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Effects of a Spatially and Temporally Predictable Chlorophyll Maximum on Bottlenose Dolphin Distribution in a South Carolina Estuary

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By

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ABSTRACT

Numerous studies have focused on the complex relationship between phytoplankton and zooplankton in estuarine environments, but few have scrutinized the effects of this connection on organisms in higher trophic levels. This study examined chlorophyll *a* concentrations and zooplankton densities in North Inlet, South Carolina, a site where a stable chlorophyll *a* maximum has been documented to exist at low tide, to determine if they influenced the distribution of resident bottlenose dolphins (*Tursiops truncatus*). We hypothesized that patterns of estuarine circulation in the salt marsh serve to concentrate phytoplankton and zooplankton predictably in time and space, and that these patterns influence the distribution of organisms at all trophic levels, including apex predators, in the marsh. During surveys in September through November of 2008, water samples for chlorophyll and tows for zooplankton were taken at two-hour intervals throughout the tidal cycle along a gradient of five sites centered around the historic chlorophyll maximum. Correlations between zooplankton densities and phytoplankton concentration were unexpectedly low and the chlorophyll *a* maxima were more spatially unpredictable than in previous studies. However, the distribution of dolphin sightings, both present and from 1999 through 2003, suggests that chlorophyll *a* maxima influence dolphin distribution in North Inlet, particularly during the warmer months out of the year.
Keywords: Estuary, chlorophyll *a* maximum, zooplankton density, bottlenose dolphin distribution

INTRODUCTION

Many previous studies have been conducted on the water dynamics of the North Inlet Estuary that focus on nutrient fluxes into the nearby ocean, water quality and ecological importance, with most of the ecological studies focusing on the lower end of the estuarine food web. The ecological studies have examined the relationship between phytoplankton and zooplankton, but many have not explored the effects of this relationship on organisms in higher trophic levels, such as fish and piscivores. The goal of this study was to study the entire North Inlet estuarine food web by associating phytoplankton abundance, specifically chlorophyll *a* concentrations, with zooplankton abundance and the feeding behavior of bottlenose dolphins.

Salt marshes on the southeastern coast of the United States have been known to be so productive in terms of organic material, that the excess material is exported to the nearby ocean. This in turn makes the oceanic waters more productive, as part of the Outwelling Hypothesis (Gardner and Kjerfve 2006, Gardner et al. 2006). Many studies have also shown that estuaries are major exporters of inorganic suspended sediments (Gardner and Kjerfve 2006). The North Inlet Estuary is on the East Coast of South Carolina, with three main tidal creeks, Debidue, Town, and Jones, connecting to North Inlet, which itself borders the Atlantic Ocean (Fig. 1 and 2) (Chrzanowski et al. 1982).

In North Inlet, currents created by the daily tides transport nutrients out of the inlet, while nutrients are brought into the portion of the estuary closer to inland South Carolina (Gardner and Kjerfve 2006). North Inlet is considered to be a high-salinity estuary that is bar-built and shallow, with an average water depth of less than 3 m, and experiences semi-diurnal tides (Lewitus et al. 2004). The water is high in salinity because of high influxes of tidal water and low influxes of freshwater into the estuary. More specifically, the inlet contains between 32 and 34 km^2 of salt marsh, has a mean diurnal tidal range of 1.5 m and with each ebb tide, 40% of the total water in the estuary drains due to its shallow depth (Schwing and Kjerfve 1980, Gardner and Kjerfve 2006). When water leaves the estuary, dissolved oxygen and nutrients are swept out, with nutrients tending to be exported to the ocean more readily than oxygen (Gardner and Kjerfve 2006, Gardner et al. 2006). Comparative studies done on water quality and phytoplankton in North Inlet and Murrells Inlet, another estuary around 32 km north of North Inlet, have confirmed the relatively pristine state of North Inlet, due to the fact that few urbanization activities have taken place nearby (Lewitus et al. 2004, White et al. 2004). As such, it is unlikely that most of the phytoplankton blooms in North Inlet are caused by nutrient runoff from terrestrial sources (Paerl 2006).

Primary production in estuarine environments has been shown to be influenced by a variety of factors. These factors can biotic, which include primary consumers, or abiotic, such as river flow, water temperature, and salinity (Alpine and Cloern 1992, Mallin and Paerl 1994). There is some debate as to how primary production is quantitatively affected by the interaction of predator "top-down" and environmental "bottom-up" controls, but both do play a role in phytoplankton abundance (Alpine and Cloern 1992, Lewitus et al. 1998, Griffin et al. 2001, Posey et al. 2002). A study in San Francisco Bay found that phytoplankton biomass was inversely proportional to average monthly river flow, which indicated that phytoplankton abundance was in fact affected by abiotic controls (Alpine and Cloern 1992). In years where an exotic species of bivalve, *Potamocorbula amurensis*, were more common in the bay, phytoplankton biomass remained low (Alpine and Cloern 1992). This occurred even when water conditions were favorable for blooms, which indicated that biotic controls also play a role (Alpine and Cloern 1992).

It has been argued that grazing by zooplankton is the leading factor contributing to changes in phytoplankton abundance, but grazing rates themselves fluctuate depending on variables such as the season and the dominant zooplankton taxa in the area (Mallin and Paerl 1994, Lewitus et al. 1998, Griffin et al. 2001). Zooplankton grazing on phytoplankton in North Inlet has been documented to produce the most dramatic changes in chlorophyll *a* concentrations during the summer. In the winter, grazing becomes somewhat less prevalent and nutrient concentrations play a larger role in the chlorophyll *a* concentrations during this time of year (Lewitus et al. 1998). The rates of zooplankton grazing have been used to estimate planktonic trophic transfer in a North Carolina estuary, which was between 38 and 45% (Mallin and Paerl 1994). Nutrients added into the water column usually promote primary production rather than inhibiting it (Lewitus et al. 1998). Animals, including zooplankton and fish, provide nutrients to the water most directly through excretion. It is these nutrients, particularly ammonium, that are taken up by algae and bacteria, which could in turn affect the amount of primary production in the water (Haertel-Borer et al. 2004). North Inlet is no exception, as nekton have been found to be major sources of ammonium and inorganic nutrients, with excretion being the primary method of nutrient release into the water column (Haertel-Borer et al. 2004). All of these factors control the lower end of the North Inlet estuarine food web, which could subsequently affect the higher end of the web as well.

The top of this food web is dominated by bottlenose dolphins (*Tursiops truncatus*), which have been estimated to occupy a trophic level between 4 and 4.5 (Young and Phillips 2002). North Inlet is within the home range of many resident, inshore dolphins, which tend to remain in or around the estuary (Gubbins 2002).

Detritivores and tertiary consumers such as croaker, sea trout, weakfish, spot, silver perch, mullet, pinfish, herring, and menhaden serve as the primary prey for bottlenose dolphins in North Inlet and along the southeastern coast of the United States in general (Young and Phillips 2002, Barros and Wells 1998). Studies analyzing dolphin stomach contents have been able to correlate dolphin prey with dolphin habitat use. It was through this methodology that dolphins in Sarasota Bay, Florida were confirmed to frequent the shallow bays and seagrass forests during spring and summer, and then travel farther off the Gulf Coast during the fall and winter months (Barros and Wells 1998). In North Inlet, bottlenose dolphins have been known to use the shallower, more landward creeks most often in the summer, possibly because of a higher diversity of fish during the warmer parts of the year (Young and Phillips 2002). It still contains several potential prey species during the winter, most of which stay in the estuary all year (Young and Phillips 2002). Primary production estimates of a previous study, using a net trophic transfer efficiency between 10 and 20% in the North Inlet Estuary, yielded percentages between 0.5% and 1.1% of the total primary production that would be required to support each dolphin in the estuary (Young and Phillips 2002). Since primary production was known to decrease over the winter months, this transfer efficiency estimate was expected to increase during this time period (Young and Phillips 2002). Over the winter, it was assumed that primary productivity would decrease by half and the number of dolphins would stay constant, as indicated by the preliminary field studies, and the corresponding trophic transfer efficiency increased to between 7.3% and 40.4% (Young and Phillips 2002).

Jones Creek, an intertidal creek that connects North Inlet and Winyah Bay (Fig. 1 and 2), is the site of a stable, observable chlorophyll *a* maximum around the midpoint of the creek near Noble Slough at low tide (Koepfler, unpub.). This maximum may be partially due to the fact that Jones contains at least one "nodal point" where little water is exchanged between both ends of the creek (Schwing and Kjerfve 1980). These points can move up and down the creek with time, but they seem to congregate in the portion of Jones south of Noble Slough and north of Winyah Bay (Schwing and Kjerfve 1980). There are likely numerous other factors behind the chlorophyll *a* maximum but regardless of the reason, these stable chlorophyll *a* concentrations offer a unique opportunity to observe the North Inlet estuarine food web from start to finish, using the extreme ends of the web as indicators.

It was hypothesized that higher chlorophyll *a* concentrations throughout the creek will make prey more readily available for the dolphins, as fish will congregate in these productive areas to feed upon the zooplankton that consume the phytoplankton. As such, a higher abundance of dolphins and fish should be seen in these areas where the chlorophyll *a* concentrations are the highest. This study was aimed at looking at this chlorophyll *a* maximum over the short-term and how this unique feature affected the entire estuarine ecosystem from the perspective of a food web. If the chlorophyll *a* maximum at the northernmost part of Jones Creek where it intersects with North Inlet stays relatively constant, dolphin feeding behavior and dolphin and fish abundance should also exhibit a similar, constant pattern.

MATERIALS AND METHODS

Chlorophyll *a* concentrations and zooplankton densities

Seven boat trips to Jones Creek were conducted between late September and early November in 2008, where special attention was directed towards the date and time of each data collection, so that corresponding tidal information could be documented. This information was taken from the National Oceanic and Atmospheric Administration's (NOAA) "Tides and Currents" website, where the tidal predictions for Clambank Creek, Goat Island, North Inlet were used to time each field day such that data collection would center around low tide, when the chlorophyll *a* maximum was thought to occur. This information was compared to the chlorophyll *a* concentrations in the water, which were measured by obtaining 50 ml triplicate water samples and later analyzing them in the laboratory with a fluorimeter, the primary method for determining the amount of phytoplankton in seawater (American Public Health Association 1998). Weather and water conditions were also recorded on every day of data collection.

The water samples to be used for chlorophyll *a* measurements were collected at five locations/stations along the entire length of Jones Creek, with Station 1 being situated closest to North Inlet, and Station 5 being closest to Winyah Bay (Fig. 3). Station 3 was situated at the mouth of Noble Slough, where the chlorophyll α concentrations were thought to be the highest at low tide, based on the numbers from the chlorophyll *a* study in the spring of 2003 (Fig. 3). A zooplankton net with a 330 μm mesh was then towed behind the boat for five minutes and rinsed down with water to collect any trapped zooplankton into a sieve with a mesh size of 63 μm. The organisms were finally transferred into formalin jars, one jar for every station, which had been previously treated with Borax to bring the pH of the formalin to around 7. The zooplankton net was equipped with a model 2030 mechanical flowmeter, which attached to the mouth of the net and used to determine the relative amounts of water that were filtered at each station. These procedures were repeated two more times for every field day, with the intention of collecting samples two hours prior to high slack tide, right at high slack tide, and two hours after high slack tide.

A variation of the method of analyzing the chlorophyll *a* samples outlined in Clesceri et al. 1998 was used in this study, which involved filtering the samples under ½ atmospheric pressure, transferring the filters to 15-ml centrifuge tubes filled with 1 ml of $MgCO_3$, and then storing the filters in the freezer for around 40 to 60 days. After this time period had elapsed, 9 ml of 90% acetone were added to each centrifuge tube, which were then stored in the refrigerator. After 24 hours, the tubes were shaken vigorously for around five seconds, before being stored in the refrigerator for another 24 hours. Afterwards, a small amount of sample from each centrifuge tube was transferred into a fluorimeter cuvette, placed into a Turner Fluorimeter, and the fluorescence of the samples was subsequently recorded.

Once the formalin was filtered out and replaced by freshwater in each zooplankton jar, a Folsom plankton splitter was used to take subsamples of every jar, which were then examined under a microscope. All zooplankton present in the subsamples were identified and counted by using the equation:

$$N = 2^n \qquad (1)$$

where N is the number of particular planktonic organisms present in the sample, and n is the number of times the original sample was divided by the plankton splitter. Guidelines and drawings used in classifying the plankton were taken from Johnson and Allen 2005.

Dolphin surveys

Dolphin counts were conducted all throughout Jones Creek, including areas where water samples were not collected. If any dolphins were located, careful observations of their behavior were made, particularly whether or not they appeared to be feeding. The methods and criteria of Barros & Wells (1998) were used in classifying these various behaviors. Feeding behavior was recorded by observing dolphins either visibly holding one or more fish in their mouths or fish exiting the water with one or more dolphins in pursuit. The location of each observational survey was documented using GPS and its location relative to the closest station where the water samples were collected, and dorsal fin photographs of every individual dolphin were taken as a means of identification. These photographs were compared with the University of South Carolina Baruch Marine Field Lab's running database of bottlenose dolphin photographs taken in and around North Inlet over the years.

Great caution was taken to stay as far away from the dolphins as possible, yet close enough to observe their behavior. In a study done by Gannon et al. (2005), bottlenose dolphins in Sarasota Bay, Florida were found to hunt using passive listening, a technique where dolphins listen for the vocalizations of target fish species. An explanation for the use of passive listening over echolocation could be that echolocation is energetically costly and may also give away the dolphins' positions to their prey, thus losing the element of surprise (Gannon et al. 2005). If the same is true for dolphins in North Inlet, the boat engine would have had to have been used as little as possible, so as not to mask the underwater sounds of fish and thus possibly prevent the dolphins from feeding. The waters of North Inlet are rather turbid, especially in productive areas, so the dolphins may be forced to rely on this technique of passive listening rather heavily, if they do in fact use passive listening more often than echolocation.

Data analysis

Chlorophyll *a* concentrations and zooplankton densities at every station were plotted against tidal stage to examine any temporal changes in these two variables. Zooplankton was plotted against chlorophyll *a* for every tidal stage that was sampled on each sampling date, to determine if there was any correlation between them at any time during the study. All of the data was then pooled together and plotted, to see if there was an overall trend between zooplankton and phytoplankton.

For spatial comparison, the GPS coordinates of each station and dolphin sighting were plotted in a GIS, which was then used to generate a density plot of the sightings, to determine where dolphins were sighted most often. Aerial photographs of North Inlet were provided by a 1994 survey conducted by the USDA. Spreadsheets containing coordinates of dolphin sightings from surveys that were conducted in North Inlet over the course of the year from 1999 to 2003 were written to the GIS and density plots were constructed to compare amongst our own data. The historical data was organized according to year, season, and tidal stage, the latter of which was separated into low tide and all other tides grouped together, for which a set of 33 density plots was generated. The second set of eight plots was constructed from pooling all the seasonal data together, regardless of year, and organizing those data by tidal stage.

RESULTS

Salinity and temperature

Salinity was almost always greatest at Station 1, around 30 psu, always lowest at Station 5, around 10 psu, and had the tendency to decrease from North Jones to South Jones. Surface water temperatures remained relatively constant across all five stations.

Chlorophyll *a* concentrations

Chlorophyll *a* concentrations tended to increase at low tide and decrease during flood tide at all five stations over the course of the study (Fig. 4). These concentrations were not highest at station 3, as predicted, but near stations 4 and 5 (Fig. 4). The highest concentrations were observed at the earliest sampling date, while the lowest concentrations were noted on the last day of the study.

Zooplankton identification and quantification

A total of 18 zooplankton taxa were identified, with copepods and crab zoea being the most common, but copepods outnumbered crabs around 2.5 to 1 overall (Table 1). There was no clear trend in zooplankton density with respect to tidal cycle, sampling date, or chlorophyll *a* concentration (Fig. 5). Even though there was a weak, but negative relationship between zooplankton and chlorophyll *a* in all but two of the regression graphs that were generated for each station on every sampling day (Fig. 6, 7, 8, and 9), no relationship was found between the two variables when all the data was pooled onto one graph, to determine if any general trends existed for all of the obtained data ($R^2 = 0.0072$, Fig. 10).

Dolphin surveys

Dolphins were seen throughout North Inlet but they were most commonly found in Jones Creek near station 3, at the mouth of Noble Slough, around low tide (Fig. 11). The historical surveys have shown similar results in the fall months, but they differ from our findings because they show the greatest dolphin densities as being located in Town Creek at low tide during this time of year (Fig. 12). In addition, the historical data shows that during the warmer months, dolphins cluster around an area adjacent to station 3, and several areas in Town Creek, but during the colder months, they tend to congregate in areas closer to the mouth of the inlet regardless of tidal stage (Fig. 12).

DISCUSSION

North Inlet Estuary in South Carolina is a productive body of water that is known to contain a chlorophyll *a* maximum at low tide in one of its major tidal creeks, Jones Creek. This study examined the effects of this maximum on the estuarine food web by examining the concentrations and distributions of organisms on different trophic levels, including phytoplankton, zooplankton, and bottlenose dolphins. It was assumed that as phytoplankton, and therefore chlorophyll *a* concentrations increased, zooplankton densities would also increase as these organisms congregated to feed on the phytoplankton. We also expected dolphins to gather in these areas to feed on the large numbers of fish that had moved in to feed on the zooplankton. However, our data indicated that the relationship between trophic levels of the estuarine food web is not as simple as we expected.

Salinity was measured to determine the strength of the salinity gradient from northern Jones Creek to southern Jones Creek. Station 1 was more directly exposed to the waters of the Atlantic than any of the other stations, and therefore had the highest salinity of all the stations, while Station 5 was closest to Mud Bay, an area of lower salinity. Therefore, the salinity values were not surprising due to the spatial arrangement of the sample collection stations.

To confirm the presence of a chlorophyll *a* maximum near Station 3 in Jones Creek at low tide, chlorophyll *a* concentrations were determined from surface water samples taken at each station. The chlorophyll *a* concentrations at Station 3 increased around low tide as expected. However, unexpected peaks were seen at Stations 4 and 5 and could be explained by a potential influx of phytoplankton into southern Jones Creek from Clambank Creek. This is an intertidal creek that empties into Jones near these two stations. The nodal point that is thought to exist in this part of Jones may be an additional reason for the chlorophyll *a* maximum that was seen in this part of the creek. Plankton can collect and become concentrated within this area of little water exchange between Jones Creek and Mud Bay during tidal shifts, although these points are typically thought to exist near the creek bed (Schwing and Kjerfve 1980). Our water samples were taken from the surface, so this nodal point may have been too deep for us to sample, but because of the creek's shallow depth, especially at low tide, we may have inadvertently been able to collect plankton that had been harbored in this area.

The zooplankton tows allowed us to determine the zooplankton densities at each sampling station in Jones Creek. These densities were expected to correlate directly with the chlorophyll *a* concentrations throughout Jones Creek, but no correlation was found to exist. The absence of a clear relationship between chlorophyll *a* and zooplankton density, spatially and temporally, may be due to nutrients, rather than zooplankton grazing, playing a larger role in phytoplankton concentration in the estuary (Lewitus et al. 1998). Our study was conducted in the fall, when fewer organisms, including plankton, are present in the estuary during the colder parts of the year. This would explain the declining chlorophyll *a* concentrations that were observed as the study progressed, but would not explain the fluctuating zooplankton densities with time. An alternative explanation for these fluctuations could be diel vertical migration of zooplankton, since all zooplankton tows were taken just below the surface. Zooplankton may remain lower in the water column during the day and move closer to the surface as nighttime approaches (Barans et al. 1997). This may function as a means of avoiding predators (Barans et. Al 1997). However, almost all of our tows were taken during the mid-day hours. In order to rectify this anomaly in the future, samples should be taken at night, as well as other times, to test this possibility.

Bottlenose dolphin surveys were conducted to ascertain if dolphins clustered around areas with large chlorophyll *a* concentrations to search for prey that had gathered to feed in the same area. Bottlenose dolphins were most commonly seen around Station 3, as was hypothesized. However, our study was biased towards spotting dolphins in Jones because we spent most of our time in this creek, since we were primarily concerned with dolphin distribution in Jones Creek alone. We seldom penetrated many of the minor creek systems because our sample collections were centered around low tide, when the water was shallower. Historical surveys have shown that if dolphins were present in Jones, they tended to cluster around the location of Station 3 at both high and low tide. The historical data has additionally shown that areas of higher dolphin densities outside of Jones were somewhat consistent throughout the year, including an area at the mouth of Town Creek. This might indicate the presence of other chlorophyll *a* maximums or nodal points in other parts of the inlet. However, dolphins rarely clustered around the chlorophyll *a* maximum near Stations 4 and 5. These conflicting observations suggest that dolphins search everywhere for food since they have the freedom to move around the entire inlet, except during extremely low tides.

A number of constraints were present in our study, including limited samples and the absence of fish counts. Future studies will need to be conducted over the course of at least a year in order to obtain a larger sample size over multiple seasons. We had only five successful days of data collection out of the seven days that were organized. We had no concrete method of carrying out fish counts, but it should be completed. This would help to complete our examination of the estuarine food web, since we examined most of the trophic levels except for the secondary and tertiary consumers (Young and Phillips 2002). It is reasonable to assume that if dolphins are seen, then there are fish in the area, but data describing the number of fish in a particular place give this supposition more validity. Although the historical data covered most of the inlet, some months in certain years did not have enough data to allow any conclusions to be made from them, which was the reasoning behind combining all of the seasonal data and then separating them into the tidal stages during which they were collected. In the future, dolphin surveys need to be run along established boat routes to ensure that an equal amount of time is spent looking for dolphins in every part of the estuary. Future studies may also want to consider searching for the presence of other nodal points and chlorophyll *a* maximums in other tidal creeks in the inlet, to determine if current, higher dolphin densities, as well as those seen in the historic surveys, coincide with these points. This would support the notion that dolphin distribution is influenced by chlorophyll *a* concentrations.

CONCLUSION

There is not a definite relationship between intermediate trophic levels in terms of organism abundance within the North Inlet estuary during the fall, possibly due to the movement of organisms out of the estuary during this time of year. However, these organisms do not include dolphins, as historical surveys indicate they stay in or around the estuary during the fall and winter, although the highest dolphin densities tend to be in areas that are more seaward than the areas that see the highest densities during the warmer months. Furthermore, our study and past sightings indicate that dolphins may congregate around the chlorophyll *a* maximum at low tide in Jones Creek as a result of an increased supply of prey items, but this contradicts the indistinct relationship among organisms in lower trophic levels, an observation for which future studies are needed to confirm.

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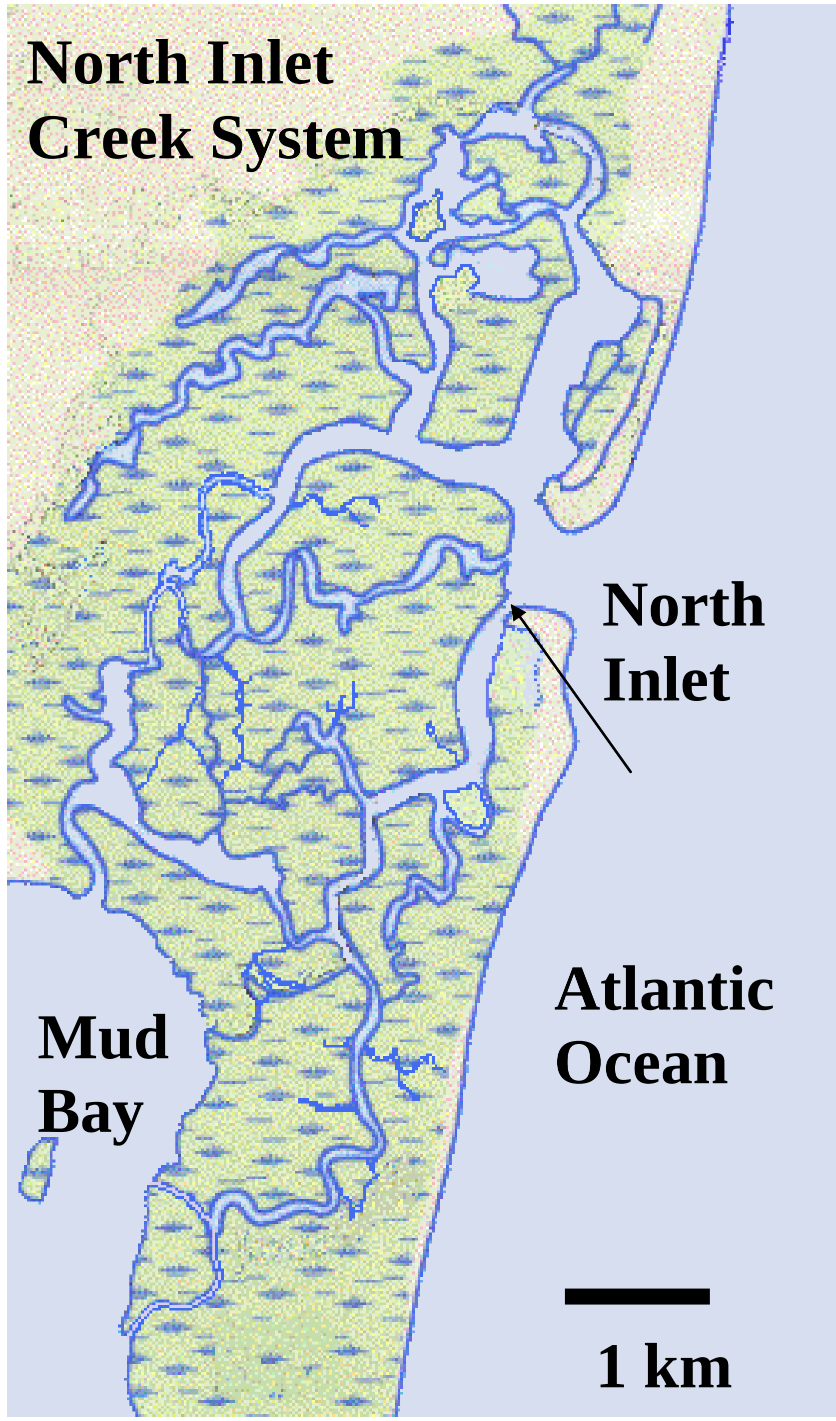


Figure 1: Map of North Inlet, with the seaward mouth of Jones Creek indicated by the arrow.

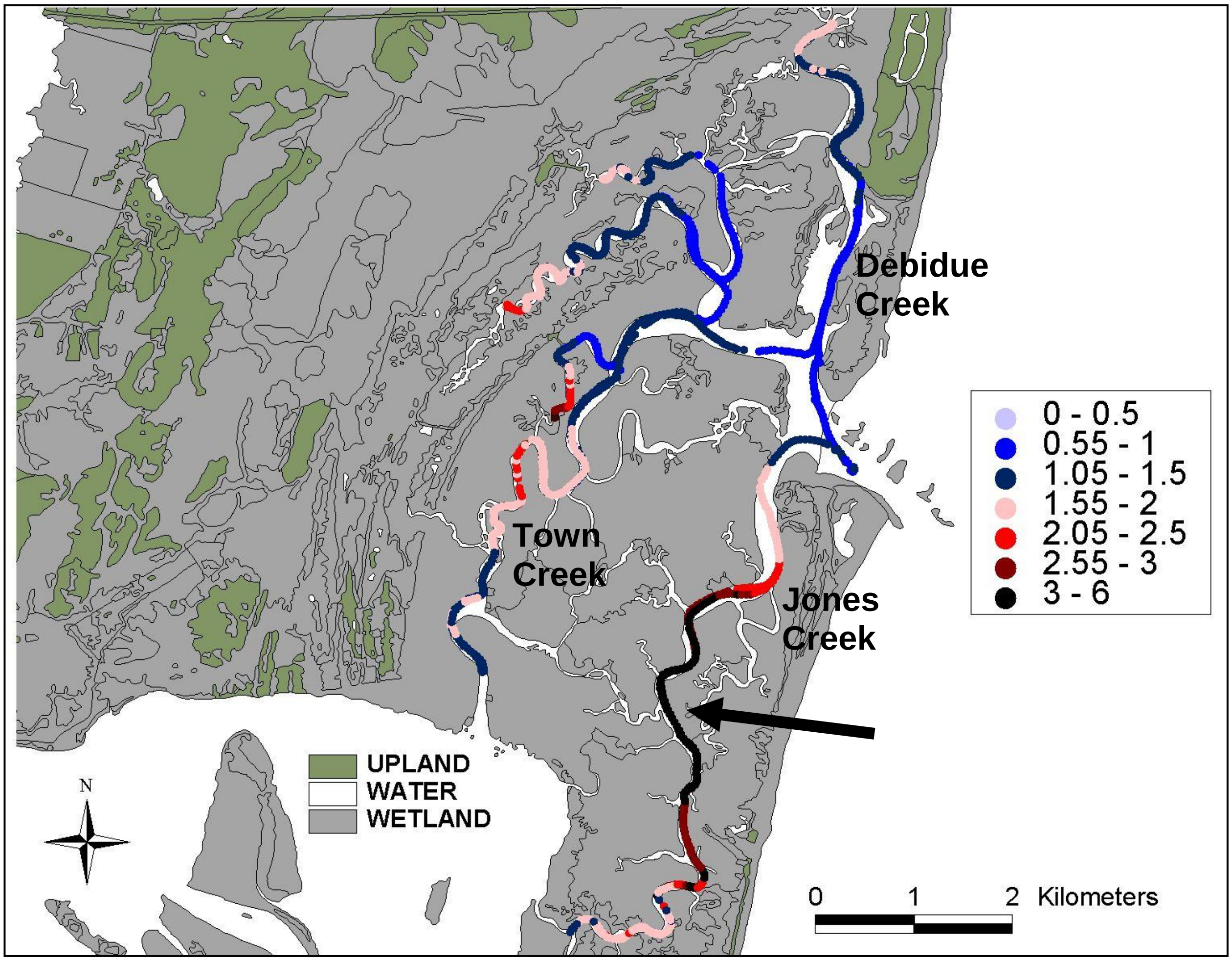


Figure 2: Chlorophyll α concentration study conducted at low tide in April 2003 within North Inlet. The arrow indicates the observed chlorophyll *a* maximum in Jones Creek, where station 3 was located (Koepfler, unpub.).

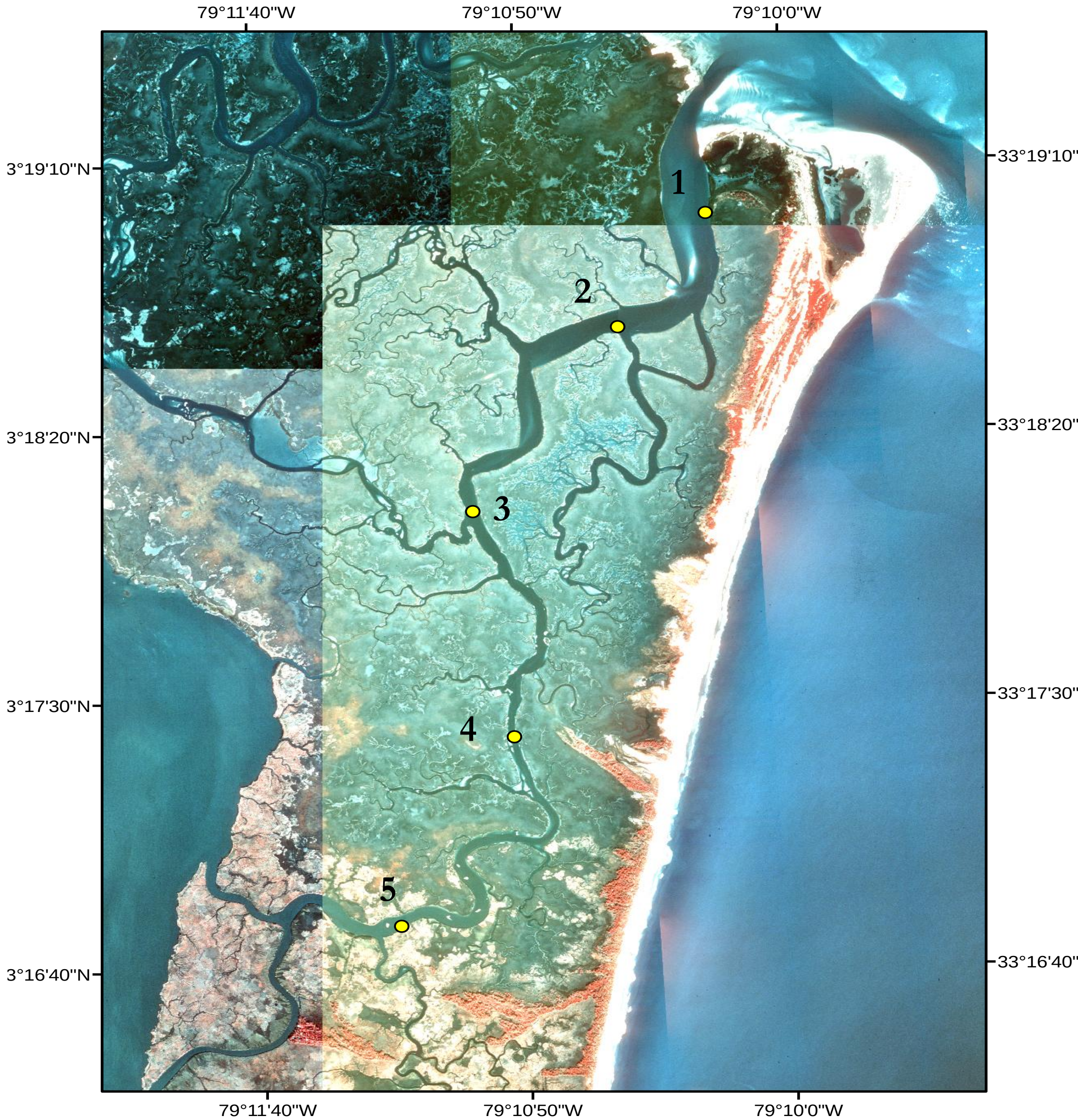


Figure 3: Jones Creek with sampling station locations. Station 3 is located where the chlorophyll *a* maximum is thought to exist at low tide.

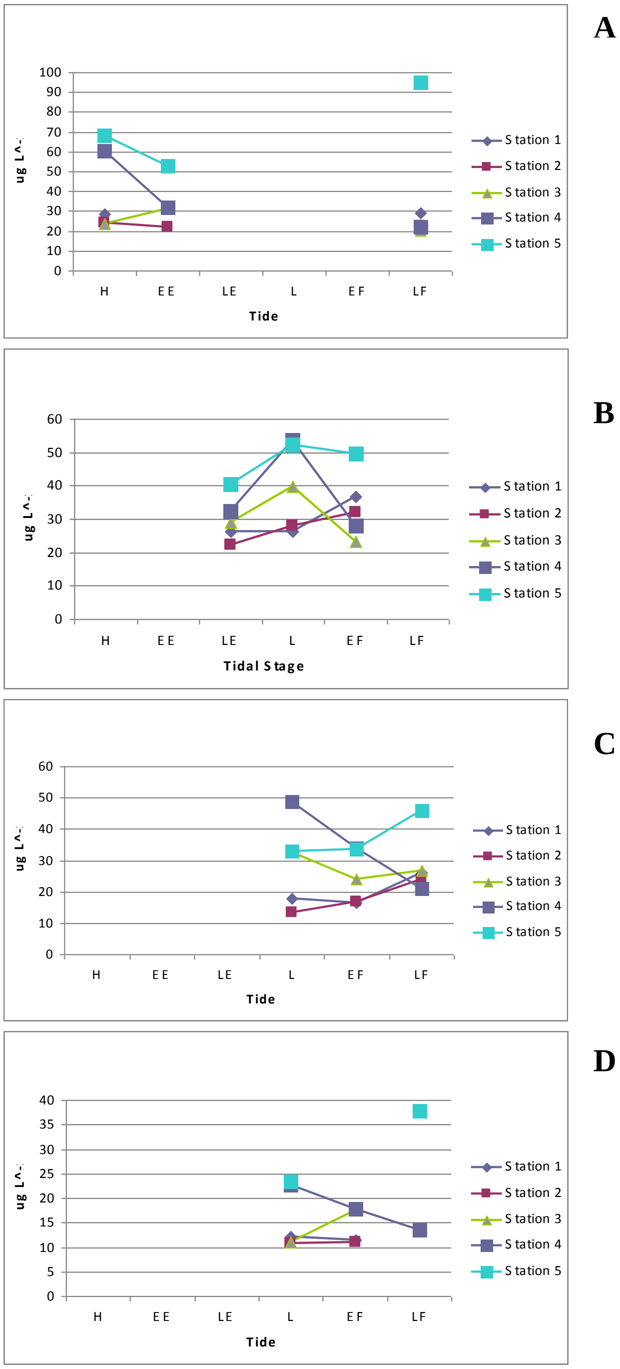


Figure 4: Chlorophyll *a* concentrations (μg L^{-1}) for (A) 10/4/08, (B) 10/11/08, (C) 10/26/08, and (D) 11/8/08 relative to tidal stage, where H = high, EE = early ebb, LE = late ebb, L = low, EF = early flood, and LF = late flood.

Table 1: Total abundances of all zooplankton taxa identified in the 90 samples collected from the zooplankton tows.

Organism	Abundance[α]
Copepods	39716
Crab Zoea	15612
Shrimp Larvae	1424
Zoothamnium	1148
Cladocerans	1052
Barnacle Larvae	1012
Hydrozoans	592
Molluscan Larvae	512
Globigerina bulloides	428
Polychaetes	420
Isopods	180
Amphipods	112
Myrionecta rubra	104
Jellyfish Larvae	40
Tintinnopsis	16
Paranassula microstoma	16
Mites	8
Cumacean	4

[α]**Calculated using Eq. (1).**

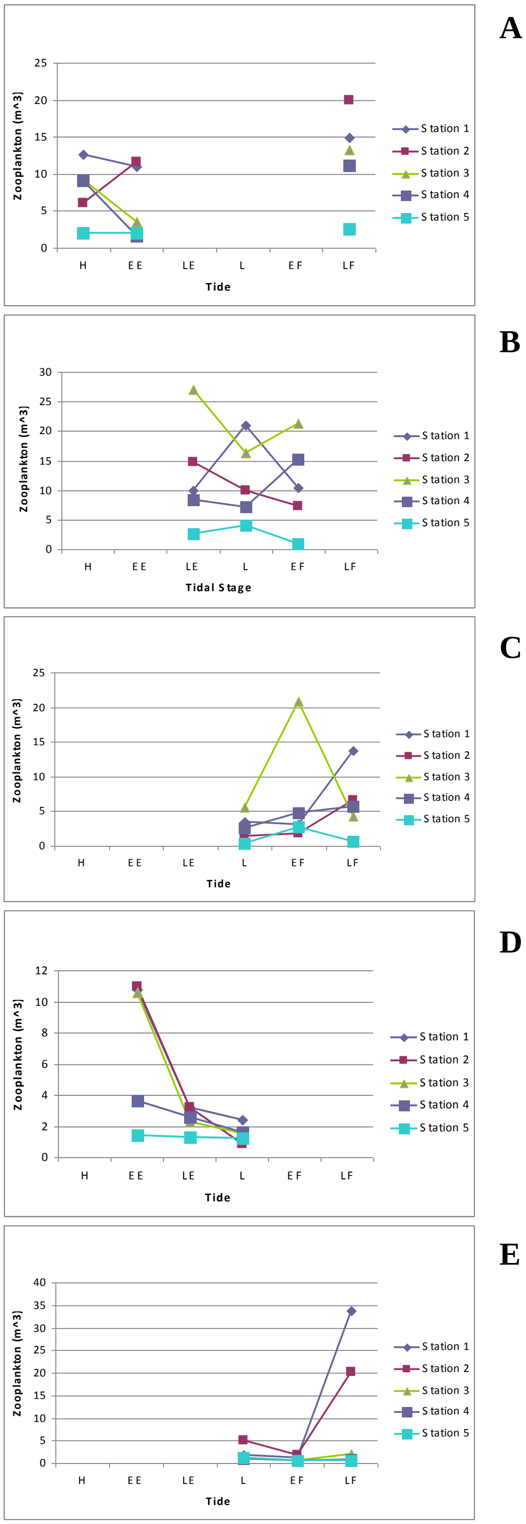


Figure 5: Zooplankton densities (organisms $(m^3)^{-1}$) for (A) 10/4/08, (B) 10/11/08, (C) 10/26/08, (D) 11/1/08, and (E) 11/8/08 relative to tidal stage, where H = high, EE = early ebb, LE = late ebb, L = low, EF = early flood, and LF = late flood.

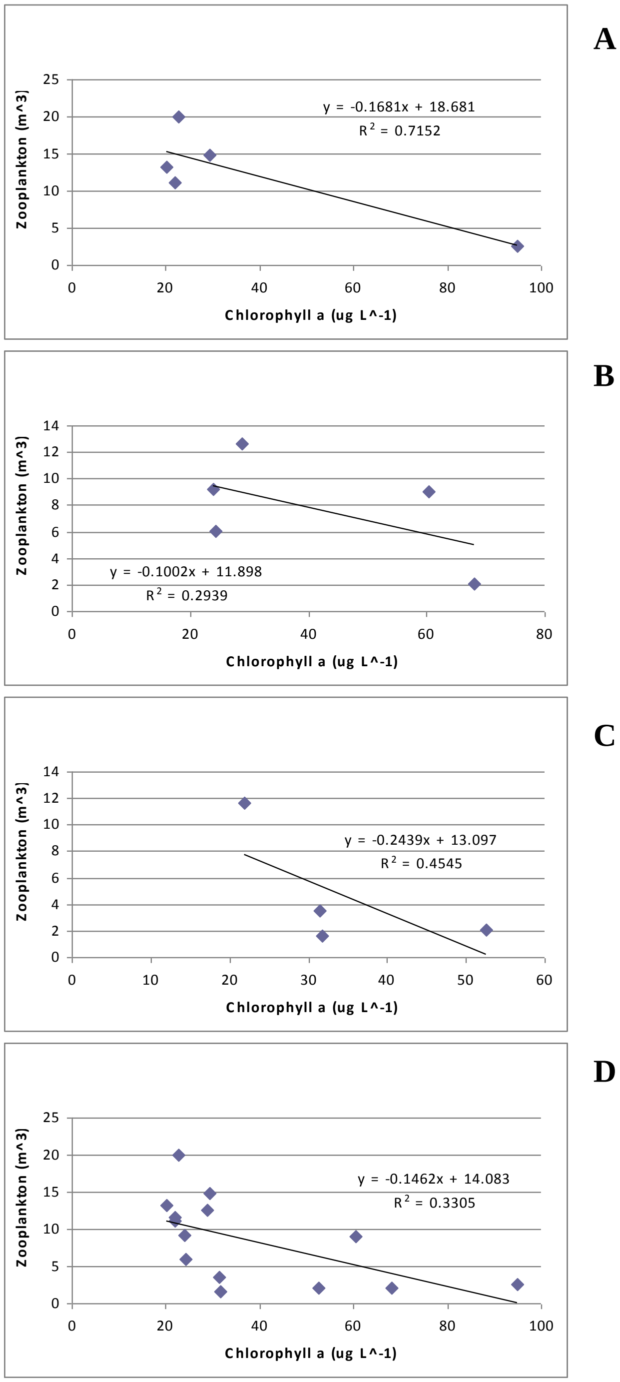


Figure 6: Zooplankton densities (organisms $(m^3)^{-1}$) and chlorophyll *a* concentrations for 10/4/08 during (A) late flood, (B) high tide, and (C) early ebb as well as (D) 10/4/08 overall.

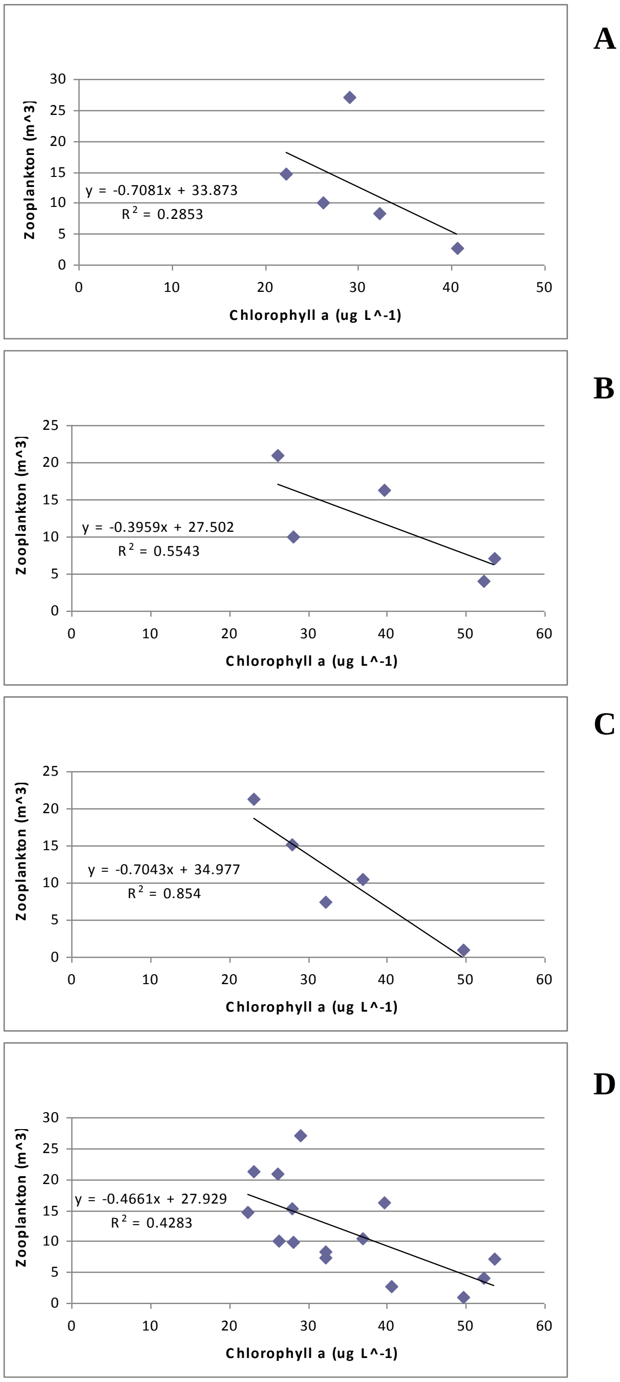
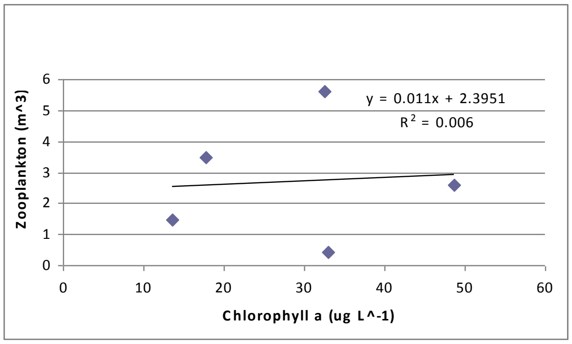
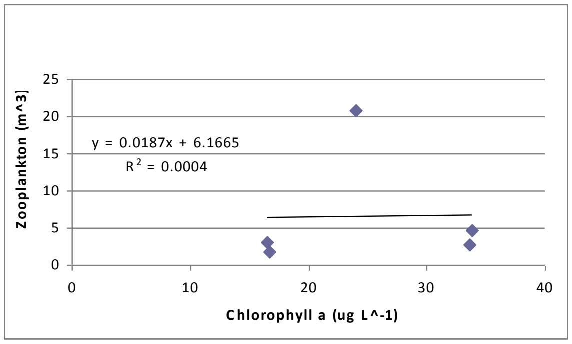


Figure 7: Zooplankton densities (organisms $(m^3)^{-1}$) and chlorophyll *a* concentrations for 10/11/08 during (A) late ebb, (B) low tide, and (C) early flood as well as (D) 10/11/08 overall.

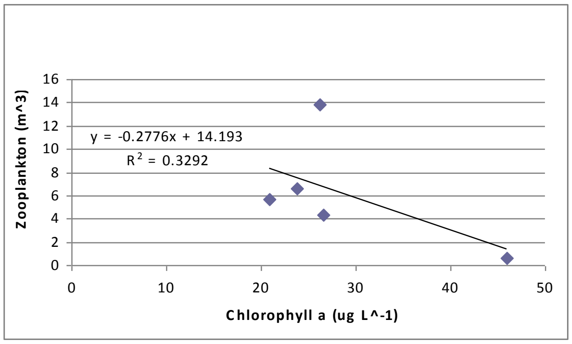
A



B



C



D

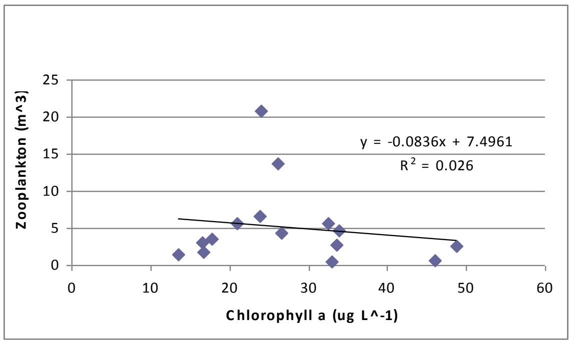


Figure 8: Zooplankton densities (organisms $(m^3)^{-1}$) and chlorophyll *a* concentrations for 10/26/08 during (A) low tide, (B) early flood, and (C) late flood as well as (D) 10/26/08 overall.

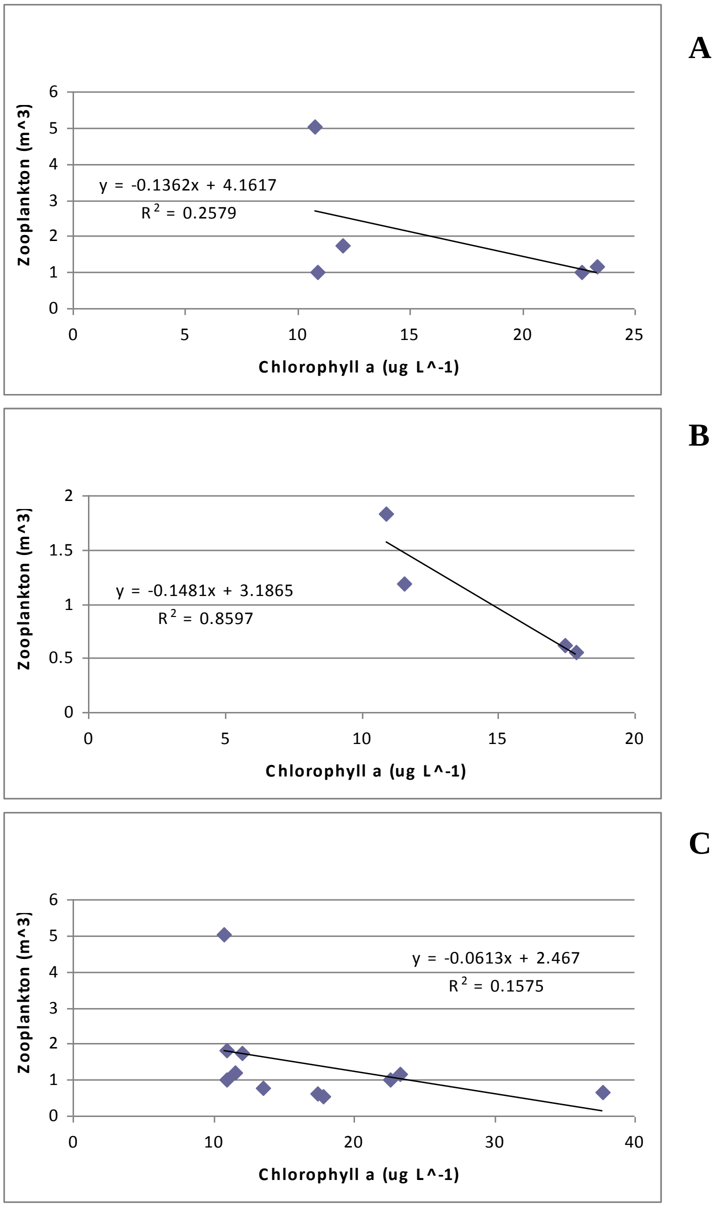


Figure 9: Zooplankton densities (organisms $(m^3)^{-1}$) and chlorophyll *a* concentrations for 11/8/08 during (A) low tide and (B) early flood, as well as (C) 11/8/08 overall.

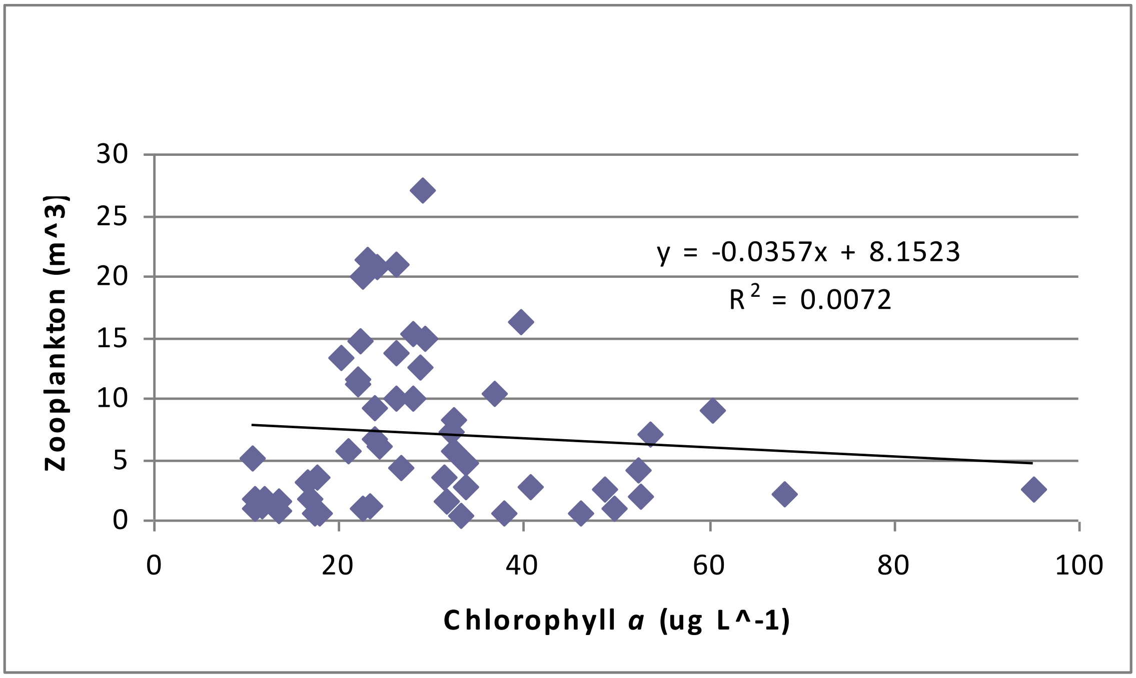


Figure 10: Zooplankton densities (organisms $(m^3)^{-1}$) and chlorophyll *a* concentrations for all sampling days.

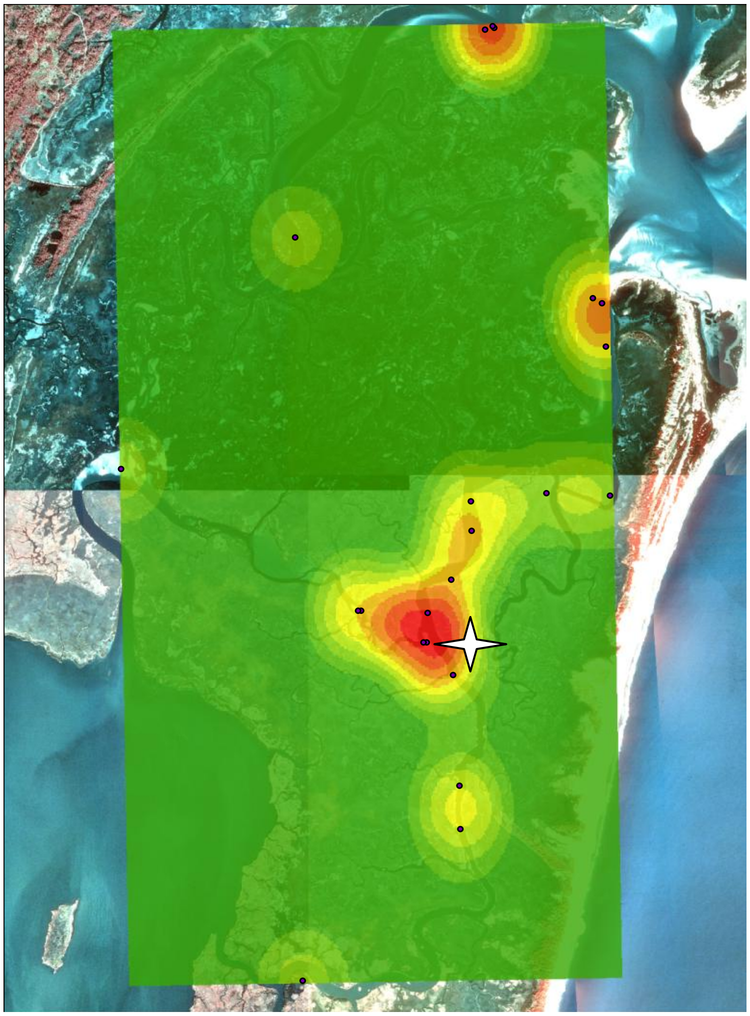
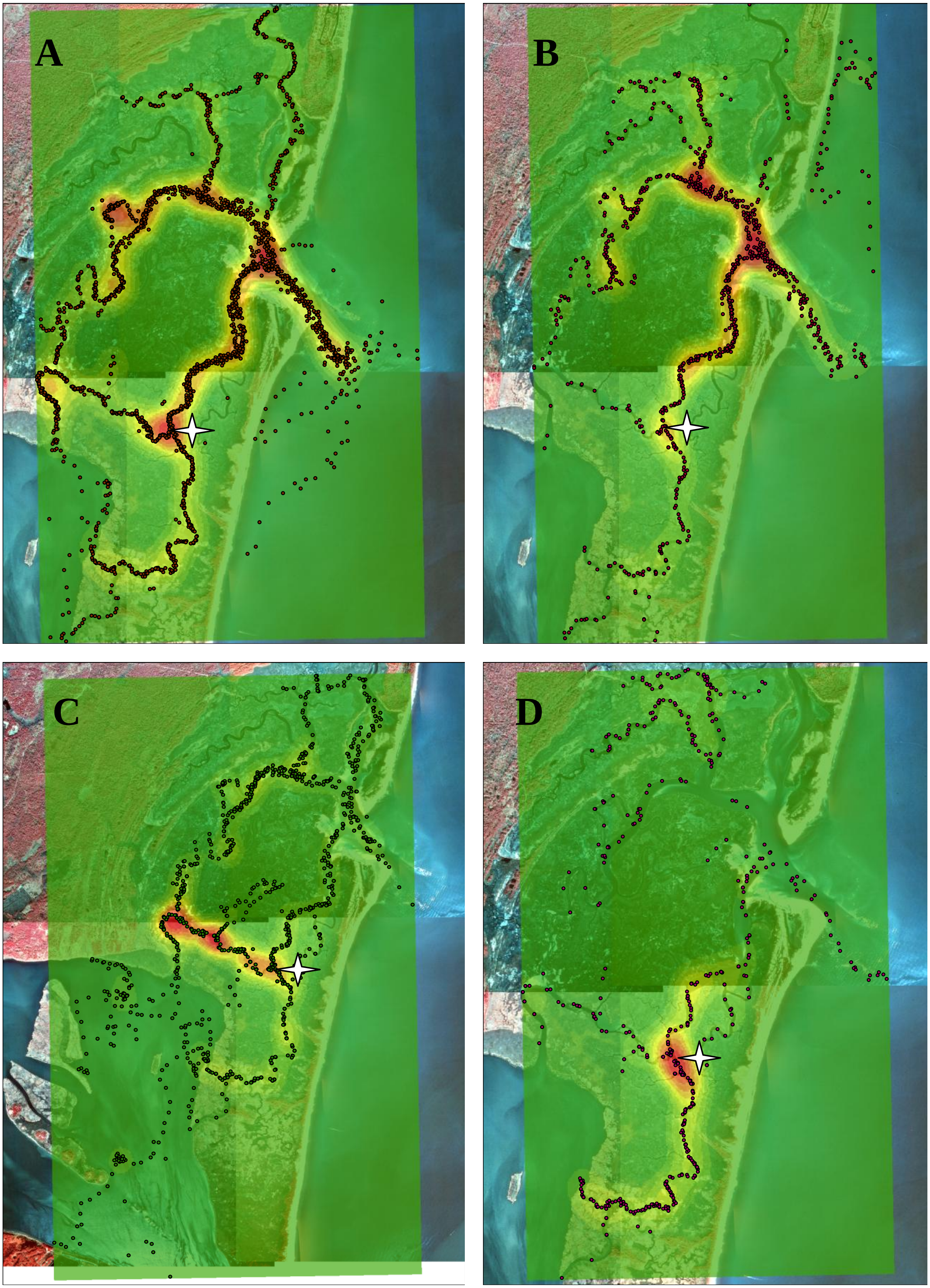


Figure 11: GIS density plot of dolphin sightings from September through November of 2008. The star indicates the area of predicted chlorophyll *a* maximum at low tide.


A
B
C
D

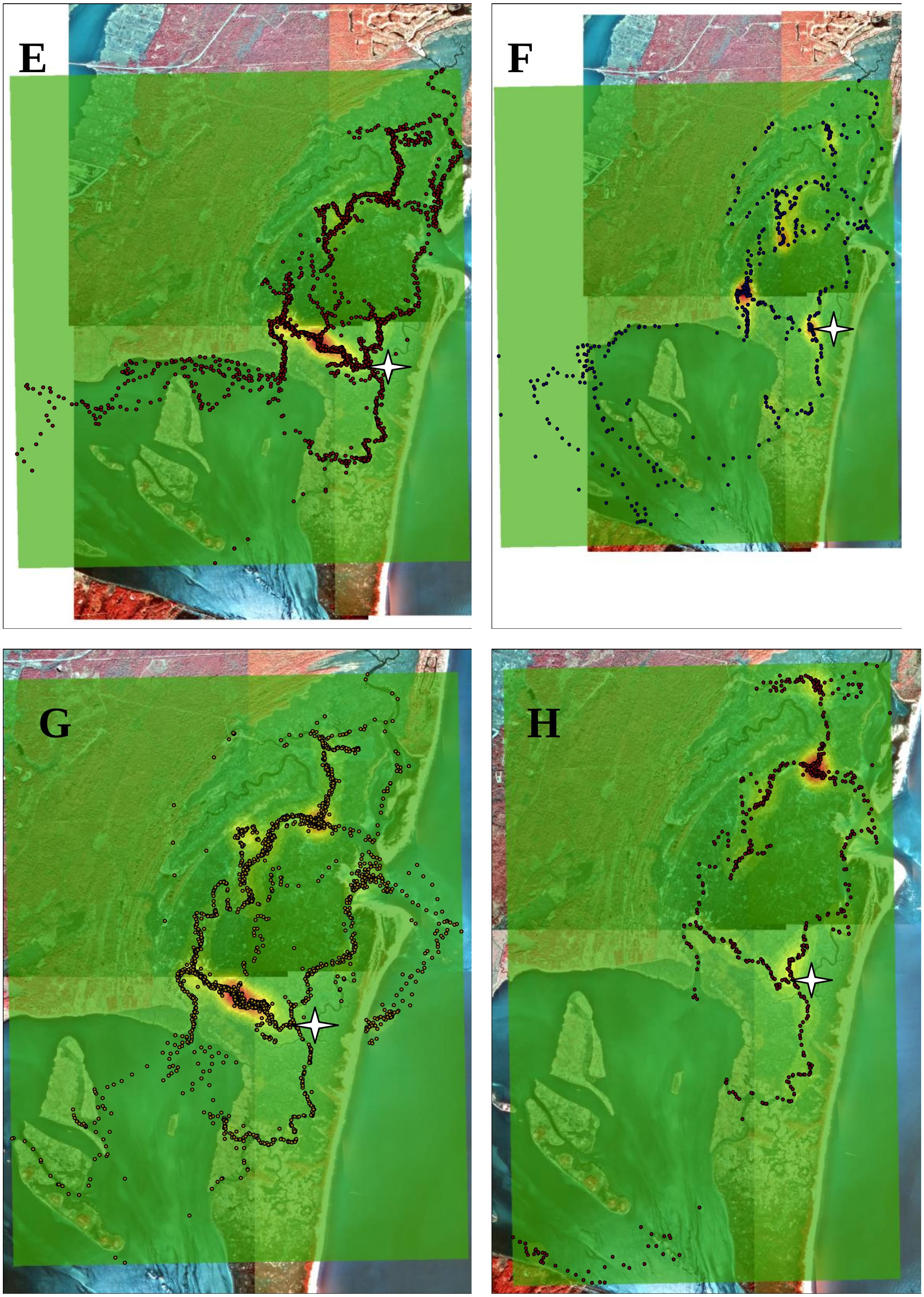


Figure 12: GIS density plots of dolphin sightings from 1999 to 2003 (A) in winter excluding low tide, (B) winter at low tide, (C) spring excluding low tide, (D) spring at low tide, (E) summer excluding low tide, (F) summer at low tide, (G) fall excluding low tide, and (H) fall at low tide. The stars indicate the area of predicted chlorophyll *a* maximums at low tide.