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Fish larval distribution in a macro-tidal regime: an *in situ* study in São Marcos Bay (Amazon Coast, Brazil)

Distribuição de larvas de peixes em regime de macro-marés: um estudo *in situ* na Baía de São Marcos (Costa Amazônica, Brasil)

Distribución de larvas de peces en régimen de macromareas: un estudio *in situ* en la Bahía de São Marcos (Costa Amazónica, Brasil)

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Abstract

The occurrence of ichthyoplankton is associated to the hydrodynamics and spawning behavior of adults. In this study we aimed to detect regions of concentration of ichthyoplankton in São

Marcos Bay, which has macro tidal amplitudes in Amazon Coast, Brazil. Ichthyoplankton was acquired by way of drag technique, using with 300 μm mesh. The density was obtained considering the number of eggs and larvae in filtered water. The sources of Ichthyoplankton were defined continuous and organized to denote the asynchronously the distribution conditions. To this was done using Voronoi polygon to determine the spatial shape of the region of operation of all sampling points. The use of CESM, as a spawning site and breeding fish larvae, was verified at all times of the year, with a higher density of eggs in the wet period and a higher density of larvae during the dry period. The position of the higher ichthyoplankton densities varied, considering concentrations in the area at south-east channel of the CESM in the rainless period, going to the central area in the wet period. The southeast of CESM is, therefore, a nursery for fish, requiring environmental management actions.
Keywords: Ichthyoplankton; Voronoi polygon; Environmental protection.

Resumo

A distribuição do ictioplâncton está diretamente relacionada à hidrodinâmica de uma região e ao comportamento de desova dos adultos. Neste estudo, objetivamos mapear as zonas de maior ocorrência de ictioplâncton observadas na Baía de São Marcos, que possui uma das maiores amplitudes de maré da Costa Amazônica, Brasil. O ictioplâncton foi coletado por meio de técnica de arrasto horizontal na camada superficial, utilizando rede de rolos cônicos com malha de 300 μm acoplada a medidor de vazão. A densidade foi calculada considerando a razão entre o número total de ovos e larvas de cada amostra e o volume de água filtrada. As fontes de ictioplâncton foram consideradas contínuas e foram organizadas para representar de forma assíncrona as condições de distribuição. Para isso foi feito utilizando o polígono de Voronoi para determinar a forma espacial da área de atuação de todos os pontos de amostragem. O uso do CESM, como local de desova e reprodução de larvas de peixes, foi verificado em todas as épocas do ano, com maior densidade de ovos no período chuvoso e maior densidade de larvas no período de seca. A localização das maiores densidades de ictioplâncton variou, com as maiores concentrações mais próximas do canal sudeste do CESM na estação seca, deslocando-se para o centro na estação chuvosa. O canal sudeste do CESM era, portanto, viveiro de muitas espécies de peixes, exigindo ações prioritárias de proteção ambiental.
Palavras-chave: Ictioplâncton; Polígonos de Voronoi; Proteção ambiental.

Resumen

La aparición de ictioplancton está asociada a la hidrodinámica y al comportamiento de desove de los adultos. En este estudio, nuestro objetivo fue detectar regiones de concentración de ictioplancton en la bahía de São Marcos, que tiene amplitudes de macromama en la costa amazónica, Brasil. El ictioplancton se adquirió mediante técnica de arrastre, utilizando malla de 300 µm. La densidad se obtuvo considerando el número de huevos y larvas en agua filtrada. Las fuentes de Ictioplancton se definieron de forma continua y organizada para denotar asincrónicamente las condiciones de distribución. Para esto se hizo usando el polígono de Voronoi para determinar la forma espacial de la región de operación de todos los puntos de muestreo. El uso de CESM, como lugar de desove y cría de larvas de peces, se verificó en todas las épocas del año, con una mayor densidad de huevos en el período húmedo y una mayor densidad de larvas durante el período seco. La posición de las mayores densidades de ictioplancton varió, considerando concentraciones en el área del canal sureste del CESM en el período sin lluvias, yendo al área central en el período húmedo. El sureste de CESM es, por tanto, un vivero de peces, que requiere acciones de gestión ambiental.

Palabras clave: Ictioplancton; Polígono de Voronoi; Protección del medio ambiente.

1. Introduction

São Marcos Bay (Complexo Estuarino de São Marcos - CESM, Maranhão) has greater tides in Brazil (Filho & Martins, 2005) and his dynamics is in focus to converrsion of energy (González-Gorbeña, Rosman, & Qassim, 2015). CESM is a representative estuaries of northeastern Brazil (Pereira & Harari, 1995), operates onde mais um porto carrying loads potential impact com os Aquatic organisms (Carvalho-Net, Torres, & Abreu-Silva, 2012; R. N. F. Carvalho Net & Abreu-Silva, 2013). In addition, in this region there is a continuous mangrove environmental protection initiative in Maranhão (Carvalho Neta & Castro, 2008). Environments with hydrodynamics similar to CESM are found in the Amazonas estuary in Pará. (Geyer, 1995; Le Bars, Lyard, Jeandel, & Dardengo, 2010; Rockwell Geyer et al., 1996) and in Amapá, Brazil (Santos et al., 2005), and in other locations like Bristol Channel and Severn River, England (Allen, 1991, 1992; Allen & Rae, 1987; Kirby & Parker, 1983), Mont Saint-Michel Bay, France (Larsonneur, 1994) and Cook Inlet, Alaska (Bartsch-Winkler & Ovenshine, 1984; Bartsch-Winkler & Schmoll, 1984).

A disposition of ichthyoplankton is associated with the hydrodynamics Chia, Buckland-Nicks, & Young, 1984), which impacts its accumulation (Rumrill, 1990;

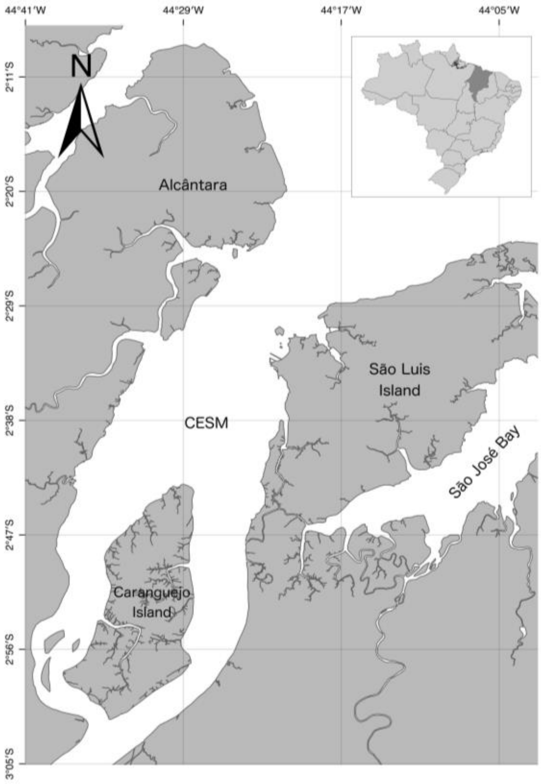
Sfakiotakis, Lane, & Davies, 1999) and also the dispersion of the larvae (Cowen, Lwiza , Sponaugle, Paris, & Olson, 2000; Green et al., 2014; Shima & Swearer, 2010). Knowledge about the region where larval fish accumulation and retention occurs is important for conservation and creation of protected areas (Warner, Swearer, & Caselle, 2000). However, there are no studies that show that protected areas are successful with larvae of fish species (Christie et al., 2010). We aim to identify areas of higher occurrence of ichthyoplankton observed in São Marcos Bay. The knowledge of the distribution of fish larvae is of supreme importance for fisheries management. It will also help environmental control agencies to define fisheries and environmental protection policies.

2. Metetial and Methods

Study Area

The CESM is in the center of the coastal region of Maranhão (Figure 1), on the Brazilian equatorial margin. This estuarine complex extends from the division of the Mearim River through Ilha do Caranguejos to the border with the adjacent maritime area (Ribeiro et al, 2012). The average depth of the CESM is around ten meters and has an area of approximately 3.000m² (Filho & Martins, 2005). The region has the highest tidal ranges in Brazil (González-Gorbeña et al., 2015). The sea level variation in the region range from 3.3 meters to 7 meters height in spring tide (Silva et al., 2009).

Figure 1 - São Marcos Bay.



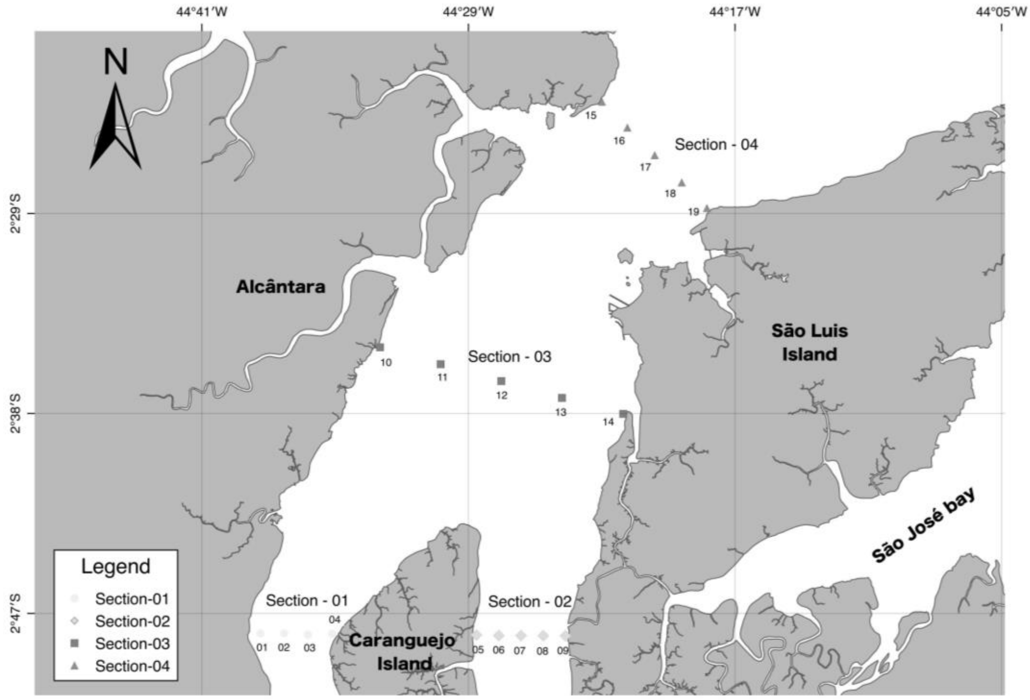
Source: Authors.

At CESM there is a hydrodynamics, with speeds above 4m.s-1 (Teixeira Bonecker, de Castro, & Teixeira Bonecker, 2009). The climate is defined as tropical with two seasons: the wet season (January to June) when about 94% of the rains occur; and dry season (July to December) with 6% of precipitation (INMET, 2015).

Data acquisition

The ichthyoplankton sampling took place in November 2014, and in March, June and September 2015. The collection points were distributed in four cross sections (Figure 2). Section 01 was located on the west bank of CESM with the influence of the Pindaré River. Section 02 was on the east bank of CESM, influenced by the Mearim River. Section 03 was located in the center of CESM. Section 04 was located in the northernmost portion of CESM. 90 samples were taken at 3-month intervals. For each period of the year (dry and rainy) an identical series of data acquisition was carried out.

Figure 2 - Identification of sampling.



Source: Authors.

Ichthioplankton was collected using horizontal drag on the surface layer in layer 0 at 0.5 m (Smith & Richardson, 1977). Tapered roller nets with a mesh of 300 micrometers (net mouth diameter = 60 cm) were used, coupled to flow meters manufactured by Hydro Bios® model 438-115 to estimate the water volume.

The nets were dragged for three minutes at a speed of 2 knots. The sample was fixed in 4% formalin and screened with a Zeiss Stemi DV4 magnifier with a focal resolution of 8-32x.

The density (individuals 100m-3) was estimated considering the count of eggs and larvae and the volume of filtered water (Barkley, 1964). The sources of ichthyoplankton were considered continuous in space and represent the distribution asynchronously. The interpolation, dog in space was made using the Voronoi polygon method (Aurenhammer, 1991; Fortune, 1992) to determine the spatial shape of the area of operation of all sampling points. Once the location of the 19 generating points was geographically defined, the polygons were constructed. Options for its construction can be found in several "packages", such as, for example, the GIS SpanMap that was used.

3. Results

We peformed 90 sampling on the two periods of the year (rainy season and dry season) were collected 4,934 eggs and fish larvae, we identified samples correspond to the (03 Order), (07 Family) and (12 Group), 60% was recorded in the dry season. In the table below, we can see the species founded.

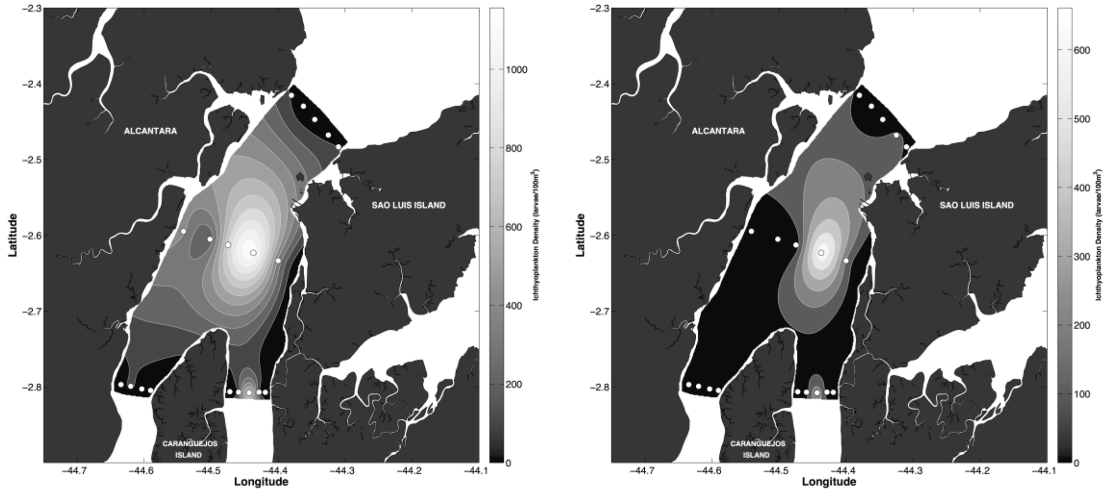
Table 1 -

	Family	**Group taxonomic**	
Clupeiformes	Engraulinae	*Anchoviela lepidentostole*	(Fowler, 1911)
		Anchovia clupeoides	(Swainson, 1839)
		Lycengraulis grossidens	(Spix & Agassiz, 1829)
		Centegraulis edentulus	(Cuvier, 1829)
	Clupeidae	*Sardinella brasiliensis*	(Steindachner, 1879)
Perciformes	Gobiidae	*Bathygobius sp*	n.i
		Coryphopterus sp	n.i
	Ephippidae	*Chaetodipterus faber*	(Broussonet, 1782)
	Sciaenidae	*Cynoscion acoupa*	(Lacepède, 1801)
		Stellifer stellifer	(Bloch, 1790)
	Lutjanidae	*Lutjanus sp*	n.i
Tetraodontiformes	Tetraodontidae	*Colomesus psittacus*	(Bloch & Schneider, 1801)

Source: Authors.

In the wet period, the highest ichthyoplankton densities were found near Section 03, where concentrations of 1100-100m-3 occurred in November 2014. In March 2015, the concentration of ichthyoplankton reached values of 661-100m3 individuals, 30% lower than the previous sample (Figure 3).

Figure 3 - Spatial distribution of Ichthyoplankton in the wet period. A) November 2014; B) March 2015.

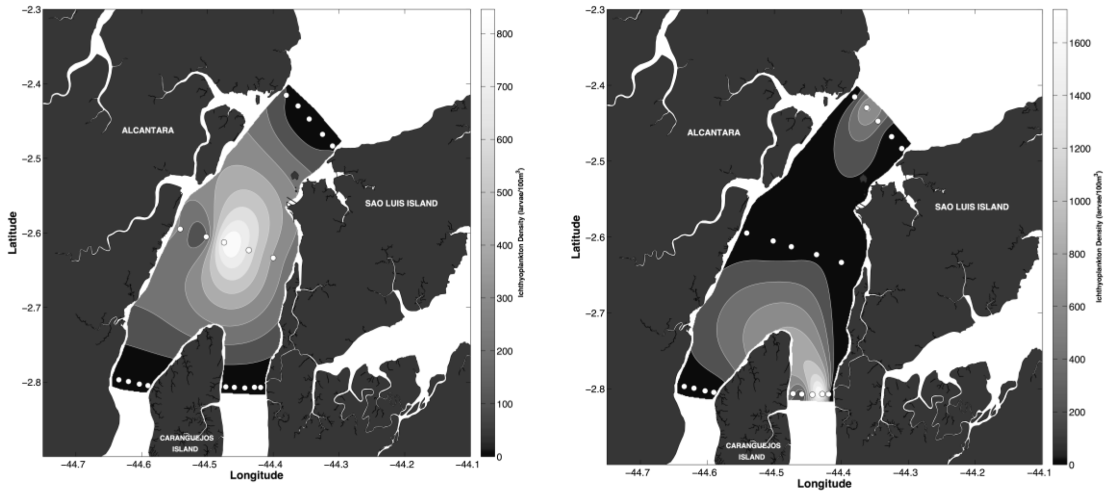


Source: Authors.

In the dry season (June 2015) a density of 906 individuals was obtained 100m-3, 17% less than the sampling of the wet period. We highlight that the area with the highest density of ichthyoplankton occurred in the center of Section 03.

The highest density of ichthyoplankton was observed in the dry season (September 2015). The point of highest density of larvae (1727 individuals 100m-3) also differed from that previously observed, in section 02 (Figure 04).

Figure 4 - Spatial distribution of Ichthyoplankton in the dry season. A) sampling conducted in June 2015; B) sampling conducted in September 2015.



Source: Authors.

The location of the largest Ichthyoplankton densities vary with seasonality, where the highest concentrations were closer to the east bank of the CESM (facing the mouth of the Mearim River) in the dry season, moving to the center in the rainy season.

4. Discussion

Higher ichthyoplankton densities east of section 02 suggest a spawning region. Ilha dos Caranguejos has been an area of environmental protection since 1991 (R. Carvalho Neta & Castro, 2008; Soares et al, 2018). This island seems to export fish larvae to the central region, the center of CESM. A survey of the island's fish assembly showed that the number of species, the Margalef richness index and the Sanders rarefaction curves have higher values on the side of the island with greater influence from the Mearim River, and a large proportion in the samples of juveniles of all taxa suggest that in this area it is characterized as feeding and reproduction. Previous studies suggest that protected estuaries are important because they provide the ideal conditions for feeding and breeding many species of fish (Pauly et al., 2002). In addition, these areas are important because they function as egg and larvae exporters to other areas (2010; Pauly et al., 2002). Larval connectivity shows that marine protected areas successfully seed unprotected areas with fish larvae (Christie et al., 2010).

The BIGGEST larval retention occurred in the area of influence of the Mearim River (2180-100m³ individuals) close to Ilha dos Caranguejos. These results indicate that the fish spawn on the island (September) before the beginning of the rains (November) and the tides contribute to disperse the larvae to the center of CESM. Some authors show that several species of fish have restricted spawning periods (Lowe-McConnell, 1987a), usually at the end of the dry season so that the larvae are active during the rainy season (Araujo-lima, 1994). This strategy guarantees feeding conditions (Nikolskii, 1963), reduction of predators (Lowe-McConnell, 1987b, 1987a) and dispersal of larvae in outward periods (Helfman, Collette, Facey, & Bowen, 2009; Wootton, 1990). This happens in fluvial environments, as the rain makes it possible for flooded areas to provide shelter (Puebla, 2009), which reduces the effect of density-dependent processes such as competition and predation (Araujo-lima, 1994; Lowe-McConnell, 1987b). This expansion of the flooded area increases the amount of organic matter available in the system for the larvae (Godinho, Lamas, & Godinho, 2010), by submersion and decomposition of marginal vegetation (Junk et al. 1983).

Considering marine protected areas as methodologies for increasing fisheries has not been successful as there is a lack of evidence that they successfully seed unprotected sites with larvae of target species (Christie et al., 2010). Some studies with marine, estuarine and freshwater species on Ilha dos Caranguejos have shown that this area is an important breeding ground for species economically exploited in the region. In this study, the large concentration of larvae in this region suggests that the protected area is essential for the conservation and management of fishery resources.

5. Conclusion

The tide, the physiographic characteristics and the leak of the Rio Mearim (Parrish et al. 1981; Chiappa-carrara et al., 2003) influence the distribution of the ichthyoplankton. In the eastern portion of CESM there is a breeding ground for many species of fish.

The high concentration of ichthyoplankton at CESM is influenced by precipitation patterns (rains), with the highest percentage (60%) of ichthyoplankton at the end of the dry season.

References

Allen, John Robert Laurence, & Rae, J. E. (1987). Late Flandrian shoreline oscillations in the Severn Estuary: A geomorphological and stratigraphical reconnaissance. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *315*(1171), 185–230. https://doi.org/10.1098/rstb.1987.0007

Allen, J. R. L. (1991). Fine sediment and its sources, Severn Estuary and inner Bristol Channel, southwest Britain. *Sedimentary Geology*, *75*(1–2), 57–65. https://doi.org/10.1016/0037-0738(91)90050-N

Allen, J. R. L. (1992). Large-scale textural patterns and sedimentary processes on tidal salt marshes in the Severn Estuary, southwest Britain. *Sedimentary Geology*, *81*(3–4), 299–318. https://doi.org/10.1016/0037-0738(92)90077-5

Araujo-Lima, C. A. R. M. (1994). Egg size and larval development in Central Amazonian fish. *Journal of Fish Biology*, *44*(3), 371–389. https://doi.org/10.1111/j.1095-8649.1994.tb01219.x

Arthur, J. F., Ball, M. D., & Baughman, S. Y. (1996). *Summary of federal and state water project environmental impacts in the San Francisco Bay-Delta Estuary, California*. San Francisco State University.

Aurenhammer, F. (1991). Voronoi diagrams—A survey of a fundamental geometric data structure. *ACM Computing Surveys*, *23*(3), 345–405. https://doi.org/10.1145/116873.116880

Barkley, R. A. (1964). The Theoretical Effectiveness of Towed-Net Samplers as Related to Sampler Size and to Swimming Speed of Organisms. *ICES Journal of Marine Science*, *29*(2), 146–157. https://doi.org/10.1093/icesjms/29.2.146

Bennett, W. A., & Moyle, P. B. (1996). *Where have all the fishes gone?: Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary*. San Francisco State University.

Bone, Q., Marshall, N. B., & Blaxter, J. H. S. (1995). Diversity of fishes. In Q. Bone, N. B. Marshall, & J. H. S. Blaxter, *Biology of Fishes* (p. 1–24). Springer US. https://doi.org/10.1007/978-1-4615-2664-3_1

Bonecker, F., Castro, M., & Bonecker, A. (2009). Larval fish assemblage in a tropical estuary in relation to tidal cycles, day/night and seasonal variations. *Pan-American Journal of Aquatic Sciences*, *4*(2), 239–246.

Brasil, I. N. de M. (2015). *Banco de Dados Meteorológicos para Ensino e Pesquisa (BDMEP), Precipitações históricas (1961 – 1990) para Ilha de São Luis*. INMET; 23/10/2016. https://portal.inmet.gov.br/

Carvalho Neta, R., & Castro, A. (2008). Diversity of the estuarine fish assemblages on Crabs Island, Maranhão state. *Arquivos de Ciência do Mar*, *41*, 48–57.

Carvalho-Neta, R. N., & Abreu-Silva, A. L. (2013). Glutathione S-Transferase as biomarker in Sciades herzbergii (Siluriformes: Ariidae) for environmental monitoring: The case study of São Marcos Bay, Maranhão, Brazil. *Latin American Journal of Aquatic Research*, *41*(2), 217–225. https://doi.org/10.3856/vol41-issue2-fulltext-2

Carvalho-Neta, R. N. F., Torres, A. R., & Abreu-Silva, A. L. (2012). Biomarkers in Catfish Sciades herzbergii (Teleostei: Ariidae) from Polluted and Non-polluted Areas (São Marcos' Bay, Northeastern Brazil). *Applied Biochemistry and Biotechnology*, *166*(5), 1314–1327. https://doi.org/10.1007/s12010-011-9519-1

Chao, N. L., & McConnell, R. H. L. (1988). Ecological Studies in Tropical Fish Communities. *Estuaries*, *11*(1), 76. https://doi.org/10.2307/1351725

Chia, F.-S., Buckland-Nicks, J., & Young, C. M. (1984). Locomotion of marine invertebrate larvae: A review. *Canadian Journal of Zoology*, *62*(7), 1205–1222. https://doi.org/10.1139/z84-176

Chiappa-Carrara, X. (2003). Ichthyoplankton distribution as an indicator of hydrodynamic conditions of a lagoon system in the Mexican Caribbean. *Journal of Plankton Research*, *25*(7), 687–696. https://doi.org/10.1093/plankt/25.7.687

Christie, M. R., Tissot, B. N., Albins, M. A., Beets, J. P., Jia, Y., Ortiz, D. M., Thompson, S. E., & Hixon, M. A. (2010). Larval Connectivity in an Effective Network of Marine Protected Areas. *PLoS ONE*, *5*(12), e15715. https://doi.org/10.1371/journal.pone.0015715

Cowen, R. K. (2000). Connectivity of Marine Populations: Open or Closed? *Science*, *287*(5454), 857–859. https://doi.org/10.1126/science.287.5454.857

dos Santos, V. F., Figueiredo Jr, A. G., da Silveira, O. F. M., Polidori, L., de Oliveira, D. M., & Dias, M. B. (2005). *Processos Sedimentares em área de Macro-marés Influenciados Pela Pororoca-Estuário do Rio Araguari-Amapá-Brasil*.

Fortune, S. (1992). Fast topological construction of delaunay triangulations and voronoi diagrams. *Computers & Geosciences*, *19*(10), 1463–1474. https://doi.org/10.1016/0098-3004(93)90062-A

Geyer, W. R. (1995). Tide-induced mixing in the Amazon Frontal Zone. *Journal of Geophysical Research*, *100*(C2), 2341. https://doi.org/10.1029/94JC02543

Godinho, A. L., Lamas, I. R., & Godinho, H. P. (2010). Reproductive ecology of Brazilian freshwater fishes. *Environmental Biology of Fishes*, *87*(2), 143–162. https://doi.org/10.1007/s10641-009-9574-4

González-Gorbeña, E., Rosman, P. C. C., & Qassim, R. Y. (2015). Assessment of the tidal current energy resource in São Marcos Bay, Brazil. *Journal of Ocean Engineering and Marine Energy*, *1*(4), 421–433. https://doi.org/10.1007/s40722-015-0031-5

Green, A. L., Maypa, A. P., Almany, G. R., Rhodes, K. L., Weeks, R., Abesamis, R. A., Gleason, M. G., Mumby, P. J., & White, A. T. (2015). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews*, *90*(4), 1215–1247. https://doi.org/10.1111/brv.12155

Kirby, R., & Parker, W. R. (1983). Distribution and Behavior of Fine Sediment in the Severn Estuary and Inner Bristol Channel, U.K. *Canadian Journal of Fisheries and Aquatic Sciences*, *40*(S1), s83–s95. https://doi.org/10.1139/f83-271

Larsonneur, C. (1994). *The Bay of Mont-Saint-Michel: A Sedimentation Model in a Temperate Macrotidal Environment*. Kramer in Komm. https://books.google.com.br/books?id=faAVNQAACAAJ

Le Bars, Y., Lyard, F., Jeandel, C., & Dardengo, L. (2010). The AMANDES tidal model for the Amazon estuary and shelf. *Ocean Modelling*, *31*(3–4), 132–149. https://doi.org/10.1016/j.ocemod.2009.11.001

Lowe-McConnell, R. H. (1987). *Ecological Studies in Tropical Fish Communities* (1º ed). Cambridge University Press. https://doi.org/10.1017/CBO9780511721892

Moriyama, A., Yanagisawa, Y., Mizuno, N., & Omori, K. (1998). Starvation of drifting goby larvae due to retention of free embryos in upstream reaches. *Environmental Biology of Fishes*, *52*(1–3), 321–329.

Nikolʹskiĭ, G. V. (1963). *The ecology of fishes*. Academic press.

Parrish, R. H., Nelson, C. S., & Bakun, A. (1981). Transport mechanisms and reproductive success of fishes in the California Current. *Biological Oceanography*, *1*(2), 175–203.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., Watson, R., & Zeller, D. (2002). Towards sustainability in world fisheries. *Nature*, *418*(6898), 689–695. https://doi.org/10.1038/nature01017

Pereira, J. E. R., & Harari, J. (1995). Modelo numérico tri-dimensional linear da plataforma continental do Estado do Maranhão. *Brazilian Journal of Oceanography*, *43*(1), 19–34. https://doi.org/10.1590/S1679-87591995000100002

Puebla, O. (2009). Ecological speciation in marine *v.* freshwater fishes. *Journal of Fish Biology*, *75*(5), 960–996. https://doi.org/10.1111/j.1095-8649.2009.02358.x

Ribeiro, E. B., Almeida, Z. S., & Carvalho-Neta, R. N. F. (2012). Hábito alimentar do bagre Sciades herzbergii (Siluriformes, Ariidae) da Ilha dos Caranguejos, Maranhão, Brasil. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, *64*(6), 1761–1765. https://doi.org/10.1590/S0102-09352012000600048

Rockwell Geyer, W., Beardsley, R. C., Lentz, S. J., Candela, J., Limeburner, R., Johns, W. E., Castro, B. M., & Dias Soares, I. (1996). Physical oceanography of the Amazon shelf. *Continental Shelf Research*, *16*(5–6), 575–616. https://doi.org/10.1016/0278-4343(95)00051-8

Rumrill, S. S. (1990). Natural mortality of marine invertebrate larvae. *Ophelia*, *32*(1–2), 163–198. https://doi.org/10.1080/00785236.1990.10422030

Sfakiotakis, M., Lane, D. M., & Davies, J. B. C. (1999). Review of fish swimming modes for aquatic locomotion. *IEEE Journal of Oceanic Engineering*, *24*(2), 237–252. https://doi.org/10.1109/48.757275

Shima, J. S., & Swearer, S. E. (2010). The legacy of dispersal: Larval experience shapes persistence later in the life of a reef fish: Legacy effects of dispersal. *Journal of Animal Ecology*, *79*(6), 1308–1314. https://doi.org/10.1111/j.1365-2656.2010.01733.x

Silva, I. da, Pereira, L., de O. Guimarães, D., Trindade, W., Asp, N., & Costa, R. da. (2009). Environmental status of urban beaches in São Luís (Amazon coast, Brazil). *Journal of Coastal Research*, 1301–1305.

Smith, P. E., & Richardson, S. (1977). Standard techniques for pelagic. *FAO Fisheries Techniques Paper*, *175*, 27–73.

Soares, R. de A., Junior, A. R. T., Dias, F. J. da S., & Neta, R. N. F. C. (2018). *The eventual presence of freshwater of Amazonas river over the continental shelf of the state of Maranhão – Brazil*. 100009. https://doi.org/10.1063/1.5079164

Souza Filho, P. W. M. (2005). Costa de manguezais de macromaré da Amazônia: Cenários morfológicos, mapeamento e quantificação de áreas usando dados de sensores remotos. *Revista Brasileira de Geofísica*, *23*(4), 427–435. https://doi.org/10.1590/S0102-261X2005000400006

Susan Bartsch-Winkler (2), Henry R. (1984). Bedding Types in Holocene Tidal Channel Sequences, Knik Arm, Upper Cook Inlet, Alaska. *SEPM Journal of Sedimentary Research*, *Vol. 54*. https://doi.org/10.1306/212F85AD-2B24-11D7-8648000102C1865D

Susan Bartsch-Winkler, A. Thomas Ov. (1984). Macrotidal Subarctic Environment of Turnagain and Knik Arms, Upper Cook Inlet, Alaska: Sedimentology of the Intertidal Zone. *SEPM Journal of Sedimentary Research*, *Vol. 54*. https://doi.org/10.1306/212F85A8-2B24-11D7-8648000102C1865D

Warner, R. R., Swearer, S. E., & Caselle, J. E. (2000). Larval accumulation and retention: Implications for the design of marine reserves and essential habitat. *Bulletin of Marine Science*, *66*(3), 821–830.

Wootton, R. J. (1990). *Ecology of teleost fishes* (2a ed.). Springer Science & Business Media.

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