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**The effect of a phytoplankton maximum on the trophic food chain of the bottlenose
dolphin (*Tursiops truncatus*) in North Inlet, South Carolina.**

By

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ABSTRACT

Jones Creek, part of North Inlet-Winyah Bay, South Carolina, is known to have a chlorophyll *a* maximum that exists during low tide. The goal of this study was to determine if an increase in phytoplankton, demonstrated by chlorophyll *a* levels, would lead to an increase in zooplankton, fish, and bottlenose dolphins in the area. Sampling for chlorophyll *a* concentrations, zooplankton and dolphin densities occurred in fall of 2008. Based on the samples obtained, as chlorophyll *a* concentrations increased at low tide, zooplankton densities decreased. Dolphin density plots showed an increased density in Jones Creek during low tide for spring, summer, and winter seasons. While the hypothesis was not supported, it is suspected that chlorophyll *a* levels affect bottlenose dolphin distribution. Future studies should include sampling in surrounding tidal creeks to determine the any input these waters play on Jones Creek, as well as sampling during other seasons.

INTRODUCTION

North Inlet-Winyah Bay is a 4856 hectare area of marsh and wetlands located north of Charleston in South Carolina (Fig. 1). The North Inlet portion of Winyah Bay is a highly saline (due to minimal freshwater input), well mixed estuary that intersects a *Spartina alterniflora* salt marsh. North Inlet is known to have a regular semi-diurnal tide with a neap range of 0.9m and a spring tidal range of 2.5m (Uncles & Kjerfve 1986).

The residence time for this area is around fifteen hours. This study focused on Jones Creek, one of the many meandering creeks that connect the North Inlet to Winyah Bay (Gardner et. al. 1989).

As chlorophyll *a* is a structural component of photosynthetic organisms, chlorophyll *a* concentrations can be used to estimate the amount of primary production (mainly phytoplankton) in a given area. This in turn gives a basis for understanding the levels of primary production which results from the conversion of carbon dioxide to organic carbon molecules. If chlorophyll *a* concentrations are high, primary production is abundant and vice versa. It is known that photosynthesis varies with the tides and the correlation with chlorophyll *a* levels is accurate enough to use a measure of primary production (Williams & Murdoch 1966).

Previous studies in Nova Scotia revealed that chlorophyll *a* maximums occur with changing tides, but are not known to be caused by internal waves or to have any correlation with temperature (Denman 1977). Concentrations of chlorophyll *a* seem to be lower during the ebb tides and vary by month as well as tides (Huang et. al. 2002). The chlorophyll *a* concentrations may vary but in many cases do not decrease to levels in which life is not sustainable.

During the low tide in Jones Creek, chlorophyll *a* levels increase to a maximum level. This has been the focus of many previous studies and forms the basis of this one (Koepfler unpub.). Maximal chlorophyll *a* levels would indicate maximal nutrient availability at the lowest trophic level. The question becomes - as chlorophyll *a* levels increase, what is the effect on exceedingly higher trophic levels? Studies in South

Africa have found that the density of top predators increases when the chlorophyll *a* concentration is higher (Gremillet et. al. 2008). Chlorophyll *a* levels are believed to change every time the tide changes, a twice daily occurrence. In order to get a better understanding of the local environment, research is needed to determine the effect of the frequent tidal changes on the surrounding populations of animals.

Bottlenose dolphins (*Tursiops truncatus*) are common in the coastal waters of South Carolina. They have also been observed in the tidal creeks of North Inlet, including Jones Creek. These dolphins feed on many types of fish and crustaceans. The fish that are most prevalent to the habitat of the particular dolphin are the ones usually consumed while crustaceans seemed to be consumed unintentionally (Blanco, Salomon & Raga 2001). Pinfish, spot, and menhaden are three of the most common fish year round in North Inlet (Lonsdale & Coull 1977). Conflicting results have been found on whether male and female dolphins forage on different items; however it seems the juveniles feed on the same pelagic organisms as their mothers.

The actual foraging behavior of bottlenose dolphins depends whether they normally remain in coastal areas or offshore. The coastal bottlenose dolphins are usually observed feeding close to shore and at all times during the day and night (Barros & Wells 1998). Dolphins use the entire water column to feed and may be able to sense their prey when at the surface (Hastie et. al. 2006). Since dolphins consume a wide variety of prey, they may engage in opportunistic feeding as well (Santos et. al. 2007). Previous studies on South Carolina bottlenose dolphins indicated that two populations exist; (1) a near shore, shallow, warm water ecotype and (2) an offshore, deep, cold water ecotype

(Klatsky et. al. 2007). While bottlenose dolphins have fission/fusion societies, these two populations do not mix and remain in their respective areas. The near shore dolphins were only observed in coastal areas which may be due to protection from disease and increased prey availability (Gubbins 2002). Dolphins have been known to forge in an area with a very small radius and continue to return to this same area. They have the ability to pick up cues in the water to determine the best possible location to feed (Bailey & Thompson 2006). Despite a high abundance of prey, dolphins will, however, resort to areas where forging may be more difficult in order to escape predation from animals such as sharks (Heithaus & Dill 2002).

Chlorophyll *a* maximums indirectly indicate a maximum in phytoplankton production. This produces a net concentration at all trophic levels including the amount of fish available for dolphin feeding. If more fish are present in the area, more bottlenose dolphins should travel to the area to feed. I hypothesize that the chlorophyll *a* maximum at low tide in Jones Creek is an indicator of phytoplankton productivity that will support an increase in the amount of zooplankton, invertebrates and fish, and ultimately, bottlenose dolphins which feed in the area.

METHODS

Sampling Stations and Sample Collection

All sampling took place in Jones Creek, part of Winyah Bay in North Charleston, South Carolina. Seven single day trips were taken in a small watercraft to the creek, from mid-September to mid-November in 2008. Five trips were used for sample collection at five pre-determined stations in Jones Creek. The stations were set up so that station 3

was centered in the middle of the creek, nearest the suspected point of maximum chlorophyll *a* concentration. The remaining stations stretched the length of the creek to account for input from the Atlantic Ocean and Mud Bay (Fig. 1). Each day trip was scheduled so as to come as close to low tide as possible.

Estimation of Chlorophyll *a* concentrations

Three surface water samples were collected at each location three times each day as the boat moved down the creek. The samples were filtered under $\frac{1}{2}$ atmospheric pressure. The filters were transferred to 15-ml centrifuge tubes filled with 1 ml of MgCO_3 , and then stored in the freezer. After 40 to 60 days, nine milliliters of 90% acetone were added to each centrifuge tube and stored in the refrigerator. After 24 hours, the tubes were shaken vigorously for five seconds before being stored in the refrigerator for another 24 hours. 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. Chlorophyll *a* concentration was used as an indicator of phytoplankton productivity (Williams and Murdoch 1966).

Estimation of zooplankton concentrations and identification of individual types

At each station during each run, zooplankton were also collected. A 330-micrometer mesh zooplankton net was towed behind the boat for five minutes. The zooplankton were transferred to labeled formalin jars and taken back to the laboratory. A Folsom plankton splitter was used to divide the each sample four times. A dissecting

microscope was used to count and identify the zooplankton and these numbers were used to estimate the total zooplankton present in each sample (Johnson & Allen 2005). Pearson's R and regression tests were run on the chlorophyll *a* concentrations and zooplankton densities.

Estimation of fish concentrations and species

Due to the unreliability of the fish finder, fish estimates were removed from the study.

Estimation of dolphin numbers and feeding behavior

During each sampling trip, dolphin sightings were observed. If dolphins were found, their GPS location and behavior was recorded. The dolphins were considered to be foraging if actual consumption of the fish is observed or the fish are seen repeatedly jumping from the water. Pictures were taken of the bottlenose dolphin dorsal fins in hope of identifying the residents. Previous sighting records from 1999-2003 were also used in my final analysis (Young unpub.).

RESULTS

Chlorophyll *a*

The highest chlorophyll *a* concentrations at any of the stations occurred during high tide. There was however a relative maximum at most of the stations during low tide on October 11, 2008 (Fig. 2). Throughout all sampling dates, stations 4 and 5 towards

the southern end of Jones Creek had the highest chlorophyll *a* concentrations, although station 3 generally had a higher concentration than both stations 1 and 2 (Table 1).

Zooplankton

Many species of zooplankton were found in the samples with copepods dominating. The samples also contained crab zoea, shrimp larvae, zoothamnium, barnacle larvae, and cladocerans. Zooplankton densities fluctuated throughout low tide on all sampling days. On October 11, 2008, stations 1 and 5 showed a zooplankton density maximum at low tide while stations 3 and 4 demonstrated a density maximum during early flood (Fig. 3).

Relationship between Chlorophyll *a* concentrations and zooplankton densities

Chlorophyll *a* concentrations and zooplankton density exhibited an inverse relationship. As concentrations of chlorophyll *a* increased, the zooplankton densities decreased across all samples. A relatively weak correlation was obtained between zooplankton and chlorophyll *a* during most sampling trips and based on total samples (Fig. 4).

Dolphin Density

Dolphin density graphs developed from observations during this study show a higher density around the area predicted for chlorophyll *a* concentration maximum (Fig. 5). The only feeding behavior observed during the sampling trips occurred during low tide near station 3. Data recorded from 2002 only show feeding behavior during low tide

but the locations are varied. Density plots for the fall of other years show dolphins sightings at low tide occur throughout the Winyah Bay/North Inlet area (Fig. 5). However, during the winter, spring, and summer seasons, the dolphin density is increased around the middle of Jones Creek during low tide (Fig. 6).

DISCUSSION

It was expected that chlorophyll *a* concentration would be the highest during low tide at station 3 towards the middle of Jones Creek. The sampling completed during this study showed the chlorophyll *a* maximums actually occurred at stations 4 and 5 towards the end of Jones Creek. This could be due to the water input from Mud Bay. If a node existed past station 4 then water may be flowing into Jones Creek possibly adding to the chlorophyll *a* levels. In addition, there are numerous tidal creeks that empty into the creek around the location of station 5. The drainage may also be responsible for the increase in chlorophyll *a* concentration and subsequently phytoplankton concentration. It was expected that the overall highest chlorophyll *a* concentration would occur during low tide. The highest chlorophyll *a* concentration was found at high tide and may be due to the variability of the water during the fall season. Sunlight begins to decrease in the fall and the water begins to cool off which may cause less chlorophyll *a* to be present in general. If this is the case, the increase of water during high tide could be responsible for the high chlorophyll *a* concentration. This study was based on a previous study recording chlorophyll *a* concentrations in Winyah Bay. The samples collected for the initial study were collected during the spring season and resulted as the basis for the location for the chlorophyll *a* maximum location.

Chlorophyll *a* concentrations and zooplankton densities showed a weak inverse relationship which was unexpected. One possible explanation for this finding is the time of year in which the sampling was completed. It is possible that the zooplankton densities are changing during the fall. The reproductive cycle of the zooplankton may also play a role in determining higher densities. Continuous sampling throughout the fall season would demonstrate any zooplankton density changes. The surface water sampling may also have influenced the zooplankton densities. If more sampling is done, different water depths should be used. In addition, it is unknown if the plankton are in constant abundance throughout the water column or if they are re-suspended as the tides change. If re-suspension occurs then zooplankton densities at the surface would be low during high and low tide and higher at flood and ebb. There did seem to be increased densities during or soon after low tide which was expected.

The dolphin sightings from the current study show a higher density in the middle of Jones Creek however, these are the total sightings from all tidal stages. Since the sampling was focused on the Jones Creek area for this study, the results may be slightly biased. It can be noted that the only observation of feeding behavior was recorded nearest station 3 at the time of low tide which demonstrates the expected results. This is further supported by data from 2002 in which observations of feeding behavior only occurred during low tide. Historic data for the fall season show that dolphin density is not high around station 3 during low tide. The dolphins seem much more concentrated towards the beginning of Jones Creek which may be due to fish distribution changing in the fall season. As the water temperature begins to cool, both the fish and dolphins may migrate to possible warmer waters. The historic data from winter, spring, and summer

during low tide did show a higher bottlenose dolphin density around the area of suspected chlorophyll *a* maximum. These results were expected as previous studies have shown a high chlorophyll *a* concentration during low tide in the spring.

Additional research is warranted to further investigate the relationship between chlorophyll *a* and zooplankton density. And to confirm the finding that bottlenose dolphins are present in the area during times of low tide for winter through spring. Current findings are limited to one time of year, to one body of water (Jones Creek), and are based on limited samples and historical data. Specifically, additional research could be used to collect chlorophyll *a* concentrations and zooplankton densities during different seasons across a series of years in Jones Creek as well as the surrounding creeks. More sampling of chlorophyll *a* and zooplankton could be collected during other tidal stages and at different depths within the water column. An abundance of dolphin sighting data helped in this study, but more recent data should be obtained and examined.

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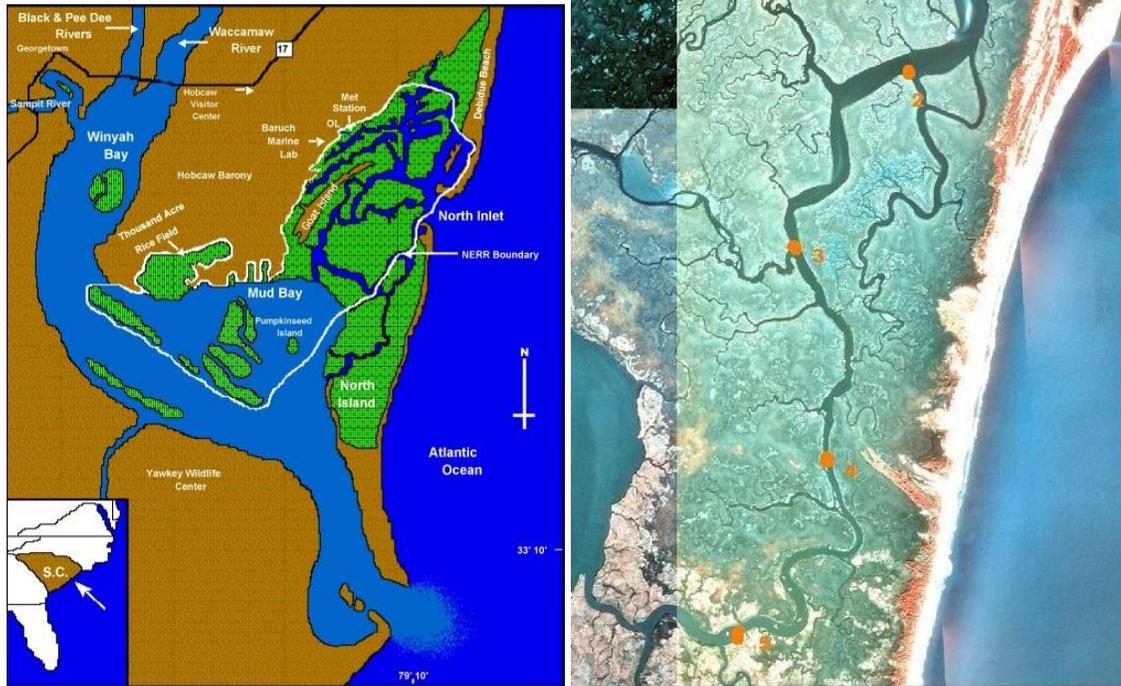


Figure 1: (L) Map of the North Inlet-Winyah Bay Area. (R) Sample sites in Jones Creek.

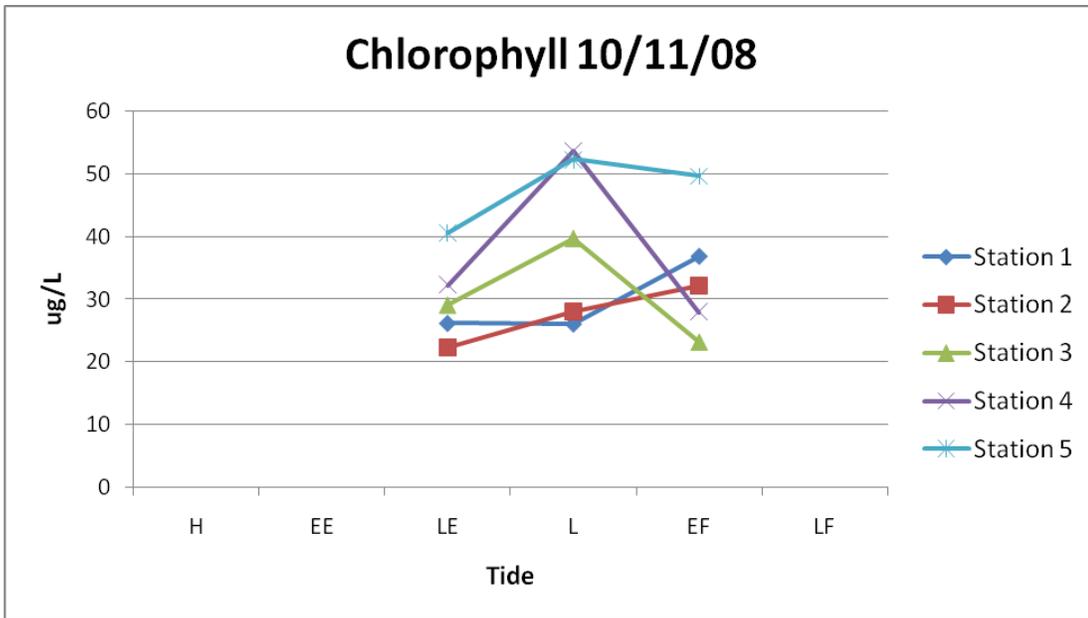


Figure 2: Chlorophyll *a* concentrations from late ebb through early flood at all five stations on October 11, 2008. Chlorophyll *a* concentrations at each station have a maximum at low tide or continue to increase through low tide.

Table 1: Chlorophyll *a* concentrations during low tide at all stations collected on October 11, October 26, and November 8, 2008.^a

Chlorophyll <i>a</i> Concentrations at Low Tide			
Station	10/11/2008	10/26/2008	11/8/2008
1	26.63	17.70	12.03
2	28.07	13.53	10.73
3	39.67	32.50	10.90
4	53.63	48.70	22.63
5	52.30	33.03	23.30

^aChlorophyll *a* concentrations at all stations during low tide show higher concentrations at station 4 and station 5.

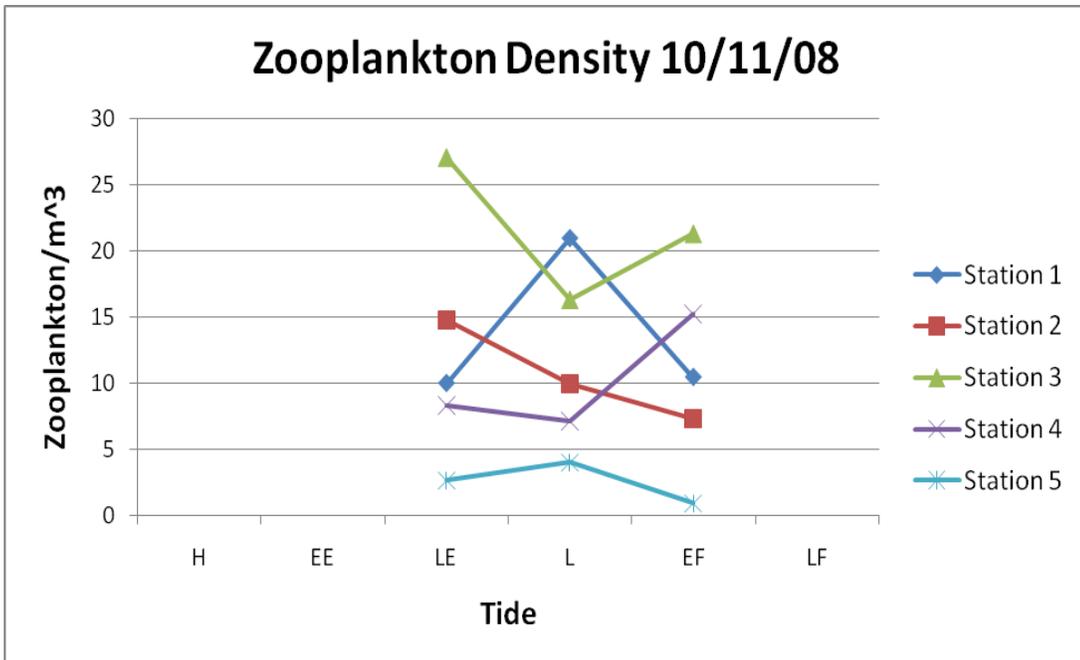


Figure 3: Zooplankton density from late ebb through early flood at all five stations on October 11, 2008. Zooplankton densities at each station do not have a common relationship during low tide.

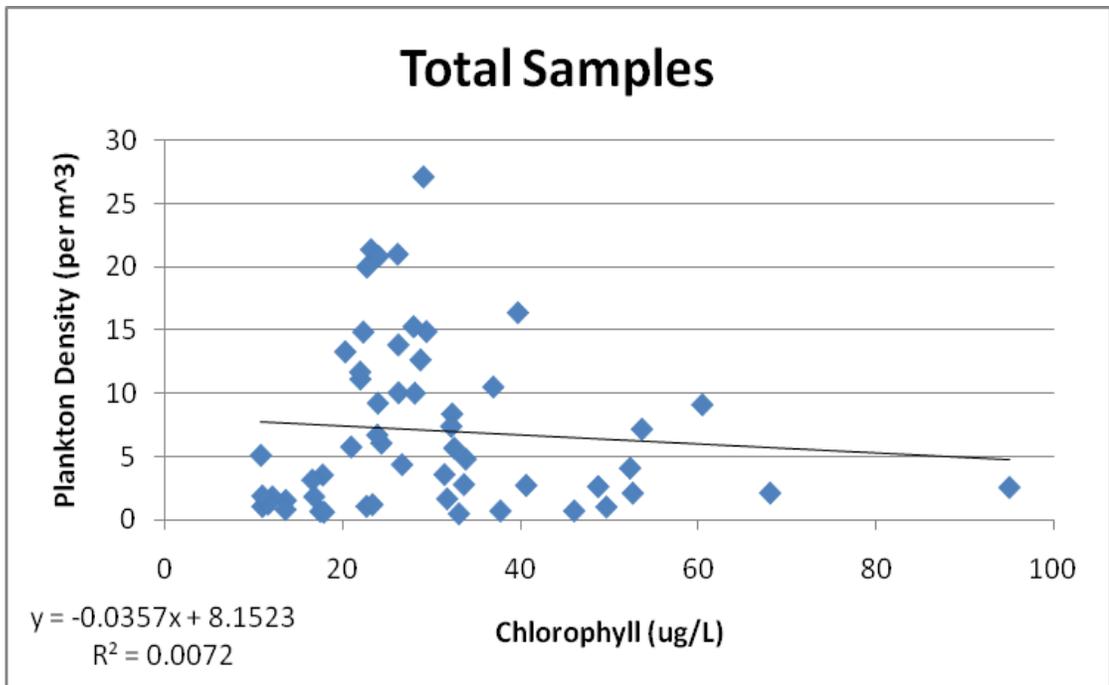


Figure 4: Chlorophyll *a* concentration correlated with zooplankton density for all samples collected during the study. Chlorophyll *a* shows a slight inverse relationship with zooplankton density for all samples collected.

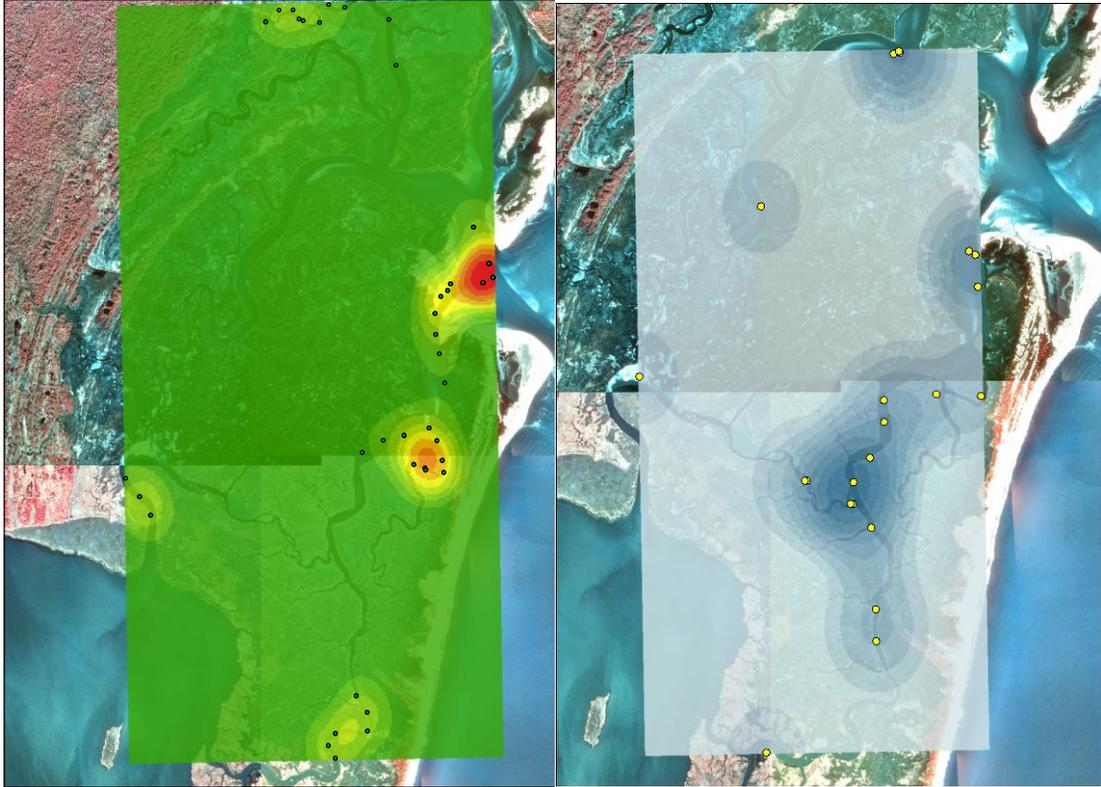


Figure 5: Dolphin density plots. (L) These samples were collected during low tide in the fall of 1999. They show a dolphin density maximum near the northern end of Jones Creek. (R) Dolphin density was highest near station 3 in the middle of Jones Creek. These samples were collected from fall of 2008.

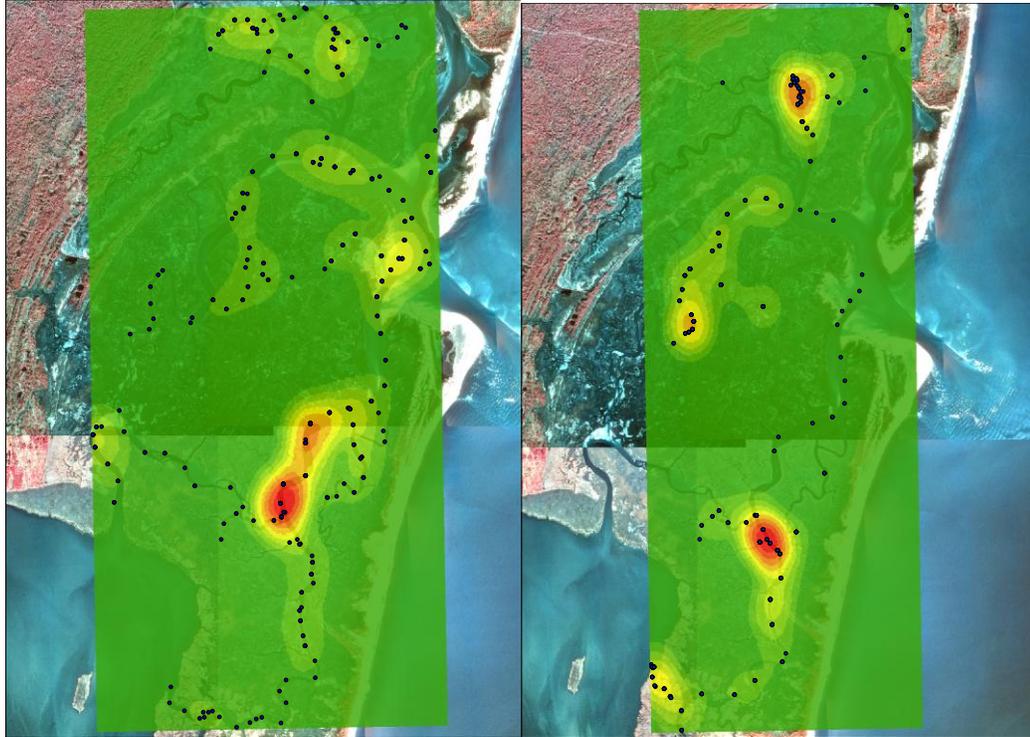


Figure 6: Dolphin Density Plots. These samples were collected winter, spring, and summer of 1999(left) and 2001(right) at low tide. They show a dolphin density maximum around the middle of Jones Creek.