

Universidade Federal do Rio Grande  
Pós-Graduação em Oceanografia Biológica

Variação interanual da composição de comprimento e crescimento juvenil  
do camarão-rosa *Farfantepenaeus paulensis* (Pérez-Farfante 1967)  
(Decapoda: Penaeidae) em zonas rasas do estuário da Lagoa dos Patos, sul  
do Brasil

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## **Resumo**

Este trabalho tem por objetivo descrever a variação temporal e espacial de longo prazo na distribuição de frequências de comprimento e crescimento de juvenis do camarão *F. paulensis*, no estuário da Lagoa dos Patos (ELP) e sua relação com fatores abióticos. O trabalho faz uso de uma longa série temporal mensal de dados (1996 a 2012 Projeto Ictio/PELD CNPq-MCT), trazendo novas perspectivas sobre a variação do crescimento, recrutamento e estrutura populacional e suas relações com as variáveis ambientais, sob a hipótese de que estas têm efeito na variabilidade tanto do crescimento, quanto do recrutamento e estrutura de tamanho no estuário. Adicionalmente, foi desenvolvida uma nova abordagem para a estimação dos parâmetros de crescimento da equação de von Bertalanffy usando a perspectiva do paradigma da decisão bayesiano de acordo com sua coerência biológica, sob a hipótese de que esta abordagem trará estimativas mais precisas e mais coerentes com a biologia da espécie.. As coletas foram realizadas, em zonas rasas, em 5 sítios amostrais (PL1 a PL5) que descrevem o gradiente ambiental da salinidade do estuário, com uma rede de praia do tipo picaré. Os dados de temperatura, salinidade e transparência foram obtidos em conjunto com as amostragens biológicas para cada ponto amostral. Informações complementares sobre vazão do sistema (unidade), captura de adultos (unidade), Índice Enso Multivariado, e Radiometria da Cor Oceânica foram obtidos em órgãos que disponibilizam publicamente esses dados – ANA; CEPERG, NOAA; NASA, respectivamente. Foi medido o comprimento total (CT) em milímetros dos camarões e, posteriormente, agrupados em classes de tamanho com intervalos de 5 e 10 mm para as análises de crescimento e composição de tamanho, respectivamente. O crescimento foi descrito (para os sexos agrupados) pelo modelo de crescimento de Von Bertalanffy. Uma abordagem alternativa para a análise de crescimento utilizando métodos bayesianos para

o modelo de von Bertalanffy foi utilizada para a estimação de parâmetros da curva de crescimento. Os parâmetros de crescimento estimados usando o método de mínimos quadrados foram  $L_{\infty}=146$  mm,  $k=3.17$  ano<sup>-1</sup>,  $T_0=1.46$  dia<sup>-1</sup> e longevidade de 1.44 anos. Os parâmetros de crescimento estimados usando o método Bayesiano com as cadeias Markov foram:  $L_{\infty}=128.8\pm9.4$  mm;  $k=0.01\pm0.001$  dia<sup>-1</sup> ( $3.65\pm0.3$  ano<sup>-1</sup>);  $t_0=1.94\pm1.03$  dia<sup>-1</sup>. A longevidade foi de  $1.2\pm0.1$  anos. A alternativa Bayesiana mostra-se mais adequada, pois pode medir a incerteza dos parâmetros contribuindo com um maior embasamento na aceitação de uma coorte com coerência biológica. O modelo de crescimento sugere que a espécie leva aproximadamente 111 dias após o nascimento para alcançar o tamanho mínimo de captura sugerido pela legislação (90 mm). Os números de coortes e de modas tiveram significativa correlação com as variáveis vazão e salinidade, indiciando a importância dessas variáveis para o recrutamento, no entanto as estimativas de abundância relativa dos juvenis (CPUE) não apresentaram correlação com nenhuma variável ambiental investigada. Contudo a CPUE apresenta correlação significativa com as coortes, sugerindo que ela pode sofrer efeitos indiretos das variáveis ambientais. Portanto, a salinidade e vazão regulam a entrada de larvas no estuário, mas não necessariamente influenciam diretamente a abundância dela. Os camarões, ao longo do seu crescimento, não se distribuem homogeneamente no ELP ( $p<0.05$ ), e aparentemente não apresentam nenhum padrão relacionado à distância da boca do estuário e nem a temperatura e salinidade. A Análise de cluster sugere que os ambientes agrupados apresentam semelhanças quanto a sua composição sedimentológica, levantando hipóteses de que o tipo de sedimento aparenta ser um dos principais fatores a influenciar a distribuição de classes ao longo do estuário. Contudo, ainda existe a necessidade de uma melhor comprovação da existência real de tal relação. Os pontos PL3 e PL4 possuem maior abundância, e são apontadas como áreas propícias

a pesca de indivíduos de tamanhos maiores. O ponto PL1 e PL2 apresentaram predominância das classes menores, sugerindo uma potencial área de proteção da pesca.

## Abstract

This work aims to describe the temporal and spatial variation of the length and growth frequency distribution of the *F. paulensis* shrimp, an important fishery resource in the south and southeast of the country, along the Patos Lagoon Estuary (PLE) and its relationship with abiotic factors. This work uses a long time series dataset to bring new perspectives on growth, recruitment and population structure variation and its relationship with environmental variables under the assumption that these have an effect on the variability of both growth, recruitment and size structure in the estuary. This information would be hardly obtained with short data series. Additionally, we developed a new approach for the estimation of growth parameters of the von Bertalanffy equation using the Bayesian paradigm for decision in accordance with the biological coherence, under the assumption that this approach will yield more accurate and consistent estimates for the specie's biology. Sampling, between the years 1996-2012, was obtained under the project of long-term ecological research (Ictio / PELD CNPq - MCT). The collections were made in shallow areas, at 5 sites sampled with a beach seine net type. Temperature, salinity and transparency data were obtained in conjunction with the biological sample for each sampling point. Information about flow, catch, Multivariate Enso Index and Ocean Color Radiometry were acquired in institutions that makes this data available publicly - ANA; CEPERG, NOAA; NASA, respectively. Biometrics was done by measuring the total length (TL) in millimeters. The shrimps were grouped into size classes with intervals of 5 and 10 mm for the growth and size composition analysis, respectively. Growth was described for the pooled sexes using the von Bertalanffy growth model. Diversity analysis and statistical inferences were used to evaluate the difference in the distribution of size classes along the estuary. Estimated growth parameters using the Least Squares method were  $L_{\infty} =$

146 mm,  $K = 3.17 \text{ year}^{-1}$ ,  $T_0 = 1.46 \text{ day}^{-1}$  and 1.44 years longevity. Estimated growth parameters using the Bayesian method were  $L_{\infty}=128.8\pm9.4\text{mm}$ ;  $k=0.01\pm0.001 \text{ day}^{-1}$  ( $3.65\pm0.3 \text{ year}^{-1}$ );  $t_0=1.94\pm1.03 \text{ day}^{-1}$  and the longevity was  $1.2\pm0.1 \text{ years}$ . The Bayesian method has the advantage of measuring the uncertainty from the parameters, adding more information to the judgment for accepting a biological coherent cohort. The number of cohorts and modes had significant correlation with the variables flow and salinity, indicating the importance of these variables on shrimp recruitment. The CPUE showed no correlation with any environmental variable investigated, yet it presents a significant correlation with the cohorts, suggesting that it may suffer indirect effects from environmental variables. Thus, the salinity and flow regulating the entry of larvae in the mouth, but not necessarily directly influence the abundance of it. The prawns, along its growth are not distributed homogeneously in the PLE ( $p < 0.05$ ) and apparently do not exhibit any pattern related to distance from the mouth of the estuary or the temperature and salinity. The cluster analysis grouped the PL3 and PL4 points; and PL1, PL2 and PL5 as the closest in its class structure. The PL3 and PL4 points have greater abundance, and are pointed as propitious areas for fishing large size individuals. The PL1 point showed predominance of smaller classes, suggesting a potential area for fisheries protection.

## 1- Introdução Geral

A espécie *Farfantepenaeus paulensis* tem ampla distribuição na plataforma continental brasileira, do nordeste (Ilhéus, Bahia) ao sul do Brasil (Rio Grande do Sul), estendendo-se até a Argentina (Mar del Plata) (D’Incao 1999; 1991).

O estuário da Lagoa dos Patos possui importância no seu ciclo de vida que assim como ao de outras espécies do gênero (e.g. *Farfantepenaeus aztecus*; *Farfantepenaeus subtilis*, etc) possui as fases adultas e larvais no oceano com as larvas migrando até a zona costeira pela ação de correntes oceânicas; e as fases de pós-larva e juvenil (quando se desenvolvem até a fase de pré-adultos e retornam para o oceano, completando seu ciclo de vida) nos estuários e baías (D’Incao *et al.* 1991). Os mecanismos que larvas e pós-larva, de peneídeos, usam para chegar até os estuários são altamente variáveis dependendo da espécie e do ambiente físico no qual eles se desenvolvem (Criaes 2003). No caso do Estuário da Lagoa dos Patos a pluviosidade e o aporte de água salgada são indicados como os principais fatores no sucesso do recrutamento (D’Incao 1984; D’Incao 1991; Castelo & Möller 1978, Möller *et al.* 2009).

Apesar da região não sofrer com o efeito da maré devido a sua baixa amplitude (Moller *et al.* 2009), ela esta sob forte influência de ventos sudoeste e nordeste (Möller & Fernandes 2010). Tanto o fluxo de maré quanto o regime de vento na região apresentam um grande variabilidade (Closs & Madeira 1968; Möller *et al.* 2009) que acarreta em consequências para a salinidade e nível de água ao longo do estuário, com variações de 0.3 a 0.4 m (Möller & Fernandes 2010; Möller *et al.* 2001; Fernandes *et al.* 2002). As variações sazonais são constituídos por precipitação elevada na transição do inverno para a primavera elevando o nível da água (Marques *et al.* 2010) e expelindo a água salgada do estuário (Moller & Fernandes 2010). Contudo, o que não é



necessariamente uma constante, de fato, interações oceano e atmosfera e fenômenos ENOS tornam estas variações altamente complexas e difíceis de padronizar (Grimm *et al.* 1998;. Pereira & D'Incao 2012).

Grande parte da captura global de camarão é tomada por grandes operações de pesca industrial, mas algumas das maiores atividades pesqueiras de camarões estão baseadas na atividade de pequena escala, incluindo as operações não-motorizados; e em grande parte dos países a produtividade dos tipos de pescarias estão relacionadas (uma depende da outra, face a biologia da espécie) o que ocasiona em vários conflitos sociais (Gillet 2008). Este contexto se aplica ao presente local de estudo – pescadores artesanais do Rio Grande do Sul com pescadores industriais de Santa Catarina que dependem dos recursos uns dos outros, tendo em vista que os juvenis de *F. paulensis* do rio grande do sul migram e compõem o estoque de adultos em Santa Catarina (D'Incao 1991, D'Incao 2002).

A pesca do *F. paulensis* na Lagoa dos Patos representa cerca de 40% da produção da espécie, sendo o mais importante berçário do camarão-rosa ao longo de toda a sua área de distribuição. Entretanto, estatísticas de desembarque indicam uma tendência clara de declínio nas capturas, a despeito dos elevados níveis de esforço aplicados (D'Incao *et al.* 2002, D'Incao & Dumont 2010).

Na tentativa de prevenir que esse recurso se esgote, são adotadas medidas de manejo e gestão para a pesca na região, cujas principais normas destacam a proibição da captura de camarões com comprimento total inferior a 9 cm e o período de defeso entre fevereiro e maio com uma tolerância de 20% do peso total capturado (IN nº3 de 9 de fevereiro de 2004), visando permitir o retorno dos juvenis à plataforma continental e conseqüentemente ao estoque adulto em Santa Catarina.

Visando proporcionar um manejo adequado para pescarias em desenvolvimento, foram desenvolvidos alguns modelos para estudos com dinâmica populacional, dentre eles um dos mais básicos envolvem a estimação do crescimento, mudanças no corpo do animal (Hoggarth *et al.* 2006) e avaliações de biomassa (ex. D’Incao & Fonseca 1999). Outros estudos envolvem relações entre o meio físico com a produção biológica. Um dos mais importantes trabalhos desenvolvidos nesse contexto, na Lagoa dos Patos, foi realizado por Castelo & Möller 1978; Fernandes *et al.* 2004; Möller *et al.* 2009; Pereira *et al.* 2012; D’Incao 1991, onde os autores através do uso de séries temporais longas nos possibilitaram avançar no entendimento a respeito da influência de variáveis ambientais na abundância e recrutamento do *F. paulensis* na Lagoa dos Patos. O uso desse tipo de informação com longas séries de dados têm beneficiado o gerenciamento de estoques pesqueiros, face as suas necessidades de avaliação contínua, gestão adaptativa e considerações de cenários futuros (Driscoll 2012).

Séries temporais longas ainda não foram utilizadas em estudos de crescimento na Lagoa dos Patos e estudos relacionados com o recrutamento não utilizam dados de coortes se limitando a apenas dados de CPUE. Sendo assim, apesar de importantes, os trabalhos realizados sobre o crescimento do camarão-rosa na região (D’Incao & Calanzans 1978; D’Incao 1983, 1984; Peixoto *et al.* 2001), são fragmentados, sem que haja um entendimento da variação interanual na estrutura de tamanho e dos parâmetros de crescimento, o que pode ser obtido somente a partir de dados provenientes de séries temporais abrangentes e contínuas. Adicionalmente, o efeito dos parâmetros ambientais na estrutura de tamanho e no crescimento ainda não foram avaliados, embora fatores como temperatura, salinidade e dieta fossem reportados como os principais reguladores dos orçamento energético e conseqüentemente da energia investida para o crescimento

(Lemos & Phan 2001). O entendimento da relação entre fatores como a vazão e salinidade é fundamental para a compreensão do sucesso do recrutamento na região.

A idéia de heterogeneidade na estrutura de classes de tamanho ao longo do estuário e do crescimento de espécies do gênero *Farfantepenaeus* foi sugerida por Perez-Castaneda & Defeo (2004). Estes autores mencionam a importância da distância da boca do estuário como uma característica relevante no padrão de distribuição de classes, com as classes maiores mais distantes da foz e as menores mais próximas desta. O padrão inverso é sugerido por Porto & Fontenelles-Filho (1982; 1984; 1988), que descrevem a ocorrência de *F. subtilis* e *L. schmitti* em áreas mais internas do estuário e indivíduos maiores mais próximas da sua boca. Não temos conhecimento de estudos usando grandes séries de tempo para relatar a estrutura de classes ao longo do crescimento para qualquer espécie do gênero *Farfantepenaeus*, apesar de esclarecerem padrões nas estruturas de classe de tamanho para os outros gêneros (por exemplo, *Pandalus borealis* - Aschan 2000). Estudos detalhados sobre a estrutura de comprimentos podem trazer benefícios ao manejo pesqueiro, principalmente quanto à implementação de áreas protegidas da pesca, caso de fato ocorra heterogeneidade na distribuição de classes de tamanho em uma região, trazendo benefícios a potenciais berçários.

Para os peixes e outros organismos marinhos (por exemplo, tubarões, raias, etc) existem estruturas de aposição bem definidas - como otólitos, vértebras - que são usadas para as determinações de idade. Embora, em alguns casos, as estruturas de leitura de idade não estejam disponíveis no banco de dados (por exemplo, dados de captura) ou a estrutura de aposição simplesmente não existe. Em crustáceos, por exemplo, a determinação da idade é dificultada pelo processo de muda, o que resulta na perda constante de estruturas rígidas que possam estar relacionadas com o envelhecimento.

Portanto, como um "equivalente" para as estruturas de aposição, a quantificação de lipofuscina no tecido do sistema nervoso está surgindo como uma alternativa para estudos de envelhecimento de crustáceos (Sheehy 1989; 1996; Vila *et al.* 2000). No entanto, esta abordagem é demorada, e abordagens baseadas no comprimento ainda são dominantes para estimativas de crescimento em todo o mundo.

Para os métodos baseados em comprimento podemos destacar o Bhattacharya (1967), o Powell - Wetherall (Powell 1979; Wetherall 1987), e a rotina ELEFAN (Pauly 1979, 1984), como as abordagens mais utilizadas para estimar o crescimento de crustáceos - por exemplo, *F. californiensis*; *Litopenaeus stylirostris* na Califórnia Golfo (Medina & Soto 2001); *Metopenaeus joyneri* na Coreia (Cha & Choi 2004); *Solenocera membranacea* no Mar Mediterrâneo (Demestre & Abello 1993).

No Brasil, uma adaptação da análise de progressão de modas para crustáceos têm sido difundido, cujos detalhes estão em uma dissertação não publicada (Fonseca 1998) e sucintamente descritos em um artigo (D'Incao & Fonseca 1999). No entanto, apesar da pouca repercussão no cenário acadêmico internacional, existem muitos artigos publicados utilizando essa metodologia neste país (Ferreira & D'Incao 2008; Pimenta *et al.* 2005; Fernandes *et al.* 2014). O ajuste não-linear utilizando modas foi desenvolvido pela alegação de que os métodos baseados em médias (por exemplo, Bhattacharya, ELEFAN) geram grupos etários de forma limitada, pois excluem as classes maiores gerando curvas achatadas e apresentam dificuldades em identificar grupos etários mais velhos e de baixa abundância. A presente abordagem propõe a escolha de cada coorte por tentativa e erro e mantém aqueles que são biologicamente coerentes de acordo com os parâmetros de crescimento de von Bertalanffy e longevidade (D'Incao & Fonseca 1999), fornecendo ao pesquisador um maior controle sobre a estimativa da curva. No entanto, essa característica do método também está sendo alvo de críticas por seu

excesso de subjetividade na escolha de grupos etários. Adicionalmente, a análise de uma série temporal longa traz vantagens quanto à validação dos parâmetros de crescimento baseada em uma abordagem que apresente coerência biológica e considerando suas variações interanuais.

Em geral, todas as abordagens sobrescritas usam os mínimos quadrados para estimativa dos parâmetros de crescimento. Mais recentemente, o paradigma bayesiano tem se difundido pela popularidade de alguns softwares estatísticos (Kinas & Andrade 2010). Não temos conhecimento de sua aplicação na modelagem do desempenho de crescimento para camarões selvagens, mas alguns trabalhos foram realizados para a aquicultura (Yu & Leung 2010) - descrevem um modelo Bayesiano hierárquico para indivíduos com idade conhecida.

Embora métodos Bayesianos possam conter muitos dos procedimentos utilizados nas estatísticas convencionais, estes podem prolongar significativamente a aplicabilidade da estatística, incluindo o importante processo de tomada de decisão sob incerteza (Kinas & Andrade 2010). Ele também tem a vantagem de usar apenas probabilidade como métrica e nenhuma restrição sobre o tamanho da amostra (Kinas & Andrade 2010; McCarthy 2007)

Considerando a atual demanda por conhecimentos que contribuam para o entendimento da biologia de espécies de importância econômica e social, visto que ainda existe uma lacuna de conhecimento da ontogenia da espécie na relação estuário-oceano, é importante o levantamento de informações detalhadas da ecologia e estrutura populacional desta, com ênfase no entendimento da idade e estrutura de tamanho dos juvenis, subsidiando decisões de manejo e gestão pesqueira.

## 2- Objetivos e Estrutura da Dissertação

O presente trabalho é uma iniciativa do Laboratório de Crustáceos Decápodes em parceria com o Laboratório de Ictiologia através do projeto de pesquisas ecológicas de longa duração (Ictio/PELD CNPq-MCT), com vistas ao aprimoramento de conhecimentos sobre a dinâmica espacial e temporal das frequências de comprimento e crescimento do camarão *F. paulensis* no Estuário da Lagoa dos Patos.

Os resultados da dissertação estão sumarizados em três capítulos escritos em forma de artigo e em inglês.

Capítulo 1: Spatio-temporal variation in structure of the pink shrimp (*Farfantepenaeus paulensis*) (Pérez-Farfante 1936) in the Patos Lagoon

Objetivo geral:

Descrever a variação espaço-temporal da distribuição de comprimento dentro do estuário da Lagoa dos Patos, bem como suas relações com fatores abióticos.

Os objetivos específicos são:

- Verificar a influência de fatores abióticos, como salinidade e transparência, na distribuição de classes de tamanho ao longo do estuário da Lagoa dos Patos.
- Verificar se existem diferenças na composição de tamanhos ao longo de um gradiente salino estuarino.

Capítulo 2: Interannual variability in growth of pink shrimp (*Farfantepenaeus paulensis*) in the Patos Lagoon.

Objetivo geral:

Descrever a variação temporal das coortes e estimar os parâmetros de crescimento para o ciclo de vida da espécie dentro da Lagoa dos Patos, bem como suas relações com fatores abióticos.

Os objetivos específicos são:

- Estimar os parâmetros  $k$ ,  $L_{\infty}$ , e  $t_0$  para a espécie *F. paulensis* e sua variação interanual.
- Verificar a relação das coortes com o CPUE e parâmetros abióticos.

Capítulo 3: Juvenile growth of pink shrimp (*Farfantepenaeus paulensis*) in a choked Lagoon from South Brazil: A Bayesian approach

Objetivo geral:

Desenvolver uma versão bayesiana da metodologia proposta por D'Incao & Fonseca (1999), em uma série temporal de longo prazo.

O objetivo específico:

- Descrever de maneira comparativa os prós e contras de ambos os métodos, levando em consideração critérios como precisão na estimação de parâmetros e subjetividade na escolha de coortes.

### **3- Metodologia Geral**

#### **3.1- Área de Estudo**

Este estudo foi realizado no estuário da Lagoa dos Patos (32° S 52° W), Rio Grande do Sul, região que está sob forte influência da salinidade oriunda do aporte de água dos oceanos, formando uma região estuarina com limite médio até a região da Ponta da Feitoria, porém sua amplitude pode se estender até a parte norte da laguna, ou ficar restrita à desembocadura na Barra do Rio Grande (Moller 2001, 2009, 2010). A salinidade e hidrodinâmica são influenciadas principalmente entre as relações da descarga fluvial e a ação dos ventos (Nordeste e Sudoeste), possuindo a maré apenas efeito secundário, com amplitude considerada baixa (0.4 m) (Moller 2009).

### 3.2- Amostragem e Biometria

Foram utilizados os dados de amostragem, entre os anos 1996 a 2012, obtidos no âmbito do projeto de pesquisas ecológicas de longa duração (Ictio/PELD CNPq-MCT). As coletas foram realizadas - em zonas rasas com profundidade média inferior a 1,5m - em 5 sítios amostrais com 5 arrastos mensais realizados em cada sítio (totalizando 216 amostragens durante todo período de estudo) (Figura 01), com uma rede de praia do tipo picaré (9m de comprimento; 13 mm de distância entre os nós nas asas e 5 mm no centro). Os dados de temperatura, salinidade e transparência foram obtidos em conjunto com as amostragens biológicas para cada ponto amostral. A biometria foi feita com a medição do comprimento total (CT) (que vai da ponta do rostro até o final do telson) em milímetros. Os camarões amostrados foram agrupados em classes de tamanho com intervalos de 5 e 10 mm para as análises.

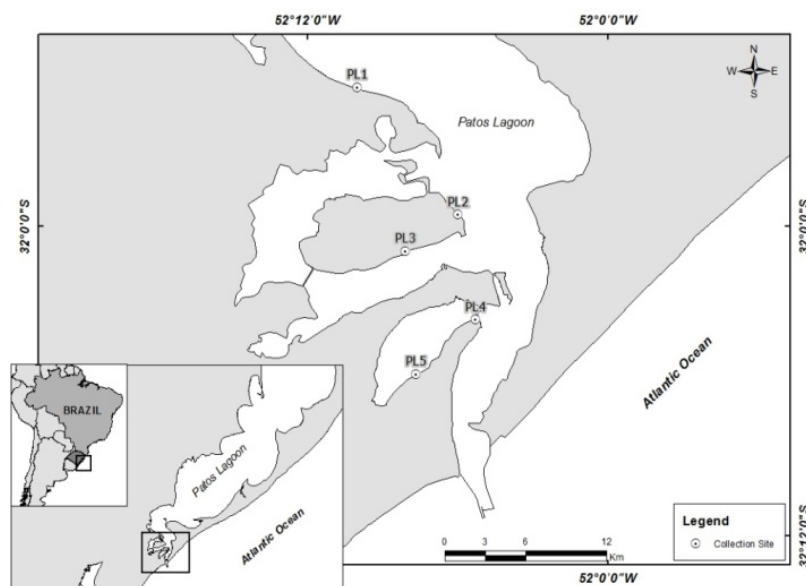


Figura 01: Localização das estações de amostragem do material biológico



## **Capítulo 01**

**Variação espaço-temporal na estrutura do comprimento do camarão-rosa (*Farfantepenaeus paulensis*) (Pérez-Farfante, 1936) em uma lagoa estrangulada no sul do Brasil**

Artigo será submetido para revista internacional: Noleto-Filho, E. M.; Dumont, L.F.C; Pucciarelli, P. M. **Spatio-temporal variation in length distribution of the pink shrimp (*Farfantepenaeus paulensis*)(Pérez-Farfante, 1936) in a choked Lagoon from South Brazil. Continental Shelf Research, Elsevier.**

A forma integral desse artigo encontra-se no anexo I.

## **Resumo**

Este trabalho tem por objetivo descrever a variação espaço-temporal na distribuição de frequências de comprimento dentro do estuário da Lagoa dos Patos (ELP), bem como suas relações com fatores abióticos. Foram utilizados os dados de amostragem, entre os anos 1996 a 2012, obtidos no âmbito do projeto de pesquisas ecológicas de longa duração (Ictio/PELD CNPq-MCT). As coletas foram realizadas, em zonas rasas, em 5 sítios amostrais, com uma rede de praia do tipo picaré. Os dados de temperatura, salinidade e transparência foram obtidos em conjunto com as amostragens biológicas para cada ponto amostral. Os camarões foram agrupados em classes de tamanho com intervalos de 10 mm para as análises. Os índices de diversidade e dominância de Simpson e uma análise de variância fatorial sem réplicas foram utilizados para verificar a variação espacial das classes de tamanho ao longo do estuário e ao longo do tempo. Uma análise de cluster foi utilizada para verificar a semelhança dos locais amostrados. Os camarões, ao longo do seu crescimento, não se distribuem homogeneamente no ELP ( $p < 0.05$ ), e aparentemente não apresentam nenhum padrão relacionado à distância da boca do estuário, temperatura e salinidade. Análise de cluster agrupou os pontos PL3 e PL4; e PL1, PL2 e PL5 como os mais próximos em sua estrutura de classes. Os pontos PL3 e PL4 possuem maior abundância de classes de tamanho, e são apontadas como áreas propícias a pesca de indivíduos de tamanhos maiores. O ponto PL1 apresentou maior predominância das classes menores, sugerindo uma potencial área de proteção da pesca. Uma análise temporal mostra que o tamanho médio dos indivíduos está diminuindo, o que talvez possa sugerir a ocorrência de sobrepesca na região.

## **Capítulo 02**

### **Variabilidade interanual no crescimento juvenil do camarão rosa (*Farfantepenaeus paulensis*) em uma lagoa estrangulada no sul do Brasil**

Artigo submetido para revista internacional: Noletto-Filho, E. M.; Dumont, L.F.C; Pucciarelli, P. M.; Viera, J. P. **Interannual variability in juvenile growth of pink shrimp (*Farfantepenaeus paulensis*) in a choked Lagoon from South Brazil. Estuaries and Coasts, Springer.**

A forma integral desse artigo encontra-se no anexo II.

## Resumo

Este trabalho tem como objetivo descrever a variabilidade interanual no crescimento de juvenis do camarão *F. paulensis* ao longo do estuário da Lagoa dos Patos (ELP) e sua relação com fatores abióticos. Foram utilizados os dados de amostragem, entre os anos 1996 a 2012, obtidos no âmbito do projeto de pesquisas ecológicas de longa duração (Ictio/PELD CNPq-MCT). As coletas foram realizadas, em zonas rasas, em 5 sítios amostrais, com uma rede de praia do tipo picaré. Os dados de temperatura, salinidade e transparência foram obtidos em conjunto com as amostragens biológicas para cada ponto amostral. Informações da vazão, captura de adultos, Índice Enso Multivariado e Radiometria da Cor Oceânica foram adquiridas em órgãos que disponibilizam publicamente esses dados – ANA; CEPERG, NOAA; NASA, respectivamente. A biometria foi feita com a medição do comprimento total (CT) em milímetros. Os camarões foram agrupados em classes de tamanho com intervalos de 5 mm para as análises de crescimento. O crescimento foi descrito, para os sexos agrupados utilizando o modelo de crescimento de von Bertalanffy. Os parâmetros de crescimento estimados usando o método de mínimos quadrados foram  $L_{\infty}=146$  mm,  $k = 3.17 \text{ ano}^{-1}$ ,  $t_0 = 1.46 \text{ dia}^{-1}$  e longevidade de 1.44 anos. A idade estimada em tamanho migração (90 mm) foi de  $111,7 \text{ dia}^{-1}$ . Essas estimativas são aceitáveis para essa fase do ciclo de vida espécie, caracterizada por um rápido crescimento. O número de coortes encontrado variou de 0 a 6. Os números de coortes e de modas tiveram significativa correlação com as variáveis vazão e salinidade, indiciando a importância dessas variáveis para o recrutamento. As estimativas de abundância relativa (CPUE) não apresentaram correlação com nenhuma variável ambiental investigada, contudo ela apresenta correlação significativa com as coortes e grupos modais, sugerindo que ela pode sofrer efeitos indiretos das variáveis ambientais. Portanto, a salinidade e vazão regulam a entrada de larvas no estuário, mas não necessariamente influenciam diretamente a abundância dela. A temperatura, também, aparenta ter efeito sobre a abundância.

## **Capítulo 03**

### **Crescimento juvenil do camarão-rosa (*Farfantepenaeus paulensis*) (Pérez-Farfante, 1936) em uma lagoa estrangulada no sul do Brasil: Uma abordagem Bayesiana**

Artigo submetido para revista internacional: Noleto-Filho, E. M.; Dumont, L. F. C.; Viera, J. P. **Juvenile growth of pink shrimp (*Farfantepenaeus paulensis*) in a choked Lagoon from South Brazil: A Bayesian approach.** Continental Shelf Research, Elsevier.

A forma integral desse artigo encontra-se no anexo III.

## Resumo

Foram utilizados os dados de amostragem, entre os anos 1996 a 2012, obtidos no âmbito do projeto de pesquisas ecológicas de longa duração (Ictio/PELD CNPq-MCT). As coletas foram realizadas, em zonas rasas, em 5 sítios amostrais, com uma rede de praia do tipo picaré. Os camarões foram agrupados em classes de tamanho com intervalos de 5 mm para as análises de crescimento. Os parâmetros de crescimento foram descritos para os sexos agrupados usando o modelo de crescimento de von Bertalanffy pelos Mínimos Quadrados e abordagens Bayesianas para a escolha de cada coorte por tentativa e erro, mantendo aquelas que são biologicamente coerentes. As estimativas de parâmetros obtidas pelos Mínimos Quadrados foram:  $L_{\infty} = 146$  mm;  $K = 0,0087 \text{ dia}^{-1}$  ( $3,17 \text{ ano}^{-1}$ );  $t_0 = 1.46 \text{ dia}^{-1}$ ; a longevidade encontrada foi de 1,44 anos. Os parâmetros estimados pelo método de Bayes através das cadeias Markov foram:  $L_{\infty} = 128,8 \pm 9,4$  mm;  $k = 0,01 \pm 0.001 \text{ dias}^{-1}$  ( $3,65 \pm 0,3 \text{ anos}^{-1}$ );  $t_0 = 1,94 \pm 1,03 \text{ dia}^{-1}$ ; A longevidade foi de  $1,2 \pm 0,1$  anos. O método Bayesiano provou ser um instrumento melhor para a aplicação da abordagem de crescimento baseada na coerência biológica proposta por D'Incao & Fonseca (1999), uma vez que, ele fornece informações sobre a incerteza dos parâmetros necessárias para uma apropriada aceitação das coortes, eo método de Mínimos Quadrados é impróprio para amostras pequenas, gerando estimativas imprecisas.

#### 4- Conclusões Gerais

##### - Capítulo 01:

- ✓ Os juvenis ao longo de seu crescimento não se distribuem homogeneamente na Lagoa dos Patos. Apresentando predominância de classes maiores nas regiões de sedimento mais fino (silte) (PL3 e PL4) e menores substratos mais arenosos (PL1, PL2 e PL5).
- ✓ Existe uma forte evidência de sobreexploração da espécie baseada na tendência de diminuição na diversidade do comprimento médio ao longo dos anos, e na redução da proporção de indivíduos maiores em relação aos menores.

##### - Capítulo 02:

- ✓ A taxa de crescimento ( $k$ ) de  $3.17 \text{ ano}^{-1}$  é consistente com o ciclo de vida de *F. paulensis* dentro da Lagoa dos Patos.
- ✓ O modelo de crescimento sugere que a espécie leva aproximadamente 111 dias após o nascimento para alcançar o tamanho mínimo de captura sugerido pela legislação (90 mm)
- ✓ As variáveis ambientais salinidade e vazão apresentam significativa correlação com o número de coorte e grupos modais, evidenciando a influência de tais variáveis no recrutamento da espécie no estuário.

##### Capítulo 03:

- ✓ O método Bayesiano é o instrumento mais apropriado para a implementação do modelo de crescimento baseado na coerência biológica, tendo em vista que este fornece informações a respeito da incerteza dos parâmetros.
- ✓ A abordagem utilizando mínimos quadrados é inapropriada para pequenos conjuntos de dados gerando estimativas enviesadas.

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**Spatio-temporal variation in juvenile size distribution of the pink shrimp (*Farfantepenaeus paulensis*) (Pérez-Farfante 1936) in the Patos Lagoon, RS, Brazil**

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**Abstract**

This work aims to describe the spatio-temporal variation in length distribution of pink shrimp *Farfantepenaeus paulensis* within Patos Lagoon estuary (PLE) as well as its relations with abiotic factors. Sampling, between the years 1996-2012, was monthly performed under the project of long-term ecological research (Ictio/PELD CNPq - MCT). The collections were made in shallow areas, at 5 different sites sampled with a beach seine net type. Temperature, salinity and transparency data were obtained in conjunction with the biological sample for each sampling point. Sampled shrimps were grouped into size classes with 10 mm intervals. A Factorial ANOVA was used to check the spatial variability along the estuary and through the years. A cluster analysis was used to identify similar sites. During their ontogenetic growth, shrimps are not distributed homogeneously in the ELP ( $p < 0.05$ ), and apparently do not exhibit any pattern related to distance from the mouth of the estuary or from temperature and salinity. Cluster analysis grouped the PL3 and PL4 points; and PL1, PL2 and PL5 as the closest in its class structure. The PL3 and PL4 points have greater abundance of size classes, and are identified as areas conducive to fishing for individuals of larger sizes. The point PL1 and PL2 showed predominance of smaller classes, suggesting a potential fishing closed area. A temporal analysis shows that the average size of individuals is decreasing, suggesting the occurrence of overfishing in the region.

**Key words: Shrimp structure, Spatial distribution, Overfishing**

## 1- Introduction

The *Farfantepenaeus* is a very important genus of the family *Penaeidae*, especially in tropical and subtropical regions. Among them, the specie *F. paulensis*, desert attention due to its economic and social importance in southeast Brazil (Perez Farfante & Kensley 1997). The species distribution ranges from the continental shelf from the northeast (Ilheus, Bahia) to south Brazil (Rio Grande do Sul), extending to Mar del Plata in Argentina , as well as in estuaries and bays along these regions (D'Incao 1999). Part of it's life cycle is already understood. The adult and larval stage takes place in the ocean (between 40 and 60 meters deep) with a strong influence of ocean currents affecting their migration to the coastal areas. The post-larval and juvenile phase, (when they develop to pre-adults and return to the ocean, completing their life cycle) in the estuaries and bays (D' Incao *et al.* 2002). Information about these post-larvae in the Estuary of Patos Lagoon (PLE) are already known, where both rainfall and salt wedge penetration have great influence (D' Incao 1984, 1991; Castelo & Möller 1978; Möller *et al.* 2009). However, there is still a lack of knowledge regarding to larval movements during their ontogeny within the estuary. Artisanal fisheries produces size composition and species data that often resemble the structure found in ecosystems (King 2007), which enables the development of researches for evaluation and management purposes of some fisheries resources, including crustaceans (Ku & Lopez 2006; Aschan 2000; Defeo & Perez-Castaneda 2000).

Some authors suggest the use of more internal regions of the estuary as the shrimp grow for *Farfantepenaeus* genus, making distance from the mouth an important feature influencing the classes' distribution (Perez-Castaneda & Defeo 2004). The inverse pattern is suggested by Porto & Fontenelles-Filho (1982; 1984; 1988), which describe the occurrence of *F. subtilis* e *L. schmitti* in more inland areas and larger individuals closest to the mouth of the estuary bay areas. We are not aware of studies wearing a long time series for any specie of the genus *Farfantepenaeus*, although they have being used to clarify size class structures patterns for others (e.g. *Pandalus borealis* – Aschan 2000). Detailed length structure studies can bring benefits to fisheries management, particularly regarding the implementation of protected areas for fisheries, if indeed occurring heterogeneity in size structure distribution in a region it may benefit the areas of smaller individuals.

Long term size structure also helps to know about the stock health. Fisheries can destabilize populations by the removal of elder individuals (D'Incao 2002; Berkeley *et al.* 2004; King 2007; Hsieh *et al.* 2010), and increase the risk of commercial fishery to collapse. More age diversity and with an improvement in proportion of adults age structures are essential to also improve recruitment and the stocks productivity (Marteinsdottir & Thorarinsson, 1998).

Considering the knowledge gap about the juvenile pink shrimp dynamic (*F. paulensis*) within the Patos Lagoon estuary, and the importance of this estuary for the sustainability of southern Brazil's stocks, it is relevant to study the aspects related to the specie's ecology, especially for decision and fisheries management aspects, such as: population structure; location of priority areas for management; and influence of abiotic parameters. Therefore, this paper aims to describe the spatio-temporal variation in length distribution within Patos Lagoon estuary as well as its relations with abiotic factors.

## **2- Materials and Methods**

### **2.1- Study Area**

This study was conducted in the Patos Lagoon estuary (32 ° S 52 ° W), Rio Grande do Sul, a region that is under a strong influence of the ebb's flow effect and the northeast and southwest winds (Möller & Fernandes 2010). The large seasonal variability of these factors (Closs & Wood 1968; Möller *et al.* 2009) brings consequences for both salinity and water level in the estuary and along it, with variations from 0.3 to 0.4 m (Möller & Fernandes, *op cit.*; Möller *et al.* 2001; Fernandes *et al.* 2002). The tide effect is considered only as a secondary, seeing its low amplitude (Möller *et al.* 2009).

### **2.2- Sampling and Biometrics**

The data from the 1996 to 2012 period was obtained from the ecological long-term research project (Ictio/PELD CNPq - MCT). The samples were performed with a beach seine (9m in length, 13 mm distance between the wing nodes and 5 mm in the center) in the shallow areas (average depths lower than 1.5 m). Samples were monthly performed in 5 sites with 5 replicates (a total of 4800 samples) (Figure 01). The temperature, salinity and transparency data (Secchi disk) were obtained in conjunction with the biological samples for each sampling site. Biometry analyzes were done by measuring the total length (TL) (i.e. from the tip of the rostrum to the end of the telson)

in millimeters. Sampled shrimps were grouped into size classes with 10 mm intervals for the analyzes.

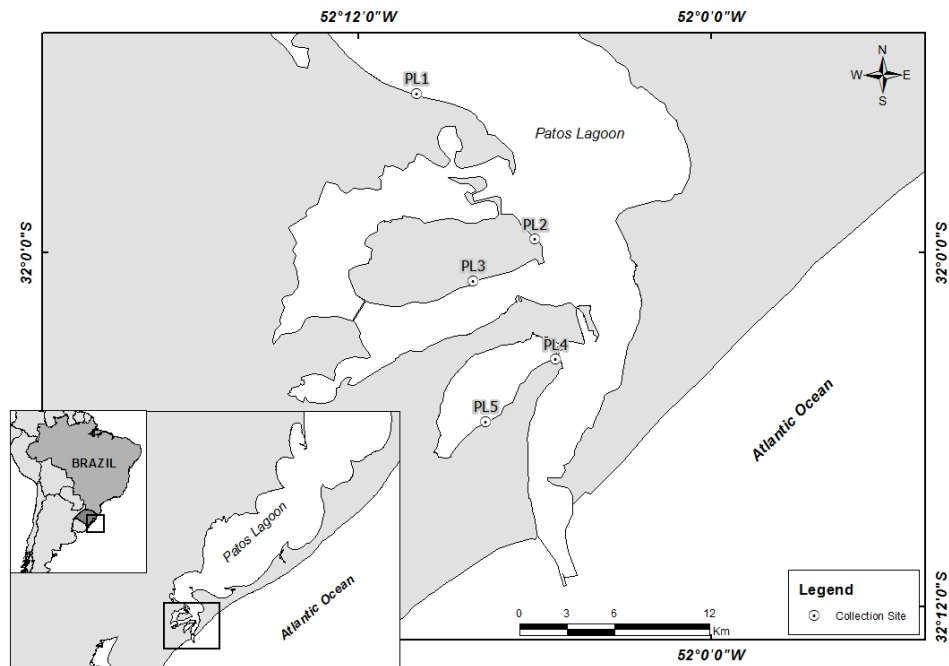


Figure 01: Sampling stations

### 2.3- Data analysis

The data from the sum of the monthly abundance (by size class) for each year will be used in the following analysis:

A boxplot chart will be performed for checking the capture size of the fishing gear and analyzing the distributions of size classes in the lagoon. The relative frequency was given for each size class yearly. The small size classes (25-45mm) and the big/intermediate size classes (55-105mm) were correlated with the environmental variables. A boxplot chart was yearly and monthly performed; all outliers were removed from the analysis. A Factorial ANOVA without replicates (Ireland, 2010) were used to check for differences of the size classes among the collection points

A cluster analysis was used to check the similarity between sites using the Bray- Curtis index. A Non-Metric Dimensional Scale (NMDS) was used to check the similarity between the size classes using the Bray-Curtis index. The relative frequency of each size class was calculated for the different. The sites were compared for its environmental variables (salinity and transparency) through a box-plot and inference tests (Factorial ANOVA - respecting the assumptions of normality, homoscedasticity and independence; and Spearman Correlation). The ANOVA without replicates was

done by the PAST 3.0 (Hammer *et al.* 2001); the whole other analyses were done by the free excel Spreadsheet, Action 2.5 (© Copyright® Estatcamp, 1997-2014)

### 3- Results

A total of 5200 individuals divided into 10 size classes, ranging from 15-105 mm, was sampled along the 16 years analyzed.

#### 3.1- Environmental Variables

The salinity and transparency showed a high variability in all sampling points (Figure 02 A and B) during the study period. In general, the average salinity tends to gradually increase between sites - the closer to the mouth of the estuary, the higher salinity is. Transparency had greater variance in point PL1 (Variance = 0.05); the points with the highest and lowest average transparency were PL4 (0.05 cm) and PL2 (0.04 cm), respectively (Figure 2B). For the factorial ANOVA without replicates, the sites presented no effect on the salinity and transparency average ( $p > 0.05$ ,  $F = 99.9$ ;  $p > 0.05$ ,  $F = 1.2$ ), however, time (years) does have effect on the salinity average ( $p < 0.05$ ,  $F = 1.7$ ). Time (years) have no effect on transparency ( $p > 0.05$ ,  $F = 1.7$ ).

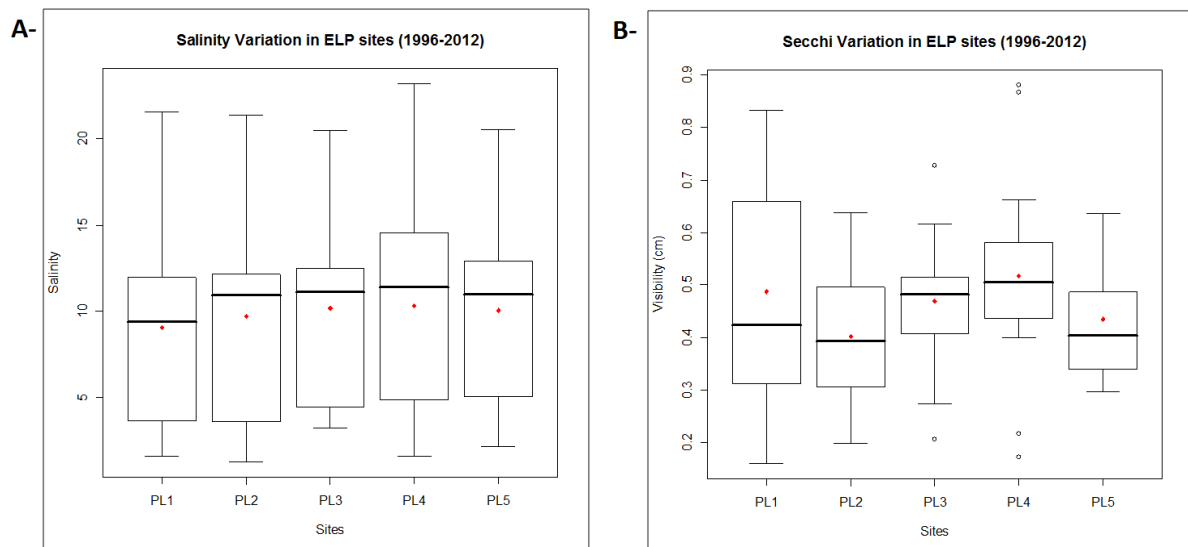


Figure 02: Variation in Salinity (A) and Transparency (B) in each of the survey site (point = mean; bar = mode; box superior = superior quartile; box inferior = inferior quartile)

#### 3.2- Interannual variation in length frequency in the PLE

The 25-55 mm size classes are the most abundant in the shallow areas of the estuary (Figure 03). The significant difference between class size of 25 mm and smaller class indicates recruitment size is 25 mm.



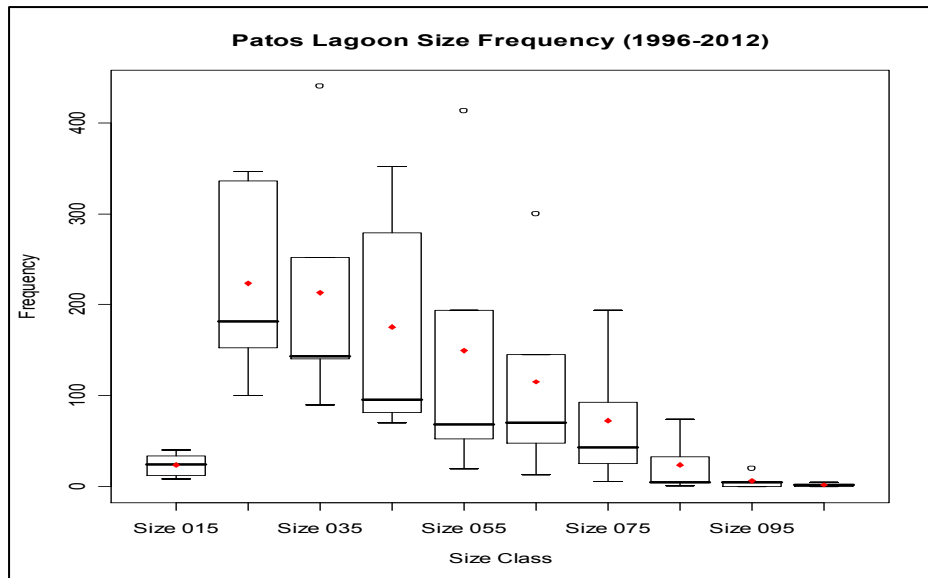


Figure 03: Size frequency distribution in the Patos Lagoon whole estuary (point = mean; bar= mode)

The percentage frequency analysis shows a sharp decrease from the percentage of the 55-105 mm size classes and an increase of the 25-45 mm size class percentage along the years (Fig. 04). Both size groups didn't correlated with any environmental variable (salinity, temperature and transparency) (Table 0.1).

The Non Metric Dimensional Scale grouped the sizes 25 mm to 45 mm, 55 to 75mm and 85 to 95 mm as more similar (Fig. 09). Therefore small, intermediate and bigger classes have similar abundances frequencies.

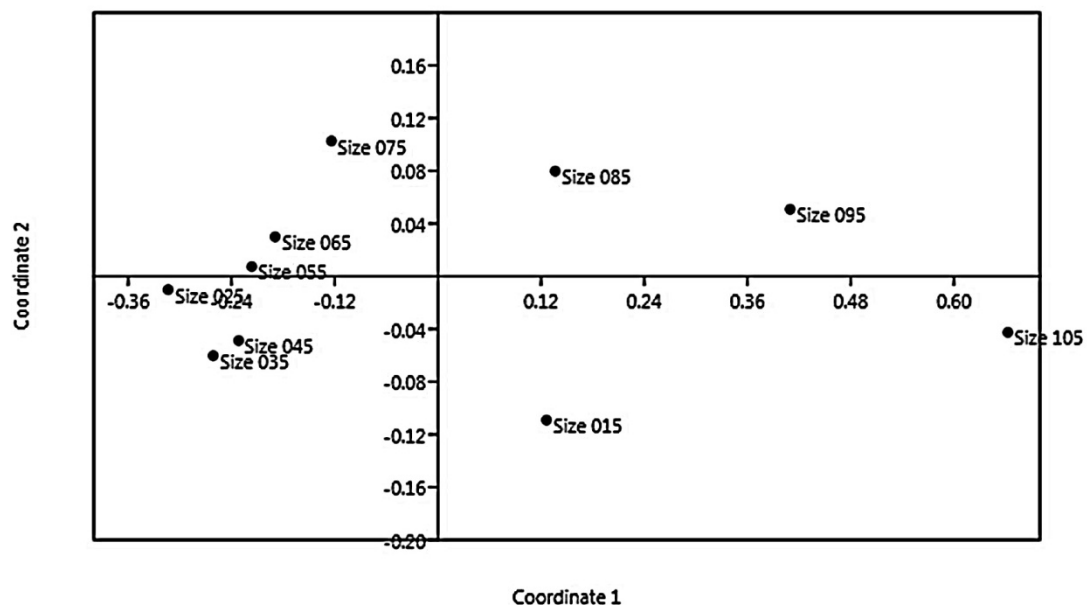


Figure 04: Non-metric Dimensional Scale with a Bray Curtis index. The variables are size classes in millimeters.

Table 01: Pearson Correlation table between the abundance from the big and small classes with the environmental variables. The statistically significant values are emphasized (\*)

<b>Pearson Correlation</b>					
	<b>Temperature</b>	<b>Salinity</b>	<b>Secchi</b>	<b>Small_Class</b>	<b>Big_Class</b>
Temperature	1.00	0.10	0.30	0.16	-0.37
Salinity	0.10	1.00	0.70*	0.31	0.15
Secchi	0.30	0.70*	1.00	0.20	-0.15
Small_Class	0.16	0.31	0.20	1.00	0.63*
Big_Class	-0.37	0.15	-0.15	0.63*	1.00

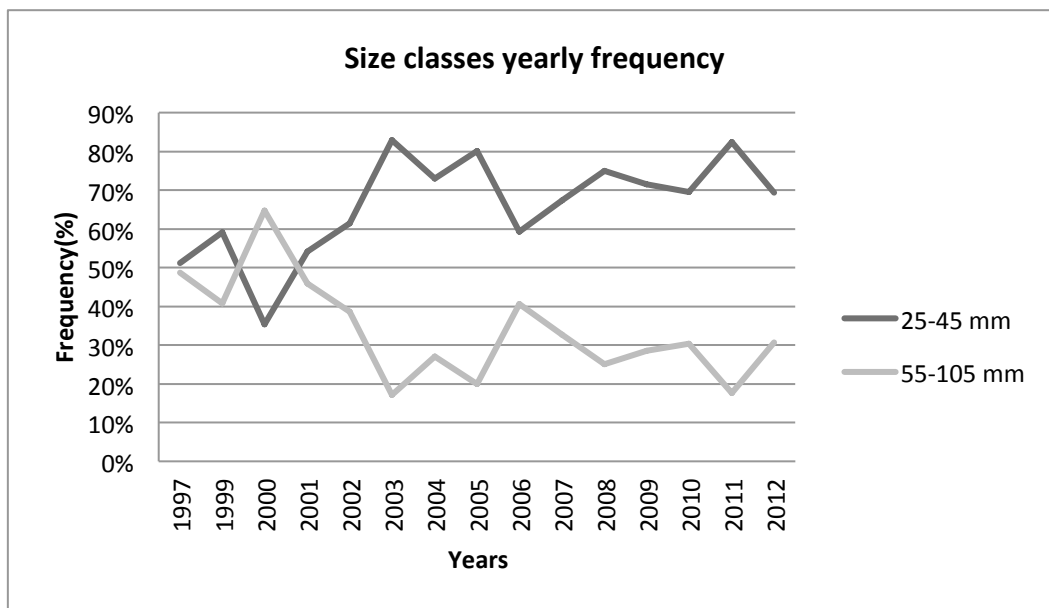


Figure 05: Yearly size frequency contribution in the Patos Lagoon. The gray line represents the 55-105mm size classes, and black line represents the 25-45mm size classes.

### 3.3- Seasonal variation in Length Frequency

The histogram shows a sharp decrease in abundance of all size classes from June to November (winter and spring). From December to May (summer and autumn) an increase in frequency occurs, with smaller classes (25-45 mm) been more important in December and January. From March to April the small sizes abundances reduces considerably, prevailing the intermediate and larger classes (Figure 06).

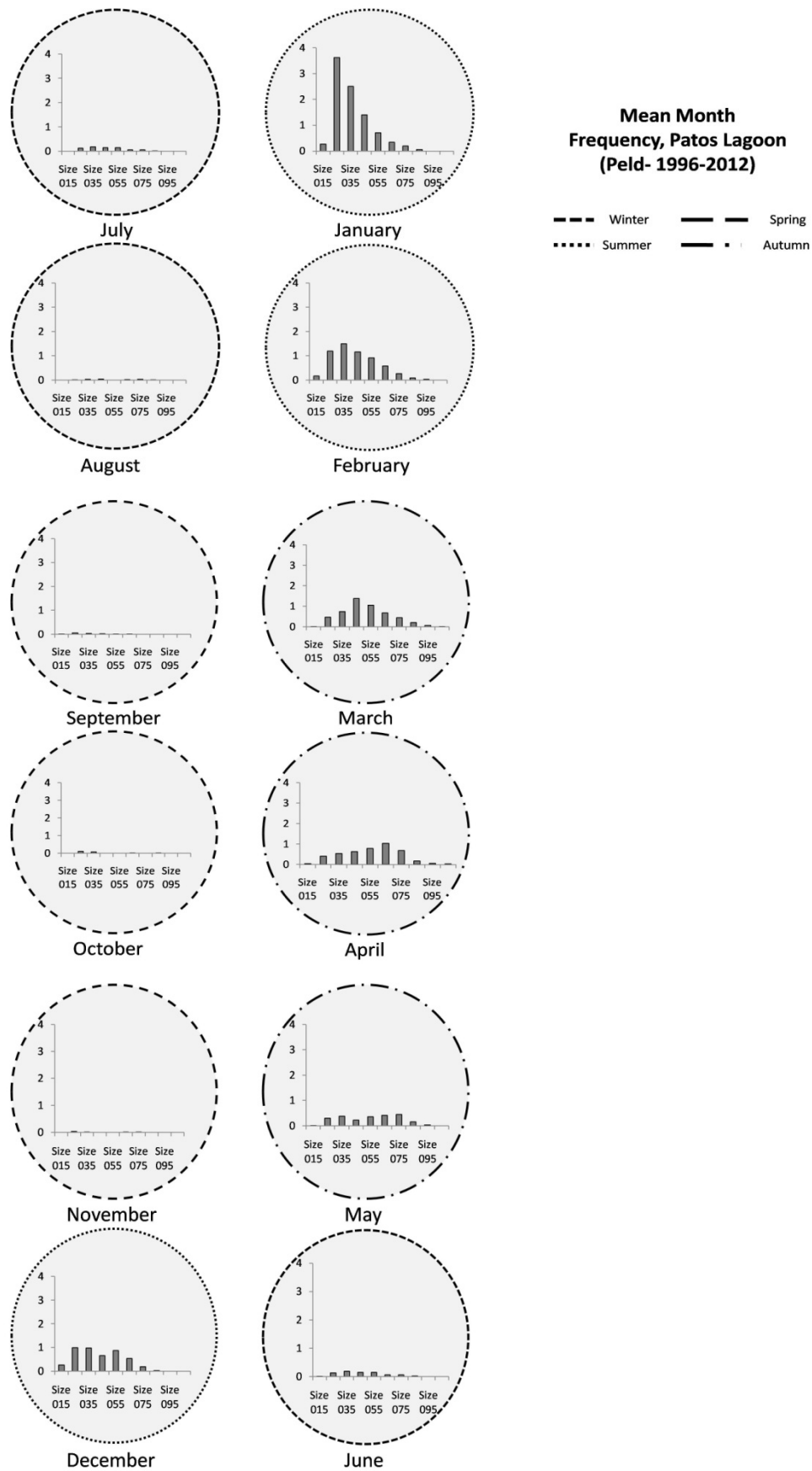


Figure 06: Monthly Variability in size class distribution. The Y axis is the mean frequency between all the years. The X axis is the size classes.

### 3.4- Spatial Variability in length frequency along the estuary

The PL4 and PL3 points were those with greater abundance in the PLE (Figure 06). The length frequency histogram shows that PL1 has a great percentage of small individuals. The 25 and 33 mm classes constitute 77% of abundance from individuals at this site (Fig.7). A factor analysis without replicates shows that there is significant difference between the sites ( $p < 0.05$ ). The PL1, PL2 and PL5, points have proportionally higher values of individuals in 25 and 35 mm classes. Points PL3 and PL4 have higher ratios from the 45 mm class onward (Fig. 7 A and B).

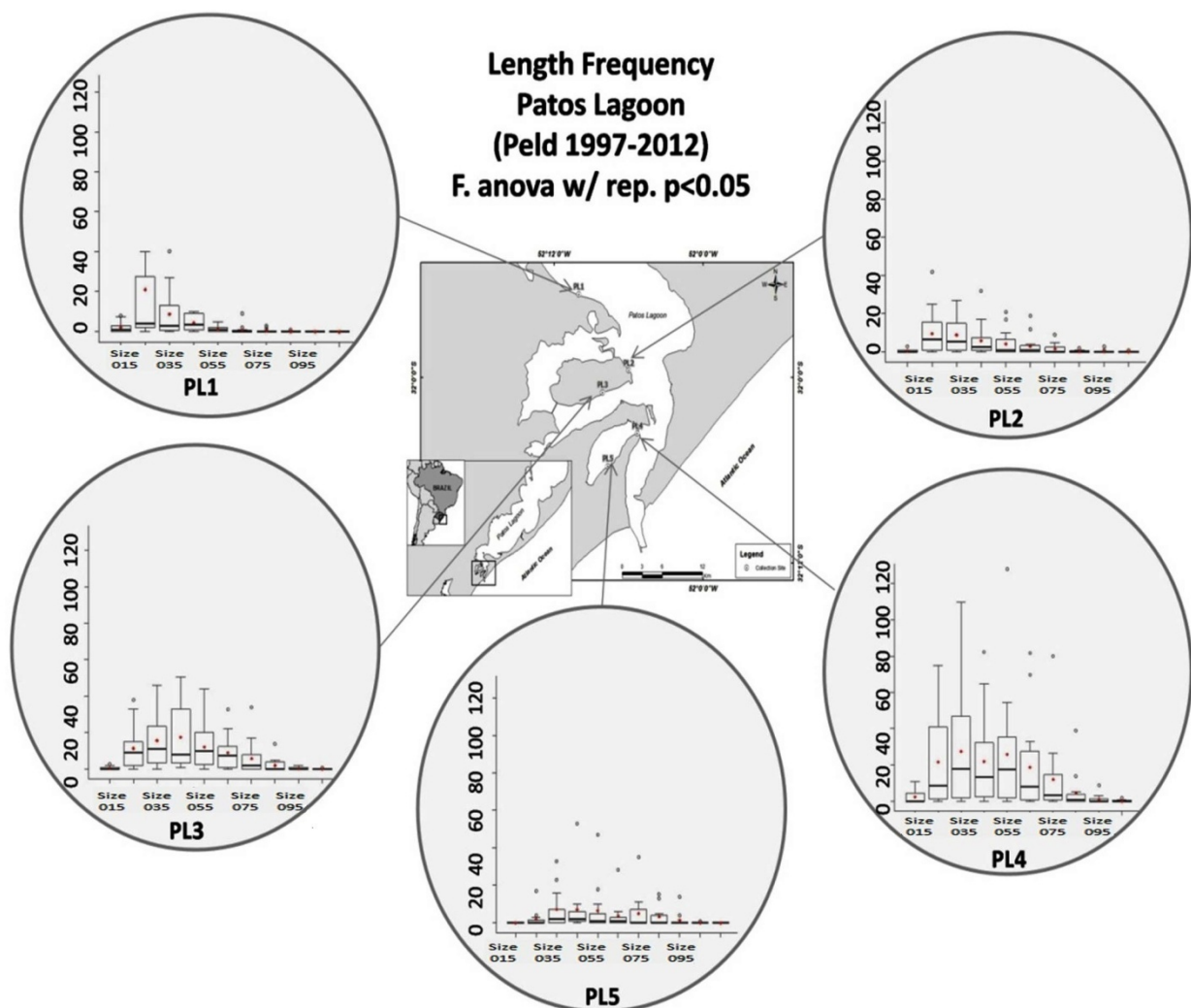


Figure 07: Length frequency analysis in five sites of Patos Lagoon estuary. Red point = mean; Lower bar= First quartile; Upper bar = third quartile; Middle bar= mode.

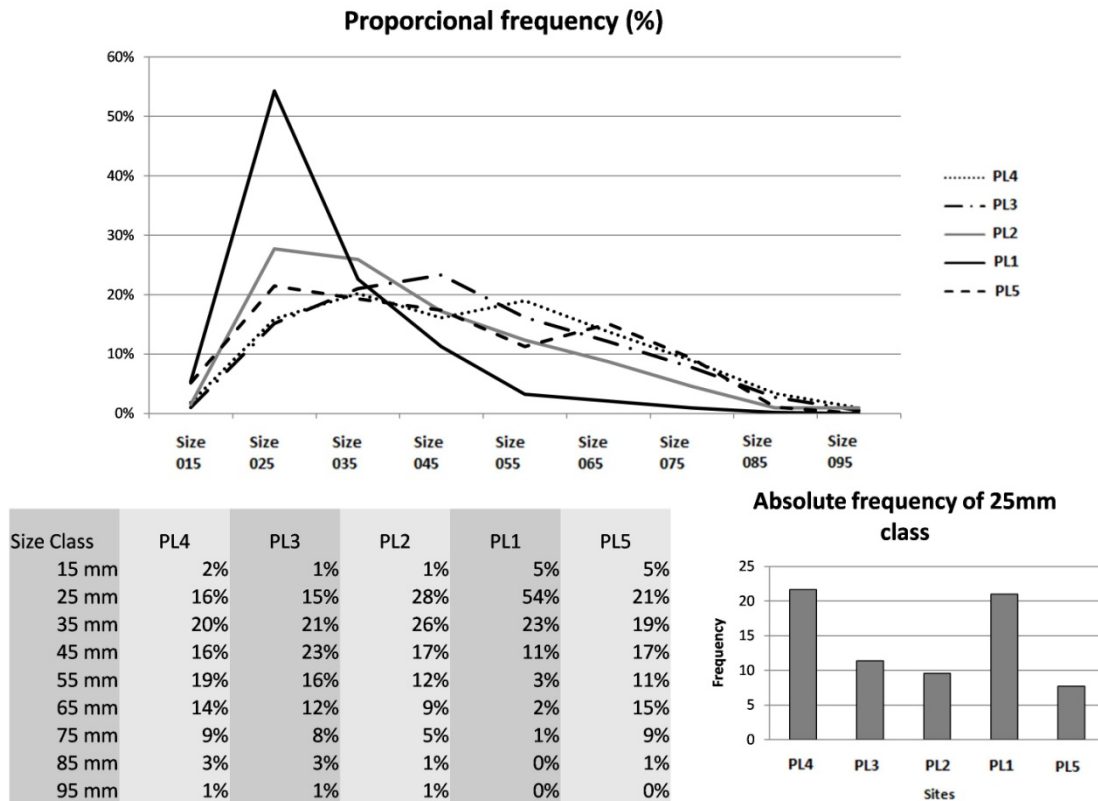


Figure 8: Graph and table of the length frequency classes ratio (A and B, respectively); Actual frequency of the class of 25 mm (C).

### 3.5- Similarity analysis

Cluster analysis with the Bray-Curtis index showed a cophenetic correlation index of 0.898 showing the good fit of the analysis (Sokal & Rohlf, 1962). Two groups and one subgroup were formed (Figure 08), the first comprising PL4 and PL3 and a second by PL2 and PL5; with PL1.

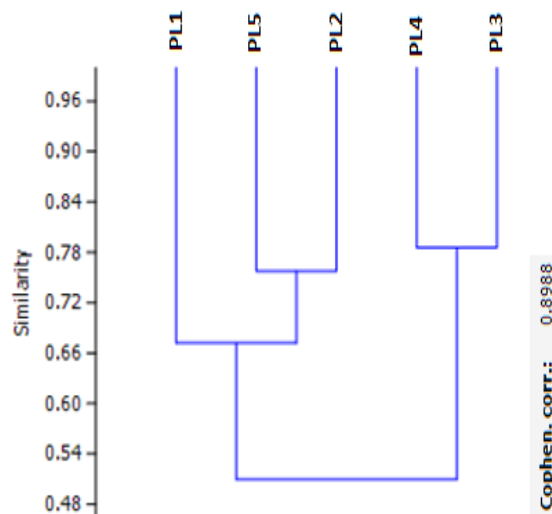


Figure 09: Cluster analysis with Bray-Curtis index

#### 4- Discussion

##### 4.1- Length frequency in PLE

Through the analysis of length frequency in PLE, the size of recruitment from the sampling gear is 25 mm, so the data will be analyzed from this size class onwards. A pattern of decreasing density was found with increasing the size class (Figure 03). The species has characteristics of r-strategists (high fecundity, short life cycle, etc.) (Garcia & Le Reste 1981; Odum 1983; D'Incao 1991, 1999), being congruent with the high densities of small size classes individuals. Crustaceans with smaller sizes presents a higher susceptibility to predation (Bemvenuti, 1987), and the larger sizes a susceptibility to fishing mortality (D'Incao & Calanzans 1978; D'Incao 1984, 1991), justifying this decline pattern along the size classes increase.

The NMDS distinguish three groups based on its abundance: A small size class (25-45mm), an intermediate size class (55-75mm), and a big size class (85-95mm). A tendency of increasing the 25-45mm size classes abundance and decreasing the decreasing the 55-105 mm through the years is shown in Figure 05 (A and B). The pearson correlation shows that salinity, temperature and transparency have no effect in the abundance of the small and big to intermediate size classes. Therefore, why are the big classes decreasing? Since the last century, the *F. paulensis* stock is being indicated as overexploited (D'Incao 1991), and within the multiple causes of overexploitation in the literature there is the growth (when the individuals are fished before reaching the commercial size) and genetic one's (harvesting takes the individuals with a genetic that provides a better growth, remaining the individuals with less genetic potential to growth - Bohnsack, 1989. Although legislation restrictions for a minimum catch size exists (IN n°3 de 9 de fevereiro de 2004), it's sometimes hard to police the many artisanal fishers of the Patos Lagoon, whose huge fishing effort applied on the juvenile phase may have caused the stocks growth exploitation (D'Incao *et al.* 2002, D'Incao & Dumont 2010). Unfortunately, Noletto-Filho & Dumont (non published data) has indicated to be hard to detect variations in growth by Modal progression in Patos Lagoon, because of its high environmental variation, that gives few length frequencies, not enabling the progression of modes through time in some years; and cause there is only the juvenile phase at the lagoon underestimating the analysis for the whole life cycle. Another possibility is that the bigger juvenile classes are becoming more susceptible to natural mortality, with the city development the Lagoon is being exposed to more bioaccumulating pollutants (e.g. heavy metals), making shrimps more vulnerable to diseases (Pinto & Sanches-Filho,

2013), so when the juvenile reach a bigger size he has a critical level of contamination leading to death.

#### 4.2- Seasonal Variability in Length Frequency PLE

Figure 06 shows that the abundance of shrimp begins to be notorious in the months of January and December with the 25 and 35 mm size classes and decreases in April and May with the predominance of the 55-85 mm classes. Given that the size of recruitment to the gear is 25 mm, we can speculate that the post- larvae entry in the estuary, based on the von Bertalanffy growth equation parameters suggested by Noleto-Filho & Dumont (non published data), should occur one to two months prior to the first catch (October and November; Spring). From March to May the larger size classes becomes outstanding, suggesting the migration of most individuals from the estuary to the ocean in this period. Individuals of all size classes were found in all months, probably caused by the high variability of environmental factors that allows the entrance of larvae in the estuary during several opportunities (e.g. wind direction, rainfall, etc.) (Castelo & Möller 1978; D' Incao 1984, 1991; Fernandes *et al.* 2004; Möller *et al.* 2009).

#### 4.3- Spatial Variability of the Length Frequency along the estuary and environmental variables

Some authors suggest the positive influence of salinity (D'Incao 1984, 1991; Castelo & Möller 1978; Fernandes *et al.* 2002, 2004; Möller *et al.* 2009) and transparency (Minello *et al.* 1987) on shrimp's density; however, there are still few studies about the effect of these factors on the size classes' composition in the PLE. The sampling sites did not differ regarding salinity and transparency ( $p > 0.05$ ), and showed a wide amplitude for these variables - the average salinity of the upper points of the estuary is similar to the lower in many years (Fig. 02). However, some sites show no occurrence of some size classes over the study period (e.g. PL1 do not have classes larger than 75 mm size), suggesting that these factors do not directly influence the distribution of classes within the PLE.

Temperature and vegetation variables were not used in this study. Temperature data was collected but was considered inconsistent and vegetation are not part of the database availed to this research. Field observations showed that the temperature tended to be similar between sites, with only seasonal differences. The absence of vegetation data is considered a more relevant bias, given that in many researches their importance to the penaeid shrimp abundance has been highlighted (Coen *et al.* 1981; Heck &

Thoman 1981; Perez-castaneda & Defeo 2004). So even with none of these works relating the influence of vegetation to the size composition, it is still necessary to consider this bias in the research.

The study sites differed significantly regarding the size classes ( $p < 0.05$ ), and the cluster distinguished two groups as similar (Fig. 09): the first consisting of the PL1, PL2 and PL5 sites; and second by PL3 and PL4. The analysis results of the relative frequency of size classes showed that the first group (PL1, PL2 and PL5) have a greater number of individuals in the smaller size classes - mainly 25 mm - than the other points (Fig. 08). The PL1 point stood out in this analysis, with much higher values of the class of 25 mm than the others (54%) suggesting that this point may be important for recruitment. Therefore, does the small classes like that place or, instead, the big size classes don't like. Only 16% of the PL4 is constituted by 25 mm size classes. However, the mean frequency value is almost the same as those of PL1. Such pattern leads for the second option, suggesting that somehow big size classes are not suitable at PL1. Probably those individuals migrate from that region to other or to the ocean when they grow. At the other places is evident that it receives individuals migrating from other areas since the 35 to 55 mm classes are more abundant than the 25 mm (Figure 10). The class 65mm was more abundant at the PL5 point, this is probably because this region is closer to the estuarine mouth, so it receives more individuals migrating back to the ocean. Therefore it seems that PL1 and PL2 are an important place for managing purposes, but more detailed studies are still needed to critically evaluate the significance of this region for fisheries management for this species.

Therefore the distance from the mouth does not seem to be an important feature influencing the classes distribution, Unlike results obtained by Perez-castaneda & Defeo (2004) studying the spatial distribution and structure of four species of penaeid shrimp (*F. astecuz*, *F. notialis*, *F. brasiliensis* and *F. duorarum*) in a Mexico estuary. These authors suggest the use of more internal regions of the estuary as the shrimp grow. However, they did not make any statistical inference proving this pattern, relying only on a peak abundance occurring in that study year. Therefore, ignoring the annual variability of abiotic factors. Some important variables for abundance and size composition studies as sediment and transparency, has not been taken by the authors.

Demore (2001) made the sediment characterization of the Patos Lagoon. The PL1 and PL2 points are characterized in the survey as having very fine to medium sand and points PL3 and PL4 having very fine to medium silt. The sediments dynamics had a



series of changes associated with anthropic impacts in the whole XIX century (Calliari *et al.* 2010), but no dramatic event is described to his research study period, so we assume that the survey data of Demore (op.cit.) is reasonable to be considered in our own investigations. No studies characterizing the sediments of the point PL5 were found. The fact that the components of groups of similar size classes showed similar sedimentary compositions may be indicative that the type of sediment may influence the abundance of different sizes to this shrimp species in this estuary. Williams (1958) suggests that penaeid shrimp have distribution influenced by sediment type, and that *Farfantepenaeus aztecus* species - the most phylogenetically close to *F. paulensis* (Voloche *et al.* 2005) - differ in the distribution of organisms according to their size, with larger shrimps buried in soft substrates (silt) and the small hiding on the surface of coarser substrates like shell sand.

The type of sediment may influence the amount of organic material accumulated in the substrate - larger quantities of organic matter are more associated with silt (Buchanan & Longbottom, 1970; Tyson 1995). Jones (1973) reports that individuals of *F. aztecus* change their diet as they grow: with individuals between 25 and 44 mm feeding indiscriminately from the substrate surface; from 45 to 65 mm feeding only "portion of the organic matter"; and from 65 mm - as they begin to migrate to deeper ocean regions - become "more predacious" and may eventually feed debris and algae. Considering the above phylogenetic proximity, we believe in the possibility that the distribution pattern by size class from *F. paulensis* is similar to that found by *F. aztecus*, occurring major influence on the sediment type to the specie's biology.

## **5- Conclusions**

The shrimps, along its growth are not distributed homogeneously in the PLA; There is an evidence of overexploitation based on the tendency of abundance decreasing of the big sized classes through the years.

## **6- Acknowledgments**

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**Interannual variability in juvenile growth of pink shrimp (*Farfantepenaeus paulensis*) in a choked Lagoon from South Brazil.**

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**Abstract**

This investigation aims to describe the interannual variability in juvenile growth of the *F. paulensis* shrimp along the Patos Lagoon Estuary (PLE) and its relationship with abiotic factors. Sampling, between the years 1996-2012, was monthly performed under the project of Long-Term Ecological Research (Ictio/PELD CNPq - MCT). The collections were obtained in shallow areas, at 5 different sites sampled with a beach seine net type. Temperature, salinity and transparency data were obtained in conjunction with the biological sample for each sampling point. Information about flow, catch, Multivariate Enso Index and Ocean Color Radiometry were acquired in institutions that makes this data available publicly - ANA; CEPERG, NOAA; NASA, respectively. Size structure was analyzed by measuring the total length (TL) in millimeters. The shrimps were grouped into size classes intervals of 5 and 10 mm for the growth and correlation analysis, respectively. Growth was described for the pooled sexes using the von Bertalanffy growth model. Estimated growth parameters were  $L_{\infty} = 146$  mm,  $k = 3.17 \text{ year}^{-1}$ ,  $t_0 = 1.46 \text{ day}^{-1}$  and 1.44 years longevity. The estimated age at migration size (90 mm) was  $111.7 \text{ day}^{-1}$ . These estimates are acceptable for this phase of the life cycle species, characterized by a rapid growth. The number of cohorts and modal groups had significant negative correlation with river flow and positive with salinity, indicating the importance of these variables for recruitment. The juvenile abundance (CPUE) showed no correlation with any environmental variable investigated. Unlike the majority of the previous investigations on pink shrimp, cohorts and juvenile CPUE/Adult Catch are not always directly related. On the other hand, salinity and river flow may participate in the larval penetration process at the estuary, but not necessarily directly influence the abundance of it. Temperature seemed to influence shrimp abundance too.

**Keywords: Growth, pink shrimp, long term.**

## 1- Introduction

The Penaeid family includes many shrimp species of commercial interest worldwide, especially in tropical and subtropical coastal regions. Among them, it is important to highlight those belonging to the *Farfantepenaeus* genus, including *Farfantepenaeus paulensis*. This species, in conjunction with the *Farfantepenaeus brasiliensis*, has high economic and social importance in Brazilian South and Southeast regions (Perez Farfante & Kensley 1997), since they account for 17% of shrimp landings in Brazil (IBAMA 2007) and 0.2% of the world's mainly shrimp production (FAO 2007). The species is widespread distributed from the northeast (Ilheus, Bahia) to the south of Brazil, (Rio Grande do Sul), extending to Mar del Plata in Argentina is restricted as sporadic occurring. This species presents a complex life cycle, since adult broodstock occurs in the inner continental shelf (40m-80m), where mature females release their benthic eggs that hatch in a planktonic larva. The larvae are transported southwards and penetrate, as post larvae (PL), in several estuaries through the coast, including the Patos Lagoon (Brazil). Catches in this estuary reached about 8000 tons in the late 70's, representing 40% of the shrimp production of the country (D'Incao *et al.* 2002), being the most productive nursery ground in the country.

The oceanographic mechanisms that post larvae use to reach the estuaries are highly variable and yet poorly understood. Previous studies suggested that the post larval penetration of pink shrimp in the PLE is associated to low rainfall and low river discharge (Castelo & Möller 1978, D'Incao 1984, 1991; Möller *et al.* 2009, Pereira *et al.* 2012). Post larvae migrate down to the deeper and denser water layers when are transported inside the estuaries taking advantage of the salt wedge. Therefore, the frequency and the intensity of these salt wedge penetration events regulate the recruitment success of the pink shrimp, to a certain extent (D'Incao 1984, 1991; Möller *et al.* 2009).

Once the post larvae settle in shallow estuarine zones, their increment in size and weight are critical to the final production of the fishery. Understanding the main factors influencing growth of the pink shrimp during the juvenile growout phase is critical for stock assessment and management. (Hoggarth *et al.* 2006). The influence of several factors on growth, including temperature and salinity, have been investigated under laboratory conditions (Wasielesky 1999), indicating that growth and survival may change with salinity and temperature variation. However, the assessment of long term

variation in juvenile growth is unknown. Long term changes in growth may be related to environmental and fishery factors, and have been used to point out shifting patterns of several stocks (Cardoso & Haimovici 2011).

Estimation of individual growth for crustaceans is hindered by the molting process; that results in the absence of an age related apposition structure, such as otoliths (e.g. fish). As a consequence, direct methods of age estimation cannot be applied (e.g. analysis of calcified structures) in crustaceans. The modal progression analysis is, therefore, a widespread used approach to estimate growth (Garcia & Le Reste 1981; Sparre 2000; Chang *et al.* 2011), around the world – e.g. *F. californiensis*; *Litopenaeus stylirostris* in California Gulf (Medina & Soto 2001); *Metopenaeus joyneri* in Korea (Cha & Choi 2004); *Solenocera membranacea* in Mediterranean Sea (Demestre & Abello 1993).

Considering the great importance of the juvenile phase of the pink shrimp's life cycle (*F. paulensis*) for southern Brazil's stocks sustainability, it is important to survey for more detailed information about its ecology, emphasizing the comprehension of growth and recruitment pulses in an estuary driven by winds and rain. We are not aware of long term studies with the juvenile phase, especially in estuaries that are not regulated by ocean tides. For the adult phase, this kind of research is also rare; one of the most cited is the López-Martínez *et al.* (2003) for *Farfantepenaeus californiensis* in Sonora, Mexico. Therefore, this work aims to describe the temporal variation of the cohorts and to estimate growth parameters for the specie's lifecycle phase within the Patos Lagoon, as well as its relations with abiotic variables.

## **2- Material and Methods**

### **2.1-Study Area**

This study was conducted in the Patos Lagoon estuary (32 ° 52 S ° W), Rio Grande do Sul, the largest choked lagoon in the world (Kjerfve 1986). The salinity is regulated by atmospheric process, such as winds and rain, since the tidal range is despicable (0.4m) (Moller 2001, 2009; Moller & Fernandes 2010). The seasonal variations are constituted by high precipitation at the transition from winter to spring raising the water level inside the estuary (Marques *et al.* 2010) and expelling the salty back to the ocean (Moller 2010). However, it is not necessary a constant, in fact, ocean atmosphere interactions and ENOS phenomenon make the water dynamic inside the estuary highly variable and difficult to standardize (Grimm *et al.* 1998; Pereira & D'Incao 2012).

## **2.2-Biological Sampling and Biometry**

The size structure data, from the period of 1997 to 2012, were monthly obtained through the *Programa Ecológico de Longa Duração- Ictio* (PELD CNPq - MCT). The samples were collected by using a standardized beach seine, 9m in length; 13 mm of mesh size in the wing and 5 mm mesh size in the body (Moraes *et al.* 2012). Sampling stations were performed in shallow areas (average depths lower than 1.5 m). Samples were monthly obtained in 5 sites with 5 replicates each (totalizing 4800 samples during 16 years) (Fig 01). The water's temperature °C, salinity and transparency (secchi cm) data were also obtained for each sampling site. Monthly discharge from the main Patos-Mirim system rivers (Jacuí, Taquarí and Camaquã) were acquired from the National Water Agency site (ANA - [hidroweb.ana.gov.br](http://hidroweb.ana.gov.br)). The shrimp adult Catch data from the industrial vessels were acquired from the Research and Management Center for Lagoon and Estuarine Fishery Resources (CEPERG/IBAMA/MMA - <http://www4.icmbio.gov.br/ceperg>) and the Ranked Multivariate Enso Index (MEI) at the National Oceanic and Atmospheric Administration (NOAA) (Wolter & Tim 1993, 1998). An Ocean Color Radiometry analysis and visualization were produced, monthly for the 2001-2012 period, with the Giovanni online data system, developed and maintained by the NASA GES DISC (Acker & Leptoukh, 2007).

The total length (TL in mm)(i.e. from the tip of the rostrum to the end of the telson) was used to estimate growth in size. Length class interval adopted was 5 mm. The growth curves were established grouping both genders, since the legislation and the enforcement is based on a single TL disregarding gender, assuming the bias from the sex specific differences (D'Incao 1978, 1984).

## **2.3- Growth Analysis**

Provided that recruitment inside PLE starts in Spring and may extend to early Autumn, the recruitment years were analyzed, instead of the calendar years. Growth of cohorts was estimated through Modal Progression Analysis (MPA), using a length class interval of 5 mm to obtain length-frequency histograms. Modal groups were obtained from the length frequency histograms. They were connected by trial and error for the cohort composition according to the biological coherence with longevity and maximum length observed in samples (D'Incao & Fonseca 1999). Length data were fitted to von Bertalanffy Growth Model (VBGM) (1938) by an automated least square procedure using the Nonlinear Regressive model, ordinary least squares (Legendre 1805), varying



the parameters  $k$ ,  $L_{\infty}$ , and  $t_0$  with the "generalized reduced gradient" algorithm (Lasdon 1975). The VBGM is given by:  $L_t = L_{\infty} [1 - e^{-k(t-t_0)}]$ , where  $L_{\infty}$  is the asymptotic length,  $k$  is coefficient of growth and  $t_0$  is the theoretical age when the size is equal to 0. The seeds parameters  $k$  and  $L_{\infty}$  ( $0.00349 \text{ day}^{-1}$  and 220 mm, respectively) were determined from mean of males and females obtained from the literature (D'Incao 1984); and  $t_0$  being zero. A residual analysis was performed to test the assumptions of homogeneity of variances ( $\chi^2$  test) and autocorrelation (Davis, 1986), the normality of the residuals (D'Agostino test) (D'Agostino *et al.* 1990) by using the software R. 2.13. The coefficient of determination ( $R^2$ ) was calculated by the formula:  $R^2 = 1 - \frac{\sum(Y - Y_{\text{model}})^2}{\sum(Y - Y_{\text{mean}})^2}$  which value ranges between 0 and 1 (the closer to 1, the better the fit) and the confidence interval adopted was 5%, which is calculated by the formula:  $\sqrt{\frac{\sum(Y - Y_{\text{model}})^2}{df}} \times \varphi$ . Where  $Y$  = observed independent variable;  $Y_{\text{model}}$  = estimated independent variable;  $df$  = degrees of freedom;  $\varphi = T$  student table value. The longevity ( $t_{\text{max}}$ ) was estimated by the inverse von Bertalanffy equation (1938):  $T_{\text{max}} = t_0 - (1/k) \ln [1 - (L/L_{\infty})]$ . The parameters described above were estimated yearly and for entire time series. The yearly estimated parameters  $K$  and  $L_{\infty}$  were compared by a  $T$  student test.

#### 2.4- Cohort Analysis

The cohort, at the present work is a group of individuals that had born at the same period, and it's constituted by modal groups with biological coherence as aforesaid. The correlation between the number of cohorts and the environmental parameters collected (water's temperature, salinity and transparency) during a recruitment year was tested by a Pearson correlation. Additionally, modal groups obtained from length-frequency data were correlated with environmental variables (water's temperature, salinity, transparency, flow, etc.) in order to obtain a more direct estimate, enabling the detection and correction of any possible bias that a cohort-only analysis could generate (e.g. insufficient sampling; presence of modal groups, but the impossibility of forming biologically coherent cohorts, etc). It is important to realize that modal groups are not the same as cohorts groups - the first includes the second one - and both are being used separately at the correlation analysis.

#### 2.5- Juvenile Abundance

The juvenile abundance was calculated by the Capture by Unit Effort (CPUE), dividing the total catch in the sampling by the number of replicated takings. The index was used for correlations with cohorts, modal groups and environmental variables

## **2.6- Multivariate Enso Index - MEI**

Years classified by the ranked multivariate Enso index (MEI)(Enso region 3.4) (Wolter & Timlin 1993, 1998) as having an Enso phenomenon, were analyzed graphically and statistically with modal groups, cohorts numbers (obtained from the modal groups), adult catch and environmental variables. The MEI was estimated taking the mean ranked data from the months of second semester of the preceding year and the first semester of the adult catch year (and variables related to it) (e.g. MEI from 1997 was calculated from months of the second semester of 1996 and the first semester of 1997) instead of the whole catch year, because the recruitment of a given year starts on the second semester of its preceding, and any environmental anomaly at that period would influence the yield of the year after (Pereira *et al.* 2012). The ENSO information was validated with the CEPTEC/INPE data (<http://www.cptec.inpe.br>).

## **2.7- Statistical Software's**

The correlation and normality and homocedasticity assumption's analyses (Pearson correlation; Anderson-Darling normality;  $X^2$  test for variance homogeneity) were done by the free Microsoft Excel Spreadsheet, Action 2.5 (©Copyright ®Estatcamp, 1997-2014). The independency analysis was made by the PAST 3.0 (Hammer *et al.* 2001).

## **3- Results**

During the study period (Jan 1997 - Dec 2012) a total of 5200 shrimps were collected, ranging in size from 10 to 105 mm (TL) and classified into 19 size classes of 10 mm interval, generating a total of 426 modal groups. The total length ranged from 10 mm sampled in 1997 to 105 mm recorded in 2011. Abundance (CPUE) was higher in absolute values at the 2000, 2005 and 2009 years and lower at the 1998, 2001, 2003, 2010 and 2011 (Fig 2).

### **3.1- Growth Analysis**

A total of 40 cohorts were found in the 16 years of study, ranging from 0 to 6 per year. The parameters estimated by non-linear regression model, fitted to the von Bertalanffy equation were  $L_{\infty} = 146$  mm,  $k = 0.0087 \text{ day}^{-1}$  ( $3.17 \text{ year}^{-1}$ ),  $t_0 = 1.46 \text{ day}^{-1}$  (Fig. 03) and longevity of 1.4 years. The parameters  $k$  ranged from 2.2 to 5.9 and  $L_{\infty}$  ranged from 100 to 210 (Table 01). The  $k$  ( $p > 0.05$ ; T student = 0.02) and the  $L_{\infty}$

( $p > 0.05$ ; T student = 0.28) did not statistically differ within the years. The longevity found for the migration size of 90 mm (D’Incao & Calazans 1978) was  $111.7 \text{ day}^{-1}$ . All assumptions of the analysis were obtained (homoscedasticity and independence). The coefficient of determination ( $R^2 = 0.95$ ) was significant ( $p < 0.05$ ) showing the good fit of the model VBGM. The model residues showed normal distribution, which makes it similar to the maximum likelihood method.

### **3.2- Correlation Analysis**

All the correlation analyses are summarized in Table 02. All assumptions of the Pearson correlation analysis were achieved (normality, homoscedasticity and independence).

The variables transparency, flow and salinity were significantly correlated ( $p < 0.05$ ) with each other. Temperature didn’t presented no significant correlation with any other variable.

The number of cohorts was significant correlated with salinity, flow, CPUE and Adult Catch. The modal values presented high correlation with cohorts ( $r \text{ Pearson} = 0.85$ ;  $p < 0.05$ ) and, also, with salinity, river discharge, juvenile CPUE and Adult Catch (Fig. 04). The juvenile CPUE was correlated only with the number of modes, cohorts, and adult Catch, exhibiting no direct relationship with environmental variables (e.g. salinity, flow, etc). The adult catch correlated with salinity. The modal values, adult catch, river discharge ( $r = 0.6$ ;  $p < 0.05$ ) and salinity ( $r = -0.7$ ;  $p < 0.05$ ) significantly correlated with MEI.

The modal groups was highly significant with cohorts ( $r \text{ Pearson} = 0.85$ ;  $p < 0.05$ ) and with all the same variables as this one correlates (e.g. salinity, river discharge, juvenile CPUE and Adult Catch). The juvenile CPUE was significantly correlated with the number of modes, cohorts, and Adult Catch exhibiting no direct relationship with environmental variables (e.g. salinity, flow, etc). The Adult Catch correlated with salinity. The MEI significantly correlated with the Adult Catch ( $r = -0.8$ ;  $p < 0.05$ ), modes ( $r = -0.8$ ;  $p < 0.05$ ), river discharge ( $r = -0.7$ ;  $p < 0.05$ ) and salinity ( $r = -0.9$ ;  $p < 0.05$ ) (Fig. 05).

### **3.3- Surface temperature analysis**

The surface temperature analysis (2001-2012) showed that the 2003, 2007, 2010 and 2011 as being the more enduring and cold years, and the 2001, 2004 and 2005 with the less severe winters (Fig. 06).

## **4- Discussion**

#### 4.1- Growth Analysis

Defining what would be an acceptable von Bertalanffy curve for a given specie is still controversial. Since there are different methods (e.g. Bhattacharya; Elefan I and II; D’Incao and Fonseca method; etc) (Bhattacharya 1967; Pauly 1979, 1984; D’Incao & Fonseca 1999) and surveys are being done at different conditions – at different environments, or in ponds. So different places in time or location may result in different parameters estimations, so it is difficult to establish what would an acceptable standard for all individuals of a given specie in the midst of such methodological diversity.

The parameters estimated by the von Bertalanffy equation were  $L_{\infty}$  = 146 mm,  $k$  = 3.17 years<sup>-1</sup> and  $t_0$  = 0.004 years<sup>-1</sup>. The suggested  $k$  values for penaeid shrimp in the literature range from 0.25 to 2.5 years<sup>-1</sup> (Pauly *et al.* 1984); 1.8 to 3.6 years<sup>-1</sup> (Garcia & Le Reste 1981); and around 2 years<sup>-1</sup> (D’Incao & Fonseca 1999). Therefore, our results are above the Pauly’s estimate (op.cit) and within the suggested by Garcia & Le Reste (op.cit). D’ Incao (1978), studying the 76/77 years catch at Patos Lagoon, had estimated the value of  $k$  for *F. paulensis* juveniles. The author found an estimate of 3.38 years<sup>-1</sup> for females and 4.48 years<sup>-1</sup> for males, which are consistent with the data found in this study with the pooled sexes. Six years later, D’ Incao (1984) developed a new study because he considered the previous one as underestimated for the specie’s entire life history, and found values for  $k$  of 1.27 years<sup>-1</sup> for males and 1.047 years<sup>-1</sup> for females. Branco & Verani (1998), studying pre-adults and juveniles - in *Lagoa da Conceição*, Santa Catarina – have found  $k$  values of 2.76 years<sup>-1</sup> for males and 2.4 years<sup>-1</sup> for females, using the methodology proposed by Santos (1978). These results are below those found in the present study, which can be attributed to differences in methodologies – Santos methodology (1978) was developed for intensive farming, where are expected higher growth rates - or differences on the individual’s growth rates among the study sites – organic content, salinity, and temperature may influence growth (Riera, 2000; Wasielesky, 1999).

The  $k$  value found with the present methodology is considered high, because it is greater than or very close to the limit suggested in the literature for this specie and genus. The use of only juvenile shrimp life stages can be the cause of this difference, because during this phase the specie presents the highest growth rates (Dall *et al.* 1990). Then we consider the results consistent with the phases of life cycle that takes place within the Patos Lagoon.

The  $k$  values didn't significantly changed between the years. Since methodologies involving model progression analysis (e.g. Bhattacharya; D'Incao & Fonseca 1999, etc) depends of some empiricism, where the researcher decides what would be biological coherent for that specie. It's expected the cohorts of all years to be chosen by the same criteria, resulting in similar  $k$  values, and this is one of the limitations of model progression in time series analysis.

The  $L_{\infty}$  values were below those found for the specie by D'Incao (1984) – 192 for males and 248 for females - as already expected since we only had the juvenile phase. For the same reason the growth curve obtained didn't formed an asymptote (Fig. 03), therefore, the  $L_{\infty}$  in our model is not the “maximum asymptote length”. The  $L_{\infty}$  values are consistent with the 127.68 for males and 151 for females (data transformed by the D'Incao & Calazans – 1978 - biometric equation) found by D'Incao (1978) for pink shrimp juveniles. The data is also coherent with the values found by Branco & Verani (1998) (118 for males and 132 for female – data transformed according to D'Incao & Calanzans 1978) for juveniles and pre-adults in estuaries.

#### **4.2- Longevity**

The longevity value estimated was 1.4 years. However, the longevity value must be interpreted with caution. In many papers, researches interpret their longevity found by the model as “the maximum age that the species live” without checking whether or not an asymptote was formed – this can be made visually, looking at the growth curve. Therefore, in our case, the longevity value estimated by the von Bertalanffy model can only tell the age limit that the individual reach, with a growth coefficient  $k$  to size length  $L_{\infty}$ , and not necessarily when the individual may die (most may never even come to that size), because the model didn't formed an asymptote. The point is that  $k$  and  $L_{\infty}$  are the keys for understanding the longevity results, since we only have a juvenile length frequency, and it must be interpreted as: the maximum age that shrimps grows with the  $k$  coefficient of  $3.17 \text{ years}^{-1}$  to the size of 148 mm.

The literature suggested values for longevity ranges from 1.5 to 2.3 years (D'Incao and Fonseca 1999) and for penaeids are from 2 to 2.5 years (Garcia & Le Reste 1981). Considering that this study is with only one part of the specie's life cycle, it is expected for the longevity values to be below those found in the literature. The D'Incao (1984) equation is a good standard to validate our model, since our study region is encompassed at his study, and he also used adult shrimps. Inverting his equation to find longevities for a  $L_{\infty}=148$  (from our equation), the results found are 0.8 years for

females and 1.12 years for males, these results are not so far from the 1.4 years for pooled sexes from the present article. So it is suggested that if it is estimated *F. paulensis* growth equation for its whole life cycle, however, from that equation is gathered information about the juvenile phase, the results found would be equivalent to use a growth equation using only the juvenile phase. Although it wouldn't be possible to extrapolate the results from a juvenile growth equation to the adult phase.

The average time that the cohort takes to reach the migration size was 110 days, which is consistent with the results found by D' Incao (1984) (150 males and 110 females days), and to the 3 to 4 months values found by Noletto-Filho & Dumont (Unpublished results).

#### **4.3- Cohort, Modal analysis and environmental variables**

The Pearson's correlation analysis suggests that salinity and river discharge influenced the cohorts and modes ( $p < 0.05$ ). The ENSO are noticed to increase the magnitude of these variables (except salinity) because of the estuary's geographic position, reflecting in interannual changes in wind and river discharges (Fernandes *et al.* 2002; Moller 2009; Möller & Fernandes 2010). Since ENSO affects environmental variables that directly influence shrimps abundance and recruitment (e.g. river discharge,  $r = 0.7$ ; salt water inlet – salinity,  $r = -0.9$ ) it is expected to also correlates to abundances, modes (recruitment indirect measure) ( $r = 0.6$ ) and Adult Catch ( $r = 0.7$ ).

The salty water wedge, driven by winds, is considered the responsible for carrying the recruits from the ocean to the estuary, but if river discharge is too high it doesn't allow the salty water to penetrate inside the estuary as well as the recruits in the surf zone. This logic has been built since half of the 20<sup>th</sup> century, resulting from deductive inferences (D'Incao 1984, 1991) or from statistical inferences from Adult Catch data (Castelo & Möller 1978; Fernandes *et al.* 2004; Möller *et al.* 2009; Pereira *et al.* 2012). Catch data are not recommended to estimate abundance, since the applied effort is unknown, and its use may mislead conclusions (Jennings 2001; Hinton & Maunder 2003; King 2007). For example, catch information (from public data base; CEPERG/IBAMA) significantly correlated with salinity, but the juvenile CPUE (recommended for most fishery bibliography) measured from our database, did not.

Most researches treat abundance and recruitment as always being synonyms or directly related, and that is not always true. It may be true for some years (e.g. 1997, 2000, 2005, etc) since a moderate correlation between Adult Catch and Juvenile CPUE and modes exist, but a more detailed analysis shows different patterns in some years.

Taking as an example the 2004, 2005 and 2006 years (Fig 04), we can see a close numbers of modes which directly follow the salinity line; however the same is not true for the Adult Catch, which greatly varies in those years, with a peak in 2005 and then decreasing in 2006, even with “favorable environmental conditions”.

Although, temperature didn't significantly correlated with any environmental variable, the visual image analysis that was acquired from NASA (Fig. 06) (Acker & Leptoukh, 2007), shows that, the more severe cold water years coincides with low number of modal groups and low abundance years. The impact of temperature on shrimp catch was indicated by other author too, for other shrimp species (Ayub 2010; Barko & Harabic 2002)

Therefore, we can conclude that environmental factors influence the entrance of larvae in the estuary (recruitment), however, the same is not true for juvenile CPUE and Adult Catch. In other words, it is not because the conditions are favorable for juvenile's recruitment in the estuary that this will necessarily result in a good catch. The reasons for the absence of a strong correlation between abundance and recruitment are not yet clear. Density dependent factors could be one possibility since it was described to occur between recruits and juveniles of *Farfantepenaeus duorarum* in Florida (Ehrhardt *et al.* 2001), but sampling on post larvae is necessary to clarify such thing. Other possibility is the influence of fishing effort with the natural resilience time of the stock (D'Incao 1991) or some kind of natural oscillation in the population, given that it is observed abundance peaks at intervals of one to two years (Fig 04 and 05).

The number of cohorts ranged from 0 to 6 through the study period. No one had discussed what it would be a reasonable number of cohorts to the PLE, most of the papers doesn't even say how many were found. Probably, that's because most of them utilize only short time series, which makes it difficult to establish a limier in a place with such environmental variance. The number of cohorts found by the present work may not be exactly the one that happens in nature - in fact it's truly difficult to a model do it – but, the correlations with some environmental variables (e.g. salinity; river discharge; MEI) makes us believe that it's at least proportional to the real one.

#### **4.4- Results Validation**

The model exhibited an excellent fit, given the index of determination of 0.95 ( $R^2$ ) and the sanction of the independence and homoscedasticity assumptions. Many studies neglect the importance of those assumptions for the model's proper validation, and this can bias the estimates obtained. Normality is not an assumption of ordinary

least squares analysis. However, the achievement of normality, approaches the method to the maximum likelihood, bringing the advantage of working with a better understood distribution in the scientific community and a more consistent model, which generates lower variance's estimators (Naghettini 2007).

The methodology proposed by D'Incao & Fonseca (1999), although still needs some improvements (Noieto-Filho *et. al.* non-published data), had its validity improved mainly by: The significant correlation between cohorts and environmental variables; and the consistency of the parameters calculated by the model with a good correspondence to the observed in the environment and literature.

## **5- Conclusions**

The growth rate (k) of 3.17 years<sup>-1</sup> is consistent with the life cycle's phase of *F. paulensis* within the Patos Lagoon. The growth model suggests that this specie takes about 111 days to reach the 90 mm capture size. Environmental factors influence the entrance of larvae in the estuary, with abundance (CPUE) being only indirectly influenced by these.

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## Tables

Table 01: Yearly growth parameters.  $L_{\infty}$  is the asymptotic length,  $k$  is coefficient of growth and  $t_0$  is the theoretical age when the size is equal to 0.

Year	1997	1999	2000	2001	2002	2004	2005	2006	2007	2008	2009	2011	2012
$L_{\infty}$ (mm)	122	114	117	109	113	105	148	141	138	113	148	100	210
$K(\text{year}^{-1})$	3.91	4.52	5.99	4.39	4.42	5.47	3.11	3.12	3.24	4.79	3.11	4.78	2.20
$t_0$ (Day <sup>-1</sup> )	1.37	2.78	2.78	2.57	0.34	1.81	1.83	2.24	1.51	0.82	-8.21	-9.65	1.33
Longevity (year)	1.175	1.01	7.67	1.04	1.03	0.84	1.47	1.47	1.42	0.95	1.47	0.54	2.092

Table 02: Pearson correlation matrix, emphasizing the statistically significant values (\*)

	<i>Cohorts</i>	<i>Discharge</i>	<i>Salinity</i>	<i>Transparency</i>	<i>Cpue</i>	<i>Modes</i>	<i>Temperature</i>	<i>Catch</i>
Cohorts	1	-0.549*	0.775*	0.45	0.544*	0.868*	0.035	0.762*
Discharge	-0.549*	1	-0.811*	-0.577	-0.157	-0.598*	-0.462	-0.434
Salinity	0.775*	-0.811*	1	0.681*	0.449	0.711*	0.333	0.653*
Transparency	0.450	-0.577*	0.681*	1	0.183	0.437	0.497	0.126
Cpue	0.544*	-0.157	0.449	0.183	1	0.542*	0.214	0.670*
Modes	0.868*	-0.598*	0.711*	0.436	0.542*	1	0.320	0.755*
Temperature	0.0349	-0.461	0.333	0.497	0.213	0.320	1	0.039
Catch	0.762*	-0.433	0.653*	0.125	0.670*	0.755*	0.039	1

## Figures

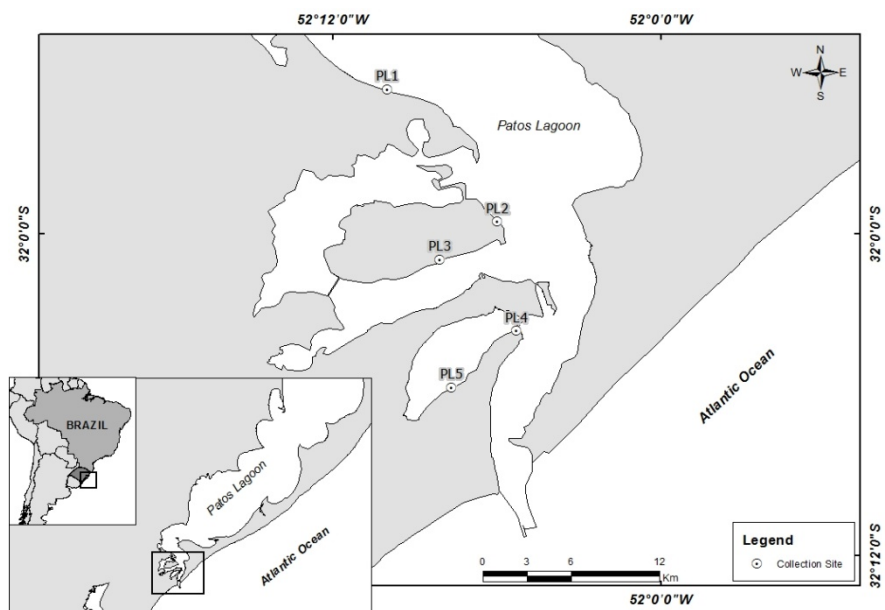


Fig 01: The location of the five sampling stations along the Patos Lagoon estuary.

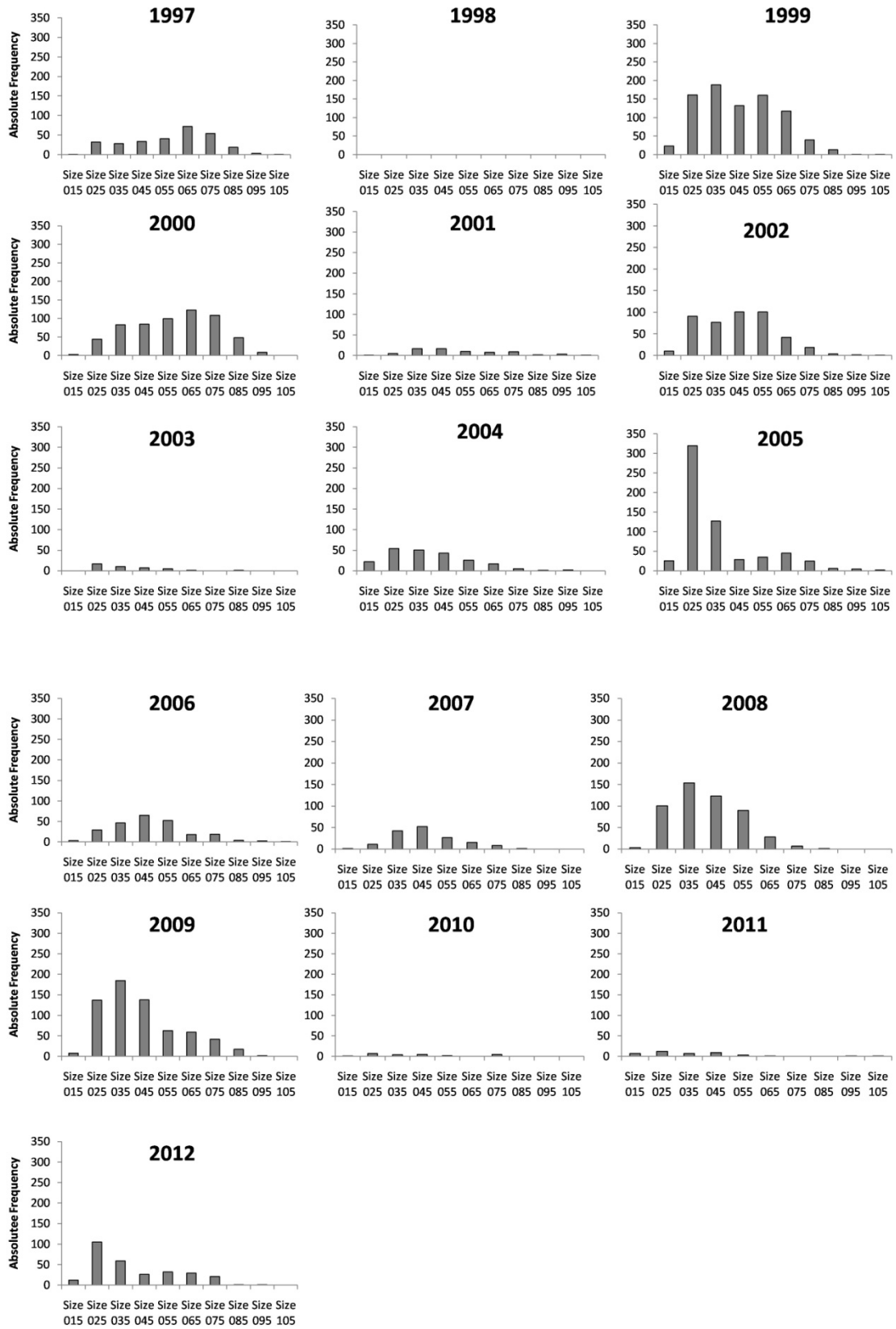


Fig 02: The 1997-2012 yearly absolute size frequency histograms of *F. paulensis*. The shrimp are divided in 10 mm size classes.

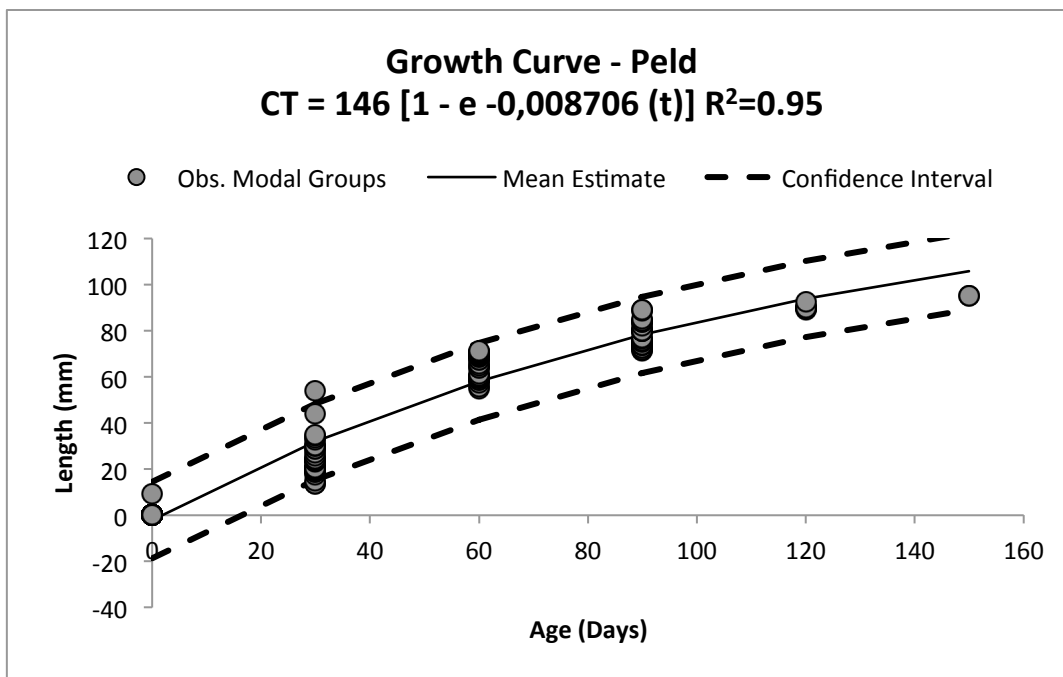


Fig 03: *F. paulensis* juvenile total length growth curve in PLE. The von Bertalanffy growth equation is shown together with determination coefficient ( $R^2$ ). The middle line is the predicted curve. The up and down lines are the 95% confidence interval.

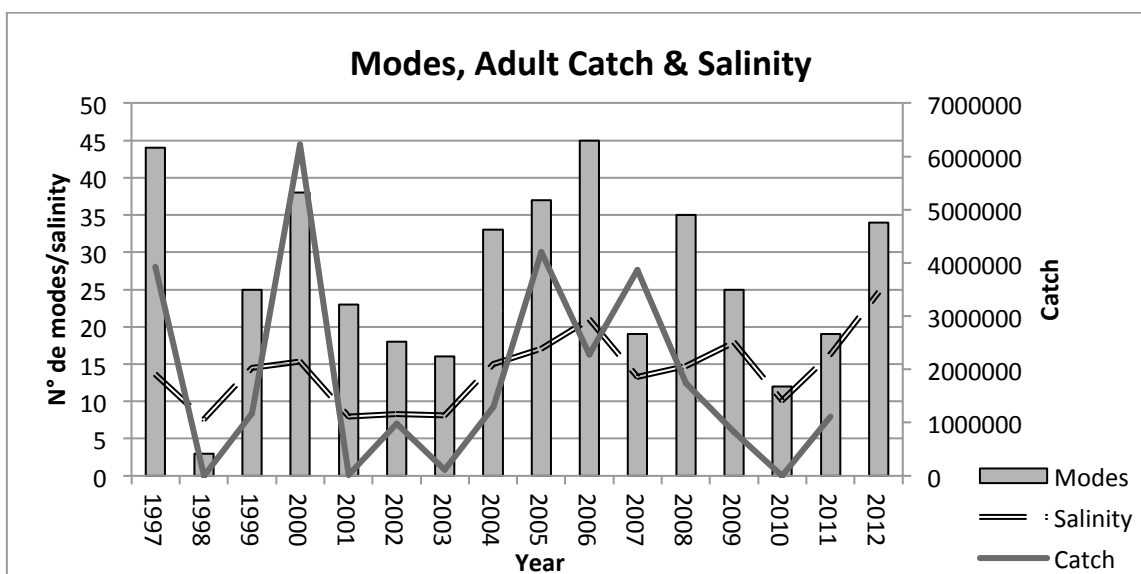


Fig 04: Annual mean of the most significant correlated variables in sixteen years of study (PELD 1996 - 2012). The gray column represents the mean modal groups; the white column is the Multivariate Enso Index; The dashed line is the salinity.

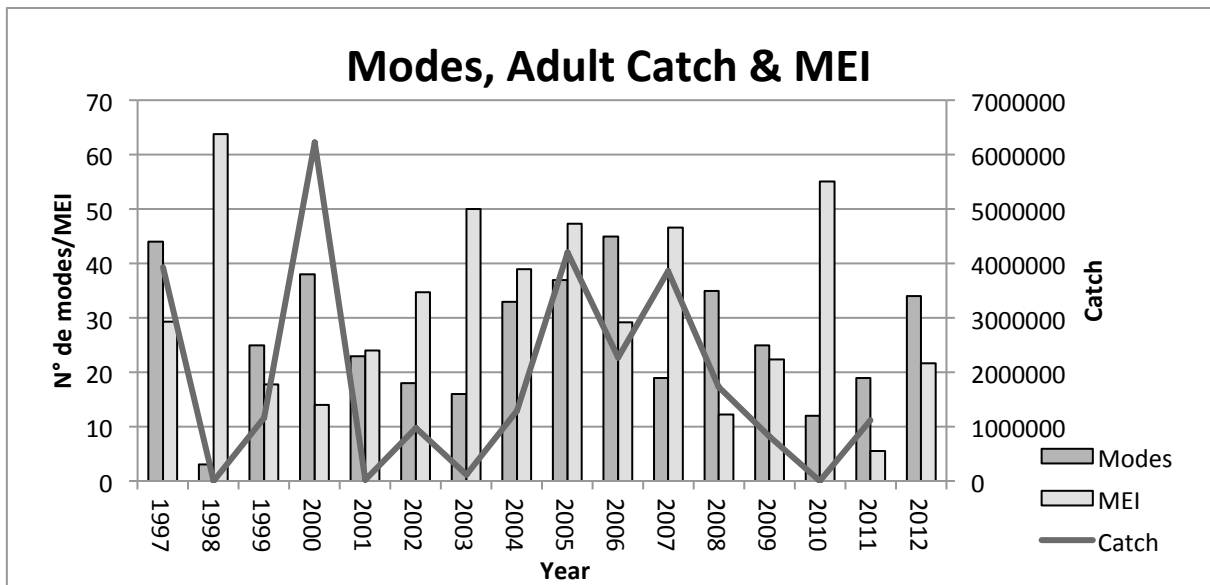


Fig 05: Annual mean of the most significant correlated variables in sixteen years of study (PELD 1996 - 2012). The gray column represents the mean modal groups; the white column is the Multivariate Enso Index; and the dark gray line is the Adult Catch.

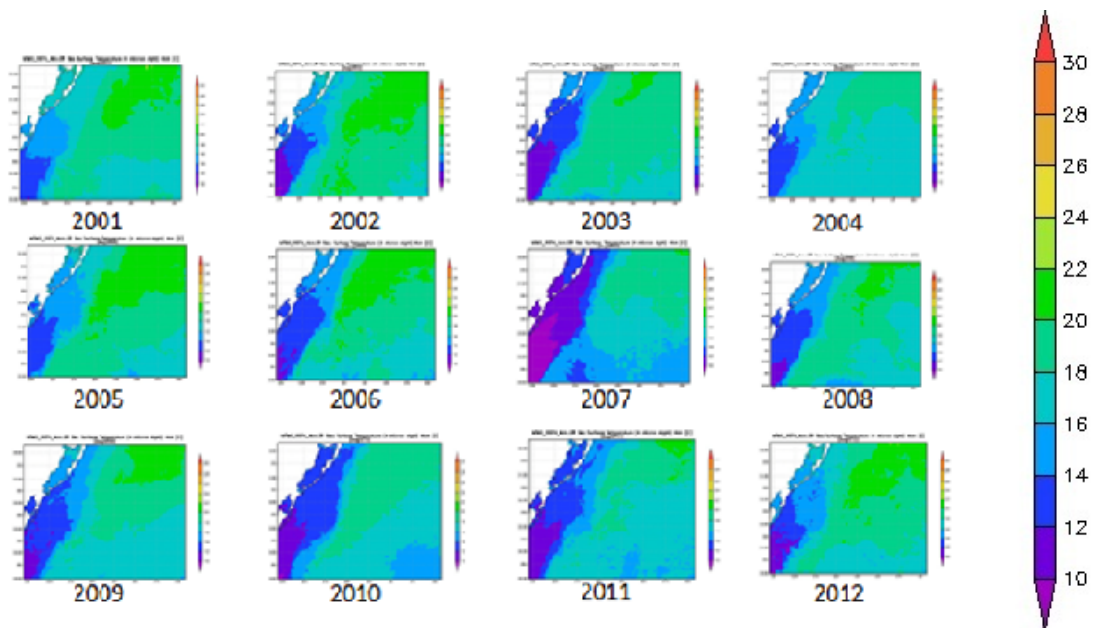


Fig 06: Ocean Color Radiometry analysis and visualization produced for August month (Winter) at the 2001-2012 years, with the Giovanni online data system, developed and maintained by the NASA GES DISC.



## **Juvenile growth of pink shrimp (*Farfantepenaeus paulensis*) in a choked Lagoon from South Brazil: A Bayesian approach**

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### **Abstract**

Traditional modal progression analysis (e.g. Bhattacharya, ELEFAN) has the problem of not accounting for growth variability of individuals and cohorts. A big shrimp is not necessarily older than a small one, and this may lead to unreliable parameter estimates. For an unknown age organism as a wild shrimp, infer its individual growth variability is very difficult. However for well studied species, it might be interest let the researcher insert a robust and responsible knowledge at the model. This work aims to minutely describe and make public the growth methodology proposed by D'Incao-Fonseca (1983; 1998; 1999). It also intends to enhance this methodology with the Bayesian paradigm in a long term time series, emphasizing the gained improvements and limitations bypassed. Such as inserting the researcher knowledge upon individual growth and measure the cohorts growth variability. The collections were made in shallow areas, at 5 different sites sampled with a beach seine net type. Growth parameters were described for the pooled sexes using the von Bertalanffy growth model by the Least-Squares and Bayesian approaches for choosing each cohort by trial and error and keeping those that are biologically coherent. The Least-Squares estimated parameters were:  $L_{\infty} = 146$  mm;  $k = 0.0087 \text{ day}^{-1}$  ( $3.17 \text{ year}^{-1}$ );  $t_0 = 1.46 \text{ day}^{-1}$ ; the longevity found was 1.44 years. The Bayesian through Markov's chains parameters estimate were:  $L_{\infty} = 128.8 \pm 9.4$  mm;  $k = 0.01 \pm 0.001 \text{ day}^{-1}$  ( $3.65 \pm 0.3 \text{ year}^{-1}$ );  $t_0 = 1.94 \pm 1.03 \text{ day}^{-1}$ ; The longevity was  $1.2 \pm 0.1$  years. Both provided good estimates, but the Bayesian method proved to be a better instrument for the implementation of the growth method, given that, it provides information about the uncertain of the parameters which proved to be necessary for a more suitable cohort acceptance. The Bayesian approach also improved some weak points of the D'Incao-Fonseca such as inaccurate estimates from small samples, low information gathering for cohort acceptance.

**Key words: Shrimp, Growth, Bayes.**

## **1- Introduction**

The shrimp species of commercial interest worldwide are included at the Penaeid family, especially in tropical and subtropical coastal regions. Among them, it is important to highlight those belonging to the *Farfantepenaeus* genus, including *F. paulensis*. This specie is widespread from the northeast (Ilheus, Bahia) to the south of Brazil, (Rio Grande do Sul), extending to Mar del Plata in Argentina where presents a sporadic occurrence. It presents a complex life cycle, since adult broodstock occurs in the inner continental shelf (40m-80m), where mature females release their benthic eggs that hatch in a planktonic larva. The larvae are transported southwards and penetrate as post larvae (PL), several estuaries trough the coast, including the Patos Lagoon (PLE) (Brazil), where the catches reached 8000 tons in the late 70`s, representing 40% of the shrimp production of the country (D`Incao et al. 2002).

There is a gap of knowledge about the oceanographic mechanisms which post-larvae utilize to reach the estuaries. Previous studies suggested that the post larval penetration of pink shrimp in the PLE is associated to low rainfall and river's low discharge (Castelo & Möller 1978, D'Incao 1984, 1991; Möller et al. 2009, Pereira et al. 2012). Post-larvae migrate down to the deeper and denser water layers when are transported to the inside of the estuary at the salt wedge. Therefore, the recruitment success of the pink shrimp, to a certain extent is regulated by the frequency and the intensity of these salt wedge penetration events.

Modeling individual growth is one of the main goals of population dynamics (Hoggarth et al. 2006). Therefore, many models were idealized to measure changes in size of animals (e.g. mammals, fish, crustaceans, etc.). Methods for estimating individual growth goes from a simple index that describes the rate of change in size over a defined time period, to mathematical functions and probabilistic models that mimic the change in size over life span of fish, those may differ in complexity of assumptions, data requirement, and output (Chang et al.2011).

For fish and other marine organisms (e.g. sharks, rays, etc) there are well-defined apposition structures – such as otholiths, vertebrae – that are used for age determinations. Although, in some cases the age reading structures are not available in the database (e.g. catch data) or the apposition structure does not exist. In crustaceans, for instance, age determination is hindered by the molting process, which results in the constant loss of rigid structures that might be related to ageing. Therefore, as a “tantamount” for the apposition structures, the quantification of lipofuscin in the

nervous system tissue is emerging as an alternative for crustacean's ageing studies (Sheehy 1989; 1996; Vila et al. 2000). However, this approach is time consuming, and methods based on length are still dominant for growth estimations worldwide. For length-based methods we can highlight the Bhattacharya (1967), the Powell – Wetherall (Powell 1979; Wetherall, 1987), and the ELEFAN routine (Pauly 1979, 1984), as the most used approaches for estimating crustaceans growth – e.g. *F. californiensis*; *Litopenaeus stylirostris* in California Gulf (Medina & Soto 2001); *Metopenaeus joyneri* in Korea (Cha & Choi 2004); *Solenocera membranacea* in Mediterranean Sea (Demestre & Abello 1993).

Although modal progression analysis is a reasonable path for length-based methods, it still carries problems. Length-age relations are, sometimes, complicated. A big shrimp is not necessarily older than a small one (Sparre 1998; King 2007). Therefore the uncertainty upon the growth from individuals and cohorts must be, somehow, taken into account.

An interesting length-based method for crustaceans is used on Brazil. It is an adaptation of the modal progression analysis that increases the number of modes, raising the chances of forming a coherent cohort. It was first described by D’Incao (1983), then, adapted by Fonseca (1998) and D’Incao & Fonseca (1999). Despite its little effect on the international academic scene, there are many published articles using this methodology at this country (Ferreira & D’Incao, 2008; Pimenta et al. 2005; Fernandes et al 2014). Although D’Incao (1983) and Fonseca (1998) are MsC. theses. D’Incao & Fonseca (1999) is published, but only describes the method briefly

From the Portuguese “Ajuste não linear usando modas”, AJMOD- that means non-linear adjustment using modes – was developed by the claim that methods based on mean (e.g. Bhattacharya, ELEFAN) generates age groups in a limited way. They exclude the big size classes, providing flatter curves; having trouble to identify elder and low-abundances age groups. They also generate biologically incoherent longevities (Fonseca 1998). The current approach is based on modes, therefore, it does not exclude the big size classes. It proposes to choose each cohort by trial and error, keeping those that are biologically coherent according to its growths parameters and the longevity estimates (D’Incao & Fonseca 1999). Then, providing more control over the growth curve different from models with an automated process (e.g. Bhattacharya, ELEFAN). However, what may be seen as an advantage is also being a target for criticism, the excess of subjectivity on choosing coherent cohorts does not please everyone.

Despite some limitations that we are going to explore in this article. It is very pleasant the idea of giving more power for the researcher on choosing the cohorts, based on his knowledge upon the species biology. That gave us an insight of how to introduce the growth variability from individuals and cohorts for modeling through a Bayesian method.

In general, all the approaches mentioned (including D’Incao-Fonseca 1983; 1998; 1999) utilize the Least-Squares for parameter's estimations. They provide fixed parameters, not accounting the growth variability of individuals or cohorts. Recently, the use of the Bayesian paradigm has been increasing by the popularity of some statistical softwares (Kinas & Andrade, 2010). The Bayesian paradigm has already been used for fish and other organisms (e.g. manatees) to account individual growth with length-at-age data (Siegfried & Sanso 2006; Eveson, Polacheck, & Laslett 2007; Schwarz & Runge 2009). It was also used for length-at-age (shrimp data) in aquaculture operations Yu & Leung (2010). However, we are not aware of its application in modeling the growth performance for wild shrimp with length data. Although, Bayesian methods can contain many of the procedures used in conventional statistics, it can extend significantly the applicability of the traditional statistical approaches, including the important process of decision making under uncertainty (Kinas & Andrade 2010). It also has the advantage of wearing only probability as metric and no restriction about the sample size (Kinas & Andrade, 2010; McCarthy, 2007). Such process is going to be used at the present article for improving the decision making for choosing coherent cohorts according to the individual growth variability.

Considering that modal progression approach is still controversial. The aim of this work is to minutely describe the methodology by D’Incao-Fonseca (D’Incao 1983; Fonseca 1998; D’Incao & Fonseca 1999) and propose some improvements with the Monte Carlo Markov chains, in a long term time series, intending to account the growth variability of individuals and cohorts in parameter's estimations.

## **2- Material and Methods**

### **2.1- Dataset**

The dataset was obtained from the Programa Ecológico de Longa Duração-Ictio (PELD CNPq - MCT) and it is composed by pink-shrimp's size structure data (*Farfantepenaeus paulensis*) from 1997 to 2012. The samples were taken along the Patos Lagoon estuary (32 ° 52 S ° W), Rio Grande do Sul. A south Brazilian choked lagoon

(Kjerfve 1986), whose waters are the main nursery area for the pink shrimp at the south region (D’Incao 1978; 1984).

## 2.2 Sampling and Biometrics

The samples were collected by using a standardized beach seine, 9m in length; 13 mm of mesh size in the wing and 5 mm mesh size in the body (Moraes et al. 2012). Sampling stations were performed in shallow areas (average depths lower than 1.5 m). Samples were monthly obtained in 5 sites with 5 replicates each (216 sampling stations during 16 years) (Figure 01). The total length (TL in mm) (i.e. from the tip of the rostrum to the end of the telson) was used to estimate growth in size. The length class interval adopted was 5 mm. The growth curves were established grouping both genders, since the legislation and the enforcement is based on a single TL disregarding gender, assuming the bias from the sex specific differences (D’Incao 1978; 1984).

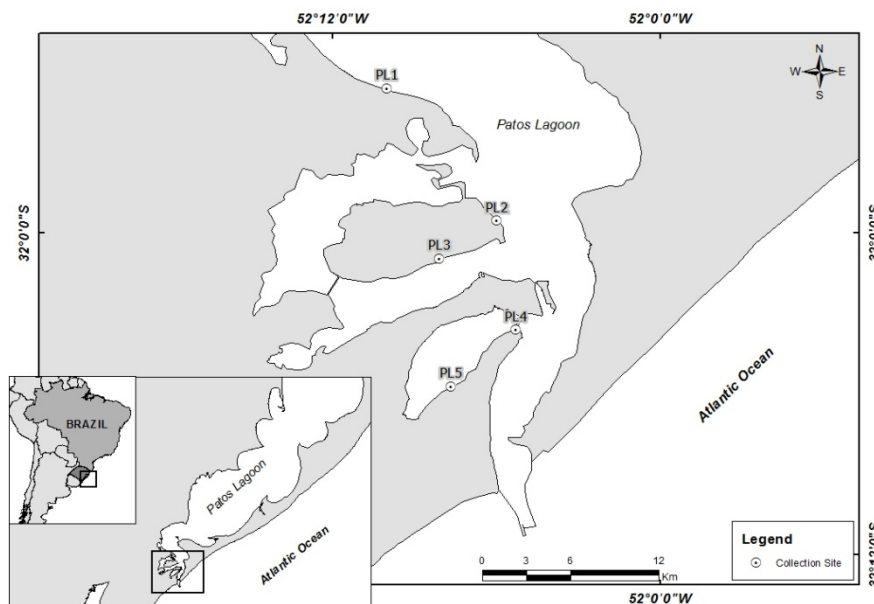


Figure 01: The location of the five sampling stations along the Patos Lagoon estuary.

## 2.3 Growth analysis

### 2.3.1 The Least-Squares Model

Growth parameters were estimated through Modal Progression Analysis (MPA), using a length class interval of 5 mm. Length frequency histograms were made, to obtain modal groups, connected by trial and error for cohort's composition according to the biological coherence (D’Incao & Fonseca 1999). These are going to be fitted to the von Bertalanffy Growth Model (VBGM) (1938) by the following automated methods.

### *Bounding modes – The trial and error method*

It was used the D'Incao-Fonseca's method (1983; 1998; 1999) of trial and error. This method consists on following some modal groups (generally three or four for *F. paulensis*'s juvenile phase) through consecutive months to estimate growth. An automated Least-Squares procedure is used to fit modal values obtained to the VBGM, using the nonlinear regressive model (Ordinary Least Squares - Legendre 1805), varying the parameters  $k$ ,  $L_{\infty}$ , and  $t_0$  from the VBGM with the "generalized reduced gradient" algorithm (Lasdon 1975). The VBGM is given by:  $L_t = L_{\infty} [1 - e^{-k(t-t_0)}]$ , where  $L_{\infty}$  is the asymptotic length,  $k$  is coefficient of growth and  $t_0$  is the theoretical age when the size is equal to 0. The initials parameters,  $k$  and  $L_{\infty}$  (0.00349 day<sup>-1</sup> and 220 mm, respectively), were determined from mean values of males and females obtained from the literature (D'Incao 1984); and  $t_0$  was set as zero. The best cohorts are chosen according to their biological coherence with biological knowledge available, such as maximum longevity to validate  $k$  and maximum sizes observed in the field to validate  $L_{\infty}$ .

#### ***Bounding cohorts – The growth curve construction***

The same method described above is repeated for building the growth curve. However, now it uses all the modes from the coherent cohorts recognized at the previous section. A residual analysis was performed to test the assumptions of homogeneity of variances (chi-square test) (Pearson 1922) and autocorrelation (Davis, 1986) by the software R. 2.13. The normality of the residuals was also performed to check the model's proximity with the maximum likelihood (D' Agostino test) (D'Agostino et al. 1990). The coefficient of determination ( $R^2$ ) was calculated by the formula:  $R^2 = 1 - \frac{\sum(Y - Y_{\text{model}})^2}{\sum(Y - Y_{\text{mean}})^2}$  which value ranges between 0 and 1 (closer to 1, better the fit) and the confidence interval utilized was 5%, which is calculated by the formula:  $(\sqrt{\sum(Y - Y_{\text{model}})^2 / df}) * (\phi)$ . Where  $Y$  = observed independent variable;  $Y_{\text{model}}$  = estimated independent variable;  $df$  = degrees of freedom; and  $\phi$  = T student table value. The longevity ( $t_{\text{max}}$ ) was estimated by the inverse von Bertalanffy equation (1938):  $T_{\text{max}} = t_0 - (1/k) \ln [1 - (L / L_{\infty})]$ .

#### ***2.3.2 The Bayesian Model***

##### ***Bounding modes – The Bayesian trial and error method***

D'Incao-Fonseca's method (1983; 1998; 1999) of trial and error was adapted to a Bayesian perspective. Modal groups (generally three or four) from consecutive months were fitted by the Monte Carlo Markov's chain (Metropolis-Hastings algorithm)

(Chib 1995; 2001) using subjective priors for the parameters  $k$  (uniform from 0 to 0.1) and  $t_0$  (uniform from -12 to 0) based on literature information (Garcia & Le Reste 1981, Pauly *et al.* 1984, D'Incao & Fonseca 1999), and a Jeffreys (1961) uninformative prior was used to the  $L_\infty$  parameter. The cohorts were chosen according to the biological coherence of the parameters.

The first 2000 samples were discarded as a “burn-in” period. To estimate the posterior distribution, every 33th of the 13000 samples were collected. The convergence was checked by the trace-plot; the criterias of Geweke (Geweke 1992) and Gelman-Rubin (Gelman & Rubin 1992). The autocorrelation was also checked (Davis, 1986). The model was specified as follows:

$$W_i \sim N(\mu(i), \sigma^2)$$

$$\mu(i) = L_\infty * (1 - \exp(-k_i * (t_i - t_0)))$$

Where the subscribed  $i$  represents  $i$ th observation. The first expression specifies the error term with an independent and normal distribution. The second expression specifies the von Bertalanffy growth equation with three parameters  $L_\infty$ ,  $k$  and  $t_0$ . Subjective priors for the parameters  $k$  and  $t_0$ , and a Jeffreys (1961) uninformative prior was used to  $L_\infty$  parameter.

### ***Bounding cohorts – The growth curve construction***

This second step is similar to the procedure described above. However, now it uses all the modes from the Bayesian coherence cohorts recognized at the previous section. Additionally, a growth curve from coherent cohorts bounded by the Least-Squares method (from the section 2.3.1 – “Bounding modes – The trial and error method”) was fitted by the Bayesian method for better comparisons between both methods. Only uninformative priors were used for all the three parameters at this second part.

- ***2.4 Statistical Software's***

The analysis of normality and homocedasticity (Anderson-Darling normality;  $X^2$  test for variance homogeneity) were performed by the free Microsoft Excel Spreadsheet, Action 2.5 (©Copyright ®Estatcamp, 1997-2014). The independency analysis was made by the PAST 3.0 (Hammer *et al.* 2001). The Bayesian analysis was done by the R software (R Development Core Team, 2009) through the package “rjags” (Plummer *et al.* 2006).

## **3- Results**

### 3.1 Least Square estimate

A total of 40 cohorts were found along the study period. The parameters estimated by non-linear regression model, fitted to the von Bertalanffy equation were  $L_{\infty} = 146$  mm,  $k = 0.0087$  day<sup>-1</sup> (3.17 year<sup>-1</sup>),  $t_0 = 1.46$  day<sup>-1</sup>. The longevity estimated was 1.44 years. The von Bertalanffy estimate with 95% confidence interval is shown in Figure 01. All assumptions of the analysis were obtained (homoscedasticity and independence). The coefficient of determination ( $R^2 = 0.95$ ) was significant ( $p < 0.05$ ) showing the good fit of the model VBGM. The model residues showed a normal distribution, which makes it similar to the maximum likelihood.

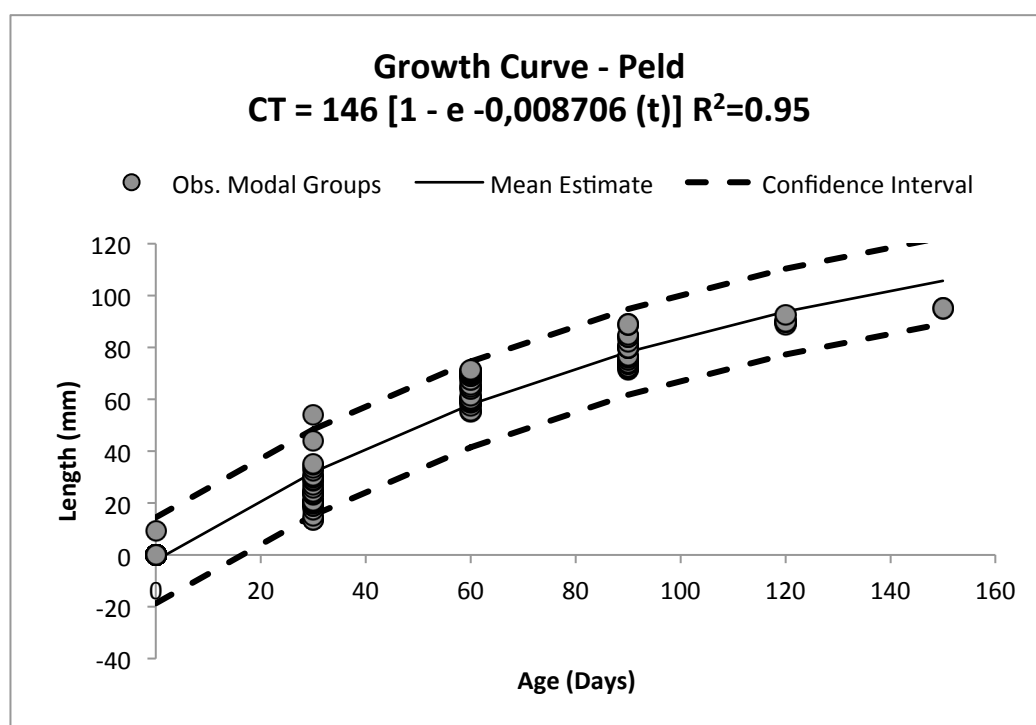


Figure 02: *F. paulensis* juvenile total length growth curve in PLE. The von Bertalanffy growth equation is shown together with determination coefficient ( $R^2$ ). The central line is the predicted curve. The dashed lines represent the 95% confidence interval.

### 3.2 Bayesian estimate

#### - Using Bayesian trial and error

The Bayesian approach generated 31 cohorts for the study period; 20 of these coincided with the Least-Squares estimates. The estimated VBGM parameters were  $L_{\infty} = 128.8 \pm 9.4$  mm;  $k = 0.01 \pm 0.001$  day<sup>-1</sup> ( $3.65 \pm 0.3$  year<sup>-1</sup>);  $t_0 = 1.94 \pm 1.03$  day<sup>-1</sup>. The longevity was  $1.2 \pm 0.1$  years. The von Bertalanffy mean estimates with 95% credible interval are shown in Figure 03.



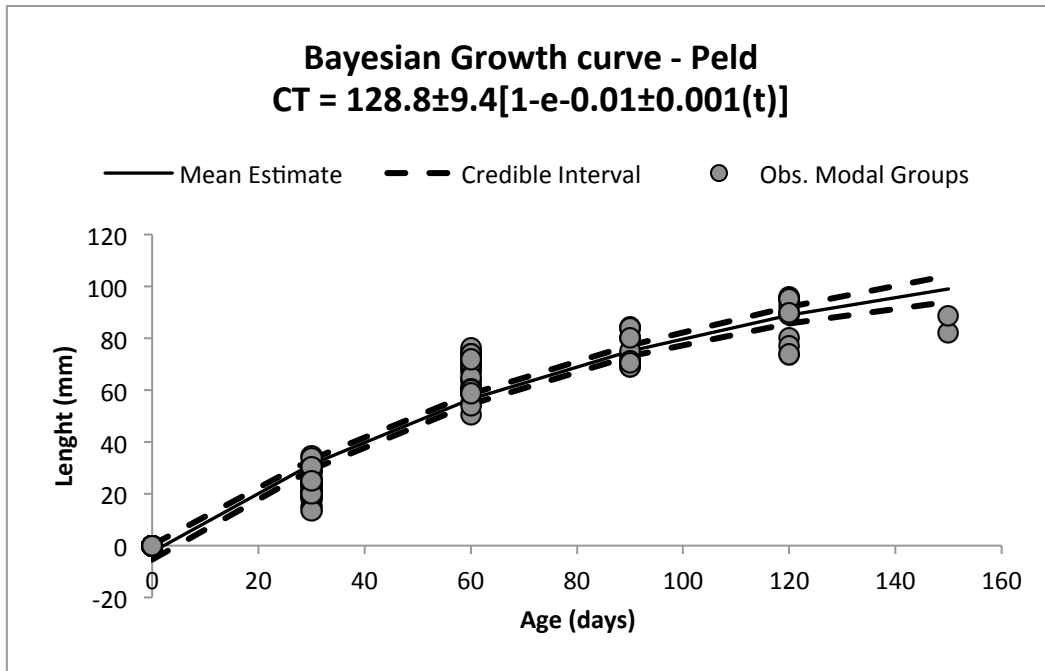


Figure 03: *F. paulensis* juvenile total length growth curve in PLE. The von Bertalanffy growth equation is shown. The middle line is the predicted curve. The up and down lines are the 95% credible interval.

- Using Least-Squares trial and error

The Figure 04 shows a comparison from both methods estimates wearing the same cohorts. Both mean estimates overlap. However, Least-Square's confidence intervals are wider than Bayesian's credible intervals. The Bayesian estimate is  $L_{\infty}=148\pm12\text{mm}$ ,  $k=0.0086\pm0.001$  and  $t_0=1.57\pm0.8 \text{ day}^{-1}$ . The mean estimated credible interval ranged from 127 to 177. The Least-Squares estimates were described in section 3.1.

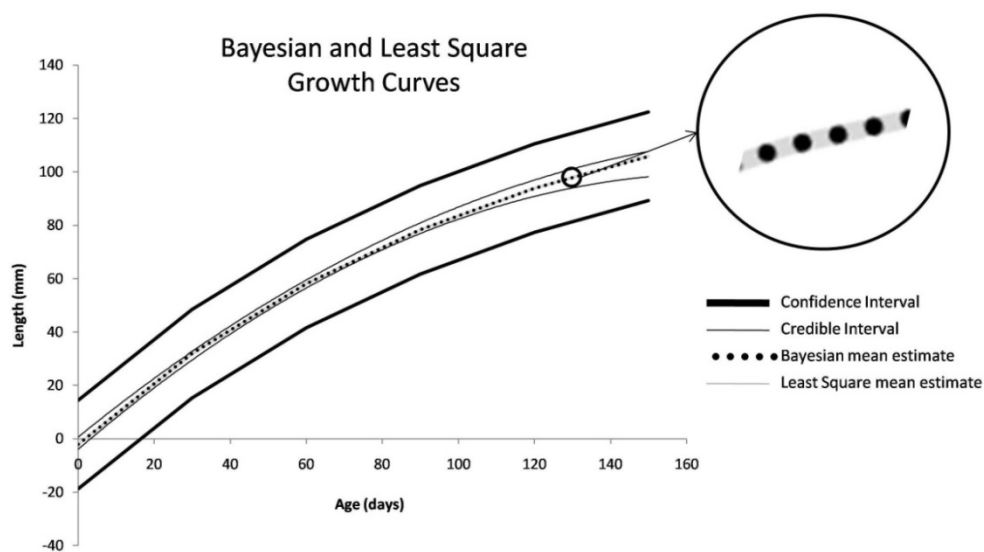


Figure 04: *F. paulensis* juvenile total length growth curve in PLE by the Least Square and Bayesian approaches. The middle dotted line is the Bayesian estimate. The middle dark gray line is Least Square estimate. The up and down black lines are the 95% credible interval. The up and down light gray lines are the 95% confidence interval

#### - Convergence

The results from the trace-plot shows good indications of convergence (Figure 05). The Gelman & Rubin and the Geweke criteria also have shown a good indicative of convergence – values close to 1 for the Gelman & Rubin, and close chain values at the Geweke. No autocorrelation was detected.

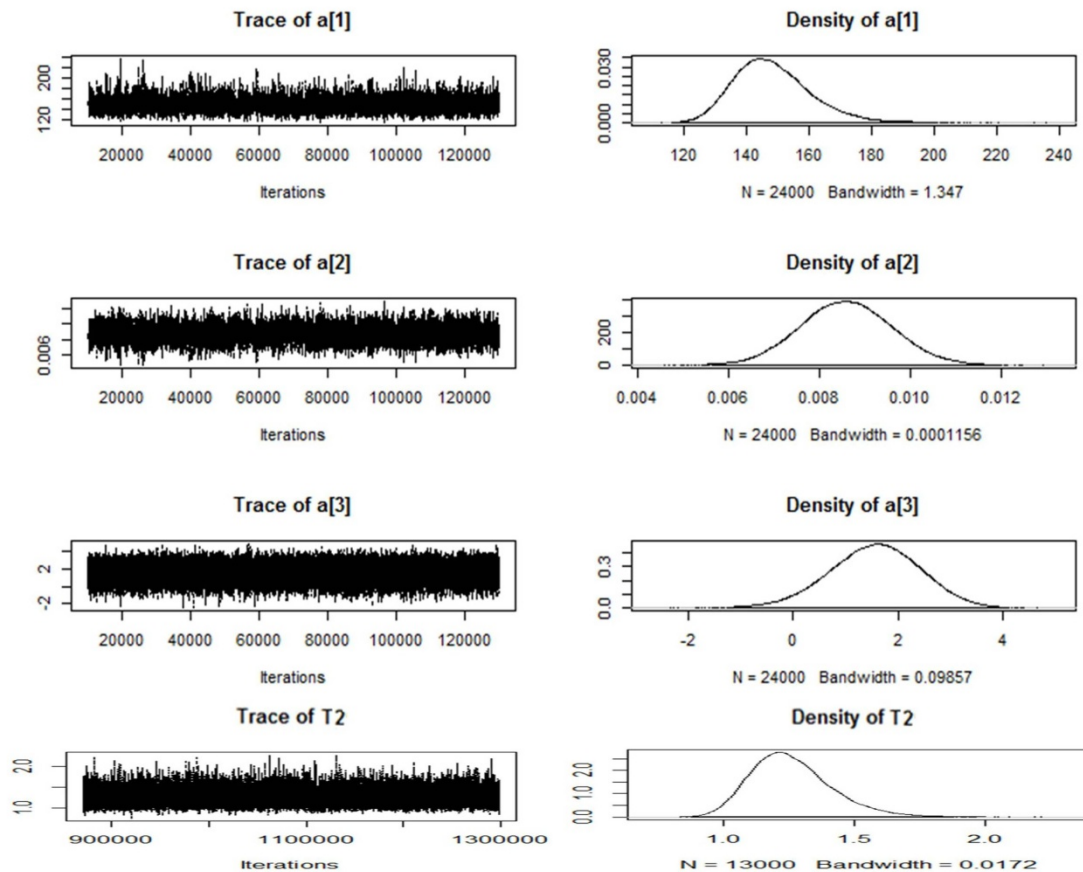


Figure 05. Convergence visual analysis. The first column is the trace plot showing a good mixing for all parameter. The second is a kernel density plot showing the posterior density estimation. The  $L_{\infty}$  corresponds to parameter  $a[1]$ ; the  $k$  corresponds to the parameter  $a[2]$ ; the  $i$  is the parameter  $a[3]$ ; the longevity is the parameter  $t2$ .

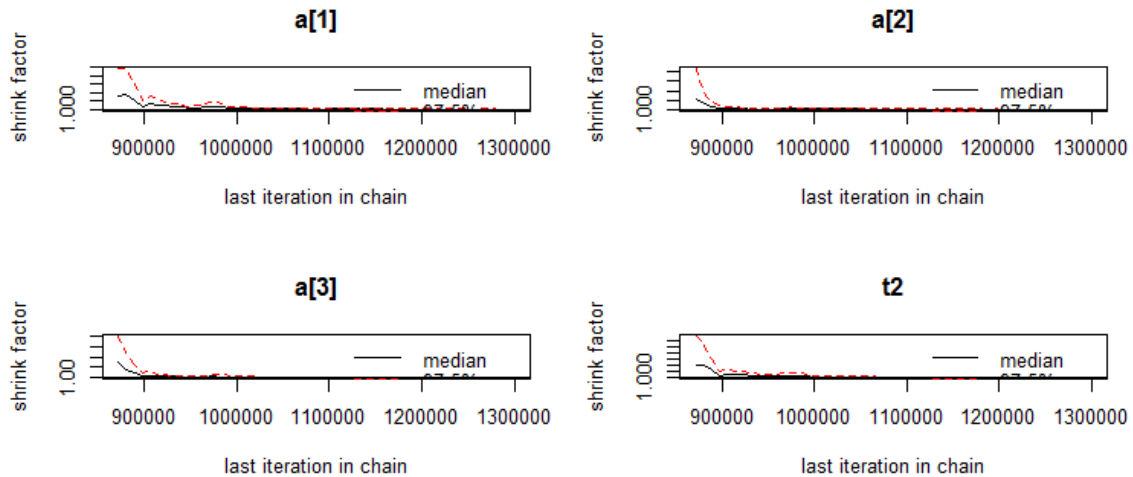


Figure 06: Convergence monitoring by the Gelman & Rubin diagnostic. It's shown that all parameters have converged by its shrink factor (close to 1).

## 4- Discussion

### 4.1- The Trial and error methods

The Least-Squares method had bounded more cohorts than the Bayesian. However, the Bayesian method provides more information for accepting or denying a cohort than Least-square approach. The Least-Squares method needs some assumptions to be fulfilled (Legendre 1805; Cook & Weisberg, 1983). Since the trial and error method works with a sample of only three to four modal groups, those assumptions – e.g. homoscedasticity, independence - are hard to be achieved, resulting in imprecise estimates. Only half of the estimated cohorts by the Least-Squares approach were accepted in the Bayesian analysis. A bootstrap could be useful to try to fix that problem, but the nature of the relation from the von Bertalanffy growth parameters are complex and a Bayesian method may overcome this problem more easily through prior information.

The Bayesian method has the advantage of measuring the uncertainty from the parameters, adding more information to the judgment for accepting a cohort with biological coherent. It allows the researcher to choose cohorts with reliable individual growth variability. Although, the researcher is limited by the precision of the samples - in general, three or four modal groups won't provide any high precision. Then, a more robust standard deviation should be taken account. For juvenile pink shrimp we suggest that it should not be more than the double of the mean value. The credible interval is also an important instrument; it should not be too wide. We suggest divide the mean by

two, then, the mean plus and less its half should be a good pattern for the credible interval range. It's important to mention that the uncertainty of the parameters may vary among species and locations, and the decision upon accepting and denying a cohort should be supported by previous knowledge upon the specie. These suggested tips should be a reference for a starting point at the learning process during cohort's making decision, and not necessary a rule.

#### 4.2- The Subjective prior for Bayesian trial and error

In most of the cases, for choosing biologically coherent cohorts, the mean estimate from the Least-Squares approach was inside the Bayesian standard error, being the same or very close to the mean estimate from Bayesian method in many cases. Therefore, it has led us to believe that the subjective uniform priors -  $k$  from 0 to 0.1;  $t_0$  from -12 to 0 –were successfully implemented at our model.

#### 4.3- Bounding Cohort

The Least-Squares and the Bayesian methods had found different parameter estimates. The  $k$  values of both – Bayesian= $3.65 \pm 0.3 \text{ years}^{-1}$ ; Least squares=  $3.17 \text{ years}^{-1}$  - are above the  $0.25$  to  $2.5 \text{ years}^{-1}$  suggested by Pauly *et al.* (1984) and within the  $1.8$  to  $3.6 \text{ years}^{-1}$  suggested by Garcia & Le Reste (1981). This study was performed with only the juvenile phase, therefore, it was already expected for the  $k$  parameter value to be high. D'Incao (1978) found similar results for the *F. paulensis* juveniles at the Patos Lagoon ( $3.38 \text{ years}^{-1}$  for females and  $4.48 \text{ years}^{-1}$  for males).

The longevity found by the Bayes estimate was  $1.2 \pm 0.1$  years, and by the Least-Squares was 1.4 years. The suggested values, at literature, for the specie are from 1.5 to 2.3 years (D' Incao and Fonseca, 1999) and for penaeids are from 2 to 2.5 years (Garcia & Le Reste, 1981). Both estimates are above the suggested by the literature, but it was already expected since only the juvenile size was used on the research. Therefore, the asymptotic properties were not reached. Looking the specie's life cycle it would seem awkward for the estimate present a longevity of more than one year for individuals from the estuary – individuals usually stay from 3 to 5 months until its migration to the ocean (D' Incao 1984; 1991) – but there are individuals that do not migrate to the ocean, being trapped at the lagoon, and these are accounted at the model. However, these trapped individuals are not many. Therefore, a smaller value of longevity still seems more appropriate for the juvenile phase suggesting that the Bayes estimate provided a result with more correspondence with the specie's biology.

The  $L_{\infty}$  values were below the 192 mm for males and 248 mm for females found for the specie by D’Incao (1984). Since we only had the estuarine phase, and individuals from this specie start to migrate to the ocean with approximately 90mm (D’Incao 1984; 1991), it is reasonable to expect an  $L_{\infty}$  not so far from the migration size. Once more the Bayes estimate provided a result with more correspondence with the specie’s biology, although, the Least Squares have presented a good response too. Both  $L_{\infty}$  values are consistent with the 127.68 for males and 151 for females (data transformed with the D’Incao & Calazans – 1978 - biometric equation) found by D’Incao (1978) for pink shrimp juveniles. The data are also coherent with the  $L_{\infty}$  given by Branco & Verani (1998) (118 for males and 132 for female – data transformed according to D’Incao & Calanzans 1978) for juveniles and pre-adults in estuaries.

Most literature provides fixed parameters values Garcia & Le Reste 1981, D’Incao 1978; 1984; Pauly et al. 1984; Branco & Verani 1998). The use of this kind of parameter gives trouble in comparing values among studies, after all, a  $L_{\infty}$  of 120mm is so much different from a  $L_{\infty}$  of 160mm? In this sense, the parameters standard deviation from the Bayes estimate may help to better compare results among studies, because if instead of those fixed values we had a  $L_{\infty}$  of  $120 \pm 30$ mm and  $160 \pm 30$ mm, it would be possible to know that part of the standard error of both estimates overlaps, and those parameters are not so different.

Growth does not occur at the same rate among individuals and cohorts. Therefore, as subscribed, another limitation from methods that provide fixed parameters values (e.g. Bhattacharya; ELEFAN; D’Incao-Fonseca), is that they do not account for the growth variability upon individuals and cohorts in their model. As you might have realized this far, our model do not, necessarily, measures the individual growth variability. It only allows the researcher to choose what it would be reasonable for it on the cohort’s decision making. However, the model does measures the variability from cohort’s growth parameters. Therefore, the Bayesian approach provides more accurate and realist estimates.

#### 4.4- Bayesian vs Least Squares

The Bayesian and the Least-Squares approaches showed very close estimated parameters numbers, when using the same cohorts, even overlapping graphically (Figure 04). However, the Credible and Confidence intervals have a considerable difference. The Least Square confidence interval is much wider than the Bayesian credible interval (Figure 04). The basic difference between these two intervals is that the

first treats the parameters as fixed and the sample as random, and the Bayesian is just the opposite treating the sample as fixed and the variables as random (Jaynes 1976). In other words, if you repeat an experiment a million times there is 95% probability that the confidence interval encompass the true mean estimate; but there is 95% for the mean estimate be inside the credible interval (McCarthy 2007). Bayesian credible intervals and frequentist confidence are usually numerically identical if the Bayesian priors is uninformative (op. cit). However, Jaynes (1976) had shown that when intervals are different, only the Bayesian method provides logical results.

### **5- Conclusions**

The Bayesian method was successfully introduced at the D'Incao-Fonseca's approach. It improves the model's reliability, because it lets the researcher introduce the individual growth variability based on biological coherence on the model, providing more reliable results. It also is a better standard for discussing results from different works through the uncertainty of the parameters.

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