EVALUATION OF THERMAL CHARACTERISTICS OF SECONDARY WARM-WATER SITES FOR THE FLORIDA MANATEE (*Trichechus manatus latirostris)*

By

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Abstract

While the threat of collisions with recreational watercraft continues to be a serious concern for the Florida manatee population, a growing threat in the future is likely to be the loss of available winter habitat. Manatees are at risk of illness or death in water temperatures less than 20°C. To meet their thermoregulatory needs, manatees rely on sources of warm-water habitat. Currently the majority of the population is utilizing thermal discharges at coastal power plants to stay warm during winter cold periods; however, most of these power plants are expected to close down in the next t20 to 50 years. Since 1998 the Florida Fish and Wildlife Conservation Commission (FWC) has collected time-series temperature data at various sites used by manatees in winter. The goal of my project was to evaluate the thermal characteristics of 10 suspected warm-water sites in southern Florida to assess their potential suitability as winter habitat for manatees. Sites were assessed based on how frequently they were at temperatures considered threatening to manatee health and mortality, and on how many consecutive days they remained below these threshold temperatures. Delta-T and regression analysis were also used to compare the temperature of potential warm-water sites to that of nearby ambient sites. The results of this analysis will be used to make recommendations to the FWC about which sites might provide suitable warm-water habitat and should be further investigated with more detailed monitoring efforts in the future. This information could be used to meet the agency's long-term goal of creating a protected network of warm-water habitat throughout the state.

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Introduction

The Florida manatee (*Trichechus manatus latirostris*), a subspecies of the West Indian manatee, is found only in the southeastern United States, predominantly in Florida. The management of the Florida manatee has largely focused on the impacts of various anthropogenic threats to the stability of the population. While still classified as endangered under the U.S. Endangered Species Act (ESA) (U.S. Fish and Wildlife Service, 2001) and at the state level under the Florida Endangered and Threatened Species Act (Florida Fish and Wildlife Conservation Commission, 2007), the most recent annual population count recorded the largest numbers of manatees (5,076) since such monitoring efforts began in 1991 (FWC, 2010a). However mortality statistics are also at an all-time high. At least 431 carcasses were recovered within just the first three months of 2010, a record number for any 12- month period (FWC, 2010b). Collisions with recreational watercraft continues to be the single highest source of mortality for the Florida manatee population in most years, but a significant threat in the future will likely be the loss of available winter habitat (Laist & Reynolds, 2005a).

Manatees are herbivorous aquatic mammals, consuming a variety of submerged, floating, and shoreline vegetation and sea grasses (Campbell & Irvine, 1977; Baugh et al., 1989). Reliance on this abundant, but low energy food source, has led to a number of morphological and physiological adaptations, including a low mass-specific metabolic rate, low capacity for thermogenesis, and high thermal conductance (Irvine, 1983). In fact, manatees have one of the lowest metabolic rates of all mammals (Irvine, 1983). Because of these nutritional adaptations, manatees have a very limited ability to adjust to temperature decreases within their environment. A study on the metabolic rates of three captive manatees concluded water temperatures below 20°C are physiologically challenging for manatees (Irvine, 1983).

At temperatures below 20°C manatees are at risk from a complex disease process called cold-stress syndrome (CSS), which impacts the immunological, nutritional, and metabolic systems (Irvine, 1983; O'Shea et al., 1985; Bossart et al., 2003). Effects of CSS include skin lesions and abscesses (Image 1), dehydration, weight loss, internal fat loss, gastrointestinal distress including the inability to digest food, secondary infections, and eventual mortality (Bossart et al., 2003). CSS is the second greatest cause of mortality for the Florida manatee (FWC, 2010a). The number of statewide deaths from CSS during the 2008-2009 winter was 72, twice as high as the previous five winter average (FWC 2009) (Figure 1). As of February 2010, the 2009-2010 winter was marked by 189 confirmed deaths from CSS (FWC 2010). Juveniles and calves appear to be much more susceptible to CSS than adults, which is likely related to their greater surface-to-volume ratio, reduced capacity for raising metabolic rate as ambient temperature declines, and inexperience in finding and using warm-water sources (O'Shea et al., 1985; Worthy et al., 2000; Bossart et al., 2003). Mortality can occur from both acute exposure to extreme cold temperatures (less than 15°C) and chronic exposure to temperatures below 20°C (O'Shea et al., 1985). In order to avoid cold water temperatures, manatees begin to migrate to sources of warm-water habitat when water temperatures drop below 20°C (Deutsch et al., 2003). As a sub-tropical species, manatees are at the limits of their northern range in Florida (Lefebvre et al., 2001). Historically manatees likely followed a north-south migration that limited their winter distribution to the southernmost portion of

Image 1: Photo of an adult manatee suffering from cold stress syndrome (Photo by: FWC)

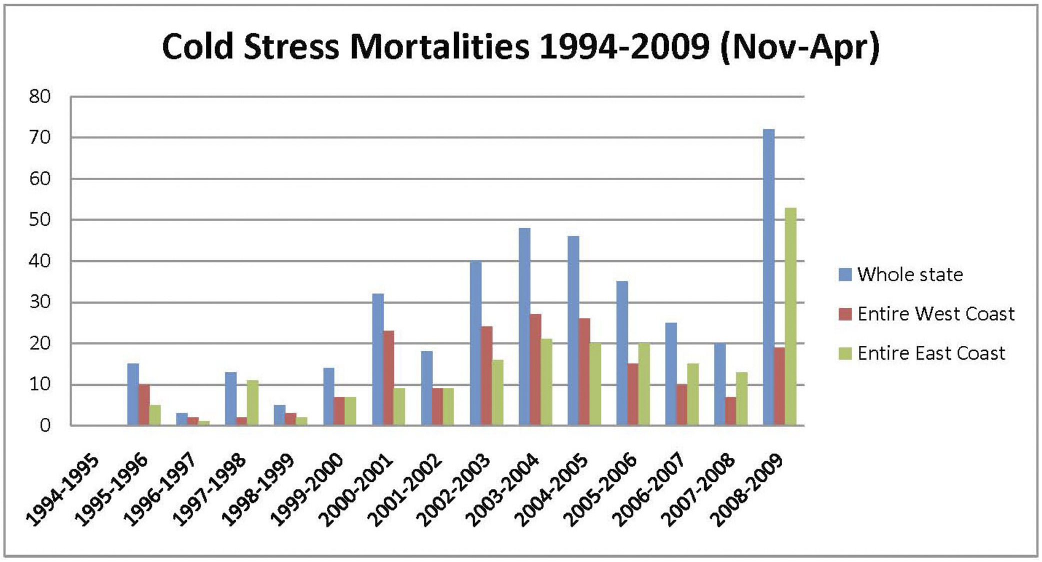


Figure 1: Number of confirmed manatee deaths due to cold stress over the past fifteen winters. (Source FWRI. http://research.myfwc.com/features/view_article.asp?id=33589, retrieved April 1, 2010)

the state, or restricted them to the natural artisanal springs located in the north-central region (Deutsch et al., 2003; Laist and Reynolds, 2005b). However, pressure from poaching and habitat alterations restricting access to many natural warm-water sites is thought to have shifted the migratory patterns (Laist & Reynolds, 2005b).

Presently manatees utilize two types of warm-water habitat: warm-water discharges and passive thermal basins (Laist & Reynolds, 2005a). Warm-water discharge sites have continuously flowing water, remaining within a consistent temperature range that is typically warmer than 20°C (Laist & Reynolds, 2005b). The natural springs used by manatees flow from artesian aquifers, and remain approximately 22°C year round. Although historically manatees probably relied principally on warm-water springs for warmth in Florida, only about 15 % of the current population utilizes four major spring systems for thermal refuge (Laist & Reynolds, 2005b). Furthermore, the quality of these sites continues to decline as spring flow decreases due to anthropogenic use (Florida Springs Task Force, 2000). The majority of manatees now utilize artificial sources of warm water, primarily outfalls from the cooling systems of eight power plants located throughout the state. Built between the 1940s and 1970s, these older plants were granted variances under the U.S. Clean Water Act (CWA), allowing them to discharge heat into the surrounding water bodies using once-through cooling technology (Laist & Reynolds, 2005a). Because of their steady output of warm water, aggregations of manatees numbering in the hundreds of individuals can be found at these power plant effluents during winter. Approximately 60% of the manatees counted during statewide synoptic surveys were found in the vicinity of power plant outfalls (Laist & Reynolds, 2005a). This growing reliance on power plant effluents places the population at risk to temporary disruptions in flow. In an effort to reduce this risk, and increase the reliability of power plant effluents for manatee use, power plants granted variances under the CWA are required to develop manatee protection plans that outline actions the plants will take to protect manatees attracted to their discharge. For certain sites, this includes a provision to endeavor to maintain outfall temperatures at a minimum of 20°C when ambient temperature drops below 16°C (Laist & Reynolds, 2005a; FWC, 2007).

Natural springs and power plant effluents are considered primary sources of warm-water habitat because of their relative stability in maintaining water temperatures above 20°C, but manatees also utilize secondary sources of warm-water habitat. Most secondary sites are passive thermal basins, pockets of warmer water that cool more slowly than the surrounding water bodies (Laist & Reynolds, 2005b). Passive thermal basins are typically areas that have been dredged or are naturally deep basins that retain heat from solar radiation or organic biodegradation (Smith, 2000). Because these sites do not have a source of continuously flowing water input as warm-water discharge sites do, their ability to remain above critical threshold temperatures during cold snaps is likely inferior to primary warm-water sites. Telemetry studies indicate that manatees use some secondary sites as stop-over refuges during brief periods of cold on their way to primary sources of thermal refuge (Deutsch, 2000; Deutsch et al., 2003). Although there are been some efforts to characterize physical properties of a small number of secondary warm-water sites visited by manatees (Barton, 2006), the locations, thermal characteristics during winter months, and use by manatees of passive thermal basins has been relatively understudied (Lasit & Reynolds, 2005b).

Management of warm-water habitat over the past thirty years has largely focused on protecting warm-water discharge sites, primarily power plants and major springs, due to the large portion of the manatee population that relies on these sites for thermal refuge. The U.S Fish and Wildlife Service (USFWS) is responsible for the management of the manatee at the federal level, while the Florida Fish and Wildlife Conservation Commission (FWC) holds management authority at the state level. Most past management efforts have focused on ensuring the reliability of warm-water habitat created by industrial thermal outfalls. Recognizing that over the long term these sources are ultimately unreliable, managers are placing increased emphasis on warm-water carrying capacity of non-industrial sources. The power plants granted variances under the CWA to operate with once-through cooling were all built between 1940 and1970, and although a number of the plants have repowered within the past 10 to 15 years, all of these plants are nearing the end of their operational lifespan and are expected to shut down in the next 10-50 years (Laist & Reynolds, 2005a; 2005b). The eventual closure of these sites will remove a major source of warm-water habitat that the manatee population has come to rely upon. Research using satellite-linked telemetry and photo-identification has found that manatees show strong site fidelity to particular warm-water sources year after year, suggesting that individuals may not migrate to new sources if their existing warm-water habitat is eliminated (Reid et al., 1991; Deutsch et al., 2000;2003). Opportunistic studies of manatee responses to temporary closures of industrial thermal outfalls have shown a shift in distribution patterns and an unexpected number of deaths associated with these closures (Packard et al., 1989; Deutsch et al., 2000).

The Florida Manatee Recovery Plan provides the framework for USFWS to conserve and manage manatees with the goal of downlisting from an “endangered” to “threatened” status and the removal from the list entirely (U.S. Fish and Wildlife Service, 2001). The most recent version of the Recovery Plan displays the growing emphasis on warm-water issues, citing the loss of warm-water habitat as one of the greatest threats to the continued existence of the species (U.S. Fish and Wildlife Service, 2001). A number of management teams arose from the recovery plan, including the 18 member Florida Manatee Recovery Team, comprised of government officials, scientists, and stakeholders. Recognizing the significance of effectively managing warm-water habitat, the Recovery Team established the Warm-Water Task Force to implement plans specific to this issue. Recent management recommendations have emphasized the growing need to address the inevitable loss of artificial warm-water discharge sites as habitat for manatees (Laist & Reynolds, 2005a).

The Florida Manatee Management Plan, the State’s management planning document, describes the need to increase the state’s effort on all aspects of warm-water issues (Florida Fish and Wildlife Conservation Commission, 2007). As with the federal plan, the State plan emphasizes the critical need to address the anticipated loss of warm-water habitat from the closure of power plants, and calls for the development of an interagency contingency plan to reduce manatee mortality as the plants change in operation. Some suggested management alternatives include the development of non-industrial but still artificial warm-water sources, for example using solar panels to heat small enclosed areas of water. The need for a more comprehensive approach to site-by-site management is increasingly being recognized (Laist & Reynolds, 2005a; 2005b; FWC, 2007).

One overarching management goal is to create a protected network of thermal refuges. Under the Florida Manatee Sanctuary Act of 1978 (370.12 (2), Florida Statutes) the entire state of Florida is considered a manatee sanctuary, and the state has the authority to establish and regulate protected areas. In addition to protecting natural springs from continued degradation, a protected network could include enhancing environmental quality and reducing recreational boat use within passive thermal basins. Following the identification of potential thermal basins based on a combination of manatee distribution data and local knowledge, the next step in creating a protected network of thermal refuges is to evaluate the physical characteristics of passive thermal basins throughout the State to determine their ability to remain at temperatures that can sustain manatees over the winter (Laist & Reynolds, 2005a; Florida Fish and Wildlife Conservation Commission, 2007).

The goal of my project is to assess the thermal quality at 11 possible passive thermal basins across southeast and southwest Florida and to determine their ability to maintain temperatures during winter months that would be suitable for manatee thermoregulation. Characterizing these sites based on their suitability as winter habitat for manatees will help with the development of recommendations to State managers about sites that could be included in a future network of protected warm-water habitat.

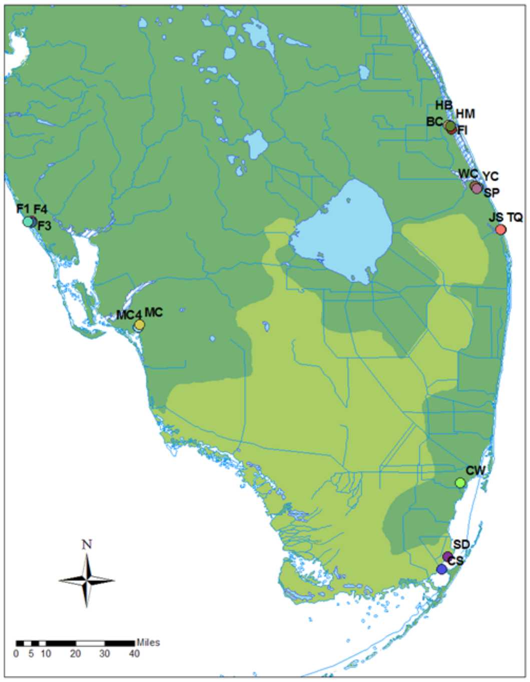


Figure 2: Location of potential thermal basins included in analysis

Methods

Study Area and Data Collection

The Florida Fish and Wildlife Research Institute (FWRI) Marine Mammal Program, a research

Probe Site	Probe Code	Region	Latitude	Longitude	Site Type	Depth	Start Date	End Date
Forked Creek, Englewood Isles Marina	F1_C	SW	27.001°	-82.3801°	Warm-Water	Column	3/16/2007	4/23/2009
Forked Creek, Englewood Isles Marina	F1_B	SW	27.001°	-82.3801°	Warm-Water	Bottom	3/16/2007	4/23/2009
Forked Creek, Alameda Isles Marina	F3	SW	26.994300°	-82.377350°	Warm-Water	Column	3/1/2007	4/24/2009
Ten Mile Canal	MC_B	SW	26.48989°	-81.852268°	Warm-Water	Bottom	11/19/2008	4/16/2009
Ten Mile Canal	MC_C	SW	26.48989°	-81.852268°	Warm-Water	Column	11/19/2008	4/16/2009
Ten Mile Canal	MC_S	SW	26.48989°	-81.852268°	Warm-Water	Surface	11/19/2008	4/22/2009
Ten Mile Canal, San Carlos Park	TC	SW	27.2097°	-80.8005°	Warm-Water	Bottom	12/8/1998	10/11/1999
Forked Creek, Lemon Bay	F4	SW	26.995°	-82.3972°	Ambient	Column	11/24/2008	4/23/2009
Ten Mile Canal, Estero Bay	MC4	SW	26.4768°	-81.8564°	Ambient	Column	11/24/2008	4/17/2009
Belcher Canal	BC	SE	27.4688°	-80.337517°	Warm-Water	Column	10/13/2006	1/22/2007
Harbor Branch Oceanographic Institute Canal	HB	SE	27.533997°	-80.356722°	Warm-Water	Column	12/15/1998	10/12/2000
Sea Dade Canal	SD	SE	25.350338°	-80.342997°	Warm-Water	Bottom	11/14/2008	5/15/2009
Tequesta	TQ	SE	26.95887°	-80.08157°	Warm-Water	Column	1/4/2008	5/4/2009
Willoughby Creek	WC	SE	27.172184°	-80.209770°	Warm-Water	Column	10/13/2006	10/24/2008
Stuart Yacht and Country Club Marina, Crooked Creek	YC	SE	27.712090°	-80.1990361°	Warm-Water	Column	8/12/1999	10/29/2002
Coral Gables Waterway	CW	SE	25.712090°	-80.279239°	Warm-Water	Bottom	10/25/2006	5/14/2009
Indian River, Harbor Town Marina	HM	SE	27.46695°	-80.32815°	Ambient	Column	10/13/2006	10/24/2008
Ft. Pierce Power Plant Intake, Indian River	FI	SE	27.45038°	-80.32297°	Ambient	Column	11/11/1999	11/2/2005
Card Sound	CS	SE	25.2892°	-80.31097°	Ambient	Column	11/14/2008	5/16/2009
Hobe Sound	HS	SE	27.05058°	-80.11178°	Ambient	Column	2/1/1999	10/5/2000
Jupiter Sound	JS	SE	26.95779°	-80.080168°	Ambient	Column	11/4/2008	5/4/2009
Sandspirit Park, Indian River	SP	SE	27.164842°	-80.192863°	Ambient	Column	1/22/2007	2/16/2007

Table 1: General information on the locations of 22 probes, including geographic information, code name, site characteristics, and deployment periods.

division within the FWC, began collecting time series water temperature data in 1998 at warm-water sites where manatees aggregate during winter. I examined a subset of these data, focusing on winter aggregation and nearby ambient sites from the southeast (south of the Sebastian River) and southwest (south of the Tampa Bay) regions of Florida (Figure 2). Temperatures were recorded at either 30 or 40 minute intervals using deployed data logging probes (Onset Corp.,Stowaway and HOBO models). Monitored sites were potential warm-water sites, where manatees have been known to aggregate at least temporarily during winter months. In most cases, water temperature was also monitored simultaneously at ambient sites in close proximity to these putative thermal basins. A total of 7 sites from the southeast region (5 with associated ambient data) and 7 from the southwest region (2 with ambient data) were included in this analysis. Because some sites had multiple probes at various depths, data from a total of 22 temperatures probes were examined (Table 1).

Two sites had loggers set at different levels in the water column in order to examine temperatures variation with depth. Surface probes were set within 0.5 meter of the surface of the water, column probes were placed in the middle range of the water column, and bottom probes were positioned within 0.5 meter of the substrate. Dates of data collection varied across probes (Table 1), ranging from December 1998 to May 2009. Data analyses that compared associated warm-water and ambient sites (Table 2) only utilized comparable time periods. Temperature data were collected at many sites year-round, only winter temperatures were examined. This time period included the principle winter months (December – February) and the transitional months (October, November, March) when manatees generally migrate to and from warm-water habitats (Deutsch et al., 2003).

Data Organization and Censoring

Data from probes were downloaded on site at varying intervals based on accessibility and time constraints. Some probes were checked approximately every month, but other probes had longer intervals (up to 6 months) between downloading of data. For various reasons, probes sometimes recorded temperatures that did not reflect potential manatee habitat. Bottom probes were sometimes disturbed from their deployed location and recorded erroneous data from the column or surface. More commonly, water column and surface probes became exposed to air, either due to unauthorized manipulation of the probes or from tidal movements.

	Warm-Water Probe Code	**Ambient Probe Code**
SW		
	F1_C	**F4**
	F1_B	**F4**
	F3	**F4**
	MC_B	**MC4**
	MC_C	**MC4**
	MC_S	**MC4**
SE		
	BC	**HM**
	HB	**FI**
	SD	**CS**
	TQ	**JS**
	WC	**SP**

Table 2: Site codes for warm-water and ambient probe pairs

In order to exclude erroneous data points from the analysis, a standardized procedure was established to identify outliers from the data files. Initial searches for outliers within each data file were conducted with HOBOware Pro (Onset Corp). This program allows users to graphically visualize time series of temperatures over selected time scales. Outlying data points are displayed as extreme daily temperature fluctuations in these graphs. Air temperatures are characterized by a larger variance than water temperatures, so erroneous data points were fairly obvious within a temperature profile. Any temperature changes of at least 2.8°C from one reading to the next (either a 30 or 40 minute interval) were flagged as an outlier. Records surrounding the flagged data point were also examined; records were removed until the data returned to an expected temperature range for the intended medium. To reduce the likelihood of removing accurate temperature data, inter-quartile ranges were calculated for a random sample of edited and unedited files to examine if removed data points were characterized as outliers using an alternative method. The amount of data removed varied across probes because some probes appeared to have spent large amounts of time out of the water in the time they were deployed and when they were checked by researchers (up to 4 months). See Table 3 for the total number of data points removed from each probe.

Probe Code	N	# Deleted
F1_C	21079	71
F1_B	24771	8
F3	45250	11282
MC_B	7100	45
MC_C	7100	45
MC_S	7378	323
TC	11043	0
F4	7206	269
MC4	6908	46
BC	2426	0
HB	21273	2
SD	8774	9
TQ	23320	113
WC	33177	4
YC	44821	2196
CW	42566	14
HM	33182	1
FI	65535	3118
CS	8879	114
HS	19763	0
JS	8709	0
SP	1197	1

Table 3: Number of erroneous data points that were deleted for each probe

Data Analysis

Descriptive statistics, including minimum, maximum, mean temperature, and variance over every 24-hour period within the entire dataset for each probe were calculated. These values were grouped by month to assess the temperature patterns of each probe location over the course of a winter season. I calculated the percentage of days and the number of consecutive days that the daily minimum, maximum, and mean temperatures were below selected threshold temperatures between October and March for each probe. Threshold temperatures used in this analysis were 20°C, 18°C, and 16°C based on the increasing metabolic stress water temperatures below 20°C place on manatee health. These analyses were used to obtain a general thermal characterization of each site over time. Temperature profiles were produced for paired ambient and warm-water probes, and for probes located at different depths at the same site.

To assess the extent to which potential warm-water sites remained above critical threshold temperatures during cold periods, a delta-T value was calculated for all matching dates between warm-water and ambient pairs. This was calculated by subtracting the mean daily temperature of the ambient site from the mean daily temperature of its paired warm-water site. Paired t-tests were also performed between paired warm-water and ambient probes to determine statistical significance of the differences between temperatures at these sites. A linear regression was performed using ambient temperature as a predictor variable for the delta-T value associated with each paired warm-water site:

Regression 1: $ß_0 + ß_1(\text{Ambient Temperature}) = \text{Delta-T}$

A second regression was performed using dummy variables for temperatures that fell within four categories: Above 20°C, between 20°C - 18°C, between 18°C - 16°C, and below 16°C.

Regression 2: $ß_0 + ß_1 D_{AMB\ 20\text{-}18} + ß_2 D_{AMB\ 18\text{-}16} + ß_3 D_{AMB\ 16\ -} = \text{Delta-T}$

The values of this regression were used to assess the suitability of each site as warm-water habitat for manatees. An ideal warm-water site would result in $ß_0 < ß_1 < ß_2 < ß_3$, as this would indicate that the Delta-T became increasing larger as the ambient site became colder, as would be the case if the thermal basin maintained a stable temperature in the face of declining ambient temperature. An increasing Delta-T with a decreasing mean ambient temperature means the associated warm-water site is remaining warmer during cold snaps than the ambient site. This is suggestive of a passive thermal basin that is able to retain heat longer than the ambient water bodies. Passive thermal sites were assessed based on the degree to which they remained warm when their ambient site dropped below threshold temperatures by categorizing the results of the second regression in terms of suitability to meet manatee thermoregulatory needs:

Excellent: Delta –T > 4°C

Good: Delta –T > 2 - 4°C

Minimal: Delta –T > 1 - 2°C

All calculations were performed using Microsoft Excel 2007.

Results

Descriptive Statistics

Most probes (n=12) recorded water temperatures for one winter period, but nine probes collected data for at least two winter seasons (Table 5). The ambient probe in the Indian River (FI) recorded the maximum number of winters (n=8). Descriptive statistics for all sites are listed in the Appendix (I). Table 4 shows the mean and standard deviation for all ambient and warm-water probes during the 2008 – 2009 winter. Data from this winter season is particularly useful for three reasons: the greatest number of probes recorded data in this season; a complete set of data for all winter months (October – March)

	Winter 2008 - 2009												
	Ambient Sites				Warm-Water Sites								
	JS	CS	MC4	F4	F1_B	F1_C	F3	MC_B	MC_C	MC_S	SD	TQ	CW
Oct	- -	- -	- -	- -	- -	- -	28.4 1.83	- -	- -	- -	- -	26.7 1.67	27.0 2.05
Nov	22.9 1.98	21.4 2.34	20.4 0.69	18.8 1.32	18.1 0.61	19.3 0.86	- -	27.5 0.19	23.4 1.04	21.2 0.60	21.7 2.16	24.2 1.11	22.6 2.17
Dec	22.7 1.19	21.7 1.21	22.5 1.25	20.8 2.12	20.1 1.50	21.3 1.54	- -	25.8 0.50	23.2 0.32	22.1 1.20	22.9 1.01	25.7 0.19	21.9 1.23
Jan	21.4 1.88	20.7 2.37	21.7 2.30	18.8 3.50	19.0 2.62	20.0 2.75	19.5 2.58	24.7 0.85	23.1 0.68	21.5 1.77	21.2 1.91	25.2 0.53	20.9 2.43
Feb	20.7 1.88	20.3 2.50	21.2 2.14	18.5 3.05	18.3 2.20	19.5 2.29	19.6 2.07	21.2 0.99	21.1 0.89	20.9 1.23	20.5 2.12	24.0 0.69	20.5 2.51
Mar	22.6 1.84	22.9 2.20	23.7 1.94	22.1 3.23	21.7 2.51	22.9 2.59	22.8 2.45	23.3 1.37	23.1 1.27	23.1 1.54	23.4 2.12	24.5 0.96	23.2 2.24

Note: Standard deviation in parenthesis

Table 4: Mean temperatures and standard deviations of all recorded water temperatures (taken every 30 or 40 minutes) by month during the 2008 – 2009 winter at both ambient and potential warm-water sites.

was available which allowed for a more comprehensive comparison of probes; and this winter was notable for its unusually cold temperatures. Prior to the 2009 – 2010 winter, the 2008 – 2009 winter had the greatest number of manatee mortalities due to cold stress syndrome of any previous monitored winter (Figure 1). During winter 2008- 2009, mean ambient site temperatures ranged from 18.8°C (F4 in November) to 23.7°C (MC4 in March). Mean warm-water site temperatures ranged from 18.1°C (F1_B in November) to 27.5°C (MC_B in November). The greatest variability in ambient and warm-water temperatures occurred in January (SD=3.50, F4 (ambient), SD=2.75, F1_C (warm-water)). February had the coldest mean temperature across all sites ($\bar{x}$=20.57) and March displayed the warmest mean temperature ($\bar{x}$=23.02).

The percentage of days each probe dropped below critical threshold temperatures of 20°C, 18°C, and 16°C is shown in Table 5. Observation periods varied between probes, so percentages are based on the total number of winter seasons observed for each probe, as shown in the third column. The percentage of total winter days below 20°C is the cumulative impact of days below threshold temperatures. The ambient sites F4 and SP had the greatest percentage of days (38%) in which mean

Probe Site	Depth	# of Winters	% Days Below 20°C			% Days Below 18°C			% Days Below 16°C		
Warm Water Sites			*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*
F1_C	Column	2	33%	12%	23%	14%	4%	8%	7%	1%	3%
F1_B	Bottom	2	37%	23%	30%	18%	9%	12%	6%	2%	4%
F3	Column	2	28%	10%	15%	16%	4%	7%	9%	1%	3%
MC_B	Bottom	1	5%	2%	3%	-	-	-	-	-	-
MC_C	Column	1	4%	2%	3%	-	-	-	-	-	-
MC_S	Surface	1	25%	3%	11%	3%	-	-	-	-	-
TC	Bottom	1	1%	-	-	-	-	-	-	-	-
BC	Column	1	10%	4%	6%	-	-	-	-	-	-
HB	Column	2	20%	26%	24%	9%	16%	13%	2%	4%	3%
SD	Bottom	1	21%	8%	14%	5%	3%	4%	-	-	-
TQ	Column	2	2%	-	1%	1%	-	-	-	-	-
WC	Column	2	6%	3%	5%	1%	-	1%	-	-	-
YC	Column	3	17%	10%	14%	5%	2%	4%	1%	-	1%
CW	Bottom	3	10%	5%	8%	3%	1%	2%	1%	-	1%
Ambient Sites			*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*
F4	Column	1	65%	15%	38%	42%	5%	18%	25%	-	11%
MC4	Column	1	28%	8%	14%	8%	-	3%	3%	-	-
HM	Column	2	19%	6%	10%	6%	1%	3%	1%	-	-
FI	Column	8	17%	7%	11%	3%	1%	2%	1%	-	-
CS	Column	1	27%	14%	20%	10%	4%	6%	4%	1%	2%
HS	Column	2	12%	8%	10%	5%	1%	3%	1%	-	-
JS	Column	1	23%	5%	12%	6%	1%	3%	2%	-	1%
SP	Column	1	62%	8%	38%	19%	-	-	-	-	-

Table 5: Percentage of days the minimum, maximum, and mean temperatures over a 24-hour period from October – March for each warm-water and ambient probe were below the critical threshold temperatures of 20°C, 18°C, & 16°C

temperatures were below 20°C. Of the warm-water sites, F1_B had the highest mean percentage of days (30%) below 20°C, while TC and TQ had mean temperatures with the lowest percentage of days (= 1%) in which mean temperatures fell below threshold temperatures. Three ambient probes recorded mean daily temperatures below 16°C, while six warm-water probes recorded mean daily temperatures below this level (Table 5).

The number of consecutive 24-hour periods that each probe had a mean temperature below critical threshold temperatures of 20°C, 18°C, and 16°C is listed in the Appendix (II) by winter season. The number of consecutive days mean temperatures were below 20°C for the 2008 – 2009 winter is shown in Table 6 for each monitored site. Because sustained temperatures below critical thresholds present an increasing threat to manatee thermoregulation (Irvine, 1983; Bossart, 2001), consecutive days of low temperatures are indicative of an environment less suitable for manatee use.

Winter 2008 - 2009																								
Probe Site	**1**			**2**			**3**			**4**			**5**			**6**			**7**			**8+**		
Warm Water Sites	20° C	18°	16°	20° C	18°	16°	20° C	18°	16°	20° C	18°	16°	20° C	18°	16°	20° C	18°	16°	20° C	18°	16°	20° C	18°	16°
F1_C	1	1	-	4	1	1	1	-	1	-	1	-	2	1	-	-	1	-	-	-	-	2 (12,13 days)	-	-
F1_B	-	1	-	-	2	1	1	-	-	-	-	2	-	1	-	-	-	-	1	-	-	3 (9,11,14 days)	2 (10,11 days)	-
F3	1	2	-	-	-	-	-	-	2	-	-	-	-	-	-	1	1	-	-	-	-	2 (12,13 days)	1 (10 days)	-
MC_B	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MC_C	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MC_S	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
SD	1	-	-	3	-	-	1	1	-	-	1	-	-	-	-	1	-	-	1	-	-	-	-	-
TQ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CW	1	-	-	2	-	2	-	-	-	1	1	-	1	1	-	-	-	-	1	-	-	1 (11 days)	-	-
Ambient Sites																								
F4	-	2	-	2	-	1	3	-	2	-	1	2	-	-	-	3	-	-	-	-	-	2 (12,14 days)	2 (10,11 days)	-
MC4	-	-	-	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2 (9 days)	-	-
CS	-	-	1	1	-	1	-	-	-	1	-	-	-	2	-	1	-	-	-	-	-	2 (10,12 days)	-	-
JS	-	2	1	3	-	-	3	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-

Table 6: The number of consecutive 24-hour periods the mean temperature fell below 20°C during the 2008 – 2009 winter.

Three of four ambient probes had at least two periods lasting more than eight days where daily mean temperatures were below 20°C. Three of the eight warm-water sites had at least two periods lasting more than eight days when the daily mean temperature was below 20°C, with F1_B having both the greatest number of consecutive cold periods (n=5) and the longest length of consecutively cold days (14 days).

Comparisons of the time series of temperatures for paired ambient and warm-water probes are most easily visualized graphically. This is illustrated for the column probe at Ten Mile Canal during winter 2008 – 2009 winter is shown in Figure 3.

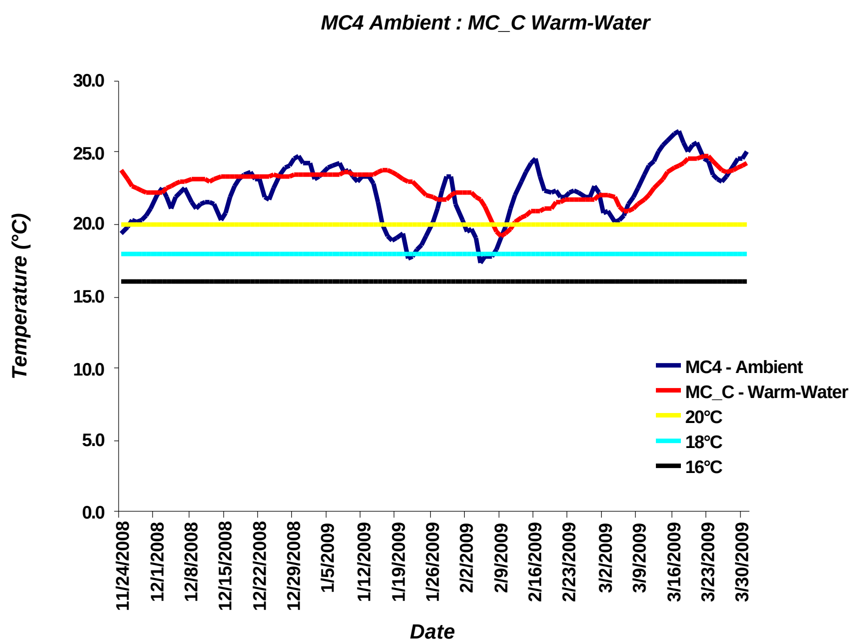
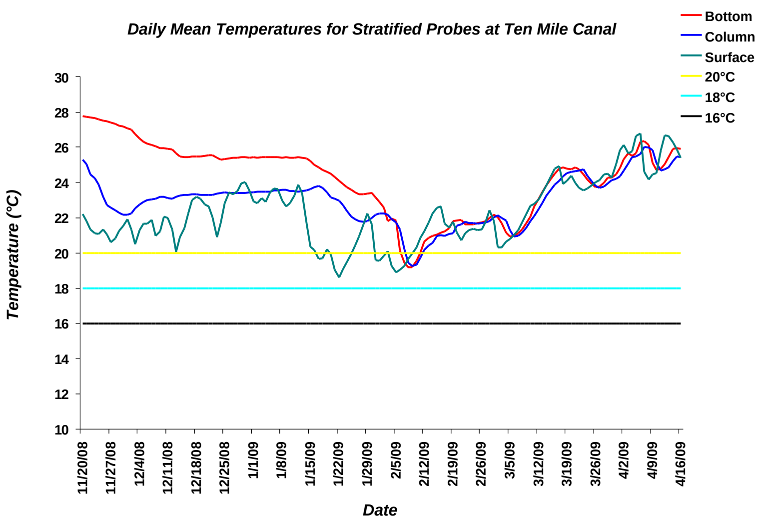
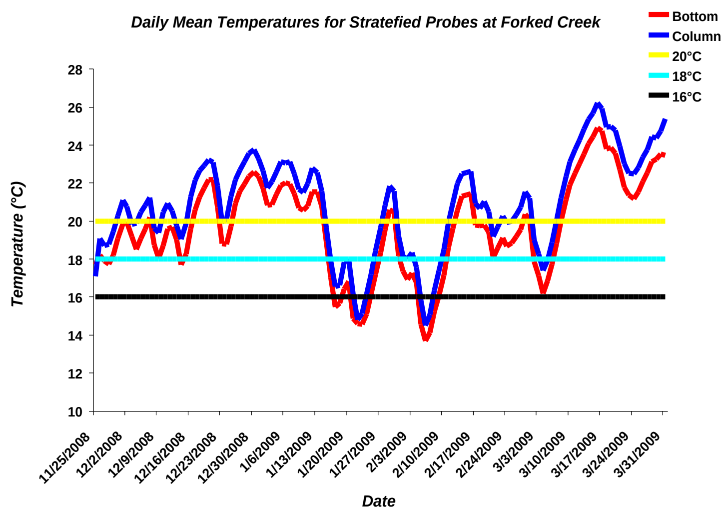


Figure 3: Water temperature at Ten Mile Canal for the paired ambient probe (MC4) and warm-water probe (MC_C) during the 2008 – 2009 winter. The horizontal lines the critical threshold temperatures.

The time the daily mean temperature for each probe fell below 20°C is shown below the horizontal yellow line. Time series of temperatures for all paired ambient and warm-water probes are provided in the Appendix (III). Temperature profiles for the two sites (MC and FC) that had multiple probes stratified across depths indicate differences between the daily mean temperatures dependent upon depth (Figures 4 a-b). The daily minimum, maximum, and mean temperatures for each probe at these two sites are presented graphically in the Appendix (IV). Bottom and column temperatures displayed less variance within and across days and were less likely to drop below threshold temperatures than surface probes (Appendix IV).



a.



b.

Figure 4 (a-c): Daily mean water temperatures during the 2008 – 2009 winter for stratified probes at two sites: (a) Ten Mile Canal; (b) Forked Creek

Delta-T Analysis

Paired t-test results (Table 7) indicate that the Delta-T between all paired ambient and warm-water probes was statistically different from zero (p<0.001), but the direction of this difference was not the same across warm-water sites. Three of the

	Southwest											
	F1_B - F4		F1_C - F4		F3 - F4		MC_B - MC4		MC_C - MC4		MC_S - MC4	
	Ambient	*WW*	*Ambient*	*WW*	*Ambient*	*WW*	*Ambient*	*WW*	*Ambient*	*WW*	*Ambient*	*WW*
Mean	20.02	19.72	20.04	20.90	19.81	20.76	22.20	23.97	22.20	22.65	22.20	21.89
Variance	11.09	6.59	11.08	7.24	13.30	8.00	4.62	4.20	4.62	1.40	4.62	2.74
Observations	5857	5857	5811	5811	3944	3944	6111	6111	6111	6111	6111	6111
Pearson Correlation	0.87		0.91		0.92		0.21		0.42		0.87	
df	5856		5810		3943		6110		6110		6110	
t Stat	13.77		-46.98		-38.74		-52.69		-17.94		22.25	
P(T<=t) two-tail	0.00		0.00		0.00		0.00		0.00		0.00	

	Southeast											
	BC - HM		HB - FI		SD - CS		TQ - JS		WC - SP		YC - HS	
	Ambient	*WW*	*Ambient*	*WW*	*Ambient*	*WW*	*Ambient*	*WW*	*Ambient*	*WW*	*Ambient*	*WW*
Mean	23.20	23.28	23.49	23.38	22.67	23.30	22.07	24.77	20.54	21.37	22.88	23.64
Variance	4.64	4.32	2.86	4.00	10.09	9.55	3.83	0.94	2.75	1.67	8.68	7.08
Observations	2424	2424	2458	2458	8765	8765	7104	7104	1177	1177	5142	5142
Pearson Correlation	0.93		0.95		0.95		0.57		0.72		0.97	
df	2423		2457		8764		7103		1176		5141	
t Stat	-4.78		8.33		-60.78		-140.52		-24.63		-76.01	
P(T<=t) two-tail	0.00		0.00		0.00		0.00		0.00		0.00	

Table 7: Pearson correlation and paired t-test results for all ambient and warm-water paired probes for paired winter seasons. All differences were statistically significant at $p < 0.001$.

twelve warm-water probes were, on average cooler, than their associated ambient probes. Additionally, despite the strong significant results in all paired t-tests, this difference is likely not ecologically significant due to the small difference between most probes, with only two out of the twelve pairs having an average Delta-T greater than 1°C.

Linear regressions were performed for each matched pair of sites to determine the relationship between Delta-T and local ambient temperature. A negative regression coefficient indicated that the temperature differential between the warm-water site and ambient increases as temperatures drop. The calculated regression coefficients were negative for all but one site (HB – FI, Harbor Branch) and they were statistically

	WW	Ambient	Regression 1 Coefficient ($ß_1$)	Above 20° C ($ß_0$)	20° - 18° C ($ß_0+ß_1$)	18° - 16° C ($ß_0+ß_2$)	Below 16° C ($ß_0+ß_3$)
SW	F1_B	F4	-0.327 *	-1.001 *	-0.248 *	0.388 *	2.167 *
	F1_C	F4	-0.263 *	0.289 *	0.947 *	1.442 *	2.848 *
	F3	F4	-0.287 *	0.199 *	1.017 *	1.342 *	2.995 *
	MC_B	MC4	-0.797 *	1.277 *	4.24 *	4.637 *	6.741 *
	MC_C	MC4	-0.769 *	-0.129 *	3.22 *	4.318 *	6.728 *
	MC_S	MC4	-0.330 *	-0.563 *	0.794 *	1.778 *	3.535 *
SE	BC	HM	-0.104 *	0.010	0.812 *	2.217 *	-
	HB	FI	0.119 *	-0.086 *	-0.92 *	-	-
	SD	CS	-0.073 *	0.513 *	0.947 *	1.199 *	1.897 *
	TQ	JS	-0.719 *	2.278 *	4.751 *	5.889 *	6.8 *
	WC	SP	-0.441 *	0.279 *	1.584 *	2.201 *	-
	YC	HS	-0.122 *	0.668 *	0.955 *	1.582 *	2.058 *

Table 8: Linear regression coefficients for Delta-T vs, ambient water temperatures of paired ambient and warm-water probes (Regression 1) and for Delta-T vs. ambient temperature using critical threshold temperature ranges as dummy variables are listed in the last four columns.
* Indicates statistically significant result ($p < 0.001$).

significant ($p < 0.001$) (Table 8, Figure 5). If a warm-water site provides better habitat for manatees during cold temperatures than an ambient site then we would expect higher Delta-Ts during lower ambient temperatures. This would result in a negative regression coefficient (Figure 5). Linear regression figures for all pairs are in the Appendix (V).

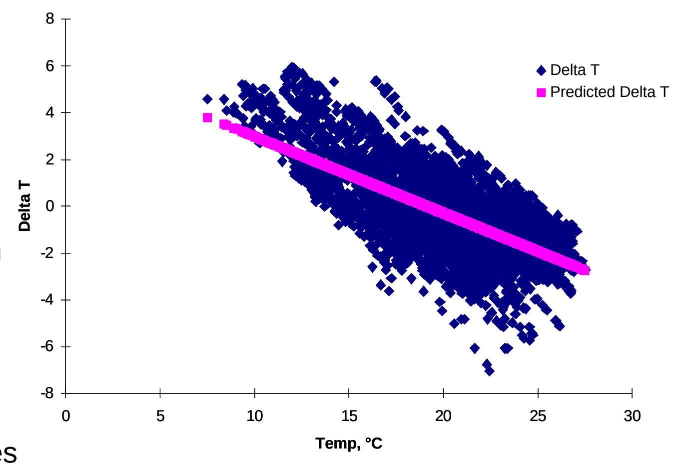


Figure 5: Example Delta-T by ambient temperature plot with predicted Delta-Ts from linear regression at warm-water site F1_C.

Results from the regression using temperature categories as dummy variables further reinforced the trend for the Delta- T to be greater at lower ambient temperatures. In all but one ambient and warm-water pair (HB – FI) the expected Delta-T monotonically increased across decreasing ambient temperature categories (Table 8). Three warm-water probes (MC_B, MC_C, & TQ) remained on average over 3°C warmer than their associated ambient probe across all three temperature categories below 20°C (Figure 6).

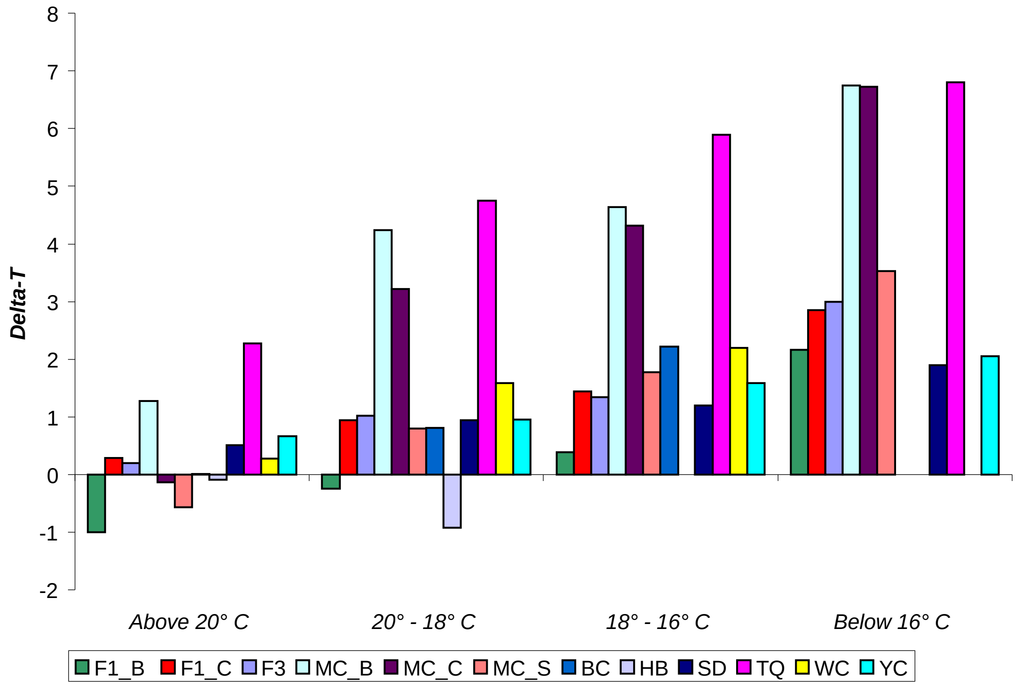


Figure 6: Average value of the Delta-T by ambient temperature category. Legend shows code for warm-water probe within each associated pair.

Discussion

Overall, the results suggest that most of the suspected warm-water sites evaluated in this investigation were able to at least temporarily provide thermal benefit to manatees during cold weather. These sites varied in thermal quality for manatees, as indicated by the delta-T above ambient during cold conditions. There was also variability in temperature within sites associated with depth.

Characterizing a site based on the thermoregulatory benefit provided to manatees should be based not only on overall temperature patterns, but specifically on the ability of the site to remain above the critical temperatures at which manatees are susceptible to cold stress. To assess potential warm-water sites, based on their ability to stay warm when it really matters (i.e., when surrounding water temperatures drop to threatening levels), standardized thermal comparisons need to be made between the potential warm-water site and nearby ambient site. The results of these comparisons, as indicated by the regressions, are the most useful in terms of assessing a site's thermal quality for manatee use. Exposure to extreme cold can cause acute mortality responses (Ackerman et al., 1995), which can have profound consequences for a population that is already coping with other strong anthropogenic sources of mortality (Marmontel et al., 1997). Passive thermal basins likely do not have the ability to retain heat during long periods of cold temperatures comparable to that of natural springs and power plant effluents (Smith, 2000; Barton, 2006), so characterizing their response to cold snaps provides an important indicator for their suitability as warm-water refuge.

Both warm-water and ambient probes were characterized as having extended periods of temperatures below threshold values across sites (Table 6, Appendix II), however all but two of the warm-water probes show evidence of providing refuge from cold ambient conditions. The dummy variable temperature categories (Table 8) were used to assess a probe's warm-water habitat suitability. Positive values represent positive Delta-T values between the associated ambient and warm-water probes, indicating the warm-water site remained warmer than the ambient when ambient water temperatures fell within the critical threshold categories. Higher values reported from the dummy regression indicate a warmer location at the warm-water probe. These results

Warm-Water Habitat Suitability	WW Site Code
Excellent (Delta-T > 4°C)	**MC_B MC_C TQ**
Good (Delta-T > 2°C)	**BC WC**
Minimal (Delta-T > 1°C)	**MC_S F1_B F3 SD YC**

Table 9: Classification of warm-water probes for their suitability as warm-water habitat for manatees. Delta-T results based on dummy regression for 18 °C-16°C category.

were used to categorize the thermal quality of each potential warm-water site based on its suitability for manatee use during cold weather (Table 9). Habitat suitability was determined using the Delta-T values calculated with the 18°C - 16°C temperature category only. I chose this temperature range to evaluate warm-water sites because it reduced the possibility that any erroneous data points (that may not have been removed during the data QA/QC phase) could influence the interpretation of a site's thermal quality. This is based on the assumption that erroneous data that could falsely influence the thermal range at a site would likely to be either extremely warm temperatures or extremely cold temperatures, which would impact the values in both the "above 20°C" and "below 16°C" ranges.

Two sites displayed the strongest temperature qualities in terms of the extent to which they stayed at least 4°C warmer than their paired ambient site when the latter was between 18°C and 16°C: Ten Mile Canal and Tequesta. Manatees are known to aggregate at the Ten Mile Canal site in winter, a 6-8 meter-deep dredged borrow pit located on the southwest coast of Florida (Figure 7); this suggests that manatees use this as a secondary warm-water sites site (USFWS, 2001; Laist and Reynolds, 2005b). Two of the three probes displayed "excellent" warm-water habitat suitability, while the other probe (a surface probe) only displayed "minimal" suitability. The bottom and column probe had comparable thermal qualities, but the surface probe was characterized by much stronger daily variability and colder temperatures (Figure 5). Manatees wallowing within bottom sediment layers at secondary warm-water sites is assumed to be a thermoregulatory behavior based on the ability of the sediment to retain more heat than the surrounding water. The water column probe and bottom probe at Ten Mile Canal both displayed relatively high delta-T values, so the ability of this site to sustain manatees may be better than sites that exhibit more temperature variation across depths. This also exemplifies the need to characterize the stratified thermal

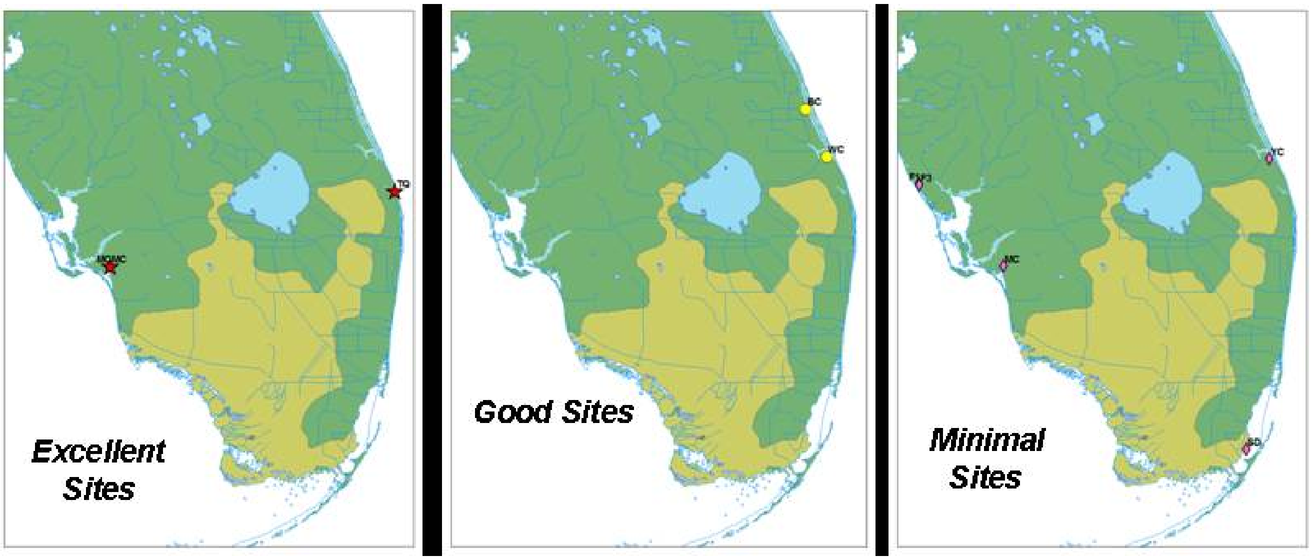


Figure 7: Location of the ten warm-water sites whose thermal quality has at least a minimal suitability to provide warm-water habitat.

quality at all suspected warm-water sites to more accurately understand their ability to support manatees during periods of cold temperatures. While the probe at Tequesta is also classified as an “excellent” site, the temperature range across depths should be explored at this site to examine its overall thermal quality. However, because this was a column probe we would expect to find bottom temperatures at either warmer or comparable values, suggesting this is also a suitable secondary warm-water site.

This analysis of thermal qualities at selected sites across southern Florida is useful for identifying possible passive thermal basins that should be included in future monitoring efforts. A number of caveats are necessary when interpreting these results however. First, the time series of temperature data at each site was collected at a single point in space, so caution should be taken when extrapolating the results to the entire surrounding water body. Although the recorded temperatures are likely indicative of the thermal qualities within the immediate area, future monitoring efforts need to include multiple probes at different locations within the same water body to characterize the total thermal quality and area of a potential warm-water site. Hydrographic surveys that measure temperature, salinity, and depth in relation to bathymetry would provide an alternative approach for developing a detailed three-dimensional map of thermal structure. Additionally, all sites should include temperature probes deployed at various depths in order to better define vertical temperature stratification. Finally, multiple habitat requisites need to be assed at each site that is considered for inclusion in a warm-water network. In addition to suitable water temperatures, sites need to be located within reasonable distances of food resources, and ideally within close proximity to other secondary warm-water sites that manatees can use while traveling and foraging. Because manatees appear to form spatial cognitive maps to locate necessary resources (Flamm et al., 2005), it is likely individuals could easily exploit such a protected warm-water network.

In addition to basing future monitoring efforts on the results of the reported sites, and focusing long-term management goals to include the sites displaying the best suitability for a protected warm-water network, these results can be used to better understand the carrying capacity for the entire manatee population. Available winter habitat is thought to be one of the major factors expected to limit the long-term carrying capacity of the Florida manatee (Haubold et al., 2006). Estimating the future carrying capacity once the power plants have stopped operation is a management priority (Haubold et al., 2006). The results of the present study provide the necessary, albeit not sufficient, information in order to characterize this important parameter for selected sites.

The current analysis provides the framework for directing future management efforts to further characterize the sites that demonstrate the ability to withstand cold temperatures and to locate other warm-water habitat areas. The human population in Florida is growing rapidly, so it is vital to locate and preserve additional sources of warm-water habitat for the future growth and recovery of the manatee population.

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Appendix

I. Descriptive statistics for each probe – Minimum, maximum, mean, and standard deviation by winter month of recorded temperatures for all ambient (n=8) and warm-water (n=14) probes. Values were calculated from the raw data that has been cleaned to remove erroneous outliers.

Southwest Region

Ambient		**F4 - Lemon Bay**			
		Min	**Max**	**Mean**	**St Dev**
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	15.84	21.99	18.84	1.32
	Dec	14.22	26.16	20.85	2.12
	Jan	9.41	24.41	18.76	3.50
	Feb	7.52	24.07	18.53	3.05
	Mar	10.44	27.51	22.09	3.23

Ambient		**MC4 - Ten Mile Canal**			
		Min	**Max**	**Mean**	**St Dev**
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	18.79	21.72	20.36	0.69
	Dec	18.49	25.43	22.48	1.25
	Jan	15.10	25.19	21.66	2.30
	Feb	13.74	25.45	21.24	2.14
	Mar	18.18	27.01	23.70	1.94

Warm-Water		**F1_B - Forked Creek**			
		Min	**Max**	**Mean**	**St Dev**
Winter 2007 - 2008	**Oct**	26.35	30.19	28.67	1.06
	Nov	20.82	26.92	23.42	1.78
	Dec	19.13	26.30	23.18	1.91
	Jan	15.75	22.56	19.78	2.06
	Feb	19.96	22.30	22.47	1.59
	Mar	-	-	-	-
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	16.96	19.60	18.07	0.61
	Dec	17.30	23.16	20.11	1.50
	Jan	13.81	22.56	18.96	2.62
	Feb	12.10	22.30	18.33	2.20
	Mar	15.20	26.01	21.70	2.51

Warm-Water		F1_C - Forked Creek			
		Min	Max	Mean	St Dev
Winter 2007 - 2008	**Oct**	25.79	31.69	28.80	1.31
	Nov	19.91	27.78	23.43	1.93
	Dec	18.70	27.04	23.20	1.97
	Jan	12.87	25.28	19.50	2.53
	Feb	19.27	25.87	23.14	1.77
	Mar	-	-	-	-
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	17.06	20.84	19.29	0.86
	Dec	17.01	24.85	21.32	1.54
	Jan	12.17	24.15	20.04	2.75
	Feb	12.03	23.69	19.50	2.29
	Mar	15.75	27.48	22.94	2.59

Warm-Water		F3 - Forked Creek, Alameda Isles Marina			
		Min	Max	Mean	St Dev
Winter 2007 - 2008	**Oct**	26.52	31.31	29.04	1.02
	Nov	20.70	27.70	23.80	1.70
	Dec	18.34	27.19	23.42	1.89
	Jan	10.69	24.87	19.76	2.17
	Feb	16.32	26.92	22.94	1.79
	Mar	13.28	26.87	22.85	1.60
Winter 2008 - 2009	**Oct**	22.01	32.33	28.36	1.83
	Nov	-	-	-	-
	Dec	-	-	-	-
	Jan	11.86	23.47	19.49	2.58
	Feb	11.49	23.21	19.61	2.07
	Mar	11.61	26.74	22.75	2.45

Warm-Water		MC_B - Ten Mile Canal			
		Min	Max	Mean	St Dev
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	27.09	27.78	27.48	0.19
	Dec	25.23	27.14	25.78	0.50
	Jan	22.82	25.48	24.66	0.85
	Feb	18.72	23.02	21.19	0.99
	Mar	20.46	25.21	23.31	1.37

Warm - Water		MC_C - Ten Mile Canal			
		Min	Max	Mean	St Dev
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	21.89	25.50	23.36	1.04
	Dec	22.08	23.50	23.15	0.32
	Jan	21.60	23.86	23.07	0.68
	Feb	19.13	22.39	21.10	0.89
	Mar	20.84	24.77	23.14	1.27

Warm - Water		MC_S - Ten Mile Canal			
		Min	Max	Mean	St Dev
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	19.72	24.20	21.22	0.60
	Dec	17.84	25.33	22.14	1.20
	Jan	16.87	24.56	21.48	1.77
	Feb	17.96	23.71	20.87	1.23
	Mar	19.08	26.26	23.14	1.54

Warm - Water		TC - Taylor Creek			
		Min	Max	Mean	St Dev
Winter 1998 - 1999	**Oct**	-	-	-	-
	Nov	-	-	-	-
	Dec	21.64	25.04	23.69	0.86
	Jan	19.51	24.17	22.65	1.11
	Feb	21.47	25.21	23.76	1.06
	Mar	20.81	25.73	23.18	1.00

Southeast Region

Ambient		CS - Card Sound			
		Min	Max	Mean	St Dev
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	18.63	27.70	21.37	2.34
	Dec	18.06	24.20	21.72	1.21
	Jan	15.08	24.80	20.66	2.37
	Feb	14.48	24.87	20.27	2.50
	Mar	17.75	27.53	22.86	2.20

Ambient		HM - Harbor Town Marina			
		Min	Max	Mean	St Dev
Winter 2006 - 2007	**Oct**	21.03	29.41	25.89	1.98
	Nov	17.78	25.81	22.67	1.98
	Dec	17.78	25.28	22.40	1.51
	Jan	16.32	25.46	21.63	2.11
	Feb	16.11	24.15	19.73	1.52
	Mar	19.46	25.50	22.84	1.28
Winter 2007 - 2008	**Oct**	25.04	29.49	27.20	0.82
	Nov	19.13	25.94	22.99	1.35
	Dec	19.13	25.04	22.93	1.16
	Jan	13.64	23.79	20.46	1.92
	Feb	19.87	24.97	22.92	1.27
	Mar	20.25	25.43	22.81	1.02

Ambient		JS - Jupiter Sound			
		Min	Max	Mean	St Dev
Winter 2008 - 2009	**Oct**	-	-	-	-
	Nov	18.32	27.26	22.86	1.98
	Dec	19.63	24.92	22.73	1.19
	Jan	16.61	24.61	21.39	1.88
	Feb	15.13	24.32	20.72	1.88
	Mar	17.30	26.06	22.62	1.84

Ambient		HS - Hobe Sound			
		Min	Max	Mean	St Dev
Winter 1998 - 1999	Oct	-	-	-	-
	Nov	-	-	-	-
	Dec	-	-	-	-
	Jan	-	-	-	-
	Feb	17.94	25.08	21.71	1.74
	Mar	19.72	25.61	22.41	1.53
Winter 1999 - 2000	Oct	22.52	30.49	26.82	2.14
	Nov	21.68	26.31	23.14	0.92
	Dec	17.14	23.87	21.00	1.90
	Jan	14.92	24.04	19.80	2.35
	Feb	17.14	24.73	20.71	2.20
	Mar	22.85	27.01	24.23	0.81

Ambient		SP - Sandspirit Park			
		Min	Max	Mean	St Dev
Winter 2006 - 2007	Oct	-	-	-	-
	Nov	-	-	-	-
	Dec	-	-	-	-
	Jan	16.87	24.29	20.52	1.94
	Feb	17.06	24.27	20.53	1.45
	Mar	-	-	-	-

Ambient		FI - Indian River			
		Min	Max	Mean	St Dev
Winter 1998 - 1999	Oct	-	-	-	-
	Nov	21.3	24.3	23.1	0.7
	Dec	18.4	23.5	21.7	1.5
	Jan	16.9	24.2	21.4	2.1
	Feb	17.7	24.5	21.7	1.8
	Mar	19.0	24.3	21.9	1.2
Winter 1999-2000	Oct	22.1	29.5	26.4	1.8
	Nov	20.8	25.5	23.2	1.1
	Dec	-	-	-	-
	Jan	-	-	-	-
	Feb	20.6	23.5	21.9	0.9
	Mar	22.3	25.9	23.7	0.6
Winter 2000-2001	Oct	22.5	28.8	25.0	1.6
	Nov	18.8	25.4	22.7	1.6
	Dec	19.0	21.1	20.0	0.6
	Feb	24.0	25.4	24.5	0.4
	Mar	18.4	24.7	22.2	1.4
Winter 2001-2002	Oct	20.6	27.8	25.4	1.6
	Nov	21.2	24.4	22.8	0.6
	Dec	19.1	25.6	22.4	2.0
	Jan	14.9	24.6	20.3	2.5
	Feb	19.1	24.4	21.1	1.2
	Mar	18.1	26.2	22.7	2.3
Winter 2002-2003	Oct	26.1	29.9	28.5	0.8
	Nov	19.9	27.7	23.7	2.2
	Dec	17.9	22.4	20.4	1.0
	Jan	13.7	22.2	17.9	2.1
	Feb	16.8	23.0	19.6	1.4
	Mar	21.4	26.8	23.8	0.9
Winter 2003-2004	Oct	-	-	-	-
	Nov	-	-	-	-
	Dec	15.6	20.0	17.8	0.9
	Jan	18.3	23.9	20.4	1.4
	Feb	18.3	23.2	21.2	1.3
	Mar	18.7	24.7	22.2	1.3
Winter 2004-2005	Oct	-	-	-	-
	Nov	21.3	25.1	23.3	0.9
	Dec	15.6	24.7	19.9	2.6
	Jan	14.8	24.0	19.5	2.6
	Feb	15.4	22.8	19.2	2.2
	Mar	17.1	26.3	21.0	2.0
Winter 2005-2006	Oct	20.2	29.5	26.4	2.3
	Nov	19.1	25.3	23.0	1.2
	Dec	16.8	23.2	19.8	1.2
	Jan	15.7	22.5	19.2	1.7
	Feb	14.0	22.7	19.5	1.5
	Mar	18.6	25.4	21.7	1.2

Warm - Water		BC - Belcher Canal			
		Min	Max	Mean	St Dev
Winter 2006 - 2007	Oct	23.31	28.76	26.07776	1.714559
	Nov	18.86	25.38	22.7751	1.977363
	Dec	19.67	24.86	22.38776	1.318135
	Jan	20.47	24.86	22.90833	1.241431
	Feb	-	-	-	-
	Mar	-	-	-	-

Warm - Water		HB - Harbor Branch Oceanographic Institute			
		Min	Max	Mean	St Dev
Winter 1998 - 1999	Oct	-	-	-	-
	Nov	-	-	-	-
	Dec	18.12	23.91	22.64	1.08
	Jan	15.73	21.88	18.51	1.97
	Feb	23.23	-	-	-
	Mar	23.23	25.13	24.03	0.38
Winter 1999 - 2000	Oct	22.05	31.32	26.59	2.30
	Nov	21.22	25.48	22.80	0.87
	Dec	16.83	22.38	20.36	1.60
	Jan	12.75	23.06	19.08	2.56
	Feb	14.77	23.74	19.32	2.63
	Mar	22.38	25.66	23.69	0.63

Warm - Water		TQ - Tequesta			
		Min	Max	Mean	St Dev
Winter 2007 - 2008	Oct	-	-	-	-
	Nov	-	-	-	-
	Dec	-	-	-	-
	Jan	17.18	24.87	22.47	1.55
	Feb	19.79	25.21	23.27	1.17
	Mar	19.84	25.53	22.94	1.18
Winter 2008 - 2009	Oct	21.60	29.62	26.69	1.67
	Nov	21.87	26.38	24.19	1.11
	Dec	25.16	26.13	25.72	0.19
	Jan	23.74	25.94	25.17	0.53
	Feb	20.94	24.92	24.00	0.69
	Mar	20.96	25.84	24.53	0.96

Warm - Water		YC - Crooked Creek			
		Min	Max	Mean	St Dev
Winter 1999 - 2000	Oct	23.53	29.92	26.93	1.55
	Nov	21.86	26.48	24.05	1.02
	Dec	18.76	24.22	22.00	1.51
	Jan	16.99	24.04	20.66	1.86
	Feb	17.95	24.74	21.35	2.01
	Mar	23.19	28.27	25.15	0.89

Warm - Water		CW - Coral Gables Waterway			
		Min	Max	Mean	St Dev
Winter 2006 - 2007	Oct	26.26	28.77	27.37	0.47
	Nov	21.82	27.68	25.86	1.41
	Dec	23.32	26.62	25.19	0.62
	Jan	19.03	26.62	24.01	2.17
	Feb	16.89	24.77	21.41	1.59
	Mar	21.75	27.46	23.84	1.17
Winter 2007 - 2008	Oct	25.55	30.27	28.21	1.10
	Nov	21.39	26.94	24.27	1.41
	Dec	20.72	26.55	24.19	1.49
	Jan	16.61	26.26	21.76	1.98
	Feb	20.20	27.68	24.28	1.61
	Mar	20.70	26.97	23.91	1.50
Winter 2008 - 2009	Oct	21.89	30.50	26.96	2.05
	Nov	19.25	27.68	22.64	2.17
	Dec	18.84	24.58	21.91	1.23
	Jan	15.08	24.41	20.94	2.43
	Feb	14.70	25.04	20.54	2.51
	Mar	18.03	28.02	23.16	2.24

Warm - Water		SD - Sea Dade Canal			
		Min	Max	Mean	St Dev
Winter 2008 - 2009	Oct	-	-	-	-
	Nov	18.58	26.84	21.69	2.16
	Dec	19.60	24.99	22.88	1.01
	Jan	16.96	23.86	21.15	1.91
	Feb	16.56	23.33	20.54	2.12
	Mar	18.82	27.21	23.42	2.12

Warm - Water		WC - Willoughby Creek			
		Min	Max	Mean	St Dev
Winter 2006 - 2007	Oct	24.54	31.42	27.52	1.79
	Nov	18.57	26.46	23.38	2.34
	Dec	20.51	25.93	23.32	1.29
	Jan	18.68	25.76	22.93	1.80
	Feb	16.44	25.60	20.80	1.63
	Mar	20.87	25.72	23.82	1.12
Winter 2007 - 2008	Oct	26.11	30.34	28.34	0.76
	Nov	22.78	27.24	24.85	1.15
	Dec	22.06	27.38	24.55	1.16
	Jan	18.13	25.14	22.14	1.49
	Feb	21.58	26.40	24.15	0.90
	Mar	20.70	26.60	24.00	1.10

II. Number of consecutive days the daily mean temperature was below threshold temperatures for each site by winter

	Winter 1998 - 1999																							
Probe Site	***1***			***2***			***3***			***4***			***5***			***6***			***7***			***8 +***		
Warm Water Sites	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°
TC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HB	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1 (10 days)	1 (9 days)	-
Ambient Sites																								
FI	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1 (10 days)	-	-
HS	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Winter 1999 - 2000																							
Warm Water Sites	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°
HB	-	1	-	-	-	1	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-	2 (8,32 days)	1 (18 days)	-
YC	-	-	-	1	1	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	1 (19 days)	-	-
Ambient Sites																								
FI	-	-	-	1	-	-	2	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
HS	-	1	-	-	1	1	-	-	-	1	1	-	-	-	-	-	1	-	-	-	-	2 (8,30 days)	-	-

Winter 2000 - 2001

Warm Water Sites	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°
YC	-	-	-	-	-	2	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	2 (8,19 days)	1 (13 days)	-
Ambient Sites																								
FI	1	-	-	1	-	-	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1 (12 days)	1 8 (days)	-

Winter 2001 - 2002

Warm Water Sites	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°
YC	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1 (11 days)	-	-

Winter 2006 - 2007

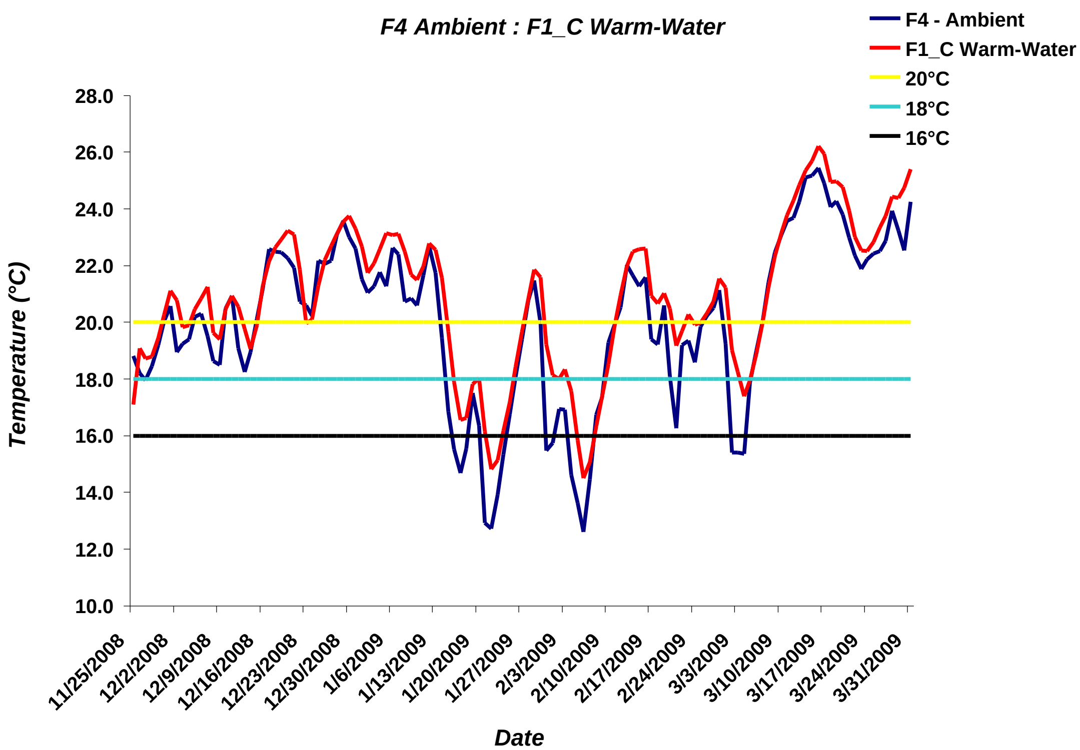
Warm Water Sites	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°
F1_C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F1_B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BC	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WC	-	-	-	-	1	-	-	-	-	1	-	-	1	-	-	1	-	-	-	-	-	-	-	-
CW	-	1	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ambient Sites																								
HM	1	1	-	-	1	-	1	1	-	1	-	-	1	-	-	-	-	-	2	-	-	-	-	-
SP	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-

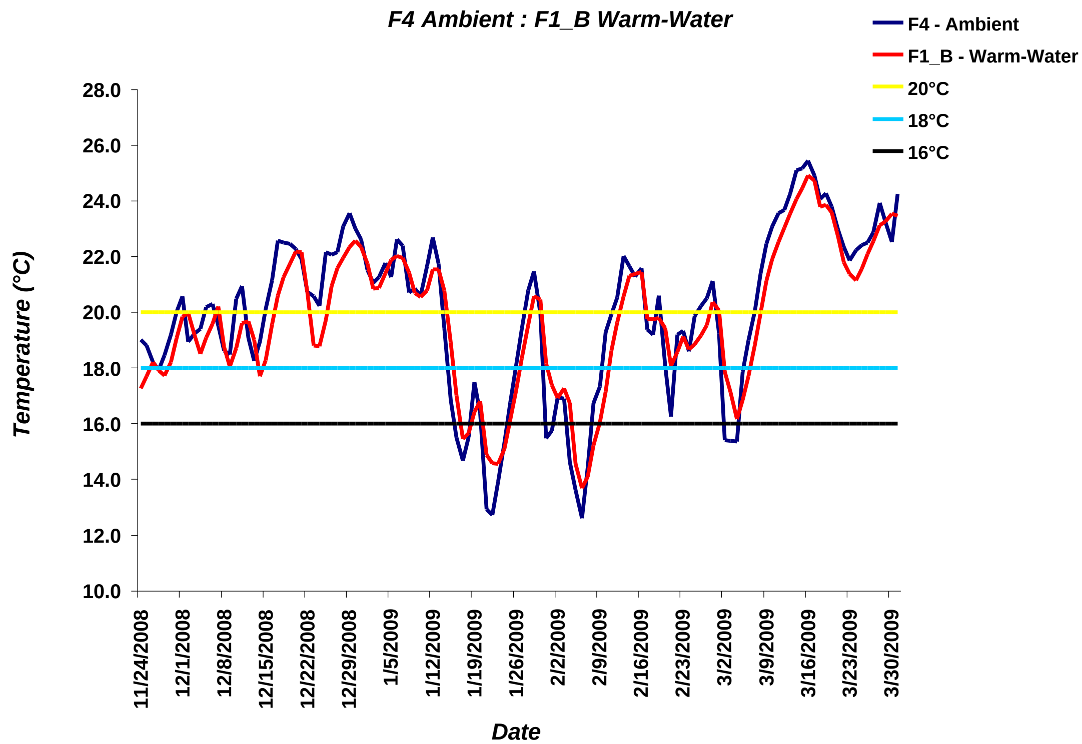
Warm Water Sites	**Winter 2007 - 2008**																							
	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°
F1_C	1	-	-	1	1	-	1	-	-	-	-	1	-	1	-	1	-	-	-	-	-	1 (8 days)	-	-
F1_B	-	-	1	-	-	-	3	-	-	1	-	-	-	-	-	-	1	-	1	-	-	-	-	-
F3	3	-	-	2	1	-	1	-	1	1	-	-	-	-	-	-	1	-	-	-	-	1 (8 days)	-	-
TQ	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WC	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CW	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ambient Sites																								
HM	-	-	1	1	-	-	1	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-

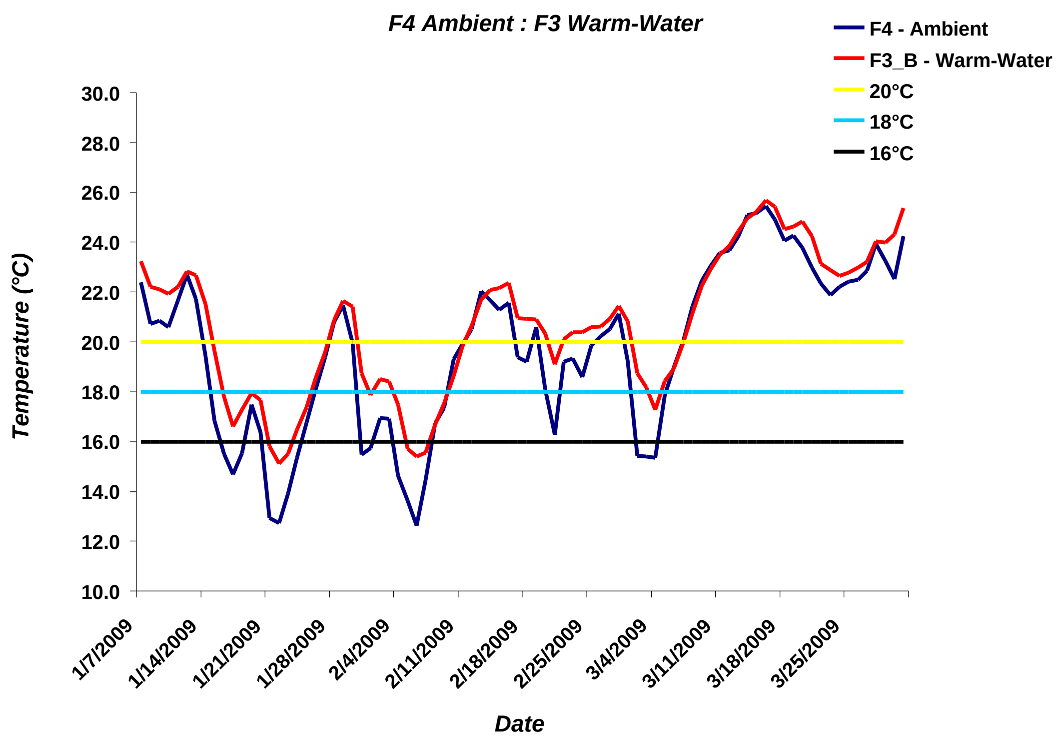
	Winter 2008 - 2009																							
Warm Water Sites	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°	20°	18°	16°
F1_C	1	1	-	4	1	1	1	-	1	-	1	-	2	1	-	-	1	-	-	-	-	2 (12,13 days)	-	-
F1_B	-	1	-	-	2	1	1	-	-	-	-	2	-	1	-	-	-	-	1	-	-	5 (9,11,13,13,14 days)	2 (10,11 days)	-
F3	1	2	-	-	-	-	-	-	2	-	-	-	-	-	-	1	1	-	-	-	-	2 (12,13 days)	1 (10 days)	-
MC_B	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MC_C	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MC_S	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
SD	1	-	-	3	-	-	1	1	-	-	1	-	-	-	-	1	-	-	1	-	-	-	-	-
TQ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CW	1	-	-	2	-	2	-	-	-	1	1	-	1	1	-	-	-	-	1	-	-	1 (11 days)	-	-
Ambient Sites																								
F4	-	2	-	2	-	1	3	-	2	-	1	2	-	-	-	3	-	-	-	-	-	2 (12,14 days)	2 (10,11 days)	-
MC4	-	-	-	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2 (9 days)	-	-
CS	-	-	1	1	-	1	-	-	-	1	-	-	-	2	-	1	-	-	-	-	-	2 (10,12 days)	-	-
JS	-	2	1	3	-	-	3	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-

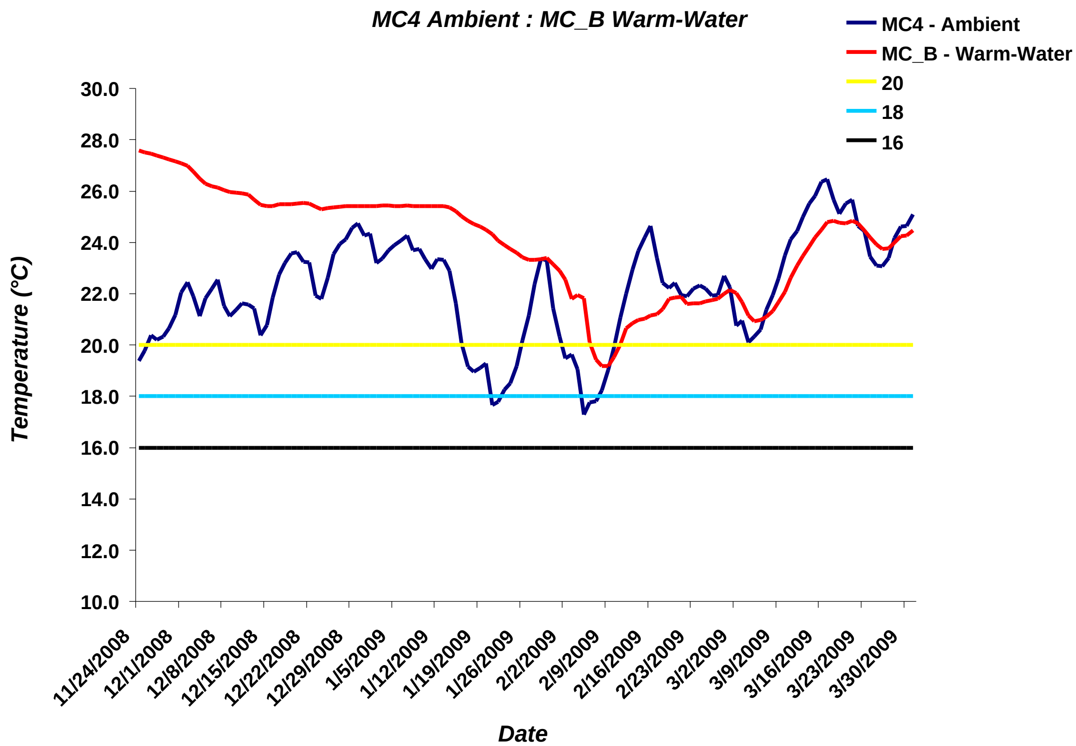
III. Temperature profiles for ambient – warm-water pairs – Daily mean temperatures for paired ambient and warm-water probes recorded during the same winter months. Horizontal lines represent three critical threshold temperatures for manatee thermoregulation, with the threat of cold-stress syndrome increasing as temperatures decrease.

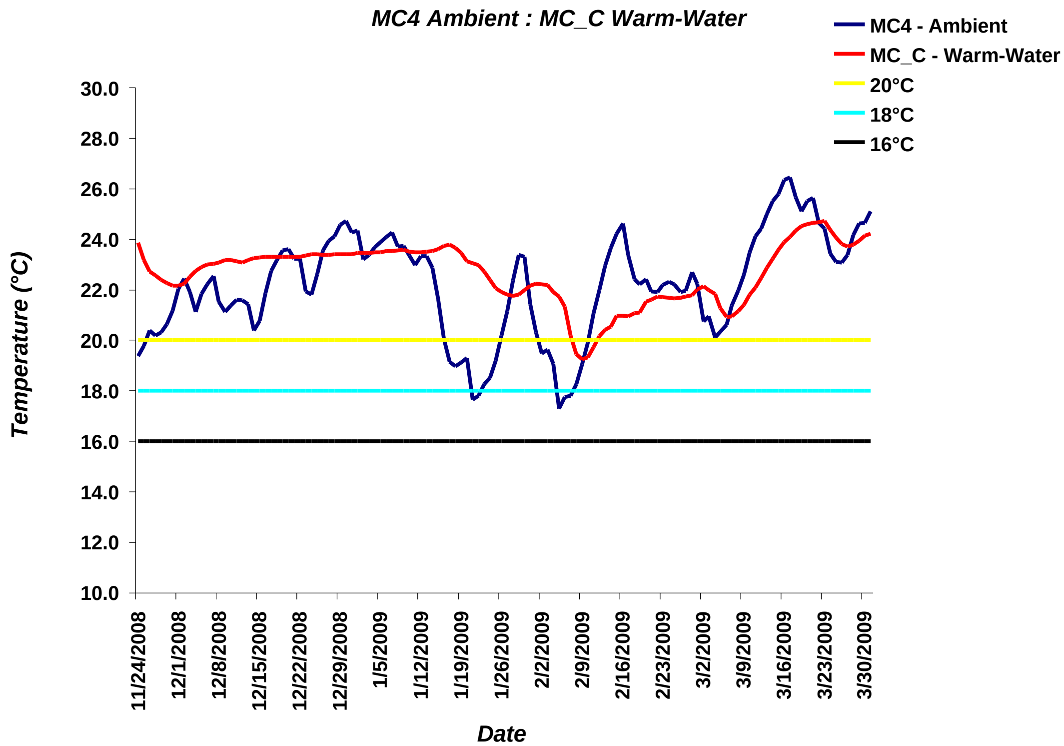
Southwest Region

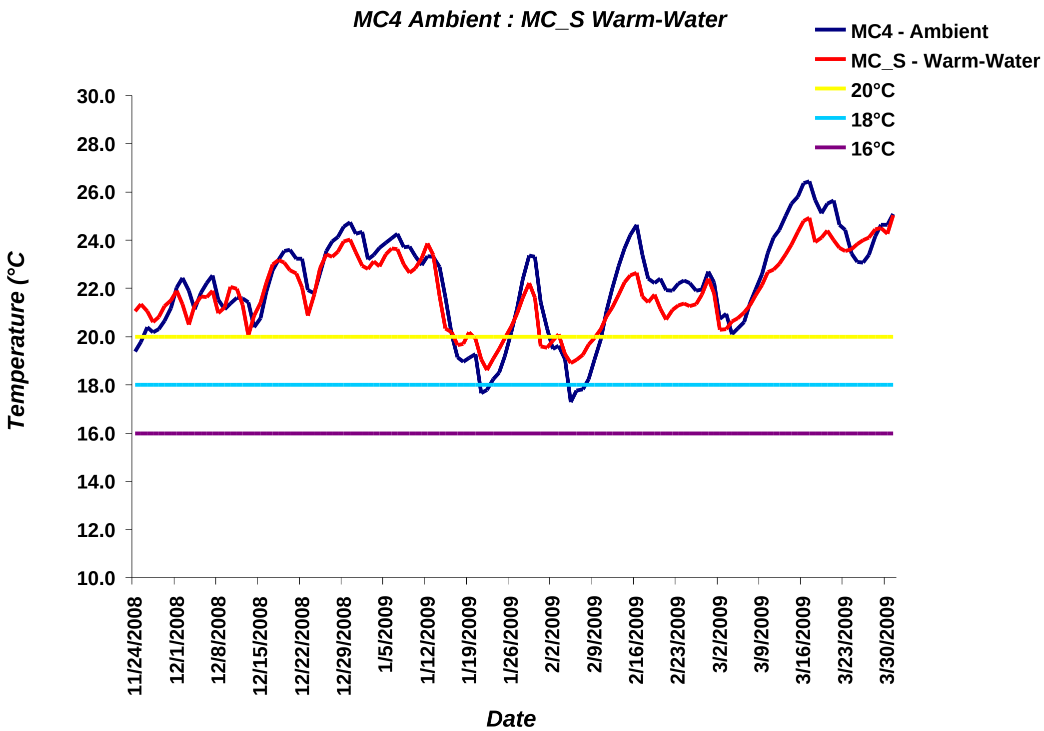



F4 Ambient : F1_B Warm-Water
F4 - Ambient
F1_B - Warm-Water
20°C
18°C
16°C
Temperature (°C)
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
11/24/2008
12/1/2008
12/8/2008
12/15/2008
12/22/2008
12/29/2008
1/5/2009
1/12/2009
1/19/2009
1/26/2009
2/2/2009
2/9/2009
2/16/2009
2/23/2009
3/2/2009
3/9/2009
3/16/2009
3/23/2009
3/30/2009
Date

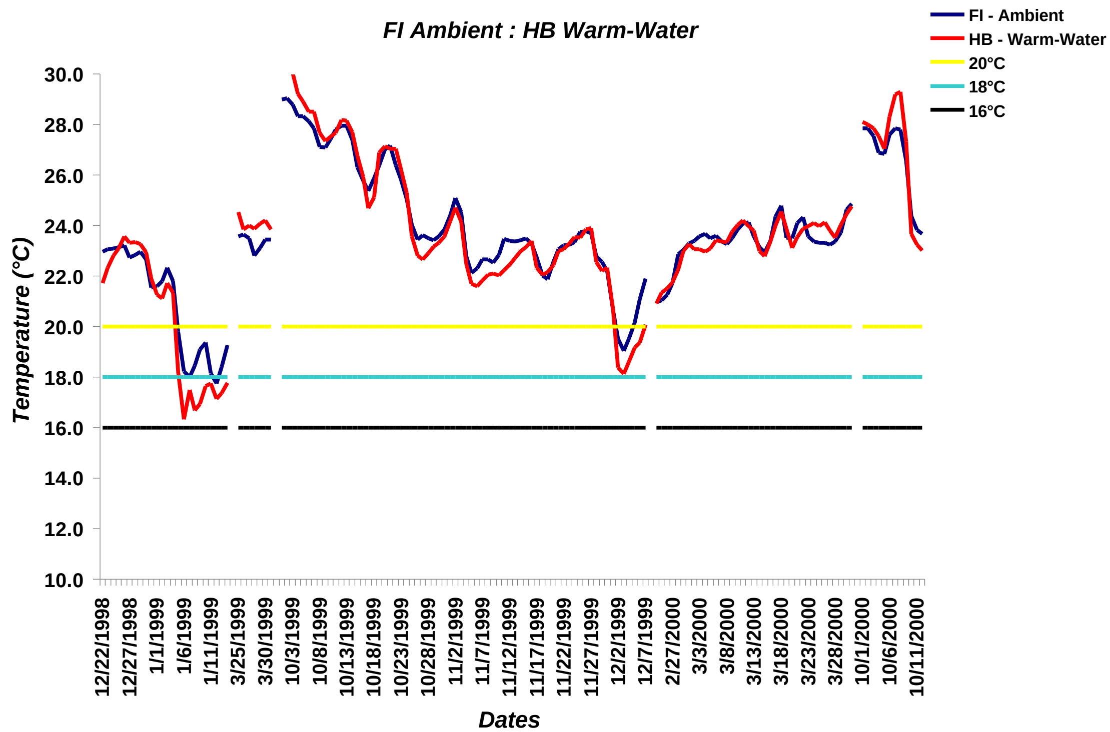

F4 Ambient : F3 Warm-Water
F4 - Ambient
F3_B - Warm-Water
20°C
18°C
16°C
Temperature (°C)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
1/7/2009
1/14/2009
1/21/2009
1/28/2009
2/4/2009
2/11/2009
2/18/2009
2/25/2009
3/4/2009
3/11/2009
3/18/2009
3/25/2009
Date

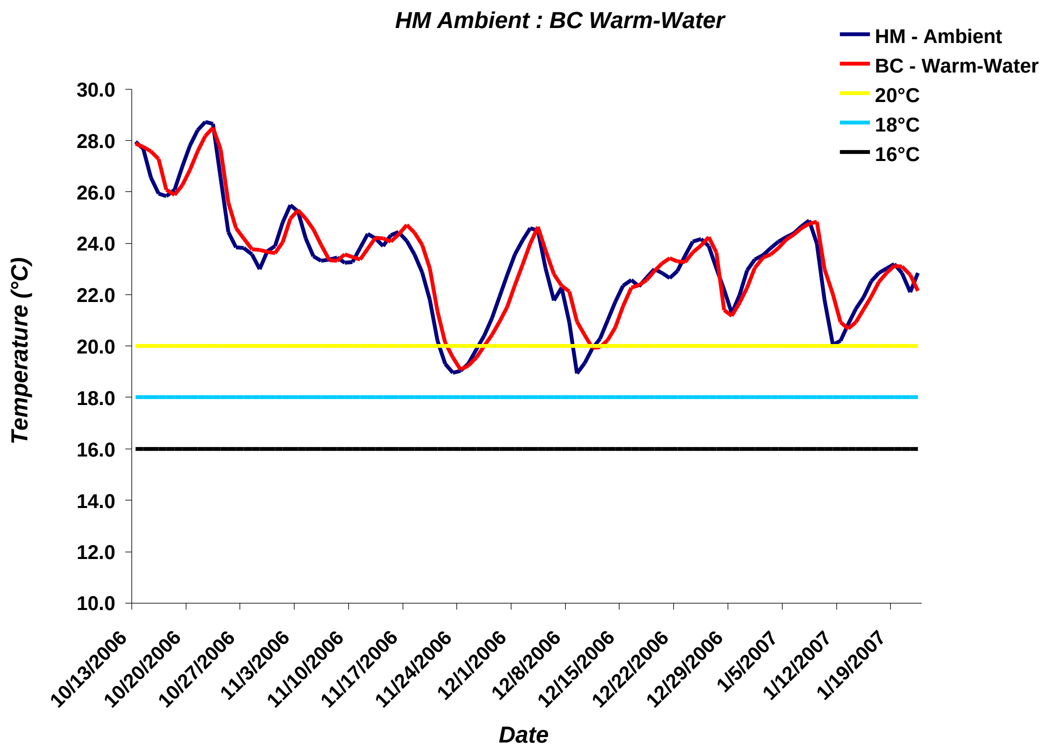

MC4 Ambient : MC_B Warm-Water
MC4 - Ambient
MC_B - Warm-Water
20
18
16
Temperature (°C)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
11/24/2008
12/1/2008
12/8/2008
12/15/2008
12/22/2008
12/29/2008
1/5/2009
1/12/2009
1/19/2009
1/26/2009
2/2/2009
2/9/2009
2/16/2009
2/23/2009
3/2/2009
3/9/2009
3/16/2009
3/23/2009
3/30/2009
Date

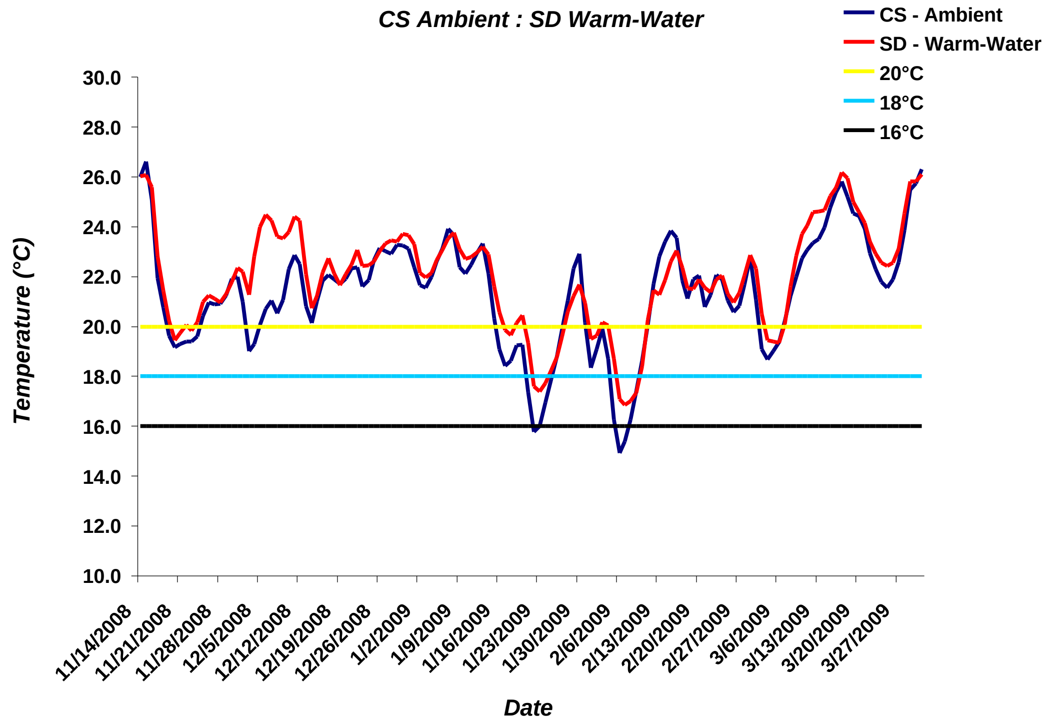

MC4 Ambient : MC_C Warm-Water
MC4 - Ambient
MC_C - Warm-Water
20°C
18°C
16°C
Temperature (°C)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
11/24/2008
12/1/2008
12/8/2008
12/15/2008
12/22/2008
12/29/2008
1/5/2009
1/12/2009
1/19/2009
1/26/2009
2/2/2009
2/9/2009
2/16/2009
2/23/2009
3/2/2009
3/9/2009
3/16/2009
3/23/2009
3/30/2009
Date

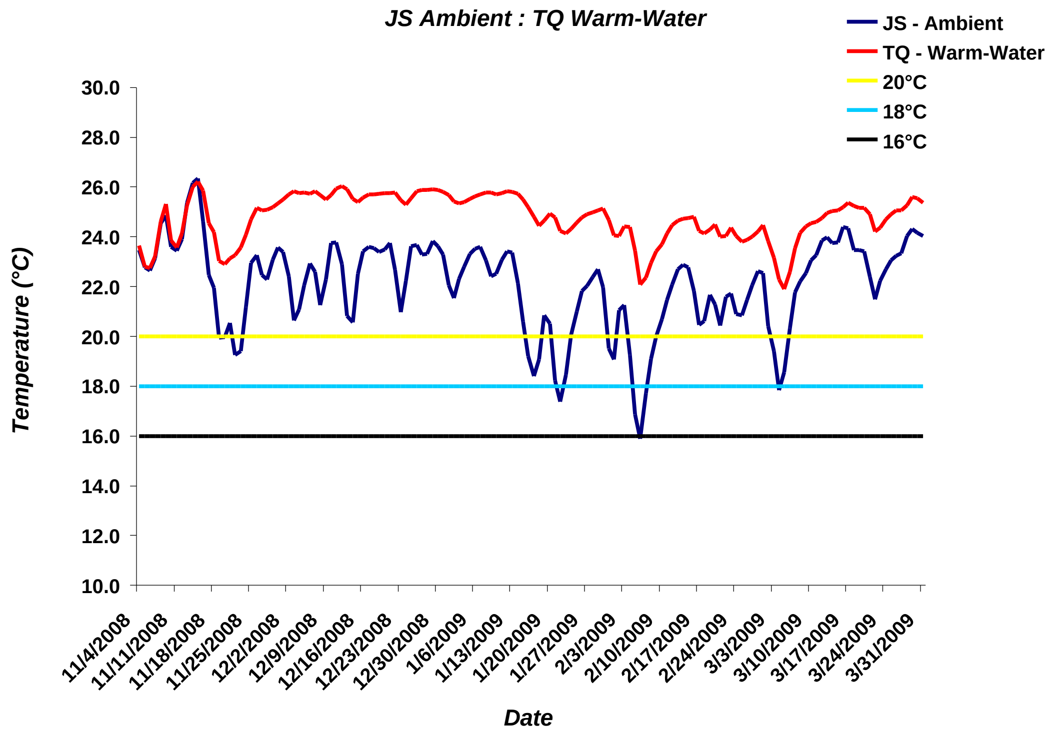

MC4 Ambient : MC_S Warm-Water
MC4 - Ambient
MC_S - Warm-Water
20°C
18°C
16°C
Temperature (°C
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
11/24/2008
12/1/2008
12/8/2008
12/15/2008
12/22/2008
12/29/2008
1/5/2009
1/12/2009
1/19/2009
1/26/2009
2/2/2009
2/9/2009
2/16/2009
2/23/2009
3/2/2009
3/9/2009
3/16/2009
3/23/2009
3/30/2009
Date

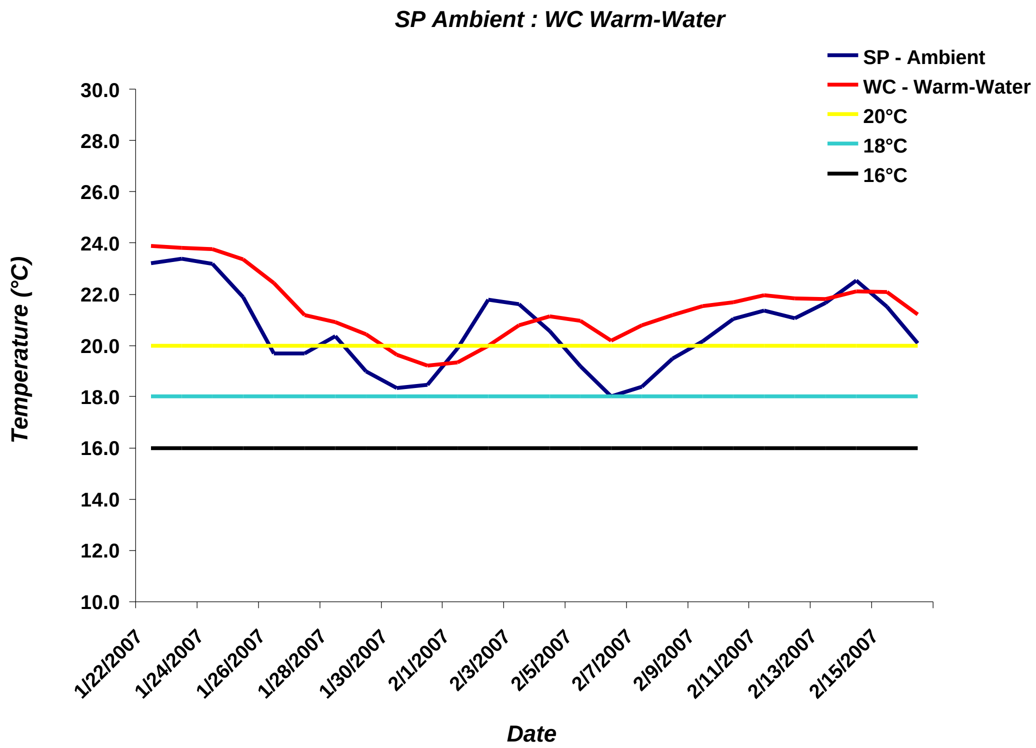
Southeast Region

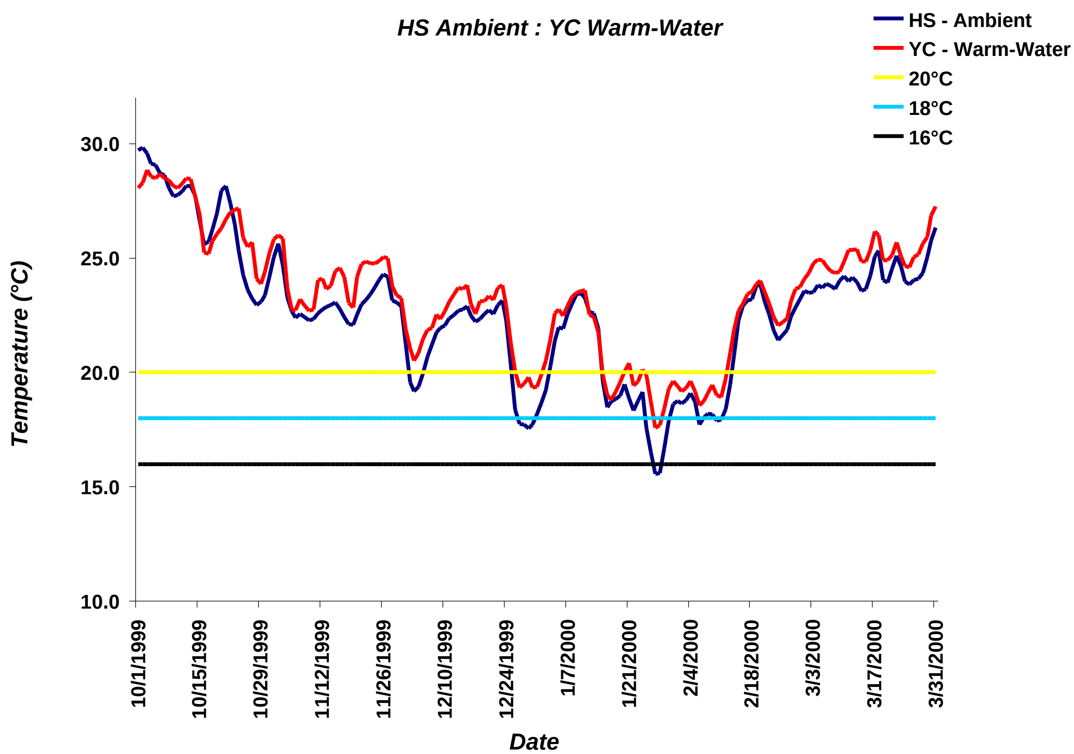





CS Ambient : SD Warm-Water
CS - Ambient
SD - Warm-Water
20°C
18°C
16°C
Temperature (°C)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
11/14/2008
11/21/2008
11/28/2008
12/5/2008
12/12/2008
12/19/2008
12/26/2008
1/2/2009
1/9/2009
1/16/2009
1/23/2009
1/30/2009
2/6/2009
2/13/2009
2/20/2009
2/27/2009
3/6/2009
3/13/2009
3/20/2009
3/27/2009
Date

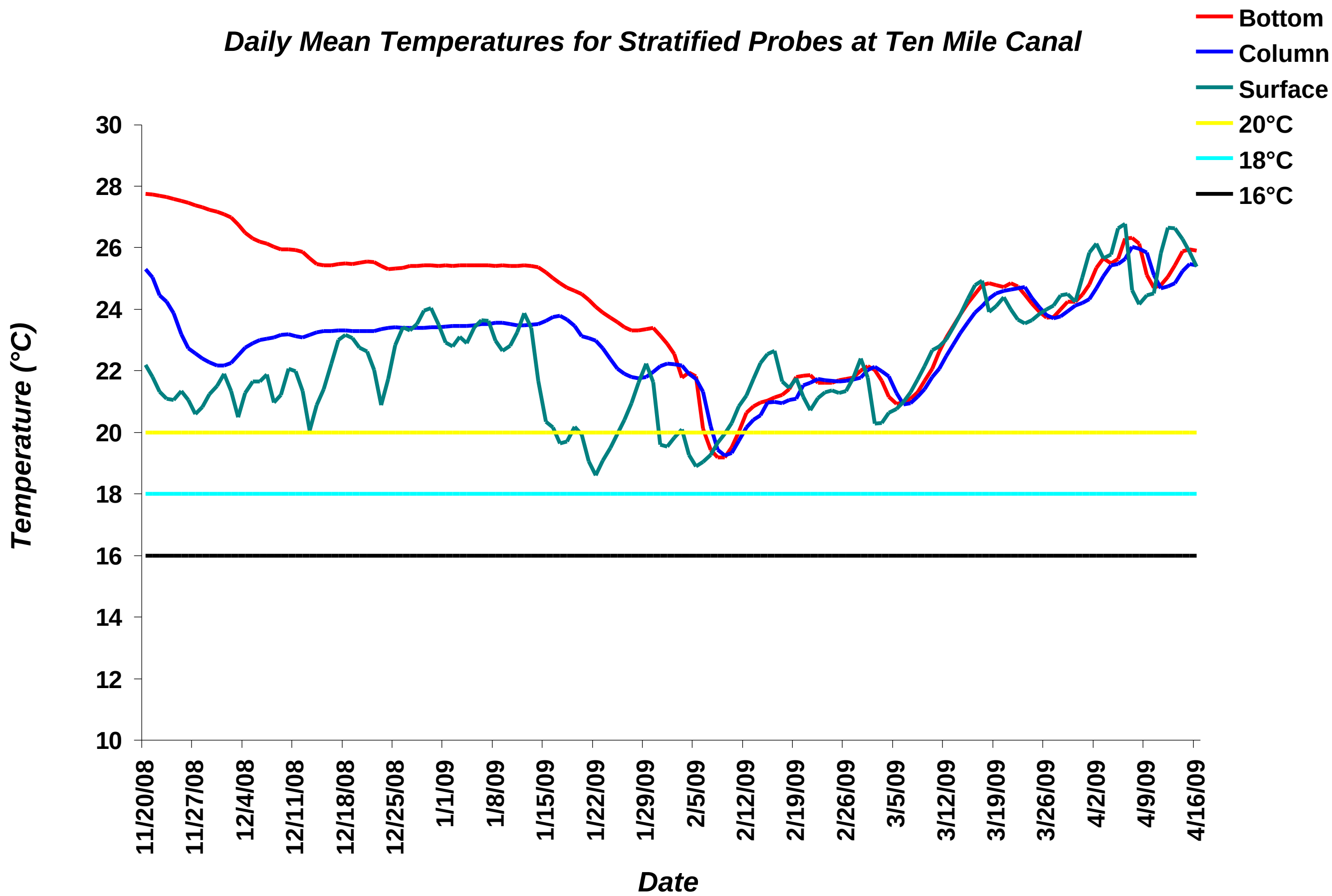

JS Ambient : TQ Warm-Water
JS - Ambient
TQ - Warm-Water
20°C
18°C
16°C
Temperature (°C)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
11/4/2008
11/11/2008
11/18/2008
11/25/2008
12/2/2008
12/9/2008
12/16/2008
12/23/2008
12/30/2008
1/6/2009
1/13/2009
1/20/2009
1/27/2009
2/3/2009
2/10/2009
2/17/2009
2/24/2009
3/3/2009
3/10/2009
3/17/2009
3/24/2009
3/31/2009
Date

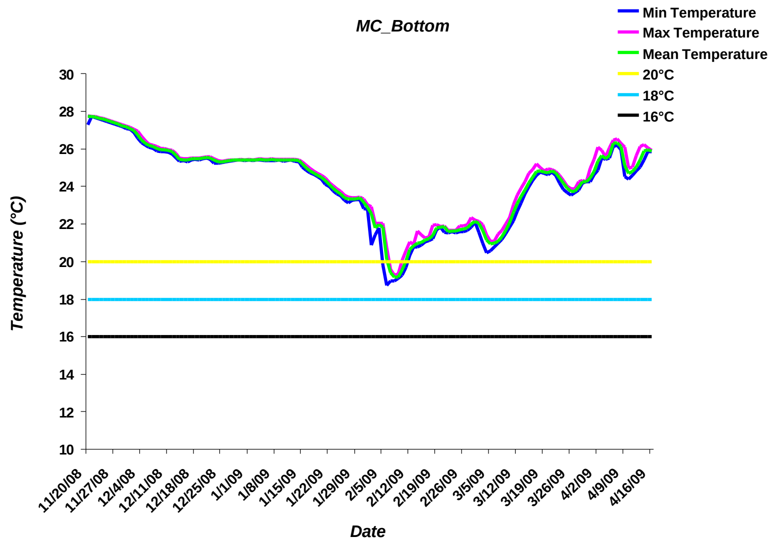

SP Ambient : WC Warm-Water
SP - Ambient
WC - Warm-Water
20°C
18°C
16°C
Temperature (°C)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
1/22/2007
1/24/2007
1/26/2007
1/28/2007
1/30/2007
2/1/2007
2/3/2007
2/5/2007
2/7/2007
2/9/2007
2/11/2007
2/13/2007
2/15/2007
Date

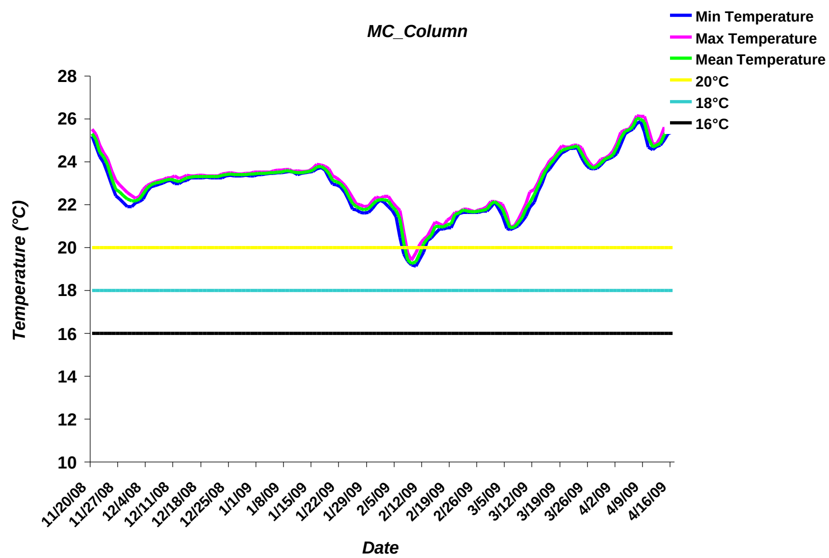

HS Ambient : YC Warm-Water
HS - Ambient
YC - Warm-Water
20°C
18°C
16°C
Temperature (°C)
30.0
25.0
20.0
15.0
10.0
10/1/1999
10/15/1999
10/29/1999
11/12/1999
11/26/1999
12/10/1999
12/24/1999
1/7/2000
1/21/2000
2/4/2000
2/18/2000
3/3/2000
3/17/2000
3/31/2000
Date

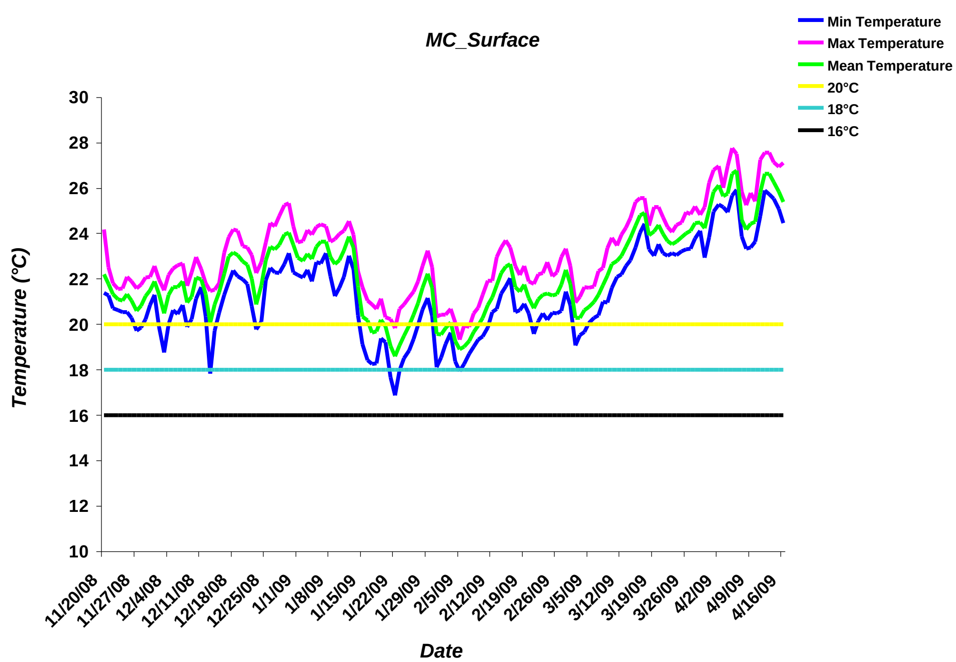
IV. ***Stratified probe temperature profiles*** – Temperature profiles for two warm-water sites where probes were stratified within the water column. Figure A represents a bottom, column, and surface probe at Ten Mile Canal. Figure B represents a bottom and column probe at Forked Creek. Figures B1 display temperature profiles for the 2007 – 2008 winter. Figures B2 display temperature profiles for the 2008 – 2009 winter. Data is for mean daily temperatures.

A. Ten Mile Canal (MC), warm-water site



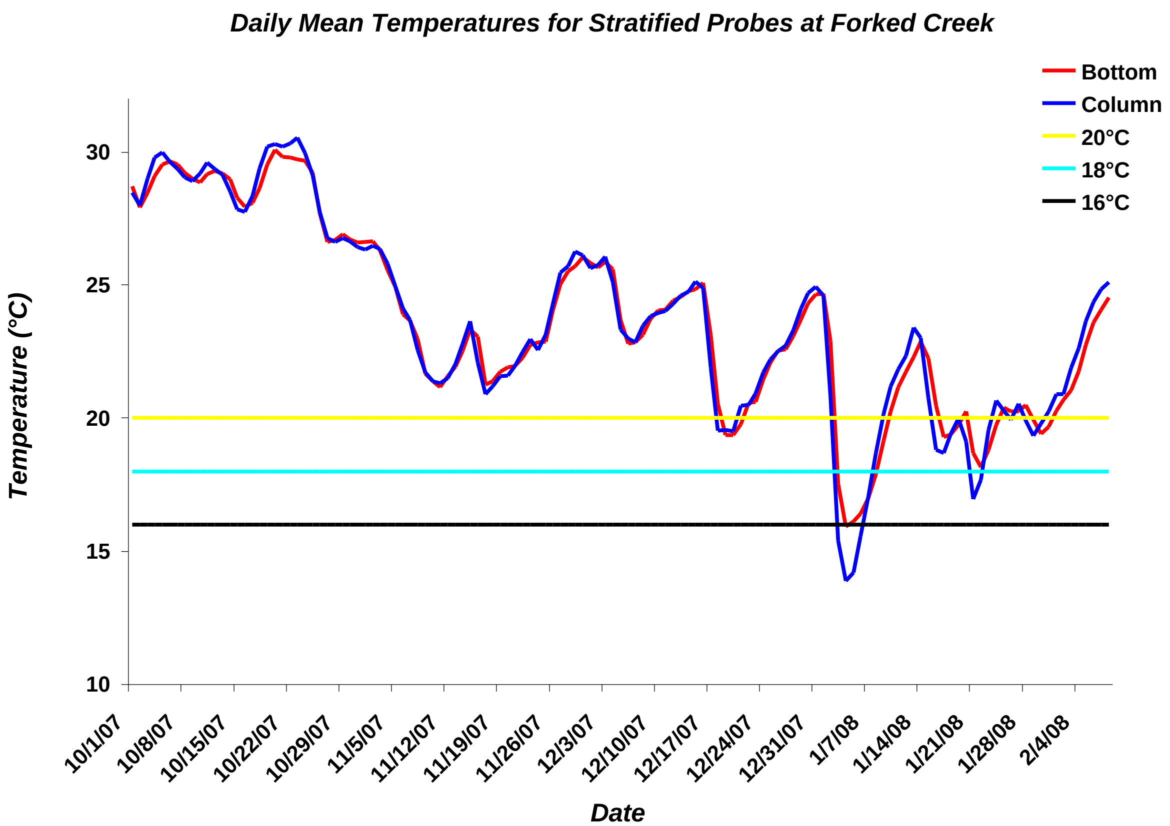

MC_Bottom
Min Temperature
Max Temperature
Mean Temperature
20°C
18°C
16°C
Temperature (°C)
30
28
26
24
22
20
18
16
14
12
10
11/20/08
11/27/08
12/4/08
12/11/08
12/18/08
12/25/08
1/1/09
1/8/09
1/15/09
1/22/09
1/29/09
2/5/09
2/12/09
2/19/09
2/26/09
3/5/09
3/12/09
3/19/09
3/26/09
4/2/09
4/9/09
4/16/09
Date

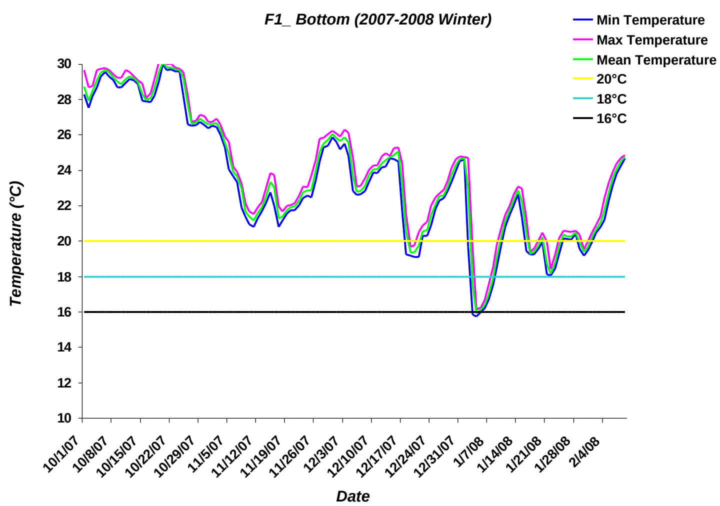

MC_Column
Min Temperature
Max Temperature
Mean Temperature
20°C
18°C
16°C
Temperature (°C)
28
26
24
22
20
18
16
14
12
10
11/20/08
11/27/08
12/4/08
12/11/08
12/18/08
12/25/08
1/1/09
1/8/09
1/15/09
1/22/09
1/29/09
2/5/09
2/12/09
2/19/09
2/26/09
3/5/09
3/12/09
3/19/09
3/26/09
4/2/09
4/9/09
4/16/09
Date

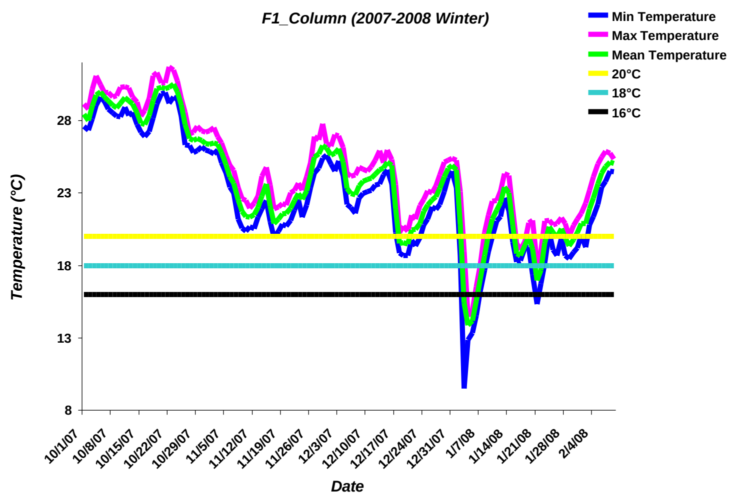

MC_Surface
Min Temperature
Max Temperature
Mean Temperature
20°C
18°C
16°C
Temperature (°C)
30
28
26
24
22
20
18
16
14
12
10
11/20/08
11/27/08
12/4/08
12/11/08
12/18/08
12/25/08
1/1/09
1/8/09
1/15/09
1/22/09
1/29/09
2/5/09
2/12/09
2/19/09
2/26/09
3/5/09
3/12/09
3/19/09
3/26/09
4/2/09
4/9/09
4/16/09
Date

Forked Creek (F1), warm-water site

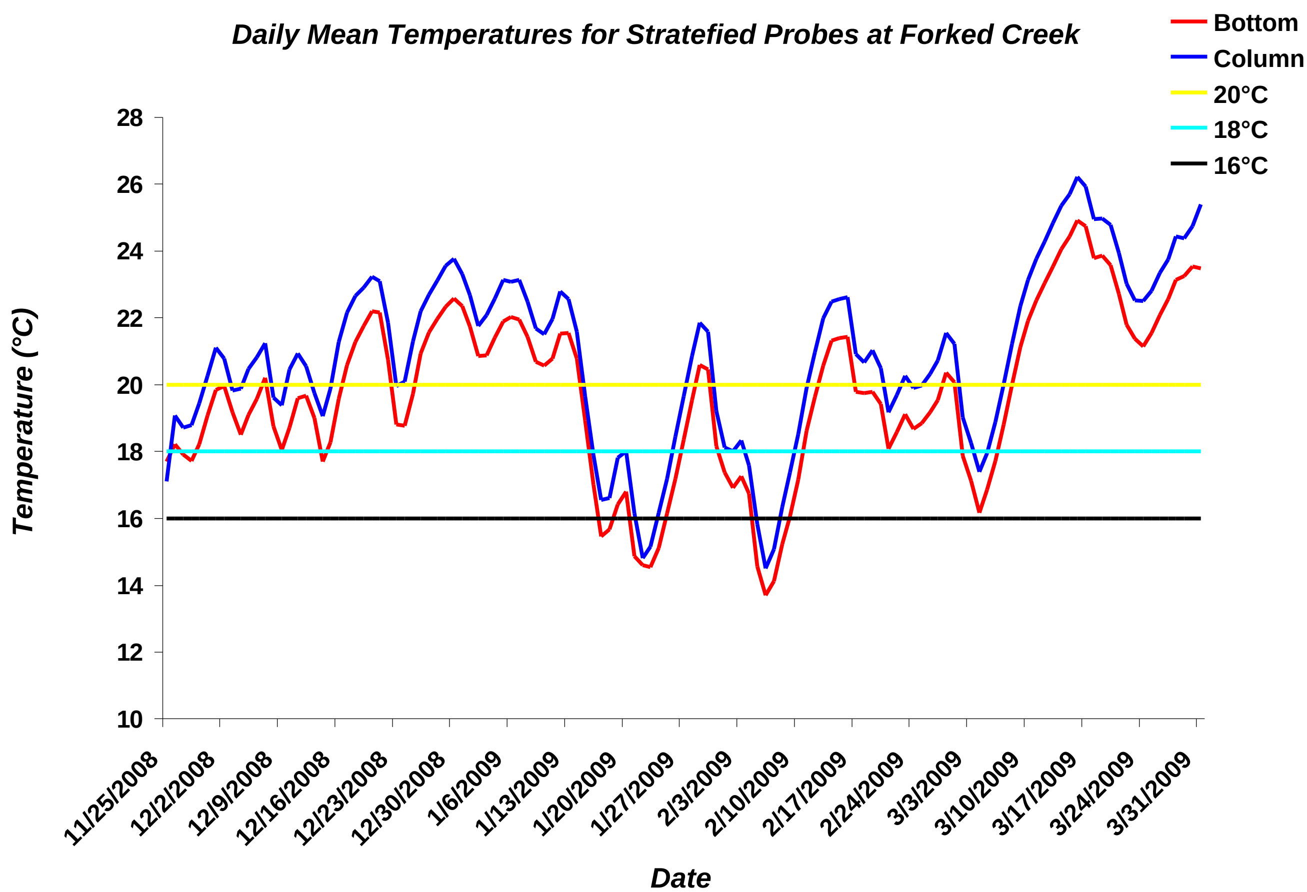
1. Winter 2007-2008

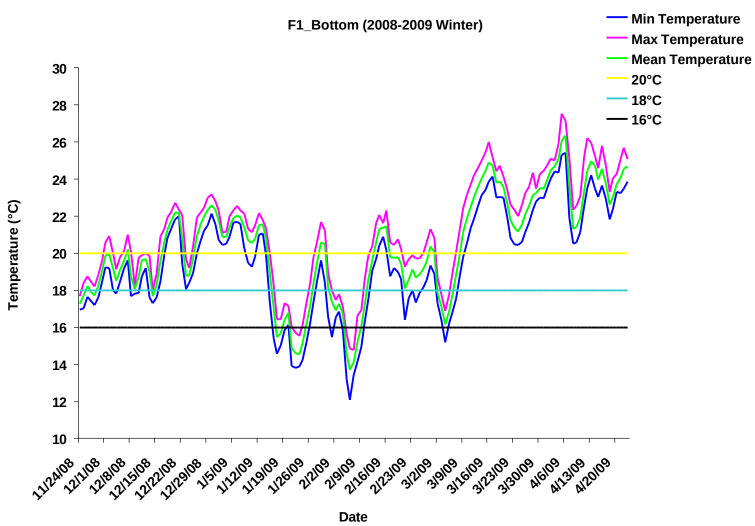


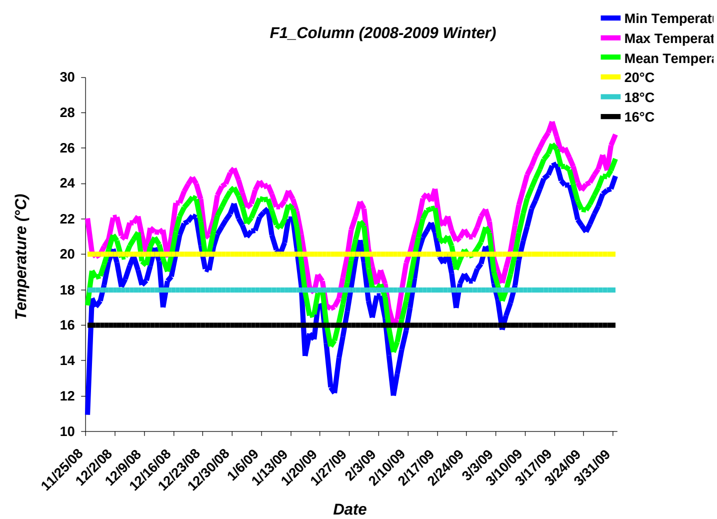




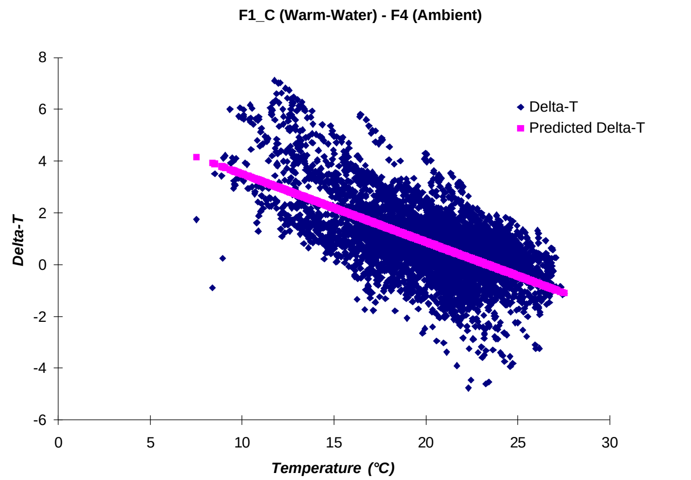
2. Winter 2008-2009

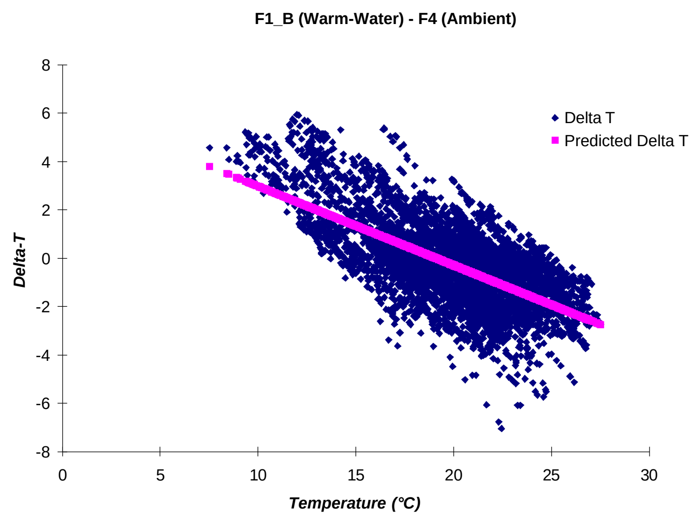


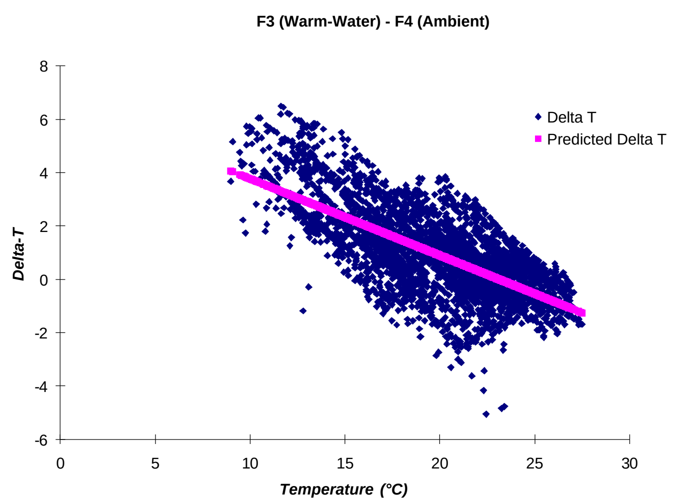




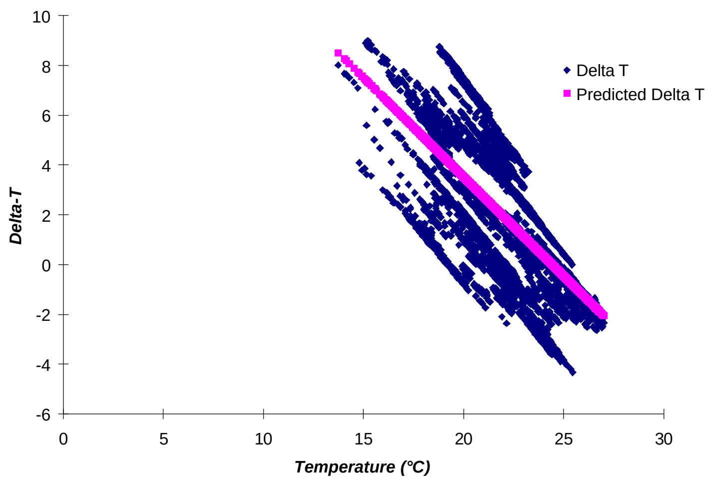
V. Difference between temperature of warm-water site and paired ambient site (i.e. Delta-T, ° C) versus ambient temperature. The lines show the predicted Delta-Ts from linear regressions.



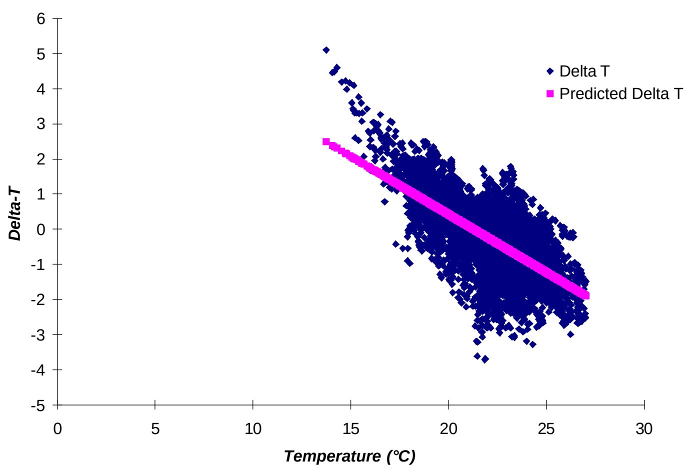




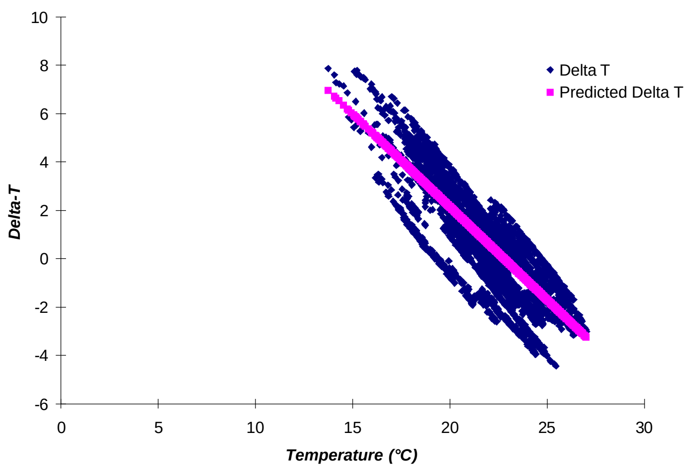
MC_B (Warm-Water) - MC4 (Ambient)

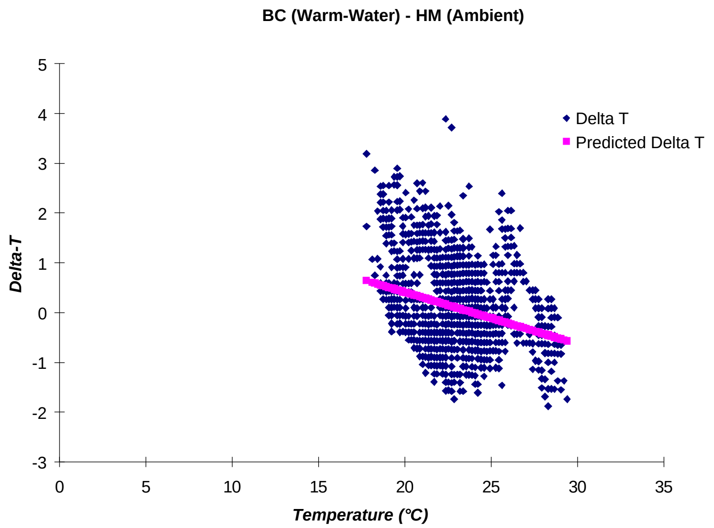


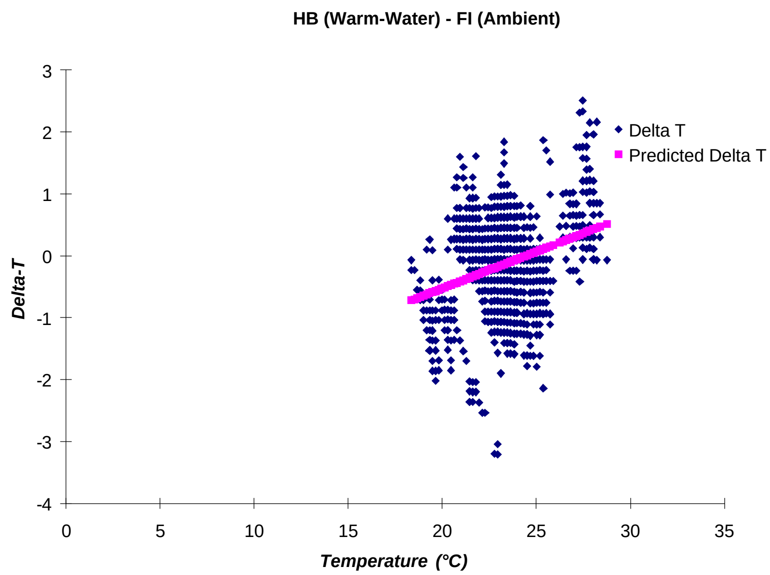
MC_S (Warm-Water) - MC4 (Ambient)

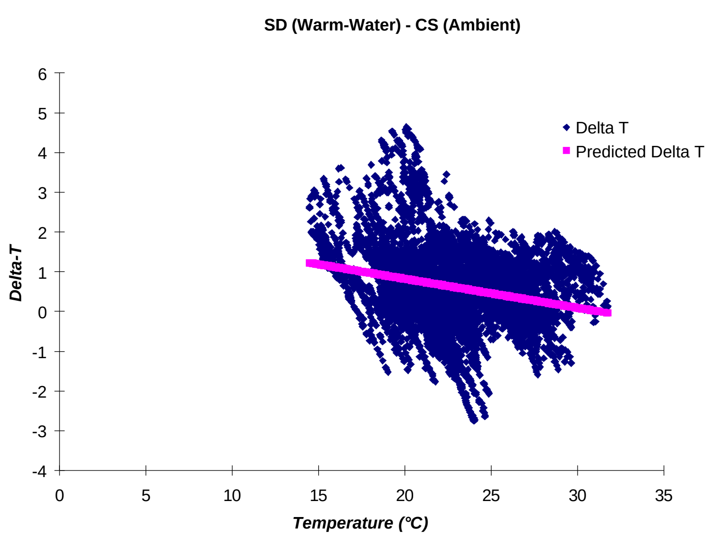


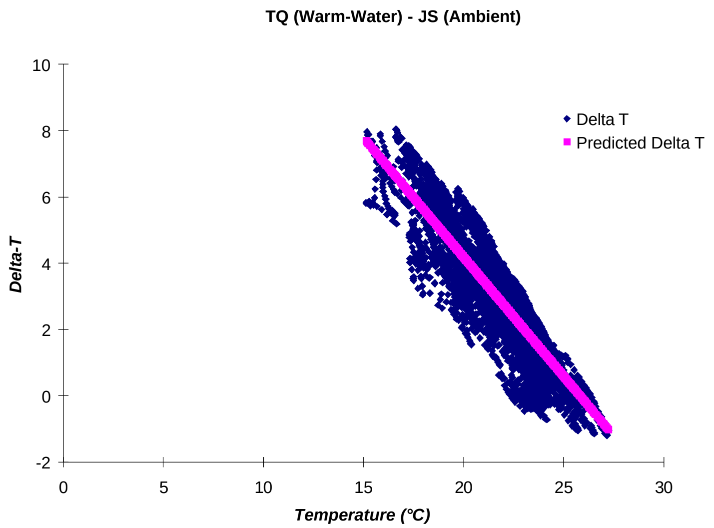
MC_C (Warm-Water) - MC4 (Ambient)

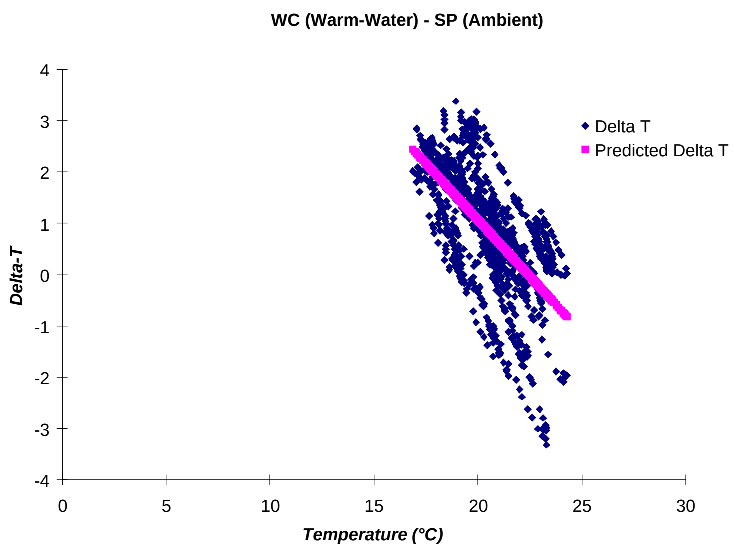


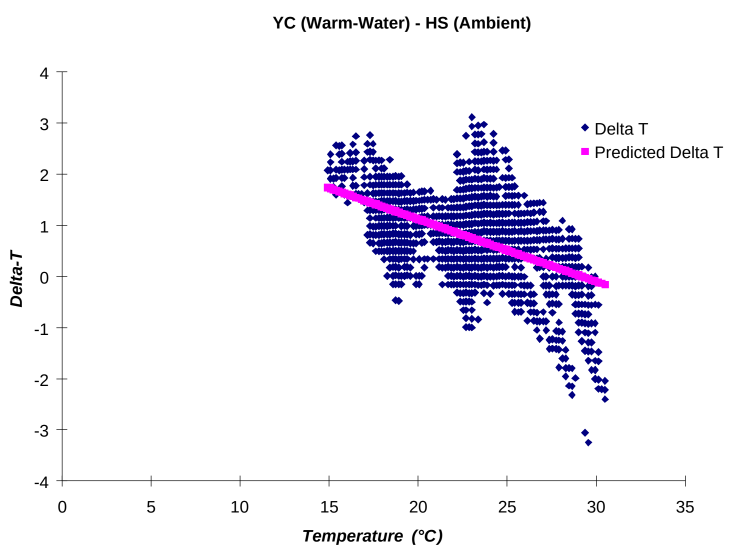

BC (Warm-Water) - HM (Ambient)
Delta T
Predicted Delta T
Delta-T
Temperature (°C)
5
4
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
30
35


HB (Warm-Water) - FI (Ambient)
Delta T
Predicted Delta T
Delta-T
Temperature (°C)
3
2
1
0
-1
-2
-3
-4
0
5
10
15
20
25
30
35


SD (Warm-Water) - CS (Ambient)
Delta T
Predicted Delta T
Delta-T
Temperature (°C)
6
5
4
3
2
1
0
-1
-2
-3
-4
0
5
10
15
20
25
30
35


TQ (Warm-Water) - JS (Ambient)
Delta T
Predicted Delta T
Delta-T
Temperature (°C)
10
8
6
4
2
0
-2
0
5
10
15
20
25
30


WC (Warm-Water) - SP (Ambient)
Delta T
Predicted Delta T
Delta-T
Temperature (°C)
4
3
2
1
0
-1
-2
-3
-4
0
5
10
15
20
25
30


YC (Warm-Water) - HS (Ambient)
Delta T
Predicted Delta T
Delta-T
Temperature (°C)
4
3
2
1
0
-1
-2
-3
-4
0
5
10
15
20
25
30
35