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**Examining the Ecological Role of White Perch (*Morone americana*) using Acoustic  
Telemetry in the Great South Bay Estuary, New York.**

A Thesis Presented

by

**Martha Marie Divver**

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Abstract of the Thesis

**Examining the Ecological Role of White Perch (*Morone americana*) using Acoustic Telemetry in the Great South Bay Estuary, New York.**

by

**Martha Marie Divver**

**Master of Science**

in

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Stony Brook University

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Acoustic telemetry was used to investigate movement and behavior of the semi-anadromous white perch (*Morone americana*) in the Great South Bay system. Fifteen Vemco® VR2 acoustic receivers were deployed in the Carmans River and another fifteen were placed in tributaries throughout the Bay. Forty fish were tagged with Vemco® V9 acoustic transmitters from August 2010 - 2011, fifteen of which returned 28+ days of movement data. Spatial use of the River varied seasonally with an expanded range during autumn and spring and contracted range during summer and winter. Both residential and migratory individuals existed within the population, suggesting connectivity between rivers. Activity level varied on a seasonal basis, with increased activity during pre-winter foraging and spring spawning periods, and reduced activity during the winter. Temperature was shown to influence fish activity levels, with seasonal extremes suppressing activity. Salinity had little effect on perch movement and activity, however, the reduced fluctuations in salinity may influence white perch to overwinter in upriver areas.

Acoustic tracking revealed adult perch exhibiting diel movement behavior, which has not been previously described in adults of this species. Movements were tested for cyclical patterns using autocorrelation analysis. The frequency of diel behavior across individuals was found to be dependent on season, with the behavior significantly reduced in winter and maximized in summer. Directionality in diel movement was also seasonal, where nightly upriver movements were favored in summer and autumn months and nightly downriver movements were preferred in winter. Diel behavior was also affected by temperature and salinity, with high salinities and low temperatures reducing the frequency of occurrence. Additional but uninvestigated drivers that may influence diel movement include the presence of predators, movement to preferable forage habitat, and summer declines in dissolved oxygen.

## Dedication Page

For Mom and Dad –  
Who supported and encouraged  
my crazy passion for the marine world;

For Emily and Claire –  
My amazing sisters  
who are both an inspiration  
and a shoulder to lean on;

And for Kyle –  
The love of my life,  
who helped me through my battles,  
and never let me quit.

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## **THESIS INTRODUCTION**

The Great South Bay Ecosystem Study (GSBES) is an effort by Stony Brook University School of Marine and Atmospheric Sciences and funded by the New York Department of State to thoroughly investigate and monitor environmental factors of the Great South Bay system. The main goal of the GSBES is to fill in knowledge gaps regarding the Bay's structure and function for the construction of an ecosystem-based model and for the improvement of management efforts in the region. The Great South Bay was selected as the focal study site as it is historically a highly-productive estuary, but as a result of recent pollution and fishing pressure, habitat quality has deteriorated, changing the marine community (Schubel et al. 1991). Current research in the Bay includes factors affecting plankton community structure, the ecological role of benthic suspension feeders, effects of nutrient loading, invasive tunicates, foraging by ctenophores, and the effects of water quality on seagrass beds. An upper trophic model using historical data has been developed to map changes in trophic structure (Nuttall et al. 2011). Additional models are being developed to couple the hydrodynamic and trophic structure of Great South Bay. The focus for this thesis, which is another component of the GSBES, is the investigation of habitat use by white perch (*Morone americana*) and factors that control perch movement within Great South Bay and its largest tributary, the Carmans River.

The white perch was selected as the focal species in this study to investigate the ecological role of a pelagic species that resides year-round in the Great South Bay system. There is little information regarding white perch movement and behavior in the Great South Bay when compared to more thoroughly studied populations, such as the Chesapeake Bay (i.e., Mansueti 1961, Kraus and Secor 2005, Shoji et al. 2005, Kerr and Secor 2009, Hanks and Secor 2010). White perch are currently unregulated and there are no restrictions on take size or quantity by

recreational fishermen (NYSDOS 2012). Perch have been recognized as an ecologically important species in other locations as both a predator (Danehy et al. 1991, Moring and Mink 2002, Weis 2005) and a prey source (Setzler-Hamilton 1991, Juanes and Marks 1993). The knowledge gap regarding the ecological function of white perch in the Great South Bay system is addressed in this study.

The Great South Bay estuary is considered a vital habitat for the Long Island marine community and is identified as a significant coastal fish and wildlife habitat by the New York State Department of State (NYS DOS 1987). It is unique for being a shallow, well-protected estuary; this creates ideal conditions for highly productive eelgrass (*Zostera marina*) beds and phytoplankton communities (Schubel et al. 1991). High levels of primary productivity can provide a solid and abundant resource for the marine food web in the Bay, including anadromous finfish. As a result, the Great South Bay had historically abundant shellfisheries, including oysters and clams, as well as menhaden fisheries. Sportfishing in Great South Bay also historically contributed to the economic value of the estuary (Foehrenbach 1969) and is still actively pursued today. A number of diadromous species are known to travel through the bay for both forage and spawning habitat, including alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), rainbow smelt (*Osmerus mordax*), brook trout (*Salmo trutta*), American eel (*Anguilla rostrata*), and Atlantic sturgeon (*Acipenser oxyrinchus*) (NYSDOS and USFWS 1998). Species, including alewife, brook trout, and the semi-anadromous white perch (*Morone americana*) have been known to spawn in several tributaries of Great South Bay (USFWS 1999). However, recent increases in pollution and fishing pressure in the Bay have resulted in a decline in habitat quality, changing the marine community (Schubel et al. 1991). By developing



an ecosystem approach to the management of this region, the GSBES aims to restore and preserve this critical Long Island habitat.

The Carmans River possesses a high level of species diversity and a variety of migratory fishes. The lower 5.5km of the Carmans is a part of the Wertheim National Wildlife Refuge, which offers the flora and fauna additional protection from human use and development. A wide variety of waterfowl, mammals, and fishes utilize the riverine habitat. Migratory fishes in addition to perch seen in the river include striped bass (*Morone saxatilis*), American eel, bluefish (*Pomatomus saltatrix*), river herring (*Alosa* sp.), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*) (USFWS 1999). The Carmans and Great South Bay contain patches of submerged aquatic vegetation (SAV) and salt marsh habitat, which enhances survival of young migratory fishes reared in this system. The Hards Lake Dam, located ~5.5km upriver in the Carmans, has traditionally blocked fish movement between lower estuarine and upriver freshwater habitat. In March of 2008, an Alaskan steep pass fish ladder was installed. Alewives have been observed using the fish ladder (NYOGLECC 2009) however it is unclear whether perch utilize the passageway.

The thesis objective is to examine how white perch utilize the Carmans River, Great South Bay, and other tributaries on both long- and short-term scales. Habitat use, activity, home range, and behavior are expected to vary with environmental factors, including seasonality, temperature, salinity, and daylight. Essential fish habitat and migratory pathways are identified and analyzed. The results suggest white perch exhibit complex behaviors based on behavioral, environmental, and physiological changes. The incorporation of these factors and the ecology of white perch are necessary for the success of the GSBES.

# **CHAPTER 1 – White perch habitat use and activity within the Carmans, and environmental and biological drivers that influence movement**

## **INTRODUCTION**

The importance of migration to understanding population connectivity (Gillanders et al. 2003), ecosystem dynamics (Holdo et al. 2011) and for developing management strategies (Aguilar et al. 2005) has been demonstrated in marine and freshwater environments for a wide range of species (Deegan 1993, Willson and Halupka 1995, Kraus and Secor 2004, Frisk et al. 2008, Kerr et al. 2009). The life history diversity of diadromous fishes is often highlighted as examples of the ecological importance of migration to metapopulation structure and nutrient exchange between habitats (Cederholm et al. 1999, Nislow and Kynard 2009, Walters et al. 2009). Upstream movement of diadromous fish provides nutrient deposition via fish mortality, egg production and excretion (Cederholm et al. 1999, Nislow and Kynard 2009, Walters et al. 2009), which has been shown to increase upstream productivity (Durbin et al. 1979). Additionally, many diadromous species provide prey for terrestrial species, such as birds and bears, while serving as a forage base in coastal and ocean environments (Willson and Halupka 1995). In estuarine species' assemblages, anadromous fish often act as keystone species structuring community interactions (Willson and Halupka 1995, Whitfield and Elliott 2002, Helfield and Naiman 2006).

The north Atlantic region has seen declines in multiple diadromous stocks, including alewife, blueback herring, and American shad (*Alosa sapidissima*), among many others (Limburg and Waldman 2009). Contributing factors to diadromous fish declines include

overfishing, increased levels of pollution into stream habitats, the construction of dams, and climate change (Powles et al. 2000). The decline of diadromous fishes and the increase in predator species (Heimbuch 2008) has increased predation pressure on species such as river herring (Schultz et al. 2009), white perch, and Atlantic tomcod (*Microgadus tomcod*). For example, in Maine, dams have blocked all but a small fraction of accessible upriver habitat, which was identified as the leading cause of the decline of river herring populations (Hall et al. 2010).

Acoustic telemetry provides an approach for collecting high resolution data on spatial and temporal movement of individuals. Variations in individual movement can further be connected to environmental and biological changes. For instance, Stokesbury *et al.*, (2009) describes a new form of acoustic telemetry where acoustic tags act as both a transmitter and a receiver, which would aid in uncovering species interactions and environmental responses of diadromous fish at sea. Individual tracking can also decipher variations in behavior, which can be attributable to different degrees of gene flow (Maclean and Evans 1981). Ecological and behavioral barriers that can be identified through acoustic tracking, such as spatial and temporal isolation, may identify subpopulations and their connectivity (Cooke 2008). The presence of subpopulations and the degree of gene flow are components that should be included in fisheries management, since these biological variables may suggest a local stock approach is a more appropriate management method (Maclean and Evans 1981). Acoustic telemetry has been used on migratory fishes to investigate habitat use, migratory pathways, essential habitat, and mortality rates (Hightower et al. 2001). Through acoustic telemetry, iteroparous fish can be tracked through the adult outmigration, which provides information on temporal habitat use within the system after spawning season.

The white perch is an abundant diadromous species that occurs in coastal and riverine environments along the eastern seaboard. White perch are commonly described as a semi-anadromous fish, migrating from their natal rivers and streams to estuarine bays (Mansueti 1961, Setzler-Hamilton 1991, Collette and Klein-MacPhee 2002), but never entering the ocean. It is a schooling fish, moving between locations in relatively small groups (Collette and Klein-MacPhee 2002). Recent studies have suggested that some populations of white perch exhibit complex contingent behavior with migratory and resident individuals (Kerr and Secor 2009, Kerr et al. 2009). The fish have been known to overwinter in deep saline waters (Setzler-Hamilton 1991) and can withstand extended periods of below-freezing temperatures (Fitzgerald et al. 2006). Spawning season varies geographically along the East Coast, but generally occurs between May and July (Collette and Klein-MacPhee 2002). Environmental drivers of migration and daily movement patterns are poorly understood and the degree of connectivity between tributaries is unknown.

The white perch has an essential ecological role in its environment, where it forages on multiple food groups, acts as a food source to other animals, and is actively harvested by fishermen. Perch are opportunistic feeders, taking advantage of peak seasonal abundance of a variety of prey types. Their diet ranges from plant material to fish (Moring and Mink 2002), including fish eggs (Schaeffer and Margraf 1987) such as alewife (Danehy et al. 1991), thus consuming multiple components of the food web (Weis 2005). Perch may even have the capacity to alter the zooplankton diversity in some aquatic ecosystems (Couture and Watzin 2008). Predation on perch by other species occurs in both the larval (Smith and Kernehan 1981, Margulies 1990, Setzler-Hamilton 1991) and juvenile (Juanes and Marks 1993) life stages. White perch are also a popular recreational fish and are commercially harvested in the

Chesapeake Bay watershed (Setzler-Hamilton 1991, Genovese et al. 2005), though the fish previously sustained commercial fisheries in multiple regions (Stanley and Danie 1983). There are currently no rules or regulations restricting number, size, or season of white perch catches for recreational fishermen in New York State (NYSDOS 2012). Since little is known about the ecological role of white perch in Great South Bay, it is unclear how the unrestricted recreational fishery for perch could impact the estuary over time.

White perch are known to frequent the Great South Bay estuary (Dowhan et al. 1997) and its major tributary, the Carmans River (Cashin Associates 2002). It is uncertain whether the perch enter other tributaries to Great South Bay, though it has been suggested that they occasionally spawn in the Connecticut River (Dowhan et al. 1997). Great South Bay had an established white perch commercial fishery, but today they are primarily caught recreationally (Kahnle et al. 1991). There is no known record of assessing the location of essential fish habitat (NMFS 2008) or understanding the ecosystem use and function of this species. Assessing white perch use of habitat, migratory pathways, and seasonal movement patterns will therefore contribute important information on the ecological role of this species.

The Carmans River, one of the largest tributaries to the Great South Bay system, is an ideal location for examining white perch habitat use since both the river and the Bay are very dynamic in their physical environment. With large amounts of freshwater input and a tidal connection to the ocean, salinity averages between 25 and 30ppt in the Bay (Hinga 2005). The Carmans River contains a large salinity gradient, with a salt wedge that extends at least 2 km upriver (Table 1), though spikes of high salinity have been noted to occur upriver as far as ~4.5km (Figure 11a). Temperatures also fluctuate from below freezing up to daily average temperatures of nearly 30°C. The Great South Bay and Carmans are subject to ice formation

during winter due to the area's shallow, well-protected conditions (Divver, pers. obs.). Such variability in physical factors has been shown to influence swimming patterns of migratory fishes (Sims et al. 2004, Thorstad et al. 2007).

By using acoustic telemetry in the Great South Bay and Carmans River, this project investigated white perch spatial and temporal movements and their responses to biological and environmental factors. Chapter 1 discusses temperature and salinity as environmental drivers of movement. Light effects are discussed in Chapter 2. Information on perch movement provided insight on essential habitat, including overwintering grounds, spawning areas, and migratory pathways, all of which can be applied to future fisheries management plans. Additionally, white perch migratory behavior and connectivity was investigated. White perch populations are known to be strictly semi-anadromous, as previously understood for the species (Mansueti 1964, Collette and Klein-MacPhee 2002), though perch are also known to be strictly residential, as populations of perch have been shown to complete all stages of their lifecycle in freshwater habitats (Scott and Crossman 1973, Hawes and Parrish 2003, Couture and Watzin 2008). White perch can also exhibit partial migration (Kerr and Secor 2009, Kerr et al. 2009).

## **MATERIALS AND METHODS**

### **Receiver deployment**

The project was conducted on the Carmans River between the Hards Lake Dam and the mouth of Great South Bay (See Appendix). This 5-km section of the river is characterized by wetlands, salt marsh, and forests and is enclosed within the Wertheim National Wildlife Refuge (Dowhan et al. 1997). A total of fifteen Vemco© VR2W acoustic receivers were deployed at 500m intervals from the mouth to the dam, providing nearly complete coverage of the 5km tidal section of the river. Three pairs of receivers were placed at the mouth of the Carmans River to create a

gate to monitor movement into Great South Bay. All acoustic receivers were activated in the laboratory prior to deployment to ensure proper functionality. A 27-36kg concrete mooring was constructed to hold each receiver. The mooring design included a 4"-diameter PVC pipe and stainless steel anchor shackles. The receiver was fitted into the PVC pipe and secured in place with a pair of large zip ties. Receiver locations were marked with a surface buoy attached by a line secured to the concrete mooring.

To assess movement between tributaries within the Great South Bay ecosystem, receivers were placed in the following locations: Connectquot River, Browns River, Beaverdam Creek, Swan River, Champlin Creek, Carlls Creek, and the Mastic Bridge (See Appendix – Map 1). Receivers were placed at the mouth of each tributary with an additional receiver placed ~250m to the north to indicate direction of movement.

### **Collection of telemetry and environmental data**

From June 2010 to December 2011, receivers were routinely downloaded and maintained on a monthly basis to prevent storage overload and extreme biofouling. Acoustic receiver data were downloaded to a laptop using Vemco™ VR3HS software. From mid-December 2010 to February 2011, monthly retrieval of receiver data was delayed during cold periods when the river was frozen.

A SeaCAT SBE-16 profiler (Sea-Bird Electronics) was deployed in the Carmans River to collect temperature and salinity measurements. The device was mounted in a steel cage and moored with a concrete block and buoy to maintain a vertical orientation in the water column. The expected battery lifetime was estimated at three months, so the SeaCAT was removed and replaced on a quarterly basis. The SeaCAT was placed mid-river and acquired a salinity and

temperature measurement every hour. A second SeaCAT was deployed from May 2011 to August 2011 upriver by the Wertheim Refuge Station and boat launch.

### **Collection of White Perch**

White perch were collected from a 4.27m outboard motor boat with the following gear: a 61m beach seine with 0.6cm mesh, hook and line, and a 18.3 x 1.8m three panel monofilament gillnet with 5.1, 7.6, and 10.2cm mesh in 6.1m sections. Additional collection via electrofishing took place on one occasion on October 2010. The beach seine was used from June to August 2010 at sites with clear coastline to facilitate seine retrieval. Several 6-foot barrel rod and reels with size 4 hooks and 40-lb monofilament #1/4 fishing line were used throughout the study to target adult white perch inhabiting deep, mid-channel regions where seines and gillnets could not reach. Fish collected via electrofishing were captured as a part of a NY Department of Environmental Conservation's (DEC) survey of the Carmans River. One vessel that surveyed upstream areas was a 5.5-m Clark Hull and used a Smith Root pulsator and was operated for 30-minute periods with 354 volts DC at 9amps at a pulse rate of 60Hz. The second vessel was a 5-m Smith Root 16H electrofishing boat that surveyed mid- stream regions and used 170 volts DC at 30amps and a 60Hz pulse rate. Downstream sampling with this method did not occur since the salinity downriver reached levels too high for the electrofishing probes to be effective. A gill net was used on four separate occasions in August 2011 and soaked for 30 minutes to reduce fish mortality.

### **Surgical procedures**

All procedures were consistent with guidelines provided by the American Society of Ichthyologists and Herpetologists (Nickum et al. 2004). Tagging methods were adapted from the



National Oceanic and Atmospheric Administration and National Marine Fisheries Services *A Protocol for Use of Shortnose and Atlantic Sturgeons* (Moser et al. 2000). Adult white perch with high levels of activity, minimal external damage, and exceeding a total length of ~25cm, were retained for acoustic tagging. All tagging was conducted at the site of capture. Selected fish were anesthetized by adding a non-lethal dose (80ppm) of the anesthetic, MS-222, to the holding tank. Fish were deemed anesthetized when buoyancy and most movement was lost, but gill movement remained. The immobilized fish was measured for total length, and temporarily placed on a clean, flat surface with its left side facing up. The incision area on the fish was cleaned and disinfected prior to surgery. Using a disinfected scalpel, a 30-mm incision was made through the skin and muscle in the abdominal cavity region. This location reduces abrasion from the transmitter on the incision. Coded Vemco™ V9-2X transmitters (frequency = 69kHz, average ping rate = 120s) were used on all individuals. The acoustic tag was activated and the identification numbers on the tag were recorded. The tag was inserted through the incision and into the abdominal cavity, and the incision was sutured closed with 2-3 sutures. Betadine was again applied to the sutured incision to reduce the possibility of infection. Total time for the procedure was five minutes. Any unhealthy specimens were euthanized with a lethal dosage of MS-222.

When the acoustic tag application was complete, the animal was held in an aerated recovery tank under ambient conditions. The total allotted time for recovery was 5-10 minutes. A 'recovered' fish exhibited steady breathing, controlled buoyancy, and normal swimming behavior. The fish was then released at the same location it was caught. If a fish did not return to consistent breathing and movement behavior, the animal was euthanized according to the

protocol issued by the American Fisheries Society (Nickum et al. 2004) and the tag was removed and deactivated.

In addition to tagged individuals, white perch were also collected for dietary analysis. Onsite euthanasia was carried out by using a lethal dose of MS-222. Fish were bagged and ice-packed for wet mass preservation and transportation to the laboratory. Upon arrival at the lab, fish were given identification information regarding location and date of capture and frozen until needed.

### **Dietary analysis**

Fish were thawed in a refrigerator for 12-24 hours, weighed (kg), and measured (cm) prior to dietary analysis. Stomachs were removed from the left side of the fish by making an incision from the anus to just below the operculum, and two vertical incisions from each end of the horizontal incision. The stomach was removed by cutting above the intestine and including the majority of the esophagus. Fish were re-weighed after the stomach was removed, and the full stomach was weighed (g) separately. Stomach contents were later removed and the empty stomach was re-weighed. Under a dissection microscope, stomach contents were sorted by Order and identified down to the lowest taxonomic level possible. Sorted contents were weighed individually and preserved in a vial with 70% ethanol.

Stomach content data were examined for seasonal variations in food quantity and type preferences. Food uptake was assessed using the index of stomach fullness (ISF) for each season where data were available. ISF is estimated by dividing stomach content weight by the total weight of the fish (Hyslop 1980, Shoji et al. 2005, Couture and Watzin 2008). Identified stomach contents were compared by average weight both seasonally and for all fish to examine preferred food sources. Food types were evaluated using the percent Index of Relative Importance (%IRI),

which is based on the percent number (%N), weight (%W), and frequency of occurrence (%O) of each identified food group (Pinkas et al. 1971, Liao et al. 2001).

### **Otolith aging**

White perch otoliths were removed and aged from specimens used in the dietary analysis. A scapula was used to slice across the cranium of the perch just above the eyes. Otoliths were removed using a forceps and labeled “left” and “right” for each fish. Any otolith that split or cracked upon removal was noted.

One otolith was randomly selected from each sampled fish and placed in a rubber mold. Using Epofix™ cold-setting embedding resin, otoliths were encased in a hardening resin. After 24 hours of hardening time, the embedded otoliths were vertically sliced using a saw to create a central ‘slice’ through the otolith. The slice was lightly sanded and mounted to a glass scale. All aging estimates were taken by the same student using a compound light microscope.

### **Statistical analyses**

#### **Data filtering**

To remove false detections, data pings were removed if the fish was assumed dead or if the detections were deemed unreliable. A fish was assumed dead if a tag was detected continuously by a single receiver for at least one month. False detections can result in bias and incorrect estimation of animal behavior and movement patterns. Detections with identical time stamps within a single receiver were considered duplicate pings and removed. However, if identical detections were recorded on adjacent receivers it was assumed to be a good detection, as this was a result of receiver overlap.

For distance estimates, which were based on the distances between adjacent receivers, pings occurring less than 63 seconds apart were filtered to remove any receiver overlap pings. These pings can bias the distance estimates by suggesting a fish is traveling quickly between two adjacent receivers when it is simply in an overlap region. Overlap pings do not always have identical timestamps, as the time of communication may be shorter to one receiver, so removing duplicates alone is not sufficient. The coded V9 acoustic tags used have a minimum ping rate of 60 seconds and require an additional 3 seconds for the communication between the tag and the receiver. For each paired sequence of hits that occurred less than 63 seconds apart, the ping with the later time stamp was identified as the false hit and was removed.

### **Migration**

White perch migration was investigated by combining the receiver ping time series within the Carmans River with pings from receivers within the Great South Bay system. Hourly average receiver locations were plotted for the Carmans River and any absences of detection for consecutive hours within the lower receiver gates was noted as an excursion out of the river. These detection 'gaps' were further investigated by examining Great South Bay receiver detections outside the Carmans. Individuals were considered: "residents" if they remained within the river; "migrants" if they spend only a few days outside the river, and "long-term migrants" if they spent multiple days outside of the Carmans.

### **Habitat Selection and Home Range**

The receiver locations were used to identify active habitat selection by white perch in the Carmans River. Receiver detections for each fish were averaged over a 24-hour period and the

frequencies of occurrence at each receiver were compiled into histograms, with each season having a unique histogram. Frequency distributions were then tested against the null hypothesis, assuming no preference for particular receivers at any time of the year, using a G-Test for the analysis of frequencies.

Fish home ranges were evaluated by examining receiver data over time for both the Carmans River and locations throughout Great South Bay. Receiver detections for each individual fish were combined and labeled with their corresponding receiver number. The average hourly receiver number was taken as the fish location. The hourly averages were plotted over time to observe short- and long-term location preferences by each fish. Plots were created for both individual fish and all fish to examine trends in spatial movement. Receivers in the Carmans River were also grouped (1-7 = Lower; 8-11 = Mid; 12-15 = Upper) and fish detections were pooled to identify river segments with high levels of activity. Raw receiver detections were examined on a weekly basis for the groupings, with percentage breakdowns corresponding to location preferences. These data were examined for seasonal and temperature effects for individual and overall fish movement by comparing movement to hourly temperature and salinity data.

White perch home range size was examined by estimating the standard deviation of the number of receivers frequented by fish from their daily average receiver location. Average standard deviation across all fish for the total detection period was plotted over time and examined for fluctuations in range. Changes in standard deviation were used to describe the size range of the river area used by the perch throughout the year.

### Breakpoint analysis

*Daily distance*: Estimates of distance traveled by an individual fish per day, termed ‘daily distance’, were determined by estimating movement between the receivers in the array. Daily distance estimates for a single fish were determined by:

$$D = \sum_{t_0}^{t_f} \begin{cases} 25 & (\Delta t) \leq 2 \\ M_{i,i+1} + \bar{M}(|i-j| - 1) & (\Delta t) > 2 \end{cases} \quad (\text{Eq. 1})$$

where  $D$  is total daily distance traveled,  $t_f$  is the final detection period,  $t_o$  is the start of the detection period,  $i$  is the receiver at the beginning of the time step,  $j$  is the receiver at the end of the time step, and  $\Delta t$  is the time step.  $M_{i, i+1}$  is the distance between the receiver at the beginning of the time step and next adjacent receiver in the movement time step, and  $\bar{M}$  is the average distance between all the receivers in the array. Movement beyond adjacent receivers, (i.e.,  $|i - j| > 1$ ) was a rare occurrence and was likely a result of fish skirting receivers in the main channel or traveling through creeks that connect different portions of the main channel.

For receiver location changes occurring in two minutes or less ( $\Delta t \leq 2$ ), the actual distance between receivers was not appropriate since it would require swim speeds that were extremely high (>40km/day, or averaging ~0.5m/s or higher), which are not physically possible for white perch to sustain for a day (Mellas and Haynes 1985). Instead, a distance of 25m was used. This correction assumes swim speeds closer to 0.2-0.3m/s which is the expected optimal speed for white perch (Stanley and Danie 1983). Assuming a fish is swimming between two receivers at a rate of ~0.2m/s, it would travel approximately 25m in two minutes.

Time series were analyzed to estimate significant changes in daily distance traveled by plotting estimates of daily distance over time and seasons. Seasons were defined based on the calendar start date for each season according to the NOAA National Weather Service

([www.erh.noaa.gov](http://www.erh.noaa.gov)). Periods of behavior switches, or "state" changes, in the time series were determined using a break point analysis (R; library 'strucchange'). The break point analysis in R applied a segmented regression to daily distance versus time, with the resulting breakpoint(s) indicating significant changes in slope based on the Bayesian Information Criterion (BIC) (Frisk et al. 2011).

*Activity levels and Temperature:* Changes in daily average temperature were compared to the break point analysis that was applied to the daily distance estimates. Temperature readings for the Carmans were acquired from the mid-river SeaCAT. These readings were averaged over a 24-hour period and plotted against time. Break point locations in the daily distance analysis corresponded to a specific date, which could be compared to that day's average temperature and the general trend in average temperature around the break point.

### **Temperature and Salinity variations within the Carmans**

*Variations between Upriver and Downriver Locations:* Temperature and salinity were compared between an upriver and downriver location to identify temporal and spatial differences between the two locations. SeaCAT data was used to evaluate the two locations. Data are recorded on separate SeaCATS every hour, which can then be compared to one another over time. Samples were collected in the Summer of 2011 for both temperature and salinity comparisons. The downriver SeaCAT collected readings for the duration of the project.

*Upriver salinity excursions:* Behavioral data was also compared to see if upriver salinity incursions had an effect on selection of location. Upriver salinity levels reaching 10ppt or higher

were selected for analysis if they persisted for multiple days. Plots of both individual fish receiver location and daily distance over time were examined during different incursion periods. The data were examined for any noticeable patterns between the salinity excursions and fish behavior.

## **RESULTS**

### **General Information**

All receivers and SeaCATs in the Carmans River were regularly recovered and maintained, with the exception of the very end of the study (August 2011), where two receivers gating the mouth of the river were not located via surface buoys. Two of the fifteen receivers located outside the Carmans were recovered in December 2010, and an additional four receivers were recovered in January 2011. Eleven of the fifteen outside receivers were later recovered in June 2011. However, only six were found in August 2011 at the completion of the study. Only one tributary had no receiver recovery through the duration of the project (Browns Creek); all others had at least one receiver recovered throughout the year. Four receivers never recorded hits from white perch (Champlin and Mastic).

A total of 40 fish were acoustically tagged, with fifteen fish detected for approximately 30 or more days. These fifteen individuals were the only fish incorporated into the data analysis (Figure 1a). The maximum number of detection days on an individual fish (as of 9/30/11) was 420 days; minimum for fish used in data analysis was 28 days. Individual detection coverage averaged around 98% for daily average detections (Table 2), thus nearly every day during a fish's detection period had at least one ping.

The remaining twenty-five fish that were acoustically tagged but not used in the data analyses had insufficient detection periods (Figure 1c). Of these fish, twelve were detected



consistently at the same location for more than four weeks, suggesting they either died or lost their acoustic tag. An additional twelve fish had detection periods of less than four weeks, which was considered an insufficient time period to be included in the study. Short detection periods may have been a result of fishing mortality, predation, natural mortality outside of the receiver range, or in a few cases, migration out of the Carmans. One fish tagged in August 2011 was never detected, suggesting that tag failure may have occurred.

### **Dietary Analysis**

Gut fullness suggested that white perch food acquisition varied throughout the year (Figure 2). Sample size was small for each season ( $n_{\text{Fall}} = 44$ ;  $n_{\text{Spring}} = 2$ ;  $n_{\text{SummerI}} = 2$ ;  $n_{\text{SummerII}} = 18$ ), but the data suggested that a higher amount of food was consumed in the fall months than in summer. Fall also had the highest variation in stomach fullness, ranging from nearly 0.03 to nearly zero (Figure 2). Analysis of stomach contents suggested that amphipods (Amphipoda) were a priority food source in white perch diet, dominating the diet mass in the Fall and being the most abundant non-plant material found in summer (Figures 3a, 3b). Amphipods a %IRI value of 97, with the next highest groups (crabs and fish) each only attaining a %IRI about 1 (Figure 3c, Table 3). Fall diet showed a high level of consumption of both crustaceans and fish. Five fish caught were found to have empty stomachs. These fish were included in the %IRI analysis but excluded from the stomach fullness and gut content analyses. There were no fish collected for dietary analysis in the winter season.

## **Otolith aging**

A total of sixty-seven adult and juvenile white perch were used in the otolith aging analysis. Fish ranged in age from 1 to 11 years old, with thirty-four individuals having an estimated age of 6 or 7 years (Figure 12). Sixteen individuals were estimated to be in the young-of-year age class. Only three individuals were 10+ years old, and all three of these fish had the longest total lengths in the sample. There was a lack of individuals between the ages of 3 and 5 and a complete absence of 8- and 9-year-old fish. Based on the estimated von Bertalanffy growth curve and the total length data collected from acoustically tagged perch (Table 2), it is estimated that most tagged perch were between 4 and 7 years old. Two exceptions include one fish that was 24.8cm and another that was 37.2cm.

## **Migration**

A total of six individuals left the Carmans throughout their detection period (Figure 1b). Four of the six fish made short excursions out of the Carmans at different points and returned within 24 hours. Two fish that made short migrations out of the Carmans either had detections at Beaverdam Creek, which is the closest tributary to the Carmans, or had a gap in their detection period that started and ended on receivers at the mouth of the Carmans for a period of three days (one in October 2010; one in March 2011). Two fish left for 12 and 13 days in March-April, respectively, and were detected periodically at Beaverdam Creek. Two of the six fish that migrated out of the Carmans in March-April did not return. One of these fish entered Connectequot River and Carlls River, traveling over 32 km in 10 days (Figure 1b). An additional six fish never made an excursion out of the Carmans, but did travel downstream toward the mouth of the river during the same time period as the migration.

## Home Range

White perch followed a general movement pattern throughout the year (Figures 4, 5). In the summer and early fall, movement became restricted to upriver habitat, with nearly 90% of all detections coming from receivers 9-11 during the summer and receivers 13-14 in early fall. During late fall and early winter, white perch movement expanded in range. By November, the entire river was being utilized with the majority of the activity occurring at receiver 9 and above. From mid- to late winter movement became restricted again, where all fish spent the majority of their time between receivers 8 and 13, and with a two-week period where movement was further constricted to receiver 13. During this two-week period, receiver 13 detected as many as 70% of the pings in one week.

As winter ended, the fish slowly expanded their range. In March, there was a shift in detections to primarily mid-river (80%) receivers, along with a substantial increase in detections in the lower section of the river (up to 25% in two weeks). Shortly after the low-river peak, detections were again split primarily between mid- and upriver receivers, though all sections of the river were used. By May, fish were detected only in the upper half of the river, with further suppression to upriver habitat as summer approached. By late July 2011, upriver receivers dominated the detection location (70-80%) and low-river detection declined to 0%. The restricted movement patterns from Summer 2011 were similar to the restricted movement of Summer 2010. While individual fish showed variability in movement throughout the year, all monitored fish in this study closely reflected the general annual pattern.

Home range expanded and contracted throughout the year, with peaks in November and March/April, and restrictions in December and July. Average receiver location was farther north

during periods of low activity and moved south as activity increased (Figure 7a). Summer average receiver location bounced between mid- to upper receivers, with a standard deviation of 1-2 receivers (Figure 7b). In fall, fish moved downriver towards receivers 7-9 and standard deviation increased to 3 receivers. Standard deviation was close to zero in winter, when receivers 12-13 were the mean receiver locations. Receiver standard deviation began to slowly increase again in late winter, spiking in early spring at a maximum standard deviation value of 5 receivers. After this spike, average receiver location shifted from receiver 8 to receiver 12 as spring turned into summer and receiver standard deviation declined from 2 to 1 in June. These changes in home range size parallel the use of the river by all fish as seen in the average daily and weekly receiver location estimates (Figures 4, 5).

The frequency distribution of receiver locations for each season revealed that perch are actively selecting for different regions of the Carmans river throughout the year, and selective preferences vary depending on the time of year (Figures 6a – 6e). The G-Test for the analysis of frequencies resulted in significant G values for all seasons ( $P < 0.05$ ; Table 4). Summer 2010 and 2011 frequency distributions both peaked at receiver 12 and had a range restricted to receivers 8 – 14. Fall and Spring seasons revealed distributions spanning the entire study site, with a peak around receiver 10. Winter had a slightly smaller range, spanning from receiver 5 through 14, with a steep peak at receiver 13.

### **Break Point Analysis**

*Daily Distance:* Three break points (10/23/10, 12/30/10, and 5/26/11) defined significant changes in trends of distance traveled over time (Figure 8a). Daily distance traveled increased in time prior to the first break point. This was followed by a sharp decline in distance traveled

between break points 10/23/10 and 12/30/10. Daily distance steadily increased between 12/30/10 and 5/26/11. After 5/26/11, distance traveled declined but the slope remained positive and the pattern resembled summer 2010. Break points varied between individuals but almost all fish had breakpoints very close to the average. There were also three cases that suggested the possibility of a fourth breakpoint in late February/early March, but there was no evidence of this breakpoint in the breakpoint analysis on overall average fish movement.

*Activity Levels and Temperature:* Break points approximately corresponded to inflection points and extremes in temperature (Figure 8b). The two break points at 10/23/10 and 5/26/11 occurred during periods of rapid temperature change in spring and fall, respectively. The third break point at 12/30/10 occurred as temperature reached its seasonal minimum. Peak temperatures corresponded to the beginning and end of the data sequence and the series was too short to define further break points. As might be expected with nonlinear relationships, correlation between temperature and daily (Figure 9a,  $r^2 = 0.2033$ ) and weekly (Figure 9b,  $r^2 = 0.3904$ ) distance traveled was weak.

*Seasonality:* Weekly distance was most reduced in both summer and winter months and peaked in spring and fall (Figure 9b). Fall weekly distances were also lower when compared to identical temperatures occurring in either spring or winter.

### **Temperature and Salinity Variations between Upriver and Downriver SeaCats**

During summer 2011, the lower SeaCAT tended to have lower temperature and higher salinity compared to the upper SeaCAT (Figures 10a-11b). Temperatures at the two SeaCATs tended to

vary in nearly identical patterns, however the upriver SeaCat was consistently lower in temperature by 3-4°C (Figure 10a, 10b). There was one day where this difference was not seen (6/9/2011) but the lower SeaCAT data for that date were unusual and contained some erroneous readings. Salinity between the two locations was much more variable (Figure 11a); however, the lower SeaCAT tended to have higher salinity (Figure 11b). Surprisingly, the upper SeaCAT attained salinity levels as high as 18ppt during 4-5 day salinity excursions. These events occurred on a regular basis during the summer (appx. 10-14 day intervals).

### **Upriver Salinity Excursions**

Individual salinity excursions at the upriver SeaCAT were examined more closely with white perch movement and location data to see if marked changes in salinity had any influence on fish movement. Movement and distance data were examined for periods before and after the excursion, as well as activity during the excursion period (Example fish in Figures 11c and 11d). Activity levels remained fairly consistent on a daily basis despite the change in salinity. Similarly, there were no noticeable changes in fish location during the salinity excursions.

## **DISCUSSION**

White perch were found to exhibit variations in movement in response to seasonal changes, temperature changes, and spawning behavior. Seasonality was found to influence white perch by shifting spatial use of the Carmans River, varying home range size, and changing daily average activity levels. Temperature changes similarly altered daily average activity levels and home range, particularly at low daily average temperatures. Spawning season, which typically occurs

from mid-March to June in white perch (Setzler-Hamilton 1991, Collette and Klein-MacPhee 2002), was found to trigger migratory movement in some individuals, while others remained residential to the Carmans though their spatial use of the river increased to the entire receiver array.

Daily average salinity trends and salinity excursions from external events (such as wind and storms) had no noticeable influence on white perch range, daily movement patterns, habitat selection, or activity levels at any point during the year. White perch have been known to tolerate a wide salinity range (Stanley and Danie 1983), with some introduced populations living solely in freshwater (Couture and Watzin 2008, Gosch and Pope 2011). Despite their salinity tolerance, adult perch show a preference for salinities between 5 and 18ppt, and tend to only spawn in salinities less than 8ppt (Hardy 1978). Although no behavior with salinity was identified, it is possible that overwintering habitat was selected in part as a habitat with an average salinity that reduced energetic demand for osmoregulation.

Similarly, tidal cycle had no noticeable effect on white perch movement or activity levels. Fish have been known to passively use the tides to travel without expending much energy (Groot et al. 1975, Almeida 1996). White perch have also been known to move inshore during high tides for feeding (McGrath and Austin 2009). This does not appear to be the case for the Carmans River white perch, as no connection between the semidiurnal tide cycle and small-scale spatial movement was detected.

### **Summer Movement and Behavior**

White perch were largely restricted to the upper portions of the Carmans River in the summer with a reduced home range and low activity levels. High daily average temperatures were shown

to reduce perch daily average distance. While white perch can tolerate a temperature range of 2 – 32.5°C (Stanley and Danie 1983), temperature tolerances can vary for perch populations based on their geographical location, providing each population with different optimal temperatures (Hardy 1978, see references in Setzler-Hamilton 1991). The high daily average temperatures during the summer in the Carmans River may have been above optimal temperature conditions for white perch, since fish can become stressed under continuous high temperatures (Coutant 1976). High temperature stress and avoidance has been previously documented in white perch (Texas Instruments 1979, Margulies 1990), which suggests that a response to thermal stress is not an uncommon behavior in this species. Carmans river perch responded to high temperatures by reducing their activity levels, which will reduce their energy expenditure.

Home range may be limited during the summer months to the upper portion of the study site due to an increased abundance of predators. The Carmans is utilized by several other migratory fishes, including bluefish and striped bass (Dowhan et al. 1997). Striped bass have been known to feed on white perch in the Hudson River (Heimbuch 2008). The increase in abundance of adult striped bass during the spring and summer (Hill et al. 1989) could pressure perch into choosing between either a restricted forage area or an increased risk of predation. Diet samples additionally suggest that perch stomach fullness was relatively low during the summer when compared to the fall. Predator avoidance is a common behavior found in fish, which may create trade-offs for the prey species (Ryer and Olla 1998, Borcharding 2006, Bronmark et al. 2008). White perch may have been actively avoiding predation despite the increased intra-specific competition and reduction in forage ground.

Dissolved oxygen (DO) content may act as a possible driver of movement during summer months as perch may actively avoid regions that are subject to hypoxic events. White perch are



commonly found in areas with DO levels of at least 6mg/L, and were found to be absent in trawl surveys where DO levels were less than 4mg/L (Setzler-Hamilton 1991). The Carmans River is subject to seasonal hypoxia during summer months in the deeper portions of mid-river locations (~ receivers 7- 11 in this study), though most of the year the river is well oxygenated due to the freshwater input from the north and the tidal mixing from the south (Zaikowski et al. 2008). During the warmest months of the year (June – August), the average receiver location for the tagged perch is between receivers 10 and 11, with an average standard deviation of approximately one receiver. The fish spend the majority of the summer above the region in the Carmans that is subject to occasional hypoxia. However, DO levels cannot be the sole driver of spatial movement, as fish rarely spent time at the mouth of the Carmans during the summer months. Both the mouth and upper portions of the river have regular flushing and input of oxygen-rich water (Zaikowski et al. 2008), so it would be expected to see perch habituating both upriver and downriver locations.

### **Fall Movement and Behavior**

During fall, white perch home range and activity levels increased to the point where fish were utilizing the entire river. During this season there was also a rapid change in daily average temperature. High daily average temperatures have already been described to influence perch movement; here, daily temperatures entered a range that was more conducive for increased activity. Optimal temperatures actively selected by perch vary by geographic location and acclimation temperature (Setzler-Hamilton 1991). In the Hudson River, white perch actively avoided temperatures  $<9.5^{\circ}\text{C}$  and  $>34.5^{\circ}\text{C}$  while selecting for a temperature of  $27.8^{\circ}\text{C}$  (Texas Instruments 1979). Since white perch show variation in optimal temperature preference (Hardy

1978, Setzler-Hamilton 1991) and average daily temperatures for the Carmans are relative since temperatures were only recorded from a single location, actual optimal temperatures for Carmans River perch are uncertain. Optimal temperatures provide suitable conditions for white perch maximum growth rates (Mansueti 1961, Stanley and Danie 1983). Dietary samples suggested that perch consume more food during the autumn than they do during summer months. Additionally, migratory predators and competitors of perch, such as striped bass, which commonly migrate to overwintering grounds during the autumn (Chapoton and Sykes 1961), were no longer in the system. Perch utilized a more expansive forage area, since predation and competition avoidance no longer have precedence over feeding. The increase in consumption during autumn would also prepare perch for the winter months when activity is extremely reduced.

### **Winter Movement and Behavior**

Winter resulted in a reduction in perch spatial movement and activity, with a distinct, two-week overwintering period where all tagged perch were detected within the same area. Minimum bottom average temperatures were found to correspond to reductions in both perch home range and activity levels. During winter, a decline in temperature corresponds to a decline in metabolic rate (Pough 1980, Crawshaw 1984), reducing the animal's need to forage. Large fat reserves and body size increase fish survival through winter (Johnson and Evans 1991, Garvey et al. 2004). White perch are known exhibit overwintering behavior (Setzler-Hamilton 1991), and similar forage responses to temperature are seen in largemouth bass (Crawshaw 1984). Prior to this period of semi-hibernation, individuals were most likely heightening their forage activity in preparation for the winter season. Low water temperatures could be a trigger to slow feeding

rates. Feeding behavior was found to halt altogether in American eels at temperatures below 14°C (Barila and Stauffer Jr. 1980).

During periods of high stress, such as below-freezing temperatures, it is possible that perch selected a region of the river near receiver 13 that had salinities suitable for the fish to reduce the need to osmoregulate. Osmoregulation can be energetically costly by increasing metabolic rate and reducing growth rate (Boeuf and Payan 2001). White perch overwintered in the Carmans River in a location that was well above the salt wedge (Figures 4 and 5; Table 1). Salinity may have varied substantially in this area on brief occasions since upriver salinity excursions were detected during the summer (Figure 11a). By avoiding large changes in salinity, striped bass overwintering survival has been shown to be enhanced at specific salinity ranges (Hurst and Conover 2002) suggesting that fish prefer specific salinity regimes during times of stress. Carmans River perch tended to select towards lower salinities with low variability.

Ice was present in the Carmans River during the winter and may have influenced perch habitat selection and movement. Anchor ice can exclude fish from river habitat they normally access, forcing fish to use a different area (Brown 1999). Frazil ice can be harmful to fish, as the fine crystals can get inhaled (Brown et al. 1994, Brown 1999). Surface ice formation was limited in the Carmans River and its formation pattern unknown.

Overwintering has been previously noted in white perch (Setzler-Hamilton 1991), and they can enter a form of semi-hibernation (Collette and Klein-MacPhee 2002). However, feeding may not entirely cease during winter despite the metabolic cost of digestion. In the Patuxent River, white perch populations actively fed during winter months at depths of 20-100 feet (Mansueti 1961). However, the Patuxent River is a larger, deeper habitat appropriate for sustaining much larger populations of white perch than the Carmans River. Zaikowski et al.

(2008) estimated the overwintering location in the Carmans to have a below mean low tide depth of 0.9m, which is extremely shallow when compared to the Patuxent River. Here, the observed overwintering period was characterized by both a reduction in activity levels and restriction in spatial use of the Carmans River.

### **Spring Movement and Behavior**

During the spring season, a rapid change in daily average temperature corresponded to an increase in perch home range and activity. As water temperature begins to increase, fish generally respond by awakening from their state of dormancy and start to actively forage (Crawshaw 1984). Post-overwintered fish are generally malnourished, and both migration and spawning events require a high expenditure of energy for traveling, osmoregulation, and gonad production (e.g., Jonsson et al. 1997, Bransden et al. 2007). Spawning season starts around the end of March for white perch (Setzler-Hamilton 1991). Average location data reflect an increase in home range during this time period as well as an increase in activity level. Like the autumn movement pattern, these increases suggest that white perch were foraging throughout the entire length of the river. Unfortunately only two individuals were collected during the spring period for dietary analysis, so assumptions on forage activity and success during the spring are largely based on spatial movement and activity data. Further study is needed to fully understand how feeding behavior in white perch relates to temperature changes.

### **Migration and Metapopulation Structure**

A migration event occurred at the end of March that coincided with the start of spawning season. Perch were observed moving towards the mouth of the Carmans during the same two-week

period, but varied in their succeeding movement patterns. Because of the matched timing between spawning season and the observed migratory behavior, it is clear that the variation in migratory response by the perch was linked to their drive to spawn. There were three migratory behaviors seen in the white perch tagged in the Carmans: residency, where fish migrated to the mouth of the river but never left; semi-anadromy, where fish left the Carmans, entered the Bay, and did not return, presumably completing their life cycle in another tributary; and partial anadromy, where fish left the river for a short period of time and later returned to stay.

Variations in migratory behavior have been seen in white perch in other regions (e.g., Kerr et al. 2009), though there has been no previous evidence of migratory variation in the Great South Bay population. There are clear tradeoffs between the migratory and residential contingents.

Migration allows movement to richer feeding grounds, reduced competition, increased spawning group size, and enhancing genetic diversity, while residency allows for reduced energetic expenditure on locating a new habitat and fewer predators (Jonsson and Jonsson 1993, Mangel and Stamps 2001, Brodersen et al. 2008, Kerr et al. 2009).

Temperature is a known mechanism used by fish to determine when to migrate. White perch are known to spawn in temperatures ranging from 10 to 15°C (Mansueti 1961). In this study, the first instance of multiple white perch migrating to the mouth of the Carmans was on 3/27/10 when daily temperatures at the mid-river SeaCAT averaged 8.7°C. Average daily temperature steadily increased six weeks prior to the migration date (Figure 8b), suggesting the general trend of increasing temperatures, as well as temperatures approaching ~10°C may have initiated perch migration to spawning grounds. This is comparable to white perch migratory behavior described in the literature (e.g., Stanley and Danie 1983, Setzler-Hamilton 1991). Striped bass also use temperature as a cue to both start and cease spawning (Hill et al. 1989).

Recruitment success from perch spawning in other tributaries may be variable as white perch are periodic strategists, where recruitment success is periodical as it is largely dependent on environmental conditions (Winemiller and Rose 1992, Kraus and Secor 2004), which includes temperature. The correlation between temperature and recruitment success by perch in Great South Bay should be investigated in the future for management purposes. It would provide information on age-class strength, population fluctuations, and optimal environmental conditions for white perch recruitment.

Further research is needed on this population to identify characteristics of individuals and mechanisms used by fish to determine which migration mode is most appropriate for each individual. One character used to determine migratory patterns is body size, as shown to be the case in bull trout (Monnot et al. 2008). Larger trout were more likely to migrate downriver whereas the migratory behavior was more variable in smaller fish. White perch in the Patuxent River estuary were found to have two contingents with different growth rates; adult fish that left their natal habitat on average grew at a faster rate in their first five years of life and had a higher survival than their freshwater counterpart (Kraus and Secor 2004). There is not sufficient evidence for the identification of contingents within the white perch population in this study. Fish of both the smaller and larger body lengths were seen to exhibit some form of migration, and mid-sizes were mixed between the three migration modes.

Tagged fish were also estimated to be older than four years, which is beyond the point of using size and growth rate as a differentiating characteristic for migration. White perch have been reported to mature at age 2, with maturity occurring as late as four years for some individuals (Hardy 1978, Stanley and Danie 1983). Length-at-age data collected for white perch in the Carmans suggests the acoustically tagged fish, which were required to be ~25cm in TL for

tagging, were four years at youngest. This suggests that the acoustic study may not have included the smaller mature group of the population that may have migrated during the same period as the tagged fish. Variability in migratory behavior of the smaller size range of perch targeting fish younger than five years should be investigated to see if migration patterns can be correlated to body length.

Differentiation in migratory behavior could be attributed to phenotypic variation between individuals exhibiting each migration type. Kraus and Secor (2004) suggested two alternative hypotheses for determining the inheritance of migratory behavior: either the contingents exhibiting each behavior are genetically distinct, or that the migratory variation derives from plasticity of a single genotype. If the first hypothesis is true, then migratory behavior is 'pre-programmed' in each individual. However, if the latter is the case, life history, environmental conditions and biological stressors play a much more critical role in the determination of migratory behavior. Juvenile white perch were found to exhibit variable degrees of downriver migration, and fish reared in freshwater and brackish water habitats were found to have differing growth trajectories even though they were spawned in the same habitat (Kraus and Secor 2004). Kerr et al. (2009) additionally argued that slower-growing fish remained residential as the trade-offs of staying in their natal habitat outweighed those associated with migration. Thus, it can be assumed that white perch have some phenotypic plasticity in determining what migratory behavior is appropriate. Perch have even been known to switch from residential to migratory behavior (Kerr et al. 2009).

In this study, there is evidence for both a migratory and a residential behavior within the same white perch population based on their migratory behavior during spawning season. Whether these groups should be considered one or multiple genetically unique populations is

essential to successful fisheries management. Genetic variation and phenotypic plasticity should be investigated in the Great South Bay white perch population.

### **Acoustic Telemetry Use and Management Applications**

The current study achieved nearly 100% coverage of both the focal habitat area and the daily fish detection period. Most acoustic studies encompass large areas for monitoring an animal's movement, which leads general conclusions about movement behavior and assumptions about the intermittent temporal coverage (i.e., Pecl et al. 2006, DeGrandchamp et al. 2008, Sackett et al. 2008). Receiver locations in these studies are too sparse to provide information regarding short-term animal behavior and spatial use of the focal habitat. The acoustic array used in this study incorporated a small-scale and a larger-scale component. Fine-scale information on white perch movement was collected in their primary habitat and more scattered information concerning migratory pathways was obtained outside the Carmans River. The numerous benefits incorporated into small-scale acoustic studies of commercially- and ecologically-important fish will significantly enhance the effectiveness of fisheries management plans if included in management research efforts.

States with implemented white perch management plans are concerned with limiting further dispersal of white perch into new habitats (Foster et al. 2009), and culling existing populations, which reduces the occurrence of stunted growth in populations and limits overfeeding (Smith 2002). One method for successfully implementing both of these strategies is to have a thorough understanding of white perch home range and how it varies daily and seasonally. Daily home range estimates can reveal information on critical habitats and routine behaviors that may be lost if detection periods contain large gaps. The robust spatial data on



white perch in this study provides a foundation to infer daily behavior. Such information will largely benefit both management strategies described, which relate to both invasive and native populations of perch.

A small-scale study with an extensive detection period coverage can also be used to estimate variations in activity level. Because of the extensive detection coverage for each fish over their detection period, daily activity levels could be estimated based on changes in receiver location. While resolution is lost since estimates of activity within the range of a single receiver are unknown, a general picture can be created of how fish activity level changes over the course of the year. Variations in activity were attributed to changes in behavior, as shown through the break point analysis (Frisk et al. 2011). These responses can be used in management plans to determine when fish interact with other species. By identifying periods of high activity, management efforts to cull the population (e.g., Smith 2002) can target certain times of day and seasons to enhance catchability.

Continuously monitoring environmental changes provides insight on the correlations between within-habitat environmental changes and movement. Changes in temperature and salinity can have a significant effect on fish movement and behavior (Sackett et al. 2008). In this study, white perch were found to expand and contract their home range based on seasonal average temperatures. Finding connections between environmental and behavioral changes can provide mechanisms for predicting fish movement based on current environmental conditions. This becomes important when constructing fishery management plans since predicting fish movement can provide information for both the opening and closure of recreational and commercial fisheries. Some environmental cues, such as temperature, can initiate migration in fish (Hill et al. 1989, Setzler-Hamilton 1991). A similar response to an increase in temperature

after overwintering was seen in the perch in this study. This suggests that environmental and behavioral correlations can also be used for stock assessments as some diadromous fish stocks can be evaluated during spawning runs (Hughes and O'Reilly 2008, Kocik et al. 2009). Thus, continuous monitoring of environmental changes should be included in small-scale acoustic studies.

## **CHAPTER 1 CONCLUSION**

White perch behavior is complex, where fish spatially and temporally use regions of the Carmans River and Great South Bay habitat to exhibit distinct behaviors. Foraging behavior is coupled with an expansion in habitat range and an increase in activity. The overwintering period corresponds to restricted spatial movement and activity, where fish reduce activity in response to cold temperatures. Spring spawning season results in an increase in spatial use of the river, increased activity, and movement outside of the Carmans River. During the summer, movement and activity are largely reduced and limited to upriver areas. By identifying variations in white perch behavior, spatial and temporal habitat use can be incorporated into management efforts, as essential fish habitats should be conserved and monitored.

White perch behavior is influenced by a number of biological and environmental factors. Temperature effects corresponded to changes in home range and activity levels, with fish confining their movement to a few upriver receivers during winter. Their restricted movement suggests a period where perch enter a state of semi-hibernation, as described by Collette and Klein-MacPhee (2002), which they are aroused from when the river temperature increases during spring. Seasonality was also shown to influence activity, home range, and behavioral switching in perch, where higher levels of movement were displayed during spring and fall, and reduced activity and spatial movement occurred during summer and winter. Some factors that may

influence perch movement, but were not thoroughly investigated in this study, include predator presence, intra-specific competition, prey availability, and dissolved oxygen. Migratory predators of perch, such as adult striped bass (Heimbuch 2008), are only present in the rivers during certain times of the year to feed (Hill et al. 1989). The seasonal appearance of this predator may restrict perch to specific habitats and feeding times to avoid becoming prey – a common behavior seen in fish. By restricting the perch population to specific regions, the competition between individuals for food increases. Forage opportunities are more apparent during the fall and spring, when adult striped bass are absent from the system. The perch also have a high energetic need for food during these seasons since they recently endured stressful environmental conditions. White perch may also actively avoid low-DO regions of the river, primarily during the summer, since perch tend to require DO levels of 6ppm (Setzler-Hamilton 1991).

A single white perch population can exhibit a variety of migratory behaviors during spawning season. White perch spawning season in the Carmans River occurred in late March/early April. During this period, all tracked perch increased their activity and spatial use of the Carmans, particularly by receivers at the river mouth. A few individuals remained in the Carmans River during the spawning period while others migrated out of the system and were detected on receivers within Great South Bay. This suggests that within the same population of white perch there can be variation in migratory behavior. Partial migration has been previously described in white perch (Kerr and Secor 2009, Kerr et al. 2009), and this may also be the case for Carmans river perch. Future investigation on the Carmans River white perch is needed to determine if the residential and migratory contingents are from the same population.

## LITERATURE CITED

- Aguilar, R., A. Hines, T. Wolcott, D. Wolcott, M. Kramer, and R. Lipcius. 2005. The timing and route of movement and migration of post-copulatory female blue crabs, *Callinectes sapidus* Rathbun, from the upper Chesapeake Bay. *Journal of Experimental Marine Biology and Ecology* **319**:117-128.
- Almeida, P. R. 1996. Estuarine movement patterns of adult thin-lipped grey mullet, *Liza ramada* (Risso) (Pisces, Mugilidae), observed by ultrasonic tracking. *Journal of Experimental Marine Biology and Ecology* **202**:137-150.
- Barila, T. Y. and J. R. Stauffer Jr. 1980. Temperature behavioral response of the American eel, *Anguilla rostrata* (Lesueur), from Maryland. *Hydrobiologia* **74**:49-51.
- Bayless, J. D. 1972. Artificial propagation and hybridization of striped bass, *Morone saxatilis* (Walbaum). South Carolina Wildlife Resource Department. 135pp.
- Boeuf, G. and P. Payan. 2001. How should salinity influence fish growth? *Comparative Biochemistry and Physiology C-Toxicology & Pharmacology* **130**:411-423.
- Borcherding, J. 2006. Prey or predator: 0+perch (*Perca fluviatilis*) in the trade-off between food and shelter. *Environmental Biology of Fishes* **77**:87-96.
- Brandsen, M. P., S. C. Battaglione, R. C. Goldsmid, G. A. Dunstan, and P. D. Nichols. 2007. Broodstock condition, egg morphology and lipid content and composition during the spawning season of captive striped trumpeter, *Latris lineata*. *Aquaculture* **268**:2-12.
- Brodersen, J., P. A. Nilsson, L. A. Hansson, C. Skov, and C. Brönmark. 2008. Condition-dependent individual decision-making determines cyprinid partial migration. *Ecology* **89**:1195-1200.

- Bronmark, C., C. Skov, J. Brodersen, P. A. Nilsson, and L. A. Hansson. 2008. Seasonal Migration Determined by a Trade-Off between Predator Avoidance and Growth. *Plos One* **3**: 1-6.
- Brown, R. S. 1999. Fall and early winter movements of cutthroat trout, *Oncorhynchus clarki*, in relation to water temperature and ice conditions in Dutch Creek, Alberta. *Environmental Biology of Fishes* **55**:359-368.
- Brown, R. S., S. S. Stanislawski, and W. C. Mackay. 1994. Effects of frazil ice on fish. National Hydrology Research Institute, Saskatoon. NHRI Symposium Series **12**: 261-278.
- Cashin Associates, P. C. 2002. Carmans river environmental assessment Hauppauge, NY. 135pp.
- Cederholm, C. J., M. D. Kunze, and A. Sibatani. 1999. Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. *Fisheries* **24**:6-15.
- Chapoton, R. B. and J. E. Sykes. 1961. Atlantic coast migration of large striped bass as evidenced by fisheries and tagging. *Transactions of the American Fisheries Society* **90**:13-20.
- Collette, B. B. and G. Klein-MacPhee. 2002. The sea basses. Family Serranidae. Pages 405-406 *Bigelow and Schroeder's fishes of the Gulf of Maine*. Smithsonian Institution Press, Washington D.C.
- Cooke, S. J. 2008. Biotelemetry and biologging in endangered species research and animal conservation: relevance to regional, national, and IUCN Red List threat assessments. *Endangered Species Research* **4**:165-185.
- Coutant, C. 1976. Thermal effects on fish ecology. Pages p. 891-896 *Encyclopedia of Environmental Science and Engineering*. Gordon and Breach Publishers, New York.

- Couture, S. C. and M. C. Watzin. 2008. Diet of invasive adult white perch (*Morone americana*) and their effects on the zooplankton community in Lake Champlain. *Journal of Great Lakes Research* **34**:485-494.
- Crawshaw, L. 1984. Low-temperature dormancy in fish. *The American Physiological Society* **246**:R479-R486.
- Danehy, R. J., N. H. Ringler, and J. E. Gannon. 1991. Influence of nearshore structure on growth and diets of yellow perch (*Perca flavescens*) and white perch (*Morone americana*) in Mexico Bay, Lake Ontario. *Journal of Great Lakes Research* **17**:183-193.
- Deegan, L. A. 1993. Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migration. *Canadian Journal of Fisheries and Aquatic Sciences* **50**:74-79.
- DeGrandchamp, K. L., J. E. Garvey, and R. E. Colombo. 2008. Movement and habitat selection by invasive asian carps in a large river. *Transactions of the American Fisheries Society* **137**:45-56.
- DOS, N. 1987. Great South Bay - East. New York State Department of State, Division of Coastal Resources. 7pp.
- Dowhan, J., T. Halavik, A. Milliken, A. MacLachlan, M. Caplis, K. Lima, and A. Zimba. 1997. Significant habitats and habitat complexes of the New York Bight watershed. U.S. Fish and Wildlife Service, Charlestown, RI.
- Durbin, A. G., S. W. Nixon, and C. A. Oviatt. 1979. Effect of the spawning migration of the alewife, *Alosa pseudoharengus*, on freshwater ecosystems. *Ecology* **60**:8-17.

- Fitzgerald, D. G., J. L. Forney, L. G. Rudstam, B. J. Irwin, and A. J. Van De Valk. 2006. Gizzard shad put a freeze on winter mortality of age-0 yellow perch but not white perch. *Ecological Applications* **16**:1487-1501.
- Foster, A., J. Boxrucker, G. Gilliland, B. Wentroth, and C. Tackett. 2009. Oklahoma aquatic nuisance species management plan. Oklahoma Department of Wildlife Conservation. 125pp.
- Frisk, M. G., D. E. Duplisea, and V. M. Trenkel. 2011. Exploring the abundance-occupancy relationships for the Georges Bank finfish and shellfish community from 1963 to 2006. *Ecological Applications* **21**:227-240.
- Frisk, M. G., T. J. Miller, S. J. D. Martell, and K. Sosebee. 2008. New hypothesis helps explain elasmobranch "outburst" in Goerges Bank in the 1980's. *Ecological Applications* **18**:234-245.
- Garvey, J. E., K. G. Ostrand, and D. H. Wahl. 2004. Energetics, predation, and ration affect size-dependent growth and mortality of fish during winter. *Ecology* **85**:2860-2871.
- Genovese, P., C. Lewis, and M. Tarnowski. 2005. Maryland's commerical fisheries annual landings data set. Maryland Department of Natural Resources.
- Gillanders, B. M., K. W. Able, J. A. Brown, D. B. Eggleston, and P. F. Sheridan. 2003. Evidence of connectivity between juvenile and adult habitats for mobile fauna: an importnat component of nurseries. *Marine Ecology Progress Series* **247**:281-295.
- Gosch, N. J. C. and K. L. Pope. 2011. Using consumption rate to assess potential predators for biological control of white perch. *Knowledge and Management of Aquatic Ecosystems* **403**: 1-9.

- Groot, C., K. Simpson, I. Todd, P. D. Murray, and G. A. Buxton. 1975. Movements of sockeye salmon (*Oncorhynchus nerka*) in the Skeena River estuary as revealed by ultrasonic tracking. *Journal of Fisheries Research Board of Canada* **32**:233-242.
- Hall, C. J., A. Jordaan, and M. G. Frisk. 2010. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. *Landscape Ecology* **26**:95-107.
- Hanks, D. M. and D. H. Secor. 2010. Bioenergetic responses of Chesapeake Bay white perch (*Morone americana*) to nursery conditions of temperature, dissolved oxygen, and salinity. *Marine Biology* **158**:805-815.
- Hardy, J. D. 1978. Development of fishes of the mid-Atlantic bight: An atlas of egg, larval, and juvenile stages. Volume III, Apheroderidae through Rachycentridae. U.S. Fish and Wildlife Service, Biological Service Program, Washington, D.C.
- Hawes, E. J. and D. L. Parrish. 2003. Using abiotic and biotic factors to predict range expansion of white perch in Lake Champlain. *Journal of Great Lakes Research* **29**:268-279.
- Heimbuch, D. G. 2008. Potential Effects of Striped Bass Predation on Juvenile Fish in the Hudson River. *Transactions of the American Fisheries Society* **137**:1591-1605.
- Helfield, J. M. and R. J. Naiman. 2006. Keystone Interactions: Salmon and Bear in Riparian Forests of Alaska. *Ecosystems* **9**:167-180.
- Hightower, J. E., J. R. Jackson, and K. H. Pollock. 2001. Use of telemetry methods to estimate natural and fishing mortality of striped bass in Lake Gaston, North Carolina. *Transactions of the American Fisheries Society* **130**:557-467.
- Hill, J., J. W. Evans, and M. J. Van Den Avyle. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) - striped



- bass. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.118). Army Corps of Engineers TR EL-82-4.
- Hinga, K. R. 2005. Water quality and ecology of Great South Bay (Fire Island National Seashore Science Synthesis Paper). National Park Service, Boston, MA. 39pp.
- Holdo, R. M., R. D. Holt, A. R. E. Sinclair, B. J. Godley, and S. Thirgood. 2011. Migration impacts on communities and ecosystems: empirical evidence and theoretical insights. Pages 131-143 in E. J. Milner-Gulland, J. M. Fryxell, and A. R. E. Sinclair, editors. Animal migrations: A synthesis. Oxford University Press.
- Hughes, A. and C. O'Reilly. 2008. Monitoring alewife runs in the south shore estuary reserve. South Shore Estuary Reserve. 12pp.
- Hurst, T. P. and D. O. Conover. 2002. Effects of temperature and salinity on survival of young-of-the-year Hudson River striped bass (*Morone saxatilis*): implications for optimal overwintering habitats. Canadian Journal of Fisheries and Aquatic Sciences **59**:787-795.
- Hyslop, E. J. 1980. Stomach contents analysis - a review of methods and their application. Journal of Fish Biology **17**:411-429.
- Texas Instruments Incorporated. 1979. Hudson river ecological study in the area of Indian Point 1977 Annual Report. Consolidated Edison Company of New York, Inc., New York. 208pp.
- Johnson, T. B. and D. O. Evans. 1991. Behaviour, energetics, and associated mortality of young-of-the-year white perch (*Morone americana*) and yellow perch (*Perca flavescens*) under simulated water conditions. Canadian Journal of Fisheries and Aquatic Sciences **48**:672-680.

- Jonsson, B. and N. Jonsson. 1993. Partial migration: niche shift versus sexual maturation in fishes. *Reviews in Fish Biology and Fisheries* **3**:348-365.
- Jonsson, N., B. Jonsson, and L. P. Hansen. 1997. Changes in proximate composition and estimates of energetic costs during upstream migration and spawning in Atlantic salmon *Salmo salar*. *Journal of Animal Ecology* **66**:425-536.
- Juanes, F. and R. E. Marks. 1993. Predation by age-0 bluefish on age-0 anadromous fishes in the Hudson River estuary. *Transactions of the American Fisheries Society* **22**:348-356.
- Kahnle, A., K. Hattala, and E. Stegemann. 1991. The true bass of New York. *The Conservationist* **46**.
- Kerr, L. A. and D. H. Secor. 2009. Bioenergetic trajectories underlying partial migration in Patuxent River (Chesapeake Bay) white perch (*Morone americana*). *Canadian Journal of Fisheries and Aquatic Sciences* **66**:602-612.
- Kerr, L. A., D. H. Secor, and P. M. Piccoli. 2009. Partial migration of fishes as exemplified by the estuarine-dependent white perch. *Fisheries* **34**:114-123.
- Kocik, J., R. Haas-Castro, G. Shepherd, and C. Lipsky. 2009. Atlantic anadromous fisheries. NMFS-F/SPO-80.
- Kraus, R. and D. Secor. 2005. Connectivity in estuarine white perch populations of Chesapeake Bay: evidence from historical fisheries data. *Estuarine, Coastal and Shelf Science* **64**:108-118.
- Kraus, R. and D. H. Secor. 2004. Dynamics of white perch *Morone americana* population contingents in the Patuxent River estuary, Maryland, USA. *Marine Ecology Progress Series* **279**:247-259.

- Liao, H., C. L. Pierce, and J. G. Larscheid. 2001. Empirical assessment of indices of prey importance in the diets of predacious fish. *Transactions of the American Fisheries Society* **130**:583-591.
- Limburg, K. E. and J. R. Waldman. 2009. Dramatic Declines in North Atlantic Diadromous Fishes. *BioScience* **59**:955-965.
- Maclean, J. A. and D. O. Evans. 1981. The stock concept, discreteness of fish stocks, and fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences* **38**:1889-1898.
- Mangel, M. and J. Stamps. 2001. Trade-offs between growth and mortality and the maintenance of individual variation in growth. *Evolutionary Ecology Research* **3**:583-593.
- Mansueti, R. J. 1961. Movements, reproduction, and mortality of the white perch, *Roccus americanus*, in the Patuxent Estuary, Maryland. *Chesapeake Science* **2**:142-205.
- Mansueti, R. J. 1964. Eggs, larvae, and young of the white perch, *Roccus americanus*, with comments on its ecology in the estuary. *Chesapeake Science* **5**:3-45.
- Margulies, D. 1990. Vulnerability of larval white perch, *Morone americana*, to fish predation. *Environmental Biology of Fishes* **27**:187-200.
- McGrath, P. and H. A. Austin. 2009. Site Fidelity, Home Range, and Tidal Movements of White Perch during the Summer in Two Small Tributaries of the York River, Virginia. *Transactions of the American Fisheries Society* **138**:966-974.
- Mellas, E. J. and J. M. Haynes. 1985. Swimming performance and behavior of rainbow trout (*Salmo gairdneri*) and white perch (*Morone americana*): effects of attaching telemetry transmitters. *Canadian Journal of Fisheries and Aquatic Sciences* **42**: 488-493

- Mihursky, J. A., W. R. Boynton, E. M. Setzler, K. V. Wood, H. H. Zion, E. W. Gordon, L. Tucker, P. Pulles, and J. Leo. 1976. Final report on Potomac Estuary fisheries study: Ichthyoplankton and juvenile investigations. University of Maryland Center for Environmental and Estuarine Studies. 241pp.
- Monnot, L., J. B. Dunham, T. Hoem, and P. Koetsier. 2008. Influences of body size and environmental factors on autumn downstream migration of bull trout in the Boise River, Idaho. *North American Journal of Fisheries Management* **28**:231-240.
- Moring, J. R. and L. H. Mink. 2002. Anadromous alewives, *Alosa pseudoharengus*, as prey for white perch, *Morone americana*. *Hydrobiologia* **479**:125-130.
- Moser, M. L., M. Bain, M. R. Collins, N. Haley, B. E. Kynard, J. C. O'Herron II, G. Rogers, and T. S. Squiers. 2000. A protocol for use of shortnose and Atlantic sturgeons. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and National Marine Fisheries Service. 21pp.
- Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* **16**:4-21.
- Nickum, J. G., H. L. Bart Jr., P. R. Bowser, I. E. Greer, C. Hubbs, J. A. Jenkins, J. R. MacMillan, J. W. Rachlin, J. D. Rose, P. W. Sorensen, and J. R. Tomasso. 2004. Guidelines for the use of fishes in research. American Fisheries Society; American Institute of Fishery Research Biologists; American Society of Ichthyologists and Herpetologists. 58pp.
- Nislow, K. H. and B. E. Kynard. 2009. The role of anadromous sea lamprey in nutrient and material transport between marine and freshwater environments. *American Fisheries Society Symposium* **69**:485-494.

- NMFS. 2008. Summary of essential fish habitat (EFH) and general habitat parameters for federally managed species. National Marine Fisheries Service, Northeast Regional Office, Habitat Conservation Division.
- Nuttall, M. A., A. Jordaan, R. M. Cerrato, and M. G. Frisk. 2011. Identifying 120 years of decline in ecosystem structure and maturity of Great South Bay, New York using the Ecopath modelling approach. *Ecological Modelling* **222**:3335-3345.
- NYOGLECC. 2009. Great South Bay ecosystem-based management demo area. New York Ocean and Great Lakes Ecosystem Conservation Council. 4pp.
- NYSDOS. 2012. Sportfishing regulations. *in* N. D. o. S. D. o. A. Rules, editor. 6. New York codes, rules, and regulations, USA.
- NYSDOS and USFWS. 1998. Estuarine finfish. South Shore Estuary Reserve Council. 45pp.
- Overton, A. S. and M. J. Van Den Avyle. 2005. Effects of salinity on survival, growth, and nutritional condition of striped bass: possible environmental factors effecting their distribution in southeast estuaries. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies* **59**:313-324.
- Pecl, G. T., S. R. Tracey, J. M. Semmens, and G. D. Jackson. 2006. Use of acoustic telemetry for spatial management of southern calamary *Sepioteuthis australis*, a highly mobile inshore squid species. *Marine Ecology Progress Series* **328**:1-15.
- Pinkas, L., M. S. Oliphant, and I. L. K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. *California Department of Fish and Game Bulletin* **152**:1-105.
- Pough, F. H. 1980. The advantages of ectothermy for tetrapods. *The American Naturalist* **115**:92-112.

- Powles, H., M. J. Bradford, R. G. Bradford, W. G. Doubleday, S. Innes, and C. D. Levings. 2000. Assessing and protecting endangered marine species. *Ices Journal of Marine Science* **57**:669-676.
- Ryer, C. H. and B. L. Olla. 1998. Shifting the balance between foraging and predator avoidance: the importance of food distribution for a schooling pelagic forager. *Environmental Biology of Fishes* **52**:467-475.
- Sackett, D. K., K. W. Able, and T. M. Grothues. 2008. Habitat dynamics of summer flounder *Paralichthys dentatus* within a shallow USA estuary, based on multiple approaches using acoustic telemetry. *Marine Ecology Progress Series* **364**:199-212.
- Schaeffer, J. S. and F. J. Margraf. 1987. Predation on fish eggs by white perch, *Morone americana*, in western Lake Erie. *Environmental Biology of Fishes* **18**:77-80.
- Schubel, J. R., T. M. Bell, and H. H. Carter. 1991. *The Great South Bay*. SUNY Press, Albany, NY. 107pp.
- Schultz, E. T., J. P. Davis, and J. Vokoun. 2009. Estimating predation on declining river herring: Tag-recapture study of striped bass in the Connecticut River. *EEB Articles* **21**:43pp.
- Scott, W. B. and E. J. Crossman. 1973. *Freshwater fishes of Canada*. Fisheries Research Board of Canada **184**:966pp.
- Setzler-Hamilton, E. M. 1991. *White perch (Morone americana)*. U.S. EPA Chesapeake Bay Program. 20pp.
- Shoji, J., E. W. North, and E. D. Houde. 2005. The feeding ecology of *Morone americana* larvae in the Chesapeake Bay estuarine turbidity maximum: the influence of physical conditions and prey concentrations. *Journal of Fish Biology* **66**:1328-1341.

- Sims, D. W., V. J. Wearmouth, M. J. Genner, A. J. Southward, and S. J. Hawkins. 2004. Low-temperature-driven early spawning migration of a temperate marine fish. *Journal of Animal Ecology* **73**:333-341.
- Smith, M. R. 2002. White perch management plan. Department of Inland Fisheries and Wildlife Division of Fisheries and Hatcheries. 19pp.
- Smith, R. E. and R. J. Kernehan. 1981. Predation by the free-living copepod, *Cyclops bicuspidatus thomasi*, on larvae of the striped bass and white perch. *Estuaries* **4**:81-83.
- Socrates, J. B. 2007. A study of the striped bass in the marine district of New York state. New York State Department of Environmental Conservation. 137pp.
- Stanley, J. G. and D. S. Danie. 1983. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic - white perch). U.S. Fish and Wildlife Service; U.S. Army Corps of Engineers. 12pp.
- Stokesbury, M. J. W., M. J. Dadswell, K. N. Holland, G. D. Jackson, W. D. Bowen, and R. K. O'Dor. 2009. Tracking diadromous fishes at sea: the electronic future using hybrid acoustic and archival tags. *American Fisheries Society Symposium* **69**:1-10
- Thorstad, E. B., F. Økland, K. Aarestrup, and T. G. Heggberget. 2007. Factors affecting the within-river spawning migration of Atlantic salmon, with emphasis on human impacts. *Reviews in Fish Biology and Fisheries* **18**:345-371.
- USFWS, N. S. D. o. S. a. 1999. Diadromous fish. South shore estuary reserve technical report series: 24pp.
- Walters, A. W., R. T. Barnes, and D. M. Post. 2009. Anadromous alewives (*Alosa pseudoharengus*) contribute marine-derived nutrients to coastal stream food webs. *Canadian Journal of Fisheries and Aquatic Sciences* **66**:439-448.

- Weis, J. S. 2005. Diet and food web support of the white perch, *Morone americana*, in the hackensack meadowlands of New Jersey. *Environmental Biology of Fishes* **74**:109-113.
- Whitfield, A. K. and M. Elliott. 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. *Journal of Fish Biology* **61**:229-250.
- Willson, M. F. and K. C. Halupka. 1995. Anadromous fish as keystone species in vertebrate communities. *Conservation Biology* **9**:489-497.
- Winemiller, K. O. and K. A. Rose. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* **49**:2196-2218.
- Zaikowski, L., K. T. McDonnell, R. F. Rockwell, and F. Rispoli. 2008. Temporal and Spatial Variations in Water Quality on New York South Shore Estuary Tributaries: Carmans, Patchogue, and Swan Rivers. *Estuaries and Coasts* **31**:85-100.



## **CHAPTER 2 – Diel behavior in the white perch revealed through acoustic telemetry in the Carmans River, Long Island, NY**

### **INTRODUCTION**

The decline of diadromous species' abundance and diversity has received a lot of attention (Limburg and Waldman 2009). Declines are attributed to a number of factors, including habitat degradation, overfishing (Nehlsen et al. 1991), climate change (Limburg and Waldman 2009), and increased levels of predation (Heimbuch 2008, Schultz et al. 2009). Habitat loss via dam construction and other man-made obstacles has resulted in the extirpation and near extinction of several diadromous species (Nehlsen et al. 1991, Powles et al. 2000, Hall et al. 2010). The loss of important commercial fisheries in both marine and freshwater systems, and the loss of nutrients to terrestrial ecosystems are a few of the reasons research has focused on these important species. However, there are numerous species that occur in downriver locations that migrate on smaller scales, termed semi-anadromous, and occupy a similar ecological role connecting marine, estuarine and freshwater habitat. In many systems upriver damming has eliminated species that undertake longer distance migrations, often leaving only semi-diadromous species (Hall et al, 2011; Hall et al., 2012). Semi-anadromous species have received comparatively little research and management attention and now represent the only remaining exchange between marine and riverine habitat. As the anadromous species continue to decline in

contemporary ecosystems, these semi-anadromous migrants will play an increasingly important role, highlighting the need to understand the drivers and ecological significance of their migrations.

There is a paucity of research on the fine-scale behavior of diadromous fishes, leaving a critical gap in the understanding of migratory pathway choice, species interactions, and behavioral responses to environmental factors (Stokesbury et al. 2009). As a result, short-scale movements, such as daily feeding behavior, predator avoidance, and migration between habitats is commonly overlooked, often because it is unknown and/or difficult to quantify (Beck et al. 2001). Diel movement is an important biological strategy to take advantage of small scale temporal and spatial variation to maximize survival and reduce energetic expenditure. Different strategies, such as predator avoidance (Gibson et al. 1998, Baumgartner et al. 2008), movement to preferred feeding grounds (Bohl 1980, Rooker and Dennis 1991, Gibson et al. 1998), and the maintenance of optimal environmental conditions (Gibson et al. 1998) have all been connected to different forms of diel behavior. However, traditional fisheries management strategies do not incorporate many ethological and ecological factors including diel movement, but instead focus on broad-scale catch rates to maintain a sustainable yield without depleting the stock's productivity (Pitcher 2001).

The white perch (*Morone americana*) is a semi-anadromous species that frequents coastal systems of the eastern Atlantic Ocean. Its range extends inland and it is commonly found in freshwater, estuarine and marine habitats. The life cycle of white perch is dependent on a diversity of habitats with spawning and overwintering occurring in freshwater and seasonal and daily migrations between estuarine and freshwater habitat during the summer and fall (see Chapter 1). The spatial behavior of perch is tied to daily and seasonal variation in environmental

conditions (Setzler-Hamilton 1991). Resource managers must consider behavior and habitat requirements in coastal regions that are often heavily altered by anthropogenic activities such as development, artificial lighting (Riley et al. 2012) and eutrophication (Ludsin et al. 2009), as fish use different habitats at different times.

Here we investigate the daily movement patterns of white perch in the Carmans River utilizing passive acoustic telemetry. Through investigating otolith chemistry (Kerr et al. 2009) and juvenile white perch physiology (Kerr and Secor 2009), it was discovered that there is a residential and migratory contingent of white perch coexisting in the Chesapeake Bay system. In the Great South Bay system, white perch are categorized as a semi-anadromous fish that may exhibit partial migration (see Chapter 1, Figure 1a). Perch movement is restricted by the Hards Lake dam and consists of a 5.5 km section of river that spans from freshwater to estuarine environments (See Appendix – Map 2). Little is known about the daily behavior of adult white perch and how their behavior may change over time. Through acoustic telemetry, this study reveals diel behavior in adult perch and examines factors that may influence the occurrence of this behavior. Variations in diel behavior and activity levels are expected to correlate with environmental drivers including temperature, salinity, and seasonality. Ecological implications of fine-scale habitat use and implications to conservation of diadromous species are discussed.

## **MATERIALS AND METHODS**

### **Receiver deployment and acoustic tagging**

A total of thirty Vemco™ VR2W acoustic receivers were deployed throughout the Bay, with fifteen in the Carmans River and two or three at the entrances of the Connecticut River, Browns

River, Beaverdam Creek, Swan River, Champlin Creek, Carlls Creek, and Smith Point to Fire Island. The receivers in the Carmans River were placed 500m apart from the Great South Bay to Montauk Highway including six receivers gating the mouth (Appendix – Map 2). A SeaCAT SBE-16 profiler (Sea-bird Electronics) was also deployed in the Carmans River to continuously monitor temperature and salinity (Appendix – Map 2). A second SeaCAT was deployed upriver by the Wertheim Refuge dock in the summer of 2011 to evaluate the salinity and temperature structure of the Carmans River.

Sampling for white perch was conducted by hook-and-line, gillnetting, and electrofishing. Hook-and-line was conducted year-round throughout the river using Size 4 hooks, 18.1kg monofilament #1/4 fishing line, and 0.56m barrel rod and reels. Electrofishing sampling consisted of a single event in October 2010 and was carried out by the New York Department of Environmental Conservation (DEC). Freshwater habitat was electro-sampled using a 5.5m RV the Clark with a Smith Root pulsator operated for 30-minute periods with 354 volts DC at 9amps at a pulse rate of 60Hz. Estuarine habitat was sampled with a Smith Root 16 H pulsator at 170 volts DC at 30amps and a 60Hz pulse rate. Additionally, during 2011, a 18.3m by 1.8m monofilament float-and-lead gill net was used. The net was equipped with three panels consisting of 5.1, 7.6 and 10.2cm stretch mesh, respectively. Gill net soak time was thirty minutes with 8-10 sets per field day.

Healthy fish 25cm or larger were surgically implanted with Vemco© V9 acoustic transmitters. Prior to surgery a low dose (80ppm) of MS-222 was administered until the specimen was immobilized. Following surgery fish were placed in a recovery tank for 5-10 minutes prior to release. If normal buoyancy and respiration did not return following the recovery period fish were euthanized with a lethal dose of MS-222 and used for dietary analysis.

Further explanatory details on both the receiver deployment and tagging procedures can be found in Chapter 1.

### **Statistical Analyses**

*Diel Behavior Identification:* Acoustic detections from individual fish were plotted over time and examined for diel movement. Potential instances were identified visually as upriver/downriver cyclical movements within a 24-hour duration and a minimum period of two days. These instances, termed ‘diel days’, showed fish spending day hours at one receiver location and night hours at a different receiver, with the movement repeated on consecutive days. The spatial variation in cycle location within the receiver array could vary; however, the general movement pattern had to be consistent over the duration of the cycle period. Potential instances were randomly selected from different fish for evaluation of the pattern strength using the autocorrelation function (acf) in R, which was used to identify significant periodicity within a single time series. The lags at peak correlations within a 24-hour period were used to verify diel movement.

*Seasonality in Diel Behavior:* Counts of diel days were used to evaluate seasonality in diel behavior. Diel days were plotted on a timeline to indicate the presence and absence of diel behavior for each individual fish. The frequency of diel days for individual fish was tested for dependence on seasonality using a G-Test for Analysis of Frequencies. Diel days were also summed across fish and compared for overall seasonality dependence using R x C Test for Independence with a G-test. Season start and end dates were based on calendar dates assigned by the NOAA National Weather Service ([www.erh.noaa.gov](http://www.erh.noaa.gov)).

Diel days were also classified into two types of diel behavior: positive cycling, where a fish traveled upriver during the night and downriver during the day and the reverse pattern was termed negative cycling. Seasonal preferences for the two types of diel behavior were tested with a Chi-square test of significance.

*Spatial Variation in Diel Movement:* Locations of diel movement in the Carmans were evaluated by plotting both the average ‘peak’ and ‘trough’ receiver values over time. Peak receiver values corresponded to the upriver acoustic receiver that detected the fish during the diel cycle, and the trough receiver was the furthest downriver receiver. Daily peak and trough receiver values were averaged across all fish.

*Temperature and Salinity Effects on Diel Behavior:* Daily average temperature and salinity derived from SEACAT records were used as measures to evaluate the potential effects of temperature and salinity on the presence and absence of diel behavior. The frequency of diel days and the fraction relative to the total number of days was compiled in a histogram for each 2-unit temperature or salinity bin. Changes in frequencies over the span of the environmental factors were examined for trends. A break point analysis was used to identify changes in the diel day frequencies for the temperature and salinity ranges. The break point analysis groups data based on the optimal number of linear regressions estimated by Bayesian Information Criterion (BIC). Variations in regression slope indicate a behavioral change in response to the investigated variable (Frisk et al. 2011). Here, variations in regressions indicated an effect of temperature or salinity on the occurrence of diel behavior.

*Day and Night Activity:* The daily distance traveled by fish, termed "activity", was estimated and compared for day and night. Daily activity was estimated by using the known distances between adjacent receivers and summing these distances as fish are detected on new receivers over the course of the day. However, if rapid 'turnarounds' were observed between receivers, defined as movement between two adjacent receivers in less than two minutes, a set distance of 25m was assumed (see Eq. 1 in Chapter 1). This distance is based on white perch swim speed findings by Stanley and Danie (1983) and assumed that a white perch travels optimally at a speed between 0.2 and 0.3m/s. Distances between receivers were known based on their GPS coordinates and were used as distance for a fish that left one receiver and remained at another receiver for over two minutes. Start and end points used to designate day and night hours were based on sunrise and sunset times for the region, which were obtained from the U.S. Naval Observatory database. The receiver changes that occurred between dawn and dusk cumulated the daytime activity, while the movement between receivers from dusk to dawn was the night activity. The difference between daily average distance traveled during the day and night was plotted over time, with positive values corresponding to higher levels of activity during the day, and negative values representing higher levels of nighttime activity. A paired t-test of sample means was used test for significant differences between activity during day or night.

## **RESULTS**

### **Seasonality of Diel Behavior**

White perch were collected in the Carmans River from August 2010 – 2011, and a total of 40 fish were tagged with Vemco V9 acoustic transmitters. Fifteen of the 40 tagged fish returned 28+ days of acoustic tracking data. The twenty-five fish that did not return sufficient data had faulty

tags, were caught by fishermen or predators, migrated out of the system, or suffered tagging mortality (see Chapter 1 Results for details). Of the fifteen tagged fish that returned twenty-eight or more days of acoustic data, fourteen fish were identified with days of diel behavior (Figure 1a). Between August 2010 and September 2011 detections were recorded an average of 234 (SD = 114 d) days with an estimated average of 64 (SD = 46 d) diel days per fish.

Thirty time series with diel movement samples were selected to test how accurately diel patterns were identified from each fish's time series. The autocorrelation tests resulted in significant peak hour lag averages of 10.5 (SD = 1.5 h) and 21.3 (SD = 2.9 h) hours. Variation in hourly lags may be due to variations in the number of daylight hours over a 24-hour period, as this will vary between 8 and 14 hours depending on the season. In five cases, only one lag was significant, and two cases resulted in no significant lags. Missing significant lags are due to missing data in the time series, short duration periods at upstream and downstream locations, or variation in upmost receiver location between days. Each of these factors could cause the autocorrelation test to miss identify the periodicity.

Diel behavior occurred throughout the year with a peak frequency during the summer (Figure 2). Winter contained the lowest average percent diel days out of the total average detection period ( $\%_{\text{avg}} = 13.73$ ,  $\%_{\text{SD}} = 10.5$ ). Summer II, which corresponded to the 2011 summer period, had a high average percent diel days out of the total detection period, averaged across fish ( $\%_{\text{avg}} = 33.8$ ,  $\%_{\text{SD}} = 33.9$ ). The large standard deviation for the Summer II data was due to low sample size resulting from two fish mortalities (detection periods  $n = 7$  and  $32$ ), which were one-third the length of the detection periods of the other three fish ( $n = 94$ ,  $94$ , and  $94$ , respectively), and contributed no diel days to the count. When these two fish are removed, the mean increased and the standard deviation decreased ( $\%_{\text{avg adj}} = 56.3$ ,  $\%_{\text{SD adj}} = 19.7$ ).



Summer I ranged from August to mid-September in 2010, which only represents about half of the summer season. Average percent diel days was highest during this period ( $\%_{\text{avg}} = 46.1$ ;  $\%_{\text{SD}} = 27.5$ ). Autumn and spring both had comparable occurrences of diel movement ( $\%_{\text{avg}} = 24.5$ ,  $30$ ;  $\%_{\text{SD}} = 16.1, 18.9$ , respectively).

The results for the G-Test and the RxC Test for the analysis of frequencies suggested that the frequency of diel behavior is dependent on seasonality for both individual fish with data for more than two seasons and overall for all fish. A total of twelve individuals had detection days in two or more seasons (Table 1b). The frequency of diel days was tested for dependence on seasonality, with results being significant for each fish with three or more seasons of diel days. Three fish resulted in non-significant G-values, but these three fish only had diel days in two seasons, which suggests that two seasons of data are not sufficient for testing for diel behavior dependence on seasonality. Total detection days for all fish were also tested for seasonality dependence and had significant results, suggesting a general dependence on seasonality for the occurrence of diel behavior.

Diel behavior differences in cycle type between seasons were also observed. Autumn and summer had a higher frequency of positive diel cycling (Fall:  $\chi^2 = 4.46$ ,  $P < 0.05$ ; Summer I:  $\chi^2 = 8.92$ ,  $P < 0.01$ ; Summer II:  $\chi^2 = 14.34$ ,  $P < 0.001$ ; Table 2). Negative diel cycling was more abundant during the winter ( $\chi^2 = 4.89$ ,  $P < 0.05$ ). During autumn and spring, individuals transitioned between cycle type (positive to negative and negative to positive, respectively) (Figure 5a).

*Spatial Variation of Diel Behavior:* During the summer, fish exhibited upriver diel movement between receivers 11 and 14 with positive diel cycling. In the autumn most individuals showed

negative diel movement between receivers 9 and 11. Diel movement was rare during winter, but was observed between receivers 8 and 13 as a negative cycle. In early spring, negative cycling continued with an expanded use of the river, ranging between gate 1 receivers (receivers 1 and 2) and receivers 12 and 13. In late spring diel cycling is reduced to between receivers 10 and 14 and has transitioned back to positive. During summer individuals showed positive diel cycling between receivers 11 and 14.

*Temperature and Salinity Effects on Diel Behavior:* The SEACAT provided temperature and salinity data that were relative to the location of the tagged fish, since the SEACAT represents absolute temperature and salinity values for a single location in the Carmans River and not the present location of the fish. However, relative changes in temperature and salinity at the SEACAT was assumed to be representative for the entire river.

Diel behavior occurred throughout the entire temperature and salinity range of the Carmans, but was less frequent at low temperatures and high salinities (Figures 6a – 7b). Diel behavior was most apparent between 8 and 20°C, where it occurred in nearly 100% of the observations (Figure 6b). Above a temperature of 20°C the frequency of diel behavior declined to 80%. Diel cycling was greatly reduced when temperatures were < 8°C. For salinity, diel behavior declined gradually from 100% at 2ppt to 60% at 24ppt.

The break point analysis identified trends for the temperature frequency data but not for salinity. Three break points were identified at 3, 7, and 20°C, with a sharp increase in percent diel days through the first break point (Figure 6c). The break points at low temperatures correspond to a reduction in occurrence of diel days at these temperatures. The break point at

20°C corresponds to a dip in diel day occurrence, which steadily increases back to 100% by 30°C.

*Day and Night Activity:* Activity varied between day and night with increased activity at night from autumn to early spring (Figure 8a, 8b). Daytime activity increased in late spring and remained high through the summer. Summer, Fall, and Winter 2010 and Spring 2011 all had significant differences between activity levels at day versus night, with all seasons favoring nighttime activity ( $P < 0.001$ ) (Table 3). There was not a significant difference between average day and night activity levels in Summer and Fall 2011 ( $P > 0.05$ ). However, variation during the summer and fall 2011 may have resulted from a small sample size of three individuals.

## **DISCUSSION**

Research has begun to unravel the complex behavioral strategies in fishes including Atlantic cod migration highways (Rose 2009), striped bass divergent migration (Wingate and Secor 2007) and residency in winter flounder (Sagarese and Frisk 2011). The development of acoustic telemetry methods has elucidated the connection between finescale movement and environmental drivers (Humston et al. 2005, Bellquist et al. 2008, Espinoza et al. 2011). Here we provide evidence for finescale habitat use and seasonally varying diel movement of white perch in the Carmans River, New York. Diel movement was a common strategy with significant seasonal variation in frequency, magnitude and direction of movement. The results suggest additional research is needed to understand how white perch maximize fitness through spatial strategies in response to a varying environment (Krebs and McCleery 1984, Kerr and Secor 2009). We discuss the potential ecological implications of behavior in white perch and present potential physiological and environmental mechanisms.

Diel behavior is performed as a response to environmental and biological changes, such as the maintenance of optimal environmental conditions, fluctuation in stream flow, predator avoidance, and movement to optimal foraging grounds (i.e., Bohl 1980, Rooker and Dennis 1991, Gibson et al. 1998, Baumgartner et al. 2008, Carey et al. 2010). Drivers of diel behavior may change depending on the season and ontogenetic stage of the individual (Jakober et al. 2000, Pagano et al. 2004). Diel movement in adult white perch appears to be important as fourteen out of the fifteen white perch used in the data analysis exhibited diel behavior. There have been reports of diel behavior YOY white perch, where onshore trawl-sampled fish were found to increase in abundance at night suggesting a diel onshore-offshore movement (Stapanian et al. 2007). Diel feeding behavior was indicated in adult perch, where perch stomach contents and fullness evaluated at different time periods suggested nighttime feeding preferences (Weisberg and Janicki 1990). The extensive use of diel behavior in this study suggests white perch have adapted a strong response to seasonal and spatial variability to maximize survival, growth, and maintenance (Krebs and McCleery 1984).

During the summer, temperature effects, which may be linked to variations in dissolved oxygen (DO) in the Carmans River, appear to drive movement with the highest frequency of diel activity corresponding to high summer temperatures and periods of potential hypoxia. White perch are sensitive to dissolved oxygen levels below 6ppm (Setzler-Hamilton 1991) and the Carmans River is subject to hypoxic events during high temperatures on calm summer days with reduced wind-driven mixing (Zaikowski et al. 2008). It is unknown how commonly hypoxic conditions occur in the river; however, Zaikowski et al. (2008) observed hypoxic conditions in mid-river locations. During the summer white perch showed significantly more positive diel

cycling than other seasons preferring cooler groundwater fed freshwater at night and mid-river saline habitat during the day potentially as a means to avoid hypoxic conditions.

As temperature cooled from September to November, diel behavior switched to downriver locations, eventually transitioning from positive to negative cycling in mid-November when temperatures fell below 10°C. This transition may be related to either temperature or the decline of seasonal competitors and predators, which would open forage area throughout the river prior to winter semi-hibernation. Fall diet largely consisted of amphipods (see Chapter 1, Figure 3b), which are known to exhibit diel behavior, increasing activity at night as the amphipods leave the substrate and enter the water column (Russell 1931, Karrtvedt 1986, Macquartmoulin 1993, but see Avery et al. 1996). Gammarid amphipods are common in the diets of white perch, suggesting that increased night activity of an important prey source may drive temporal and spatial behavior in white perch, as is the case for other species exhibiting prey-driven diel migration (Bohl 1980, Lorke et al. 2007, Carey et al. 2010), though on occasion, diel movement by fish is occurring for other reasons, such as predation risk (Holzman et al. 2007). The diel behavior thus may be movement to ideal feeding grounds, which may fluctuate as food sources are depleted and intra-specific competition increases. Further investigation is needed on amphipod seasonal abundance, vertical movement and changes in nocturnal activity in the Carmans River system.

During winter months perch activity was reduced as most fish entered a state of semi-hibernation in response to low temperatures (Collette and Klein-MacPhee 2002). However, a few individuals did show diel behavior during winter characterized by a negative cycle between receivers 8 and 11. Movement between these two locations may be attributed to the perch maintaining energetic needs through foraging when opportunities become available. White perch

vary their behavior based on food availability and energetic demands (Kerr and Secor 2009). In winter when foraging can be energetically costly (Garvey et al. 2004), perch may select specific conditions in which to break from semi-hibernation and feed. Similar alterations of foraging behavior have been observed in other fish (Jakober et al. 2000).

White perch springtime behavior may be a response to environmental drivers and spawning, including migration to other systems and daily movement to synchronize spawning activity. Many fish spawn at specific locations and periods of the day, leading to a high degree of spawning synchronicity within local populations (Taylor et al. 1998, Asoh and Yoshikawa 2002, Bransden et al. 2007, Durham and Wilde 2008). Perch are multi-clutch group-synchronous spawners (Jackson and Sullivan 1995, Harrell 1997) and can exhibit complex courtship (Salek et al. 2001, 2002). White perch spawning events may incorporate diel behavior, as it provides an environmental cue for fish to congregate on spawning areas in the river. Diel spawning exists in a number of species including scud (McBride et al. 2002), red snapper (Jackson et al. 2006), and some sciaenid fishes (Holt et al. 1985). Snook exhibit diel spawning and are also group-synchronous spawners, spawning multiple times over several months (Taylor et al. 1998). White perch may be exhibiting a similar reproductive strategy by practicing common diel movement patterns to better aggregate spawners and synchronize spawning.

Spawning season in perch occurs between late March and early June, with peak activity in April and May, at water temperatures  $>10^{\circ}\text{C}$  for Chesapeake Bay white perch (Mansueti 1964, Setzler-Hamilton 1991). This timing coincides with an increase in daily total distance traveled (see Ch. 1 – Figure 8a) and an expansion of habitat use to the entire river (see Ch.1 – Figure 4) suggesting initiation of spawning in early April. Additional sampling of the water column for eggs and larvae is needed for determining the exact spawning time, duration, and location within

the Carmans. Interestingly, several individuals left the system and were detected in other rivers connected to Great South Bay, possibly choosing to spawn with other stocks and providing evidence for migrant white perch in the Carmans River. These individuals may represent a migratory contingent within the Carmans River white perch population. Further analyses of these individuals, such as the otolith strontium:calcium profile analysis described in Kerr et al. (2009), and life history, growth, and maturity variability within YOY and juvenile fish populations (Jonsson and Jonsson 1993, Kerr and Secor 2009), could help determine if there are distinct behavioral contingents within the Carmans River white perch population.

Positive and negative diel cycling was found to vary in frequency with season, suggesting that certain movement patterns within the Carmans are advantageous at different times of the year. However, it appears that perch are targeting an average receiver range between receivers 10 and 12 during the daytime, with the exception of the overwintering period at receiver 13 (see Chapter 1 for overwintering description). Thus, the variation in cycle type is largely driven by the location frequented during the night. It is unclear what the driving mechanism is for these cycle transitions during the spring and fall. Perch appear to be actively feeding at night during the fall (see Chapter 1), so variation in nighttime movement may be attributed to the selection of preferable forage habitat over time. This could be a similar case for springtime, though the dietary sampling was lacking sufficient numbers for the spring season. White perch activity was also highest at night throughout the year, further suggesting that perch are primarily feeding at night. Some prey types exhibit diel behavior, showing an increase in activity and vulnerability, which causes their predators to replicate their diel patterns (Mehner 2012). White perch may be following a similar pattern in response to amphipod availability. Amphipods have been identified as a primary food source for white perch in the Carmans River (see Chapter 1, Figure 3c).

Investigation of the distribution and behavior of amphipods in the Carmans River is needed to address this hypothesis.

Determining if a fish exhibits diel behavior is essential to retaining accurate information for effective management. Estimates of population abundance, age structure, home range and essential habitats can be affected and even biased by selective daytime sampling. Identification of diel movement in a fish creates need for population sampling during both day and night hours. Fish communities can change drastically in both abundance and diversity between day and night hours, leaving estimates on population and community structure biased towards diurnally active fish (Griffiths 2005). The extent of habitat utilization could also be underestimated by excluding nighttime sampling, which could lead to inaccurate recommendations on land use (Griffiths 1998, 2005). Diel movement in fish requires additional precautions in habitat conservation. Essential habitat and protected area mapping need to incorporate both locations used by the species exhibiting diel behavior, along with the migratory pathway. Degradation of either location or blockage of access could be detrimental to the population (Riley et al. 2012).

## **CHAPTER 2 CONCLUSION**

The acoustic tracking used in this study revealed adult white perch exhibiting upstream/downstream diel movement on a regular basis. Diel behavior is common in a number of fish and is driven by food availability, predator presence, and changing environmental conditions (Gibson et al. 1998). White perch seem to exhibit diel behavior for a combination of these reasons, as the behavior is displayed year-round. Summer diel behavior may be a mechanism perch use to avoid hypoxic conditions, as perch have specific dissolved oxygen requirements (Setzler-Hamilton 1991). Active foraging in the absence of predators may be the



reason perch display diel behavior during the fall, since their pelagic competitors and predators have left the Carmans River system (Chapoton and Sykes 1961). Winter diel behavior, though infrequent, may be an attempt for perch to forage during environmentally stressful conditions, though winter dietary sampling is needed to investigate this hypothesis. Diel behavior in spring coincides with spawning season. As perch are multi-clutch synchronous spawners (Jackson and Sullivan 1995, Harrell 1997), diel movement during spawning season may be a mechanism to synchronize spawning to maximize productivity and fertilization success.

Temporal and environmental changes affected the frequency of diel behavior. Seasonality was found to be directly connected to diel behavior, where, depending on the time of year, the frequency of diel behavior changed. The general trend showed summer with the highest average frequency of diel behavior, possibly due to a combination of environmental maintenance and predator avoidance, while winter displayed the lowest average diel frequency, which is attributed to white perch entering a state of semi-hibernation (Collette and Klein-MacPhee 2002).

Similarly, low temperatures were found to suppress diel behavior, as is expected since there is less need to feed regularly (Pough 1980, Crawshaw 1984) assuming fish have gained winter energy reserves (Johnson and Evans 1991, Garvey et al. 2004). High salinity may also suppress diel behavior, but this may be attributed to the low frequency of high salinity days in upriver regions, since the Carmans is normally freshwater above receiver 8.

Directionality in diel movement was found to vary on a temporal scale. During the summer, white perch moved downriver during the day and upriver at night. Entering mid-fall, perch began to transition their location during their diel movement, moving upstream during the day and downstream at night. By winter, this form of diel movement became the norm. Perch began to transition back to downriver during the day throughout spring, until the movement was

established again in the summer. While it is unclear why perch switch their diel cycle type, it appears that the transition is largely due to the change in nighttime location, while the daytime location in the river remains fairly constant. This may be connected to nocturnal foraging by perch, as it was found that perch are more active during the night throughout the year. Fish assessed for diet in this study were primarily collected during the night (see Chapter 1).

Additional dietary sampling is needed to supplement nocturnal feeding, as gut contents should be investigated during both day and night hours.

## LITERATURE CITED

- Asoh, K. and T. Yoshikawa. 2002. The role of temperature and embryo development time in the diel timing of spawning in a coral-reef damselfish with high-frequency spawning synchrony. *Environmental Biology of Fishes* **64**:379-392.
- Avery, D. E., J. Green, and E. G. Durbin. 1996. The distribution and abundance of pelagic gammarid amphipods on Georges Bank and Nantucket Shoals. *Deep-Sea Research II* **43**:1521-1532.
- Baumgartner, L. J., I. G. Stuart, and B. P. Zampatti. 2008. Determining diel variation in fish assemblages downstream of three weirs in a regulated lowland river. *Journal of Fish Biology* **72**:218-232.
- Beck, M. W., K. L. H. Jr, K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan, and M. P. Weinstein. 2001. The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates. *BioScience* **51**:633-641.
- Bellquist, L. F., C. G. Lowe, and J. E. Caselle. 2008. Fine-scale movement patterns, site fidelity, and habitat selection of ocean whitefish (*Caulolatilus princeps*). *Fisheries Research* **91**:325-335.
- Bohl, E. 1980. Diel pattern of pelagic distribution and feeding in planktivorous fish. *Oecologia (Berl.)* **44**:368-375.
- Brandsen, M. P., S. C. Battaglione, R. C. Goldsmid, G. A. Dunstan, and P. D. Nichols. 2007. Broodstock condition, egg morphology and lipid content and composition during the spawning season of captive striped trumpeter, *Latris lineata*. *Aquaculture* **268**:2-12.

- Carey, C. C., M. P. Ching, S. M. Collins, A. M. Early, W. W. Fetzer, D. Chai, and N. G. Hairston. 2010. Predator-dependent diel migration by *Halocaridina rubra* shrimp (Malacostraca: Atyidae) in Hawaiian anchialine pools. *Aquatic Ecology* **45**:35-41.
- Chapoton, R. B. and J. E. Sykes. 1961. Atlantic coast migration of large striped bass as evidenced by fisheries and tagging. *Transactions of the American Fisheries Society* **90**:13-20.
- Collette, B. B. and G. Klein-MacPhee. 2002. The sea basses. Family Serranidae. Pages 405-406  
Bigelow and Schroeder's fishes of the Gulf of Maine. Smithsonian Institution Press,  
Washington D.C.
- Crawshaw, L. 1984. Low-temperature dormancy in fish. *The American Physiological Society* **246**:R479-R486.
- Durham, B. W. and G. R. Wilde. 2008. Asynchronous and synchronous spawning by smalleye shiner *Notropis buccula* from the Brazos River, Texas. *Ecology of Freshwater Fish* **17**:528-541.
- Espinoza, M., T. J. Farrugia, D. M. Webber, F. Smith, and C. G. Lowe. 2011. Testing a new acoustic telemetry technique to quantify long-term, fine-scale movements of aquatic animals. *Fisheries Research* **108**:364-371.
- Frisk, M. G., D. E. Duplisea, and V. M. Trenkel. 2011. Exploring the abundance-occupancy relationships for the Georges Bank finfish and shellfish community from 1963 to 2006. *Ecological Applications* **21**:227-240.
- Garvey, J. E., K. G. Ostrand, and D. H. Wahl. 2004. Energetics, predation, and ration affect size-dependent growth and mortality of fish during winter. *Ecology* **85**:2860-2871.

- Gibson, R. N., L. Pihl, M. T. Burrows, J. Modin, H. Wennhage, and L. A. Nickell. 1998. Diel movements of juvenile plaice *Pleuronectes platessa* in relation to predators, competitors, food availability and abiotic factors on a microtidal nursery ground. *Marine Ecology Progress Series* **165**:145-159.
- Griffiths, S. P. 1998. Diversity and distribution of fishes in an intermittently open coastal lagoon at Shellharbour, New South Wales. *Wetlands (Australia)* **18**:13-23.
- Griffiths, S. P. 2005. Diel variation in the seagrass ichthyofaunas of three intermittently open estuaries in south-eastern Australia: implications for improving fish diversity assessments. *Fisheries Management and Ecology* **8**:123-140.
- Hall, C. J., A. Jordaan, and M. G. Frisk. 2010. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. *Landscape Ecology* **26**:95-107.
- Harrell, R. M. e. 1997. Striped bass and other Morone culture. Elsevier Scientific Publishing Company, Amsterdam. 386pp.
- Heimbuch, D. G. 2008. Potential Effects of Striped Bass Predation on Juvenile Fish in the Hudson River. *Transactions of the American Fisheries Society* **137**:1591-1605.
- Holt, G. J., S. A. Holt, and C. R. Arnold. 1985. Diel periodicity of spawning in sciaenids. *Marine Ecology Progress Series* **27**:1-7.
- Holzman, R., M. Ohavia, R. Vaknin, and A. Genin. 2007. Abundance and distribution of nocturnal fishes over a coral reef during the night. *Marine Ecology-Progress Series* **342**:205-215.

- Humston, R., J. S. Ault, M. F. Larkin, and J. Luo. 2005. Movements and site fidelity of the bonefish *Albula vulpes* in the northern Florida Keys determined by acoustic telemetry. *Marine Ecology Progress Series* **291**:237-248.
- Jackson, L. F. and C. V. Sullivan. 1995. Reproduction of white perch: The annual gametogenic cycle. *Transactions of the American Fisheries Society* **124**:563-577.
- Jackson, M. W., D. L. Nieland, and J. H. Cowan. 2006. Diel spawning periodicity of red snapper *Lutjanus campechanus* in the northern Gulf of Mexico. *Journal of Fish Biology* **68**:695-706.
- Jakober, M. J., T. E. McMahon, and R. F. Thurow. 2000. Diel habitat partitioning by bull charr and cutthroat trout during fall and winter in Rocky Mountain streams. *Environmental Biology of Fishes* **59**:79-89.
- Johnson, T. B. and D. O. Evans. 1991. Behaviour, energetics, and associated mortality of young-of-the-year white perch (*Morone americana*) and yellow perch (*Perca flavescens*) under simulated water conditions. *Canadian Journal of Fisheries and Aquatic Sciences* **48**:672-680.
- Jonsson, B. and N. Jonsson. 1993. Partial migration: niche shift versus sexual maturation in fishes. *Reviews in Fish Biology and Fisheries* **3**:348-365.
- Karrtvedt, S. 1986. Diel activity patterns in deep-living cumaceans and amphipods. *Marine Ecology Progress Series* **30**:243-249.
- Kerr, L. A. and D. H. Secor. 2009. Bioenergetic trajectories underlying partial migration in Patuxent River (Chesapeake Bay) white perch (*Morone americana*). *Canadian Journal of Fisheries and Aquatic Sciences* **66**:602-612.

- Kerr, L. A., D. H. Secor, and P. M. Piccoli. 2009. Partial migration of fishes as exemplified by the estuarine-dependent white perch. *Fisheries* **34**:114-123.
- Krebs, J. R. and R. H. McCleery. 1984. Optimization in behavioural ecology. Pages 91-121 in J. R. Krebs and N. B. Davies, editors. *Behavioral ecology*. Blackwell Scientific Publications, Oxford.
- Limburg, K. E. and J. R. Waldman. 2009. Dramatic Declines in North Atlantic Diadromous Fishes. *BioScience* **59**:955-965.
- Lorke, A., A. Weber, H. Hofmann, and F. Peeters. 2007. Opposing diel migration of fish and zooplankton in the littoral zone of a large lake. *Hydrobiologia* **600**:139-146.
- Ludsin, S. A., X. Zhang, S. B. Brandt, M. R. Roman, W. C. Boicourt, D. M. Mason, and M. Costantini. 2009. Hypoxia-avoidance by planktivorous fish in Chesapeake Bay: Implications for food web interactions and fish recruitment. *Journal of Experimental Marine Biology and Ecology* **381**:S121-S131.
- Macquartmoulin, C. 1993. Vertical distribution, surface stratifications, and migrations of pelagic mysids and amphipods over the French Atlantic and Mediterranean margins. *Journal of Plankton Research* **15**:1149-1170.
- Mansueti, R. J. 1964. Eggs, larvae, and young of the white perch, *Roccus americanus*, with comments on its ecology in the estuary. *Chesapeake Science* **5**:3-45.
- McBride, R. S., F. J. Stengard, and B. Mahmoudi. 2002. Maturation and diel reproductive periodicity of round scad (*Carangidae: Decapterus punctatus*). *Marine Biology* **140**:713-722.
- Mehner, T. 2012. Diel vertical migration of freshwater fishes - proximate triggers, ultimate causes and research perspectives. *Freshwater Biology* **57**:1342-1359.

- Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* **16**:4-21.
- Pagano, M., E. Kouassi, R. Arfi, M. Bouvy, and L. Saint-Jean. 2004. In situ spawning rate of the calanoid copepod *Acartia clausi* in a tropical lagoon (Ebrié, Côte d'Ivoire): Diel variations and effects of environmental factors. *Zoological Studies* **43**:244-254.
- Pitcher, T. J. 2001. Managed to rebuild ecosystems? Reconstructing the past to salvage the future. *Ecological Applications* **11**:601-607.
- Pough, F. H. 1980. The advantages of ectothermy for tetrapods. *The American Naturalist* **115**:92-112.
- Powles, H., M. J. Bradford, R. G. Bradford, W. G. Doubleday, S. Innes, and C. D. Levings. 2000. Assessing and protecting endangered marine species. *Ices Journal of Marine Science* **57**:669-676.
- Riley, W. D., B. Bendall, M. J. Ives, N. J. Edmonds, and D. L. Maxwell. 2012. Street lighting disrupts the diel migratory pattern of wild Atlantic salmon, *Salmo salar* L., smolts leaving their natal stream. *Aquaculture* **330**:74-81.
- Rooker, J. R. and G. D. Dennis. 1991. Diel lunar and seasonal changes in a mangrove fish assemblage off southwestern Puerto Rico. *Bulletin of Marine Science* **49**:684-698.
- Rose, G. A. 2009. Variations in the target strength of Atlantic cod during vertical migration. *Ices Journal of Marine Science* **66**:1205-1211.
- Russell, F. S. 1931. The vertical distribution of marine macroplankton. X. Notes on the behaviour of *Sagitta* in the Plymouth area. *Journal of the Marine Biological Association* **17**:391-414.



- Sagarese, S. and M. G. Frisk. 2011. Diet composition and feeding habits of common fishes in Long Island Bays, New York. *Northeastern Naturalist* **18**:291-314.
- Salek, S. J., C. V. Sullivan, and J. Godwin. 2001. Courtship behavior of male white perch, *Morone americana*: evidence for control by androgens. *Comparative Biochemistry and Physiology a-Molecular and Integrative Physiology* **130**:731-740.
- Salek, S. J., C. V. Sullivan, and J. Godwin. 2002. Arginine vasotocin effects on courtship behavior in male white perch (*Morone americana*). *Behavioural Brain Research* **133**:177-183.
- Schultz, E. T., J. P. Davis, and J. Vokoun. 2009. Estimating predation on declining river herring: Tag-recapture study of striped bass in the Connecticut River. *EEB Articles Paper* **21**:43pp.
- Setzler-Hamilton, E. M. 1991. White perch (*Morone americana*). U.S. EPA Chesapeake Bay Program. 20pp.
- Stanley, J. G. and D. S. Danie. 1983. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic - white perch). U.S. Fish and Wildlife Service; U.S. Army Corps of Engineers. 12pp.
- Stapanian, M. A., M. T. Bur, and J. V. Adams. 2007. Temporal trends of young-of-year fishes in Lake Erie and comparison of diel sampling periods. *Environmental Monitoring and Assessment* **129**:169-178.
- Stokesbury, M. J. W., M. J. Dadswell, K. N. Holland, G. D. Jackson, W. D. Bowen, and R. K. O'Dor. 2009. Tracking diadromous fishes at sea: the electronic future using hybrid acoustic and archival tags. *American Fisheries Society Symposium* **69**:10p.

- Taylor, R. G., H. J. Grier, and J. A. Whittington. 1998. Spawning rhythms of common snook in Florida. *Journal of Fish Biology* **53**:502-520.
- Weisberg, S. B. and A. J. Janicki. 1990. Summer feeding patterns of white perch, channel catfish, and yellow perch in the Susquehanna River, Maryland. *Journal of Freshwater Ecology* **5**:391-405.
- Wingate, R. L. and D. H. Secor. 2007. Intercept telemetry of the Hudson River striped bass resident contingent: Migration and homing patterns. *Transactions of the American Fisheries Society* **136**:95-104.
- Zaikowski, L., K. T. McDonnell, R. F. Rockwell, and F. Rispoli. 2008. Temporal and Spatial Variations in Water Quality on New York South Shore Estuary Tributaries: Carmans, Patchogue, and Swan Rivers. *Estuaries and Coasts* **31**:85-100.

## Chapter 1 - Figures

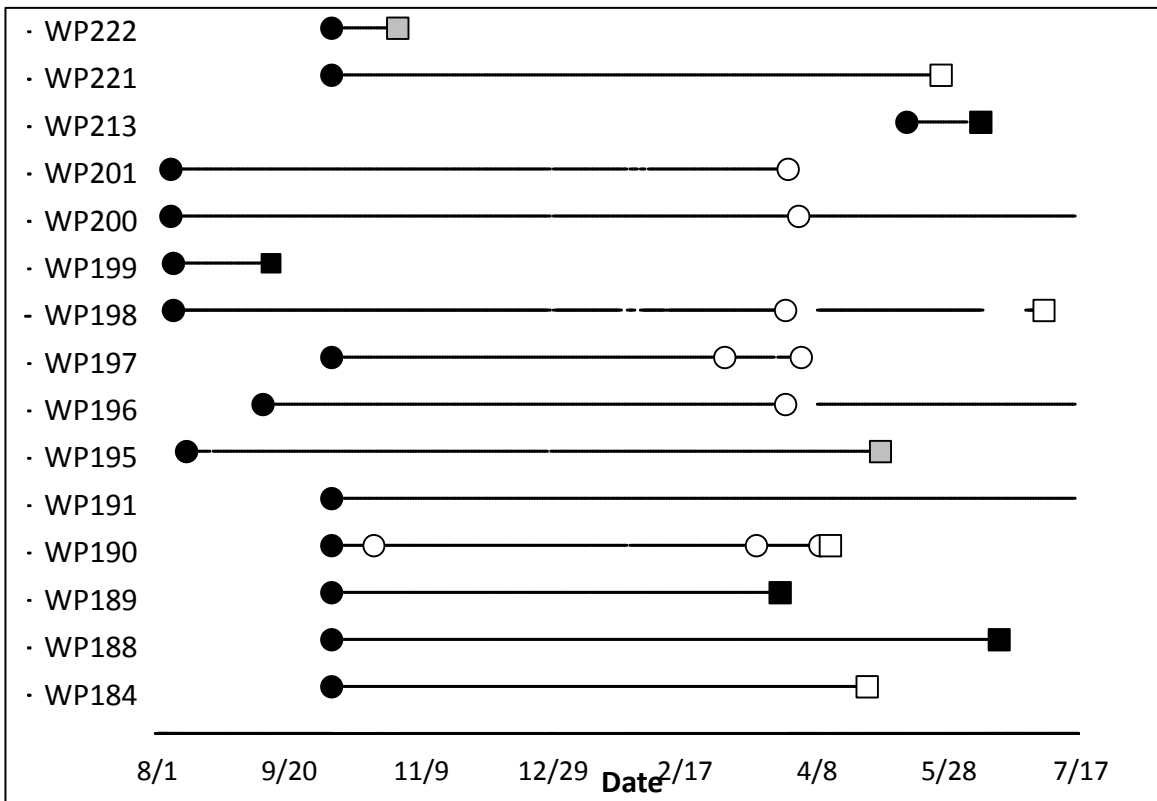


Figure 1a – Temporal detection coverage (represented by the horizontal black lines) of acoustically tagged fish included in this study. Black circles indicate release date. White circles are dates where fish left the Carmans River. Deceased fish are indicated with white boxes, and missing fish are indicated with either black (possibly deceased) or grey (possibly migrated).

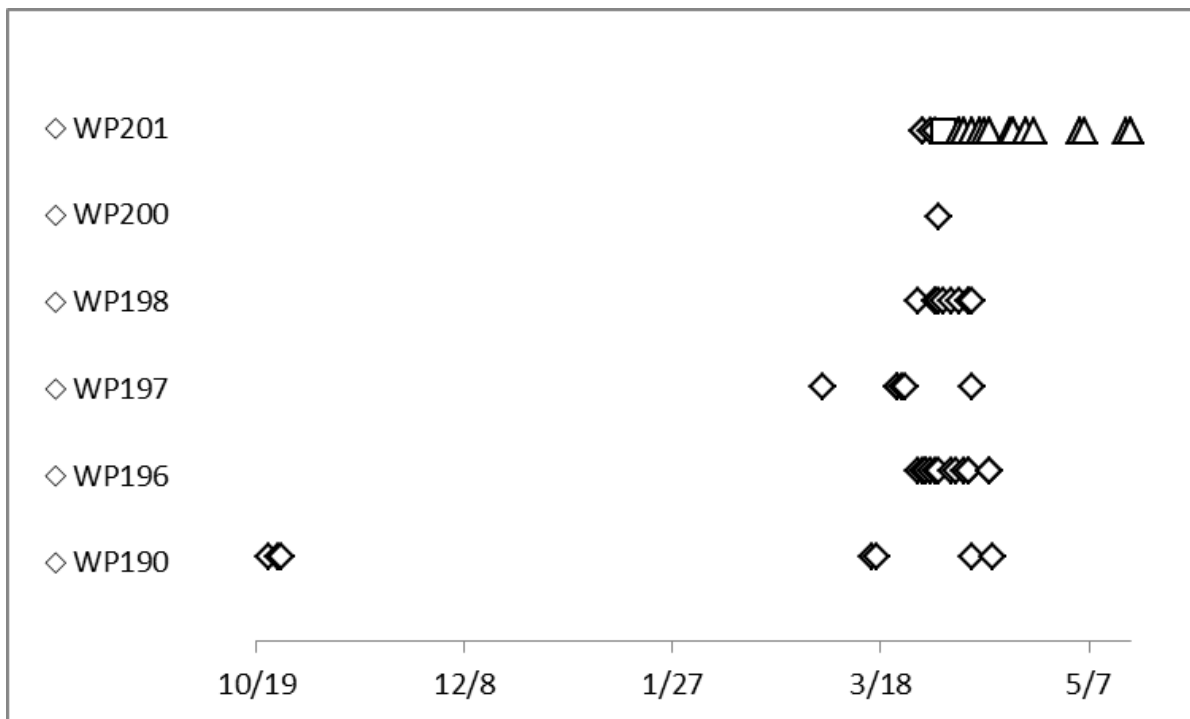


Figure 1b – Daily detections of individual fish from receivers outside of the Carmans River. Diamonds correspond to detections at Beaverdam Creek, squares are the Connectquot River, and the triangles are Carlls Creek. Two fish that were detected outside of the Carmans (WP197 and WP201) did not return to the river.

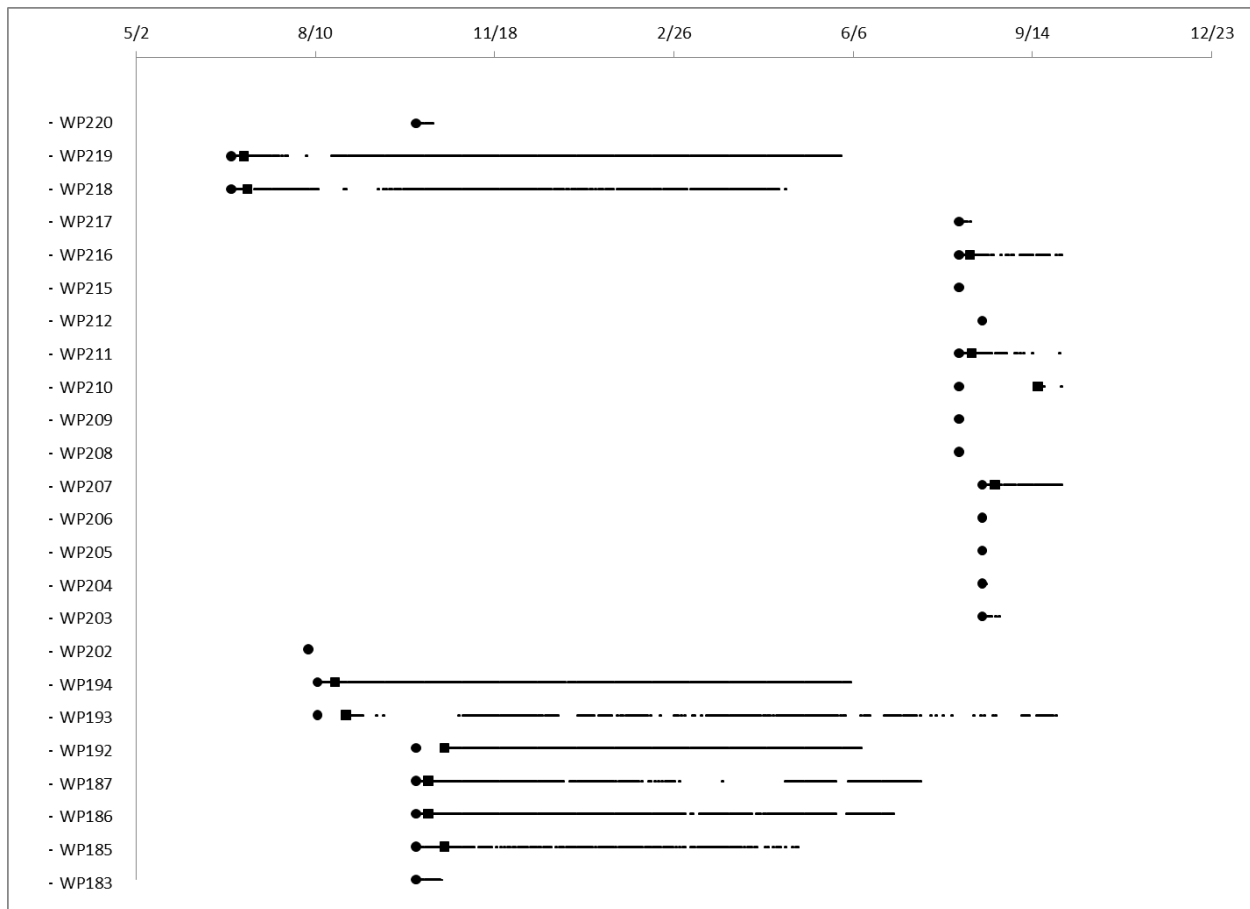


Figure 1c – Detection periods for fish that were not used in statistical analyses. Black horizontal lines correspond to the detection period for each fish. Black circles indicate the first date of detection for each fish. Black squares correspond to the estimated date of mortality for individuals that exhibited a ‘death pulse’ consistently for four weeks in detections. One fish (WP214) had zero detections.

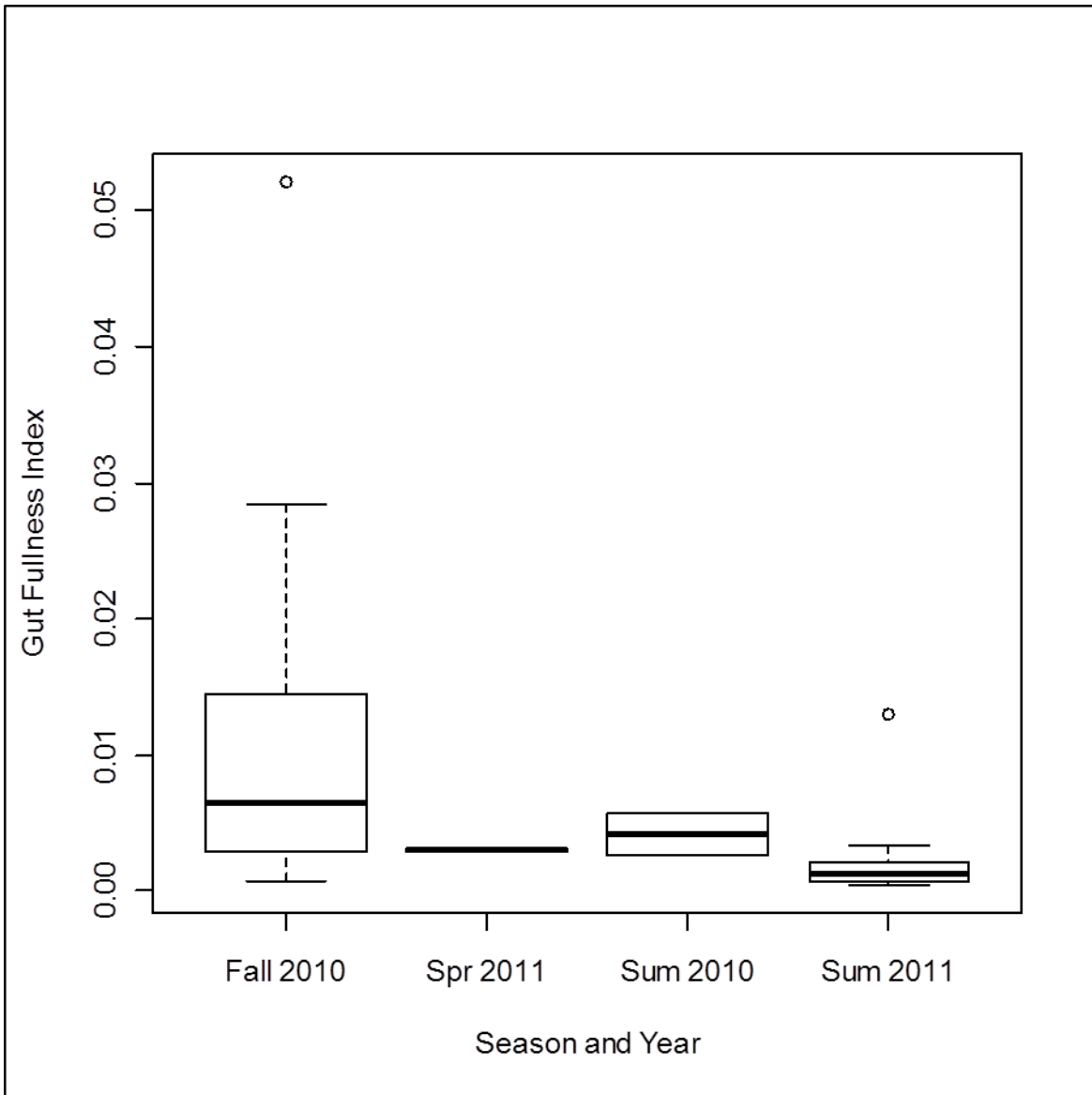


Figure 2 – Gut fullness content of juvenile and adult white perch sampled in the Carmans River. Note that Summer 2010 and Spring 2011 only consist of two samples each.

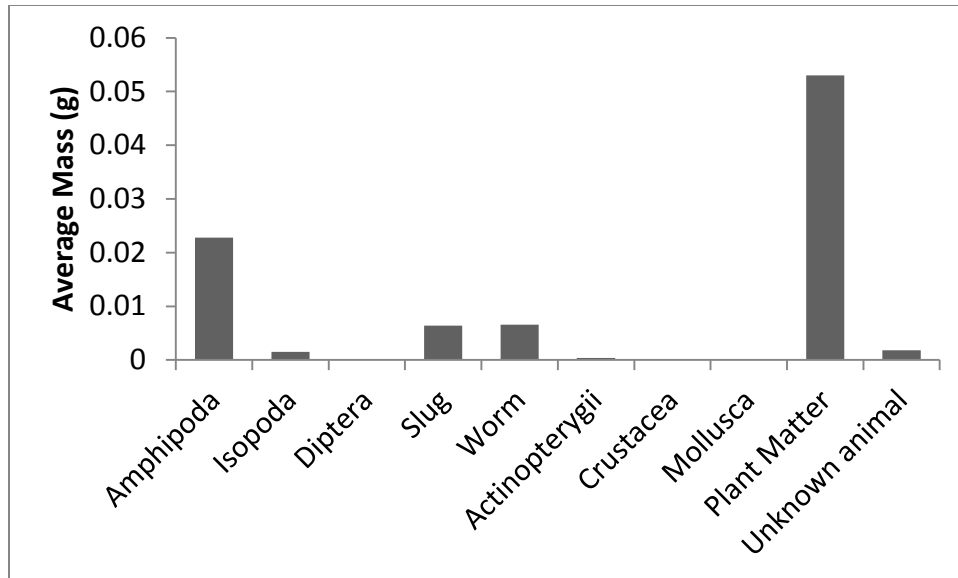


Figure 3a – Summer average stomach contents by mass (g). A total of 20 individuals were included in this analysis. The summer data includes both samples from 2010 and 2011. All groups listed had a presence in white perch stomachs, though the quantities were extremely low, hence there is no visible bar.

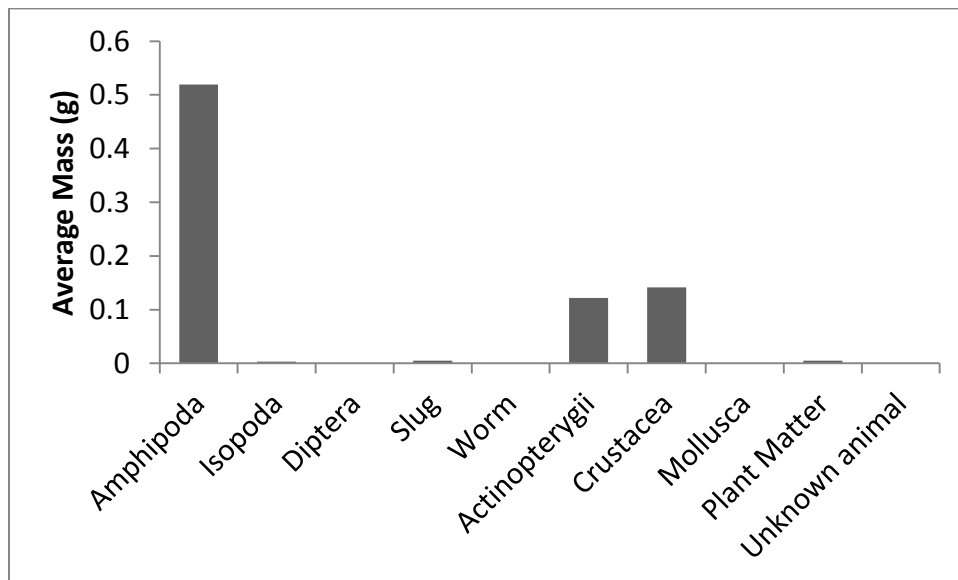


Figure 3b – Fall average stomach contents by mass (g). A total of 44 individuals were included in this analysis. All groups listed had a presence in white perch stomachs, though the quantities were extremely low, hence there is no visible bar.

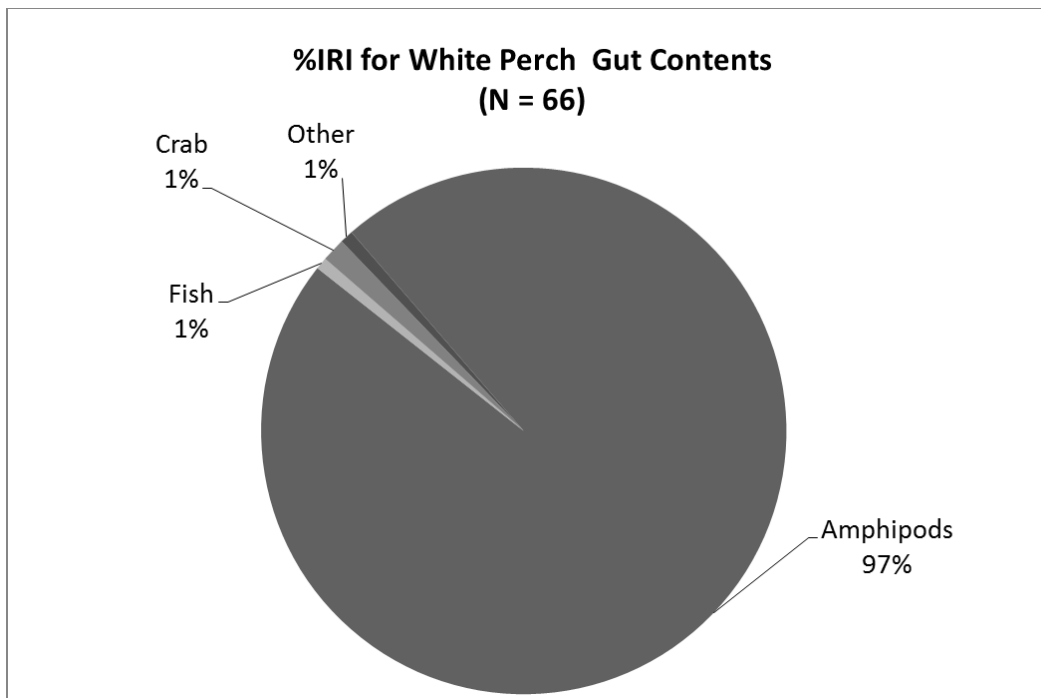


Figure 3c - % Index of Relative Importance for the identified gut contents of white perch sampled from the Carmans River. Of the 66 fish sampled, five had empty stomachs. The "Other" category is other identified animals that had extremely low %IRI values, such as slugs, worms, insects, isopods, and bivalves.



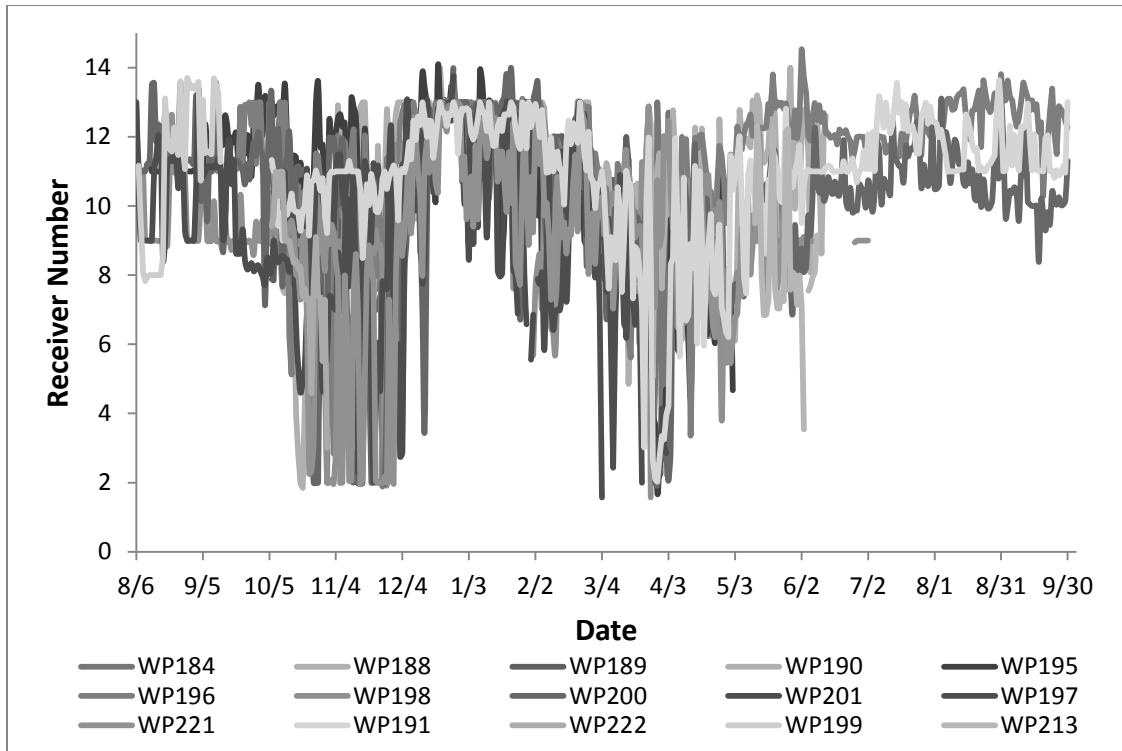


Figure 4 – Daily average receiver location for fish throughout their detection period.

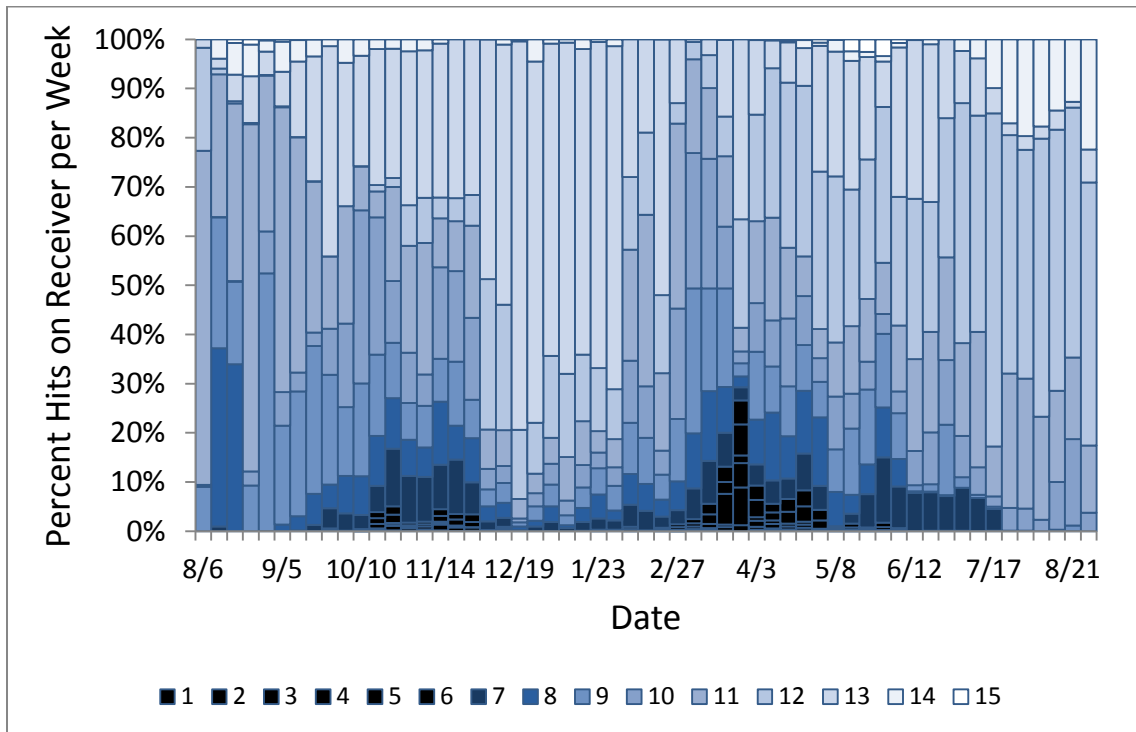
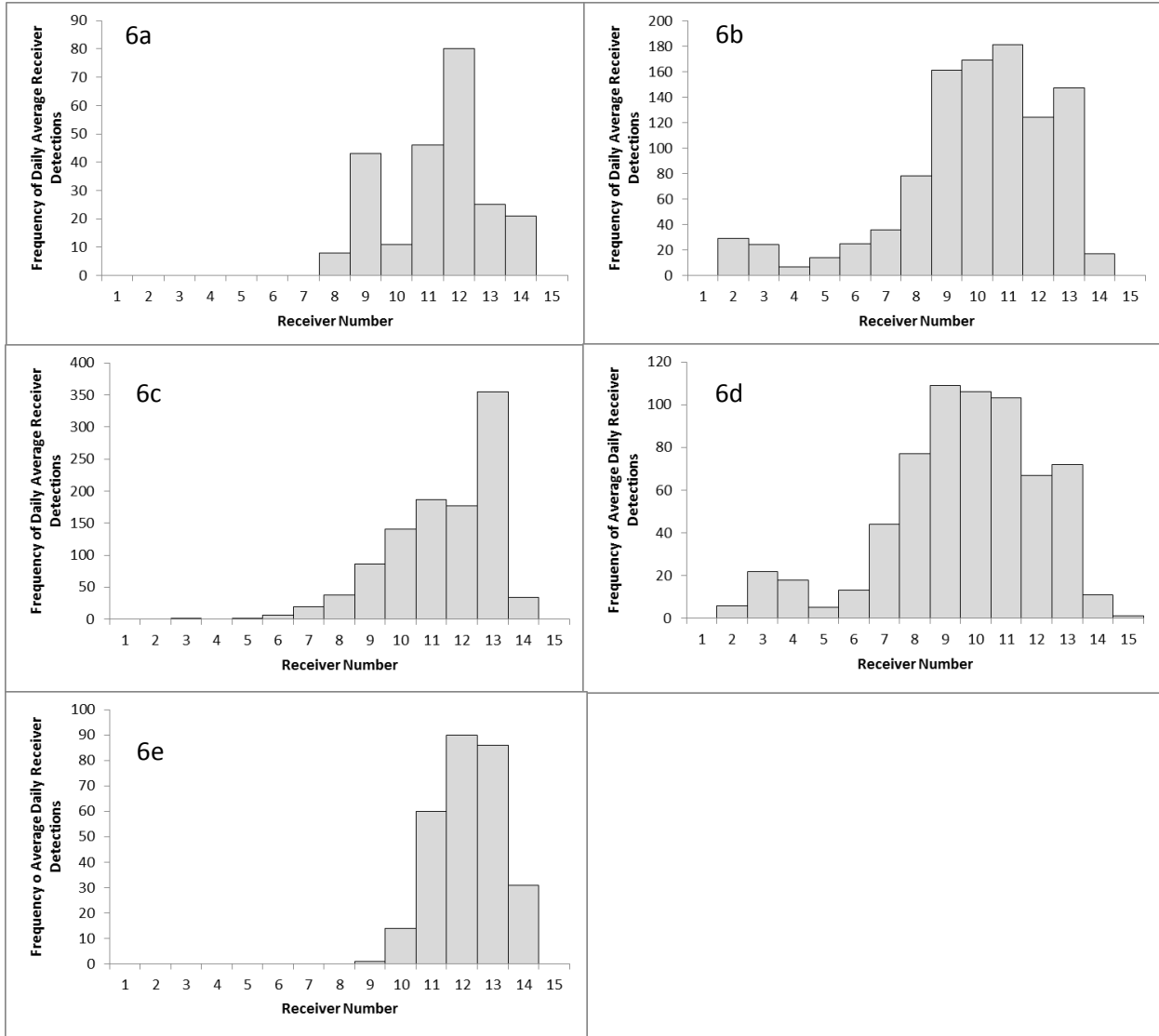


Figure 5 – Weekly receiver usage for all fish. Darker colors correspond to downriver receivers, while lighter colors are upriver receivers.



Figures 6a – 6e – frequency distributions of daily average receiver detections for Summer 2010, Fall, Winter, Spring, and Summer 2011. Averages are based on the receiver detections for each fish over a 24-hour period.

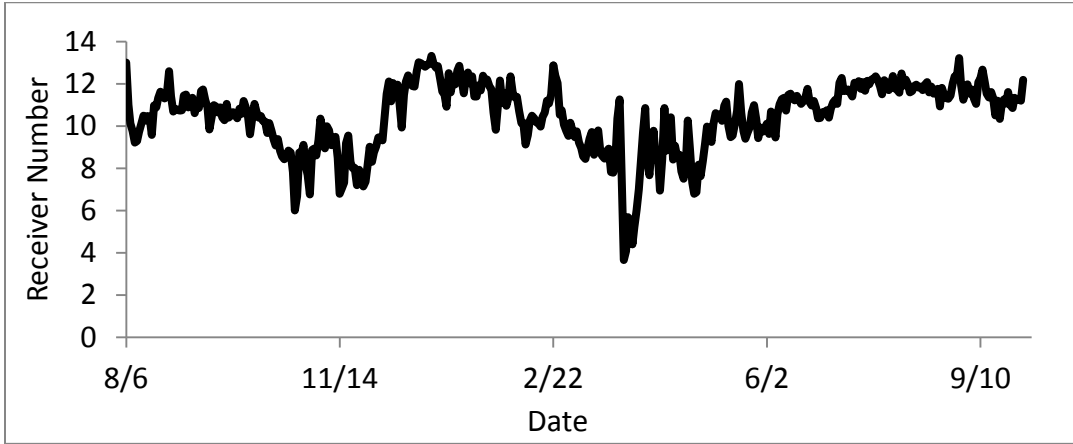


Figure 7a – Mean Receiver location for all fish from Summer 2010 – Summer 2011.

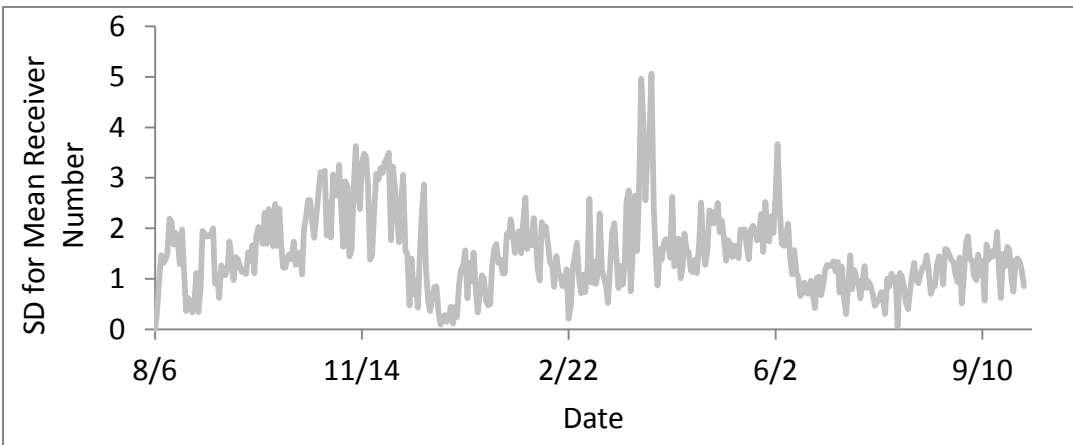


Figure 7b – Receiver standard deviation of the mean (7a) for all fish from Summer 2010 – Summer 2011.

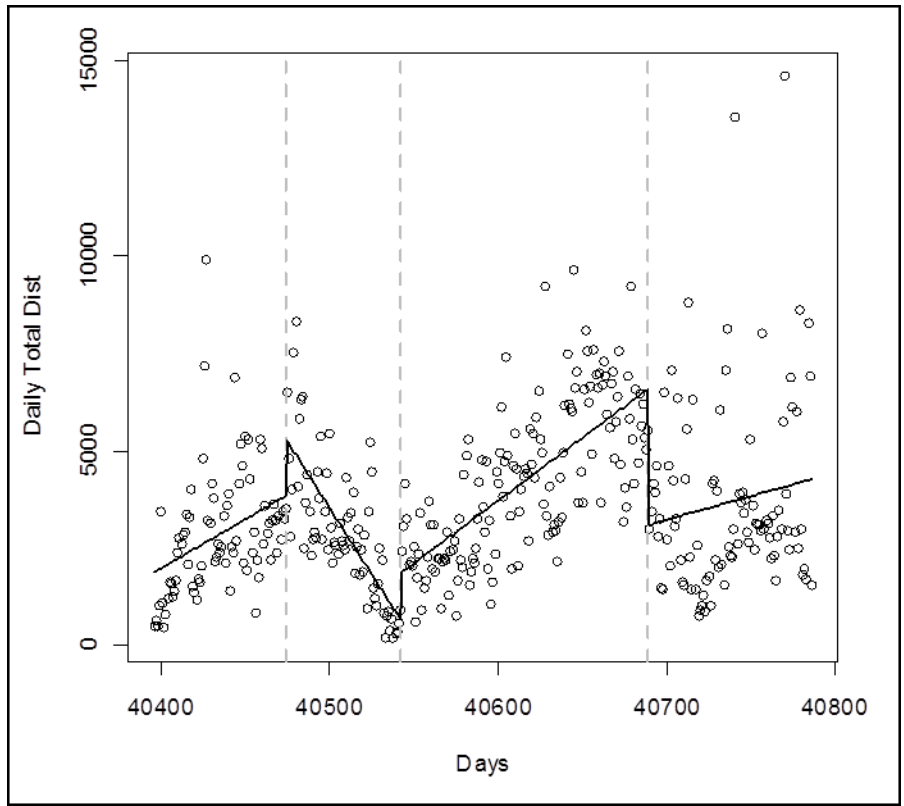


Figure 8a – A break point analysis done in R on daily average distance (m) traveled for all fish. Dotted lines correspond to breakpoint dates (10/23/10, 12/30/10, and 5/26/10).

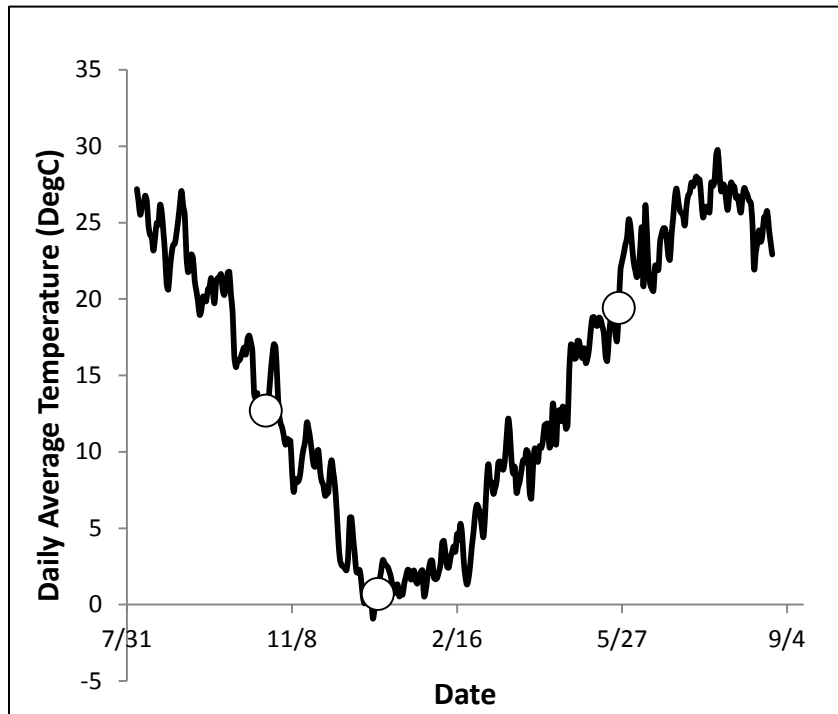


Figure 8b – Daily average temperatures of the Carmans River from the lower SeaCAT. White dots correspond to temperatures at the breakpoints from Figure 5a.

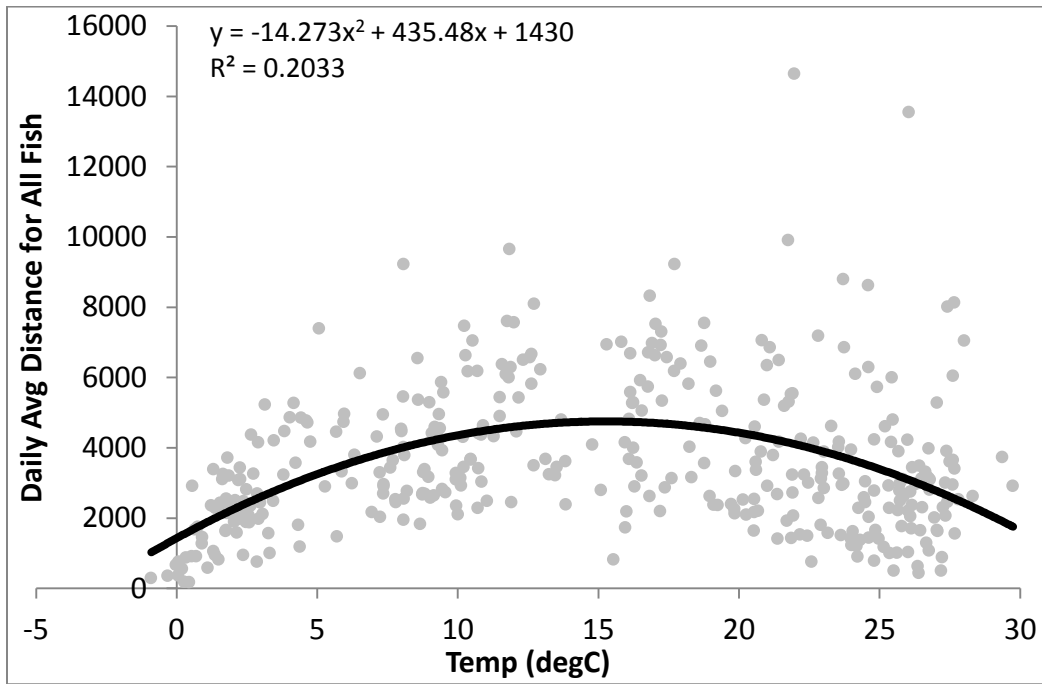


Figure 9a – Relationship of daily average temperature to daily average distance for all fish. The black line represents the best fit line for the data ( $R^2 = 0.2033$ ).

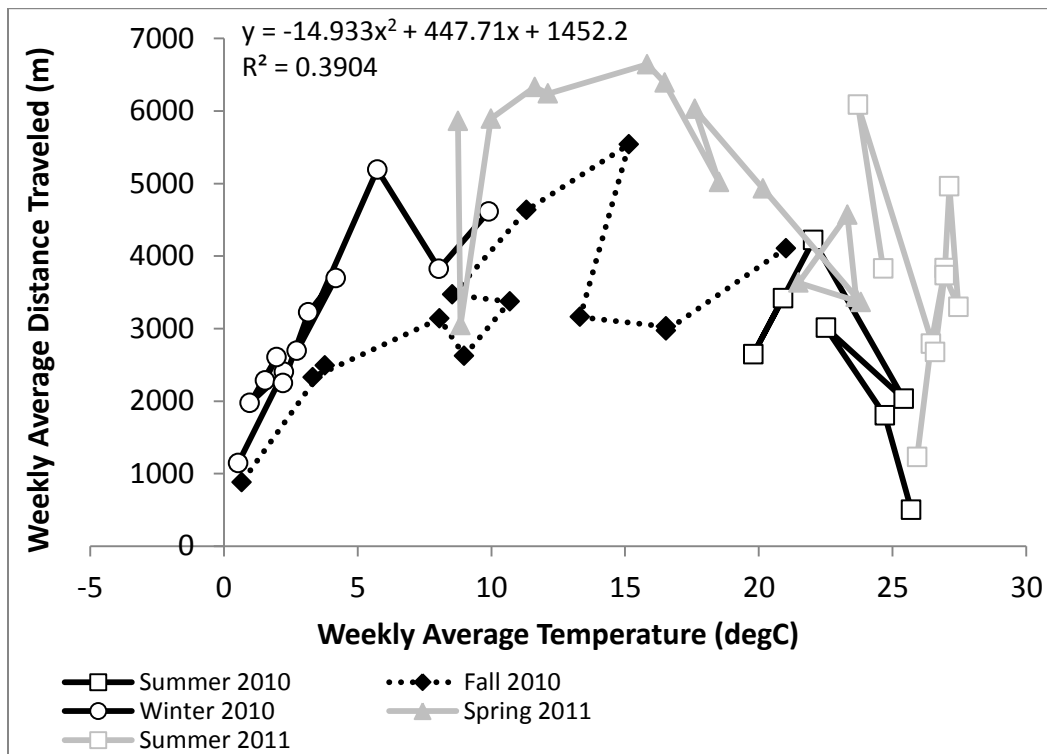


Figure 9b – Weekly average temperatures and weekly average distance traveled for all fish. The equation at the top corresponds to the best-fit line through the data ( $R^2 = 0.3904$ ). Variations in lines and points correspond to different seasons. The summer season had enough fish tracking data for two year

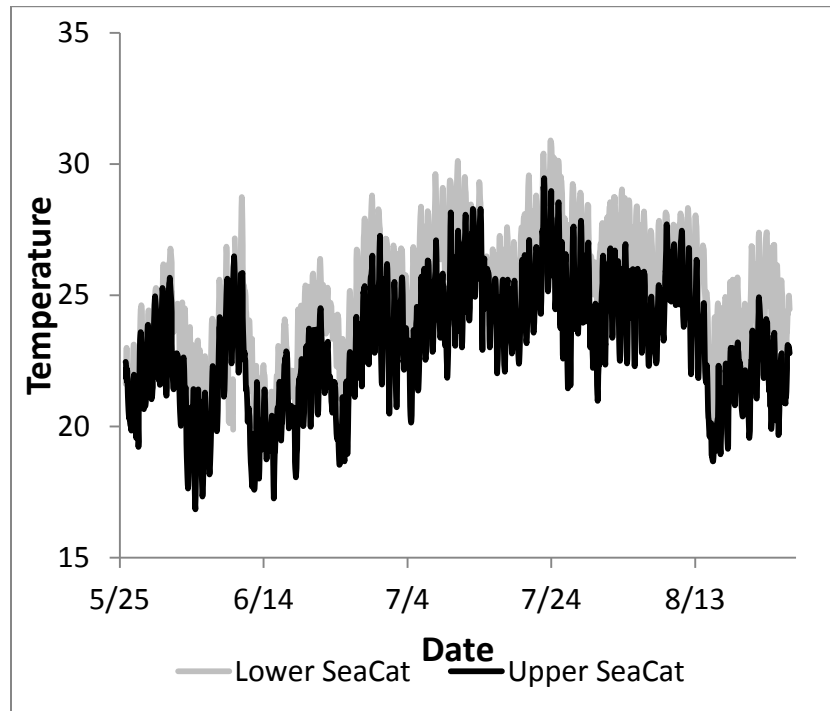


Figure 10a – Hourly temperatures ( $^{\circ}\text{C}$ ) for the two SeaCATs in the Carmans River in the Summer of 2011.



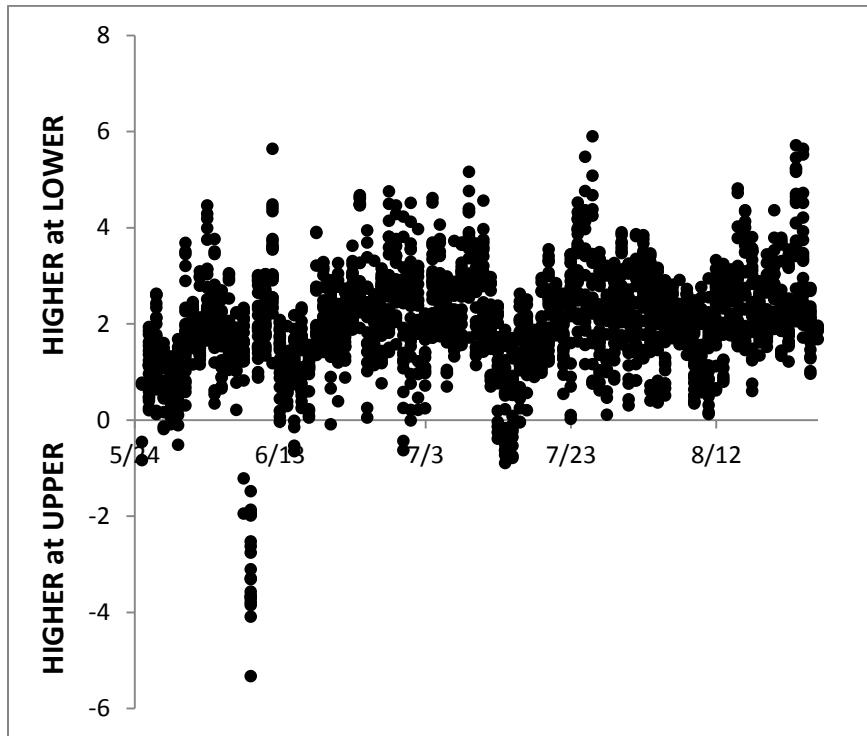


Figure 10b – The hourly difference in temperature between the two SeaCATs in the Carmans river in the Summer of 2011. Positive numbers indicate higher temperatures at the lower SeaCAT, while negative numbers correspond to higher temperatures at the upper SeaCAT. The unique excursion in temperature on 6/9/2011 may be a result of erroneous recordings on the lower SeaCAT.

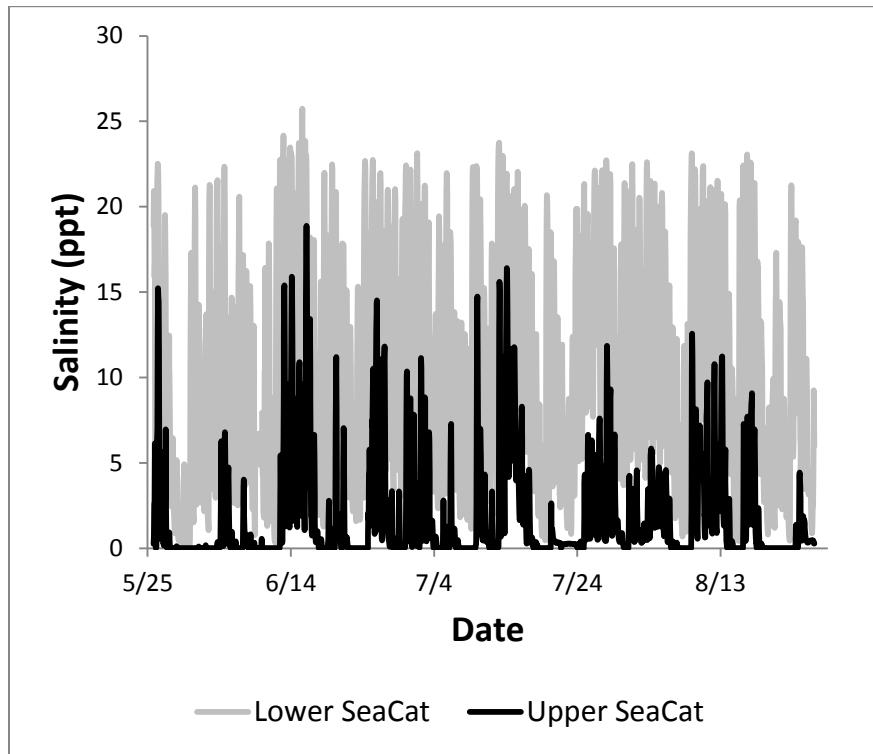


Figure 11a – Hourly salinity recordings for the two SeaCATs in the Carmans river in Summer 2011.

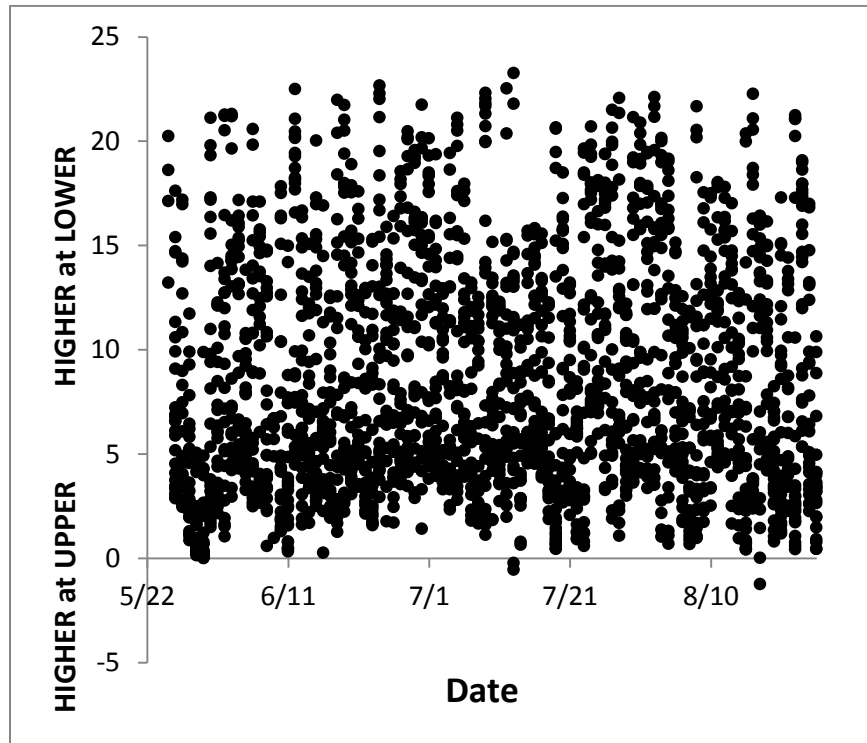


Figure 11b – Hourly differences in salinity between the two SeaCATs in Summer of 2011. Positive differences indicate higher salinities at the lower SeaCAT. Negative differences correspond to higher salinities at the upper SeaCAT.

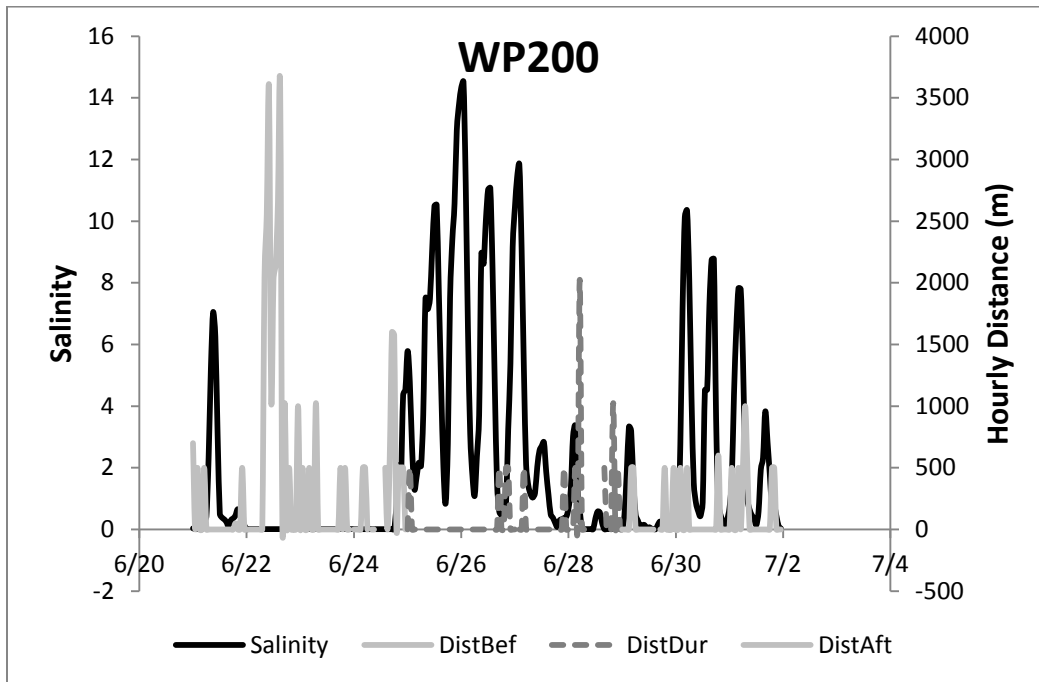


Figure 11c – Example individual fish for hourly distance traveled during a salinity excursion at the upper SeaCAT (see Figure 8a). Yellow lines correspond to movement periods before and after the main excursion. Red lines correspond to movements during the salinity excursion.

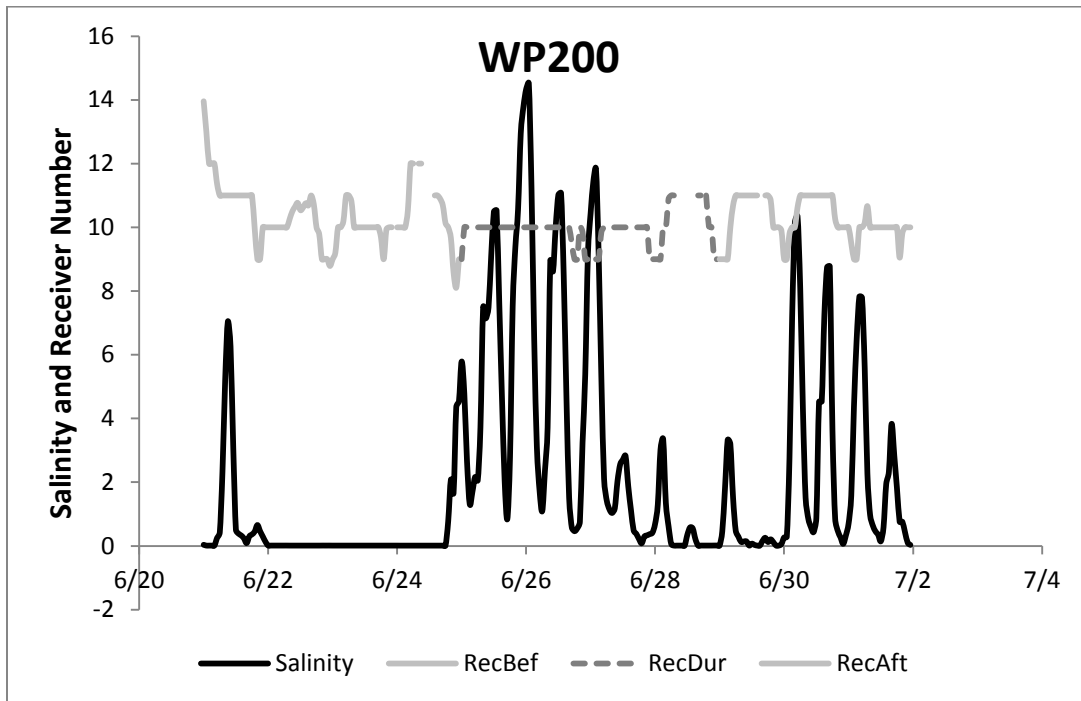


Figure 11d – Example individual fish for hourly receiver location during a salinity excursion recorded on the upper SeaCAT (see Figure 8a). Yellow lines show locations before and after the salinity excursion, while the red line corresponds to location during the excursion. The upper SeaCAT is located between receiver numbers 12 and 13.

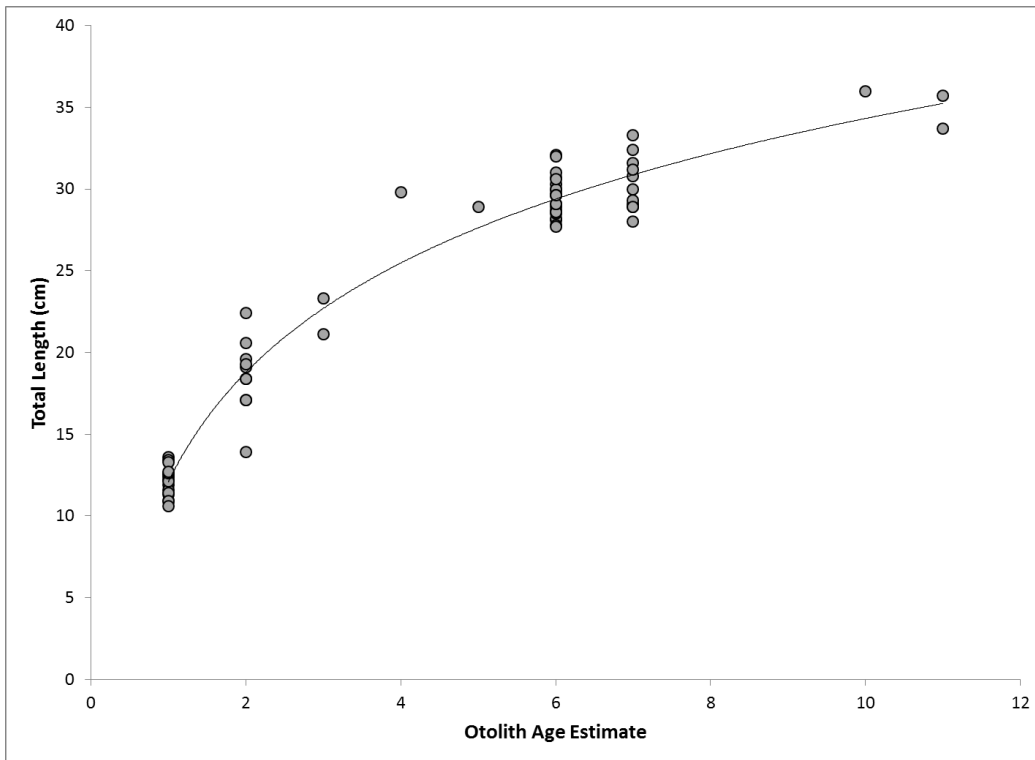


Figure 12 – White perch age-length estimate based on perch collected from the Carmans river (n = 67). Total length was measured for each fish and otoliths were randomly selected for age estimates. The logistic equation fitted to the data is  $y = 9.6533\ln(x) + 12.086$  ( $R^2 = 0.964$ ).

## Chapter 1 - Tables

Table 1 – Average temperature and salinity at each receiver location in the Carmans River.  
Temperature and salinity data were collected during low tide in April 2011.

<b>Receiver Name</b>	<b>Mean Temp (°C) (Apr Low Tide)</b>	<b>Mean Salinity (Apr Low Tide)</b>
15	12.68	0.1
14	12.25	0.12
13	12.29	0.17
12	11.92	0.25
11	12.25	0.34
10	12.08	0.81
9	12.42	1.81
8	12.33	13.3
7	---	---
6	11.78	14.62
5	---	---
4	11.58	23.3
3	---	---
2	11.33	22.09
1	---	---
SeaCAT	---	---

Table 2 – Individual fish information and detection coverages. ID numbers refer to the acoustic tag number of individual white perch. Percent coverage is (# Days Detected / # Days to Last Detection)\*100. Fish with asterisks after their ID numbers had detections outside of the Carmans after their last detection date in the river.

<b>ID</b>	<b>Release Date</b>	<b>Total Length (cm)</b>	<b>#Days to Last Active Detection</b>	<b># Days Detected</b>	<b>% coverage (Days)</b>	<b>Plausible Fate</b>
<b>198</b>	8/6/10	24.8	331	293	<b>88.5</b>	Fishing
<b>199</b>	8/6/10	27	38	38	<b>100</b>	Deceased
<b>200</b>	8/6/10	25.5	421	420	<b>99.7</b>	Present
<b>201*</b>	8/6/10	27.5	235	231	<b>98.7</b>	Migrated
<b>195</b>	8/11/10	>30	264	262	<b>99.2</b>	Migrated
<b>196</b>	9/10/10	30	386	375	<b>97.1</b>	Present
<b>184</b>	10/5/10	31.8	204	204	<b>100</b>	Deceased
<b>188</b>	10/5/10	31.7	254	252	<b>99.2</b>	Deceased
<b>189</b>	10/5/10	28.8	171	171	<b>100</b>	Fishing
<b>190</b>	10/5/10	28.7	190	187	<b>98.4</b>	Deceased
<b>191</b>	10/5/10	32	360	360	<b>100</b>	Present
<b>197*</b>	10/5/10	32.1	179	176	<b>98.3</b>	Migrated
<b>221</b>	10/5/10	30.1	232	232	<b>100</b>	Deceased
<b>222</b>	10/5/10	31.7	26	26	<b>100</b>	Migrated
<b>213</b>	5/12/11	37.2	29	28	<b>96.6</b>	Fishing



Table 3 – Index of Relative Importance results for 66 white perch sampled from the Carmans River.

<b>Animal Group</b>	<b>%N</b>	<b>%W</b>	<b>%O</b>	<b>IRI</b>	<b>%IRI</b>
<b>Amphipods</b>	96.15	80.14	27.87	4913.04	97.00
<b>Fish</b>	0.12	7.44	4.92	37.19	0.73
<b>Crabs</b>	0.06	8.91	8.20	73.57	1.45
<b>Bivalves</b>	0.04	0.01	1.64	0.08	0.00
<b>Slugs</b>	0.56	0.48	1.64	1.70	0.03
<b>Isopods</b>	0.93	1.23	6.56	14.14	0.28
<b>Insects</b>	0.35	0.20	21.31	11.75	0.23
<b>Worms</b>	1.75	0.98	4.92	13.42	0.27

Table 4 – results of G-Test for analysis of frequencies on the frequency distributions of daily average receiver locations for each season (See Figures 6a-6e). Daily average receiver location was estimated for each fish and accumulated into frequency distributions for each season. Distributions were tested against a distribution assuming no active selection by fish for specific receiver locations. Results for the G-Test are listed below, suggesting all seasons portray fish actively selecting habitat.

Statistical Values	Summer 2010	Fall 2010	Winter 2010	Spring 2011	Summer 2011
<b>G</b>	465.9	1034.2	1898.0	606.7	699.5
<b>Gadj</b>	464.3	1032.1	1894.7	604.9	698.7
<b>df</b>	14	14	14	14	14
<b><math>\chi^2</math> (<math>\alpha = 0.05</math>)</b>	23.69	23.69	23.69	23.69	23.69

## Chapter 2 Figures

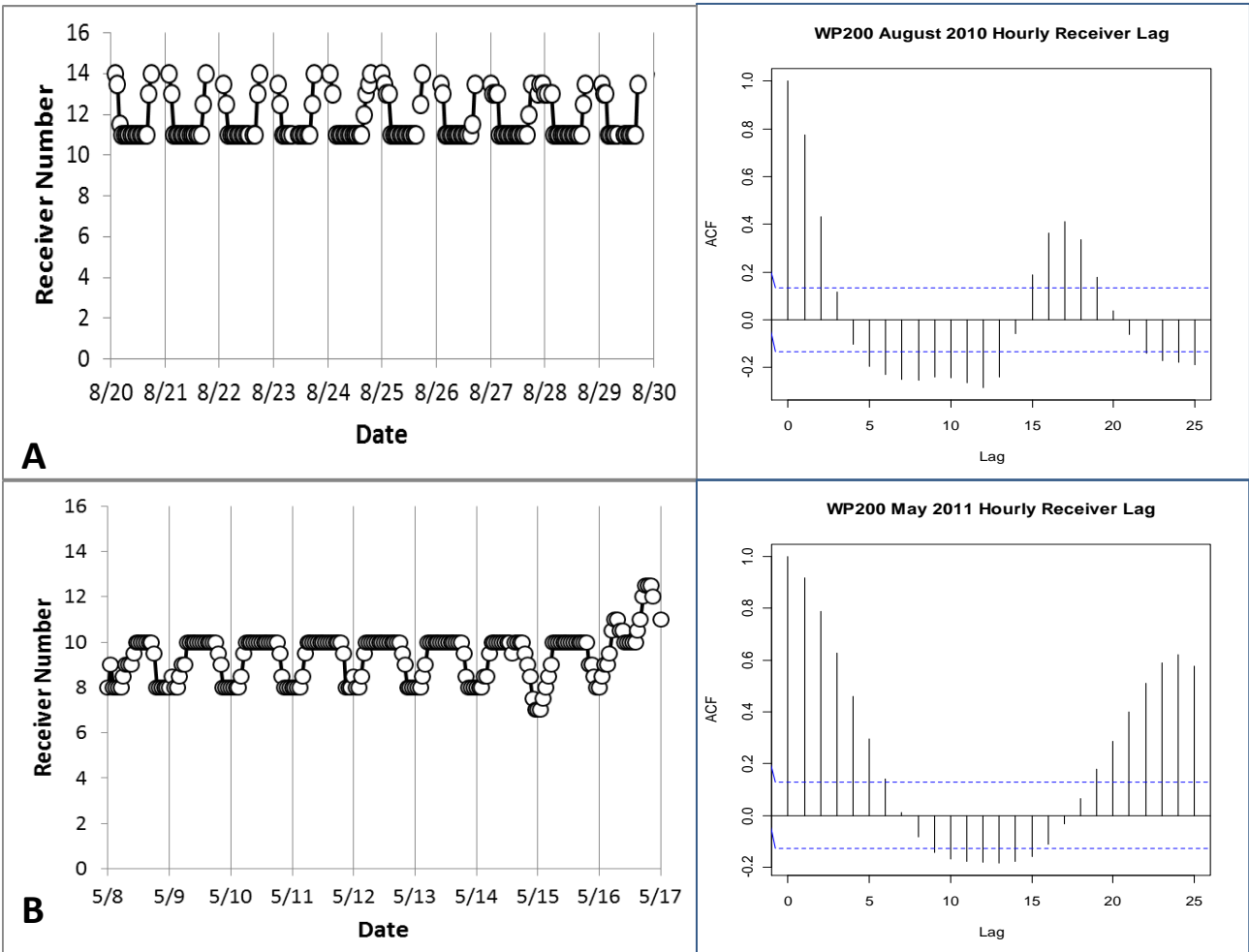


Figure 1a and 1b – Diel behavior in white perch as exemplified by this individual. Positive diel cycling is shown in figure 1a, and 1b shows an example of negative diel cycling. Each time series plot is provided with their corresponding autocorrelation function plot to the right. Significant lags correspond to hours where peaks in diel movement occur.

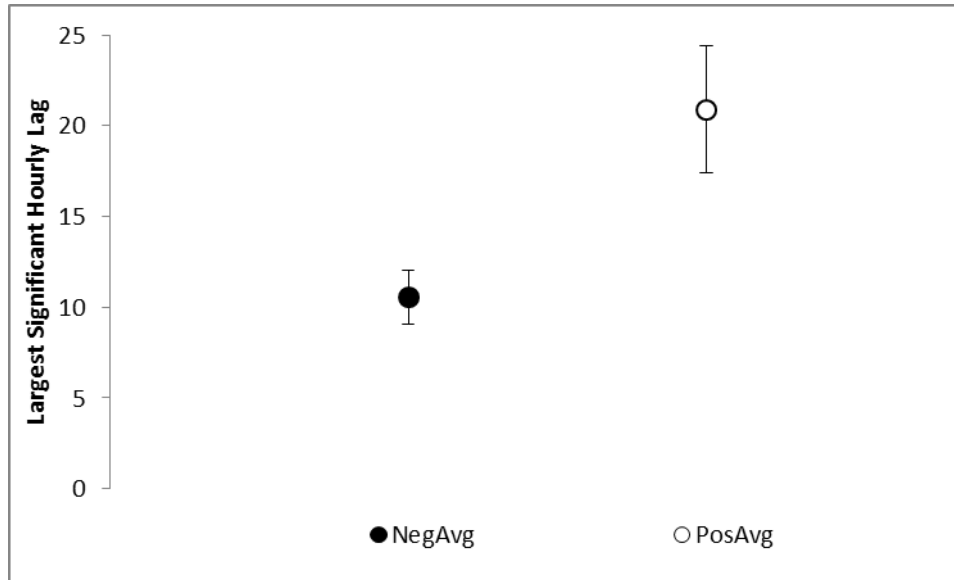


Figure 1c – Estimate of autocorrelation peaks of thirty random samples of manually identified diel days. Of the samples, six samples only had one significant lag, and one sample had no significant lags.

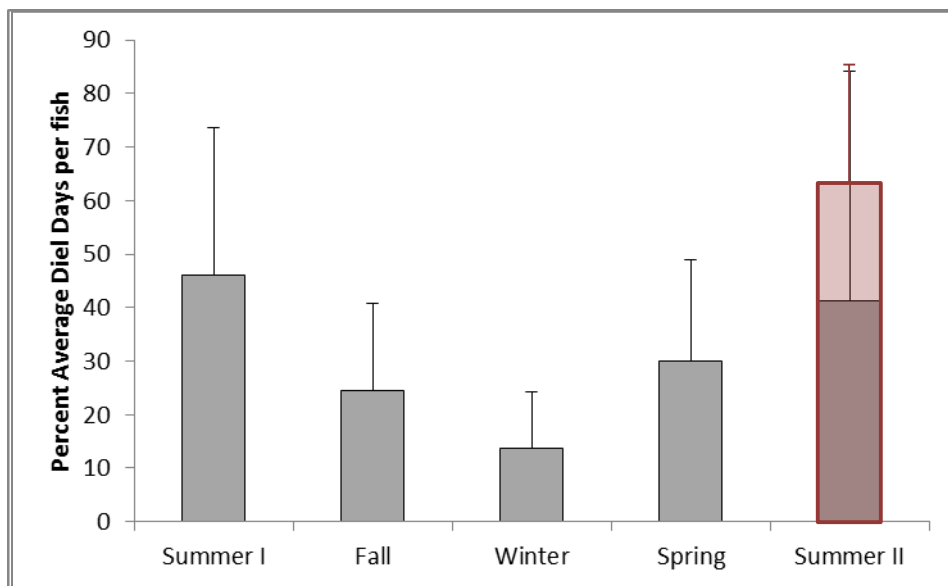


Figure 2 – Average percent diel days for each fish detected in each season. Standard deviation bars correspond to the standard deviation of the percent diel days. Summer II has a corrected mean and standard deviation (red) overlaying the original values; two of the five fish included in this season had very low detection periods and no diel days.

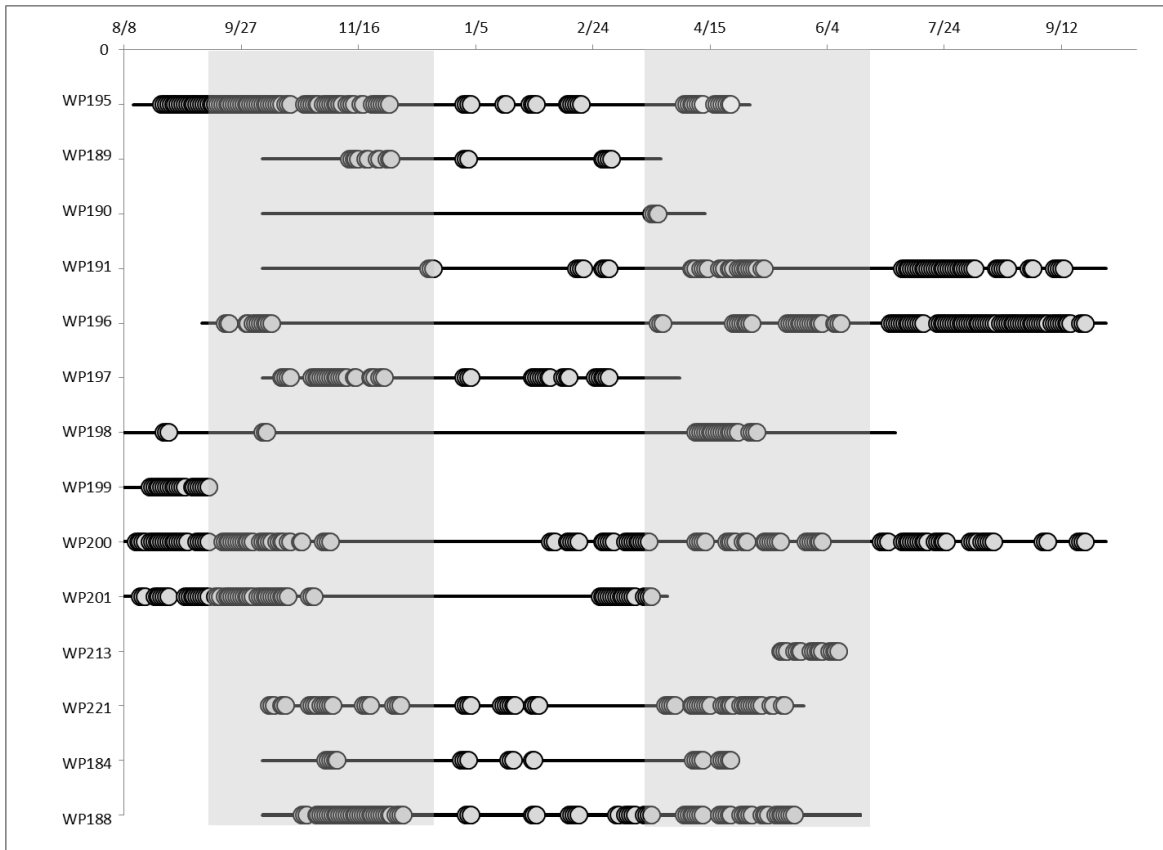


Figure 3 – Locations of Diel Days within the detection period for each fish. Circles indicate the presence of diel behavior on the corresponding date. Black horizontal lines correspond to the start and end of the detection period for each fish. Greyed out sections correspond to autumn and spring, respectively, and the white sections represent summer 2010, winter, and summer 2011, respectively.

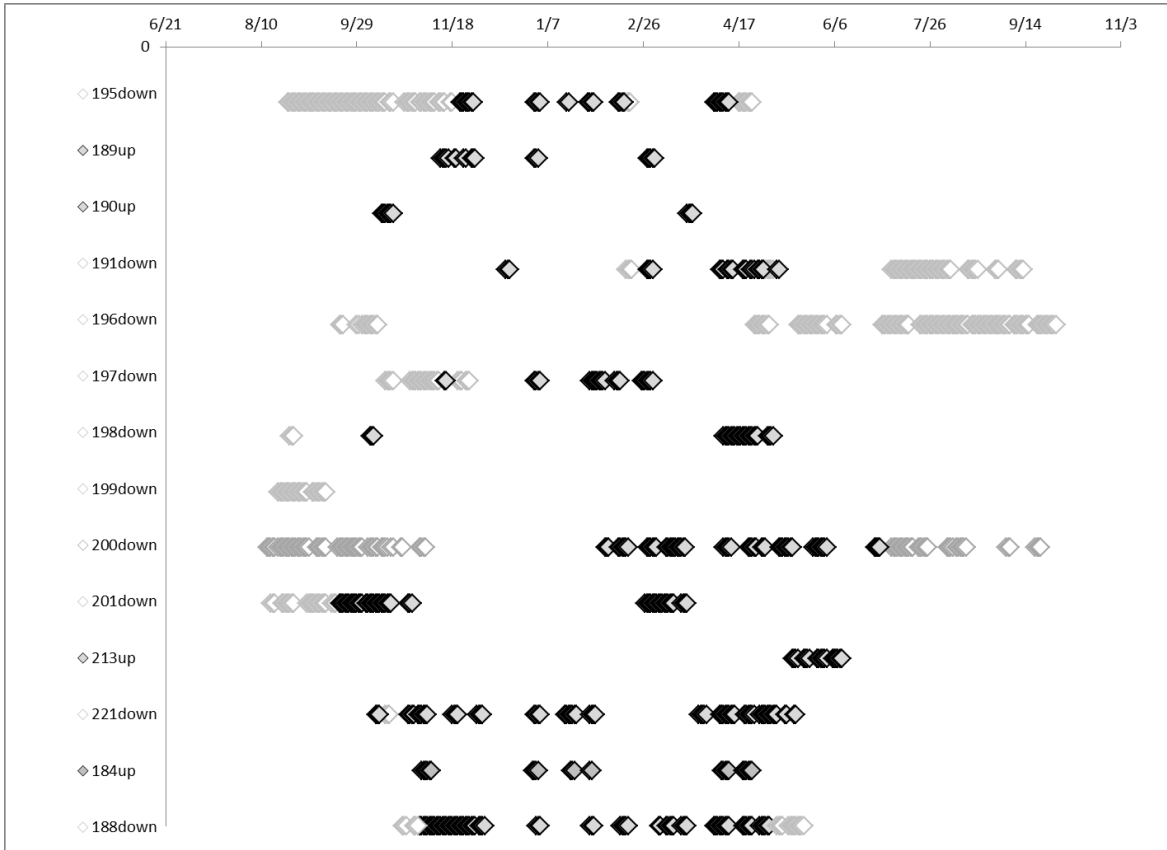


Figure 4 – Presence/absence of diel data within the detection period of each fish, differentiated by diel cycle type. Diamonds indicate the presence of diel behavior on the corresponding date, with grey diamonds with white filling indicating positive diel migration, and black with grey filling as negative diel migration.

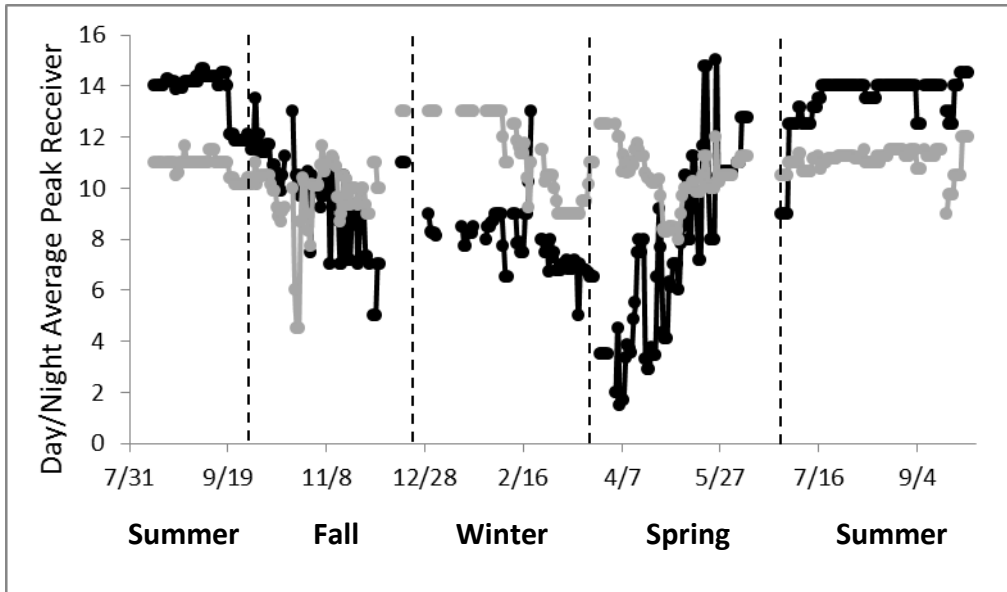


Figure 5a – Daily average Day (grey) and Night (black) “Peak” and “Trough” receivers across all fish. Notice that the oscillation type switches in both autumn and spring. Dotted lines correspond to the start of a new season.

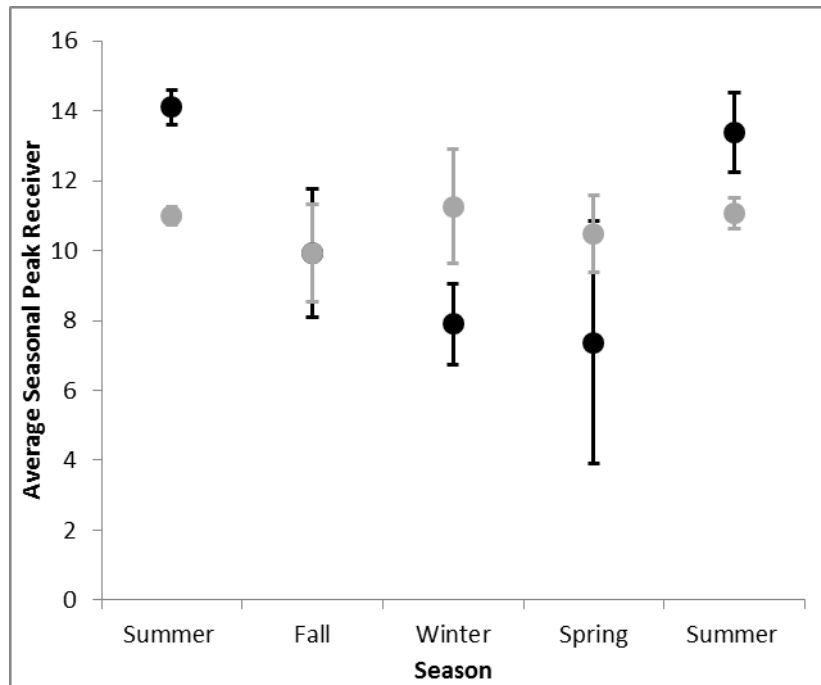
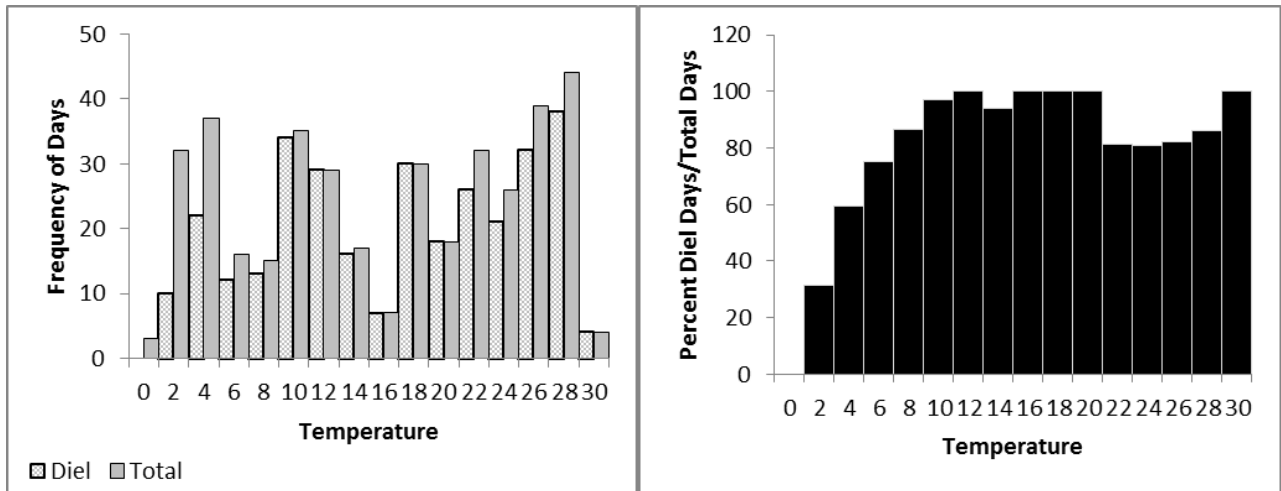


Figure 5b – Average seasonal Day (grey) and Night (black) receiver location across all fish and their standard deviation. The two summer seasons correspond to 2010 and 2011, respectively. Fall day and night averages are overlapping.



Figures 6a – Number of days (grey) and diel days (textured grey) averaged across all fish with corresponding average daily temperatures. Temperature data are based on a single SeaCAT’s acquired hourly data and are relative to fish location.

Figure 6b – Percent of diel days to total days for the corresponding temperatures. Percent totals of 100 imply that all days in the temperature range were diel days.

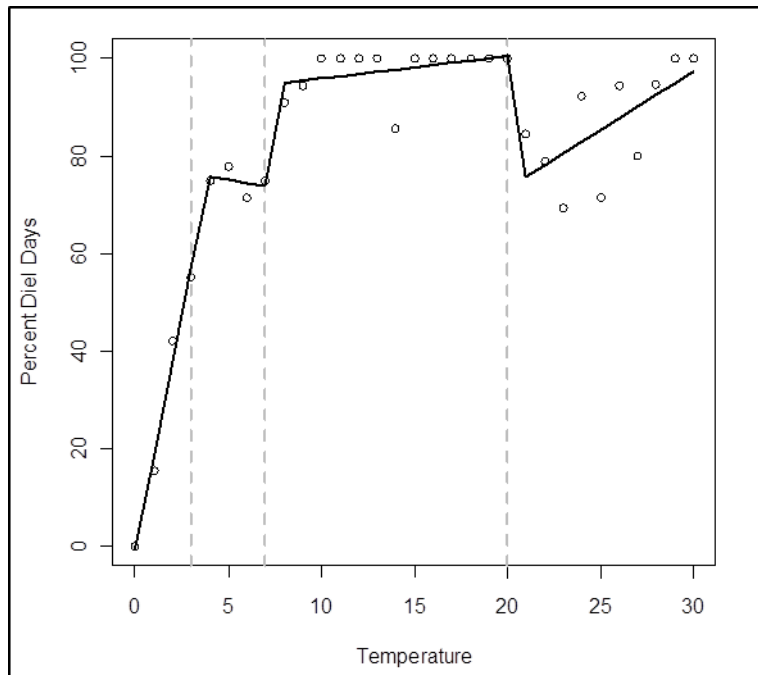
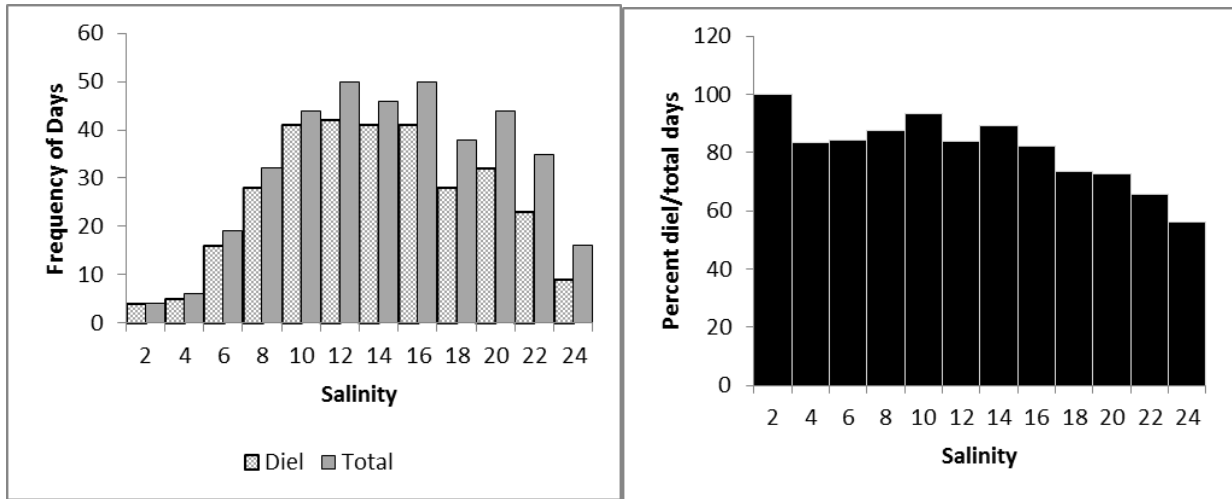


Figure 6c – break point analysis results for Figure 6b (percent of diel days for each daily average temperature). Results suggest that there is a steep decline in frequency of diel days as temperatures decline past 10°C. High temperatures may also have an effect.





Figures 7a - Number of days (grey) and diel days (textured grey) with corresponding average daily salinities. Salinity data are based on a single SeaCAT's acquired hourly data and are relative to fish location.

Figure 7b - Percent of diel days to total days for the corresponding salinities. Percent totals of 100 imply that all days in the salinity range were diel days.

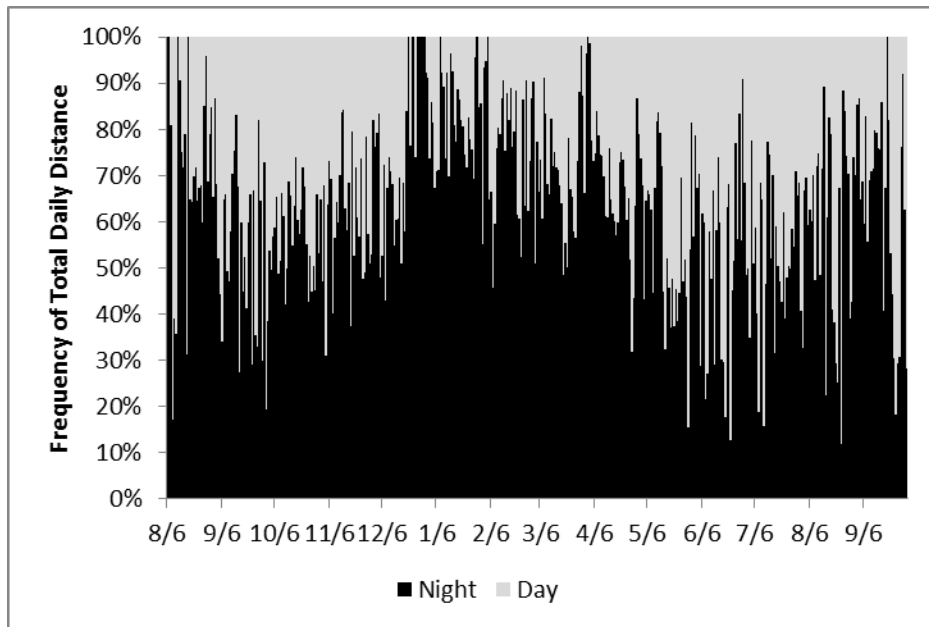


Figure 8a – Percent of total daily distance traveled during daylight and night hours. Day and night are differentiated based on sunrise and sunset times.

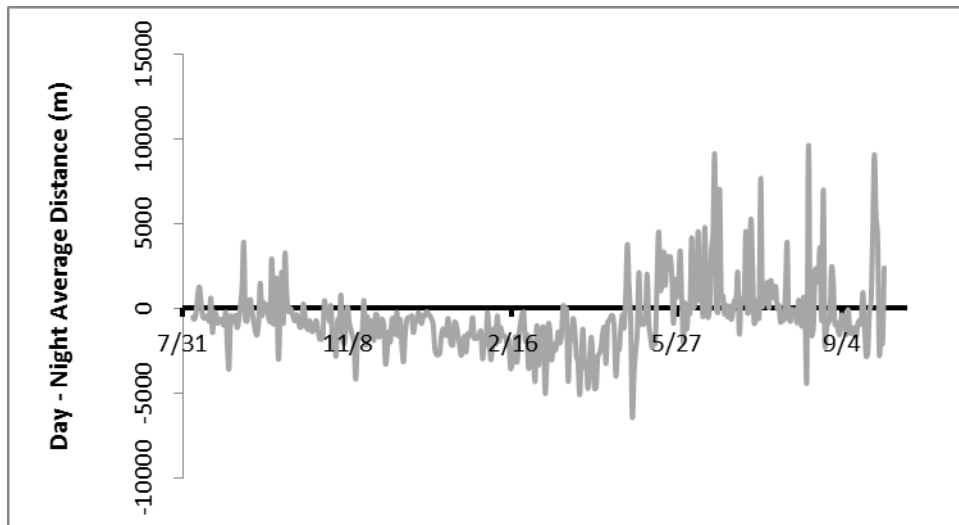


Figure 8b – Time series of the difference in daily average distance between day and night. The grey line represents night activity (m) subtracted from day activity (m), where negative values correspond to increased levels of night activity, and positive values show increased daytime activity. Values of zero suggest that day and night activity levels are equal.

## Chapter 2 Tables

Table 1a – Diel day frequency data by season used in an R x C Test for Independence using a G-Test, and the results of the statistical analyses. The adjusted G-value was shown to be significant ( $G > \chi^2$ ,  $P < 0.001$ ), suggesting that diel day frequencies are not independent of seasonality.

\*Summer I is August – mid-September of 2010, thus represents only half the season.

Season	Total Diel Days	Total Non-Diel Days	Total Days of Detections	Percent Diel Days	G	
Summer I*	115	118	233	49.4%	q	1.002
Fall	249	736	985	25.3%	G <sub>adj</sub>	287.52
Winter	144	898	1042	13.8%	df	4
Spring	233	445	678	34.3%	$\chi^2$	18.47
Summer II	159	118	277	57.4%	Significance Level	P < 0.001

Table 1b – G-Test for analysis of frequencies used to determine if individual fish show diel day frequency dependence with seasonality. Results are only displayed for fish exhibiting diel behavior in more than one season. All fish with data from three or more seasons showed significant dependence on seasonality for the frequency of diel behavior ( $P < 0.05$ ).

Fish ID	Nseasons	Gadj	Chisq	Outcome
WP184	3	8.65	5.99	significant
WP188	3	15.72	5.99	significant
WP189	2	1.65	3.84	ns
WP190	2	0.86	3.84	ns
WP191	4	67.41	7.81	significant
WP195	4	49.22	7.81	significant
WP196	4	1151.42	9.49	significant
WP197	2	1.74	3.84	ns
WP198	3	29.97	5.99	significant
WP200	5	1102.28	9.49	significant
WP201	4	15.76	7.81	significant
WP221	3	9.55	5.99	significant

Table 2 – Results of a Chi-Square test of sample means for seasonal preference of diel cycle type. Average frequencies of each cycle type were compared. Red cells indicate non-significant differentiation based on a significance level of 0.05. Yellow cells correspond to the most preferred behavior during each season.

Season	Positive Cycle Avg. <i>f</i>	Negative Cycle Avg. <i>f</i>	Expected Pos. Cycle Avg.	Expected Neg. Cycle Avg.	ChiSq	Signif.
Summer I	18.83333	0.333333	9.583333	9.583333	8.928261	<0.01
Fall	9.416667	0.166667	4.791667	4.791667	4.46413	<0.05
Winter	0.583333	11.41667	6	6	4.890046	<0.05
Spring	4.230769	13.46154	8.961538	8.961538	2.497359	<0.1
Summer II	31	0.8	15.9	15.9	14.34025	<0.001

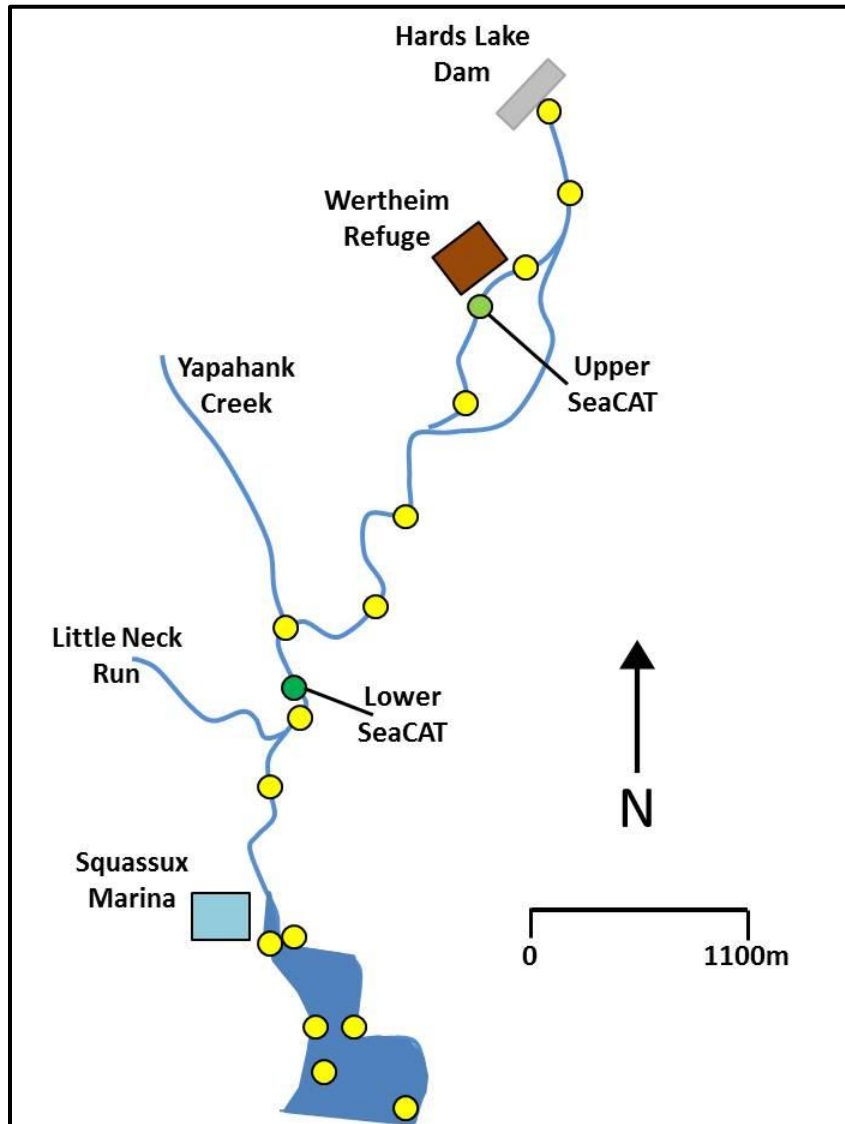
Table 3 – Paired T-Test of Sample means for Day-Night Distance data. All seasons excluding Summer and Fall 2011 have significantly greater mean hourly distances during the night. The nonsignificant seasons in 2011 could be a result of a low number of individual fish used in the analysis compared to the other seasons. Total Year comprises all days for the entire study period.

Time of Year	df	Mean Day (m)	Mean Night (m)	P-value (1-tail)
Summer 2010	46	84.7	131.2	<0.001
Fall 2010	89	126.1	164.7	<0.001
Winter 2010	88	58.1	178.3	<0.001
Spring 2011	92	191.3	300.5	<0.001
Summer 2011	93	137.1	157.5	NS (0.09)
Fall 2011	7	466.8	268.2	NS (0.07)
Total Year	420	130.5	194.2	<0.001

## APPENDIX



Map 1 – Great South Bay and the tributaries selected for receiver deployment. Receiver locations are approximated and marked by a yellow dot. Receiver distribution in the Carmans River is shown in Map 2.



Map 2 – Main channel of the Carmans River and approximate receiver locations indicated by yellow dots. The lower SeaCAT and the upper SeaCAT are the dark green and light green dots, respectively.