maturação reprodutiva das lagostas espinhosas foram realizadas há vários anos. Devido à importância dessas informações no gerenciamento sustentável dos recursos pesqueiros nos dias de hoje, é necessária uma atualização do *status quo* dos parâmetros de idade, crescimento e comprimento de primeira maturação, tornando-se os principais enunciados deste trabalho. Nesse cenário, e considerando a importância das lagostas espinhosas na região do Nordeste do Brasil, os objetivos específicos desta tese são: 1) descrever o perfil dos parâmetros de idade e crescimento do estoque das lagostas espinhosas; 2) testar se o atual tamanho mínimo de captura protege a primeira reprodução das lagostas espinhosas fêmeas e 3) implementar uma avaliação de estoques baseada no comprimento. Para atingir esses objetivos, esta tese descreve e compara cronologicamente informações biológicas de crescimento e reprodução, empregando a distribuição do comprimento como a principal ferramenta. Como resultado os parâmetros de crescimento calculados para *P. argus* são: a) machos, $L\infty = 176{,}1$ e $K = 0{,}277$; b) fêmeas, $L\infty = 139{,}4$ e $K = 0{,}282$. Da mesma forma para *P. laevicauda*: a) machos, $L\infty = 136{,}7$ e $K = 0{,}460$; b) fêmeas, $L\infty = 118{,}2$ e $K = 0{,}490$. Por outro lado, os resultados da regressão logística indicam que as fêmeas de *P. argus* e *P. laevicauda* atingiam o comprimento de primeira maturação no ano de 1966 com 87,8 mm e 66,2 mm de comprimento cefalotórax respectivamente. Os resultados da amostragem, efetuada no ano de 2018, também indicam que as fêmeas de *P. argus* atingem, na atualidade, o comprimento de primeira maturação com 96,2 mm e *P. laevicuada* com 75,2 mm de comprimento cefalotórax (CF). Além disso, os resultados da avaliação, baseada no comprimento, apresentam uma alta porcentagem nos anos de 1966 (59,5%) e 2014 (94,7%) de organismos imaturos, que foram capturados antes de participar da temporada reprodutiva e amostrados nos desembarques. Igualmente, os resultados indicam uma baixa porcentagem de lagostas grandes (≥ 140 mm CF) amostradas nos desembarques nos dois anos estudados. Como consequência, os parâmetros de crescimento de lagostas espinhosas antigamente calculados na década de 1990 não incluem observações do comprimento de cefalotórax (CF) de lagostas pequenas (< 25 mm CF) e grandes (> 125 mm CF) e por conta disso é preciso implementar uma nova avaliação de idade e crescimento. Em suma, ambas as espécies de lagosta espinhosa atingem o comprimento de primeira maturação com maior tamanho no ano de 2018 do que no ano de 1966, portanto, o atual tamanho mínimo de captura não protege as fêmeas em reprodução. Portanto, a evidência de uma alta porcentagem de lagostas espinhosas *P. argus* imaturas nos desembarques dos anos 1966 e 2018, é, possivelmente um indicador de sobrepesca de crescimento nos anos estudados. Em contrapartida, não há evidência de sobrepesca de recrutamento nos anos analisados.

Palavras-chave: *Panulirus argus*; *Panulirus laevicauda*; crescimento; maturação sexual; avaliação de estoques baseada no comprimento.

ABSTRACT

The spiny lobsters *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817), have been an important economic marine fishery resource in the Northeast Brazil region since 1960. In the mention region the last biological research of the spiny lobster parameters growth and length-at-first maturity was performed several years ago. Due to the importance of these information in the current sustainable fisheries management an updated of the *state of the art* of the growth and length-at-first maturity is needed and becoming the statements of this work. With this scenario, and due to the importance of the spiny lobster in the Northeast Brazil region the specific objectives of this thesis are: 1) To describe the age and growth of the spiny lobster stock; 2) to test if the current minimum legal landing size protects the spiny lobster female first reproduction; and 3) implement a length-based stock assessment. To achieve these objectives this thesis describes and chronologically compare biological information of growth and length-at first maturity, employing length frequency distribution as its main analysis tool. The results indicate the growth parameters for *P. argus* as fallows: a) males, $L\infty = 176.1$ and $K = 0.277$; b) females, $L\infty = 139.4$ and $K = 0.282$. In the same way for *P. laevicauda*: a) males, $L\infty = 136.7$ and $K = 0.460$; b) females, $L\infty = 118.2$ and $K = 0.490$. On the other side the results of the logistic regression indicate that the female of *P. argus* and *P. laevicauda* reach the length-at-first maturity in the years 1966 with 87,8 mm and 66,2 mm of cephalothorax (CL) length respectively. Also, the 2018 sampling shows that the *P. argus* females reach the length-at-first maturity with 96,2 mm and *P. laevicauda* with 75,2 mm of cephalothorax length (CL). Moreover, the length-based stock assessment displays a high percentage of immature organisms during the years 1966 (59,9%) and 2014 (94,7%) that were harvested before participating in the reproduction season and sampled in the landings. Equally, the results show low percentage of large spiny lobster (≥ 140 mm CL) in the landing sampled in the studied years. As a consequence, the age and growth parameters previously calculated during the 1990s did not include cephalothorax length observation of small (< 25 mm CL) and large spiny lobster (> 125 mm CL) and due this fact a new assessment is needed. In summary both species of spiny lobster reached the length-at-first maturity with larger size during 2018 than in 1966, therefore the current minimum legal landing size does not protect the reproductive female. Consequently, there is evidence of a high percentage of immature *P. argus* spiny lobsters on landings in the years 1966 and 2018 possibly indicating growth overfishing for the years studied. Besides, in counterpart there is no evidence of recruitment overfishing in those analysed years.

Keywords: *Panulirus argus*; *Panulirus laevicauda*; growth; sexual maturity; length-based stock assessment.

RESUMEN

Las langostas espinosas *Panulirus argus* (Latreille, 1804) y *Panulirus laevicauda* (Latreille, 1817) han sido económicamente un importante recurso de pesca marina en el noreste de Brasil desde 1960. En la región mencionada, los parámetros biológicos de crecimiento y longitud de la primera madurez reproductiva para el stock de langosta espinosa fueron calculados por última vez hace varios años. Debido a la importancia de esas informaciones en el manejo sustentable de los recursos pesqueros hoy en día es necesaria una actualización del *status quo* de los parámetros de edad, crecimiento y longitud de primera madurez reproductiva, que se convierten en los principales enunciados de esta tesis. Con este escenario, y considerando la importancia de las langostas espinosas en la región del Nordeste de Brasil, los objetivos específicos de esta tesis son: 1) describir el perfil de los parámetros de crecimiento del stock de langostas espinosas; 2) comprobar si el actual tamaño mínimo de captura protege a las langostas espinosas hembras en reproducción y 3) implementar una evaluación de stocks basada en la longitud. Para alcanzar estos objetivos, esta tesis describe y compara cronológicamente informaciones biológicas de crecimiento y reproducción utilizando la distribución de longitudes como principal herramienta. Como resultado, los parámetros de crecimiento para *P. argus* calculados son: a) machos, $L\infty = 176.1$ y $K = 0.277$; b) hembras, $L\infty = 139.4$ y $K = 0.282$. De la misma forma para *P. laevicauda*: a) machos, $L\infty = 136.7$ y $K = 0.460$; b) hembras, $L\infty = 118.2$ y $K = 0.490$. Por otro lado, los resultados de la regresión logística indican que las hembras de *P. argus* y *P. laevicauda* llegában a la longitud de primera madurez en el año 1966 con 87.8 mm y 66.2 mm de longitud de cefalotórax respectivamente. También, los resultados del muestreo efectuado en el año 2018 indican que las hembras de *P. argus* llegan la longitud de primera madurez con 96,2 mm y *P. laevicauda* con 75,2 mm de longitud del cefalotórax (LC). Además de eso, los resultados de la evaluación basada en la longitud indica un alto porcentaje en los años 1966 (59,9%) y 2014 (94,7%) de organismos inmaduros, que fueron capturados antes de participar en la temporada de reproducción y muestreados en los desembarques. Igualmente, los resultados indican un bajo porcentaje de langostas grandes (≥ 140 mm LC) muestreadas en los desembarques en los dos años estudiados. Como consecuencia, los parámetros de crecimiento de las langostas espinosas previamente calculados en los años 1990 no incluyen observaciones de la longitud del cefalotórax (LC) de langostas pequeñas (< 25 mm LC) y grandes (> 125 mm LC) y por ese motivo se necesita implementar una nueva evaluación de la edad y crecimiento. En resumen, ambas especies de langosta espinosa llegan a la longitud de primera madurez reproductiva con mayor tamaño en el año 2018 que en el año 1966, entonces, el actual tamaño mínimo de captura no protege a las hembras en reproducción. Por lo tanto, la evidencia de un alto porcentaje de langostas espinosas *P. argus* inmaduras en los desembarques de los años 1966 y 2018 posiblemente es un indicador de sobrepesca de crecimiento para los años estudiados. Por el contrario, no hay evidencia de sobrepesca de reclutamiento en esos años analizados.

Palabras clave: *Panulirus argus*; *Panulirus laevicauda*; crecimiento; madurez sexual; evaluación de stocks basada en la longitud.

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1 INTRODUÇÃO GERAL

As lagostas espinhosas (Decapoda: Achelata: Palinuridae) são crustáceos marinhos que possuem a capacidade de atingir grandes comprimentos de até 60 cm (KENSLER, 1967; HOLTHUIS, 1991). Na atualidade, têm sido classificadas mais de 40 espécies de lagostas espinhosas agrupadas dentro da família Paniluride (HOLTHUIS, 1991; SILVA; FONTELES-FILHO, 2011). As lagostas espinhosas estão distribuídas amplamente em mares temperados e tropicais. A maior diversidade de lagostas espinhonas parece ocorrer em águas litorais, mas também são encontradas em águas profundas (LIPCIUS; EGGLESTON, 2000). Na cadeia trófica marinha, as lagostas espinhosas têm um papel fundamental como depredadores bentônicos e fazem parte da dieta de vários depredadores (LIPCIUS; EGGLESTON, 2000).

As lagostas espinhosas, assim como outros tipos de crustáceos marinhos e de águas interiores, possuem considerável valor econômico dentro do mercado de alimentos (LIPCIUS; EGGLESTON, 2000). Mundialmente, as pescas de crustáceos marinhos e de águas interiores têm produzido mais de 5×10^6 toneladas métricas (FAO, 2006). Por conta disso, aproximadamente mais de 30 espécies de panilurídos sustentam grandes pescas comerciais e artesanais no mundo (WILLIAMS, 1988; LIPCIUS; EGGLESTON, 2000, SILVA; FONTELES-FILHO, 2011). Durante o ano de 1993, a pesca mundial de lagostas atingiu mais de 214.000 toneladas métricas, das quais as espécies do Oceano Atlântico representam 37,9% *Homarus americanus* H. Milne Edwards, 1837 e 19,2% *Panulirus argus* (Latreille, 1804) (FAO, 1993). Mais recentemente, segundo o relatório das Nações Unidas (FAO, 2016), durante o ano de 2014, a captura mundial de lagostas marcou um novo recorde especialmente para as espécies *H. americanus* e *Nephrops norvegicus* (Lineus, 1758). No entanto, a visão geral do mesmo relatório sobre o desempenho das capturas das lagostas espinhosas mundialmente é menos detalhada.

No Nordeste do Brasil a pesca de lagosta é composta principalmente por duas espécies alvo, a saber, *P. argus* e *Panulirus laevicuada* (Latreille, 1817), que têm sido um importante recurso pesqueiro desde o ano de 1955 (PINTO PAIVA, 1958; FONTELES-FILHO et al., 1988; FONTELES-FILHO, 1992). As exportações dessas duas espécies de lagosta espinhosa entre os anos de 1955 e 1991 têm gerado cerca de US$750 milhões (FONTELES-FILHO, 1994). Devido à importância biológica, científica e econômica das lagostas no Nordeste do Brasil, esta tese foca no estudo das lagostas espinhosas *P. argus* e *P. laevicauda*, que são consideradas espécies simpátricas (FONTELES-FILHO, 1997). A primeira espécie é considerada de maior importância comercial, é mais abundante e domina as capturas da pesca até 70% (em peso)

(FONTELES-FILHO, 1997; CRUZ et al., 2013a). A segunda espécie possui um menor comprimento biológico e é menos abundante nas capturas em aproximadamente 30% (FONTELES-FILHO, 1979, 1997; CRUZ et al., 2013a).

A espécie *P. argus*, comumente conhecida com lagosta vermelha ou lagosta do caribe, tem uma ampla distribuição geográfica no Oceano Atlântico desde as Ilhas Bermudas até o Estado do Rio de Janeiro, Brasil (HOULTHUIS, 1991; EHRHARDT, 2005; CRUZ; BERTELSEN, 2009). A referida espécie tem um longo ciclo de vida, que se caracteriza por possuir oito diferentes fases (HOLTHUIS, 1991; CRUS; BETELSEN, 2009). Também é considerada um predador-chave da comunidade bentônica (CRUZ; BERTELSEN, 2009; CRUZ et al., 2011). Dentro da sua distribuição geográfica, a referida espécie é um recurso pesqueiro importante que atingiu regionalmente uma produção aproximada em 35.000 toneladas durante a década dos anos de 1990 no Atlântico Centro Oriental (COCHRANE; CHAKALALL, 2009). Baseado na média da produção regional, um valor estimado da pesca de *P. argus* no Atlântico Centro Oriental foi calculado em aproximadamente US$456 milhões entre os anos de 1985 e 2005 (EHRHARDT, 2005). Desde a década dos anos de 1990, considera-se que a lagosta espinhosa vermelha *P. argus* possui suficientes diferenças genéticas nas populações do Grão Caribe e do Atlântico Oriental. Por conta disso, foram sugeridas, provisionalmente, a existência de duas sub-espécies de *P. argus* do seguinte modo: a) *P. argus argus* para a região do Grão Caribe e b) *P. argus westoni* para a população no Brasil (SILVERMAN, et al., 1994; SARVER, et al., 1998; SARVER, et al., 2000), mas o estado dessas sub-espécies propostas (*nomen nudum*) não foram aceitas pela nomenclatura internacional da taxonomia. Seguidamente, foram conferidas diferenças filogenéticas entre as populações de *P. argus* no Grão Caribe e Brasil, sugerindo a existência de espécies crípticas (DINIZ et al., 2005; TOURINHO et al., 2012). Como resultado, foi reconhecida a ocorrência de *Panulirus meripurpuratus* sp. n (GIRALDES; SMITH, 2016) como a espécie das águas do Atlântico no Brasil. Porém, neste trabalho é utilizado o nome descrito por Latreille. Nesse sentido, recentemente foi relatada a ocorrência de duas fêmeas que encaixam na descrição de *P. meripurpuratus* sp.n, em La Bahia de la Ascencíon, México (BRIONES FOURZAN et al., 2019). Na atualidade, sobre este tema existem ainda perguntas biológicas e ecológicas sobre a co-ocorrência de *P. argus* e *P. meripurpuratus* no Atlantico Centro Oriental, por exemplo: o filossoma tem características similares entre as espécies? Fecundidade e taxa de crescimento serão diferentes entre as espécies? Existe a possibilidade de hibridação entre estas espécies?

Esta temática está fora dos objetivos desta pesquisa, mas sem dúvida, formará uma futura linha de pesquisa a curto prazo.

Por outo lado, conhecida comumente como lagosta verde, ou de cabo verde, a espécie *P. laevicuada* apresenta uma distribuição geográfica semelhante à espécie *P. argus* abrangendo a área desde as Ilhas Bermudas até o Nordeste do Brasil, incluindo ilhas oceânicas do Atol das Rocas (FONTELES-FILHO, 1979; HOULTIUS, 1991; GAETA et al., 2015). Apesar de ter uma distribuição ampla, essa espécie ocorre em abundância considerável para a explotação pesqueira apenas no Nordeste do Brasil (FONTELES-FILHO, 1979, 1992; CRUZ et al., 2013a). A explotação dessa espécie no Nordeste do Brasil facilitou o estudo de fatores biológicos com destaque no crescimento que têm sido menos estudados em outras áreas da distribuição dessa espécie no Oceano Atlântico Centro Ocidental (ORELLANA SALAZAR; CRUZ, 2019).

Os estoques de *P. argus* e *P. laevicuda* começaram a ser explotados em menor escala desde o ano de 1955 e, progressivamente, foram submetidos a intenso esforço de pesca desde o ano de 1972 (FONTELES-FILHO, 1992). Teoricamente tem sido comprovado que um estoque em exploração reagirá à intensa mortalidade por pesca por meio de mecanismos regulatórios populacionais de crescimento e reprodução (SPARRE; VENEMA, 1998, FONTELES-FILHO, 2011). Por conta disso, torna-se muito importante estudar as características e dinâmicas dos processos de crescimento e reprodução do estoque de lagostas no Nordeste do Brasil, que vem sendo explotado há mais de 50 anos por uma pesca de acesso aberto e com aparelhos de captura não seletivos. Os valores atualmente utilizados como pontos de referência biológica do crescimento e do comprimento de primeira maturação para o gerenciamento do estoque de lagostas foram calculados, há várias décadas, durante uma fase de alto rendimento. Porém, as atuais medidas regulatórias utilizam parâmetros com várias décadas de desfase (SILVA; FONTELES-FILHO, 2011).

Com esse cenário, os conhecimentos sobre o crescimento e a reprodução do estoque são importantes insumos no gerenciamento e na fiscalização da pesca pelas agências de governo. Por exemplo, as informações sobre crescimento e tamanho de primeira maturação são consideradas no “Plano de Gestão para uso Sustentável de Lagostas no Brasil: *Panulirus argus* (1804) e *Panulirus laevicauda* (1817)”, (IBAMA, 2008). Dentro de uma extensa lista dos temas que o plano indica como prioritários a serem pesquisados, particularmente ressaltam-se os seguintes: a) rever as curvas de crescimento das espécies através de métodos baseados na distribuição de comprimentos e b) rever os tamanhos de primeira maturação. Porém, é importante indicar que nos últimos anos os esforços por rever àqueles parâmetros não têm sido suficientes. Por exemplo, os parâmetros de idade, crescimento e comprimento de primeira maturação do estoque das lagostas *P. argus* e *P. laevicauda* foram avaliados por última vez no Nordeste do Brasil na década de 1990 (IVO; PEREIRA, 1996a; SOARES; PERET, 1998a; 1998b). Depois desses trabalhos, e na atualidade, são escassas as análises que determinem o conhecimento teórico vigente (estado da arte) daqueles parâmetros biológicos das lagostas espinhosas naquela região. Considerando essa problemática teórica e prática no gerenciamento do recurso lagosta, surge a seguinte pergunta de pesquisa: é representativo utilizar os parâmetros biológicos desenvolvidos há várias décadas no gerenciamento atual do recurso?

A importância desta tese radica na revisão cronológica e na atualização do *status quo* dos parâmetros de idade, crescimento e comprimento de primeira maturação que são abordados nesta tese ao longo de vários anos. Além disso, emprega por primeira vez um método de avalição baseada no comprimento assessorando o estado de explotação de *P. argus* no Nordeste do Brasil. Para implementar a pesquisa, esta tese utiliza a distribuição do comprimento biológico como principal ferramenta e formula duas hipóteses sobre as lagostas espinhosas *P. argus* e *P. laevicauda*. A primeira delas afirma que os parâmetros de crescimento calculados no Nordeste do Brasil descrevem a realidade biológica do crescimento das espécies detalhadamente. Da mesma forma, a segunda hipótese sustenta que o atual tamanho mínimo de captura protege as fêmeas reprodutoras das duas espécies. Para poder testar as hipóteses formuladas, o objetivo desta tese é implementar uma revisão dos parâmetros de crescimento e primeira maturação previamente calculados pelas ciências no Nordeste do Brasil e implementar uma avaliação de estoques baseada no comprimento para a espécie *P. argus*.

O primeiro capítulo desta tese analisa cronologicamente os parâmetros de crescimento calculados anteriormente e propõe valores relativos para aos parâmetros de crescimento da função de Von Bertlanffy das duas espécies de lagostas espinhosas, até que novos parâmetros sejam desenvolvidos pelas ciências pesqueiras marinhas no Brasil, segundo o critério de precaução das pesquisas pesqueiras (FAO, 1996). O segundo capítulo foca na análise do comprimento de primeira maturação das lagostas espinhosas fêmeas comparando informações de indicadores externos de reprodução entre os anos de 1966 e 2018. Este capítulo mostra que as lagostas espinhosas fêmeas atingem o comprimento de primeira maturidade (L50) com um maior tamanho no ano de 2018 que no passado durante o ano de 1966. Neste capítulo testa-se o valor do comprimento de primeira maturação (L50) e o tamanho mínimo de captura do Nordeste do Brasil. Isso é realizado com o intuito de estabelecer a eficiência do tamanho mínimo de captura, desde o ponto de vista da biologia reprodutiva das lagostas espinhosas fêmeas. Da mesma forma, os resultados da avaliação baseada no comprimento apresentados no terceiro capitulo indicam uma alta porcentagem de organismos imaturos nos desembarque da pesca de *P. argus* nos anos de 1966 e 2014 sugiriendo um possível cenário de sobrepesca de crescimento na região do Nordeste do Brasil. Devido à sua natureza prática, a avalição baseada no comprimento tem potencial para ser implementada em pescarias com escassez de dados e por consequência pouco assessorada, embora sejam necessários mais estudos para a sua implementação.

Por último, esta tese fornecem uma substancial linha de base, destacando o que é conhecido cientificamente até os dias de hoje sobre os parâmetros de crescimento, maturação e explotação das lagostas espinhosas *P. argus* e *P. laevicauda* no Nordeste do Brasil. Então, este trabalho torna-se um importante insumo orientado às agências governamentais nacionais no gerenciamento sustentável da pescaria no Nordeste do Brasil. É importante ressaltar que os nossos esforços para reanalisar os parâmetros biológicos, identificar e entender os diferentes processos da explotação dos recursos devem ser ilimitados para garantir a sustentabilidade dos recursos marinhos Nordeste do Brasil e em consenso com as pescarias internacionais no Atlântico Centro Ocidental.

2 HIPÓTESES

Hipótese “A” parâmetros de idade e crescimento

- Os parâmetros teóricos de crescimento da função de Von Bertalanffy previamente calculados no Nordeste do Brasil para as lagostas espinhosas *Panulirus argus* (Latreille, 1804) e *Panulirus laevicuda* (Latreille, 1804) descrevem detalhadamente a realidade biológica do crescimento individual para machos e fêmeas e por espécie.

Hipótese “B” comprimento de primeira maturação

- O atual tamanho mínimo de captura para as lagostas espinhosas no Nordeste do Brasil estabelecido em 75 mm de comprimento cefalotórax para *Panulirus argus* (Latreille, 1804) e 65 mm de comprimento cefalotórax para *Panulirus laevicauda* (Latreille, 1817) garante a reprodução das fêmeas antes de ser capturadas pela pesca.

3 OBJETIVOS

3.1 Objetivo geral

Descrever os valores teóricos dos parâmetros biológicos de crescimento, reprodução e avaliar a explotação do estoque das lagostas espinhosas *P. arugus* e *P. laevicauda* no Nordeste do Brasil.

3.2 Objetivos específicos

- Descrever o perfil dos parâmetros da idade e crescimento do estoque das lagostas espinhosas *P. argus* e *P. laevicauda* na região Nordeste do Brasil e estimar valores relativos.

- Testar se o atual tamanho mínimo de captura protege a primeira reprodução das fêmeas das lagostas espinhosas *P. argus* e *P. laevicauda* na região do Nordeste do Brasil.

- Implementar uma avaliação de estoques baseada no comprimento utilizando frequências do comprimento do cefalotórax de *P. argus* dos anos de 1966 e 2014 e conhecer os comprimentos mais atingidos pela pesca.

4 MATERIAL E MÉTODOS

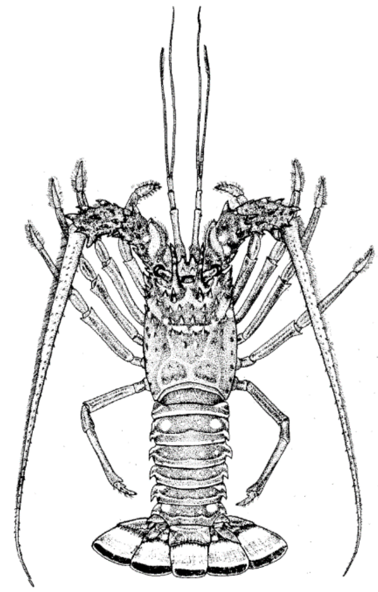
4.1 Observações gerais das lagostas espinhosas estudadas

A lagosta espinhosa é um crustáceo decápodo (possui cinco pares de patas) com um corpo cilíndrico dividido em duas partes reconhecíveis: a) cefalotórax (formado pela fusão da cabeça e tórax) e b) abdômen (formado pela cauda com seis segmentos). O corpo é coberto de espinhos de tamanho variado. O cefalotórax possui os órgãos sensoriais antênulas e antenas (HOLTHUIS, 1991; CRUZ et al., 2011).

4.1.1 Lagosta vermelha *Panulirus argus* (Latreille, 1804)

A espécie *P. argus* (Figura. 1), possui uma cor avermelhada, amarronzada e, em algumas ocasiões, esverdeada; apresenta quatro manchas de cor esbranquiçada ou amarelas localizadas no segundo segmento abdominal ou na base da pleura (CRUZ, et al., 2011). O comprimento total máximo tem sido relatado em 450 milímetros (aproximadamente 180 milímetros de comprimento cefalotórax) (HOLTHUIS, 1991). Embora, para a região Nordeste do Brasil, os comprimentos máximos observados nos desembarques da pesca tenham sido relatados para as fêmeas em 135 milímetros de comprimento cefalotórax (CC) (PINTO PAIVA; DA COSTA, 1967) e 146,9 mm CC para os machos (PINTO PAIVA; DA COSTA, 1970).

Figura 1. Fisiologia externa da lagosta espinhosa vermelha *Panulirus argus* (Latreille, 1804)

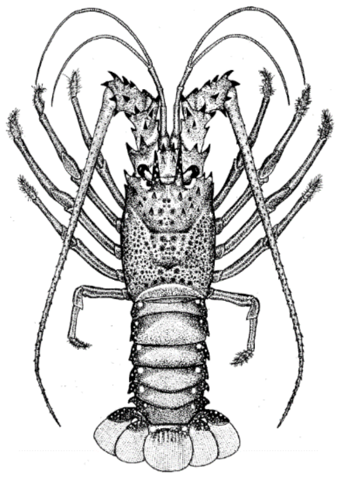


Fonte: elaborada pelo autor. Modificada de Holtius, 1991. Legenda: morfologia externa da lagosta espinhosa vermelha *Panulirus argus* (Latreille, 1804)

4.1.2 Lagosta verde *Panulirus laevicauda* (Latreille, 1817)

A lagosta *P. laevicauda* (Figura. 2) possui uma cor esverdeada e os anéis do abdômen são completamente lisos. Também possui uma linha de pontos muito pequena ao longo da margem posterior dos segmentos abdominais, o restante da superfície superior do abdômen não apresenta manchas (CRUZ et al., 2011; HOLTIUS, 1991). O comprimento máximo foi relatado para esta espécie em 131 milímetros de comprimento cefalotórax (CC) (HOLTIUS, 1991). Também na região do Nordeste do Brasil as observações do comprimento máximo nos desembarques de pesca comercial têm sido relatadas em 124 mm CC para machos e 108 mm CC para as fêmeas (PINTO PAIVA; DA COSTA, 1965; DA COSTA; LIMA PAIVA, 1974; DO NASCIMENTO et al., 1984).

Figura 2. Lagosta espinhosa verde, *Panulirus laevicauda* (1817)

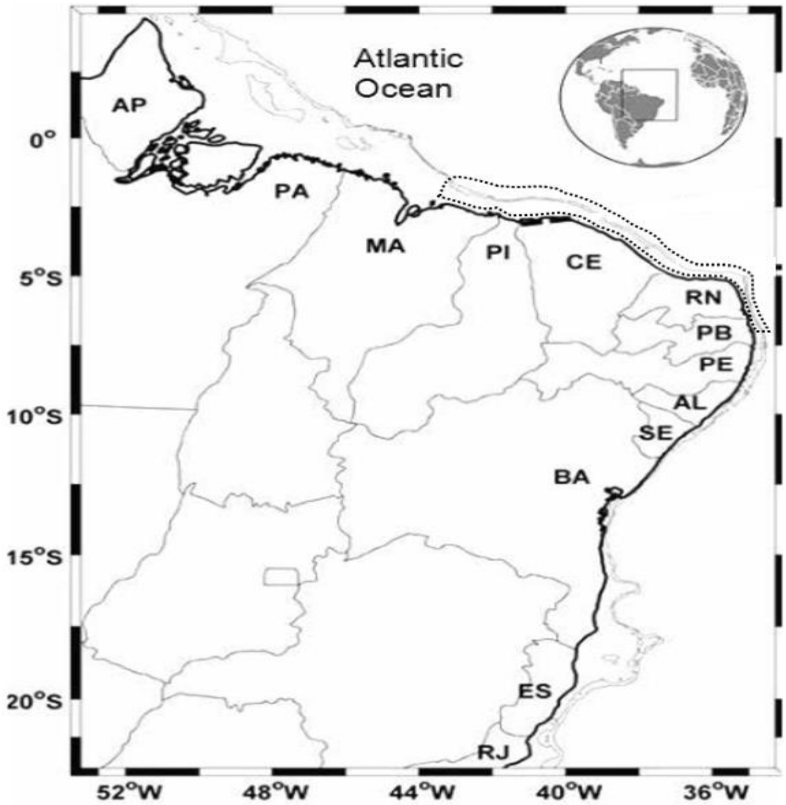


Fonte: Elaborada pelo autor. Modificada de Holtius, 1991. Legenda: morfologia externa da lagosta espinhosa verde, *Panulirus laevicauda* (Latreille, 1817)

4.2 Área de estudo

As informações analisadas correspondem às capturas da pesca comercial de lagosta que, por várias décadas, têm sido efetuadas na plataforma continental do Nordeste do Brasil entre os 2˚30'N até 18˚S e entre os 35˚W até 47˚W e com o Estado do Ceará como principal fornecedor da atividade (Figura. 2) (PINTO PAIVA, 1997; IVO; PEREIRA, 1996b; FONTELES-FILHO, 1997; CRUZ; BERTELSEN, 2009, CRUZ et al., 2011). A pesca de lagostas está concentrada em uma área de 206.119 km², que possui entre 1 e 100 metros de profundidade (CRUZ et al., 2011). Na região Nordeste, a plataforma continental tem largura variável, com notável homogeneidade do perfil. Em toda a sua extensão, as lagostas habitam fundos de águas claras com formações de algas calcárias especialmente no Ceará e no Rio Grande do Norte. (PINTO PAIVA, 1997; COUTINHO; MORAIS, 1970).

Figura 1 – Mapa mostrando a área de estudo no Nordeste do Brasil



Fonte: Elaborada pelo autor, modificada de Cruz et al., 2013. Legenda: Área tradicional de pesca da lagosta no Nordeste do Brasil (linha pontilhada).

4.3 Revisão de parâmetros de crescimento e comprimento de primeira maturação das lagostas espinhosas

Uma revisão das informações disponíveis sobre crescimento e comprimento de primeira maturação de *P. argus* e *P. laevicauda* foi implementada utilizando os métodos estabelecidos em trabalhos de revisão de paniluridos (MORGAN, 1980; BOOTH, 1984; POLLOCK, 1986; FONTELES-FILHO et al., 1988; IVO; PEREIRA 1996b; STENECK, 2006; CRUZ; BERTELSEN 2009; LECÁDIO; CRUZ, 2008; AYARA; CRUZ, 2010). Para organizar a busca e classificação da informação foram estabelecidos os seguintes critérios de seleção: a) frase-chave; b) estratégia de buscas; c) critério de inclusão e d) escala temporal. Em seguida, descreve-se cada um dos critérios.

4.3.1 Frases-chave para as buscas

Para cada uma das espécies foram estabelecidas as frases-chave:

- *Panulirus argus*; crescimento, maturação, Nordeste do Brasil.
- *Panulirus laevicauda*; crescimento, maturação, Nordeste do Brasil.

4.3.2 Estratégia de busca

A estratégia de busca foi implementada entre junho de 2017 e julho de 2018. A estratégia de buscas foi baseada na *internet*, nas seguintes fontes de informação digital: Arquivos de Ciências do Mar, Centro Nacional de Pesquisa e Conservação da Biodiversidade Marinha do Nordeste (CEPENE), Google Schoolar, Science Direct, Biblioteca Celso Furtado da Superintendência do Desenvolvimento do Nordeste (SUDENE) e o Sistema Pergamum de Bibliotecas da Universidade Federal do Ceará. Em alguns casos, as fontes de informação não estavam disponíveis em forma eletrônica, porém, foram revisadas as suas versões físicas na Biblioteca Rui Simões do Instituto de Ciências do Mar (LABOMAR), da Universidade Federal do Ceará. A informação encontrada foi organizada numa planilha electrónica, com descrições de título, autor, tema e ano de publicação.

4.3.3 Critérios de inclusão:

Informações que foram desenvolvidas geograficamente dentro do litoral do Nordeste do Brasil, artigos de publicações cientificas em português, inglês ou espanhol, indicadores de referência biológica de crescimento e comprimento de primeira maturação. Dentro dos indicadores biológicos relacionados com o comprimento de primeira maturação, foi dada prioridade às informações sobre as fêmeas das espécies estudadas.

4.3.4 Escala temporal

Para seleção dos artigos a escala temporal foi estabelecida entre os anos de 1960 e 2000. Esta escala temporal foi determinada com base no seguinte critério: abranger as diferentes etapas produtivas da biomassa do estoque relatadas, aceleração, estabilização e depleção (FONTELES-FILHO, 1999).

4.4 Distribuição de frequências do comprimento das lagostas espinhosas fêmeas

4.4.1 Dados da distribuição de frequências (machos e fêmeas) e indicadores externos de reprodução das lagostas espinhosas fêmeas do ano de 1966

Dados numéricos da distribuição de frequências dos machos e fêmeas, como também os indicadores externos de reprodução das fêmeas de *P. argus* e *P. laevicauda* foram extraídos de trabalhos publicados entre os anos de 1962 e 1970 e analisados graficamente (PINTO PAIVA; DA COSTA, 1963B – 1970; DA COSTA; PAIVA-FILHO, 1974). Devido ao tamanho da amostra, e aos valores máximo e mínimo do intervalo de classe do comprimento, os dados do ano de 1966 foram escolhidos para realizar a análise.

4.4.2 Dados da distribuição de frequências e indicadores externos de reprodução das lagostas espinhosas fêmeas do ano 2018

Foram realizadas observações das lagostas espinhosas fêmeas durante os primeiros meses (julho, agosto e setembro) da temporada de pesca 2018 na indústria de processamento de produtos pesqueiros em Fortaleza. Durante a amostragem foram selecionadas aleatoriamente 400 lagostas espinhosas fêmeas das duas espécies. Foram registradas as seguintes variáveis seguindo as recomendações de Cruz (2000) e Cruz et al., 2011, a saber: a) espécie; b) sexo; c) comprimento do cefalotórax em milímetros; d) presença de indicadores externos de reprodução (fêmeas ovígeras, com massa espermatofórica e com restos de massa espermatofórica) consideradas maduras morfologicamemente e e) sem presença de indicadores externos de reprodução, consideradas imaturas morfologicamente.

4.5 Avaliação do estoque de *Panulirus argus* (Latreille, 1804) baseada no comprimento

Para realizar a avaliação do estoque de *P. argus* baseada no comprimento, foram utilizadas as seguintes fontes de dados numéricos: a) informação das frequências do comprimento das lagostas espinhosas do ano de 1966 (ver seção 4.3.1) e b) dados das frequências do comprimento do ano de 2014 extraídos de MENDEZ SANTANA (2016).

5. CAPÍTULO 1

AGE AND GROWTH OF THE COMMERCIAL SPINY LOBSTERS *PANULIRUS ARGUS* (LATREILLE, 1804) AND *PANULIRUS LAEVICAUDA* (LATREILLE, 1817) (DECAPODA, PALINURIDAE) IN NORTHEAST BRAZIL: A REVIEW

ABSTRACT

The two spiny lobster fisheries targeting *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) have made an important economic marine resource in Northeast Brazil since 1955. The Von Bertalanffy age and growth parameters of the spiny lobster started being studied in 1960 and the last assessment was performed over 20 years ago. The objective of this review is to analyses the type of input data and the methods historically used to assess age and growth of the spiny lobster stock in Northeast Brazil. Our study reviews and updates the research on the subject and proposes relative values for the Von Bertalanffy growth parameters for *P. argus* and *P. laevicauda* as provisional reference. We recommend further age and growth research on spiny lobsters to create a new and updated growth function for commercial lobsters in Northeast Brazil.

Key words: *Panulirus argus*, *Panulirus laevicauda*, spiny lobster fishery, age and growth, Northeast Brazil

RESUMO

A pesca de lagosta de duas espécies-alvo, *Panulirus argus* (Latreille, 1804) e *Panulirus laevicauda* (Latreille, 1817) tem sido economicamente um importante recurso marinho no Nordeste do Brasil desde 1955. Em aquela região os parâmetros de idade e crescimento da função de Von Bertalanffy começaram a ser estudados desde o ano 1960 e por última vez há mais de 20 anos. O objetivo deste estudo de revisão é analisar os dados de entrada e métodos antigamente usados para assessorar a idade e crescimento do estoque de lagostas espinhosas explotadas no Nordeste do Brasil. Este trabalho atualiza o estado do conhecimento do tema e propõe valores relativos para os parâmetros da função de crescimento de Von Bertalanffy para *P. argus* e *P. laevicauda* como referência provisional. Sugerimos continuar com a pesquisa focada na idade e crescimento das lagostas espinhosas para poder facilitar a geração de uma nova e atualizada função de crescimento para as lagostas com valor comercial no Nordeste do Brasil.

Palavras-chave: *Panulirus argus*, *Panulirus laevicauda*, pescarias de lagosta, Nordeste do Brasil

INTRODUCTION

Growth in species of Crustacea has been studied over the last decades and the results indicate a complex process that involves a series of several moulting events (ecdysis) as well as intermoult (diecdysis) stages, necessary for an increase in the body size of a given organism during its lifetime (Hartnoll, 1983). As a result, crustacean age and growth data seem to fit better a non-continuous, stepped trend-line rather than a classical curve, that fits the majority of, e.g., true fish ("Pisces") growth data. The rigid exoskeleton of crustaceans simply leaves no other option. Crustacean growth can be influenced by several factors, including water temperature (Cruz et al., 1981), food availability (Phillips et al., 1992), habitat productivity (Morgan, 1985), reproduction (Hartnoll, 1985), disease (O'Brien & Van Wyk, 1985), and pollution (Fingerman, 1985).

Age and growth assessments of crustacean species are a strong tool for fisheries management to set the status of an exploited stock in function of lifespan, first capture, age at-first-maturity, age at-minimum-landing-size, cohort identification and population dynamics (Beverton & Holt, 1957; Ehrhardt, 2008), among others. Worldwide, marine and freshwater crustacean fisheries produce more than 5×10^6 metric tons (FAO, 2006). Within crustacean fisheries, lobster production worldwide reached 214,240 metric tons in 1993, composed of 37.9% *Homarus americanus* H. Milne Edwards, 1837 and 19.2% *Panuliurs argus* (Latreille, 1804) (FAO, 1993). Moreover, there has been an international effort on age and growth assessment for *P. argus* in more than ten countries across the Western Central Atlantic Region (FAO, 2001). Also, different methodologies have been tested in the Great Caribbean to assess the age and growth of *P. argus*, including: (1) tagging and recapture in Florida U.S.A., Cuba, the U.S. Virgin Islands, and the Bahamas (Little, 1972; Olsen & Klobic, 1975; Waught, 1981; Phillips et al., 1992; FAO, 2001; Ehrhardt, 2008); (2) the Bhattacharya method in Cuba (Cruz et al., 1981); and (3) the Fabens method in Bahia de la Asención, Mexico (Lozano-Alvarez et al., 1991).

Furthermore, in Northeast Brazil (NEB) the lobster stock composed of the two target species, *Panulirus argus* and *P. laevicauda* (Latreille, 1817), has been an important fishing resource since 1955 (Fonteles-Filho et al., 1988; Fonteles-Filho, 1992). The export of these two lobster fisheries in NEB between 1955 and 1991 constituted approximately 750 million US$ (Fonteles- Filho, 1994). The age and growth of *P. argus* was assessed for the first time in 1964 by Dos Santos et al. (1964), using fisheries-dependent data, total length frequency distribution, and the Von Bertalanffy growth function (VBGF). Subsequently, other important studies where performed using similar input data and methods. Age and growth assessments of *P. laevicauda* were performed for the first time in 1973 by Dos Santos & Ivo, using total length frequencies and VBGF, based on fisheries-dependent data.

Some of the limitations of the previous age and growth assessments seems to be related to the too few sources of raw data and the sampling procedures involved. The last age and growth assessment of *P. argus* and *P. laevicauda* in NEB was over 20 years ago (Ivo & Pereira, 1996), and still there are no accurate answers to basic questions like: "At what age do the lobsters reach their first maturity?" and "At what age do the lobsters reach minimum landing size?"

The objective of this review is to analyse the previous age and growth assessments used for *P. argus* and *P. laevicauda* in NEB since 1962. To do so, we collected available publications on the subject to compare and evaluate previous age and growth assessment results as claimed by several authors. We, also propose relative Von Bertalanffy growth parameters as provisional data until new growth parameters will be developed by fisheries science in NEB. We focus our discussion on the raw input data and methods used in previous assessments and propose some recommendations.

We believe there are compelling reasons to re-analyse and continue age and growth research and assessments of the commercial lobsters *P. argus* and *P. laevicauda* in NEB. The first one is the fact that we are dealing with a two-target-species lobster fishery, which is a special characteristic that is less common in other areas of the Western Atlantic Region. Another important feature is that it has been hypothesized that self-recruitment occurs in the *P. argus* stock on the Brazilian shelf (Cruz et al., 2015) and this might indicate different growth trends than those found in other areas of the species' distribution. The last reason is, to gain a better understanding of spiny lobster growth trends in relation to high exploitation with non-selective fishing gear in the last 50 years. We believe that research focused on the palinurid lobster stock in NEB will expand knowledge of fisheries science in the region of the Western Atlantic.

METHODS

Area of study

Spiny lobsters are distributed throughout the Brazilian continental shelf from Amapá state (04°26’N 51°32’W) to Espírito Santo state (21°17’S 40°56’W) (Cruz et al., 2013). For our review project we consider Northeast Brazil (NEB) as the area between 2˚30’N to 18˚S and 35˚W to 47˚W (Cruz & Bertelsen, 2009).

Length data standardization

The variable total length (TL) in centimetres was normally used to perform previous spiny lobsters age and growth assessments in NEB. In this review, the total length (TL) in centimetres was converted into cephalothorax length (CL) in millimetres using a logarithmic equation for each species and for each sex separately, as proposed by Rocha & Xavier (2000).

For *Panulirus argus*:

(1) males: $\text{Ln } Y = 1.61 + 0.86 \text{ Ln } X$

(2) females: $\text{Ln } Y = 1.29 + 0.94 \text{ Ln } X$

Likewise, for *Panulirus laevicauda*:

(3) males: $\text{Ln Y} = 1.73 + 0.82 \text{ Ln X}$

(4) and females: $\text{Ln Y} = 1.33 + 0.93 \text{ Ln X}$

Previous growth assessments for spiny lobsters in NEB

Input data and methods used for Von Bertalanffy growth parameters

A bibliographic compilation was made in order to gather all the information on spiny lobsters' age and growth previously assessed in the NEB region since 1960. The input data and methods to perform Von Bertalanffy growth function analysis (VBGF; Von Bertalanffy, 1938) used by those previous assessments were examined and chronologically compared for both species of commercial spiny lobster, i.e., *Panulirus argus* and *Panulirus laevicauda*.

Evaluating the input data and methods for the Von Bertalanffy growth function

The spiny lobster input data and the methods for VBGF used previously in NEB were evaluated by comparing with other growth estimations of *Panulirus argus* in the Great Caribbean. A total of five criteria for input data developed in the Great Caribbean by different authors were identified to set up a comparative evaluation (table I). Criteria were selected based on the kind of data used and the relevance of the studies at that time (Morgan, 1980; Cruz, et al., 1981). The same procedures were applied for *Panulirus laevicauda* due to fact that the age and growth of that species have been studied only in NEB and no publications on the subject were found from other areas of the Western Atlantic Region.

TABLE I

Criteria to evaluate the input data and methods used in previous age and growth assessments for spiny lobsters in the Northeast Brazil area

No.	Criteria	Author
1	Growth information of spiny lobsters retained in laboratory conditions	Sutcliffe, 1957
2	Planktonic age information included	Baisre, 1976 Lyons et al., 1981
3	Von Bertalanffy growth function adjustments (Beverton & Holt, 1957; Ford-Walford: cf. Ford, 1933 and Walford, 1946)	Cruz et al., 1981
4	Tag and recapture information included	Peacock, 1974; Phillips et al., 1992
5	Length frequency distribution range from < 25 to >125 mm CL	Phillips et al., 1992

Comparing and evaluating output data of the Von Bertalanffy growth function

The Von Bertalanffy growth function (VBGF):

$$L_t = L_\infty (1 - \exp(-K (t\text{-}t_o))$$

Von Bertalanffy (1938) was used to graphically compare trends between different, previous age and growth assessments for spiny lobsters, using an electronic spreadsheet. To evaluate the output performance, values of asymptotic length (L_∞) were compared with maximum length (L_{max}) observed for spiny lobster landings in the NEB area as implemented by Cruz and collaborators for the southwestern Cuban shelf (Cruz et al., 1981).

Current growth estimations for spiny lobster in NEB: calculating the relative Von Bertalanffy growth parameters L_∞ and K

The relative Von Bertalanffy growth parameters: (1) asymptotic length (L_∞), and (2) growth coefficient (K), for the spiny lobster result from the calculated mean values of previous age and growth assessments reviewed in this study. The relative Von Bertalanffy parameters were calculated by species, by sex, and graphically presented with a 95% confidence interval as implemented before for *Panulirus argus* in other regions (Phillips, 1992).

The relative values for *P. argus* and *Panulirus laevicauda* are here proposed as provisional reference data for spiny lobsters in the NEB area until values from an updated model can take their place.

RESULTS

Length data standardization

Since the beginning of spiny lobster fisheries research in the year 1961, the variable total length (TL) in centimetres was observed as “the distance between the notch formed by the rostral spines and the posterior part of the telson” (Pinto Paiva & da Silva, 1962). To perform growth assessments in NEB, some authors in those previous assessments transformed total length into cephalothorax length using the same, single linear equation for both sexes and both species. The logarithmic equations used by us in this review to convert the total length into the cephalothorax length separately by species and by sex, showed a good fit when the output in the form of growth curves was graphically compared.

Previous growth assessments for spiny lobsters in NEB

Input data and methods previously used for Von Bertalanffy parameters

The results show that from the year 1964 up to 2008, four age and growth assessments were performed for *Panulirus argus* and two such assessments for *Panulirus laevicauda*. These previous assessments collected different body measurements, like total length and tail length, as input data for both species (table II). The methods used were based on length frequency analysis purported to perform the Von Bertalanffy growth function calculations. Chronologically, the methods began with basic progression analysis in 1964 to turn to computational programs in 1996. None of the previous assessments stated why VBGF was used. Fisheries-dependent data were the only information used for both species (table II), but the reason for using such a source was not explained by any of the authors.

TABLE II

Source of the studies, input data, and methods used to perform the Von Bertalanffy growth function analysis for the spiny lobsters *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) in Northeast Brazil from 1964 to 2008

Panulirus argus (Latreille, 1804)			
Author	Measuring growth	Method	Type of data
Dos Santos et al., 1964	Total length frequencies	Modal Progression Analysis	Fisheries-dependent data
Gonzalez-Cano & Rocha, 1995	Total length frequencies	Shepard´s Length Composition Analysis	
Ivo & Pereira, 1996	Total length frequencies (including tail length*)	Electronic Length Frequency Analysis (ELEFAN, Bhattacharya´s method)	
Leocádio & Cruz, 2008	Cephalothorax length frequencies	Meta-analysis	
Panulirus laevicauda (Latreille, 1817)			
Author	Measuring growth	Methods	Type of data
Dos Santos & Ivo, 1973	Total length frequencies	Modal Progression Analysis	Fisheries-dependent data
Ivo & Pereira, 1996	Total length frequencies (including tail length*)	Electronic Length Frequency Analysis (ELEFAN, Bhattacharya´s method)	

*) Total length and tail length data were converted to cephalothorax length.

Evaluating the input data for the Von Bertalanffy growth function

The five criteria selected were adequate to highlight the relevance of using raw input data in previous age and growth assessments in NEB. The input data evaluations for the VBGF in NEB for spiny lobsters show that only one criterion (criterion No. 3, which refers to procedures for calculating the Von Bertalanffy growth parameters known as the Beverton & Holt adjustment, (cf. Beverton & Holt, 1957) and the Ford-Walford linear method (cf. Ford, 1933; Walford, 1946; Gulland, 1969; Ricker, 1975; Vaughan & Kanciruk, 1982)), matched with other studies developed in the Great Caribbean in a similar time frame (table III). The criteria selected show that all previous age and growth assessments in NEB were run with limited input data. For example, criterion number five (length frequency data) indicates that the ranges of length input data are limited to fisheries-dependent values between 50 and 132 mm

CL, with no values below 50 mm CL for *Panuliurs argus*, and from 46 to 113 mm CL with no values below 46 mm CL for *Panulirus laevicauda* (table III). Also, previous growth assessments for both species did not give raw input data regarding laboratory reared spiny lobsters, planktonic age of spiny lobsters, or tag & recapture information, for performing VBGF. There is no clear explanation why the assessments at that time were limited to only the Ford-Walford linear method, and did not include values below 25 mm CL.

TABLE III

Input data and methods used in previous age and growth assessments for the spiny lobsters *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) in Northeast Brazil and comparation with other such assessments in the Great Caribbean

<table>
<tr><th rowspan="2">Author</th><th>Method</th><th colspan="4">Input data</th></tr>
<tr><th>Beverton & Holt, 1957; Ford-Walford</th><th>Length frequency range from < 25 to > 125 mm CL</th><th>Laboratory reared information</th><th>Planktonic age information</th><th>Tag and recapture information</th></tr>
<tr><td colspan="6">Panulirus argus (Latreille, 1804)</td></tr>
<tr><td>Dos Santos et al., 1964</td><td>Ford-Walford</td><td>≥ 63 - 132 mm CL</td><td colspan="3" rowspan="4">No input data</td></tr>
<tr><td>Gonzalez-Cano & Rocha, 1995</td><td>Not available</td><td>≥ 50 - 122 mm CL</td></tr>
<tr><td>Ivo & Pereira, 1996</td><td>Ford-Walford</td><td>Not available</td></tr>
<tr><td>Leocádio & Cruz, 2008</td><td>Not available</td><td>≥ 50 - 132 mm CL</td></tr>
<tr><td colspan="6">Panulirus laevicauda (Latreille, 1817)</td></tr>
<tr><td>Dos Santos & Ivo, 1973</td><td>Ford-Walford</td><td>≥ 46 - 113 mm CL</td><td colspan="3" rowspan="2">No input data</td></tr>
<tr><td>Ivo & Pereira, 1996</td><td>Ford-Walford</td><td>Not available</td></tr>
</table>

Comparing and evaluating previous output data of Von Bertalanffy growth parameters for spiny lobsters in NEB

The first *Panulirus argus* age and growth assessments were performed by Dos Santos and collaborators (Dos Santos et al., 1964), using length frequency to adjust VBGF. The authors calculated the growth coefficient "K" with the highest values for males and females found for this review (table IV). This assessment highlights the similarity in growth between males and females that began in the first year and lasted until the third year, when males started showing graphically a different trend that becomes more pronounced in the fifth year (fig. 1A). This growth similarity between sexes during the first years of the species' life was not explained by the authors. The evaluation of the output shows a maximum length (L_{max}) > asymptotic length (L_∞) scenario for *P. argus* males and females. Wherein the Von Bertalanffy growth parameter L_∞ does not represent the observation of L_{max} found in the spiny lobster landings. The L_{max} observed in spiny lobster landings in the NEB area for males was reported to range from 141 to 146 mm CL (Pinto Paiva & Da Costa, 1970; Do Nascimento et al., 1984) and for females from 125 to 135 mm CL (Pinto Paiva & Da Costa, 1966, 1967, 1968; Do Nascimento, et al., 1984).

The age and growth assessment of Gonzalez-Cano & Rocha (1995) shows, graphically, considerable differences compared to the previous model (fig. 1B). The figures show notable differences in growth trends for males and females after the first year, that become more pronounced in the second year.

In 1996, Ivo & Pereira performed a new growth curve analysis using length frequencies, the Batacharraya method, and ELEFAN I (see Gayanilo, Jr. et al., 1989; Pauly & Gayanilo, Jr., 1990) for VBGF for males and females of *P. argus* (fig. 1C). Compared with the previous model, the Ivo & Pereira (1996) model displays a difference between males and females starting at two years, that becomes more pronounced at three years. In this assessment, the authors claim a non-growth-rate difference between males and females of the species, but they did not explain the methodological procedures to calculate that rate between sexes.

A new growth assessment was performed in 2008 by Leocádio & Cruz based on a meta-analysis graphically showing a trend different from the preceding model (fig. 1D). This model illustrates different growth trends between males and females after the first year. The evaluations of the last three assessments described above, highlight a $L_{max} < L_\infty$ scenario for males and females of *P. argus*. Wherein potentially the Von Bertalanffy parameter L_∞ might be overestimated when compared with the L_{max} observations of the species landings (table IV).

TABLE IV

Output of Von Bertalanffy growth parameters from previous assessments of *Panulirus argus* (Latreille, 1804) in Northeast Brazil; the Dos Santos et al. (1964) model is the only one showing and L_{max} greater than L_∞ scenario

Author	Asymptotic length (L_∞)		Growth coefficient (K)		Output data evaluation	
					L_{max} vs. L_∞	
	♂	♀	♂	♀	♂	♀
Dos Santos et al, 1964	142.0	130.1	0.340	0.380	$L_{max} > L_\infty$	
Gonzalez-Cano & Rocha, 1995	207.2	124.9	0.260	0.230	$L_{max} < L_\infty$	
Ivo & Pereira, 1996	178.4	160.1	0.229	0.236		
Leocádio & Cruz, 2008	176.7	142.4	0.279	0.281		

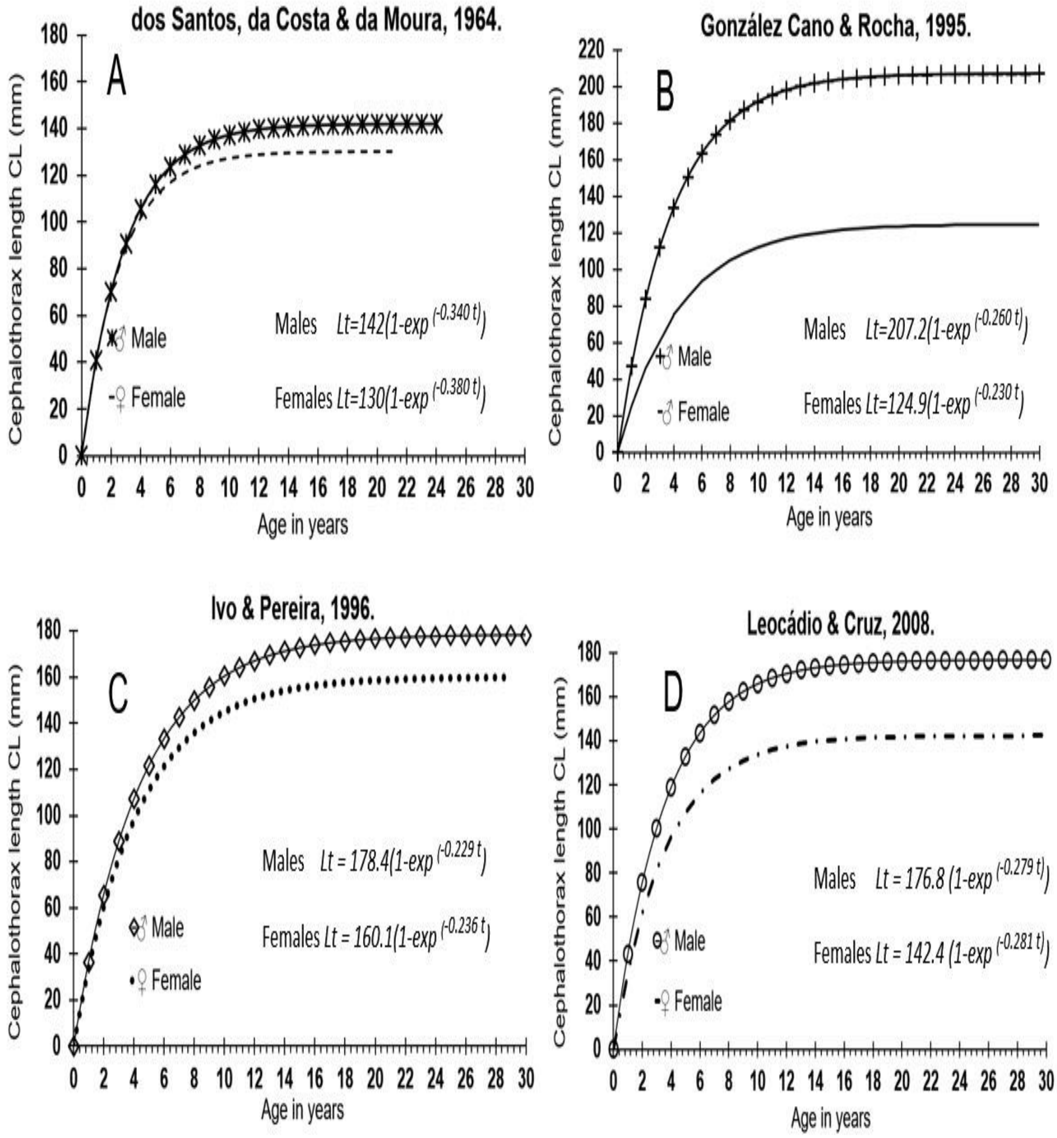


Fig. 1. Output results of the Von Bertalanffy growth function for *Panulirus argus* (Latreille, 1804) in Northeast Brazil. A, Dos Santos et al., 1964; B, González-Cano & Rocha, 1995; C, Ivo & Pereira, 1996; D, Leocádio & Cruz, 2008. A and C show different growth trends between males and females after approximately three years. B and D show different growth trends for males and females almost at their first year. Decreasing order of asymptotic length ($L\infty$) ♂, B; C; D; A. ♀, C; D; A; B. Decreasing order of growth coefficient (K) ♂, A; D; B; C. ♀, A; D; C; B.

The age and growth assessment of Gonzalez-Cano & Rocha (1995) shows, graphically, considerable differences compared to the previous model (fig. 1B). The figures show notable differences in growth trends for males and females after the first year, that become more pronounced in the second year.

In 1996, Ivo & Pereira performed a new growth curve analysis using length frequencies, the Batacharraya method, and ELEFAN I (see Gayanilo, Jr. et al., 1989; Pauly & Gayanilo, Jr.,

1990) for VBGF for males and females of *P. argus* (fig. 1C). Compared with the previous model, the Ivo & Pereira (1996) model displays a difference between males and females starting at two years, that becomes more pronounced at three years. In this assessment, the authors claim a non-growth-rate difference between males and females of the species, but they did not explain the methodological procedures to calculate that rate between sexes. A new growth assessment was performed in 2008 by Leocádio & Cruz based on a meta-analysis graphically showing a trend different from the preceding model (fig. 1D). This model illustrates different growth trends between males and females after the first year. The evaluations of the last three assessments described above, highlight a Lmax $<$ L∞ scenario for males and females of P. argus.

On the other hand, the first study to assess the age and growth of *Panulirus laevicauda* was performed by Dos Santos & Ivo (1973). In this work the authors used length frequency distribution and the Ford-Walford linear method for performing VBGF (table V). In this assessment, the authors suggest the non-growth difference hypothesis between males and females for the species mentioned. The premises of the non-growth hypothesis were, however, not fully explained by the authors. Graphically, this model shows little growth development after 5 years for both sexes (fig. 2). The output evaluation of the assessment indicates a $L_{max} > L_{\infty}$ scenario, where the asymptotic length L_{∞} (83.4 mm CL) is smaller than the L_{max} observations of the *P. laevicauda* landings, which were reported in a range from 108 to 124 mm CL for males and 94 to 108 mm CL for females in the NEB area (Pinto Paiva & Da Costa, 1965; Da Costa & Lima Paiva, 1974; Do Nascimento et al., 1984) (table V). Age and growth of *P. laevicauda* were assessed again by Ivo & Pereira (1996). This assessment graphically shows a Von Bertalanffy growth curve different between males and females after the first year, the difference becoming more pronounced at five years (fig. 2). The conclusion proposed that there was no difference in growth rate between males and females of the species. Ivo & Pereira (1996) did not explain the methodical procedures to calculate the growth rate for males and females of *P. laevicauda*.

TABLE V

Output of Von Bertalanffy growth parameters from previous assessments of *Panulirus laevicauda* (Latreille, 1817) in Northeast Brazil

Author	Asymptotic length (L_∞)		Growth coefficient (K)		Output data evaluation	
					L_{max} vs. L_∞	
	♂	♀	♂	♀	♂	♀
Dos Santos & Ivo, 1973	83.3	83.3	0.708	0.708	$L_{max} > L_\infty$	
Ivo & Pereira, 1996	190.12	153.0	0.221	0.226	$L_{max} < L_\infty$	

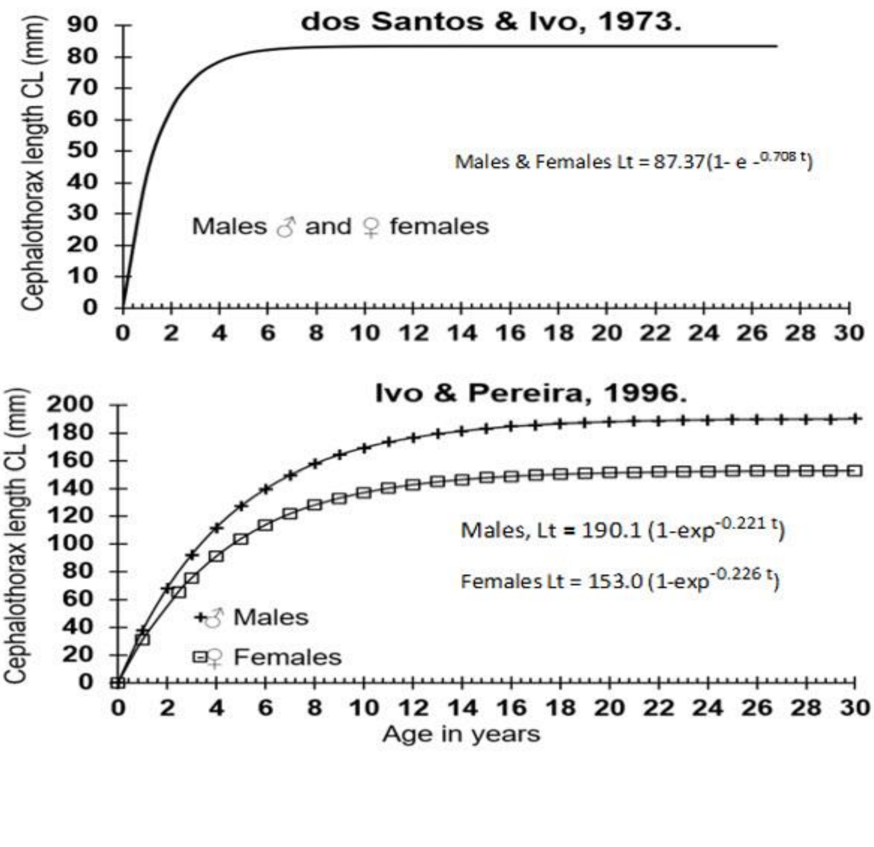


Fig. 2. Output results of the Von Bertalanffy growth function for *Panulirus laevicauda* (Latreille, 1817) males and females in Northeast Brazil. A, Dos Santos & Ivo, 1973, for males and females together, showing high growth during the first three years, with L_∞ = 83.3 mm CL and K = 0.708; B, Ivo & Pereira, 1996, showing different growth for males and females of the species after the second year. Males, L_∞ = 190.1 mm CL and K = 0.221. Females, L_∞ = 153.0 mm CL and K = 0.226.

Current calculations: Relative values for Von Bertalanffy growth parameters L_∞ and K for spiny lobsters in NEB

The relative values from previous VBGF parameters for spiny lobsters show differences between males and females for both species. *Panulirus argus* males present higher L_∞ and lower K relative values when compared with the females (table VI). Graphically, the species mentioned show similar growth trends for males and females from the first year but become different after the second year. This difference is notable after the third year (fig. 3). Relative values show that males and females from the mentioned species reach the first year measuring 41.9 mm and 33.8 mm CL, respectively (table VI). Likewise, *Panulirus laevicauda* males present higher L_∞ and lower K values compared with the females of that species (table VI). Graphically, males and females show the same growth rate until the third year, when males show a higher growth trend (fig. 3). Males and females reach the first year measuring 40.0 and 36.6 mm CL, respectively.

TABLE VI

Output of relative Von Bertalanffy growth parameters for *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) in the Northeast Brazil marine area; relative values are proposed as provisory

This review; proposal	Asymptotic length (L_∞)		Growth coefficient (K)		Cephalothorax length (mm) 1-year-old	
	♂	♀	♂	♀	♂	♀
Panulirus argus (Latreille, 1804)						
Relative value	176.1	139.4	0.277	0.282	41.9	33.8
Panulirus laevicauda (Latreille, 1817)						
Relative value	136.7	118.2	0.460	0.490	40.0	36.6

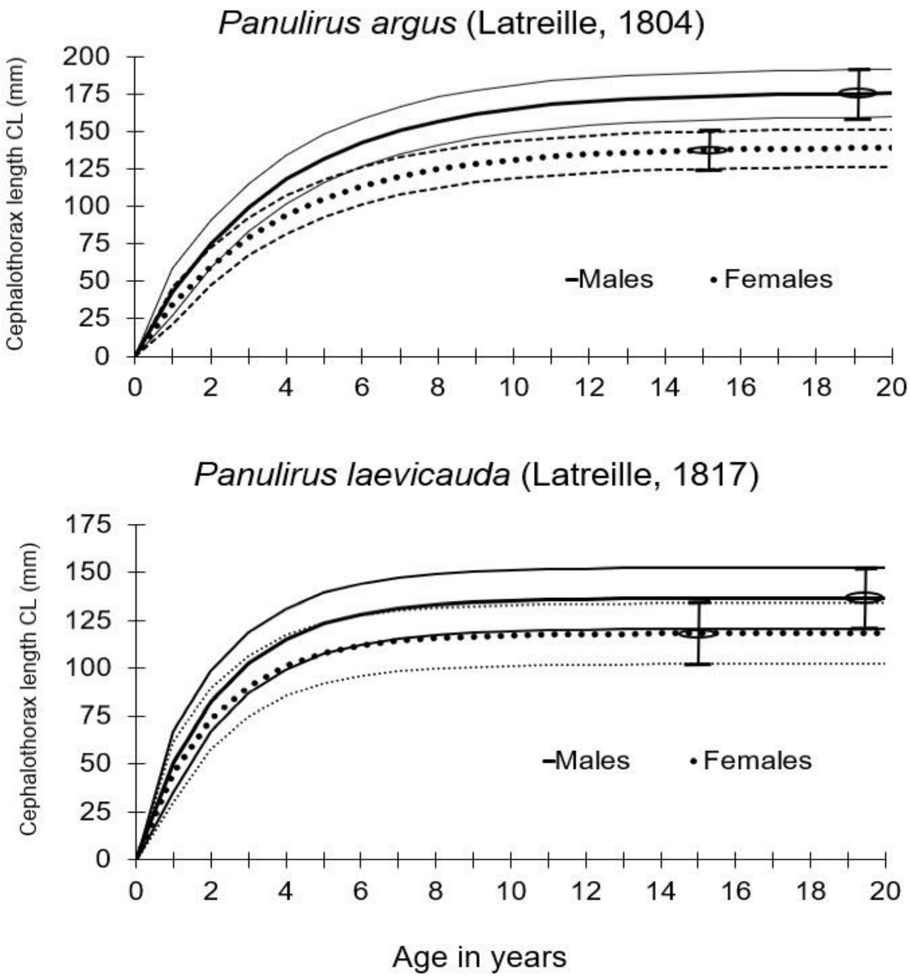


Fig. 3. Relative output results of the Von Bertalanffy growth function (95% confidence interval) for *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) in Northeast Brazil. ♂, solid line; ♀, dotted line

DISCUSSION

Spiny lobster body measurements and length data standardization

Previous spiny lobster age and growth assessments converted different spiny lobster body measurements (lengths) for analysis. This was especially noted when long time series (decades) with different body measurements were transformed and joined to create a standard data set. Some data sets included conversions of tail length to total length. For example, in Ivo & Pereira (1996) tail length was transformed to total length without reporting which formula was used for such morphometric transformation. It is important to mention that the logarithmic equations developed by Rolim & Rocha (2000) and used by us in this review showed a good adjustment for the standardization of the data by species and sexes. Even so, we consider that the different methodologies previously used to transform spiny lobster measurement in NEB created low quality length frequency distribution data and thereby a potential source of bias in the growth assessments. The observation of cephalothorax length as "notch of the supra orbital spines until the posterior part of the cephalothorax" (Cruz et al., 2011) has been considered the conventional index of body size for growth studies (Wahle & Fogarty, 2006). Observation of lobster cephalothorax length is a more accurate variable than total length, due to the flexibility of the tail during measurement. The use of linear equations to transform the tail length into total length might also be a source of bias in *Panulirus argus* research (Cruz & Bertelsen, 2009; Cruz et al., 2011).

Previous studies

Methods and raw input data used for Von Bertalanffy growth parameters and their evaluations

Previous age and growth assessments of the spiny lobsters *Panulirus argus* and *Panulirus laevicauda* in NEB used limited input data and methods when compared with other studies developed in the Great Caribbean in a similar time frame. There is no evidence of data input from laboratory reared, tag & recapture, or planktonic age material. Only fisheries-dependent data were employed to determine length frequency distributions for the Von Bertalanffy growth function analysis. Length frequency measurements can be obtained cost-effectively from fish landing places and have been used in various lobster taxa (Pauly & Morgan, 1987; Wahle & Fogarty, 2006). These data provide a medium level of biological reality for describing the average growth of individuals but have a low relevance for the individual (Chang et al., 2012). Since all length frequencies used in previous assessments come from fisheries-dependent data it is important to highlight two crucial things. The first is that different types of fishing gear normally used in commercial fishing can be a source of bias in the sampled spiny lobsters, and accordingly in the length frequency distributions, as well as in the age and growth calculations. It seems as if previous growth assessments did not consider these facts as a possible source of bias for growth analysis purposes. The second one comprises, that apparently length frequency distributions used as input in previous assessments were not designed for purposes of growth analysis. Is not clear if the length frequency used as raw input is part of some experimental design. The sample sizes, sex ratios, random sample selection, small or large spiny lobster proportion in the catch, and the externally observable information on the reproductive state of the females, were not reported. Also, the length distribution range is limited from 50 to 132 mm CL for *P. argus* and from 46 to 113 mm CL for *P. laevicauda*, with no observations available below 25 mm CL for each of the species. Observations below 25 mm CL have been described as important input data for age and growth estimations in *P. argus* (cf. Phillips, 1992).

On the other hand, previous spiny lobster age and growth assessments in NEB implemented the Von Bertalanffy growth function. None of the authors of the reviewed assessments explained clearly why VBGF was selected to perform the assessment. Also, there is no reference if other age and growth models have been used in NEB at that time. VBGF has been widely used to assess fish growth and has also been used to assess crustacean growth (Caddy, 1986; Cobb & Caddy, 1989). More than nine species of lobsters, including *P. argus*, have been assessed with VBGF in different regions worldwide (Wahle & Fogarty, 2006). Some of the problems to assess the age and growth of spiny lobsters with a continuous growth model like VBGF are, that the model does not capture discontinuous growth due to the periodic moulting process. In contrast, satisfactory outcomes of VBGF analyses result when proper data are used as input. For example, tag and recovery observations and measurements of intermoult increments, and their probabilities. Unfortunately, all this is not the case for the previously performed age and growth assessments of spiny lobsters in NEB.

From another perspective, for growth assessment it is important to have a good knowledge of the cephalothorax-length-to-body-length morphometrics of the spiny lobster in order to acquire reliable growth measurements. This kind of information is limited for *P. argus* and *P. laevicauda* in NEB. Finally, the scenario of previous age and growth assessments for spiny lobsters in NEB can be summarized as consisting of low statistical-power length frequency distributions from fisheries-dependent data, used as input in a model (VBGF) that assumes continuous growth. With this scenario, we considered that the age and growth values stated by previous assessments in NEB are doubtful, and that there obviously is a need for a new assessment.

Comparing and evaluating output data of Von Bertalanffy growth parameters for spiny lobsters in NEB

Graphically, VBGF output indicates considerable differences between the previous assessments for *Panulirus argus* in NEB. As general observation we can divide these differences into two trends. For one side, the first trend is the one with similar growth between sexes during the first three years of age. On the other side, the second one has different growth trends between sexes during the first years. Also, the L_{max} for *P. argus* indicates two different scenarios for the model outputs where the asymptotic length L_{∞} is either less than, or more than the L_{max}, and with a poor representation of the observations from the species' landings.

On the other hand, outcomes of age and growth assessments for *Panulirus laevicauda* are limited due to the fact that the male and female values have been included in the same model. Also, the L_{max} for the species is greater than the calculated L_∞, and K seems to be overestimated. The Ivo & Pereira (1996) model shows a difference between males and females from the 2nd year onward, but L_∞ seems seriously overestimated when compared with the L_{max} of the landings observations. This scenario takes us to ask the following question for both species: "If the raw input data and methodological conditions between the models (VBGF) are similar, why do we find these differences in the output?" We believe that rather than biological or environmental factors influencing the growth of the species, the differences between the models' outcomes are due to the type of input data, that concern too low-quality length frequency distributions for *P. argus* and *P. laevicauda*. Sample sizes and the proportions of small and large spiny lobsters in the samples corrupt the purity of the analyses, as was discussed in the previous section. Also, it seems as if the conversions of the various body measurements (e.g., total length and tail length) might result in the computation of considerable differences in the output. Consequently, we strongly believe that the VBGF parameters L_∞ and K must be recalculated with proper input data, and such for both species here at issue.

Current calculations: Relative Von Bertalanffy growth parameters L_∞ and K for spiny lobsters in NEB

The difference between sexes of the VBGF parameters calculated by us for *Panulirus argus* have also been reported for that species in the Great Caribbean. The L_∞ calculated by us for NEB males is lower than the values reported for males in the Great Caribbean. In the same sense, the females in the NEB area had a lower L_∞ compared with the females in the larger region mentioned (Leocádio & Cruz, 2008).

Likewise, the K figures for males in NEB are higher than those of *P. argus* males in the Great Caribbean, and the same holds true for the females: those in NEB showed higher K values than the ones reported for specimens from the Great Caribbean (Leocádio & Cruz, 2008). In the Cuban archipelago, the most likely values of K were reported within a range of 0.200 to 0.380 for *P. argus* (cf. Cruz et al., 1981). On the other hand, differences in the growth parameters L_∞ and K between *P. argus* males and females have been described for Florida, U.S.A. (Little, 1972), the U.S. Virgin Islands (Olsen & Klobick, 1975; Mateo & Tobias, 2002), and the Bahamas (Waugh, 1981). Moreover, our VBGF age calculations for *P. argus* males show that they reach the first year measuring a mean of 41.0 mm CL and that females do so with 33.8 mm CL on average. However, different results have been found for *P. argus* in the Cuban archipelago, where the species reaches the first year measuring an average of 10 mm CL (Baisre, 1979), and reaches the second year measuring an average of 63 mm CL (Cruz et al., 1981). We believe that our calculated age-at-length is overestimated, and thus needs a new assessment, based on proper input data.

As regards *Panulirus laevicauda*, that discussion does not seem to be an optimistic one. To our concern, age and growth assessments for *P. laevicauda* outside NEB and, in general, for other areas of the Western Atlantic Region, are nonexistent. This fact leaves a difficult scenario, with no information to compare. We consider, though, that our calculations can function as a stepstone for future research.

In summary, we think we can conclude that our review, rather than answering all questions about age and growth of these two commercial spiny lobsters, brings an updated perspective on the subject. We believe that the relative values for the VBGF parameters as calculated herein, can act as a starting point to enter a new era of research into age and growth of *P. argus* and *P. laevicauda* in NEB. We are proposing relative values of the Von Bertalanffy growth parameters for species and sexes as follows:

***Panulirus argus*:**

♂ Males, L_{∞} = 176.1, K = 0.277, reaching the first year measuring 41.9 mm CL

♀ Females, L_{∞} = 139.4, K = 0.282, reaching the first year measuring 33.8 mm CL

***Panulirus laevicauda*:**

♂ Males, L_{∞} = 136.7, K = 0.460, reaching the first year measuring 40.0 mm CL

♀ Females, L_{∞} = 118.2, K = 0.490, reaching the first year measuring 36.6 mm CL

We consider these relative age and growth values as provisory, under the precautionary approach to fisheries research (FAO, 1996), until a new growth parameter investigation will take place by all fisheries-science stakeholders in Northeast Brazil.

MANAGEMENT IMPLICATIONS AND CONSERVATIONS

As a consequence of our above results, we recommend the development of a new age and growth assessment for *Panulirus argus* and *Panulirus laevicauda*, with the following recommendations:

Input data for age and growth assessment

An important lesson learned, based on the deficiency of the previous age and growth assessment on the NEB spiny lobster fauna is: low quality input data should be avoided. That goal can be reached as follows:

(1) **Length frequency distribution data.** These should come from an excellent long-term fisheries-independent data-sampling design (Ricker, 1975; Pauly & Morgan, 1987; Fonteles-Filho & Holanda, 1990; Cruz et al., 2011). This should include, but not be limited to: defining the number of samples per unit time, registration of the sex ratio, standardizing gear selectivity, and observations of cephalothorax length over a range of < 25 mm to > 125 mm CL (Phillips et al., 1992).

(2) **Tag and recapture.** It is important to set a long-term tag and recapture program for the spiny lobster in NEB. A successful tag and recapture program should consider but not be limited to: be planned for five years or more, at least one thousand organisms should be tagged, double tagging should be considered to minimize total tag-loss, recapture information for males and females should be collected separately, and the time between tag and recapture should be planned in advance so as to be not less than 100 days. Interesting suggestions resulting from the tagging of *Panulirus argus* and other lobster species have been brought forward by several authors already (Cruz et al., 1986; Phillips et al., 1992; Wahle & Fogarty, 2006; Ehrhardt, 2008).

(3) **Spiny lobster morphometrics.** We believe that for a successful growth assessment it is very important to update the information on the morphometric relationships by sex and by species in order to better understand the development of the growth of the body of spiny lobsters. Interesting and easy to replicate methods for the assessment of morphometrics have been proposed by Rolim & Rocha (1972), Do Nascimento et al. (1984), and Rocha & Xavier (2000).

(4) **Spiny lobster laboratory rearing.** Rearing under laboratory conditions will generate important input data for small spiny lobsters (< 25 mm CL) and thus provide information about the pre- and post-moult stages in the ecdysis cycle, of which little is known

as yet for the populations in NEB. Important methods for the observation of ecdysis in *P. argus* were proposed by Travis (1954) and for laboratory rearing by Matthews & Maxwell (2007) and Dahlgren & Staine (2007). A regional methodology was developed by Assad and collaborators, who experimented with marine nursery cages for raising juveniles of *Panulirus argus* and *P. laevicauda* in NEB (Assad et al., 1992).

Modelling age and growth of spiny lobsters in NEB

With the construction of robust input data there will be a need to select a numerical model to assess the age and growth of spiny lobsters. However, it seems as if we can not keep thinking that way. A new way of thinking must propose the use of different types of numerical models to expand the growth of an individual spiny lobster to the average growth of a stock, according to biological reality. The following list gives an idea of the different models that potentially can be used:

(1) **Continuous model Von Bertalanffy.** VBGF will fit mainly raw input data from: (a) tag and recapture data; and (b) moult increment information (Wahle & Fogarty, 2006).

(2) **Continuous model Von Bertalanffy-Fabens-recapture.** This model takes as input information from recaptured lobsters and the delay-in-time recapture and has been used with *Panulirus argus* (cf. Campell & Phillips, 1972; Lozano-Alvarez et al., 1991; Phillips et al., 1992).

3) **Intermoult period.** This model was used with *P. argus* data from tag & recapture and from laboratory reared specimens (Ehrhardt, 2008).

(4) **Modern ELEFAN-based fitting method.** This recently developed method seems to find good adjustment with data-poor scenarios. The model uses length frequency analysis for fitting a curve with several algorithms (Schwamborn et al., 2019).

CONCLUSIONS

From the data source approach as herein applied, our findings are highlighting that the type of raw data used as input is as important as the numerical model for calculating realistic simulations of spiny lobster age and growth. The statistical standardization of fisheries-dependent data collection is also important in the growth assessment. Earlier studies in the NEB area are characterized by limitations in the source data and in the sampling efforts but can still be considered an important biological baseline for spiny lobster research. This goes especially for *Panulirus laevicauda,* which has been little studied in the Western Atlantic Region until now. We used the results of those previous studies to calculate relative age and growth values for *Panulirus argus* and *Panulirus laevicauda,* but the outcomes have to be used with caution. We strongly believe that our recommendations, especially the creation of a database of long-term fisheries-independent input data, would enhance a framework for future age and growth modelling for *P. argus* and *P. laevicauda*, according to the biological reality of the stock in the Western Atlantic Region.

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6. CAPÍTULO 2

FEMALE LENGTH-AT-FIRST MARUTIRTY OF THE COMERCIAL SPINY LOBSTER *PANULIRUS ARGUS* (LATREILLE, 1804) AND *PANULIRUS LAEVICAUDA* (LATREILLE, 1817) (DECAPODA, PALINURIDAE) IN NORTHEAST BRAZIL

ABSTRACT

Female spiny lobster of *Panulirus argus* and *Panulirus laevicauda* reproductive cycle began to be assessed in the 1960s in Northeast Brazil (NEB) and subsequently in the 1980s the length at first maturity (L50) in the commercial landings was assessed using internal and external reproduction indicators. Moreover, during the year 1994 the minimum legal landing size was stablished as management regulation for *P. argus* and *P. laevicauda* fishery in 75 mm and 65 mm of cephalothorax length (CL) respectively. Currently the studies about the efficacy of these management measures are limited. Due to that we wonder if the current minimum legal landing size effectively protect spiny lobster female reproduction? Looking for an answer the objective of this chapter it to test if the current minimum legal landing size grants protection to the female spiny lobster *P. argus* and *P. laevicauda* in NEB. We employ a logistic regression to calculate the probability of length at first maturity (L50) and chronologically compare trends for both species of female spiny lobster between the years 1966 and 2018. The results indicate that the female spiny lobster of both species achieves the length at first maturity at larger size in 2018 than in the past, during 1966 and we focus the discussion about the factors that can influence these increasing trends. Thus, the L50 results are a good benchmark to indicate that the current minimum legal landing size for both species grants little protection to the spiny lobster reproductive female and we suggest 5% increments. We believe that more research focused on the length at first maturity of the spiny lobster in NEB should be a priority for better assessment of the minimum legal landing size to achieve sustainability in the fishery.

RESUMO

O ciclo reprodutivo das fêmeas de lagosta espinhosa de *Panulirus argus* e *Panulirus laevicauda* começou a ser avaliado nos anos de 1960 no Nordeste do Brasil (NEB) e posteriormente nos anos de 1980 o comprimento de primeira maturação (L50) foi avaliado usando indicadores de reprodução interna e externa nos desembarques comerciais. Além disso, durante o ano de 1994, para a gestão do recurso o tamanho mínimo de captura foi estabelecido na pesca das lagostas espinhosas *P. argus* e *P. laevicauda* em 75 mm e 65 mm de comprimento de cefalotórax (CL), respectivamente. Atualmente, os estudos sobre a eficácia dessas medidas de manejo são escassos. Por conta disso, nos perguntamos se o atual tamanho mínimo de captura protege efetivamente a reprodução das fêmeas de lagosta espinhosa? Procurando uma resposta, o objetivo deste capítulo é testar se o tamanho mínimo de captura protege a reprodução das das lagostas espinhosas fêmeas *P. argus* e *P. laevicauda* no NEB. Empregamos uma regressão logística para calcular a probabilidade do comprimento de primeira maturação (L50) e comparar cronologicamente as tendências para ambas espécies de lagosta espinhosa entre os anos de 1966 e 2018. Os resultados mostram que ambas espécies de lagosta espinhosa atingem o comprimento em primeira maturação em maior tamanho no 2018 do que no passado durante 1966 e focamos a discussão sobre os fatores que podem influenciar esses incrementos. Assim, os resultados indicam que o atual tamanho mínimo de captura para ambas espécies concede pouca proteção à fêmea reprodutora de lagosta espinhosa e sugerimos um incremento em 5%. Acreditamos que as pesquisas focadas no comprimento na primeira maturação das lagostas

espinhosas no NEB deve ser uma prioridade para uma melhor avaliação do tamanho mínimo de captura e alcançar a sustentabilidade nas pescarias.

INTRODUCTION

Information about female lobster reproduction cycle and length at first maturity are key factors to set a minimum legal landing size that is required to achieve sustainable indicators within a fishery, but also to reach economic and social long term goals (Phillips et al., 1980, Booth, 1984; Chubb, 2000; MacDiarmid & Sainte-Marie, 2006; Ayra & Cruz, 2010). In general, the reproductive system presents similarities among lobster diversity, but unfortunately little is known about it (Eiken & Waddy, 1980) and this condition is especially noted for male lobster (Soares & Peret 1998a; Cruz & Bertelsen, 2009; Ayra & Cruz, 2010). In some cases, the reproductive biology has been studied for a long time, like is the case of the American lobster *Homarus amircanus* H. Milne Edwards, 1837 (Phillips et al., 1980). Within the lobster reproductive biology, the maturity condition can be assessed by three basic criteria as follows: a) morphological maturity, detected by external body parts; b) physiological maturity, detected by gonads analysis; and c) functional maturity revealed by internal, external body parts and behaviour (MacDiarmid & Sainte-Marie, 2006). The stock reproductive maturity stage can be assessed employing the body lengths frequencies distribution of females with signs of reproduction criteria. The length size class in which 50% of the individual maturity is defined as the length-at-first reproductive maturity (L50) wherein 50% of the female lobster carry eggs (Cruz & Bertelsen, 2009; Fonteles-Filho, 2011). The L50 is an important indicator for stock assessment and fisheries management (MacDiarmid & Sainte-Marie, 2006). The knowledge about the L50 can be useful for a sustainable management of the stock. It has been proved that the length at first maturity can vary geographically between species but also within species (Phillips et al., 1980). Subsequently it is possible to highlight the variation in L50 between species specially from the geographical point of view. For example, the *Panulirus guattatus* (Latreille, 1804) female reaches the length at first maturity with a quit small body size (32 mm cephalothorax length CL) in Florida, USA (Robertson & Butler, 2003). On the opposite side, *Jasus verraauxi* (H. Milne Edwards, 1851) can reach the length at first maturity with a larger body size equivalent to 160 mm CL in New Zealand (Booth, 1984). Moreover, in some cases the female L50 can increase or decrease within a lobster species. This fact has been theorical associated with environment, population density and overfishing (Polovina, 1989; Pollock, 1991, 1993; Waller et al., 2019). For example, its been reported the increase of female L50 for

Panulirus argus (Latreille, 1804) in a 20-year time frame in Cuban waters (Léon, 2005). It is important to highlight that long-term and high-quality data are needed to assess properly these biological changes in the female lobster length at first maturity.

In Northeast Brazil (NEB) female external reproduction criteria were characterized for the first time in the year 1962 and successively until 1973 in the commercial landings of *P. argus* and *Panulirus laevicuada* (Latreille, 1817) (Pinto Paiva & Da Costa, 1963b – 1970; Da Costa & Paiva-Filho, 1974) focusing mainly in the study of the female reproductive season and leaving the length at first maturity as a less studied subject. Subsequently, female reproductive biology and L50 was assessed employing systematic sampling from 1984 to 1993 employing internal and external reproduction criteria for both species of spiny lobster in the commercial landings (Soares & Cavalcante, 1984; Soares, 1994; Soares, 1998; Soares & Peret, 1998a, 1998b). These previous assessments created one of the few and most important base-line information for spiny lobster reproductive biology in Brazil. It is important to point out that previous female spiny lobster assessments of L50 in NEB were based on fisheries-dependent data presenting some limitations in function of experimental laboratory, environmental or geographical input data. Subsequently, in 1994 to improve the management of the spiny lobster stock the Brazil’s government promoted the minimum legal landing size in the spiny lobster fisheries, as follows: a) *P. argus* in 75 mm of cephalothorax length; and b) *P. laevicuada* in 65 mm cephalothorax length (IBAMA, 1994) these management implementation was also enforced again during 2006 (IBAMA, 2006). Currently little information is available about the effectiveness of these management measure after more than twenty years of its implementation. Moreover, The Sustainable Management Plan for the Spiny Lobster in Brazil (IBAMA, 2008) propose the re-examination of the length-at-first maturity but so far, the research efforts in this subject have been limited in the last years. The above mentioned, facts give us the chance to rise the following question: Does the current minimum legal landing size still protect any given female of *P. argus* and *P. laevicauda*, to reach the first reproductive maturity and participate in the spawning season at least once before the harvest? To answer this question the objective of these chapter is to review and analyse the information about length at first maturity of female spiny lobster in the NEB. We chronologically compare and analyse the spiny lobster L50 with published data from the year 1966 and current observations performed on a seafood processing facility during 2018.

The results display that both spiny lobster species presents a length at first maturity probability increment wherein the lobsters were achieving L50 at larger size currently in 2018 than in the past during the year 1966. The mention facts are a good benchmark to indicate that current minimum legal landing size for *P. argus* (75 mm CL) and *P. laevicuada* (65 mm CL) grants limited protection to the female reproduction and we highlight the importance of its increment for both species. We strongly believe that our results and recommendations will contribute to develop more research focused on the length at first maturity of the spiny lobster to achieve fisheries sustainability in Brazil.

METHODS

Area of study

During the time frame of our analyses the spiny lobsters P*anulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) stock was exploited mainly in Northeast Brazil fishing grounds within the areas between 2˚30'N to 18˚S and 35˚W to 47˚W (Fonteles-Filho, 1997; Cruz & Bertelsen, 2009).

Time frame

The female spiny lobster length frequency distribution and external reproduction indicators were compared and analysed within a difference of 52-year time frame. This was achieved by comparing the female external reproduction indicators observed during the months of July, August and September from the years 1966 and 2018. Among the female spiny lobster external reproductive indicator published information of the decade of the 1960s (Pinto Paiva & Da Costa, 1963b – 1970) the year 1966 was selected as base-line information due to the following characteristics: a) simple size; b) proportion of mature and immature spiny lobster female in the sampling; and d) cephalothorax length distribution. These characteristics made 1966 dataset suitable to be compared with the 2018 dataset.

Acquiring data

Female spiny lobster data from 1966

Numerical information data from July to September of the year 1966 were extracted from published spiny lobster female length frequency distribution and external reproductions indicators sampled on commercial landings in NEB (Pinto Paiva & Da Costa, 1967). To employ the external reproduction information in our analysis, two main assumption were stated for this year (1966) as follows: a) female spiny lobster with external reproduction indicators (ovigerus, with spermatophore and with spermatophore remains) were consider in a morphologically mature stage; and b) female spiny lobsters without external reproductions indicator were consider in a morphologically immature stage. The length frequency data where un-grouped using Microsoft's Excel spread sheet by creating a two-column table with the variables: a) cephalothorax length (CL) in millimetres; and b) morphological mature stage (mature or immature) to create the 1966 dataset. Moreover, at that time the observed variable was the spiny lobster total length (TL) in centimetres that was by us transformed to cephalothorax length (CL) in millimetres for our assessment using Rocha and Xavier (2000) logarithmic equation.

Female spiny lobster data from 2018

Female spiny lobster was observed during the three first months of the 2018 lobster fishing season from July to September in a seafood processing facility in Fortaleza capital of the State of Ceará. The lobster landings corresponded mainly to the fishing grounds captures of Ceará and Rio Grande states in the Northeast Brazil region. Besides, from July to September a total of 400 female spiny lobsters of the both species in issue were randomly selected. The fallowing variables were recorded fallowing the method suggested by Cruz (2000) and Cruz et al. (2011) as fallows: a) species; b) sex; c) cephalothorax length (CL); d) presence of female external reproduction indicator (ovigerus, with spermatophore and with spermatophore remains) consider as immature morphological stage; and e) no presence of reproduction criterion; consider as in an immature morphological stage. The 2018 length frequency data was grouped using an electronic spread sheet by creating a two-column table with the variables: a) cephalothorax length in millimetres; and b) maturity stage (mature or immature) to create the 2018 dataset.

Female spiny lobster cephalothorax length frequency normality test

The 1966 and 2018 length frequencies datasets were tested for normality distribution for both spiny lobster species employing the Quantil-Quantil plot test visual tool and the Shapiro-Wilk test. Equally, the 1966 and 2018 length distribution datasets were compared to each other employing the Unpaired Two-Samples Wilcoxon test (also known as Wilcoxon rank sum test or Mann-Whitney test) on the statistical package R 3.5.0 (R Core Team, 2018)

Reproductive biology assessment

The biological assessment was made using the methods employed by Booth (1984), Cruz & Bertelsen (2009) and Ayra & Cruz (2010) in previous reproductive biology analysis in panilurids. The data was analysed on the following assumption: lobster trap was the main fishing gear used in 1966 and in 2018 in NEB.

Fitting logistic regression model

Spiny lobster females' maturity data was summarized with a logistic regression and plotted in the statistical package by employing the method suggested by Ogle (2016). Logistic regression is conducted with a binomial response variable (female spiny lobster maturity) and quantitative explanatory variable (spiny lobster cephalothorax length) normally expressed in a nonlinear relation. The transformation to a linear function was achieved by the *logit* function using the formula:

$$\log (p/ 1 - p)= \alpha+\beta1 \ X \qquad (1)$$

Where p = is the probability of "success" or mature; 1- p is the probability of "failure" or immature; α = intercept; $\beta1$ = slope; and X = quantitative explanatory variable (cephalothorax length). Subsequentially to predict the probability of a lobster being mature given the observed value of the variable (x) was calculated by solving equation 1 for p as follows:

$$p = \frac{e^{\alpha+\beta 1 \ X}}{1+ e^{\alpha+\beta 1}} \qquad (2)$$

Moreover, the length class in which 50% of individual maturity is defined as the average length at first reproductive maturity (L50) wherein 50% of the spiny lobster female population carry eggs (Cruz & Bertelsen, 2009, Fonteles-Filho,2011). To calculate the length at first maturity (L50) was achieved by solving equation 1 for X as follows:

$$x = \frac{\log\left(\frac{p}{1-p}\right) - \alpha}{\beta_1} \qquad (3)$$

In addition, to the Hosmer-Lemeshow goodness of fit test was employed to assess how well the maturity data fits the logistic regression model (Hosmer & Lemeshow, 2000). This test is based on dividing the sample up according to their predicted probabilities, or risks.

Specifically, based on the estimated parameter values, β_0, β_1… β_p for each observation in the sample the probability that is calculated, based on each observation's covariate values:

$$\pi = \frac{exp\ (\beta_0 + \beta_1 X_1 + .. + \beta_p X_p)}{1 + \exp\ (\beta_0 + \beta_1 X_1 + .. + \beta_p X_p)} \qquad (4)$$

RESULTS

Panulirus argus (Latreille, 1804)

Data characteristics

The method employed was adequate to compare trends among the datasets for both spiny lobster species. The results indicate a larger sample size for the first timeframe analysed (1966), with 514 organisms sampled wherein the cephalothorax length displays a non-normal distribution ($p < 0.05$) that goes from 62 mm CL to 135 mm CL. Also, the cephalothorax length shows a mean value equivalent to 79.0 mm CL and the mature female present a mode equivalent to 77 mm CL (table I). On the other side, the 2018 sample is smaller with 184 organisms, and displaying a non-normal distribution ($p < 0.05$) that goes from 72 mm CL to 122 mm CL (table I). Moreover, the cephalothorax length mean value is equal to 86.5 mm CL and the mature female presents a mode of 87 mm CL (table I). For both datasets studied the results show and interesting fact about the high percentage of immature females in the samples reaching 71% during 1966 and 69.6% for the year 2018. (table I). The results of the Wilcoxon test indicate that the medians of the females' cephalothorax length of the 1966 and 2018 datasets are different ($p < 0.05$).

Table I. Female of *Panulirus argus* dataset characteristics during July, August and September of the years 1966 and 2018

Time frame	Sample size	Cephalothorax range (mm)	Cephalothorax length mean (mm)	Mature female cephalothorax length mode (mm)	Immature %	Mature %
1966	514	62 - 135	79.0	77	71.7%	28%
2018	184	72 - 122	86.5	87	69.6%	30.4%

Logistic regression and probability of length at first maturity (L50) and 90% maturity (L90)

The logistic regression model showed a good performance indicating that the probability of the length at first maturity (L50) of *P. argus* has increased over time. During July, August and September of the year 1966 the probability of L50 for the mention species is equivalent to 87.8 mm CL ($p > 0.05$) (Fig. 1A). Subsequently, for the mentioned months in year 2018 the probability of L50 is equal to 96.2 mm CL ($p < 0.05$) wherein there is an increase of cephalothorax length in about 8% approximately (Fig. 1B). In a similar way, the probability of length at 90% maturity (L90) presents an increase from 105.6 mm CL in 1966 (Fig. 1A) to 120.5 mm CL for the year 2018 (fig. 1B).

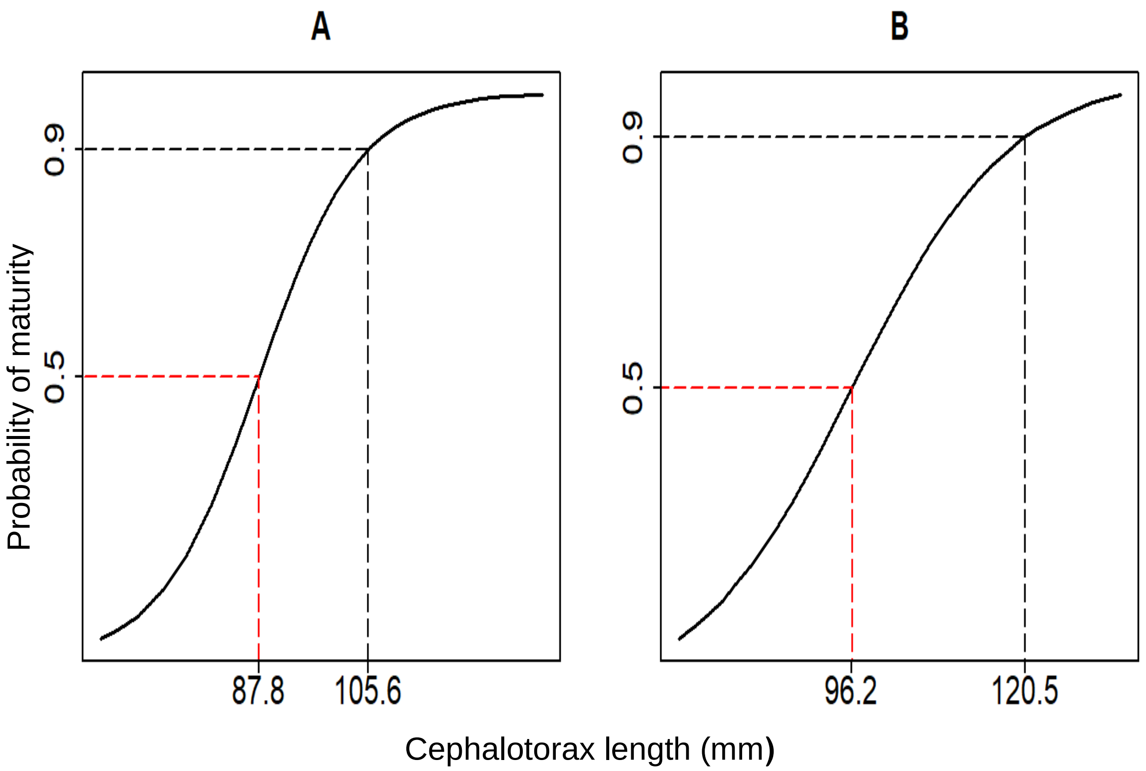

Figure 1. Logistic regression indicating probability of maturity of *Panulirus argus* (Latreille, 1804) female in Northeast Brazil. The red broken line shows the probability values of length at first maturity (L50) and the black broken line shows the probability values of length at 90% maturity (L90). Data time frame analysed as fallows: A) From July to September 1966, wherein L50 probability = 87.8 mm CL ($p > 0.05$; n = 514); and B) From July to September 2018, wherein L50 probability = 96.2 mm CL ($p < 0.05$; n=184).

Panulirus laevicauda (Latreille, 1817)

Data characteristics

The results indicate a sample size of females of *P. laevicauda* equivalent to 222 organisms that were observed during July, August and September of 1966 displaying a non-normal cephalothorax length distribution ($p < 0.05$) from 54 mm CL to 85 mm CL. The cephalothorax length mean was calculated in 67.4 mm CL and the mature female presented a mode of 66.8 mm CL (table II). Moreover, during the year 2018 were sampled 218 organisms that presented a non-normal distribution ($p < 0.05$) from 67 mm CL to 97 mm CL. The cephalothorax length mean is equivalent of 73.6 mm CL and a mode for the mature female equivalent to 82 mm (table II).

Table II.

Table II. Female of *Panulirus laevicuada* dataset characteristics during the months of July, August and September of the years 1966 and 2018.

Timeframe	Sample size	Cephalothorax length range (mm)	Cephalothorax length mean (mm)	Mature female cephalothorax length mode (mm)	Immature %	Mature %
1966	222	54 - 85	64.1	66.0	59.0%	41.0%
2018	216	67 - 97	73.2	82.0	60.1%	39.8%

It is important to point out that the percentage of immature female of *P. laevicauda* in the sample for both datasets is a little bit lower than *P. argus* (Table I and II). Subsequently, the Wilcoxon test indicate that the medians of the females' cephalothorax length between the 1966 and 2018 dataset are different.

Logistic regression and probability of length at first maturity (L50) and 90% maturity (L90)

The results indicate that the probability of length at first maturity (L50) at 66.2 mm CL ($p < 0.05$) in 1966 (Fig. C). Subsequently, the probability of L50 increased to 75.02 mm CL ($p > 0.05$) in the year 2018 (Fig. 1D). Moreover, the probability of length at 90% maturity (L90) is equal to 77.3 mm CL in 1966 and showing an increase to 81.9 mm CL in the year 2018 (Fig.1 C and D).

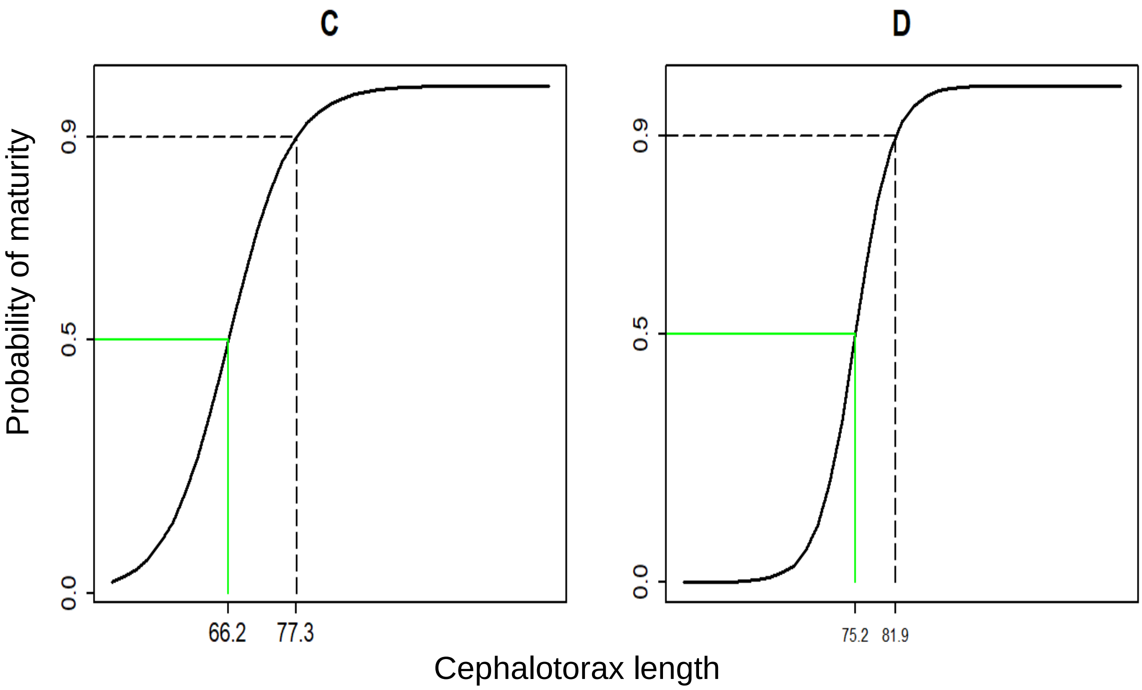

Figure 2. Logistic regression indicating probability of maturity for female of *Panulirus laevicauda* (Latreille, 1817) in Northeast Brazil. The green broken line shows the probability values of length at first maturity (L50) and the black broken line shows the probability values of length at 90% maturity (L90). Data time frame analysed as fallows: C) From July to September of 1966, wherein L50 probability = 66.2 mm CL ($p < 0.05$; n = 222); and D) From July to September of 2018, wherein L50 probability = 75.2 mm CL ($p > 0.05$; n=216).

DISCUSSION

The methods employed made possible to compare the length at first maturity (L50) probability of the spiny lobster *P. argus* and *P. laevicauda* from data of the years 1966 and 2018, compering a 52-year timeframe for the first time in NEB. The characteristics of the length frequency distribution and external reproduction indicators data of the year 1966 made possible the separation between mature and immature females' information with a reasonable degree of precision. An interesting fact is that during the decade of the 1960s the spiny lobster females' with external mature reproduction criterion, (egg-bearing, with spermatophore and with spermatophore remains) presents low frequencies during sampling in the commercial fisheries on the NEB region (Pinto Paiva & Da Costa, 1962, 1963b, 1964). This issue about sampling mature female in the commercial landings have been also reported in other lobster species (Booth, 1984; Chubb, 2000). Besides, an important fact is that at that time (1960s) the *P. argus* males' have been observed dominating the lobster trap captures in NEB in approximately in a 58% (Pinto Paiva & Da Silva, 1962; Pinto Paiva & Da Costa, 1962, 1963b, 1964) and that might be a possible explanation of the low numbers of mature females' on the sampling. The high percentage of male spiny lobster during the fisheries-dependent sampling might have an impact on the sex ratio for the total observations. In addition, despite it has not been reported fishing trap avoidance behaviour for female spiny lobster in NEB the mention fact has been reported for other lobster species. For example, female spiny lobsters trap avoidance has been reported as its size increase for the western rock lobster *Panulirus cygnus* George 1962, in Australia (Morgan, 1979), again this factor might explain the low number of large and mature females in the sampling. Equally, about the 2018 dataset is important to point out that sample size is small compared to the one of 1966. This factor is related to the fallowing conditions: a) the sampling conditions in the processing seafood facilities that restricts the sample-time by day; and b) low proportion of females' in the total landings at the beginning of the 2018 fishing season. Likewise, another important characteristic regarding to the dataset analysed is the high percentage of females' without external reproduction criterion (consider here as morphological immature) in each dataset. For example, the 71% and 69.6% of the *P. argus* female sampled in the years 1966 and 2018 respectively did not present external reproduction criterion and consider here as morphological immature. This fact might have an influence on the logistic regression model as was shown by its goodness of fitness specially for the year 2018 ($p < 0.05$). On similar scenario, was for *P. laevicauda* for the year 2018 wherein the 60% of the female sampled did not presented external reproduction sings, but this fact did not affect the logistic regression model ($p > 0.05$). Regarding to the proportion of immature and mature females within a sample, MacDiarmid & Bernard Sainte-Marie (2006) claims that if the experimental method preferentially captures either mature or immature lobsters of a certain size it would imply a source of bias in the L50 calculations. These above mentioned, facts of the datasets analysed might create a source of bias in our L50 probability calculations for both species. We are aware of this source of bias but, unfortunately it was the only way to achieve our objective and compere length at maturity trends in a timeline, since currently female reproductive biology data is non-existent for both species. Subsequently the logistic regression showed a good fit to booth species of spiny lobster datasets indicating properly the inflection point for the length at first maturity (L50) probability. For one side the *P. argus* L50 data displays from 87.8 mm CL in the year 1966 to 96.2 mm CL in the year 2018. On the other side other L50 values reported for the species (in increasing order) are: a) 75 mm CL in the Florida Keys, USA (Bertelsen & Matthews 2001); b) from 79 mm to 80 mm CL in NEB Soares & Peret (1998); c) 81 mm CL in Cuba (Cruz & Bertelsen, 2009); d) 81 mm CL in Bermuda (Evans, 1991); e) 85 mm CL, in Dry Tortugas, USA (Bertelsen and Matthews 2001); f) 85 mm CL in Belize (Tewfik & Babcock, 2018); g) 95 mm CL in Belize (Weber, 1968); h) 95 mm CL in Jamaica (Munro, 1974); i) from 91 to 95 mm CL in Florida (Lyons et al. 1981), and 102.8 mm CL in Cuba (Léon, 2005). Thus, here it must be considered some different factors: type of sampling method employed, type of data entry (fishing-dependent our independent data) and exploitation history among different *P. argus* stocks.

On the other hand, the L90 displays an increase from 115.6 mm CL in 1966 to 120.5 mm CL during 2018. This increase might be due to different proportion of large and mature females of *P. argus* sampled by year. Besides, in NEB large spiny lobster female have shown very low frequencies at its maximum length within the 125 - 135 mm cephalothorax length class in the commercial landings (Pinto Paiva & Da Costa, 1966, 1967, 1968; Do Nascimento, et al., 1984, Cruz et al., 2013). The L90 figures from us calculated seems to be higher to other reports in Cuban waters wherein the L90 have been observed withing a range that goes from 98 to 100 mm CL during the 1990s (Cruz et al., 1991). It is important to highlight that according to the results *P. argus* presents a L50 and L90 increase from the 1966 to 2018. In other words, female achieved the length at first maturity and its 90% maturity potential at larger size currently in 2018 than in the past, during 1966.

Moreover, on a similar scenario the length at first maturity probability of *P. laevicauda* presents a considerable increase going from 66.2 mm in 1966 to 77.3 mm CL in 2018. These values are higher than other repots for the species in NEB, as fallows: a) 56 mm CL, (Mota Alvez & Tomé, 1966); b) from 47.4 mm to 55.3 mm CL (De Mesquita & Gesteira, 1975), wherein both reports employed external reproductive indicators. In addition, from fisheries-dependent data from the 1980s to the 1990s Soares & Peret (1998) reported the average length at first maturity of 63 mm CL employing internal, external reproductive indicators observation and the logistic regression method. Besides, is important to highlight that the L90 show and increase, from the 1966 to 2018 potentially indicating that the species archives its 90% maturity potential at larger size currently in 2018 than 52 years ago in 1966 as the *P. argus* case discussed above. Sadly, the information about length at first maturity for *P. laevicauda* is limited among other areas of the Wester Central Atlantic region leaving a limited scenario to discuss. In summary we consider that the L50 increase trend for *P. argus* and *P. laevicaud* theoretically represents changes in the life history parameters of the stock in NEB whereas L50 is dynamic value that can adjust in space and time rather than be a static one. The L50 increment over time might be related with the different exploitation rate of the stock between the analysed timeframes. These might have and influence on the reproduction and maturity for the spiny lobster females'. On the other hand, it also might be related with different sampling methods, fisheries-dependent data and low statistical sampling design that might be the most likely scenario for the spiny lobsters' length frequencies observations during the 1960s and 1970s in NEB (Orellana Salazar & Cruz, 2019). Thus, more and updated research of the length at first maturity is needed to fallow up these facts.

In general, the lobster size at-first maturity can vary geographically, between and within species (Phillips, et al., 1980) but to prove this fact long-term biological and environmental data is needed. Changes in L50 have been reported for spiny and clawed lobster using long time series data. Thus, an increment in L50 have been reported from 82.7 mm CL in 1987 to 102,8 mm CL in 1991 for *P. argus* in Cuba (Léon, 2005) wherein the L50 increase (20,1 mm CL) have been associated with the reduction of population density due to fishing pressure. Moreover, Léon (2005) suggest that the increase of the length at first maturity might also take place in other areas wherein the species is distributed and intensively exploited. This fact can be employed to support our findings on L50 increment for *P. argus* in NEB.

The female lobster potential increment of L50 have been also reported for other lobster species in temperate waters of the South Atlantic. For example, the studies of rock lobster *Jasus lalandi* (H. Milne Edwards, 1837) in South Africa brings interesting evidence that correlates environmental and biological factors to the reproduction dynamics of the species specially the direct relation between L50 and growth (Pollock, 1995). For the mention species the length at first maturity increment is hypothetically correlated with key factors like: a) positive growth rate increase (Polloc & Beyers, 1987, Pollock, 1995); b) bentos food availability (quantity and quality) (Newman & Pollock, 1974; c) geographical distribution (latitude) of the exploited stock (Beyers & Goosen, 1987); d) environmental factors like temperature and oxygen concentration that are affecting growth rate (Pollock & Beyers, 1987); e) density dependent process (Pollock, 1995); and d) stock low density as result of intense fishing exploitation (Pollock, 1995). In other words, fishing pressure will lead to a low density with less competition for food resources improving growth rate that will conduct to an increase of length at first maturity. The increase in the length at first maturity due fisheries pressure have also been reported for *P. cygnus* Gorge 1962 in Australia (Chittleborughl, 1979). The L50 increment trends in other lobster species mentioned above are useful facts that helps to explain the increase of the length at first maturity of *P. argus* and *P. laevicauda* in the NEB specially the ones related with: a) the spiny lobster species have been and intensively exploited since 1972 (Fonteles Filho, 1992); and b) a reduction in abundance from 1970s (average abundance 2.03 kg/trap number) to the end for the 1980s (0.24 kg/trap number) as the fishery geographically expanded along different fishing banks in the NEB continental shelf (Cruz et al., 2011).

In contrasts with our results and on a different scenario a significant decrease in female length at first maturity have been reported for different lobster species in other areas. Furthermore, Polovina (1989) reports decreasing size of berried *Panulirus marginatus* (Quoy & Gaimard, 1825) recorded as the fishing pressure increase in a 10-year period in the Hawaiian Island. More recently it has been recorded the reduction of L50 in a 50-year period on the *Homarus americanus* (H. Milne Edwards, 1837) in Maine, USA (Waller et al., 2019). Equally reduction of L50 have been reported for the mention species in Canadian waters. Waller et al (2019) explain that the reduction trend in *H. americanus* in the USA have been associated with: a) sea water temperature increase, with more number of wormer days per year; b) number of moult increment but with small body size increase between moults; and c) high production of the stock that went from 1134 tons in the 1960s to 49895 tons during 2017. In a similar way the reduction trend of female length at first maturity of *H. americanus* in Canadian waters haven related with: a) rise of lobster landings reflected as increase in abundance (Boudreau et al. 2015); b) catchability in warming oceans (Drinkwater et al. 1996); and (c) reduction predation in juveniles due to the collapse of groundfish stocks (Boudreau et al. 2015). In summary exploited populations will response to fishing pressure differently, certain stock will show an increase and in other cases will show a decrease in L50, in function of density-dependent changes in growth rate and with a direct relation with food availability (Pollock, 1995). The discussed facts can conceptually be associated with the changes on L50 for the spiny lobsters' species in the Northeast Brazil, but more research is needed to better understand the L50 dynamics to significantly identify biological changes for the female spiny lobster reproduction. Finally, we strongly believe that current minimum landing size of 75 mm CL for *P. argus* and 65 mm CL for *P. laevicauda* and does not grant enough protection to reproductive females' and we consider that it is urgent matter to increase it responding to the current reproductive biology features of the spiny lobster stocks in Northeast Brazil.

MANAGEMENT IMPLICATION AND CONSERVATION

(1) Female reproduction criteria (external and internal) observation from fisheries-independent data. — Female spiny lobster external and internal reproduction criteria observation most be implemented in Northeast Brazil. 1) female spiny lobster external reproduction criteria should include a detail observation of the following: a) egg-bearing female; b) female with spermatophore; and c) female with spermatophore remains. A method to record these external reproductive characteristics have been described by Cruz (2002); c) pleopods setae stage. The setae observation method for *P. argus* have been implemented in Cuba (Piñero et al., 2011) to calculate L50 and its implementations seems to have potential in Brazil; and 3) spiny lobster internal reproduction criteria. The spiny lobster female ovarian development most be studied and updated in North and Northeast Brazil. Soares (et al., 1998) presents a good method that already have been employed in the NEB and Cruz (2002) is an excellent method that can also be employed.

(2) Spiny lobster reproduction experiments.—Experiments are key to better understanding the reproduction cycle in spiny lobster (Aiken & Weddy, 1980) and its implementation most be enforced in North and Northeast Brazil. Experiment can contribute to identify the L50 for spiny lobsters' males and females and fully characterize the external and internal reproduction criteria. Lipcius & Herrkind (1985, 1987) and more recently Butler (et al., 2015) employed interesting methods to study *P. argus* reproduction under experimental conditions than can lead the first steps to develop this line of research in in Brazil.

(3) Male spiny lobster reproduction cycle.—Little is known about the males spiny lobster reproduction cycle and length at first maturity in the NEB and this line of research most be developed. Butler (et al., 2011, 2015) presents important information for the progress of *P. argus* males reproductive research that can support experimental design in Brazil.

(4) Female spiny lobster management and conservation.— There is a urgent need for the protection of female spiny lobster in NEB for the sustainability of the fisheries. We would like to list and enforce recommendation that can contribute in the management, conservation and decision making, as fallows: a) increasing the minimum legal landing size. Increasing the current minimum legal landings size for *P. argus* (75 mm CL) at a rate of 2 mm per year until reach 80 mm CL (Soares, 1998; Cruz & Bertelsen, 2009; Cruz et al. 2013b). Besides, as precautionary approach of fisheries (FAO, 1996) we recommend the minimum legal landing size increasing strategy for *P. laevicuad*a from 65 mm CL at rate of 2 mm per year until reach the 70 mm CL. Soares (1998) and Cruz et al., (1991) claims the enforcement to increasing minimum legal landing size and enforcement closed season can benefit the stock production; b) berried female spiny lobster conservation. Fishing berried females can increase the risk of lower recruitment and its captures should be urgently prohibit in NEB (Cruz, et al., 2013b); and c) Marine protected areas. Marine protected areas for large mature and berried spiny lobster should be implemented in Brazil. The implementation of marine protected areas can help to improve the reproductive potential of the species and increase the fecundity. The implementation of no take zones focused on rebuilding the spiny lobster stock can also contribute to increase the Brazil´s marine protection percentage. We support Cruz (et al., 2014) proposal of creation a spiny lobster sanctuary in the North Brazil to restore and protect the spawning stock biomass of the spiny lobster species and specially for *P. argus*.

CONCLUSIONS

Based on fisheries-dependent data from the year 1966 and 2018 our finding displays an increasing trend of the length at first maturity probability for both species of spiny lobster in Northeast Brazil. The species *P. argus* shows and increase from 87.8 mm CL in 1966 to 96.2 in 2018. In the same way, *P. laevicauda* show an increase in L50 that goes from the 66.2 mm CL in 1966 to 75.2 mm CL in 2018. With the mention facts we can answer our research question in two parts as fallow: a) the current minimal legal landing size for *Panulirus argus* (75 mm CL) in Brazil does not protect the females reproduction properly for the species; b) The current minimal legal landing for *P. laevicauda* (65 mm CL) does not protect the females reproduction properly for the species. Our results indicate that the current minimum legal landing size for both commercial species of spiny lobster in NEB is rather more commercial oriented than reproductive biology oriented creating a risk to the stock reproductive health. A new spiny lobster research focused on the L50 is urgently needed to be implemented for the sustainability of the spawning stock in NEB and set new minimum legal landing size oriented on reproductive biology facts.

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7. CAPÍTULO 3

LENGTH -BASED STOCK ASSASSMENT OF THE COMERCIAL SPINY LOBSTER *PANULIRUS ARGUS* (LATREILLE, 1804) (DECAPODA, PALINURIDAE) IN NORTHEAST BRAZIL

ABSTRACT

The red spiny lobster *Panulirus argus* (Latreille, 1804) is one of the most important fisheries resources in the Western Central Atlantic and in the North East Brazil have made one of the most important marine resources in the region since the decade of the 1960s. Due to its importance as fishing resource the *P. argus* stock have been assessed with different surplus production models in the last decades, but on the other hand the length-based assessment (LBA) implementation seems to be limited. With this scenario we rise the fallowing question: can we characterize the exploitation trends of the stock when our data resource is only lengths frequency distribution? Traying to answer this question, the objective of this chapter is to perform a length-based stock assessment employing the species life history parameters as benchmark and length-based criteria procedures already establish to analyse the 1966 and 2014 fisheries-dependent datasets. The LBA indicates that during 1966 and 2014 the 59.5% and 94.7% of the spiny lobster sampled in the landings were below the length-at first maturity respectively. This fact suggests a growth overfishing scenario during that years. Moreover, the results indicate low percentage of large spiny lobster (> 140 mm of cephalothorax length) for the both years studied, and this might be an indicator of no recruitment overfishing of the *P. argus* stock during the two years studied. We focus the discussion on the challenges of theoretically shift the fishing effort from the immature spiny lobster towards the mature ones with the optimal harvest length here calculated. We also propose some recommendations related with the research focused on improving lobster traps, revising the minimum legal landings size and fostering a maximum legal landing size to avoid overfishing. We confirm that length-based stock assessment as practical method that can contribute to improve present-day sustainable spiny lobster fisheries management in the Northeast Brazil and Western Central Atlantic.

Keywords: *Panulirus argus*, length-based stock assessment, overfishing, Northeast Brazil.

RESUMO

A lagosta espinhosa vermelha *Panulirus argus* (Latreille, 1804) é um dos recursos pesqueiros mais importantes do Atlântico Centro Ocidental e no nordeste do Brasil é um dos recursos marinhos mais importantes da região desde a década dos anos de1960. Devido à sua importância como recurso pesqueiro, o estoque de *P. argus* foi avaliado com diferentes modelos de produção nas últimas décadas, mas por outro lado a implementação da avaliação baseada no comprimento (ABC) parece ser limitada. Com esse cenário, levantamos a questão a seguir: podemos caracterizar as tendências da explotação do estoque quando nosso único recurso é apenas dados da distribuição de frequências? Para responder a essa pergunta, o objetivo deste capítulo é realizar uma avaliação do estoque baseada no comprimento, utilizando os parâmetros da história de vida da espécie como limites referenciais e critérios baseados no comprimento já estabelecidos para analisar os dados da pesca dos anos de 1966 e 2014. Os resultados do ABC indicam durante os anos de 1966 e 2014 as lagostas espinhosas amostradas nos desembarques estvam abaixo do comprimento de primeira maturação com 59,5% e 94,7% respetivamente. Esses fatos sugerem um cenário de sobrepesca de crescimento durante esses anos. Além disso, os resultados indicam uma baixa porcentagem de lagostas espinhosas grandes (> 140 mm de comprimento do cefalotórax) nos desembarques dos dois anos estudados, e isso pode ser um indicador da não ocorrência de sobrepesca de recrutamento no estoque de *P. argus*. Focamos a discussão nos desafios teóricos da mudança do esforço de pesca da lagosta espinhosa imatura para as maduras com o comprimento ótimo de captura aqui calculado. Também propomos algumas recomendações relacionadas à pesquisa focada em melhorar as armadilhas para lagostas, revisar o tamanho mínimo de captura e promover um tamanho máximo de captura para evitar a sobrepesca. Confirmamos que a avaliação do estoque baseada no comprimento é um método prático que pode contribuir para melhorar o atual gerenciamento sustentável da pesca de lagosta espinhosa no Nordeste do Brasil e no Atlântico Centro Ocidental.

Palavras chave: *Panulirus argus*, avalição de estoques baseada no comprimento, sobrepesca, Nordeste do Brasil.

INTRODUCTION

The red spiny lobster *Panuliurs argus* (Latreille, 1804) is a long-lived species with a complex life cycle that goes through eight different phases from millimetric planktonic phyllosoma to an adult phase that can reach the maximum body length of 450 mm (Holthuis, 1991; Crus & Betelsen, 2009). Normally, inhabits shallow waters among rocks, reefs, eelgrass beds, red algae (Rhodofiyceae), calcified green algae (Chlorophyceae) or any habitat that provides protection (Holthuis, 1991; Marxs & Herrnkind, 1985; Fonteles-Filho, 1997). Occasionally, can also be found down to 100 m depth (Silva et al., 2008). The species in issue is consider a key predator in the benthic community (Cruz & Bertelsen, 2009; Cruz et al., 2011).

P. argus is geographical distributed in Western Central Atlantic Ocean (WCA), from Bermuda and the east coast of USA, including the Gulf of Mexico and the Caribbean Sea, to the Rio de Janeiro state in Brazil (Houlthuis, 1991; Ehrhardt, 2005; Cruz & Bertelsen, 2009). Within its geographical range *P. argus* is a very important fisheries resource that its regionally yield fluctuated near the 35,000 tons during the 1990s (Cochrane & Chakalall, 2001). Based on the regional average landings the estimated economic value of *P. argus* fisheries in the WCA was calculated in approximately US$456 million from 1985 to 2005 (Ehrhardt, 2005).

In order to facilitate international cooperation among the spiny lobster producers States four possible *P. argus* sub-stocks could be identify based on the distribution of the species, the nature of the coastal shelf and the prevailing current within the region (Cochrane & Venema, 2001). These four possible *P. argus* sub-stocks are: (1) northern stock (northern Cuba, Florida USA, Turk and Caicos and Bermuda); (2) north central stock (Mexico, Belize and southern

Cuba); (3) south central stock (Colombia, Nicaragua, Honduras and Jamaica); and (4) Southern stock (Brazil, Venezuela, Dominican Republic and Lesser Antilles Islands). The generation of these regional framework during the end of the 1990s gave scientist a good opportunity of simultaneously perform a collaborative stock assessment for the species and compare trends within the sub-stocks. As a brief example some of the stock assessment models employed at that time were: (a) Collie & Sissenwine's (1983) dynamic depletion models in Florida USA (Bethel et al., 2001); (b) Mohn & Cook's (1993) sequential population analysis in Cuba (Arce et al., 2001); (c) Hilborn's (1990) age structured production models, in Mexico (Arce et al., 2001); (d) Jons's length cohort analysis (1984) in Nicaragua (Barnutti et al., 2011) and Brazil (Andrade et al., 2001).

Furthermore, in Brazil *P. argus* together with *Panulirus laevicauda* (Latreille, 1816) are one of the most important fisheries in the Northeast region since the 1960s (Fonteles-Filho et al., 1988; Fonteles-Filho, 1992). Since the beginning of the fishing exploitation the captures (in weigh) of the two spiny lobster fisheries have been dominated by *P. argus* in between 70% and 75% approximately (Fonteles-Filho et al., 1988; Fonteles-Filho, 1999; Cruz, et al., 2013a). The export of this spiny lobster fishery in Northeast Brazil constituted approximately 750 million US$ between 1955 and 1991 (Fonteles- Filho, 1994). Currently, lobster products in general still are an important item in Brazil's economy with exportation figures to the USA that reached US$69,163.97 during the year 2011 (MPA, 2012).

The yield of *P. argus* stock in NEB have been through several statuses from development in the beginning of 1960s to decrease at the end of the 1990s (Fonteles-Filho, 1999). Equally, stock overexploitation sings have been addressed during the same timeperiod (Fonteles-Filho, 1988; Fonteles-Filho, 1992; Cruz et. 2013a, Andrade, 2015).

Due to its regional importance in the Northeast Brazil (NEB) the *P. argus* stock have been assessed based on different surplus models. For example: (1) Schaefer´s model (1954) maximum catch assessment, (Dos Santos, et al., 1973); (2) Fox's model (1970) maximum sustainable yield assessment (Fonteles-Filho, 1988 and 1992); Stock productivity, fishing intensity and relative abundance, (Cruz et al., 2013a); (3) Jhon's (1954) cohort analysis (Neves aet al., 2015); and (4) Hilborn and Walter's (1992) biomass dynamic models (Andrade, 2015). These facts indicate that the spiny lobster stock have been assessed with well know methods in the last decades, but it seems like length-based stock assessment have not been employed so far. It is important to point aout that the length-based stock assessment have been employed to assess maninly fish stocks, with some examples as followos: a) coral reef fish stocks in Florida

USA (Ault et al., 1998); b) Cod (*Gadus murhua*) stock in Western Chanel (Froese, 2004); and c) lane snapper (*Lutjanus sinagris*) stock in Abrolhos shelf Brazil (Aschenbrenner et al., 2017). On the other hand, the LBA seems to be less employed in lobster species fisheries. Potentially this might be related to each country legal assessment procedures and since length-based assessments give no information regarding to biomass limits (Ault, 1998; Cope & Punt, 2009; Babcock et al., 2013). As a coutrapart, its practical implementation and its graphical output seems to reach a wide audience and that might be a useful advantage. This background, take us to ask the following question: can we characterize the exploitation trends of *P. argus* stock when our data resource is only body lengths frequency distribution? To answer this question, the objective of this chapter is to perform a length-based stock assessment for *P. argus* fishery using length frequencies distribution data sampled from fisheries-dependent data in the NEB. To achieve our objective, we employed *P. argus* cephalothorax length frequency dataset from commercial landings o the years 1966 and 2014. The assessment main assumption is that length frequency distribution structure is representative of the spiny lobster fisheries. Following Froese (2004) recommendations, we developed and implemented for the first time a length-based stock assessment (LBA) to *P. argus* in NEB employing the following information as benchmarks within the species length frequencies distribution: a) spiny lobster female length at first maturity (L50); b) Optimal length (Lopt), the length at which the total biomass of a year class reaches a maximum value (Beverton, 1992); c) Von Bertalanffy growth function parameters (asymptotic length ($L\infty$) and growth coefficient (K)); and d) the larger observed size for the species in the commercial fishing landings, referd as maximum length (Lmax).

In the analyses, the LBA performed a good fit to the length frequency data and indicate high participation of immature spiny lobster in the landings during the years 1966 and 2014 potentially suggesting a growth overfishing scenario. The latter condition coincides with previous stock assessment based on catch, effort and surplus production performed in the region (Fonteles-Filho, 1992; Cruz et. 2013a). The results also show that the optimum length (Lopt) range for the spiny lobster was calculated from 118 mm cephalothorax length (CL) to 135 mm CL with limited observations within its interval. The limited participation of large spiny lobster in the landings that might be an indicator of no growth overfishing for that time. We focus the discussion of the lesson learned and the current theoretical challenges that would imply to theoretically shift the fishing effort from the immature spiny s lobster length towards the ones within the optimal length (Lopt) (118 – 135 mm CL). We also encourage and propose some recommendations especially related with the implementation of future research focused on improving lobster traps, revising the minimum landings size to avoid growth overfishing and fostering a maximum legal landing size to avoid recruitment overfishing. We believe that our efforts must be limitless to analyse as much as possible the life history exploitation of the *Panulirus argus* (Latreille, 1804) stock in NEB and find the best way to identify and understand the effects of exploitation for the sustainability of the spiny lobster stock.

METHODS

Area of study

During the time frame of our assessment (years 1966 and 2014) the spiny lobster *Panulirus argus* (Latreille, 1804) stock was exploited mainly in Northeast Brazil fishing grounds within the areas between 2˚30'N to 18˚S and 35˚W to 47˚W (Fonteles-Filho, 1997; Cruz & Bertelsen, 2009).

Acquiring *P. argus* length frequency data

The length frequencies distribution dataset of *Panulirus argus* analysed was based on fisheries-dependent data of the commercial landings for the years 1966 and 2014.

1966 cephalothorax length frequency

Spiny lobster (male and female) of *P. argus* length frequency numerical information of the year 1966 were extracted from published information that was based on commercial landings in NEB (Pinto Paiva & Da Costa, 1967). Moreover, at that time the observed variable was the spiny lobster total length (TL) in centimetres that was by us transformed to cephalothorax length (CL) in millimetres for our assessment using Rocha and Xavier (2000) logarithmic equation. The cephalothorax length frequency data were graphically analysed using electronic Excel spread sheet by creating a two-column table with the variables: a) cephalothorax length (CL) midpoint interval in millimetres; and b) relative frequency, to create the 1966 dataset. We used the 1966 length frequency dataset under the assumptions: a) lobster trap was the main fishing gear used in 1966; and b) fishing bank were from 20 to 40 meters depth.

2014 cephalothorax length frequency

Spiny lobster (male and female) of *P. argus* length frequency numerical information of the year 2014 were extracted from published information (Mendes Santana, 2016). The 2014 data was based on commercial captures at the north shore of the state of Ceará, North East Brazil. The captures took place on shallow waters artificial shelters (regionally known by the fishermans' as "marambaias" working at a depth of ≤ 10 meters) employing diving (artisanal autonomous diving). The 2014 extracted information, also included baited lobster trap captures from fishing bank between 20- and 40-meters depth (see Mendes Santana, 2016). The cephalothorax length frequency data where graphically analysed using electronic spread sheet by creating a two-column table with the variables: a) cephalothorax length (CL) midpoint interval in millimetres; and b) relative frequency, to create the 2014 dataset.

Length frequency distribution statistical analysis

The 1966 and 2014 length frequency datasets were analysed to calculate the spiny lobster cephalothorax length characteristics as follows: a) sample size; b) midpoint size class distribution; c) the mean value; and d) the mode value by year. Besides, the Shapiro-Wilk test was employed to determinate normality of the spiny lobster length frequency distribution. Equally, the unpaired two-samples Wilcoxon test (also known as Wilcoxon rank sum test or Mann-Whitney test) was employed to determinate if there was a difference in the cephalothorax length frequency distribution between the years 1966 and 2014 datasets.

Spiny lobster life cycle

The *P. argus* (Latreille, 1804) life cycle description for the Great Caribbean (Cruz & Bertelsen, 2009) was employed to better understanding of the length frequencies compositions assessed by life-stage as fallows: a) juvenile ≤ 50 mm of cephalothorax length (CL); b) pre-recruit from 50 mm to 79 mm CL; and d) adult ≥ 80 mm CL.

Spiny lobster life history parameters

The life history parameters of *Panulirus argus* (Latreille, 1804) employed in the length-based stock assessment are from two different sources: a) calculated values in this thesis (See chapter I and II); and b) published information for the species in the NEB region (table I). A total of four spiny lobster life history parameters were employed for the length-based assessment, as follows: 1) Female spiny lobster length at first maturity (L50), wherein 50% of the population is consider reproductive mature and able to successful participate in the spawning season. We employed two different values by assessed year as follows: a) L50 = 86 mm CL for the year 1966; and b) L50 = 96 mm CL for the year 2014 under the assumption that physiological maturity similarity with the year 2018 calculated (see chapter II); 2) The spiny lobster male and female average Von Bertalanffy growth coefficient (K); 3) The spiny lobster male and female average Von Bertalanffy asymptotic length (L_{∞}); and (4) natural mortality coefficient (M), we employed two different values of natural mortality by assessed year as fallow: a) The M value equal to 0.23 for a moderate exploited stock during the year 1966 and b) The M value equal to 0.14 for high exploited stock (Munro, 1975 on Morgan, 1980).

P. argus length-based stock assessment implementation

The spiny lobster 1966 and 2014 length frequency datasets were plotted and graphically analysed using an electronic spread sheet. Subsequently the length-based stock assessment was employed making use of the following indicators as bench mark on the x-axis of the 1966 and 2014 length frequency distribution, as fallows: 1) length at first maturity (L50) value graphically described with a red arrow; and 2) optimum length (Lopt) interval, was estimated as with the formula; $Lopt = 3L\infty(3+MK^{-1})^{-1}$ (Beverton, 1992). Besides, to graphically display de Lopt interval, two different values of natural mortality (M). The M value equal to 0.14 was employed to set the lowest point of the interval (table I). In a similar way the M value equal to 0.23 was employed to set the higher point of the Lopt range (table I).

TABLE I

Life history parameter values of *Panulirus argus* (Latreille, 1804) employed to perform the length-based assessment

Parameter	Value	Source
Length at firs maturity (L50) for 1966 dataset	87 mm CL	This work (chapter II)
Length-at first maturity (L50) for 2014 dataset	96 mm CL	
Growth coefficient (K)	0.279	Orellana Salazar & Cruz, 2019
Asymptotic length (L∞)	157.75 mm CL	
Natural mortality (M) for 1966 dataset	0.23	Munro, 1974 (in Morgan, 1980)
Natural mortality (M) for 2014 dataset	0.14	
Spiny lobster female Maximum length (Lmax) in NEB	135 mm CL	Pinto Paiva & Da Costa, 1967
Spiny lobster male Maximum length (Lmax) in NEB	146.9 mm CL	Pinto Paiva & Da Costa, 1970

RESULTS

Spiny lobster length frequency dataset by year

The analysis of the length frequency dataset indicates that 4476 spiny lobster (male and female) were sampled during 1966 from the midpoint length class of 51 mm to 144 mm cephalothorax length (CL). The mean value for the cephalothorax length for that year was 83.9 and a mode of 75. Besides, the Shapiro-Wilk test of normality displays that the 1996 dataset it does not present a normal distribution ($p < 0.05$) (table II). Equally, the results are also showing that 2555 spiny lobster were sampled during the year 2014 from the midpoint size class of 52 mm CL to 117 mm CL. For the same year the mean was equal to 73.3 mm CL and the mode presented a value of 72 mm CL. The 2014 dataset did not present a normal distribution according to the Shapiro-Wilk test ($p < 0.05$) (table II). Moreover, the unpaired two-samples Wilcoxon test indicates that there is difference between the median of the 1966 and 2014 datasets (table II).

TABLE II

Panulirus argus (Latreille, 1804) length frequency distribution data statistics by the years 1966 and 2019 sampled in North East Brazil. * The juvenile spiny lobster (32 – 41 mm CL) was not include in the statistical analysis.

Year	Sample size	Cephalothorax length (mm)			Test	
		Range	Mean	Mode	Normality distribution Shapiro-Wilk p-value	Unpaired Two-Samples Wilcoxon Test
1966	4476	51 – 144	83.9	75	< 0.05	< 0.05
2014	2555	52 – 117*	73.3	72	< 0.05	

1966 and 2014 spiny lobster length-based assessment indicators

The 1966 and 2014 *P. argus* length frequencies distribution was adequate to graphically separate the mature and immature organisms based on the length at first maturity (L50) benchmark on the x-axis. The 1966 cephalothorax length data displays that the 59.5% of total landing was under the L50 (< 87 mm CL) representing the immature spiny lobster (fig. 1A, withe bar) with highest observation in the midpoint class of 75 mm CL (15.35%). In other words, the 59.5% of spiny lobster landed that year were harvested before them reach its first reproduction season. On the other side, the 1966 cephalothorax length data show that the 29.6 % of the total landing sample was over the L50 (> 87 mm CL) representing the mature spiny lobster (fig. 1A, grey bar). Potentially these spiny lobsters' did participate in the reproduction season at least once before been harvest. Moreover, the optima length (Lpot) interval calculated from 118 mm CL to 135 mm CL (fig. 1A, black box) presents a small percentage of the total landing with 1.54% indicating that large spiny lobster had low representation on the landings during that year. Equally, the 2018 cephalothorax length data indicates that 94.7% of the total landing was under the length at first maturity (L50) for that year (< 96 mm CL) representing the immature spiny lobster that did not participate in the reproductive cycle with highest observation concentrated in the midpoint class interval of 72 mm CL (15.46%). It is important to highlight that withing the 2018 length distribution the juvenile spiny lobster (32 – 47 mm CL) is represented with 258 organisms (fig. 1B, black bar). Equally the 2018 length frequency data shows that the 5.3% of the total sample was over the L50 (> 96 mm CL) representing the mature organisms for that year. Subsequently the optimum length (Lopt) interval (118 mm to 135 mm CL) display no spiny lobster sampled for this area in total landing for that year (fig.1 B, black box).

In summary, the two different values of L50 employed by year were adequate benchmarks to indicate the high occurrence of immature spiny lobster *P. argus* in the NEB landings on the two studied years as follows: a) 59.5% for the year 1966; and b) 94.7% for 2014. Furthermore, the optimum length (Lopt) indicates low occurrence of large lobster for both years within the 118 mm CL to 135 mm CL range. Finally, is important to highlight that the 2014 length distribution dataset range included juvenile spiny lobster (32 – 47 mm CL). These juvenile lobsters' were kept in the frequency distribution since its occurrence is important in the two datasets comparations. The 2014 juvenile lobster were not part of the L50 benchmark percentage calculation to make both datasets comparable.

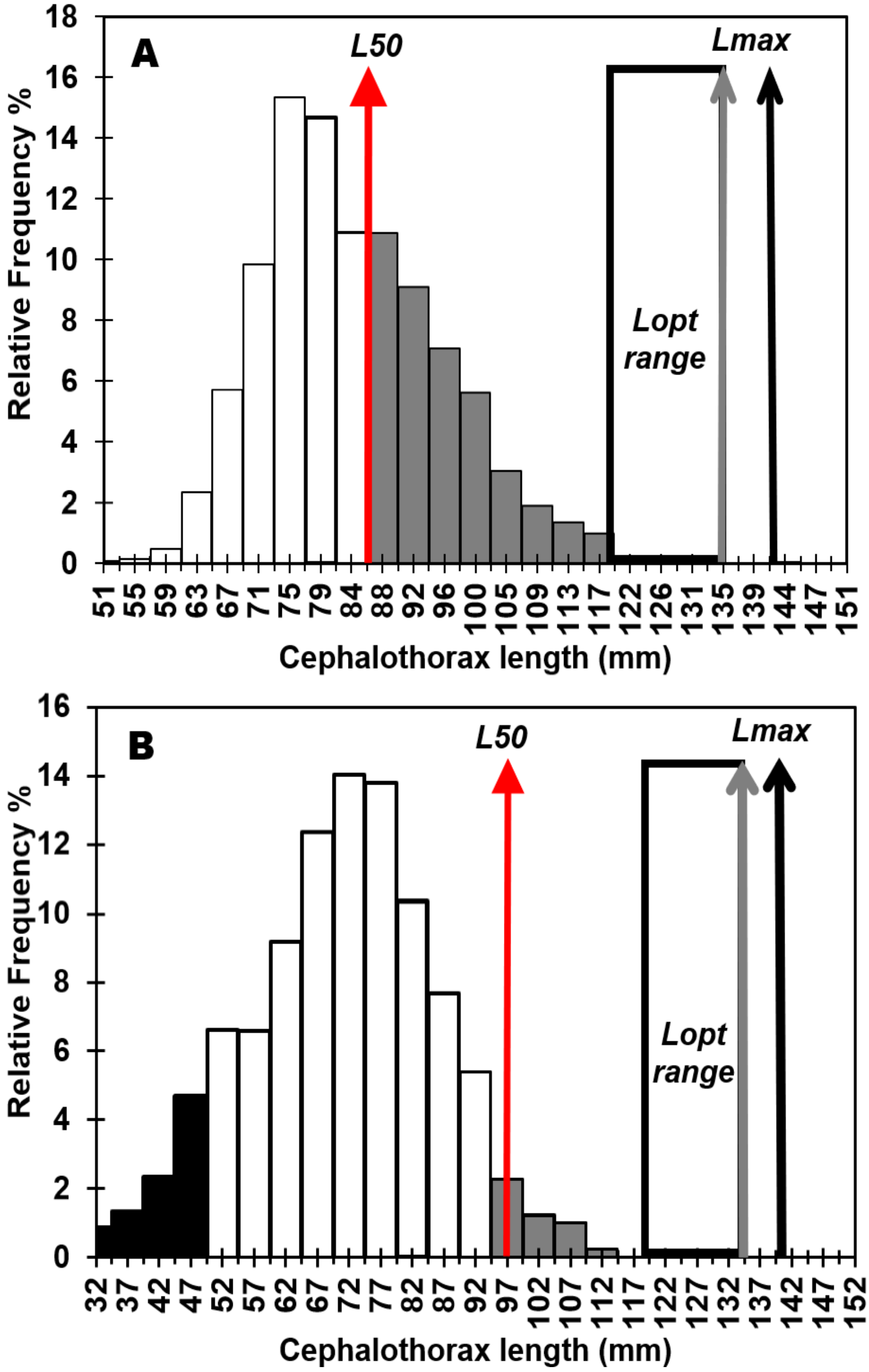

Figure 1. Results of the length-based stock assessment of *Panulirus argus* (Latreille, 1894) in the Northeast Brazil. Red arrow shows the female length at first maturity (L50) and black box shows the optimum length (Lopt) interval. Cephalothorax length distribution by time frame as fallows: A) 1966 (n = 4476); and B) 2014 (n = 2555).

DISCUSSION

Spiny lobster length frequency dataset

Comparing the 1966 and 2014 datasets as independent samples was a challenging process due to the different sampling process employed during each year. The datasets presented difference in the cephalothorax mean value and both datasets display a no normal distribution. These differences between datasets might be related with the difficulties that involves the sampling conditions and creation of fisheries-dependent dataset in commercial landing sites (Fonteles-Filho & Holanda, 1990). Thus, we consider the length frequency dataset as a valuable information that helps us to understand spiny lobster fishing exploitation trends. In some fisheries the length frequency data are the only historical information available and sometimes is not utilized (Pauly & Morgan, 1987). Based only in length frequency information, the LBA showed a good fit to the mentioned datasets and flexibility related to non-normal distributed fisheries-dependent data. This might be considered a relevant attribute that potentially be useful for small scale fisheries with data-limited scenario in the tropical areas.

Thinking about the current and future research to improve the length frequency observation in the NEB is recommended to employ a 5 mm cephalothorax length class interval that will give a better fit (Cruz, 2002) in the LBA. Also, it is very important to make separate observations for males and females. The last mention fact would maximize the performance of the length at first maturity (L50) specially for female spiny lobster. Finally employ in the commercial spiny lobster landings the stratified sampling design as suggested by Fontels-Filho & Holanda (1990) and Cruz et al., (2011).

Length-based assessment

During the timeframe of the studies, several surplus production stock assessments have been employed establishing important biological and fisheries indicators for *Panulirus argus* (Latreille, 1804) stock in NEB (Dos Santos, et al., 1973; Fonteles-Filho, 1988, 1992; Cruz et al., 2013a, 2014; Andrade, 2015; Aragão & Cintra, 2018) . These indicate that the spiny lobster stock has been assessed with well know methods in the last decades. On the other hand, is important to mention that the employment of length-based stock assessment for *P. argus* seems to be limited and according to our knowledge our assessment might be on the few.

The employment of a length-based stock assessment (LBA) presented a good fit to *Panulirus argus* (Latreill, 1804) length frequencies datasets from commercial landings. The LBA benchmarks makes a proper relation to graphically explain the length classes that are more harvested. Furthermore, the 1966 and 2014 datasets display a high percentage of immature spiny lobster harvested that did not participate in the reproductions season for each year respectively. Besides, the 2014 dataset display the occurrence of juvenile spiny lobster from 32 to 47 mm CL. The spiny lobster under this length range are the ones that have been captured in by diving on shallow waters artificial shelter or marambaias. The mention fishing technique began its implementation in the NEB since 2000 (Nascimento, 2006) and that might explain why the 1966 length distribution dataset lacks juveniles' information. The high percentage of immature spiny lobster withing the 1966 and 2014 length distribution datasets can conceptually determine the occurrence of growth overfishing (individuals are being harvested at too small size (Jamieson, 1993)). Equally, the high participation of young spiny lobster in the fishing landings in NEB have already been confirm by other authors using different methods as follows: (1) Reduction in the tail weight of exported lobster (Pinto Paiva, 1966); (2) decrease in capture per unit effort (Pinto Paiva, 1972); (3) high percentage of juvenile spiny lobster in the landing (Fonteles-Filho et al., 1988); and (4) stock assessment (Fonteles-Filho, 1992; Cruz, et al., 2013a, Cruz, et al., 2013b; Neves, et al., 2015). Specifics reports of growth overfishing in *P. arugs* fisheries seems to be limited but an interesting reference from the Great Caribbean indicates the occurrence of growth overfishing (18% annual sublegal catches) between 1965 to 1977 in the Cuban *P. argus* fishery (Cruz et al., 1991). Equally, sustainable indicators employed in fish stock assessment suggests that to achieve fishery sustainability the fraction of organisms below the maturity stage should be equal to zero (Froese, 2004). Subsequently the employment of two different values of L50 displays a difference in the number of mature spiny lobster by year. The mention difference is related with a higher value of L50 for the year 2014 in 10 mm approximate. The use of L50 for the 2014 equivalent to 97 mm CL displays higher number of immature organisms than the 1966 value. We believe that more research must be improved to develop to achieve better results in future assessments and better know of the L50 performance. Moreover, ideally the mature spiny lobster should have high percentage of the total landings representing the spiny lobster that participate in the spawning season at least once to keeping stock health's before been harvested (Froese, 2004).

On the other hand, the limited observation of spiny lobster in the Lopt interval (118 mm CL – 135 mm CL) indicates that organisms with the adequate theoretical body size for harvest are not exploited and the fishing effort target is the small and immature spiny lobster (< L50). On the other side the low frequencies withing the Lopt interval and near the (Lmax) (males = 146,9 mm CL and females = 135 mm CL) might be consider as positive scenario. Thus, the absence of spiny lobster on the mentions length distribution is a potential evidence of no recruitment overfishing (when harvesting exceeds the ability of an exploited species to replace itself (Steneck, 2006)) in the *P. argus* fishery on NEB. Equally, the no evidence of recruitment overfishing for the stock have been previous reported in the NEB (Cruz et al., 2013a, 2013b). Besides, even the no evidence for recruitment overfishing is important to mention that little is known about the biology and ecology of large *P. argus* organisms (equivalent to Lmax) in NEB and how do they response to baited traps and to other types of fishing gear. Due to that, it must be considered that the no observation of these large spiny lobster in length frequencies (fisheries-dependent data) might also be a catchability issue as nonresponse of large lobster to baited traps. Additionally, it has been proved that the catchability o large lobster decreases with lobster size increase (Morgan, 1979). Besides, since the beginning of the 1990s the *P. argus* fishery extended to the North Brazil harvesting deep water (100 m) spiny lobster with nets reporting the occurrence of large females (Silva et al., 2008). Moreover, there is a capture report of a large male (215 mm CL) from the Archipelago of São Paulo and São Pedro (Pernambuco state, Northeast Brazil) (Sankaramkutty, 2001). Related to the large spiny lobster it is important to mention that and currently for the *P. argus* fishery in Brazil there is no maximum legal landing size. Fishing very large and mature spiny lobster (over Lmax) might have an unsustainable impact. This is due to two main reproduction facts: (a) the large spiny lobster ensure the reproduction health of the spawning stock and potentially participate two times in the spawning season (Ayra & Cruz 2010; Cruz & Bertelsen, 2009; Cruz et al., 2013b); and (b) exploitation of the deep water mega- spawner stock (> 135 mm CL) might affect the reproductive potential of lobster stock (MacDiarmid & Sainte-Marie, 2006). We strongly believe that is proper to promote in our discussion the inclusion of a maximum landing size for *P. argus* fishery. We believe is proper to foster Cruz et al (2013b) suggestions that claims: (a) to of set a maximum legal size of 135 mm CL for *P. argus* fishery in Brazil; and (b) to create a marine protected area for the spiny lobster stock to avoid recruitment overfishing. The inclusion of maximum landing size was also previously proposed by Coelho (1962) over 50 years ago.

These characteristic of the LBA make its employment practical and graphically seems to be an excellent way to present and explain the relationship between overfishing and sustainability within a fishery. This attribute would be very useful to reach a wide non-scientific fisheries stakeholder like fishers, managers, coastal communities, students and seafood sellers. The mention attribute might be considered as advantage when compared with to surplus production stock assessment. Since its practical characteristics it might be viable to regionally standardize it by different fisheries agencies that deal with data-limited conditions in the *P. arugs* fishery within the Western Central Atlantic. Moreover, as mentioned before LAB presented a good fit in our assessment, but we do like to indicate a limitation of its employment: The employment of LBA requires updated and regionally reliable life history theoretical parameter of the species. This requirement was achieved for *P. argus* but it did present a limitation to include the second economically important species the green spiny lobster *Panulirus laevicauda* (Latreille, 1817) in the retrospective assessment. As far as we know the life history theoretical parameters for the species (specifically, L50, K and L∞) have been only observed in NEB and there is no information in other areas of the Western Central Atlantic to make a proper validation. Due that we do agree not to include the mention species in our LAB as precautionary approach until update biological parameters are available for the species. Potentially this situation can also affect the its employment in other tropical lobster fisheries that its species have been heavily exploited, but little studied.

Finally, an important theoretical challenge will be to relocate the fishing effort from the immature spiny lobster (< L50) to larger and mature lobster within the Lopt "sustainable range" (118 – 135 mm CL mm CL). The Lopt range should endure the whole pressure in the *P. argus* fishery, by harvesting organisms with 5 years old approximately (Orellana Salazar & Cruz, 2019). Maintaining fishing operation targeting larger lobster within the Lopt interval theoretically will avoid growth overfishing, recruit overfishing and would increase the yield, but technically in the field seems to be a difficult to be implemented. The later condition takes us to ask: can we technically achieve to harvest the Lopt interval? We believe that for a stock with a potential growth overfishing background it might be a long-term goal. Thus, beginning with a small step like the proposal of a suitable modern patented fishing gear (lobster traps) that maximize retentions of organisms within the Lopt interval and rejection of the small ones. One interesting management measurement that can be useful in our analysis is related to Venezuela's spiny lobster fishery within a marine protected area. "Parque Nacional Los Rokes" (Rokes National Park) is a 1250 km^2 Venezuelan insular marine protected area where the minimum landing size for *P. arugs* of 120 mm CL it has been stablish since 1990 (Yallonardo et al., 2001). This value is within the Lopt range calculated here by us. Perhaps we can take this as a good example of the potential catchability of spiny lobster within the Lopt range with biological sense. Keeping the fishing activities within the Lopt range will be a whole new challenge scenario in the assessment and fisheries management improvement to achieve sustainability of the stock.

MANAGEMENT IMPLICATION AND CONSERVATION

We think that is proper for this chapter to unite and promote recommendations that have been revised as a single strategy for the future. We believe that our research efforts must continue to reanalyse the life history exploitation of the *Panulirus argus* (Latreille, 1804) stock in NEB to find the right path towards to sustainability of the fisheries. The first steps to achieve that goal are listed as follows:

(1) Cephalothorax length frequency distribution data. — Spiny lobster long-term cephalothorax length observations in North and Northeast Brazil must be enforced as part of sustainable fisheries management. Length frequencies observations should come from an excellent long-term fisheries-independent data-sampling design (Pauly & Morgan, 1987; Fonteles-Filho & Holanda, 1990; Cruz et al., 2011). Cephalothorax observations should include but not be limited to: (1) cephalothorax length class interval of 5 mm CL to achieve quality data (Cruz, 2002); (2) length frequency distribution for males and females separately and (3) cephalothorax length observation that ideally include the optimum length (Lopt) range and maximum length (Lmax) observations (124 mm – ≥ 141 mm CL).

(**2) Fishing gear research and technology.—** Since the spiny lobster fishery began in the late 1950s the baited traps have been the main fishing gear used in NEB. Subsequently, several other illegal fishing gears have been employed in the fishery. The first design description of the spiny lobster artisanal and industrial fishing trap was between the 1950s and 1960s respectively (Pinto Paiva, 1958; Da Costa & Albuquerque, 1966) and basically the same scape-gap-less trap design have been passing from one generation of fishermen to other through the last 60 years. We believe that is very important to perform spiny lobster trap research accordingly to NEB growth overfishing realty. That goal can be achieved as follows: (1) Implementation of laboratory and field fishing trap experimental research. Investigation focused on the performance of the current and new potential trap designs that will reduce the capture of juveniles and increase the Lopt interval spiny lobster retention. This information will take to patent a sustainable lobster trap to reduce growth overfishing in NEB. Da Silva (1965) set a methodology to test the performance of three different-shape lobster traps in NEB. This methodology seems simple to replicate. Interesting experimental methodologies have been employed in the Western Mediterranean *Panulirus elephas* (Fabricius, 1787) fishery that can lead path in this topic (Amengual-Ramis et al., 2016); (2) Scape gap implementation. The implementation of scape gaps in lobster traps for NEB fishery have been already strongly suggested by other authors (Ivo & Pereira, 1996; Cruz et al., 2013a, 2013b, 2014) and we consider this feature as the most important for a modern spiny lobster trap. The number, size and position of scape gaps within a trap should be experimentally tested to ensure the reduction of juveniles' spiny lobster in the total catch. A good example of scape gap implementation can be found in the Central America, *P. arugs* trap fishery (scape gap of 54 mm height) since 2009 (OSPESCA, 2009). More recently, interesting multi-scape-gap lobster trap (57 mm width) have been tested for the eastern rock lobster *Sagmariasus verreauxidesi* (H. Milne Edwards, 1851) in New Zealand (Broadhurst & Millar, 2018) and might be good source of information for experimental design in NEB. Also, the optimal scape gap (45 mm width) have been experimentally tested for the American lobster *Homarus americanus* H. Milne Edwards, 1837 indicating important facts for the experimental design (Nulk, 1978).

(**3) Minimum and maximum legal landing size. —** In order to avoid growth overfishing, the current minimum landing size should be increase in at least 5%. This management measure has been already suggested by Cruz et al. (2013b). The increasing of the minimum landing size has shown satisfactory result in the *Panulirus arugs* fishery in Cuba (Cruz et al., 1991) and cape rock lobster *Jasus lalandii* (H. Milne Edwards, 1837) in South African waters (Pollock, 1986). On the other side to avoid the recruitment overfishing the maximum landing size of 135 mm CL most be implemented. According to Cruz et al (2013b) this management measurement will grant a healthy spawners stock in North and Northeast Brazil.

(**4) Marine protected areas implementation. —** As part of sustainable spiny lobster fisheries management plan the creation of a marine protected area might benefit the recruitment and adult biomass (Roberts et al., 2005). Implementation of marine protected have improve the density of *Panulirus argus* (Latreille, 1804) in: (1) Dry Tortugas in Florida, USA (Bertelsen et al. 2004); (2) Monumento Nacional Cayos Cochino in Honduras Caribbean coast (Mattews & Arronne, 2014); and (3) Loow Kay and Wester Sambos Ecological Reserve, in Florida, USA (Bertelsen et al., 2004). To secure the health of the spiny lobster stock we find proper to enforce Cruz et al (2013b) suggestions that claims the importance of setting a marine protected area as sanctuary for the deep-water mega-spawner of *P. arugs* at Northern Brazil’s continental shelf. Deep water habitat and deep-water marine fishing resources must be protected from fishing to avoid collateral damage (Roberts, 2002).

CONCLUSSIONS

The length-based stock assessment herein employed for NEB *Panulirus argus* (Latreille, 1804) indicates that 59.5 % of the total spiny lobster harvested during 1966 were immature with the highest observation in the midpoint class of 75 mm CL (15%). Equally, more than forty years latter during 2014, the 94.7 % of the spiny lobster landed were immature concentrated in the midpoint class of 72 mm CL (15%). Also, the last mention year displays the occurrence of juvenile spiny lobster (32 – 47 mm CL) in the landings. These facts can potentially suggest the presence of growth overfishing for both years studied. On the other side the analysed data present low percentage of large lobster (> 135 mm CL) on the landings samples for two studied years and this might suggest no sign of recruitment overfishing. We confirm that length-based assessment as practical method that can be employed to assess data-limited fisheries as might be the case of many lobster fisheries in the Western Central Atlantic. Its results can reach a wide audience and its implementation demands more research according to every species life history parameters and exploitation reality.

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8. CONCLUSÕES GERAIS

Parâmetros de crescimento das lagostas espinhosas

- Esta tese comprova que prévias avaliações da idade e crescimento das lagostas espinhosas *P. argus e P. laevicuada* no Nordeste de Brasil possuem algumas limitações, principalmente relacionadas com as características dos dados de entrada empregados nas simulações, especialmente:

    - a) Os dados de entrada utilizados são dependentes da pesca comercial sem possuir informações de comprimentos do cefalotórax menores de 25 mm e maiores de 125 mm, os quais são importantes nas simulações da idade e crescimento.

    - b) Os dados de entrada previamente utilizados nas avaliações de idade e crescimento foram ajustados no modelo de crescimento de Von Bertalanffy, que assume o crescimento contínuo das lagostas e não considera os efeitos da muda ou ecdice ao longo do ciclo de vida.

    - c) Os dados de entrada utilizados para ajustar o modelo de crescimento no Nordeste do Brasil não consideraram informações da idade planctônica, informações de crescimento em condições de laboratório e informações de captura, marcação e recaptura das espécies separadas para machos e fêmeas.

- Constata-se que os valores dos parâmetros de crescimento propostos aqui para *P. argus* e *P. laevicauda* são valores relativos que devem ser utilizados com precaução até que as ciências pesqueiras do Nordeste do Brasil desenvolvam novos valores com a realidade biológica das espécies.

- A hipótese "A" é rejeita para *P. argus* e *P. laevicauda*. Esta tese conclui que os parâmetros teóricos de crescimento da função de Von Bertalanffy, previamente calculados no Nordeste do Brasil para as lagostas espinhosas, não descrevem detalhadamente a realidade biológica do crescimento das espécies. Também, aqueles parâmetros devem ser calculados novamente, tentando superar as mencionadas limitações técnicas na avaliação em consenso com outros resultados da região do Atlântico Centro Ocidental.

Comprimento de primeira maturação das lagostas espinhosas *P. argus* e *P. laevicauda* no Nordeste do Brasil

- Dados da pesca analisados mostram um aumento probabilístico do comprimento de primeira maturação (L50) das duas espécies de lagostas espinhosas entre os anos de 1966 e 2018 no Nordeste do Brasil. Na atualidade (2018) as lagostas atingem o comprimento de primeira maturação (L50) com maior tamanho que há cinquenta e dois anos atrás (1966).

- *P. argus* apresenta um aumento na probabilidade do comprimento de primeira maturação (L50) desde 87,8 mm do comprimento do cefalotórax (CC) no ano de 1966 até 96,2 mm CC em 2018.

- *P. laevicauda* apresenta um aumento na probabilidade do comprimento de primeira maturação (L50) desde 66,2 mm do comprimento do cefalotórax (CC) no ano de 1966 até 75,2 mm CC em 2018.

- A hipótese "B" é rejeitada para a espécie *P. argus*. Esta tese conclui que com os resultados do comprimento de primeira maturação (L50) equivalente a 87,8 mm CC no ano de 1966 e 96,2 mm CC no ano de 2018, o atual tamanho mínimo de captura (75 mm CC) protege escassamente as fêmeas em reprodução da pesca no Nordeste do Brasil. Como medida de gerenciamento e conservação, é sugerido um aumento do tamanho mínimo de captura em pelo menos 5 mm de comprimento cefalotórax.

- A hipótese "B" é rejeitada para a espécie *P. laevicauda*. Esta tese conclui que com o resultado do comprimento de primeira maturação equivalente a 66,2 mm de comprimento cefalotórax (CC) no ano de 1966 e 75,2 mm CC no ano de 2018, o atual tamanho mínimo de captura de (65 mm CC) protege escassamente as fêmeas em reprodução da pesca no Nordeste do Brasil. Como medida de gerenciamento e conservação, é sugerido um aumento do tamanho mínimo de captura de pelo menos 5 mm de comprimento cefalotórax.

Avaliação do estoque de *Panuliru argus* (Latreille, 1804) baseada no comprimento

- Confirma-se o método de avaliação de estoques baseada no comprimento como um método prático e que pode ser empregado em pescarias de lagosta especialmente que apresentem as seguintes características: a) dados escassos e incontínuos temporalmente; b) dados (dependentes) da pesca comercial e c) dados que poderiam ter pouca representatividade estatística.

- Esta tese conclui a evidência de uma alta porcentagem de lagostas espinhosas *P. argus* imaturas nos desembarques dos anos 1966 (59,5%) e 2018 (94,7%) concentradas no intervalo médio de classe de 75 mm e 72 mm de comprimento cefalotórax, respectivamente, possivelmente indicando sobrepesca de crescimento para os dois anos analisados.

- Esta tese conclui que a avaliação de estoques baseada no comprimento indica baixa porcentagem de lagostas espinhosas grandes (≥ 140 mm comprimento cefalotórax) nos desembarques no Nordeste do Brasil, possivelmente indicando não evidência de sobrepesca de recrutamento nos anos de 1966 e 2014.

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APENDICE A: versão publicada do Capítulo 1 no jornal Crustaceana

BRILL

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AGE AND GROWTH OF THE COMMERCIAL SPINY LOBSTERS *PANULIRUS ARGUS* (LATREILLE, 1804) AND *PANULIRUS LAEVICAUDA* (LATREILLE, 1817) (DECAPODA, PALINURIDAE) IN NORTHEAST BRAZIL: A REVIEW

BY

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ABSTRACT

The two spiny lobster fisheries targeting *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) have made an important marine resource in Northeast Brazil since 1955. The Von Bertalanffy age and growth parameters of the spiny lobster started being studied in 1960 and the last assessment was performed over 20 years ago. The objective of this review is to analyse the type of input data and the methods historically used to assess age and growth of the spiny lobster stock in Northeast Brazil.

Our study reviews and updates the research on the subject and proposes relative values for the Von Bertalanffy growth parameters for *P. argus* and *P. laevicauda* as provisional reference. We recommend further age and growth research on spiny lobsters to create a new and updated growth function for commercial lobsters in Northeast Brazil.

Key words. — *Panulirus argus*, *Panulirus laevicauda*, spiny lobster fishery, age and growth, Northeast Brazil

RESUMO

A pesca de lagosta de duas espécies-alvo, *Panulirus argus* (Latreille, 1804) e *Panulirus laevicauda* (Latreille, 1817) tem sido um importante recurso marinho no Nordeste de Brasil desde 1955. Em aquela região os parâmetros de idade e crescimento da função de Von Bertalanffy começaram a ser estudados desde o ano 1960 e por última vez há mais de 20 anos. O objetivo deste estudo de revisão é analisar os dados de entrada e métodos antigamente usados para assessorar a idade e crescimento do estoque de lagostas espinhosas explotadas no Nordeste do Brasil. Este trabalho atualiza o estado do conhecimento do tema e propõe valores relativos para os parâmetros da função de crescimento de Von Bertalanffy para *P. argus* e *P. laevicauda* como referência provisional. Sugerimos continuar com a pesquisa focada na idade e crescimento das lagostas espinhosas para poder facilitar

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GLOSSÁRIO

Adulto: indivíduo que alcançou a maturação sexual.

Avaliação de estoques pesqueiros: é um processo científico em que todos os dados disponíveis (muitas variáveis) sobre um estoque de peixes, são combinados para estimar quais são as tendências históricas em abundância, qual é a porcentagem de captura e quão produtivo esse estoque tem sido.

Cefalotórax: parte superior do corpo de alguns invertebrados (crustáceos), que inclui cabeça e o tórax.

Ciclo de vida: conjunto de transformações produzidas nos indivíduos de uma espécie para assegurar sua continuidade (reprodução, crescimento e morte).

Ciclo reprodutivo: fase em que os organismos jovens de uma espécie desenvolvem gônadas maduras viáveis atingindo a maturação completa e participa nos processos temporais de reprodução na população.

Comprimento biológico: tamanho físico ou corporal de uma espécie.

Comprimento da cauda: é medido desde a borda anterior do primeiro anel abdominal até a extremidade posterior do cefalotórax.

Comprimento de maturidade (L100): comprimento com o qual 100% dos indivíduos numa população estão aptos a se reproduzirem.

Comprimento de primeira maturidade (L50): comprimento com o qual 50% dos indivíduos numa população iniciaram o ciclo reprodutivo.

Comprimento do cefalotórax: medido desde a borda dos espinhos supraorbitais até o extremo posterior do cefalotórax.

Comprimento máximo (Lmax): comprimento máximo de uma espécie observado nos desembarques da pesca como parte das capturas.

Comprimento ótimo (Lopt): comprimento no qual a biomassa de peixes numa classe anual é maximizada**.**

Comprimento total antenular: medido sobre a parte inferior do animal, desde a base das antenulas até extremidade posterior do telson.

Comprimento total: medido desde a borda dos espinhos supra-orbitais até a extremidade posterior do telson.

Coorte: conjunto de indivíduos nascidos ao mesmo tempo e no mesmo lugar.

Dados dependentes da pesca: dados não sistematizados estatisticamente, provenientes do monitoramento da pesca comercial e influenciados pelos aparelhos de pesca.

Dados independentes da pesca: dados provenientes de campanhas de navios de pesquisa com detalhados sistemas de amostragem estatístico, referencial biológico, ambiental, geográfico e batimétrico.

Espinhos supraorbitais: dois espinhos grandes e proeminentes, chamados acúles, que protegem os olhos.

Estado reprodutivo: condição de uma espécie que, através da morfologia externa, mostra sua condição reprodutiva (desova, massa espermatofórica, ovos externos).

Estoque: pode-se definir como: a) grupo intraespecífico de indivíduos que se agrupam ao caso com integridade espaço-temporal ou b) conjunto de indivíduos da mesma espécie que habitam uma área geográfica e que apresentam os mesmos parâmetros biológicos.

Estrutura do comprimento populacional: características e distribuição do comprimento biológico dos organismos de uma população.

Hipótese: Proposição admitida como um início e através da qual algo pode ser comprovado ou demonstrado; conjectura: hipótese científica.

Indicador de reprodução externo: indicador indireto representado por característica externa (macroscópica) correlacionado à maturidade sexual ou reprodutiva de um organismo.

Indicador de reprodução interno: indicador direto associado ao desenvolvimento e características físicas, macro e microscópicas das gônadas reprodutivas de um organismo.

Índice: número ou propriedade que está presumivelmente relacionado a um parâmetro populacional.

Maturação: processo de desenvolvimento dos seres vivos ou de suas partes no sentido de tornar o organismo apto para a reprodução.

Monitoramento da pesca: observação repetitiva de algumas (poucas) variáveis nos desembarques da pesca por um tempo determinado.

Parâmetro: descritor biológico quantitativos de um determinado estoque.

Parâmetros de crescimento: descritor quantitativo do crescimento teórico de uma espécie.

Oceano Atlântico Centro Oriental: considerada área de pesca (FAO), estende-se do Cabo Hatteras, na Carolina do Norte, Estados Unidos da América (35 ° N), até o sul do Cabo Recife, no Brasil (10 ° S). Inclui uma área de quase 15 milhões de km^2, das quais aproximadamente 1,9 milhão de km^2 são áreas da plataforma. As principais subdivisões nessa região são a costa sudeste dos Estados Unidos da América, o Golfo do México, o Mar do Caribe e a costa nordeste da América do Sul, que inclui as Guianas (Guiana Francesa, Guiana e Suriname) e o Brasil.

Regressão logística: é um método estatístico para analisar um conjunto de dados no qual existem uma ou mais variáveis independentes que determinam um resultado. O resultado é medido com uma variável dicotômica (na qual existem apenas dois resultados possíveis).

Realidade biológica: na simulação do crescimento de crustáceos, diz sobre a capacidade de um modelo matemático em representar de uma forma compreensiva e similar à que acontece na natureza o crescimento de um organismo.

Reprodução: a produção da prole por um processo sexual ou assexual.

Sobrepesca: explotação excessiva da pesca sobre estoques de peixes ou invertebrados marinhos reduzindo o número de organismos em níveis muito baixos, tornando a exploração não sustentável.

Sobrepesca de crescimento: indivíduos de pequeno comprimento capturados pela pesca quando são muito jovens e não têm participado nos processos de reprodução.

Sobrepesca de recrutamento: quando as capturas da pesca excedem a habilidade reprodutiva de uma espécie explorada em criar recrutas.

Valor absoluto: são números ou valores reais e precisos.

Valor relativo: são números ou valores dependentes de outros números (absolutos).

Valor relativo do parâmetro de crescimento: valor médio teórico em função de outros parâmetros de crescimento calculados.

Ponto de referência no gerenciamento de estoques: valores dos indicadores do estado desejável ou indesejável de um recurso pesqueiro da própria pesca. Os pontos de referência podem ser biológicos (por exemplo, expressos nos níveis de biomassa de desova ou de mortalidade por pesca), técnicos (níveis de esforço ou capacidade de pesca) ou econômicos (níveis de emprego ou receita).

Tamanho mínimo de captura: tamanho oficial de captura e comercialização no qual uma espécie de recurso pesqueiro pode ser explotada e que garante a proteção do estoque reprodutivo.