Habitat Characteristics of Flyingfish (Family Exocoetidae) Larvae in the Northern Gulf of Mexico

Características del Hábitat de Peces Voladores (Familia Exocoetidae) Larvas en del Norte Golfo de México

Caractéristiques de L'habitat des Larves dde Poissons Volants (Famille Exocoetidae) dans le Nord du Golfe du Mexique

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ABSTRACT

Flyingfish occupy a crucial link in pelagic food webs, and understanding their distribution and abundance can lead to an improved understanding of their population dynamics. The aim of the present study is to characterize the distribution and abundance of larval flyingfish (family Exocoetidae) and more specifically the species *Prognichthys occidentalis* in the northern Gulf of Mexico. Here, we report on summer ichthyoplankton cruises conducted in the northern Gulf of Mexico (NGoM) during 2009 - 2011. Samples were collected using neuston nets towed through the upper meter of the water column in the outer shelf and slope waters of the NGoM. Over the three year sampling period, a total of 12,646 flyingfish larvae were collected and 77% of the total catch was comprised of *P. occidentalis*. Interannual variation was detected with densities of flyingfish larvae higher in 2009 and 2010 (14.9 and 10.0 larvae 1000/m^2, respectively) than 2011 (2.7 larvae 1000/m^2). Flyingfish larvae were present in each month and year along our sampling transect, and percent frequency of occurrence ranged from 56% in July 2011 to 100% in June 2010, suggesting that flyingfish represent a common and important component of the ichthyoplankton assemblage in the NGoM. Generalized additive models were used to evaluate the influence of oceanographic conditions on the density of all flyingfish larvae and *P. occidentalis*. The overall flyingfish density model indicates that abundance of larvae increased in waters with lower temperatures and negative sea surface height, which corresponds to frontal boundaries and cyclonic features in the NGoM.

KEY WORDS: Flyingfish, Gulf of Mexico, distribution, *Prognichthys occidentalis*, Generalized additive models

INTRODUCTION

Flyingfish are essential components of pelagic food webs, and these taxa are well represented in the diets of several apex predators that reside in coastal and offshore environments (Oxenford and Hunte 1999). Despite their importance, our understanding of their life history and ecology is limited, particularly studies investigating early life processes. Early life studies provide fundamental information on adult spawning locations and population dynamics (Hunte et al. 1995). Because larval fish survival is tied closely to primary productivity and environmental conditions, changes in abundance or distribution of larvae is useful for understanding the impacts of environmental perturbations (Rooker et al. 2013). Therefore, establishing baseline data on the distribution and abundance of flyingfish larvae provides information that can be used to identify population trends and important spawning areas.

The Gulf of Mexico (GoM) is a model system for evaluating early life ecology of flyingfishes because high productivity associated with allochthonous nutrient inputs (Mississippi River) supports important recreational and commercial fisheries. In addition, the GoM is characterized by the presence of a dominant mesoscale feature (Loop Current), which frequently sheds cyclonic and anti-cyclonic eddies (Nürnberg et al. 2008). This combination of autochthonous and allochthonus drivers of production make the GoM an interesting location for investigating the early life ecology of flyingfish. Here we characterize the spatial and temporal trends in the distribution and abundance of larval flyingfish in the GoM. We hypothesize that flyingfish abundance will increase near cyclonic eddies and frontal regions because these regions are often associated with upwelling and increased nutrient availability.

METHODS

Six ichthyoplankton surveys were conducted in the outer shelf and slope waters of the northern GoM during June and July of 2009 to 2011. Our sampling corridor encompassed an area from 26 to 28°N latitude and 86 to 93°W longitude. Flyingfish larvae were collected with paired 2 m by 1 m neuston nets with mesh sizes 500 µm and 1200 µm towed for 10 minutes at a speed of 2.5 knots. A flowmeter recorded the volume of water sampled. All ichthyoplankton and associated zooplankton collected were stored in 50% ethanol and 50% seawater, and then transferred to 100% ethanol after 48 hours. In the laboratory all flyingfish larvae were sorted using a Leica MZ stereomicroscope.

A two-way ANOVA test (factors: month and year) with interaction was used to assess inter-annual and intra-annual variability in abundance. *Post-hoc* differences among the main effects were examined using a Dunnett's T3 test because of unequal variances (Brown-Forsythe $p < 0.000$) (SPSS 16.0.1).

RESULTS

Over the three years sampled, a total of 12,396 flyingfish larvae were collected from 385 stations. Mean flyingfish density ranged from 0.88 larvae/1000 m^2 in July 2011 to 22.36 larvae/1000 m^2 in June 2009, with an overall average of 9.07 larvae/1000 m^2. Frequency of occurrence was high for flyingfish with larvae collected in every month and year sampled. Percent frequency of occurrence for flyingfish ranged from 56% in July 2011 to 100% in June 2009, June 2010, and July 2010. In every year surveyed, June had a higher percent frequency than July except for 2010 where both months had 100% occurrence.

Mean density for years 2009 and 2010 (10.80 and 7.54 larvae/1000 m^2, respectively) was significantly higher than the mean density for 2011 (2.33 larvae/1000 m^2) (ANOVA, $F = 119.4230$, $p < 0.001$). June 2009 had the highest mean density of 22.36 larvae/1000 m^2 and July 2011 had the lowest mean density of 0.88 larvae/1000 m^2. In all years except 2010, June had a higher density of flyingfish larvae than July (ANOVA, $F = 29.5233$, $p < 0.001$) (Figure 1).

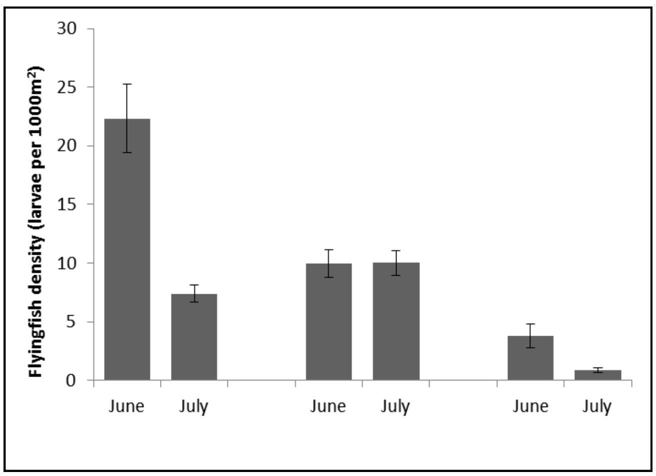

Figure 1. Mean density of flyingfish larvae collected in June and July for each sampling year 2009 - 2011. Letters denote significant differences among months based on Dunnett T3 post hoc groupings ($p < 0.05$). Error bars represent one standard error of the mean.

Spatial differences in the distribution and abundance of flyingfish larvae were detected among the six surveys (Figure 2). In 2009 and 2010, abundance of flyingfish appear consistent across transects, but in 2011 densities of flyingfish were variable with flyingfish absent from more stations than the previous two years. In June 2011, the abundance of flyingfish was higher in the 28°N transect, but in July abundance was greater in the 27°N transect. Additionally, larvae abundances generally increased in areas of lower sea surface height (Figure 2).

DISCUSSION

Flyingfish larvae were commonly collected in our surveys and observed densities were relatively high, suggesting that this group represents an important component of the ichthyoplankton assemblage in the NGoM. Comparable assessments in the GoM or other regions are rare, nevertheless, a study by Hunte et al. (1995) examined abundance of larval flyingfishes within the eastern Caribbean and found a relative abundance of 10.25 flyingfish per $1000m^{-2}$, which is similar to mean density of flyingfish reported here (9.07 larvae $1000m^{-2}$). Over the three year sampling period nearly 88% of the tows had flyingfish present, suggesting that the survey region represents an important spawning and nursery ground for flyingfish.

Inter-annual variability across the three years sampled was pronounced, with densities in 2011 be markedly lower than the two other years sampled. Temporal changes in abundance may be due to a variety of factors, including shifts in the spawning locations of adults (i.e. egg production) or variability in early life survival, both of which are influenced by oceanographic conditions. The yearly differences in density could be attributed to the location of the Loop Current. In 2011, the Loop Current intruded farther north than the previous two years as shown in figure 2 by the higher SSHA, creating unfavorable spawning habitat for flyingfish because of the warm, nutrient depleted waters associated with the Loop Current (Biggs, 1992). The oligotrophic waters of the Loop Current can also result in lower primary and secondary production, creating less feeding opportunities for larval flyingfish (Wormuth et al., 2002). The variability in oceanographic conditions, especially the Loop Current location, could lead to changes in the abundance of adult flyingfish which would impact the abundance of larval flyingfish within the NGoM. Significant monthly differences were also observed, with June having a higher density than July, suggesting spawning times of flyingfish in the NGoM are similar to spawning times of flyingfish in the eastern Caribbean (Hunte et al., 1995).

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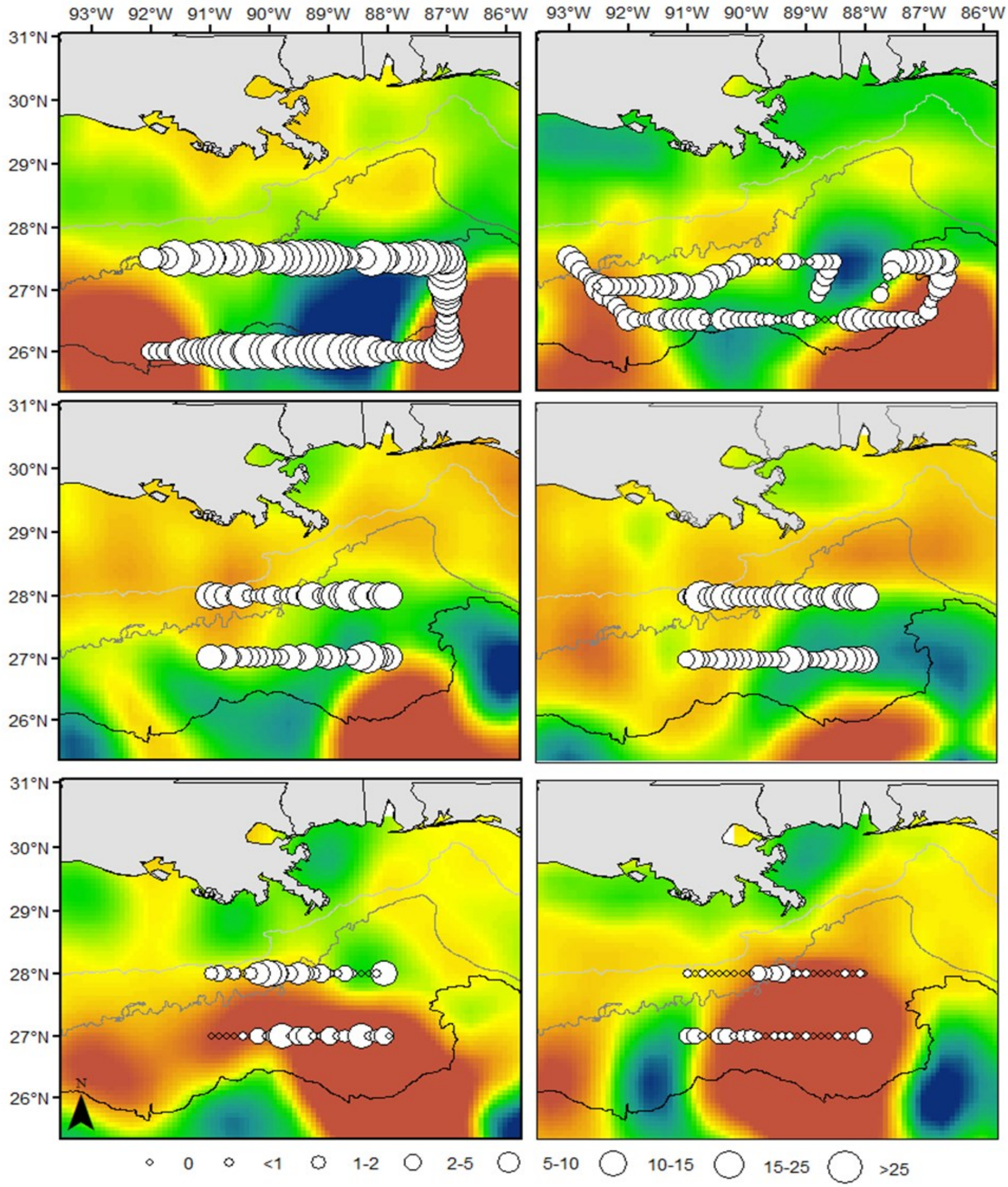

Figure 2. Spatial and temporal variability in the distributions of flyingfish larvae during summer ichthyoplankton cruises from 2009 (top), 2010 (middle), and 2011 (bottom) and June (left column) and July (right column). Sea surface height is denoted by color with red indicating areas of increased sea surface height (anti-cyclonic feature) and blue indicating areas of lower sea surface height (cyclonic feature). Density (larvae/1000m^2) is denoted by circle size.