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Short Communication

THE INFLUENCE OF THE COASTAL CURRENT ON THE ESTIMATION OF RELATIVE ABUNDANCE INDICES IN SMALL-SCALE SHRIMP FISHERY*

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ABSTRACT

The aim of this scientific note was to evaluate the influence of the coastal current on the estimation of relative abundance indices for small-scale marine shrimp trawling to indicate the best relative abundance index to be used for stock assessment and conservation. Georeferenced experimental trawls were carried out with standardized equipment and capture time on the coast of Rio Grande do Norte, northeastern Brazil. Drags followed convergent and divergent orientations in relation to the flow of the local coastal current. The results showed that the direction of the coastal current flow directly influences the distances and drag shifts, generating variations in the sampling effort and, consequently, bias when using Catch per Unit Effort (CPUE) as a relative abundance index. Conversely, the adoption of Catch per Unit of Swept Area (CPUA) as an index of relative abundance for shrimp trawling becomes more suitable since the variations in the distances of trawl shifts are perceptible through this index.

Keywords: fishing effort; Catch per Unit Effort; Catch per Unit Swept Area; fisheries research; trawl fishing; artisanal fishing.

A INFLUÊNCIA DA CORRENTE COSTEIRA NA ESTIMATIVA DE ÍNDICES DE ABUNDÂNCIA RELATIVA NA PESCA DE CAMARÕES DE PEQUENA ESCALA

RESUMO

O objetivo desta nota foi avaliar a influência da corrente costeira na estimativa de índices de abundância relativa para a pesca de arrasto de camarão marinho em pequena escala, a fim de indicar o melhor índice de abundância relativa a ser usado para avaliação e conservação de estoque. Pescarias de arrasto experimentais e georreferenciadas foram realizadas com equipamentos e tempos de captura padronizados no litoral do Rio Grande do Norte, Nordeste do Brasil. Os arrastos seguiram orientações convergentes e divergentes ao fluxo da corrente litorânea local. Os resultados mostraram que a direção do fluxo da corrente costeira influencia diretamente na distância e no deslocamento de arrasto, gerando variações no esforço amostral e, consequentemente, viés ao utilizar Captura por Unidade de Esforço (CPUE) como índice de abundância relativa. Por outro lado, a adoção da Captura por Unidade de Área (CPUA) como um índice de abundância relativa para o arrasto de camarão torna-se mais adequada, uma vez que as variações nas distâncias de deslocamento dos arrastos são perceptíveis por este índice.

Palavras-chave: esforço de pesca; Captura por Unidade de Esforço; Captura por Unidade de Área Varrida; ciência pesqueira; pesca de arrasto; pesca artesanal.

INTRODUCTION

Estimating the abundance of a fishery resource is essential for the application of stock assessment models and the consequent management of resources (Pezzuto et al., 2008; Mirzaei et al., 2019). Stock assessments of shrimp species have generally relied on biomass dynamics models by applying a time-series of relative abundance indices, which (a) are only available for a small offshore fraction of the exploited population, and (b) do not comprise patterns of the shallowest artisanal fishing grounds (Pezzuto et al., 2008). However, their precision and effectiveness depend on the reliability of the abundance indices, which are useful for assessing spatio-temporal changes in biomass and are essential as data entry in production models (Fonteles-Filho, 2011).

In marine shrimp trawling, two abundance indices are commonly used separately or simultaneously: Catch per Unit Effort (CPUE) and Catch per Unit of Swept Area (CPUA) (Asano-Filho et al., 2003; Furtado-Júnior et al., 2003; Melo et al., 2005; Perez and Defeo, 2005; Loebmann and Vieira, 2006; Pezzuto et al., 2008; Petrere-Junior et al., 2010; Valentini et al., 2012; Mendonça et al., 2013; Aragão et al., 2015; Silva-Júnior et al., 2019; Carvalho et al., 2020; Selvam et al., 2021).

The Catch per Unit Effort (CPUE) is one of the main indicators of relative abundance used in fisheries science that is directly related to stock biomass. One of the weaknesses in obtaining this index is the flawed monitoring of production and effort data and, specifically in trawling, the absence of methodological standardization (Mendonça et al., 2013). In addition, the use of indices such as CPUE to estimate the biomass of a population assumes homogeneity of the fishing power of the different fishing units involved (main assumption). This means, for instance, that two or more fishing vessels dragging their trawls simultaneously, for the same amount of time and in the same fishing area, should catch the same amount of a given resource (Perez, 1999), since they theoretically have the same capturability coefficient. However, this homogeneity is difficult to obtain. Characteristics that are inherent in the fishing operation, type of vessel and the skill of the crew (knowledge of the fisherman), as well as the technological evolution of these factors, interfere in the validity of this assumption and introduces errors into the abundance estimates of a population and its patterns of variability in several studies (Perez, 1999; Salthaug, 2001; Marchal et al., 2002; Rijnsdorp et al., 2006; Quirijns et al., 2008; Petrere-Junior et al., 2010; Fonteles-Filho, 2011; Lombardi et al., 2014; Walker et al., 2017).

In addition, CPUE also takes into consideration is that the spatial distribution of a target species is static, that is, the resources do not vary spatially. Nevertheless, spatial distribution can contract with decline in population biomass, without affecting resource densities in the species' central habitat (Rose and Kulka, 1999; Quirijns et al., 2008). Finally, the CPUE assumes that environmental conditions do not influence species capturability, but this estimate can be influenced, for instance, by changes in the spatial dynamics of a resource, in the capture probability through the device, or both (Horwood and Millner, 1998; Quirijns et al., 2008; Fonteles-Filho, 2011).

An abundance estimate, regardless of the maximum virgin biomass of a species, can be obtained through the Swept Area method, a term that defines the process of "sweeping" the substrate through trawling, taking into account the captured amount and the escape factor (Fonteles-Filho, 2011). With the incorporation of the swept area, the Catch per Unit of Swept Area (CPUA) has two main assumptions: (i) the trawl net sweeps a track defined by the width of its opening, and by the drag and current speeds; (ii) the value of the net opening varies according to the speed of the drag, climatic conditions, currents and cable lengths. Nevertheless, factors such as current speed can often be neglected in the models, due to the unavailability or difficulty in obtaining this type of data on a local scale.

In shrimp trawling, oceanographic factors (e.g., waves, current, changes in the texture and morphology of the benthic substrate, etc.), can directly influence the swept area, generating underestimation or overestimation of the CPUE of the fishery resource (Lombardi et al., 2014). However, we did not find studies in the literature that confirm the influence of such factors on shrimp trawl fishing route and, consequently, on the error of the abundance estimate of the fishery resource under study, which can interfere in the stock assessment and therefore in the regulatory measures originated from it.

In this context, the aim of this study was to evaluate the influence of the coastal current on the estimation of relative abundance indices for artisanal marine shrimp trawling carried out in the state of Rio Grande do Norte, in northeastern Brazil. It is expected that the results obtained here assist in choosing the appropriate relative abundance index for shrimp fishery in order to better correlate it with stock biomass.

MATERIAL AND METHODS

Study area

The experiment was carried out in a section of the coastal strip of the city of Baia Formosa, State of Rio Grande do Norte, in northeastern Brazil (coordinates: 06°21'S / 35°01'W) (Figure 1). The region under study has an economy based on fishery, tourism, shrimp farming and agriculture. Small-scale artisanal fisheries in the region play an important role in the local economy. Involving around a thousand fishermen, local fisheries are mainly focused on catching longfin tuna, dorado, wahoo, yellowtail amberjack, black grouper, spiny lobster and marine shrimp (Giovindin, 2014).

The study area presents a S-N longshore drift parallel to the coastline, resulting from the influence of winds and the alignment of the coastline (Amaral, 2000; Vital et al., 2016; Oliveira, 2017). On the coast of Rio Grande do Norte, coastal currents have median speeds of 0.128 m s^{-1}, 0.093 m s^{-1} and 0.08 m s^{-1} during summer, spring and autumn, respectively (Oliveira, 2017). The waves have a maximum height of 1.85 m in the summer and 0.85 m in the rainy season (winter) (Vital et al., 2016).

Sampling

During 2016, 52 georeferenced experimental trawls were carried out in a section of the coastal strip of the Baia Formosa bay, in Rio Grande do Norte (Figure 1). Half of the trawls (n = 26) were performed in the same direction of the coastal current flow (S-N direction), while the other half (n = 26) were performed in the divergent direction (N-S direction) (Figure 2). The trawls were randomly carried out between the 10 and 20 m isobath, a region regularly frequented by local fishermen during commercial shrimp fishing activities. All trawls were carried out using a motorized artisanal fishing vessel, equipped with a single-rig trawl. Each trawl was standardized at a constant speed (1.9 knots), lasting 20 minutes and carried out by the same fishing crew.

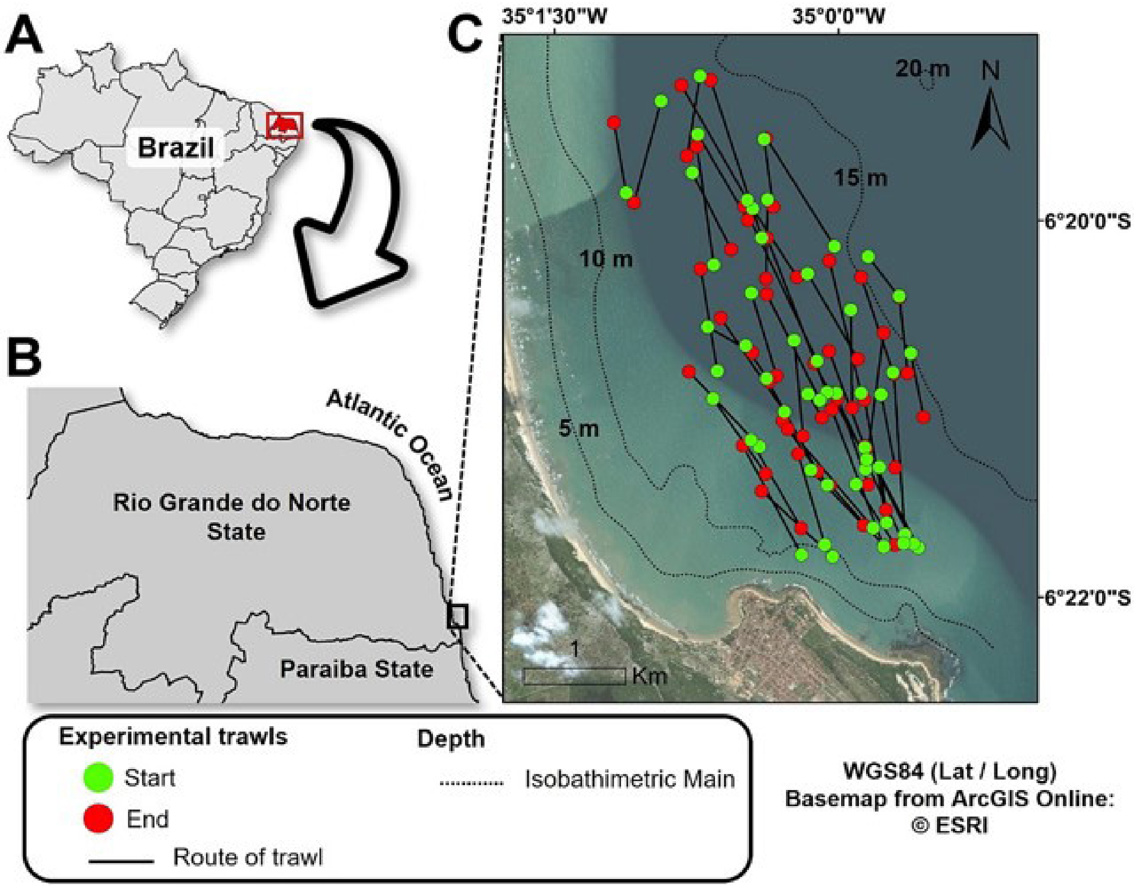

Figure 1. Location of the sampling area and spatial details of the drags carried out during the period under study: (A) Map of Brazil indicating the Rio Grande do Norte state (red rectangle); (B) Rio Grande do Norte state with the location of the Baía Formosa city (black rectangle); and (C) Sampling site with the trawls.

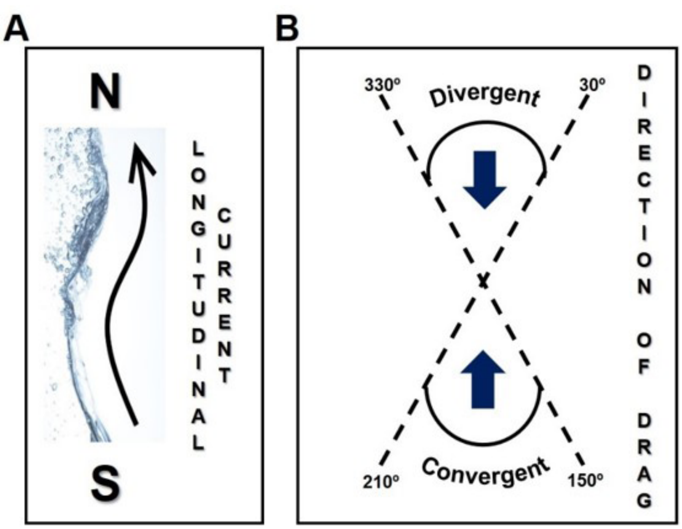

Figure 2. Schematic illustration of the relation of drag direction with the direction of the coastal current flow. (A) Predominant direction of the local longitudinal coastal current; (B) direction of drag in relation to the direction of the coastal current.

After each trawl, the captured shrimps were packed in labeled thermal boxes and, at the end of each fishing schedule, transported to the laboratory of the Federal University of Rio Grande do Norte (UFRN), where the procedures of counting and individual weighing were performed.

Data analysis

After counting and weighing the catches of each trawl, the data were tabulated in an electronic spreadsheet, correlated with their geographical coordinates, and expressed by the relative abundance indices: Catch Per Unit Effort (CPUE) and Catch Per Unit of Swept Area (CPUA).

The equation of Gulland (1964) was used to assess the CPUE index for each trawl according to Equation 1:

$$CPUE = \frac{Cw}{t} \quad (1);$$

where: *Cw* is the catch weight (kg) and *t* is the drag time (hours) in each trawl.

For calculating CPUA (kg km^{-2}), Equation 2 was used (Sparre and Venema, 1992):

$$CPUA = \frac{Cw}{a} \quad (2);$$

where: *Cw* is the catch weight (kg) and *a* is the swept area in each trawl.

For each trawl, the swept area was computed using the following formula (Equation 3):

$$a = D \times L \times X_2 \quad (3);$$

where: *D* is the trawl route distance in kilometers (km), L is the head rope length, and X_2 is the fraction of the head rope length. The value of X_2 was considered 0.5 in this study (Yesaki, 1974; Pauly, 1980).

The distance of each trawl route was defined as the linear distance between the start and the end positions of the drag, obtained automatically through a Geographic Information System (GIS).

Quantitative data were subjected to descriptive statistics regarding measures of central tendencies and dispersion (amplitude and dispersion). Later, the data were normalized according to their amplitude (min-max) (Moeller, 2015) and subjected to a parametric check (normality and homogeneity), using the Shapiro-Wilk (Shapiro and Wilk, 1965) and Levene tests (Levene, 1960). Amplitude normalization of data (min-max) is a process of transforming outliers using a scale ranging from 0, for the lowest value, to 1, for the highest. This makes it easy to compare values that have been measured using different scales. For this, the following equation (Equation 4) was used:

$$X_{normalized} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (4);$$

where: X is a value within a vector minus the minimum value of that same vector. The result of this subtraction is then divided by the maximum value minus the minimum value of the vector. As a result, all the values of the vector will be between 0 and 1.

Initially, the Spearman's rank correlation coefficient (r_s) (Spearman, 1904) was used to measure the monotonic relationship between the variables "normalized CPUE" *vs* "normalized CPUA" based on the theoretical assumption that there would be a perfect positive correlation (+1) between the two, that is, when the CPUE increased, the CPUA would necessarily increase. We also calculated the r_s between the variables "Normalized Drag Shift Distance" *vs* "Normalized Effort Difference". The "Normalized Effort Difference" was obtained through the difference between normalized CPUE - normalized CPUA. The variable "drag direction" (categorical factor) was determined by the direction of the vessel's displacement in relation to the coastal current, which may be Divergent or Convergent (Figure 2B).

The nonparametric Mann–Whitney test (Neuhäuser, 2011) was used for comparative inferences between: "normalized CPUE" *vs* "normalized CPUA"; "Normalized Effort Difference" *vs* "Drag Direction". Finally, the parametric Test T (Kim, 2015) was used for comparative inference between the "Drag Shift Distance" *vs* "Drag Direction".

In all statistical analyses, a significance value of 5% (Zar, 2010) was adopted and they were performed on R software v.3.6.2 (R Development Core Team, 2020).

RESULTS AND DISCUSSION

In total, mean drag distance was 999.37 m, with a minimum and maximum of 270.50 m and 1,690.99 m, respectively (Table 1).

Mean CPUE was 2.645 kg h^{-1}, with a minimum and maximum of 0.007 and 11.146 kg h^{-1}, respectively, while mean CPUA was 147.130 kg km^{-2}, with a minimum and maximum of 0.349 and 765.524 kg km^{-2}, respectively (Table 1). The normalized CPUE and the normalized CPUA did not show statistically significant differences (*U* test: W = 1548; *p*-value = 0.2037). However, when plotting the two variables on a line chart, sharp differences can be observed in some trawl routes, in which the normalized CPUE is

Table 1. Descriptive statistics of the distances covered, CPUE and CPUA values obtained in the trawls.

Trawl	Number of Trawl	Statistical Parameter	Trawl route distance (m)	CPUE (kg h^{-1})	CPUA (kg km^{-2})
All	52	Mean	999.37	2.645	147.130
		Minimum	270.50	0.007	0.349
		Maximum	1,690.99	11.146	765.524
		Stand. deviation	329.92	2.575	161.017
Convergent	26	Mean	1,208.07	2.880	130.900
		Minimum	675.13	0.075	2.659
		Maximum	1,690.99	11.146	575.608
		Stand. deviation	285.99	2.413	116.355
Divergent	26	Mean	790.67	2.411	163.359
		Minimum	270.50	0.007	0.349
		Maximum	1,173.06	10.090	765.524
		Stand. deviation	222.85	2.755	196.986

higher than the normalized CPUA (r_s = 0.94; S = 1316, *p*-value <0.01) (Figure 3A). In addition, the Normalized Effort Difference (normalized CPUE - normalized CPUA) has a positive correlation with the distance traveled in the trawl (r_s = 0.74; S = 6060, *p*-value <0.01) (Figure 3B). In addition, the Normalized Effort Difference shows a statistically significant difference between convergent x divergent directions (*U* test: W = 559; *p*-value <0.01) (Figure 4A), with the convergent direction showing higher values than the

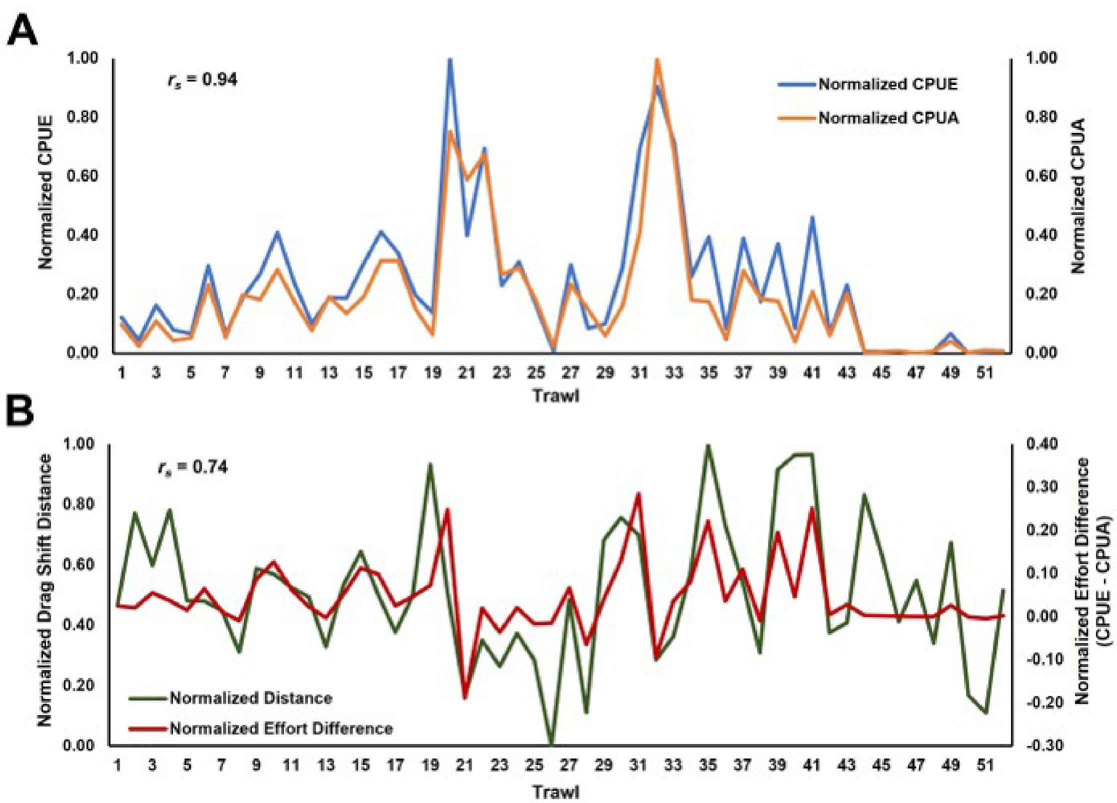

Figure 3. Correlations: (A) variation of normalized CPUE and normalized CPUA between trawls; (B) variation of normalized drag shift distance and normalized effort difference between trawls.

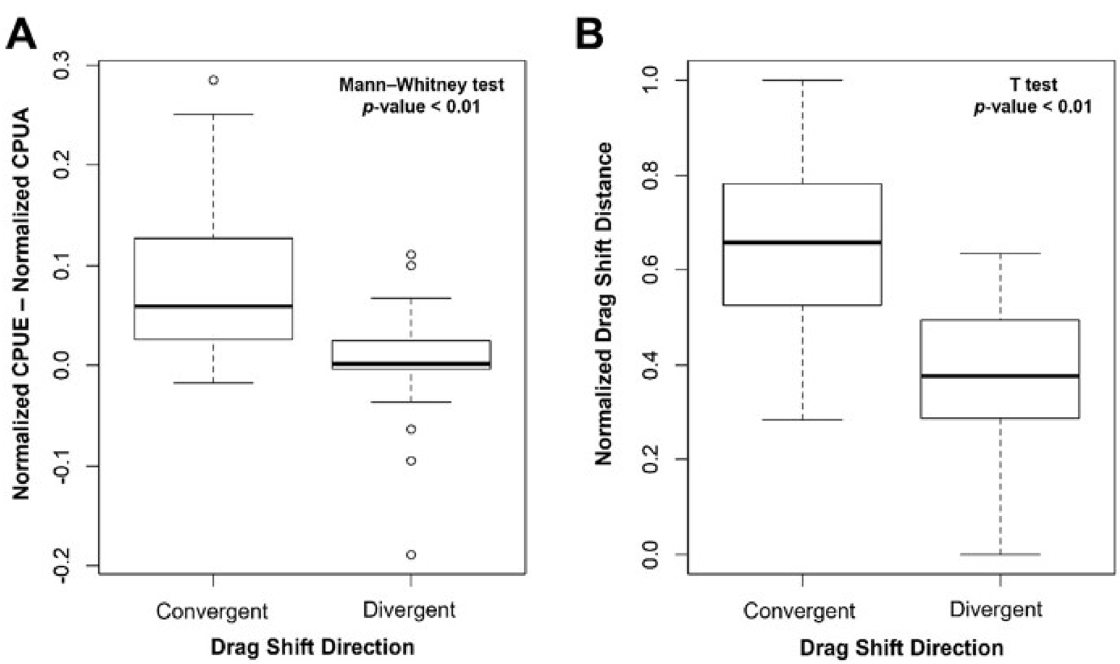

Figure 4. Statistical comparisons between drag shift directions: (A) Normalized effort difference (normalized CPUE - normalized CPUA); (B) Normalized Drag Shift Distance. Boxplot information: maximum, minimum, first, second and third quartile (median).

divergent one. Consequently, the distance covered in the trawls showed statistically significant differences between convergent x divergent directions in relation to the local coastal current (T test: t = 5.8702; df = 47.181; *p*-value <0.01) (Figure 4B).

The results revealed that when the drag is carried out in the same direction as that of the local coastal current, there is a physical tendency for the boat to travel a greater distance and, consequently, sweep a larger area, thus generating a greater sampling effort in that drag. This effort is not noticeable through CPUE, generating an overestimation of the relative abundance of the fishery resource. On the other hand, when sailing in a divergent direction, that is, against that of the coastal current, a short displacement of the swept area is produced at the end of the drag, resulting in a decrease in the sampling effort and, consequently, an underestimation of CPUE. In this context, Perez (1999) established that after identifying possible violations of the assumptions involved, such as variations in the duration of travels, the use of CPUE as an abundance index should be done with caution.

The results demonstrated the practical invalidity of one of the theoretical assumptions of the CPUE (i.e., the assumption that environmental factors do not influence capturability). Unlike the CPUE, the CPUA is sensitive to the oceanographic influence of the coastal current on navigation, since the relation between capture and sampling space is the basis for the construction of its relative abundance index.

In addition, the CPUA dismisses another questionable assumption of the CPUE, that of the spatial distribution of target species being static. Due to the georeferencing of the trawls, the geographic location enters as a variable of spatial response power and, consequently, favors the analysis of the spatial distribution dynamics of the fishery resource (e.g., Dumont and D'Incao, 2008; Martins et al., 2015; Zeinali et al., 2017; Kolling et al., 2019; Mirzaei et al., 2021).

In the present study, by applying a trawl experimental effort (20 minutes), it was noticeable the influence of the local coastal current on the CPUE and CPUA estimates. The differences between the indices could possibly become more accentuated if applied to commercial fisheries since the catch effort, in general, exceeds two hours in duration.

Locally, on the coast of Baia Formosa-RN-Brazil, as seen in other small-scale fisheries, commercial fisheries are developed in order to meet the best cost-benefit for fishermen (Kolding et al., 2014). In many cases, after the completion of a trawl in the same direction as that of the coastal current flow (convergent direction), fishermen collect the catch and immediately start another trawl in the divergent direction. Based on this operational mode, we suggest the adoption of CPUA as the standard index of relative abundance for this type of fishery, ensuring the information and regulatory measures that may arise from these inferences. Finally, the application of this index can be totally viable after encouraging the use of GPS by artisanal fishermen, with registration of the tracking of each trawl in a logbook. However, public policies must be created to foment GPS receivers' acquisition and their respective uses to the artisanal fishermen (training course).

CONCLUSIONS

The navigation pattern of vessels influenced by oceanographic conditions raises a pertinent concern regarding the standardization of the relative abundance index for marine shrimp trawling. The use of CPUE can, in most cases, underestimate or overestimate the reality of fishery resources due to the influence of the local coastal current. Therefore, we recommend the adoption of CPUA as the standard index of relative abundance during studies focused on marine shrimp trawling in Brazil.

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