

The Effects of Front-Associated Wind Events and Resultant Sediment Resuspension on Dietary Habits and Caloric Intake of Bay Anchovy and Age-0 Atlantic Croaker in Mobile Bay, Alabama

Author: Jackson, Jered B.

Source: Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 5(5) : 103-113

Published By: American Fisheries Society

URL: <https://doi.org/10.1080/19425120.2013.790862>

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

NOTE

The Effects of Front-Associated Wind Events and Resultant Sediment Resuspension on Dietary Habits and Caloric Intake of Bay Anchovy and Age-0 Atlantic Croaker in Mobile Bay, Alabama

Jered B. Jackson

Naval Facilities Engineering Command, Southeast, Post Office Box 30, Building 903, Jacksonville, Florida 32212, USA

James H. Cowan Jr.*

Department of Oceanography and Coastal Sciences, 2247 Energy, Coast, and Environment Building, Louisiana State University, Baton Rouge, Louisiana 70803, USA

Abstract

We examined the effects of wind-driven sediment resuspension on the stomach fullness, prey composition, and caloric intake of Bay Anchovy *Anchoa mitchilli*, a particulate planktivore, and age-0 Atlantic Croaker *Micropogonias undulatus*, a benthic omnivore, in Mobile Bay, Alabama. Mobile Bay is a shallow estuary in the northern Gulf of Mexico with substrates ranging from silt to small sand. High-wind events were associated with cold fronts and were characterized by wind velocities ≥ 4.0 m/s. Bay Anchovy stomachs were less full during such events and gut contents contained greater contributions by low-calorie items. Atlantic Croaker stomach fullness did not differ significantly with wind speed. However, prey composition during high-wind events shifted toward high-calorie items. These scenarios imply that high-wind events in Mobile Bay could have an adverse effect on energy uptake by resident Bay Anchovy but may benefit energy uptake by Atlantic Croaker.

Several factors can cause short-term changes in estuarine environments and have effects on resident organisms. Among the most prominent of these are tidal fluctuations and wind events. Tidal currents in most estuaries are the primary source of energy and are therefore responsible for most short-term variations in temperature, salinity, and other habitat characteristics. However, microtidal estuaries such as those common in the northern Gulf of Mexico experience relatively low tidal currents. These habitats depend greatly upon wind events for energy input and water column mixing (Demers et al. 1987; Reed 1989; Arfi

et al. 1993; Brooks and Doyle 1998; Perez et al. 2000; Chen and Valle-Levinson 2009).

Mobile Bay, Alabama, is a large (1,059-km²), shallow estuary in the northern Gulf of Mexico with a mean depth of 3 m and a mixed-semidiurnal microtidal range of only 0.4 m/d (Turner et al. 1987). However, the combination of high riverine discharge ($\bar{X} = 2,246$ m³/s) and low winds can create stratification (Turner et al. 1987). Because tidal currents in Mobile Bay are not sufficiently strong to destratify the water column, wind events constitute the predominant mixing mechanism and are typically common enough to prevent long-term stratification in Mobile Bay throughout most of the year (DiMego et al. 1976; Turner et al. 1987; Schroeder et al. 1990; Cowan et al. 1996).

In addition to destratifying estuarine water columns, wind events frequently resuspend bottom sediments in shallow estuaries (de Jonge and van Beusekom 1995). Most estuaries along the northern Gulf of Mexico experience frequent wind-driven sediment resuspension (Denes and Caffrey 1988; Miller et al. 2005). Depending upon water depth, even low wind speeds (< 4 m/s) can resuspend silt, mud, and small sand particles. Higher winds (≥ 4 m/s), characteristic of thunderstorms, cold fronts, and tropical cyclones, can suspend larger particles for longer periods of time (Schoellhamer 1995; Brooks and Doyle 1998; Booth et al. 2000), and cold fronts are the most frequent of such events in Mobile Bay during the fall, winter, and early spring (Miller et al. 2005). In a study of Barataria Bay in

Subject editor: Suam Kim, Pukyong National University, Busan, South Korea

*Corresponding author: jhcowan@lsu.edu

Received December 14, 2012; accepted March 23, 2013

southeastern Louisiana, Booth et al. (2000) reported that between 63% and 80% of bottom sediments become resuspended during the passage of cold fronts when winds range from 4 to 10 m/s and that wind velocities ≥ 4 m/s occurred more than 80% of the time during the late fall, winter, and early spring. Kobashi et al. (2006) reported similar results on a shoal in the shallow Gulf of Mexico and showed that sediments become resuspended within a few hours of frontal passage and settle back to the seafloor just as quickly once winds fall below 2 m/s.

Wind-driven resuspension events introduce small organisms and organic seston into the water column that can be utilized by grazers and suspension and deposit feeders (Bell and Sherman 1980; Frechette and Grant 1991; Grant et al. 1997; Gremare et al. 1997). While a few studies have examined the relationship between wind events and production among benthic and planktonic organisms (Frechette and Grant 1991; McKinnon and Ayukai 1996; Smaal and Haas 1997; Lawrence et al. 2004), the influence of high-velocity wind on the diets and potential growth of estuarine fishes (Boisclair and Leggett 1989a, 1989b; Hewett and Kraft 1993) has been largely neglected, although the effects of turbidity on feeding by larval and juvenile fish has been studied both in laboratory and field settings (Auld and Schubel 1978; Cyrus and Blaber 1987a, 1987b; Grecay and Targett 1996; Abrahams and Kattenfeld 1997; Fiksen et al. 2002; Gadomski and Parsley 2005; Meager et al. 2005).

This study examined short-term variations in estuarine fish feeding and caloric intake during high-wind events in Mobile Bay. Mobile Bay is a warm-temperate estuary in the northern Gulf of Mexico. In total, 337 species of fresh and saltwater fish occur in the Bay and the delta at the Bay's head (Boschung 1992). Among these is the Bay Anchovy *Anchoa mitchilli*, which occurs from the Gulf of Maine and Cape Cod, Massachusetts, south to Yucatan, Mexico, and throughout the Gulf of Mexico (Hoese and Moore 1977; Fives et al. 1986; Robbins et al. 1986). It is a common and often extremely abundant fish in some coastal and inshore waters of the western Atlantic Ocean (Hoese and Moore 1977) and in estuaries in the northern Gulf of Mexico. They are small (~ 10 cm maximum), short-lived (3 years maximum), opportunistic life history strategists (Winemiller and Rose 1992) that are often numerical dominants in estuaries where they occur (Castillo-Rivera et al. 1994; Szedlmayer and Able 1996; Rilling and Houde 1999), including in Mobile Bay (Hoese and Moore 1977). The Atlantic Croaker *Micropogonias undulatus* ranges in the western Atlantic Ocean from Massachusetts and in the Gulf of Mexico to northern Mexico. It is an estuarine-dependent species that is among the most abundant fishes in northern Gulf of Mexico estuaries. It is a relatively small (> 50 cm), short-lived (5 years maximum), early maturing (2 years), periodic life history strategist (Winemiller and Rose 1992) that usually occurs over mud and sandy-mud bottoms in coastal waters and in estuaries where the nursery and feeding grounds are located (Hoese and Moore 1977; Smith 1997). These two species were chosen for study both because they are abundant in Mobile Bay and

elsewhere and because they occupy different feeding niches; Bay Anchovy are particulate planktivores feeding mostly upon calanoid copepods and Atlantic Croaker are benthic omnivores that feed on worms, crustaceans, and larval fish (Jackson 2004). During this study, Bay Anchovy and age-0 Atlantic Croaker were sampled during a period of frequent (every 4–7 d; Miller et al. 2005) springtime cold front passages.

METHODS

Adult Bay Anchovy and juvenile Atlantic Croaker were collected over muddy substrate in southwestern Mobile Bay (Figure 1) during twice-weekly cruises in a 6.5-m outboard motor boat from 28 February to 25 March 2002, a time of frequent cold front passage. Water depth was ≤ 3 m. Wind measurements were obtained from the National Data Buoy Center, Station DPIA1 (30.248N 88.073W), on the extreme eastern end of Dauphin Island, Alabama. Wind velocity and direction were recorded once every 10 minutes for the duration of the study. Mean wind velocity was calculated for the 6 hours previous to sampling and represented a wind velocity estimate for each cruise. Additionally, a plot of continuous wind velocity from February 25 to March 25 was created to demonstrate trends in wind velocity for the entire study period (Figure 2). Sampling cruises that coincided with cold front passage experienced wind velocities ≥ 4 m/s. Therefore, wind velocity was divided into two categories for some analyses: less than 4 m/s (quiescent) and ≥ 4 m/s (windy).

Water temperature ($^{\circ}\text{C}$), salinity (psu), dissolved oxygen (DO) were measured before and after each sampling event using a YSI Model 85 DO meter. Light penetration (cm) was measured using a Li-Cor (LI-192 quantum light sensor) submersible light meter. The depth in the water column to which light penetrates is determined by the extent to which it is absorbed and scattered by dissolved compounds and suspended particles contained within the water (Kirk 1983; Oliver 1990; Kirk and Oliver 1995). In general, light intensity declines exponentially with depth as described by the Beer-Lambert equation:

$$I_z = I_0 e^{-kz},$$

where I_z is the light intensity at a depth z cm below the surface, I_0 is the immediate subsurface light intensity, and k is the rate of attenuation of light, usually referred to as the vertical attenuation coefficient. Light penetration can be converted to turbidity using the following equation (Oliver et al. 1999):

$$k = 0.04 \text{ Turbidity} + 0.73,$$

where turbidity is in NTU (nephelometric turbidity units). We combined the two equations and used the depth of light penetration measured at 0.5 m above the seafloor on windy days as I_z and the mean taken at the same distance above the seafloor on quiescent days as I_0 . This allowed us to calculate the difference in turbidity using mean light penetration between

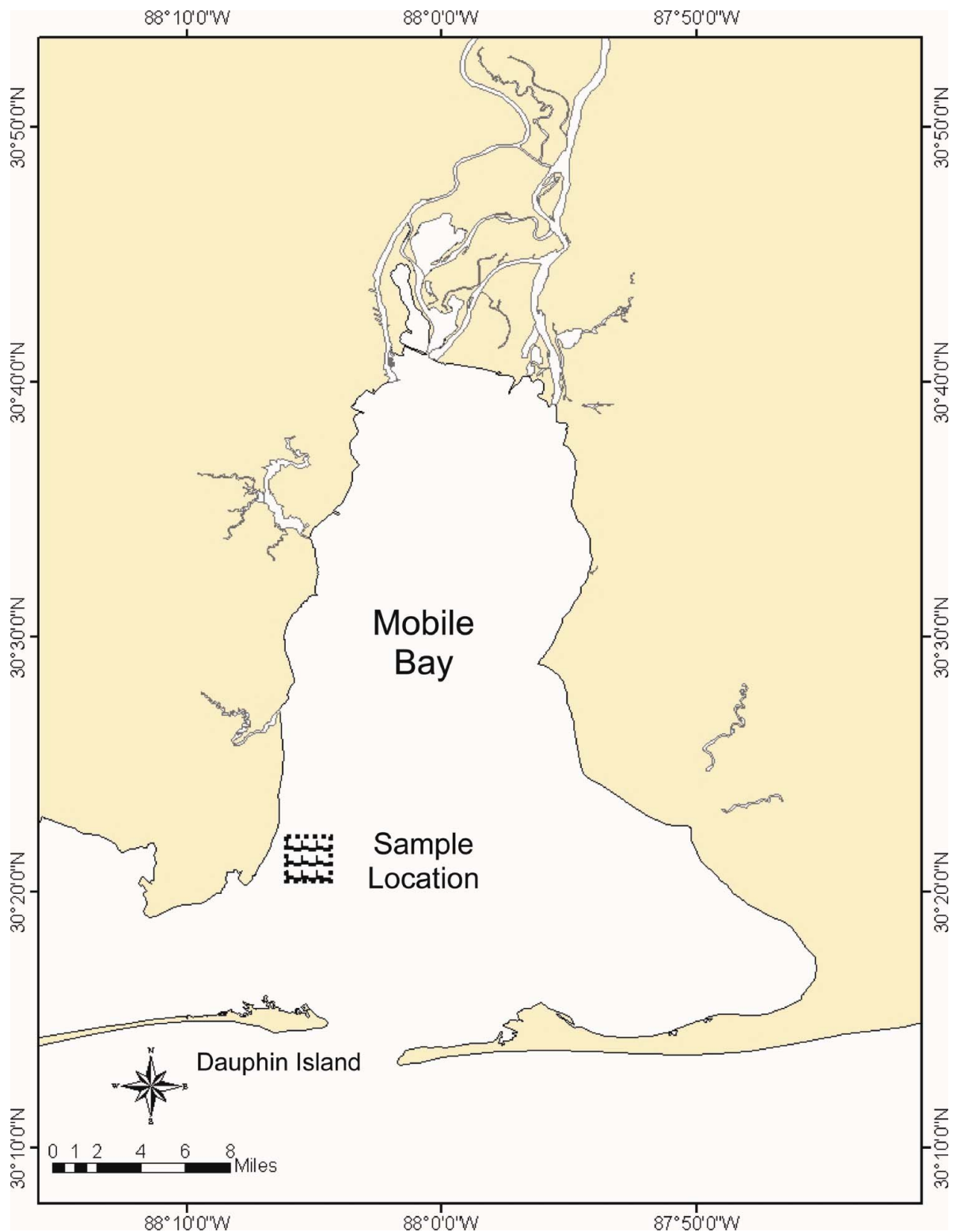


FIGURE 1. Map of Mobile Bay, Alabama. The sample location was visited twice weekly from 28 February to 25 March 2002.

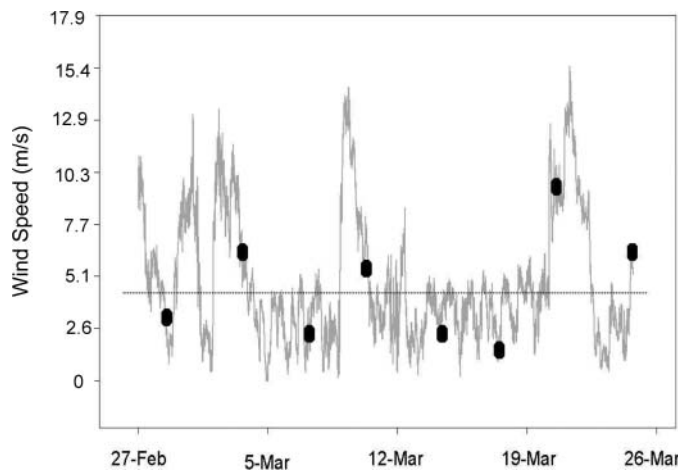


FIGURE 2. Plot of continuous wind velocity from 27 February to 26 March 2002. Wind velocity on each of the eight sampling dates is indicated by a series of eight dots. The dashed line denotes a wind velocity of 4 m/s, which represented the division between quiescent and windy days in this study.

windy and quiescent days, albeit we cannot determine the exact values of NTU on each sampling cruise.

This study was part of a larger effort that concurrently collected nutrient, primary production, and bacterial production data. Collection and analyses of these data were performed by other members of our study group. A 5-L Niskin bottle was used to collect water from the top and bottom of the water column for analysis of nitrate (NO_3), ammonium (NH_4), phosphate (PO_4), and dissolved organic carbon (DOC). Water for analysis of chlorophyll-*a* concentrations was decanted from the bottle and placed immediately on ice in a closed (dark) cooler. Water for analysis of bacterial production was collected in a 20-L carboy that was placed immediately in a cooler of ambient seawater for transport to the laboratory. Resulting data were provided to us after analyses were complete.

Fish were collected using a 3.9-m otter trawl with 12.7-mm mesh and 1.6-mm mesh cod end liner. Two replicate 5 or 10 min tows were conducted during each cruise. Trawl distance was measured with a mechanical flowmeter. All captured organisms from each replicate trawl were sorted by species, enumerated, and weighed, and up to 50 Bay Anchovy and 50 Atlantic Croaker were randomly selected for analyses. These fish were preserved in a 70% isopropyl and 2% formalin solution until they could be analyzed.

Standard length (mm) and mass (grams dry weight) were obtained for individuals in each 50-fish subsample. Density estimates (fish per 10 m^2) and biomass (grams dry weight per 10 m^2) were calculated for both species from each tow. Density and biomass parameters were \log_{10} transformed to reduce heteroscedasticity before testing for significance. *F*-tests ($\alpha = 0.05$) were used to determine if there was a statistically significant difference in density and biomass between quiescent and windy days.

Up to 20 Bay Anchovy and 20 Atlantic Croaker were randomly selected from each subsample for stomach content analysis. Each stomach was removed and laid open with a scalpel. Contents were extracted and placed on a labeled microscope slide. When necessary, the stomach lining was rinsed to ensure that all microscopic contents were completely removed.

Prey items were identified under a dissecting microscope to the lowest possible taxonomic level and sorted. All items belonging to the same taxonomic group were enumerated and collectively placed into preweighed containers. Prey items were dried at 80°C until a constant weight was achieved. Dry weights were recorded to the nearest 0.001 mg using a microbalance.

Stomach fullness was calculated using the following formula (Duarte and Garcia 1999):

$$\text{Fullness}_j = \frac{PW_j / FW_j}{P / F_{\max}}$$

j = stomach;

PW_j = cumulative dry weight of prey in stomach j ;

FW_j = dry weight of fish j ;

P / F_{\max} = greatest ratio of prey weight to fish weight.

Fullness data were normalized by arcsine transformation. *F*-tests ($\alpha = 0.05$) were applied to determine if there was a statistically significant difference between quiescent and windy days in the stomach fullness of Bay Anchovy and Atlantic Croaker.

Three indices were used to quantify prey importance in the diets of Bay Anchovy and Atlantic Croaker. These indices were percent composition by dry weight (dw), the index of prey importance (PI), and the index of caloric importance (ICI).

Percent dw was determined for each prey category using the equation (Bowen 1996)

$$\text{DW}_i = \frac{1}{P} \sum_{j=1}^P \left[\frac{W_{ij}}{\sum_{i=1}^Q W_{ij}} \right];$$

i = prey category;

P = number of stomachs with prey;

W_i = dw (g) of prey category;

Q = number of prey categories.

The PI was determined for each prey category using the following equation (Pope et al. 2001):

$$\text{PI} = \frac{1}{P} \sum_{j=1}^P \left[\frac{W_{ij} C_i}{\sum_{i=1}^Q W_{ij} C_i} \right],$$

where C_i is the estimated caloric value (cal/g dw) of prey category i .

The ICI was determined for each prey category using the following equation (McCawley and Cowan 2007):

$$ICI = PI_i \times FO_i,$$

where FO_i is the frequency of occurrence, calculated by dividing the number of stomachs in sample s that contained prey category i by the total number of stomachs in that sample.

Analysis of similarity (ANOSIM), a nonparametric multivariate test, conducted at a significance level of 0.05, was used to determine whether there was a statistically significant dissimilarity between quiescent and windy days in the diets of Bay Anchovy and Atlantic Croaker. The ANOSIM was conducted using the PRIMER-6 software package based upon percent dw of all prey categories in individual stomachs. The data were $\log_{10}(x + 1)$ transformed to account for the zero values of prey items that may have been absent in individual stomachs. The Bray-Curtis coefficient was used to describe diet similarity between all possible pairs of stomachs in a similarity matrix. The ANOSIM then performed nonparametric permutations on the similarity matrix and produced an R -statistic that described the extent of dissimilarity in diet composition between quiescent and windy days (Clarke and Gorley 2001).

The caloric content of each prey was either obtained from literature or estimated based upon the referenced caloric value of taxonomically similar prey (Table 1). Caloric intake was defined as calories per gram of fish dw (C_j) for each fish that was analyzed and was determined by multiplying the estimated caloric content of each prey item by the dry mass of that prey in an individual stomach. Calories were then summed for all prey in that stomach and divided by the dry mass of the respective fish as described in the following formula:

$$C_j = \frac{\sum_{i=1}^p W_{ij} C_i}{FW_j}.$$

Estimates of stomach fullness and caloric intake for both species were regressed (linear) on wind speed to determine if variability in either of these two metrics of food intake could be explained by changes in wind velocity (linear regression; $\alpha = 0.05$; Proc Reg in SAS; SAS Institute 2006).

RESULTS

Three cold fronts passed over Mobile Bay during this study. Low winds (<4 m/s; quiescent days) were experienced on the sample dates of February 28, March 7, March 14, and March 18 and were associated with quiescent periods between fronts. High winds (≥ 4 ; windy days) associated with these fronts were experienced on the sample dates of March 4, March 11, March 21, and March 25. The highest mean wind velocity experienced during a cruise was 10.6 m/s on March 21 while the lowest mean wind velocity experienced during a cruise was only 3 d prior (1.4 m/s on March 18; Figure 2), demonstrating how quickly conditions can change in response to cold front passages.

Although temperature slowly increased over the duration of the study, cold front passage did not significantly affect water

TABLE 1. Estimated caloric densities of the prey items found in the present study. Most estimates were obtained from the literature, although some estimates were approximated based on the cited caloric density of taxonomically similar prey.

Prey item	Estimated caloric density (cal/g dw)
Amphipods	3,635 ^d
Barnacle nauplii	6,626 ^e
Bivalves	4,600 ^a
Brittle stars	2,131 ^d
Clupeid larvae	5,508 ^d
Copepods (calanoid)	6,626 ^d
Copepods (harpacticoid)	6,600 ^e
Cumaceans	6,745 ^e
Detritus	2,229 ^a
Diatoms	3,482 ^e
Euphausiid shrimp	5,959 ^c
Foraminiferans	4,598 ^e
Gastropods	4,595 ^a
Sea Grass	3,482 ^a
Megalopae (blue crabs)	6,626 ^e
Mudcrabs	3,823 ^d
Mysid shrimp	7,533 ^d
Nematodes	5,570 ^b
Polychaetes	4,857 ^a
Ostracods	5,683 ^a
Zoea (blue crabs)	6,626 ^e

^aCummins and Wuycheck 1971.

^bDanovaro et al. 1999.

^cPurcell et al. 1981.

^dWissing et al. 1973.

^eApproximated value.

temperature, salinity, dissolved oxygen, or any of the measured chemical and biological variables— NO_3 , NH_4 , PO_4 , DOC, chlorophyll a , and bacterial production (Kiene et al. 2003). However, light penetration to 0.5 m above the seafloor, which is affected by the quantity of suspended sediments and seston material in the water column, was significantly lower on windy days (55.0 cm) than on quiescent days (142.5 cm), which represents an increase of more than 19.6 ± 4.2 NTU in turbidity between windy and quiescent days.

Bay Anchovy ranged from 16.5 to 66.9 mm SL; mean length was 45.6 mm SL. Mean length was not significantly different between quiescent (mean \pm SD, 44.6 ± 6.1 mm SL) and windy days (46.0 ± 6.7 mm SL; ANOVA: $F_{1,348} = 1.42$, $P = 0.234$). Age-0 Atlantic Croaker ranged from 13.2 to 75.1 mm SL; mean length was 31.9 mm SL. Mean length was not significantly different between quiescent (30.9 ± 15.5 mm SL) and windy days (32.5 ± 14.7 mm SL; ANOVA: $F_{1,402} = 1.07$, $P = 0.302$).

A total of 752 Bay Anchovy were captured during the course of this study. Of those, 713 were captured on windy days and only 39 (5%) were captured on quiescent days. Mean density

was significantly greater on windy days (1.46 ± 1.09 fish/10 m²) than on quiescent days (0.09 ± 0.09 fish/10 m²; ANOVA: $F_{1,8} = 6.27$, $P = 0.046$). Mean biomass of Bay Anchovy was also significantly greater on windy days (0.45 ± 0.38 g dw/10 m²) than on quiescent days (0.04 ± 0.05 g dw/10 m²; ANOVA: $F_{1,8} = 7.44$, $P = 0.034$).

A total of 697 Atlantic Croaker were captured in this study. Of those, 538 were captured on windy days and 159 (23%) were captured on quiescent days. Mean density was four-fold greater on windy days (1.61 ± 1.63 fish/10 m²) than on quiescent days (0.37 ± 0.33 fish/10 m²), although this difference was not significant (ANOVA: $F_{1,8} = 2.18$, $P = 0.191$). The mean biomass of Atlantic Croaker was greater on windy days (0.51 ± 0.57 g dw/10 m²) than on quiescent days (0.10 ± 0.07 g dw/10 m²), but this difference also was not significant (ANOVA: $F_{1,8} = 2.03$, $P = 0.204$).

The decreased capture rate of Bay Anchovy on quiescent days resulted in many fewer stomachs being analyzed for quiescent days ($n = 31$) than for windy days ($n = 134$). However, these sample sizes were sufficient for analysis. Bay Anchovy primarily consumed calanoid copepods during both quiescent and windy days. They also ate ostracods and bivalve pelecypods

in addition to occasionally preying upon barnacle nauplii, harpacticoid copepods, polychaete larvae, gammarid amphipods, euphausiid shrimp, diatoms, nematodes, and crab zoea. On windy days, Bay Anchovy consumed large quantities of detritus (Table 2). Mean fractional stomach fullness declined significantly with wind speed, albeit the data are noisy (Figure 3; Fullness [fractional] = $0.233 - 0.0239 \times \text{Wind Speed [m/s]}$; $R^2 = 0.18$; $P < 0.0001$). There was no significant dissimilarity in diet by wind classification (ANOSIM: $R = -0.12$, $P = 0.992$), due primarily to a dietary dominance by calanoid copepods during both quiescent and windy days. However, there was a considerable increase in the contribution of detritus to diets on windy days (Figure 4). Mean caloric intake (cal/g dw) by Bay Anchovy also declined significantly with wind speed, but the data were highly variable among individual anchovy (Figure 3; Caloric Intake = $20.17 [\text{cal/g dw}] - 2.124 \times \text{Wind Speed [m/s]}$; $R^2 = 0.16$; $P < 0.0001$).

In contrast to Bay Anchovy, the number of Atlantic Croaker stomachs available for analysis on quiescent days ($n = 81$) and windy days ($n = 107$) were similar. Age-0 Atlantic Croaker primarily consumed calanoid copepods, mysid shrimp, and detritus. They also ate polychaetes, gammarid amphipods,

TABLE 2. Percent dry weight (DW), index of caloric importance (ICI), and index of prey importance (PI) for stomach contents of Bay Anchovy collected on quiescent (wind <4 m/s) and windy (wind \geq 4 m/s) days in Mobile Bay during resuspension cruises in spring 2002.

Prey item	Bay Anchovy					
	Quiescent ($n = 31$)			Windy ($n = 134$)		
	DW	ICI	PI	DW	ICI	PI
Annelida				1.49	0.04	1.49
Polychaeta (Nereididae)						
Crustacea						
Barnacle nauplii	2.80	0.11	2.85			
Copepoda (Calanoida)	84.06	96.13	85.53	65.74	87.69	68.73
Copepoda (Harpacticoida)	0.05	0.00	0.05	0.94	0.07	0.94
Ostracoda	5.04	2.46	4.53	5.89	4.45	6.49
Amphipoda (Gammaridea)				1.72	0.05	1.52
Euphausiacea				0.79	0.02	1.00
Mysidacea						
Decapoda						
<i>Callinectes</i> zoea	0.03	0.00	0.03			
<i>Callinectes</i> megalopae						
Mollusca						
Bivalvia (Mytiloida)	2.89	0.71	2.63	3.86	0.85	3.59
Nematoda (Adenophorea)				0.16	0.00	0.14
Osteichthyes						
Clupeiformes						
Sarcomastigophora						
Foraminiferida						
Diatoms	3.24	0.50	3.23	0.12	0.02	0.08
Detritus	1.90	0.09	1.14	19.30	6.81	16.01

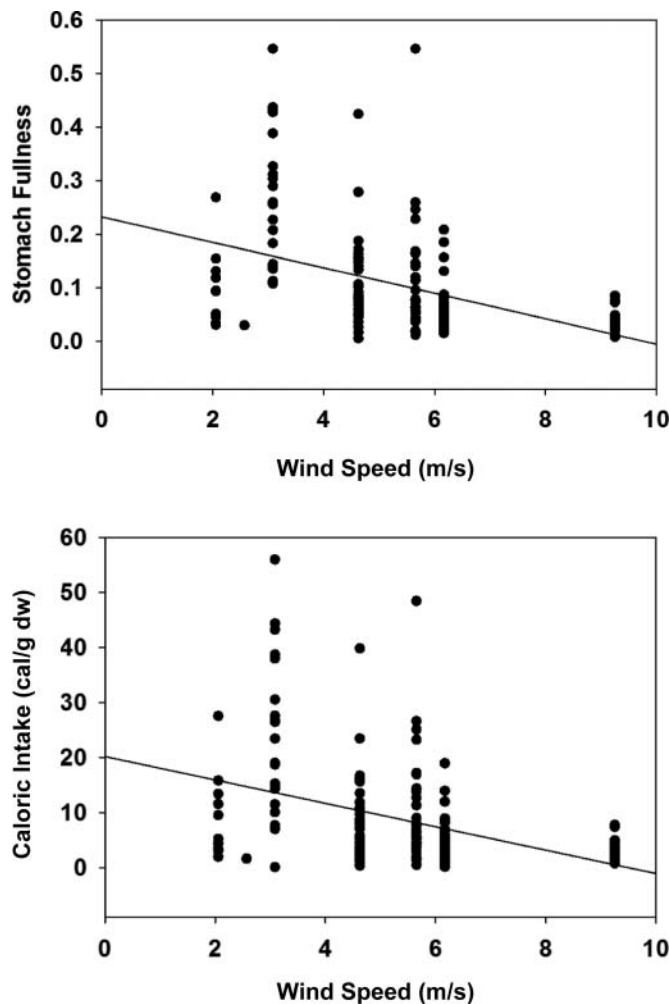


FIGURE 3. Regression relationship for Bay Anchovy between stomach fullness (fractional) and wind speed (m/s) (top panel) and the regression of caloric intake (cal/g dw) on wind speed (bottom panel).

harpacticoid larvae, ostracods, and clupeiform larvae in addition to occasionally preying upon barnacle nauplii, euphausiid shrimp, crab megalopae, pelecypods, and foraminiferans (Table 3). Stomach fullness increased slightly with increasing wind speeds, but this difference was not significant (Figure 5; $R^2 = 0.07$; $P > 0.05$). Diets were significantly dissimilar between wind classifications (ANOSIM: $R = 0.17$, $P = 0.001$), principally due to the varying dietary importance of calanoid copepods, mysid shrimp, and detritus between quiescent and windy days (Table 3; Figure 6). Caloric intake (cal/g dw) increased with increasing wind speed (m/s), but the data are variable among individual Atlantic Croaker stomachs (Figure 5; $\text{Caloric Intake} = 7.82 \text{ (cal/g dw)} + 2.46 \times \text{Wind Speed}$; $R^2 = 0.05$; $P = 0.051$). That said, mean caloric intake was twice as high on windy days ($23.9 \pm 29.9 \text{ cal/g dw}$) than on quiescent days ($12.3 \pm 11.9 \text{ cal/g dw}$).

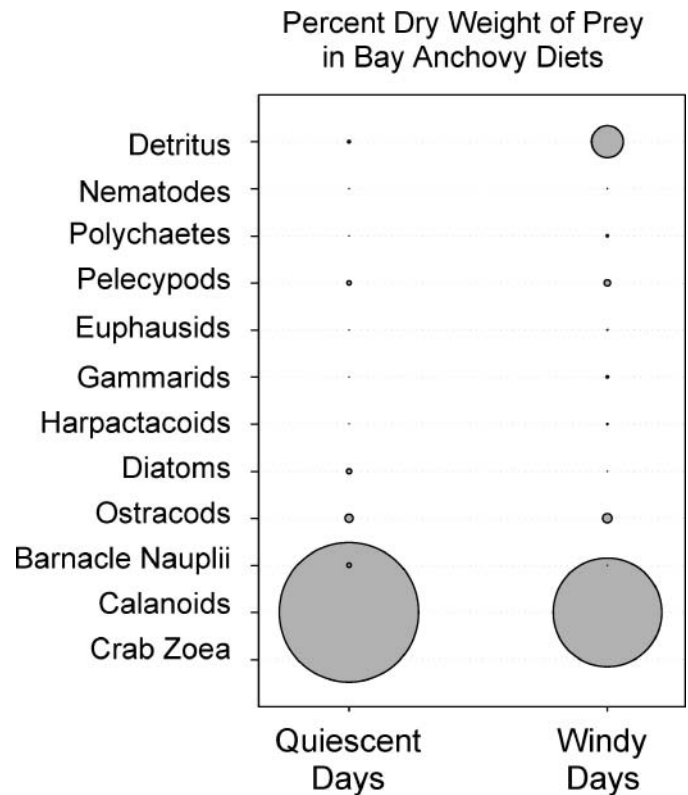


FIGURE 4. Bubble volume denotes mean percent dry weight of prey in the diets of Bay Anchovy captured on quiescent (wind $< 4 \text{ m/s}$) and windy (wind $\geq 4 \text{ m/s}$) days.

DISCUSSION

Both species examined in this study appeared to show shifts in density and biomass between windy and quiescent sampling days. One possible cause of this result is gear avoidance. Several trawling studies have reported catch increases in trawls during nighttime hours that are thought to occur because of reduced visual detection of the trawl (Walsh 1988; Casey and Myers 1998; Hjellvik et al. 2002). However, it is also possible that the fishes we studied changed their distribution in response to frontal passages. Our sampling efforts were constrained because of the size of the vessel (6.7 m) that was available for our use, given the sea states in Mobile Bay when wind velocities are high.

Bay Anchovy had fuller stomachs on quiescent days than on windy days but diet composition was not significantly dissimilar by wind category, as calanoid copepods dominated Bay Anchovy diets under both wind conditions. However, there was an increase in the mean contribution of detritus to Bay Anchovy diets on windy days (Figure 4). Calanoid copepods, while small (0.02 g per adult copepod), have an estimated caloric density of 6,626 cal/g dw, whereas detritus has a considerably lower caloric density of 2,229 cal/g dw (Table 1). Increased consumption of low-quality food has also been observed for shellfish during wind-driven resuspension events. Although high wind velocity increased seston availability for shellfish feeding, the

TABLE 3. Percent dry weight (DW), index of caloric importance (ICI), and index of prey importance (PI) for stomach contents of Atlantic Croaker collected on quiescent (wind <4 m/s) and windy (wind \geq 4 m/s) days in Mobile Bay during resuspension cruises in spring 2002.

Prey item	Atlantic Croaker					
	Quiescent ($n = 81$)			Windy ($n = 107$)		
	DW	ICI	PI	DW	ICI	PI
Annelida						
Polychaeta (Nereididae)	3.86	0.45	4.01	3.59	0.55	3.63
Crustacea						
Barnacle nauplii	1.09	0.03	1.08			
Copepoda (Calanoida)	38.12	63.67	40.71	31.21	45.71	33.07
Copepoda (Harpacticoida)	5.56	4.17	6.79	0.12	0.03	0.19
Ostracoda	3.36	1.79	3.37	0.84	0.23	0.82
Amphipoda (Gammaridea)	11.71	5.55	11.68	3.08	0.77	3.06
Euphausiacea	0.03	0.00	0.03	0.93	0.02	0.93
Mysidacea	3.39	0.47	4.23	32.09	33.97	33.80
Decapoda						
<i>Callinectes zoea</i>						
<i>Callinectes megalopae</i>				0.17	0.01	0.22
Mollusca						
Bivalvia (Mytiloida)	0.13	0.02	0.21	0.13	0.00	0.09
Nematoda (Adenophorea)						
Osteichthyes						
Clupeiformes	1.84	0.16	1.94	3.30	0.32	3.23
Sarcomastigophora						
Foraminiferida	0.18	0.04	0.28	0.03	0.00	0.05
Diatoms						
Detritus	30.73	23.65	25.66	24.50	18.39	20.91

fraction of quality seston was negatively correlated with wind velocity (Frechette and Grant 1991; Grant et al. 1997; Smaal and Haas 1997). In the present study, relatively empty stomachs and increased ingestion of low-energy food resulted in significantly lower mean caloric intake with increasing wind speed.

This scenario implies that periods of high wind velocity (>4 m/s) in Mobile Bay could have an adverse effect upon energy uptake by resident Bay Anchovy. Such energy deficits might accumulate during seasons of frequent frontal passage, or other wind events, and ultimately have a negative impact on the growth rate (Boisclair and Leggett 1989a, 1989b; Hewett and Kraft 1993) and subsequent biomass production of Bay Anchovy in Mobile Bay. An examination of historical wind data from the National Data Buoy Center Station DPIA1 revealed that during each of the four years between 2001 and 2004, wind velocity in Mobile Bay exceeded 4 m/s for at least 8 h on 81, 66, 76, and 70 d, respectively. This indicates that on 18% to 23% of the days in a year conditions existed that could have a negative impact on Bay Anchovy growth and production at vulnerable locations in Mobile Bay. During late fall (November), winter, and early spring (March), the percentage of days that winds

exceeded 4 m/s was much higher, averaging $\geq 70\%$, and was similar to the results reported by Booth et al. (2000). We believe Bay Anchovy in warm-temperate and subtropical estuaries may balance capital breeding, in which compensatory feeding takes place in advance of breeding so that reproduction initially may be financed from stored energetic capital, with income breeding, in which reproduction is financed using current energetic income during long spawning seasons in which females spawn successively over many days (Thomas 1988; Stearns 1992). If this is true, it is during the early spring period that overwintering females must obtain sufficient nutrition to prepare for spawning once waters in the estuary reach 20°C, which occurs in late April in Mobile Bay (Leak and Houde 1987; Zastrow et al. 1991; Peebles et al. 1996). These results are compelling if one considers that Bay Anchovy stomachs examined during 12 monthly sampling cruises in Mobile Bay under quiescent conditions contained little or no detritus (Jackson 2004).

Atlantic Croaker stomach fullness did not differ significantly with wind speed, although there was a weak trend toward fuller stomachs on windy days. However, Atlantic Croaker diets were significantly dissimilar between quiescent and windy days. This dissimilarity was driven by less reliance on calanoid copepods

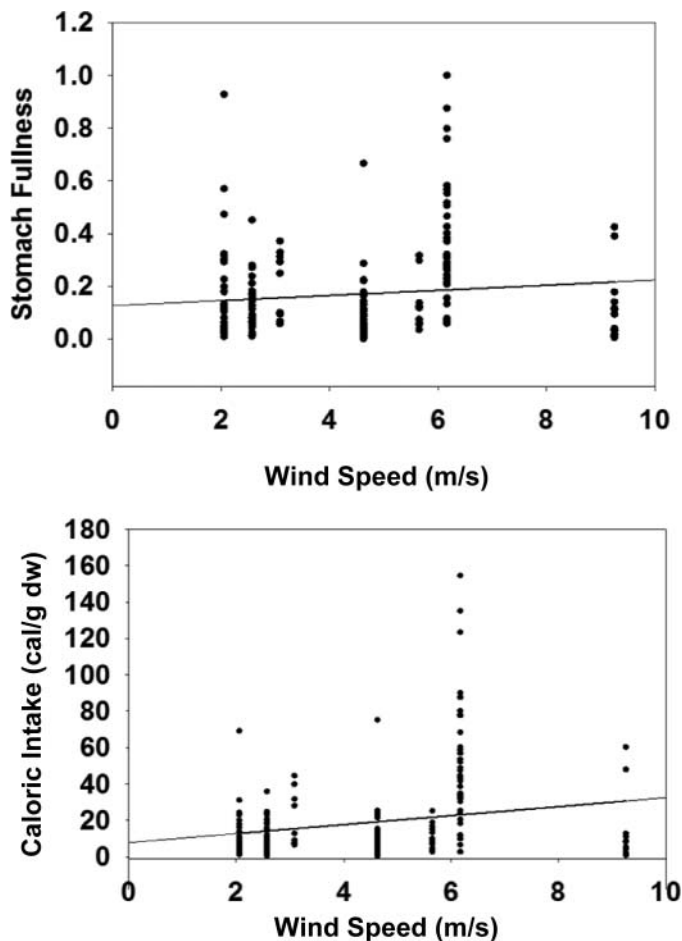


FIGURE 5. Regression relationship for Atlantic Croaker between stomach fullness (fractional) and wind speed (m/s) (top panel) and the regression of caloric intake (cal/g dw) on wind speed (bottom panel).

and detritus, coupled with increased dietary importance of larger mysid shrimp (*Mysidopsis* spp.; mean individual mass = 0.35 g dw), during windy days. As mentioned, calanoid copepods have a much higher caloric density than detritus. Additionally, mysid shrimp have a caloric value of 7,533 cal/g dw, which was the highest caloric value of any prey identified in this study (Table 1). Despite the dissimilarities in diet, caloric intake by Atlantic Croaker did not differ significantly with wind speed, but this result was likely due to high variance in the data because the mean caloric intake on windy days was twice as high as it was on quiescent days. The variance was caused by Atlantic Croaker feeding habits, particularly with regard to mysid shrimp. When they ate mysid shrimp, Atlantic Croaker either ate them in large quantities or hardly at all. We suspect that consumption could be enhanced either (1) by uncovering and exposing burrowing mysids to foraging Atlantic Croaker or (2) by increased turbidity that makes mysids more susceptible to predation because low light levels similar to that experienced during nighttime elicits a foraging response by the predatory marine mysids, causing them to exit their burrows to feed (Lasenby and Langford 1973;

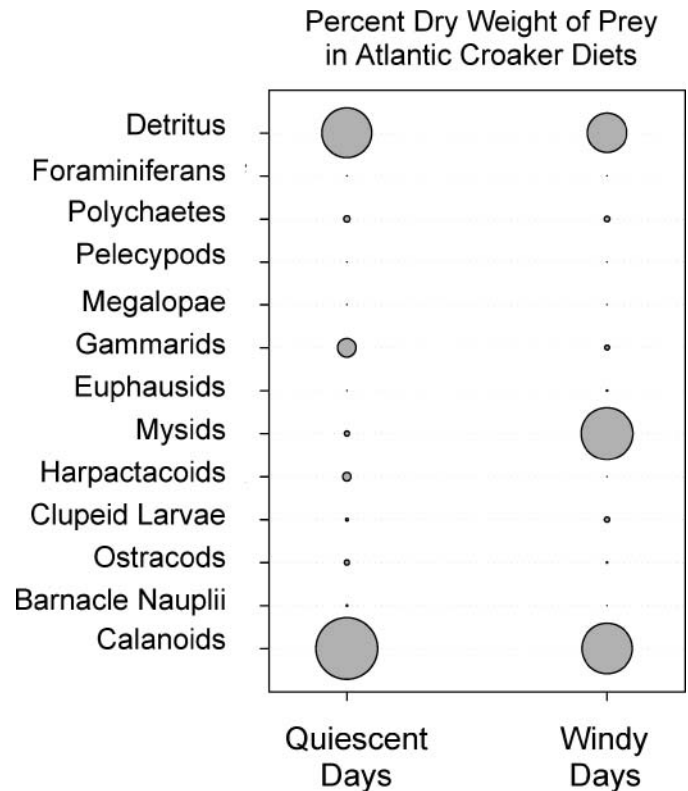


FIGURE 6. Bubble volume denotes mean percent dry weight of prey in the diets of age-0 Atlantic Croaker captured on quiescent (wind < 4 m/s) and windy (wind ≥ 4 m/s) days.

Siegfried and Kopache 1980; Fulton 1982). Consequently, individual Atlantic Croaker with mysids in their stomachs consumed a diet of extremely high caloric density while those that did not feed on mysid shrimp had a considerably lower caloric intake.

This scenario implied opposite consequences for age-0 Atlantic Croaker, which are benthic omnivores, than it did for Bay Anchovy, which are particulate planktivores. Periods of high wind velocity (≥ 4 m/s) in Mobile Bay may potentially have a beneficial effect on energy uptake by Atlantic Croaker. Enhanced uptake could accumulate during seasons of frequent frontal passage, or other wind events, and ultimately have a net positive impact on the growth rate and production of age-0 Atlantic Croaker on their nursery grounds in Mobile Bay.

ACKNOWLEDGMENTS

The authors thank Rodney Collier, Joe Sullivan, Heather Fletcher, Alvin Rainosek, Ron Keine, John Valentine, and Monty Graham for their assistance in field collections and suggestions for data analysis. We also thank Connie Mallon for aid with library resources. This research was funded by the Alabama Center for Estuarine Studies.

REFERENCES

- Abrahams, M., and M. Kattenfeld. 1997. The role of turbidity as a constraint on predator-prey interactions in aquatic environments. *Behavioral Ecology and Sociobiology* 40:169–174.
- Arfi, R., D. Guiral, and M. Bouvy. 1993. Wind induced resuspension in a shallow tropical lagoon. *Estuarine Coastal and Shelf Science* 36:587–604.
- Auld, A. H., and J. R. Schubel. 1978. Effects of suspended sediment on fish eggs and larvae: a laboratory assessment. *Estuarine and Coastal Marine Science* 6:153–164.
- Bell, S. S., and K. M. Sherman. 1980. A field investigation of meiofaunal dispersal and tidal resuspension and implications. *Marine Ecology Progress Series* 3:245–249.
- Boisclair, D., and W. C. Leggett. 1989a. Among-population variability of fish growth: I. Influence of the quantity of food consumed. *Canadian Journal of Fisheries and Aquatic Sciences* 46:457–467.
- Boisclair, D., and W. C. Leggett. 1989b. Among-population variability of fish growth: II. Influence of prey type. *Canadian Journal of Fisheries and Aquatic Sciences* 46:468–482.
- Booth, J. G., R. L. Miller, B. A. McKee, and R. A. Leathers. 2000. Wind-induced bottom sediment resuspension in a microtidal coastal environment. *Continental Shelf Research* 20:785–806.
- Boschung, H. T. 1992. Catalogue of freshwater and marine fishes of Alabama. *Bulletin of the Alabama Museum of Natural History* 14.
- Bowen, S. H. 1996. Quantitative description of the diet. Pages 518–524 in B. R. Murphy and D. W. Willis, editors. *Fisheries techniques*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Brooks, G. R., and L. J. Doyle. 1998. Recent sedimentary development of Tampa Bay, Florida: a microtidal estuary incised into tertiary platform carbonates. *Estuaries* 21:391–406.
- Casey, J. M., and R. A. Myers. 1998. Diel variation in trawl catchability: is it as clear as day and night? *Canadian Journal of Fisheries and Aquatic Sciences* 55:2329–2340.
- Castillo-Rivera, M., G. Moreno, and R. Iniestra. 1994. Spatial, seasonal, and diel variation in abundance of the Bay Anchovy, *Anchoa mitchilli* (Teleostei: Engraulidae), in a tropical coastal lagoon of Mexico. *Southwestern Naturalist* 39:263–268.
- Cheng, P., and A. Valle-Levinson. 2009. Influence of lateral advection on residual currents in microtidal estuaries. *Journal of Physical Oceanography* 39:3177–3190.
- Clarke, K. R., and R. N. Gorley. 2001. *PRIMER 6: user manual/tutorial*. PRIMER-E, Plymouth, UK.
- Cowan, J. L. W., J. R. Pennock, and W. R. Boynton. 1996. Seasonal and interannual patterns of sediment–water nutrient and oxygen fluxes in Mobile Bay, Alabama (USA): regulating factors and ecological significance. *Marine Ecology Progress Series* 141:229–245.
- Cyrus, D. P., and S. J. M. Blaber 1987a. The influence of turbidity on juvenile marine fishes in estuaries. Part 1. Field studies at Lake St. Lucia on the south-eastern coast of Africa. *Journal of Experimental Marine Biology Ecology* 109:53–70.
- Cyrus, D. P., and S. J. M. Blaber 1987b. The influence of turbidity on juvenile marine fishes in estuaries. Part 2. Laboratory studies, comparisons with field data and conclusions. *Journal of Experimental Marine Biology Ecology* 109:71–91.
- de Jonge, V. N., and J. E. E. van Beusekom. 1995. Wind- and tide-induced resuspension of sediment and microphytobenthos from tidal flats in Ems Estuary. *Limnology and Oceanography* 40:766–778.
- Demers, S., J. C. Theriault, E. Bourget, and A. Bah. 1987. Resuspension in the shallow sublittoral zone of a macrotidal estuarine environment: wind influence. *Limnology and Oceanography* 32:327–339.
- Denes, T. A., and J. M. Caffrey. 1988. Changes in seasonal water transport in a Louisiana estuary, Fourleague Bay, Louisiana. *Estuaries* 11:184–191.
- DiMego, G. J., L. F. Bosart, and G. W. Endersen. 1976. An examination of the frequency and mean conditions surrounding frontal incursions into the Gulf of Mexico and Caribbean Sea. *Monthly Weather Review* 104:709–718.
- Duarte, L. O., and C. B. Garcia. 1999. Diet of the Lane Snapper, *Lutjanus synagris* (Lutjanidae), in the Gulf of Salamanca, Columbia. *Caribbean Journal of Science* 35:54–63.
- Fiksen, Ø. L., D. L. Aksnes, M. H. Flyum, and J. Giske. 2002. The influence of turbidity on growth and survival of fish larvae: a numerical analysis. *Hydrobiologia* 484:49–59.
- Fives, J. M., S. M. Warlen, and D. E. Hoss. 1986. Aging and growth of larval Bay Anchovy, *Anchoa mitchilli*, from the Newport River Estuary, North Carolina. *Estuaries* 9:362–367.
- Frechette, M., and J. Grant. 1991. An in situ estimation of the effect of wind-driven resuspension on the growth of the mussel *Mytilus edulis* L. *Journal of Experimental Marine Biology and Ecology* 148:201–213.
- Fulton, R. S. III. 1982. Predatory feeding of two marine mysids. *Marine Biology* 72:183–191.
- Gadomski, D. M., and M. J. Parsley. 2005. Effects of turbidity, light level, and cover on predation of White Sturgeon larvae by prickly sculpins. *Transactions of the American Fisheries Society* 134:369–374.
- Grant, J., P. Cranford, and C. Emerson. 1997. Sediment resuspension rates, organic matter quality and food utilization by sea scallops (*Placopecten magellanicus*) on Georges Bank. *Journal of Marine Research* 55:965–994.
- Greay, P. A., and T. E. Targett. 1996. Effects of turbidity, light level and prey concentration on feeding of juvenile Weakfish *Cynoscion regalis*. *Marine Ecology Progress Series* 131:11–16.
- Gremare, A., J. M. Amouroux, F. Charles, A. Dinet, C. Riaux-Gobin, J. Baudart, L. Medernach, J. Y. Bodiou, G. Vétion, J. C. Colomines, and P. Albert. 1997. Temporal changes in the biochemical composition and nutritional value of the particulate organic matter available to surface deposit-feeders: a two year study. *Marine Ecology Progress Series* 150:195–206.
- Hewett, S. W., and C. E. Kraft. 1993. The relationship between growth and consumption: comparisons across fish populations. *Transactions of the American Fisheries Society* 122:814–821.
- Hjellvik, V., O. R. Godo, and D. Tjøstheim. 2002. Diurnal variation in bottom trawl survey catches: does it pay to adjust? *Canadian Journal of Fisheries and Aquatic Sciences* 59:33–48.
- Hoese, H. D., and R. H. Moore. 1977. *Fishes of the Gulf of Mexico*. Texas, Louisiana, and adjacent waters. Texas A&M University Press, College Station.
- Jackson, J. B. 2004. Changes in biomass production and diets of Bay Anchovy, Atlantic Croaker, and spot in Mobile Bay over seasons and as a result of wind-driven resuspension events. Master's thesis. University of South Alabama, Mobile.
- Kiene, R. P., J. Pennock, and J. L. W. Cowan. 2003. Effects of variation in river discharge and wind-driven resuspension on lower trophic levels of the Mobile Bay ecosystem. Alabama Cooperative Extension System, Auburn. Available: <http://www.southalabama.edu/aces/2003Reports/ACESKiene02.pdf>. (May 2013).
- Kirk, J. T. O. 1983. *Light and photosynthesis in aquatic ecosystems*. Cambridge University Press, Cambridge, UK.
- Kirk, J. T. O., and R. L. Oliver. 1995. Optical closure in an ultra-turbid lake. *Journal of Geophysical Research* 100:13221–13225.
- Kobashi, D., F. Jose, and G. Stone. 2006. Wave and bottom sediment interactions over a submerged sand bank during the winter cold-front season, western Louisiana. *Gulf Coast Association of Geological Societies Transactions* 56:395–401.
- Lasenby, D. C., and R. R. Langford. 1973. Feeding and assimilation of *Mysis relicta*. *Limnology and Oceanography* 18:280–285.
- Lawrence D., M. J. Dagg, H. Liu, S. R. Cummings, P. B. Ortner, and C. Kelble. 2004. Wind events and benthic–pelagic coupling in a shallow subtropical bay in Florida. *Marine Ecology Progress Series* 266:1–13.
- Leak, J. C., and E. D. Houde. 1987. Cohort growth and survival of Bay Anchovy *Anchoa mitchilli* larvae in Biscayne Bay, Florida. *Marine Ecology Progress Series* 37:109–122.
- McCawley, J., and J. H. Cowan Jr. 2007. Seasonal and size specific diet and prey demand of red snapper on Alabama artificial reefs: implications for

- management. Pages 77–104 in W. F. Patterson, J. H. Cowan Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red Snapper ecology and fisheries in the US Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.
- Meager, J. J., T. Solbakken, A. C. Utne-Palm, and T. Oen. 2005. Effects of turbidity on the reactive distance, search time, and foraging success of juvenile Atlantic Cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences 62:1978–1984.
- Miller, R. L., B. A. McKee, and E. J. D'Sa. 2005. Monitoring bottom sediment resuspension and suspended sediments in shallow coastal estuaries. Pages 259–276 in R. L. Miller, C. E. Del Castillo, and B. A. McKee, editors. Remote sensing of coastal aquatic environments. Springer, Dordrecht, The Netherlands.
- McKinnon, A. D., and T. Ayukai. 1996. Copepod egg production and food resources in Exmouth Gulf, Western Australia. Marine and Freshwater Research 47:595–603.
- Oliver, R. L. 1990. Optical properties of waters in the Murray–Darling Basin, southeastern Australia. Australian Journal of Marine Freshwater Research 41:581–601.
- Oliver, R. L., B. T. Hart, J. Olley, M. Grace, C. Rees, and G. Caitcheon. 1999. The Darling River: algal growth and the cycling and sources of nutrients. Murray–Darling Basin Commission, Project M386, Co-operative Research Centre for Freshwater Ecology, Commonwealth Scientific and Industrial Research Organisation Land and Water. Available: http://www2.mdbc.gov.au/_data/page/307/darling_algal_growth-whole.pdf. (May 2013).
- Peebles, E. B., J. R. Hall, and S. G. Tolley. 1996. Egg production by the Bay Anchovy *Anchoa mitchilli* in relation to adult and larval prey fields. Marine Ecology Progress Series 131:61–73.
- Perez, B. C., J. W. Day Jr., L. J. Rouse, R. F. Shaw, and M. Wang. 2000. Influence of Atchafalaya River discharge and winter frontal passage on suspended sediment concentration and flux in Fourleague Bay, Louisiana. Estuarine, Coastal and Shelf Science 50:271–290.
- Pope, K. L., M. L. Brown, W. G. Duffy, and P. H. Michaletz. 2001. A caloric-based evaluation of diet indices for Largemouth Bass. Environmental Biology of Fishes 61:329–339.
- Reed, D. J. 1989. Patterns of sediment deposition in subsiding coastal salt marshes, Terrebonne Bay, Louisiana: the role of winter storms. Estuaries 12:222–227.
- Rilling, G. C., and E. D. Houde. 1999. Regional and temporal variability in distribution and abundance of Bay Anchovy (*Anchoa mitchilli*) eggs, larvae, and adult biomass in the Chesapeake Bay. Estuaries 22:1096–1109.
- Rilling, G. C., and E. D. Houde. 1999. Regional and temporal variability in distribution and abundance of Bay Anchovy (*Anchoa mitchilli*) eggs, larvae, and adult biomass in the Chesapeake Bay. Estuaries 22:1096–1109.
- Robins, C. R., G. C. Ray, and J. Douglas. 1986. A field guide to Atlantic Coast fishes. Houghton Mifflin, Peterson Field Guide Series, Boston.
- SAS Institute. 2006. SAS/ACCESS 9.1.3 for relational databases: reference, 3rd edition. SAS Institute, Cary, North Carolina.
- Schoellhamer, D. H. 1995. Sediment resuspension mechanisms in Old Tampa Bay, Florida. Estuarine, Coastal and Shelf Science 40:603–620.
- Schroeder, W. W., S. P. Dinnel, and W. J. Wiseman Jr. 1990. Salinity stratification in a river-dominated estuary. Estuaries 13:145–154.
- Siegfried, C. A., and M. E. Kopache. 1980. Feeding of *Neomysis mercedis* (Holmes). Biological Bulletin (Woods Hole) 159:193–205.
- Smaal, A. C., and H. A. Haas. 1997. Seston dynamics and food availability on mussel and cockle beds. Estuarine, Coastal and Shelf Science 45:247–259.
- Smith, C. L. 1997. National Audubon Society field guide to tropical marine fishes of the Caribbean, the Gulf of Mexico, Florida, the Bahamas, and Bermuda. Knopf, New York.
- Stearns, S. C. 1992. The evolution of life histories. Oxford University Press, Oxford, UK.
- Szedlmayer, S. T., and K. W. Able. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19:697–709.
- Thomas, V. G. 1988. Body condition, ovarian hierarchies, and their relation to egg formation in Anseriform and Galliform species. Pages 353–363 in H. Quillet, editor. Acta XIX Congressus Internationalis Ornithologici. National Museum of Natural Science, Ottawa.
- Turner, R. E., W. W. Schroeder, and W. J. Wiseman Jr. 1987. The role of stratification in the deoxygenation of Mobile Bay and adjacent shelf bottom waters. Estuaries 10:13–19.
- Walsh, S. J. 1988. Diel variability in trawl catches of juvenile and adult Yellowtail Flounder on the Grand Banks and the effect on resource assessment. North American Journal of Fisheries Management 8:373–381.
- Winemiller, K. O., and K. A. Rose. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. Canadian Journal of Aquatic Sciences 49:2196–2218.
- Zastrow, C. E., E. D. Houde, and L. G. Moran. 1991. Spawning, fecundity, hatch-date frequency and young-of-the-year growth of bay *Anchoa mitchilli* in mid-Chesapeake Bay. Marine Ecology Progress Series 73:161–171.