# Monitoring seasonal and annual changes in the mesozooplankton community of the Indian River Lagoon, Florida

by

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Abstract

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In estuaries, like the Indian River Lagoon, mesozooplankton have a vital role in the food web by connecting trophic levels. In this study, mesozooplankton abundance and species composition were monitored weekly on the incoming and outgoing tides from September 2006 to May 2009. For the incoming tide, the mean abundance was 2298.2 mesozooplankton/$m^3$ (±325.2), and for the outgoing tide the mean abundance was 1180.0 mesozooplankton/$m^3$ (±153.1). The mesozooplankton abundance on the incoming tide was significantly greater than on the outgoing tide. The most abundant type of mesozooplankton was the copepod *Acartia tonsa*, representing 35.0% and 52.1% of the individuals on the incoming and outgoing tides respectively. Mesozooplankton abundance values were compared with environmental data obtained from the South Florida Water Management District. The strongest positive correlation was found between chlorophyll *a* concentrations and *A. tonsa* abundance, likely due to phytoplankton being the primary food source for *A. tonsa*.

Monitoring seasonal and annual changes in the mesozooplankton community of the Indian River Lagoon, Florida

List of Tables

List of Figures

## Introduction

The Indian River Lagoon (IRL) is oriented north-south, spanning both tropical and warm-temperate zones, covering over 250 km of Florida's east coast (Littler and Littler, 2003). This estuary system, which is made up of three lagoons (the Indian River, the Banana River, and the Mosquito) is the largest barrier-island/tidal-inlet system in the United States. Volusia, Brevard, Indian River, St. Lucie, Martin and Palm Beach counties are part of the IRL watershed, with major canals (such as the C-23, C-24, C-25, and C-44) draining into the estuary (Qian et al. 2007). There are six inlets in the IRL: Ponce de Leon, Cape Canaveral, Sebastian, Fort Pierce, St Lucie, and Jupiter. The IRL has also been described as one of the richest estuaries in the United States (Littler and Littler 2003). The hydrology, climate, and high habitat diversity of the IRL provide the conditions for great biological diversity, including 782 fish species (Reviewed in Gilmore 1995). The environments of the IRL, including mangrove forests and seagrass beds, provide habitats for over 1,000 plant species and 3,000 animal species (Littler and Littler 2003). The IRL is an important economic resource for commercial and recreational fishing, tourism and recreational water sports, real estate, and citrus farming, and in 2007 was valued at over $3.7 billion annually (Johns et al. 2008).

In the estuarine food web, zooplankton are an important link between primary producers and higher trophic levels (Jeong *et al*. 2001; Buskey and Hartline 2003; Sloan et al. 2007; Calliari et al. 2008; Etile et al. 2008; Kane 2009). Both fish larvae and planktivorous fish feed on mesozooplankton prey (measuring 200 to 2000μm) (Gordina *et al.,* 2005). Gelatinous zooplankton, such as *Mnemiopsis* sp., also feed on mesozooplankton, especially copepods (Monteleone and Duguay, 1988; Bishop, 1967; Larson, 1987). Since mesozooplankton feed primarily on phytoplankton, a reduction in mesozooplankton in the ecosystem can lead to phytoplankton blooms (Sullivan *et al*., 2001; Deason and Smayda, 1982). However, the trophic level interactions are more complex than just mesozooplankton feeding on phytoplankton. The picophytoplankton (measuring less than 2μm), nanophytoplankton (measuring between 2 and 20μm), microzooplankton (measuring between 2 and 200μm), and the microbial loop also have an important role in the ecosystem dynamics, but this study will focus on the mesozooplankton.

Mesozooplankton serve as a sensitive indicator of environmental changes to coastal ecosystems, such as salinity variations, pollution levels, water quality, and eutrophication (reviewed in Etile *et al*. 2008). Studies of zooplankton abundance and composition have been conducted in coastal marine environments around the world, including places such as North Africa (Ramdani *et al*. 2009), Gulf of Maine (Kane 2009), Baltic Sea (Feike and Heerkloss 2008), North Sea (Clark *et al*. 2001; Pitois et al. 2008), Brazil (Krumme and Liang 2004; Silva *et al*. 2004), Costa Rica (Brugnoli-Olivera *et al*. 2004), and Portugal (Marques *et al.* 2007), and reviewed in Etile *et al*. 2008. Monitoring changes in mesozooplankton abundance and species composition is critical for identifying ecological changes in marine environments (Kane 2009).

Copepods account for 50% of the biomass of all plankton, and 55-95% of total zooplankton abundance in marine pelagic systems (Longhurst 1985). Estuarine zooplankton communities are also dominated by copepods (reviewed in Marques *et al.*

2007). Copepods have been shown to constitute 67-80% of the planktonic community in estuaries (Brugnoli-Olivera *et al*. 2004; Froneman 2000; Marques *et al*. 2007; Silva *et al*. 2004). Copepods connect trophic levels by feeding on primary consumers, and serving as an important food source to planktonic predators including fish and gelatinous zooplankton (Sullivan and Banzon 1990; Buskey and Hartline 2003).

In the current study, certain species of copepods were abundant in the zooplankton community: *Acartia tonsa*, *Temora turbinata*, and *Euterpina acutifrons* (Dana). The species *A. tonsa* also plays a critical role in total worldwide production, due to its high biomass and rapid generation times, and functions as a primary consumer in coastal ecosystems (Reeve and Walter 1977; Schipp *et al.* 1999). *A. tonsa* has worldwide distribution in nearshore waters and estuaries of temperate and subtropical regions (Kleppel, Burkart, and Tomas 1998). In another Florida estuary, Apalachicola, *A. tonsa* is the dominant planktonic copepod species, accounting for at least 50% of the copepods (Marcus 1991). *A. tonsa*'s ability to tolerate significant changes in salinity allows it to dominate in estuarine communities (Calliari *et al.* 2008; Cervetto, Gaudy, and Pagano 1999). *A. tonsa* are 1-1.5 mm long and swim with a swim-and-sink motion (Johnson and Allen 2005). *T. turbinata* is another calanoid copepod and phytoplankton grazer, approximately 1.5 mm in length, found along the Atlantic and Gulf coasts (Johnson and Allen 2005). *T. turbinata* swims as a continuous cruiser (Paffenhofer 1978). *E. acutifrons* is a harpacticoid copepod, 0.5-0.8 mm in length (Johnson and Allen 2005), with a generation duration ranging from 23 to 85 days (Vinas and Gaudy 1995). As a eurythermic and euryhaline copepod (Vinas and Gaudy 1995), *E. acutifrons* is found mainly in coastal waters and estuaries throughout the world, with the exception of the

Arctic and Antarctic Oceans (Ara 2001). *E. acutifrons* feed on detritus and zooplankton items, in addition to phytoplankton (Diaz, Cotano, and Villate 2003).

The main objective of this study was to monitor changes, including abundance and species composition, in the mesozooplankton community of the IRL on the incoming and outgoing tides throughout the year. Changes in abundance to the mesozooplankton community and the dominant species were compared to environmental changes to attempt to determine the correlated factors.

## Methods

To monitor changes in the mesozooplankton community in the Indian River Lagoon, net tow samples were collected at least once weekly from September 2006 until May 2009, with a break in data collection from May to July 2008 due to equipment malfunction and repairs.

The sampling location was The Dockside Inn, Fort Pierce, Florida (27°28’00.71”N 80°18’07.43”W) (figure 1). This site is on Causeway Island, near the Fort Pierce Inlet of the Indian River Lagoon. On each sampling day, mesozooplankton were collected at the peak (maximum current flow speed) of both the incoming and outgoing tide during daylight hours, determined using Tides & Currents Pro for Windows Version 3.3 software. To determine if the mesozooplankton community was uniform throughout the IRL, samples were also collected at the Roosevelt Bridge in Stuart, FL (27°12’09.27”N 80°15’28.54”W) on the outgoing tide from September 2007 until May 2008. The Stuart sampling location was approximately 20 miles south of the Fort Pierce location, and located by the St. Lucie Inlet instead of the Fort Pierce Inlet.

The samples were collected using a 50 cm diameter, 333 μm mesh plankton net. A General Oceanics Mechanical Flowmeter was used to determine water volume associated with each tow. The plankton net was deployed from the east side of the dock during outgoing tides and from the west side of the dock during incoming tides, and samples were collected using the tidal flow. The net was left out for approximately three minutes within one meter of the surface. The sample collected in the cod end, the plastic jar at the end of the net, was immediately brought to the lab, a distance of approximately 0.5 km.

A FlowCAM (http://www.fluidimaging.com) combines the technologies of flow cytometry and microscopy, automatically imaging and counting the particles within a liquid sample. The FlowCAM has been used for a variety of applications, including enumerating plankton (Buskey and Hyatt 2006; Ide et al. 2008). As the sample is pumped through the flowcell, a digital image is captured of each particle within the sample (figure 2). For this monitoring study, the particles that are imaged by the FlowCAM are the mesozooplankton. After the sample has been run through the FlowCAM, all of the images can be viewed, counted, and analyzed. The images of the mesozooplankton community are detailed enough that they can be classified into groups such as mysids, fish eggs, veliger larvae, and copepods to genera, using the FlowCAM's software package Visual Spreadsheet. All of the groups are listed in table 1 and representative examples of the FlowCAM images of the groups are shown in figure 3. The abundance of mesozooplankton and types of mesozooplankton were calculated using the volume of water sampled in the net tow.

The samples were filtered between 100 to 850 µm mesh filters. Although mesozooplankton has been defined as 200 to 2000 µm (i.e. Buskey 2003), for this study, the 850 µm filter was chosen to process the sample using the FlowCAM, which has a maximum flowcell diameter of 800 µm. The FlowCAM allows for a greater volume of the sample to be analyzed than with traditional microscope methods. The filter was thoroughly rinsed with saltwater to ensure all larger mesozooplankton, such as copepods, passed through the filter, as their length may be greater than 850 µm, but their width is less than 850 µm. The filter was visually inspected after sample processing to verify that copepods had been washed through. To ensure all mesozooplankton were recognized if present, the FlowCAM was set to capture images in the size range of 100 to 2000 µm.

The filtered mesozooplankton were transferred into 200 ml of sea water in a beaker. The contents of the beaker were pumped through the FlowCAM until 2000 images had been recorded. The FlowCAM software calculates the volume of water analyzed. If the mesozooplankton was a dense sample, and may have presented a clogging risk to the FlowCAM, the sample was mixed well and then split in half. The salinity of the sample was recorded, as well as the presence of any jellyfish or ctenophores.

Environmental data were obtained from the South Florida Water Management District's environmental database DBHYDRO browser (www.sfwmd.gov) to determine if correlations existed with mesozooplankton abundances. Daily rainfall data were collected from station FT PIERCE_R, Fort Pierce Tower (27°24'37.139"N 80°20'13.166"W), approximately 5.7 miles from the study site. Daily water flow data were collected from station S50_S, spillway on canal C-25 (27°28'07.132"N

80°20’17.166”W), approximately 2.3 miles from the study site. Water quality data, such as chlorophyll concentration and temperature, were collected six to seven times a year at stations IRL 34B, at the mouth of Taylor Creek (27°28’00.66”N 80°19’21.517”W), approximately 1.7 miles from the study site, and IRL 40, south of Fort Pierce Inlet at Virginia Ave (27°24’56.138”N 80°18’33.164”W), approximately 3.4 miles from the study site. These environmental monitoring stations were selected for their proximity to the mesozooplankton sampling site.

The minimum, maximum, median, mean, and standard error were calculated for all types of mesozooplankton abundance categorized from samples (Table 1). The mean and standard error were calculated for the environmental data: flow, rainfall, salinity, chlorophyll *a*, and temperature (Table 2). Linear regression analyses were run between mesozooplankton or *A. tonsa* abundance, for both the incoming and outgoing tides, and environmental variables: rainfall, water flow rate, salinity, temperature, and chlorophyll *a* concentration (Table 3). The chlorophyll *a*, temperature, and salinity were compared with the mesozooplankton and *A. tonsa* abundance from the day the environmental data were collected and the monthly average of mesozooplankton and *A. tonsa* abundance. The mesozooplankton and *A. tonsa* abundance were compared with flow rate and rainfall from the day of, day before, and weekly total for the dates of mesozooplankton collections. Linear regressions were also run for *T. turbinata*, *E. acutifrons*, or mysid abundances, on the incoming and outgoing tides, and the environmental variables: rainfall, water flow rate, salinity, temperature, and chlorophyll *a* concentration.

## Results

### Environmental Data:

During the sampling period, salinity ranged between 20 and 35 psu. As shown in Table 2, the mean salinity of the Water Management District stations (32.1 psu at IRL 34B and 33.8 psu at IRL 40) was within one standard deviation of the mean salinity recorded at the sampling site (33.2 psu +/- 1.8). At both stations IRL34B and IRL 40, chlorophyll *a* concentration ranged from 1 to 16 mg chlorophyll $a/m^3$. As shown in Table 2, the mean chlorophyll *a* concentrations at locations IRL 34B and IRL 40 were within one standard deviation of each other. The environmental data obtained is summarized in Table 2.

### Mesozooplankton Data:

For the incoming tide, the mean mesozooplankton abundance was 2298.2 mesozooplankton/$m^3$ (± 352.2). For the outgoing tide, the mean mesozooplankton abundance was 1180.0 mesozooplankton/$m^3$ (± 153.1). Mesozooplankton abundance on the incoming and outgoing tide is presented in Figure 4.

On the incoming tide, *A. tonsa* constituted 35.0% of the mesozooplankton individuals on average (± 2.1%), with a minimum of 0% and a maximum of 88.6% *A. tonsa*. On the outgoing tide, *A. tonsa* constituted 52.1% of the mesozooplankton individuals on average (± 2.2%), with a minimum of 0% and a maximum of 98.5% *A. tonsa*. *A. tonsa* abundance on the incoming and outgoing tide is presented in figure 5.

*A. tonsa* was the most abundant copepod, followed by *E. acutifrons* and *T. turbinata*. Although *E. acutifrons* and *T. turbinata* had similar abundances on the outgoing tide, *E. acutifrons* abundance on the incoming tide was over two times that of *T.* turbinata. A comparison of the abundances of the three major species of copepods is shown in Figure 6.

Mysids were the most abundant non-copepod mesozooplankton. Nauplii may have been underestimated, as some are smaller than the 333 µm mesh plankton net used for collection, but the other types of mesozooplankton listed in Table 1 are generally larger than 333 µm. Summary data of the mean (± standard error), minimum, maximum, and median abundances of all types of mesozooplankton found on the incoming and outgoing tides is presented in Table 1.

Mesozooplankton abundance at the Fort Pierce sampling location was compared to the mesozooplankton abundance from the Roosevelt Bridge in Stuart, FL (27°12'09.27"N 80°15'28.54"W) (Figure 7). At the Roosevelt Bridge, the mean abundance of total mesozooplankton was 498.6 (±188.6), and the mean abundance of *A. tonsa* was 333.0 (±173.5). The mean mesozooplankton abundance at the Fort Pierce location on the outgoing tide was over two times that of the mean mesozooplankton abundance at the Stuart location on the outgoing tide, demonstrating variability in the mesozooplankton community along the IRL.

Statistical analysis:

Both the mesozooplankton abundance and the *A. tonsa* abundance data sets failed the normality test ($p < 0.05$), so Wilcoxon Signed Rank Tests were used to compare the incoming and outgoing tides. There was a statistically significant difference ($p < 0.001$) between the total mesozooplankton abundance on the incoming and outgoing tides.

However, there was no significant difference between *A. tonsa* abundance on the incoming and outgoing tides (p=0.571).

Linear regression analyses were conducted to compare mesozooplankton abundance and *A. tonsa* abundance from both the incoming and outgoing tides with the environmental factors: rainfall, water flow rate, salinity, temperature, and chlorophyll *a* concentration. The greatest $R^2$ value (0.418, p=0.017) was the linear regression with chlorophyll *a* concentration and the monthly average of *A. tonsa* on the outgoing tide (Figures 8 and 9). The $R^2$ values from the linear regression analyses with mesozooplankton and *A. tonsa* abundance are presented in Table 3.

Chlorophyll *a* concentration, salinity, temperature, rainfall, and water flow rate were also compared with *T. turbinata*, *E. acutifrons*, and mysid abundance. The greatest $R^2$ value (0.343, p=0.022) was the linear regression with chlorophyll *a* concentration and the monthly average of mysids on the outgoing tide. All other linear regressions had $R^2$ values less than 0.3.

## Discussion

The abundance of mesozooplankton varied significantly between the incoming and outgoing tides (p<0.001). The mean abundance of mesozooplankton on the incoming tide (2298.2 individuals/$m^3$) was twice as great as the mean abundance of mesozooplankton on the outgoing tide (1180.0 individuals/$m^3$). In addition, the maximum abundance on the incoming tide (30957.1 individuals/$m^3$) was three times greater than the maximum abundance of individuals on the outgoing tide (10791.5 individuals/$m^3$). The ocean seems to act as a source of mesozooplankton for the IRL estuary. The total volume of the IRL is 952, 833, 576 $m^3$ with an average intertidal volume of 38,700,000 $m^3$ (Smith 2001), or approximately a 4% change in the standing water of the lagoon with each tidal cycle. The location of the current study site, near the Fort Pierce Inlet, may experience greater changes in standing water than other areas of the lagoon. The Fort Pierce Inlet is the largest inlet, transporting just over 50% of the intertidal volume (Smith 2001).

The zooplankton may not leave the estuary because they are consumed by juveniles of fish species such as mullet (*Mugil* spp.), ladyfish (*Elops saurus*), and snook (*Centropomus undecimalis*) (Rey *et al.* 1991). Predation by planktivorous fish has been shown to play an important role in regulating the composition of a zooplankton community (reviewed in Horsted *et al.* 1988). In a study done by Horsted *et al.* (1988) the addition of planktivorous fish to an enclosure reduced the density of larger zooplankton species present, including *A. tonsa*. Enclosures without fish had an eight-fold increase in the number of *A. tonsa*, demonstrating that their populations are predator controlled (Horsted *et al.* 1988).

Bivalves may impact zooplankton abundance indirectly by competing for phytoplankton resources (reviewed in Prins *et al.* 1998). They may also be filter feeding the smallest of the mesozooplankton, such as copepod nauplii (reviewed in Prins *et al*. 1998). However, filtration by bivalves does not affect larger species, such as *A. tonsa* (Horsted *et al.*1988). To avoid cannibalism, adult oyster ciliary currents are strong enough for phytoplankton capture, but weak enough for larval oysters to escape, with less than 5% of larval oysters being captured, even within 1 mm of adults (Tamburri *et al.*

2007). Likewise, most mesozooplankton would be able to avoid capture by these weak currents.

Tidal changes have been shown to affect zooplankton abundance and composition in other areas as well. In a mangrove channel in northern Brazil, the greatest abundance of zooplankton and copepods was found at low water, with zooplankton remaining in the channel after entering (Krumme and Liang 2004). Krumme and Liang (2004) hypothesized that the copepods were entering the area on a flood tide and not exiting again on the ebb tide current, possibly due to sinking. Likewise, Kimmerer *et al.* (1998) found that all of the common species of zooplankton in a temperate estuary vertically migrated in response to the tides, with higher abundance in the water column during the flood tide than on the ebb tide. A similar mechanism could be occurring in the IRL, with copepods entering on the incoming tide, and then staying in the estuary instead of leaving with the outgoing tide. Thus, the mesozooplankton could be migrating into the estuary via selective tidal stream transport.

In a zooplankton study in impounded salt marshes and on a shallow flat in the IRL , the density of plankton collected at 1.5 m averaged 2,878 individuals/$m^3$ (Rey *et al.* 1987) (Figure 10). Another study at impounded salt marshes and shallow areas of the IRL found about 53% of the zooplankton individuals were the copepods *Oithona nama* and 27% were *A. tonsa* (Rey *et al.* 1991). Other copepods found at the sites included *E. acutifrons* (Rey *et al.* 1991). Although this earlier study and the current study both found *A. tonsa* present, the abundances were different with a greater percentage of *A.tonsa* in the current study. *O. nama* was only found in the shallow sites in the IRL, and was the dominant copepod there. Shallow areas may be its preferred habitat due to its weak swimming ability (Johnson and Allen 2005). *T. turbinata*, on the other hand, is a strong vertical migrator and is more common along the coast than in estuaries (Johnson and Allen 2005), and was found in the current study that sampled closer to the inlet from the Atlantic Ocean.

While studying zooplankton in the shallow areas of the IRL, Rey *et al.* (1991) noted seasonal patterns, with peaks in zooplankton density in late summer-early fall, and minima during late spring-summer and winter. These peaks in zooplankton density were attributed to phytoplankton blooms, which occur following heavy rainfalls that wash nutrients into the lagoon (Rey *et al.* 1991). Declines in zooplankton abundance may result from a combination of factors including warmer summer temperatures, lower dissolved oxygen, and higher salinity (Rey *et al.* 1991). Shallower waters may be impacted more by seasonal changes like increases in temperature, which could cause increased salinity and reduced dissolved oxygen. Rey *et al.* (1991) also reported that *A. tonsa* had the greatest abundance during the winter and spring seasons. Despite peaks in *A. tonsa*, Rey *et al.* (1991) found no consistent seasonal pattern in the number of taxa present, the majority of taxa were present year-round, and cluster analysis did not show any seasonality. Estuarine zooplankton abundance lacks seasonal patterns, which may be due to species of zooplankton in the community having different, and sometimes contrasting, seasonal patterns (Marques *et al.* 2007). In addition, the interaction of ocean and river water, and the resulting biological and environmental conditions, may create complex patterns of zooplankton abundance (Marques *et al.* 2007). Although the current study observed peaks in total mesozooplankton and *A. tonsa* abundance (Figures 4 and 5), a distinct seasonal pattern could not be determined. During the summer of 2007, low abundances were consistently observed, but sampling was unavailable during the summer of 2008 due to FlowCAM equipment malfunctions. In order to keep sampling methodology consistent, samples were not fixed and stored, nor were microscope counts conducted, but sampling was resumed as soon as the FlowCAM was successfully repaired.

*A. tonsa* dominated the planktonic estuarine community in the IRL, averaging 35.0% and 52.1% of the individuals in the mesozooplankton community on the incoming and outgoing tides respectively. At times, *A. tonsa* copepods accounted for 90% or more of the mesozooplankton. These numbers are similar to *A. tonsa* abundance in another Florida estuary, Pensacola Bay, with an average of 54% (range 20-96%) of total zooplankton abundance (Murrell and Lores 2004). Brugnoli-Olivera *et al.* (2004) summarizes that *Acartia* spp. dominate in estuarine systems because of their high reproductive rates, high food clearance rates, and ability to take advantage of multiple food sources as omnivores. *A. tonsa* also has the advantage of a high tolerance for environmental change in an estuary that experiences wide environmental fluctuations. For example, *A. tonsa* has been shown to survive osmotic change in a wide range of salinities (Cervetto *et al.* 1999; Calliari *et al.* 2008). *A. tonsa* has been reported as the most important contributor to the copepod community in other estuaries, having the greatest abundance of all types of zooplankton (Marques *et al.* 2007). Other Florida estuaries that have also found *A. tonsa* to be the dominant copepod include Apalachicola and Pensacola (Marcus 1991; Murrell and Lores 2004).

*E. acutifrons* abundance averaged 524.1 individuals/$m^3$ on the incoming tide and 81.9 individuals/$m^3$ on the outgoing tide. There were occasional peaks in abundance as high as 12897 individuals/$m^3$ on the incoming tide, and 2844.3 individuals/$m^3$ on the outgoing tide. These peaks in *E. acutifrons* abundance appeared to coincide with declines in *A. tonsa* abundance (Figure 6). In other estuaries, such as the Cananéia Lagoon in Brazil, *E. acutifrons* abundance has been correlated with higher salinities (Ara 2001). However, this Brazilian estuary has salinities ranging between 4.5 and 33 psu and higher abundances were recorded for salinities above 17 psu (Ara 2001), whereas the IRL study site had salinities ranging between only 20 and 35 psu. One possibility for the peaks in *E. acutifrons* abundance is the ability of this species to utilize detritus as a food source (Vinas and Gaudy 1995). The distribution patterns of this species are not yet understood in most estuarine ecosystems worldwide (Ara 2001).

In their study of zooplankton in shallow areas of the IRL, Rey *et al.* (1991) found few consistent correlations between environmental variables and plankton abundance. Likewise, this study found few significant correlations between environmental variables and zooplankton abundance in the IRL. Rey *et al.* (1991) did find that plankton density was positively correlated with temperature and rainfall, and *A. tonsa* abundance was negatively correlated with salinity and temperature. The current study found a statistically significant positive correlation between the concentration of chlorophyll *a* and the monthly average of *A. tonsa* abundance on the outgoing tide was 0.418, which is statistically significant (p=0.017). Thus, part (41.8%) of the variability of *A.* tonsa abundance can be attributed to the chlorophyll *a* concentration. The concentration of chlorophyll *a* is related to the concentration of phytoplankton, the primary food source of *A. tonsa*. An increase in chlorophyll *a* concentration, indicating an increase in phytoplankton abundance, could provide a means for an increase in the *A. tonsa* population. Other factors that contribute to *A.* tonsa abundance are yet to be elucidated. No correlation was found between the abundance of *A. tonsa* on the incoming tide and the total weekly rainfall ($R^2$= 0.0242, p=0.048). Although not statistically significant, a few other correlations had p-values of less than 0.1. Chlorophyll *a* concentration and the monthly average of *A. tonsa* abundance on the incoming tide had an $R^2$ of 0.214 (p=0.083). Temperature and mesozooplankton abundance on the outgoing tide had an $R^2$ of 0.223 (p=0.065), and between temperature and monthly average mesozooplankton abundance on the incoming tide had an $R^2$ of 0.200 (p=0.082). Other studies have also found that temperature may be an important factor in determining zooplankton abundance patterns (Rey *et al.* 1991; Marques *et al.* 2007).

Zooplankton abundance can also be impacted by biological factors. Ctenophores, such as *Mnemiopsis leidyi*, which prey on zooplankton, exert top-down control, reducing zooplankton abundance (Sullivan *et al.* 2001). By reducing zooplankton abundance, ctenophores can also cause increases in phytoplankton, a zooplankton food source, and potentially lead to algal blooms (Deason and Smayda 1982). Declines in zooplankton abundance can also impact fish populations, as zooplankton are a food source for larval fish (Gordina *et al.* 2005). *Mnemiopsis* spp. were occasionally found in the plankton net during sampling in the IRL, and may have impacted zooplankton abundance in the IRL prior to capture. However, not a large enough volume of water was sampled to quantify ctenophore abundance and run comparison statistics. *Mnemiopsis* spp. was also present at shallow sites in the IRL, with greatest abundance during the summer season that may have been a factor in the decline in zooplankton abundance (Rey *et al.* 1991). Zooplankton are an important food source for many juvenile fish species in the IRL, such as *Cyprinodon variegates, Gambusia affinis, Poecilia latipinna,* and *Mugil* spp. (Rey *et al.* 1991). These juvenile fish reduce mesozooplankton populations, and may account for the lower values of mesozooplankton abundance on the outgoing tide leaving the IRL compared with the incoming tide from the ocean.

In summary, this study found variability in the abundance of mesozooplankton in the IRL. Mesozooplankton abundance varies significantly between the incoming and the outgoing tide, with more mesozooplankton entering the estuary than leaving. Monitoring mesozooplankton abundance and species composition should continue in the IRL, in order to determine if trends in mesozooplankton and copepod abundance represent seasonal patterns. Although chlorophyll *a* concentration has been shown to correlate with *A. tonsa* abundance, monitoring should also continue to elucidate the complexity of factors that control abundance of the dominate copepod, *A. tonsa*.

The IRL is a diverse estuarine ecosystem, with mesozooplankton filling an important role as the connection between primary production and higher trophic levels. Copepods, in particular, serve as a crucial food source for larval fish, planktivorous fish, and gelatinous zooplankton. Monitoring changes in the mesozooplankton community are essential, as ecological and environmental changes to the ecosystem are reflected in changes to mesozooplankton abundance and species composition.

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Table 1. Mean (individuals/$m^3$) (with standard error in parentheses), minimum, maximum, and median abundance of types of mesozooplankton on the incoming (n=159) and outgoing (n=161) tides from September 2006 to May 2009, collected at the Dockside Inn, Fort Pierce, FL.

| | **INCOMING** | | | | **OUTGOING** | | | |
|---|---|---|---|---|---|---|---|---|
| **Mesozooplankton** | **Mean (±SE)** | **Minimum** | **Maximum** | **Median** | **Mean (±SE)** | **Minimum** | **Maximum** | **Median** |
| *Acartia tonsa* | 1006.5 (± 220.0) | 0.0 | 28433.1 | 226.6 | 713.1 (± 119.3) | 0.0 | 10431.8 | 187.9 |
| *Temora turbinate* | 210.8 (± 41.7) | 0.0 | 4389.1 | 34.1 | 88.6 (± 19.8) | 0.0 | 2206.5 | 12.2 |
| *Euterpina acutifrons* | 542.1 (± 137.5) | 0.0 | 12897.8 | 60.5 | 81.9 (± 25.2) | 0.0 | 2844.3 | 4.1 |
| *Labidocera* sp. | 36.5 (± 7.82) | 0.0 | 700.2 | 2.7 | 24.4 (± 7.0) | 0.0 | 814.0 | 1.2 |
| other copepods | 354.7 (± 64.0) | 0.0 | 7793.8 | 120.3 | 131.7 (± 17.6) | 0.0 | 1382.5 | 48.6 |
| other mesozooplankton | 72.7 (± 13.6) | 0.0 | 1237.4 | 17.3 | 36.2 (± 7.4) | 0.0 | 870.6 | 9.9 |
| mysid | 17.3 (± 3.8) | 0.0 | 520.3 | 2.9 | 18.0 (± 3.7) | 0.0 | 376.7 | 5.1 |
| naupliar larva | 16.9 (± 4.6) | 0.0 | 605.4 | 1.0 | 8.8 (± 1.9) | 0.0 | 188.1 | 1.5 |
| zoea | 13.5 (± 2.6) | 0.0 | 289.8 | 3.5 | 13.1 (± 1.8) | 0.0 | 168.8 | 5.7 |
| polychaete | 12.9 (± 4.8) | 0.0 | 700.0 | 0.0 | 1.2 (± 0.2) | 0.0 | 20.5 | 0.0 |
| chaetognath | 8.0 (± 2.8) | 0.0 | 426.2 | 0.6 | 5.9 (± 1.5) | 0.0 | 197.5 | 1.2 |
| veliger larva | 4.8 (± 0.9) | 0.0 | 108.4 | 0.9 | 2.4 (± 0.4) | 0.0 | 49.8 | 0.5 |
| pluteus larva | 3.9 (± 2.4) | 0.0 | 375.4 | 0.0 | 1.9 (± 1.0) | 0.0 | 120.1 | 0.0 |
| *Obelia* sp. | 2.3 (± 0.8) | 0.0 | 114.4 | 0.0 | 0.8 (± 0.2) | 0.0 | 13.9 | 0.0 |
| cladocean | 2.0 (± 0.83) | 0.0 | 117.4 | 0.0 | 1.0 (± 0.4) | 0.0 | 49.8 | 0.0 |
| other jellies | 1.1 (± 0.4) | 0.0 | 37.2 | 0.0 | 0.1 (± 0.06) | 0.0 | 9.6 | 0.0 |
| larvacean | 0.8 (± 0.56) | 0.0 | 88.9 | 0.0 | 0.1 (± 0.04) | 0.0 | 4.8 | 0.0 |
| fish eggs | 0.6 (± 0.1) | 0.0 | 11.7 | 0.0 | 1.1 (± 0.3) | 0.0 | 40.8 | 0.0 |
| mitraria larva | 0.1 (± 0.04) | 0.0 | 4.2 | 0.0 | 0.02 (± 0.01) | 0.0 | 1.9 | 0.0 |

Table 2. Summary of environmental data from September 2006 to May 2009, obtained from the South Florida Water Management Districts environmental database DBHYDRO browser (www.sfwmd.gov). Daily rainfall data was collected from station FT PIERCE_R, Fort Pierce Tower (27°24’37.139”N 80°20’13.166”W). Daily water flow data was collected from station S50_S, spillway on canal C-25 (27°28’07.132”N 80°20’17.166”W). Water quality data, such as salinity, chlorophyll *a* concentration, and temperature, were collected six to seven times a year at stations IRL 34B, mouth of Taylor Creek (27°28’00.66”N 80°19’21.517”W) and IRL 40, south of Fort Pierce Inlet at Virginia Ave (27°24’56.138”N 80°18’33.164”W).

| Location | Salinity (psu) | | Chlorophyll *a* (mg/m³) | | Temperature (°C) | |
|---|---|---|---|---|---|---|
| | n | Mean (± Std Error) | n | Mean (± Std Error) | n | Mean (± Std Error) |
| Dockside Inn (sample collection site) | 272 | 33.2 (± 0.11) | | | | |
| IRL 34B | 18 | 32.1 (± 1.34) | 13 | 5.7 (± 1.14) | 18 | 24.7 (± 0.82) |
| IRL 40 | 19 | 33.8 (± 0.54) | 15 | 4.5 (± 0.96) | | |
| | | | | | | |
| Location | Flow (cubic feet/second) | | Rainfall (daily inches) | | | |
| | n | Mean (± Std Error) | n | Mean (± Std Error) | | |
| S50 | 1035 | 156.9 (± 10.6) | | | | |
| FT_PIERCE_R | | | 972 | 0.13 (± 0.014) | | |

Table 3. R-squared values (with p-values in parentheses) of linear regression analyses run between mesozooplankton or *A. tonsa* abundance and environmental variables. The chlorophyll *a*, temperature, and salinity were compared with the mesozooplankton and *A. tonsa* abundance from the day the environmental data were collected and the monthly average of mesozooplankton and *A. tonsa* abundance. The mesozooplankton and *A. tonsa* abundance were compared with flow rate and rainfall from the day of, day before, and weekly total for the dates of mesozooplankton collections. Black boxes show p-values less than 0.05. Grey boxes show p-values less than 0.1.

| **INCOMING:** | | **Mesozooplankton** | | **A. tonsa** | |
|---|---|---|---|---|---|
| Environmental Variable | n | Day of | Monthly Average | Day of | Monthly Average |
| Chlorophyll *a* (IRL 34B) | 13 | 0.150 (0.191) | 0.00175 (0.892) | 0.0922 (0.313) | 0.132 (0.222) |
| Chlorophyll *a* (IRL 40) | 15 | 0.0874 (0.285) | 0.162 (0.137) | 0.0684 (0.346) | 0.214 (0.083) |
| Temperature (IRL 34B) | 16 | 0.127 (0.175) | 0.200 (0.082) | 0.166 (0.117) | 0.177 (0.105) |
| Salinity | 15 | 0.0276 (0.051) | | 0.0121 (0.199) | |

| **INCOMING:** | | **Mesozooplankton** | | | **A. tonsa** | | |
|---|---|---|---|---|---|---|---|
| Environmental Variable | n | Day of | Day before | Week Total | Day of | Day before | Week Total |
| Flow Rate | 161 | 0.000759 (0.729) | 0.0000403 (0.936) | 0.00214 (0.657) | 0.00723 (0.283) | 0.00634 (0.316) | 0.00532 (0.358) |
| Rainfall | 152-162 | 0.00828 (0.257) | 0.00511 (0.381) | 0.0242 (0.048) | 0.00404 (0.429) | 0.00603 (0.342) | 0.0143 (0.129) |

| **OUTGOING:** | | **Mesozooplankton** | | **A. tonsa** | |
|---|---|---|---|---|---|
| Environmental Variable | n | Day of | Monthly Average | Day of | Monthly Average |
| Chlorophyll *a* (IRL 34B) | 13 | 0.0677 (0.391) | 0.137 (0.297) | 0.000504 (0.942) | 0.418 (0.017) |
| Chlorophyll *a* (IRL 40) | 15 | 0.0731 (0.330) | 0.120 (0.206) | 0.0934 (0.268) | 0.0877 (0.284) |
| Temperature (IRL 34B) | 16 | 0.223 (0.065) | 0.126 (0.178) | 0.127 (0.176) | 0.0638 (0.345) |
| Salinity | 15 | 0.000019 (0.968) | | 0.00383 (0.478) | |

| **OUTGOING:** | | **Mesozooplankton** | | | **A. tonsa** | | |
|---|---|---|---|---|---|---|---|
| Environmental Variable | n | Day of | Day before | Week Total | Day of | Day before | Week Total |
| Flow Rate | 161 | 0.00364 (0.447) | 0.00734 (0.280) | 0.0119 (0.169) | 0.00197 (0.577) | 0.00442 (0.402) | 0.0107 (0.191) |
| Rainfall | 152-162 | 0.00122 (0.664) | 0.000588 (0.767) | 0.0193 (0.078) | 0.00226 (0.555) | 0.00284 (0.515) | 0.0109 (0.187) |

Figure 1.  Sample collection site: Dockside Inn, Fort Pierce, FL


Figure 2. FlowCAM set-up with sample running and images being collected on the computer.

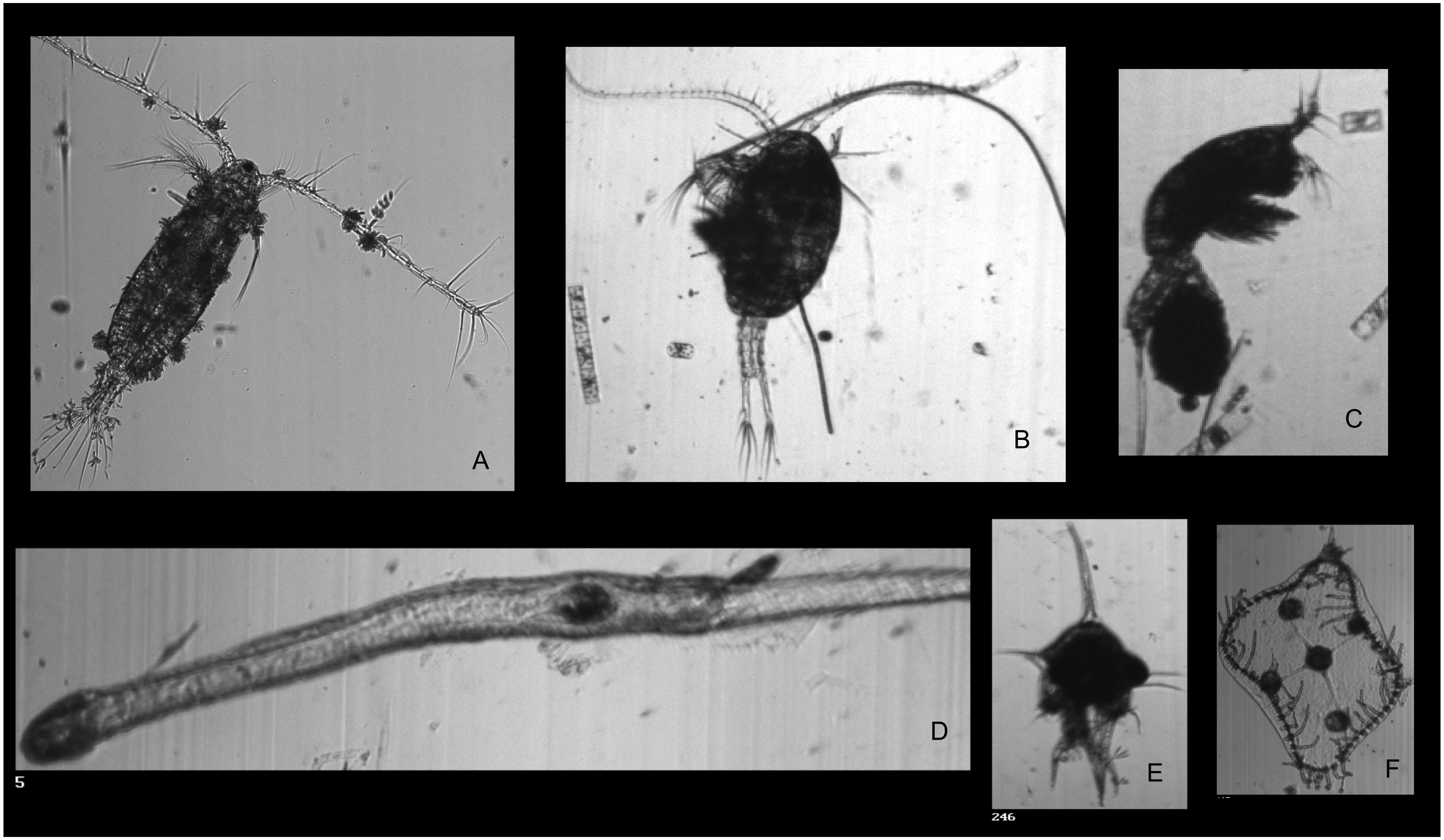


Figure 3. Examples of FlowCAM images: A) *Acartia tonsa* B) *Temora turbinata* C) *Euterpina acutifrons* D) Chaetognath E) zoea F) *Obelia* spp.

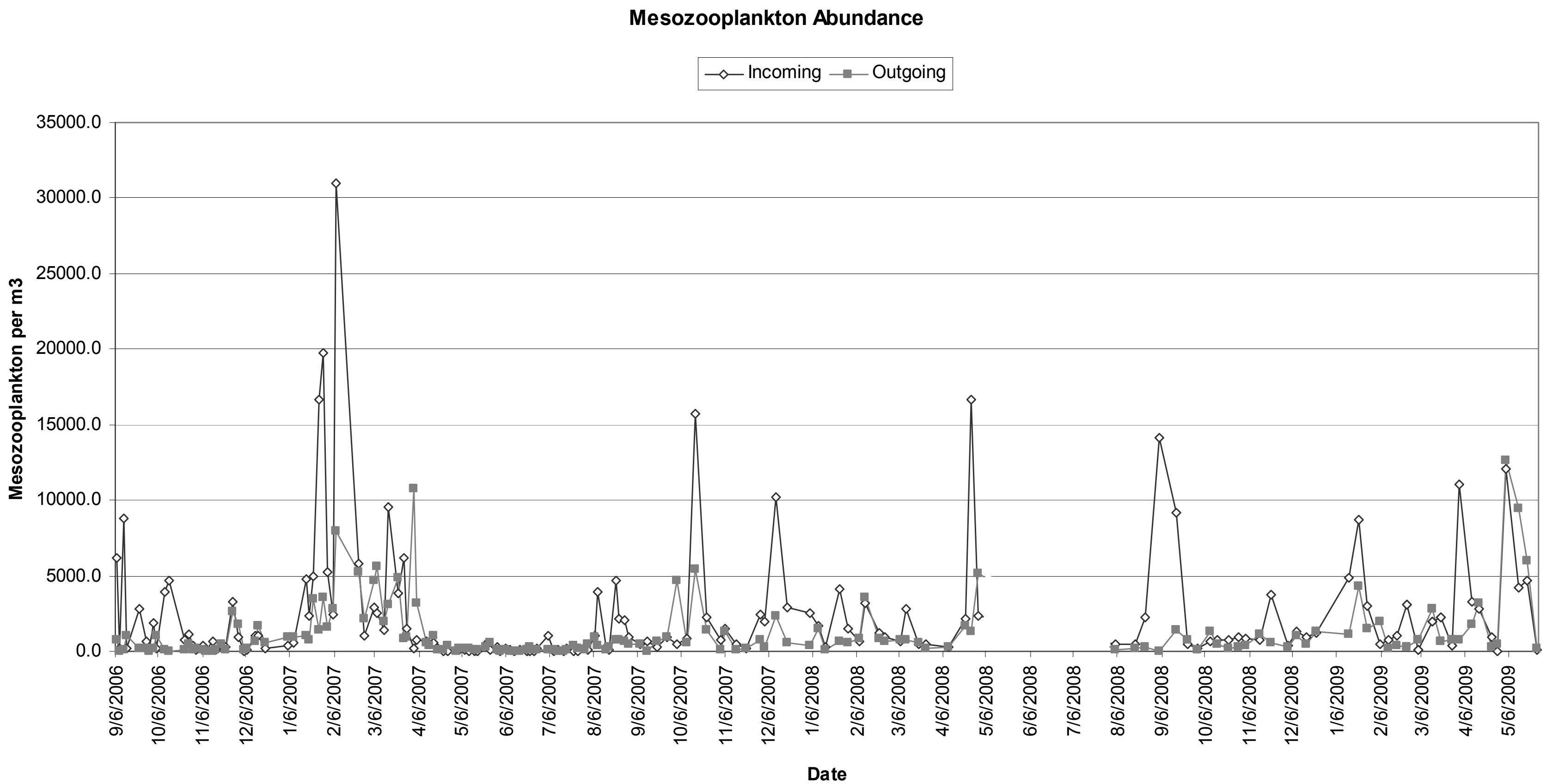


Figure 4. Mesozooplankton abundance (individuals/$m^3$) on the incoming and outgoing tides from September 2006 to May 2009, collected at the Dockside Inn, Fort Pierce, FL. (Gap in data collection during June and July 2008)

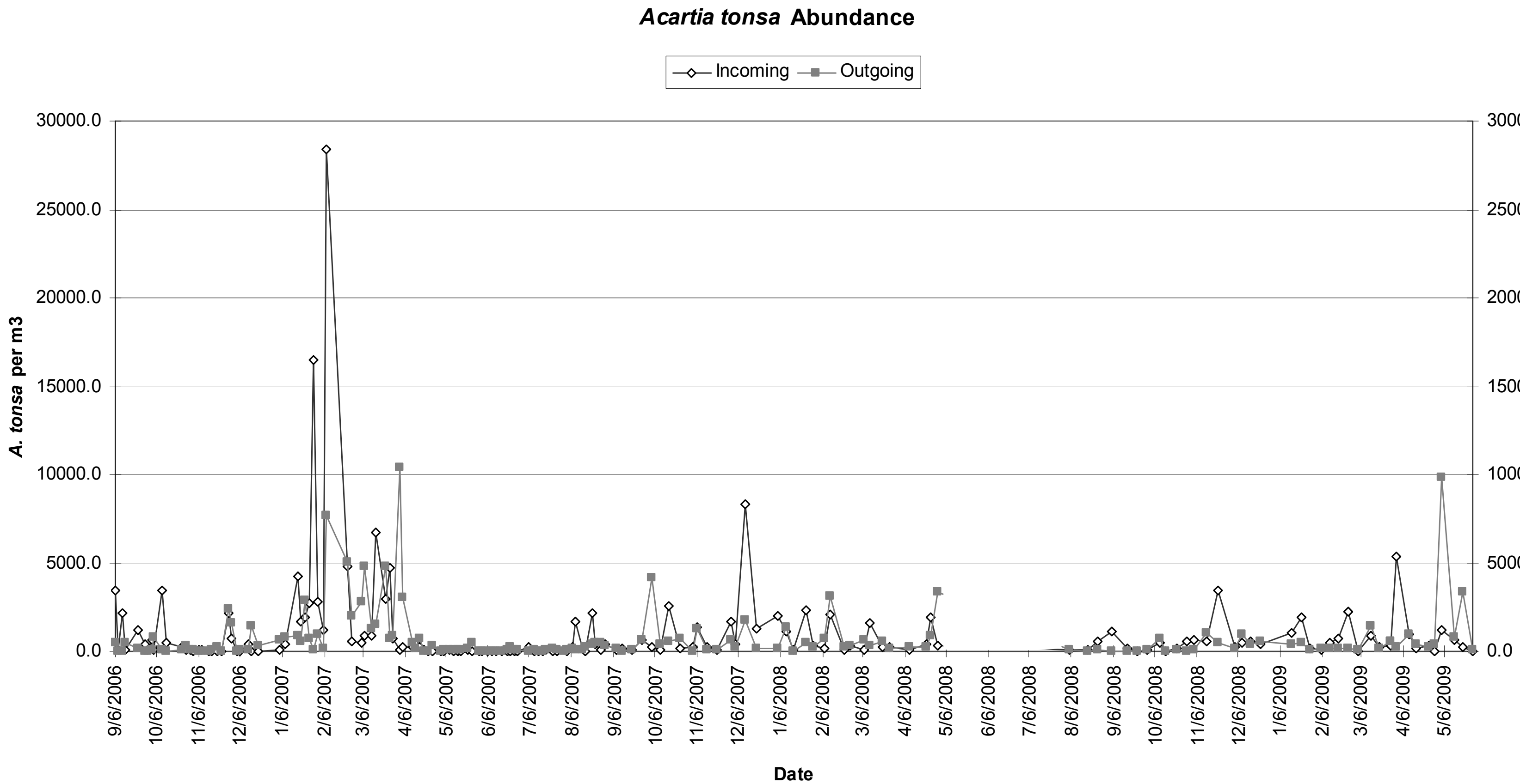


Figure 5. *Acartia tonsa* abundance (individuals/$m^3$) on the incoming and outgoing tides from September 2006 to May 2009, collected at the Dockside Inn, Fort Pierce, FL. (Gap in data collection during June and July 2008)

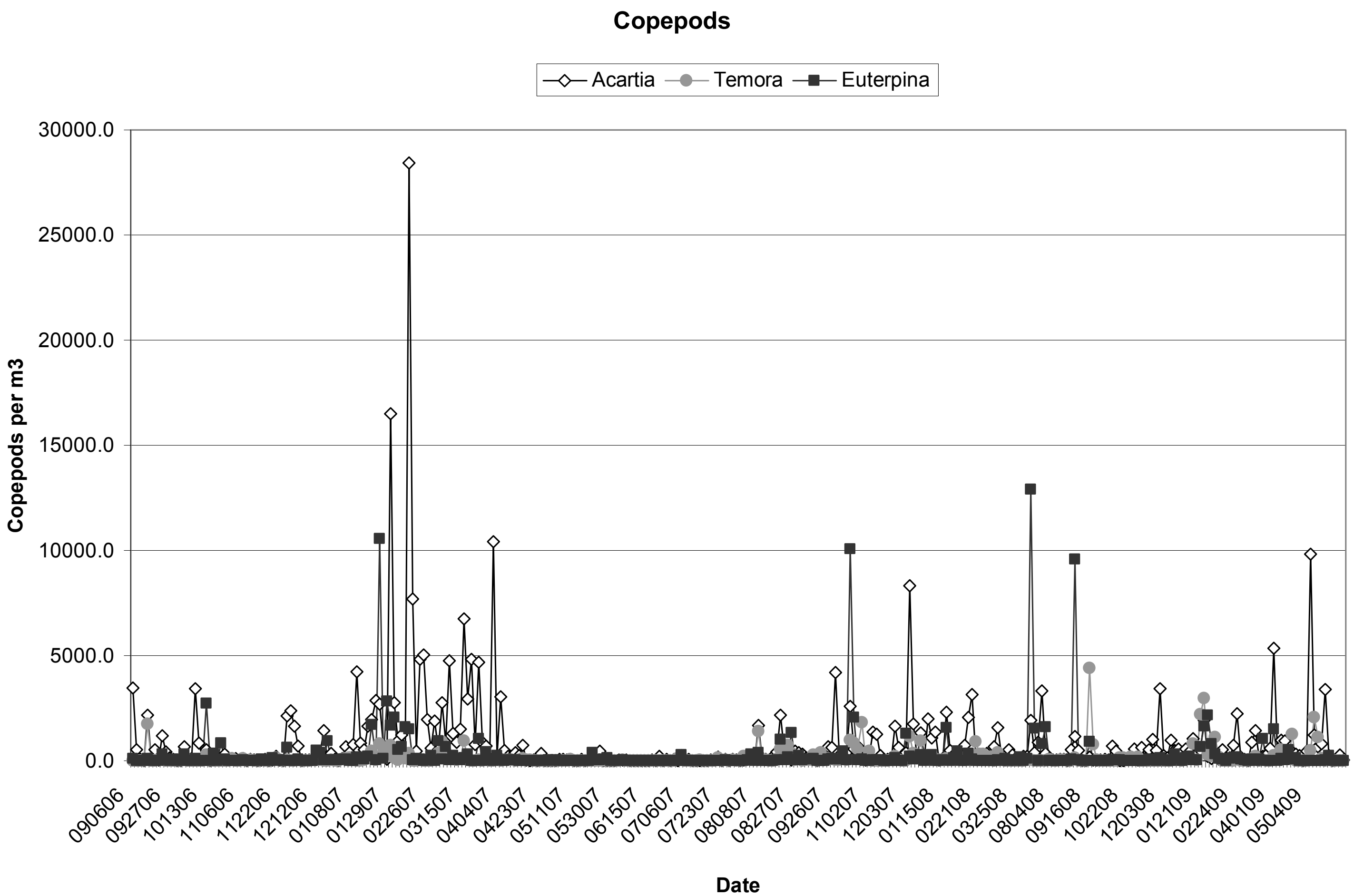


Figure 6. Abundance of the three major species of copepods found in the mesozooplankton samples: *Acartia tonsa*, *Temora turbinata*, and *Euterpina acutifrons*,

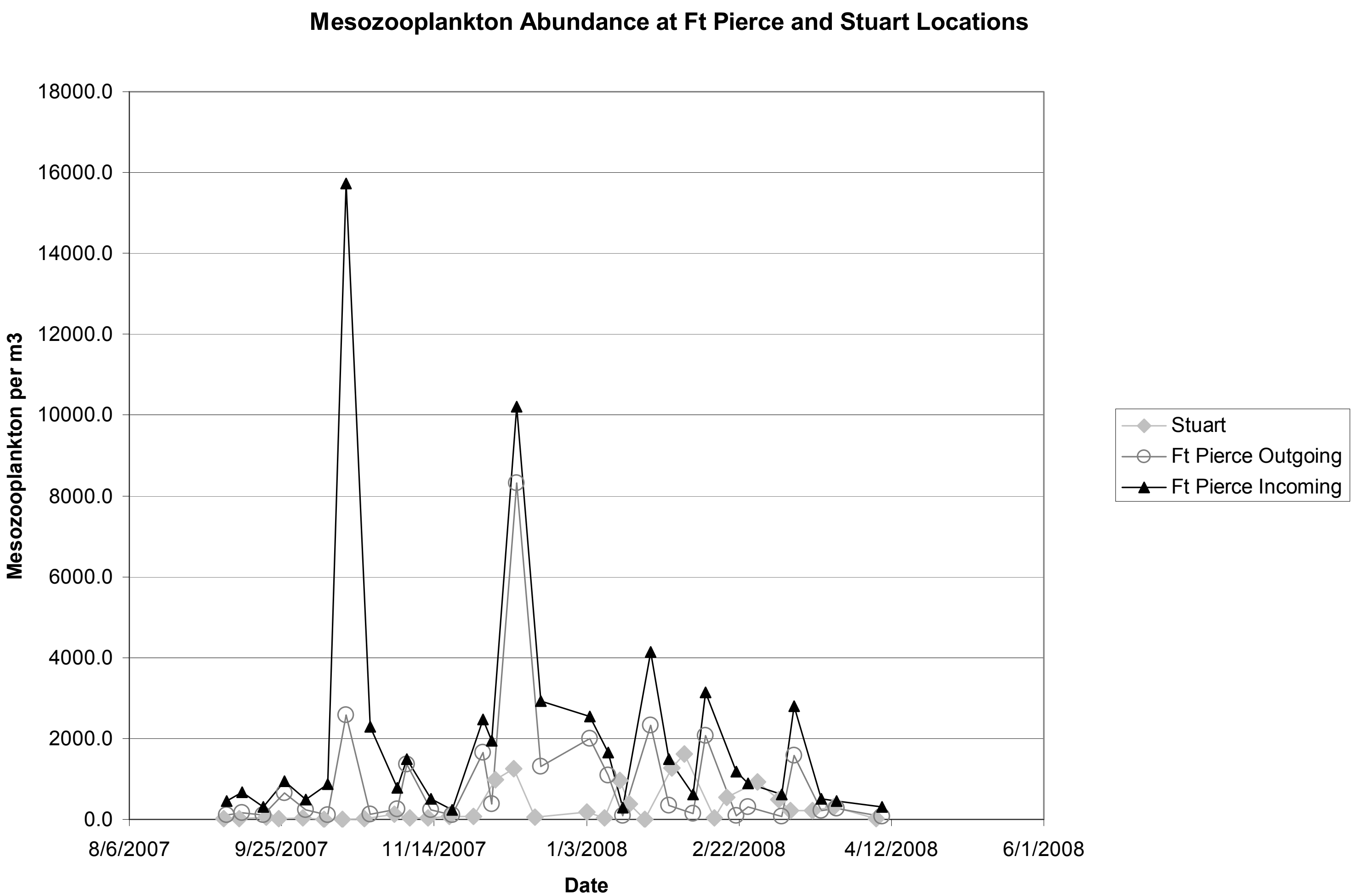


Figure 7. Mesozooplankton abundance at the Fort Pierce sampling location, on the incoming and outgoing tides, and mesozooplankton abundance from the Roosevelt Bridge in Stuart, FL

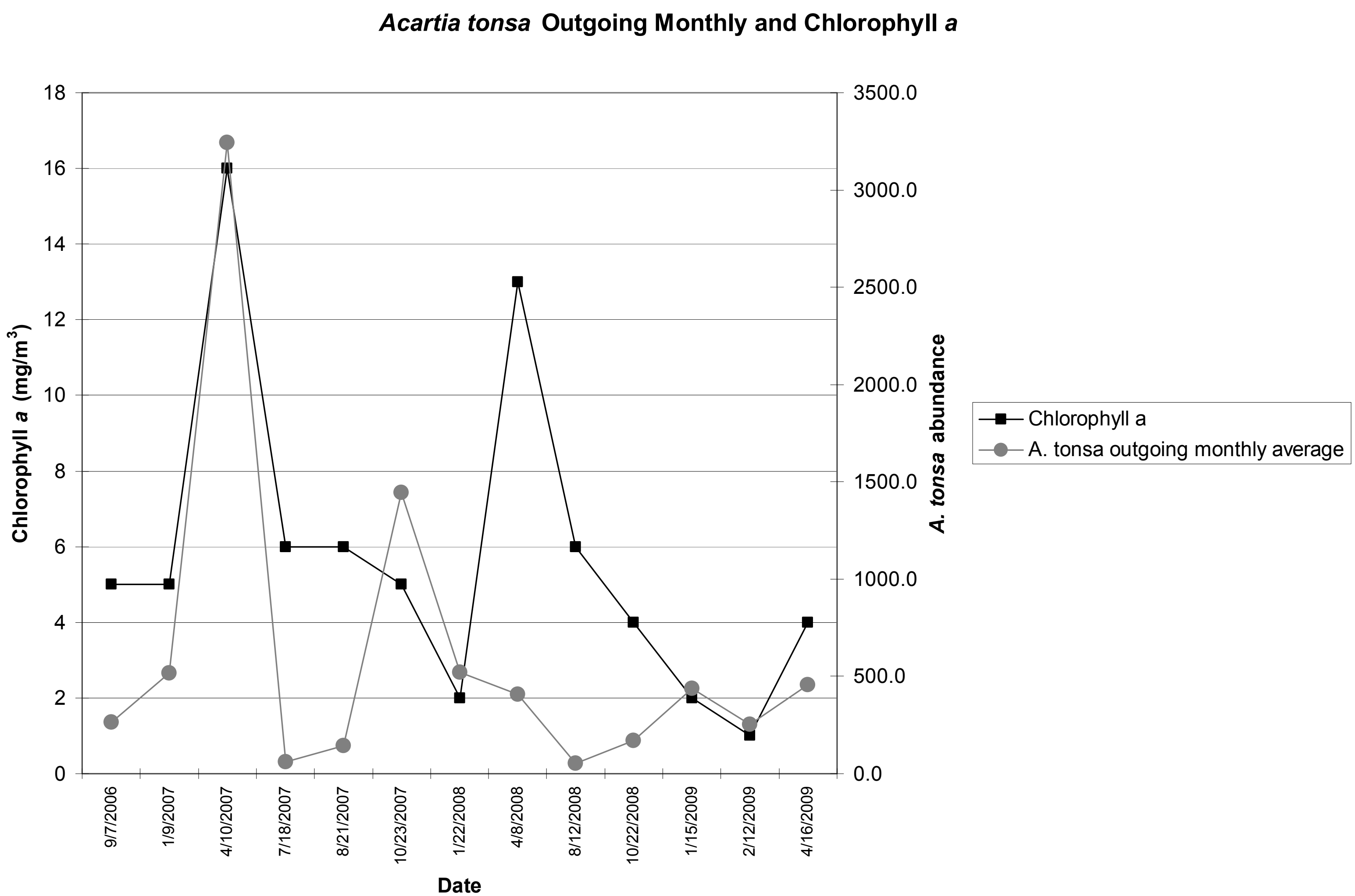


Figure 8. Chlorophyll *a* concentration and *A. tonsa* monthly average abundance on the outgoing tide

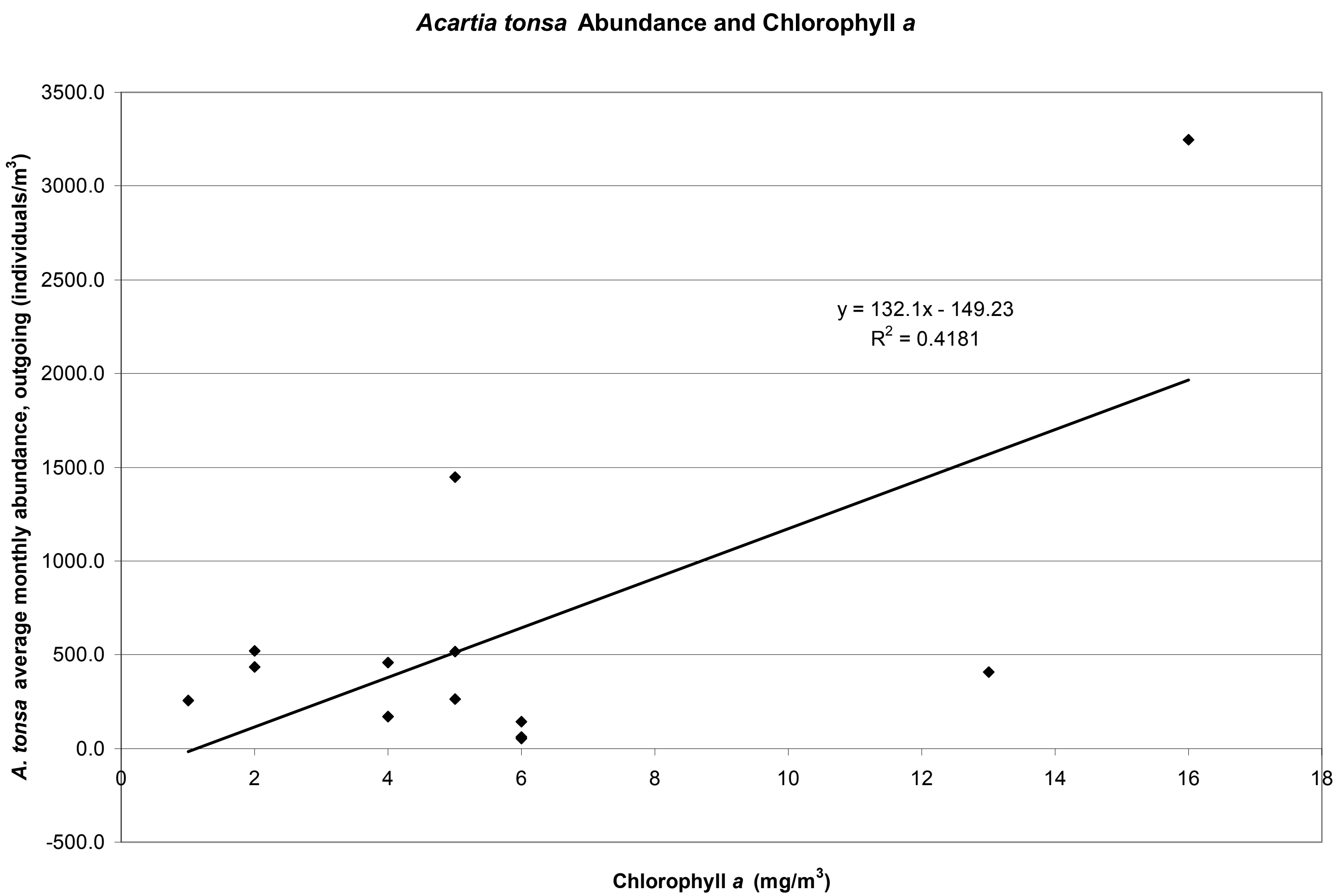


Figure 9. Linear regression analysis of chlorophyll *a* concentration and *A. tonsa* monthly average abundance on the outgoing tide.

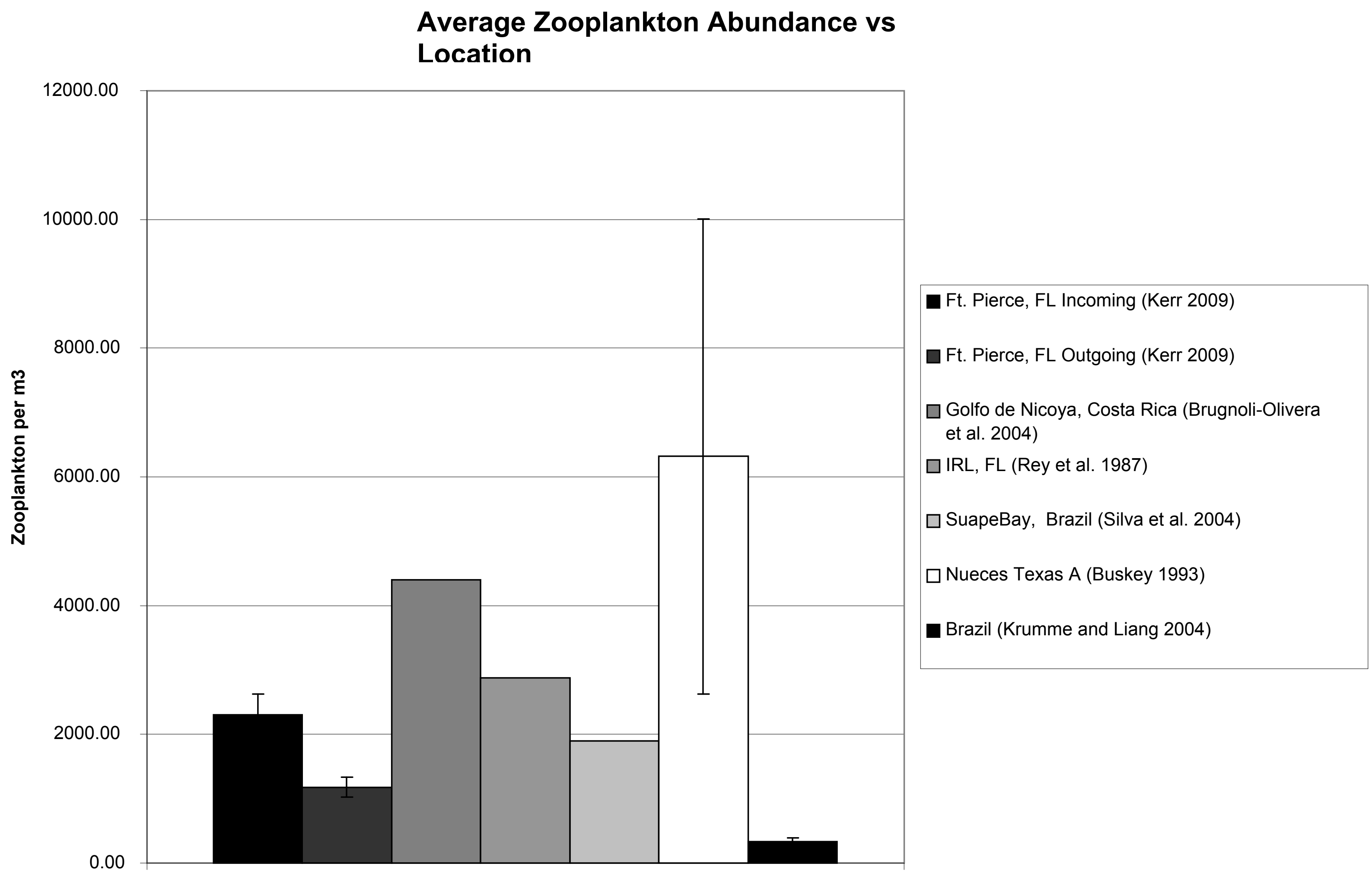


Figure 10. Mean abundance of zooplankton from the current study and five other locations. Error bars are standard error for the current study and standard deviations for the other studies.