Seasonal Temperature Profiles

at

Ontario Cage Trout Farms

and

Management Implications

Final Report submitted to the:

Ontario Sustainable Aquaculture Working Group

Environment Canada

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1. INTRODUCTION

As poikilotherms, fish are greatly influenced by water temperature. Temperature is a major factor in determining the growth rate of fish, acting as a “Controlling Factor” (Brett 1979), but it also affects health and other metabolic pathways and enzyme activities. Typically, fish can survive over a wide range of water temperature and tolerate varying rates of temperature change. Therefore, from a fish farmer’s perspective, temperature is a fundamental criterion in determining the suitability of a water source. Water temperature is also the driving force in water circulation, through its affect on density, influencing many limnological processes (Wetzel 1975).

In Ontario, aquacultural production is dominated by the open-water cage farming of rainbow trout in the North Channel of Lake Huron and Georgian Bay, accounting for approximately 80% of the 4,000 tonnes annual production (Moccia and Bevan 2009). Although the annual temperature range can be from less than 1°C to over 26°C, the average summer through early fall temperatures are usually within the optimal range of 15-16°C for rainbow trout. Some sites with suitable temperature regimens and good management can grow market sized rainbow trout (approximately 1kg) in 14 to 16 months.

Earlier studies of water temperature profiles in Georgian Bay (Tobermory and Cape Croker) have shown that not only is there a wide annual range of temperature, but extreme fluctuations can occur over very much shorter time periods (Wells 2006, unpublished data, Moccia 2002, unpublished data). Studies in Lake Michigan (Hawley and Muzzi 2003) and Lake Ontario (Rao and Murthy

2001) also reveal highly varying temperatures throughout the water column, showing that this hydrological feature is ubiquitous in the Great Lakes.

This study recorded the vertical water temperature profiles over the main growing season at eight open-water cage farms in Ontario and examined how these profiles can be integrated into an efficient fish husbandry program. From a fish husbandry perspective, these rapid temperature fluctuations can be important as they cause considerable stress to the fish, resulting in reduced feed intake and increased disease occurrence. The temperature profiles at existing aquaculture sites give an idea of the degree of physiological stress that these fish could be or already are exposed to, as well as the movement of water masses and their stratification, indicative of Georgian Bay and North Channel limnology. Furthermore aquaculturists with access to long term temperature monitoring data can make site specific management decisions to improve the health of their fish and mitigate potentially harmful changing environmental conditions.

2. METHODS

Five open water cage facilities collaborated in the study, encompassing a total of eight open water cage culture sites (Figure 1). At each site, a vertical temperature profile of the entire water column was determined using a series of temperature recording loggers recording at 15 minute intervals. The Onset loggers used included: TempPro, TempMentor and Tidbit models, with an accuracy of ± 0.2°C, 0.2°C and 0.4°C, respectively. The temperature loggers were attached to an anchored vertical cable and spaced to monitor water temperature over the entire water column, with a focus on the equivalent fish cage depth. Differences in water column depth between sites resulted in varying numbers of loggers being deployed at each site (Figure 2). Temperature loggers were deployed between May 2007 and December, 2007, except at one site where recovery was postponed until April 2008. Details of site location and logger deployment are given in Appendix I. The water temperature profiles for each site were summarized by dividing the whole water column (WWC), into two zones: the cage environment (CE) i.e. the depth of the fish cage used at the respective site and the remaining water column below the cage environment (BCE).

Figure1. Great Lakes region showing location of the eight sites monitored in the North Channel and Georgian Bay of Lake Huron.

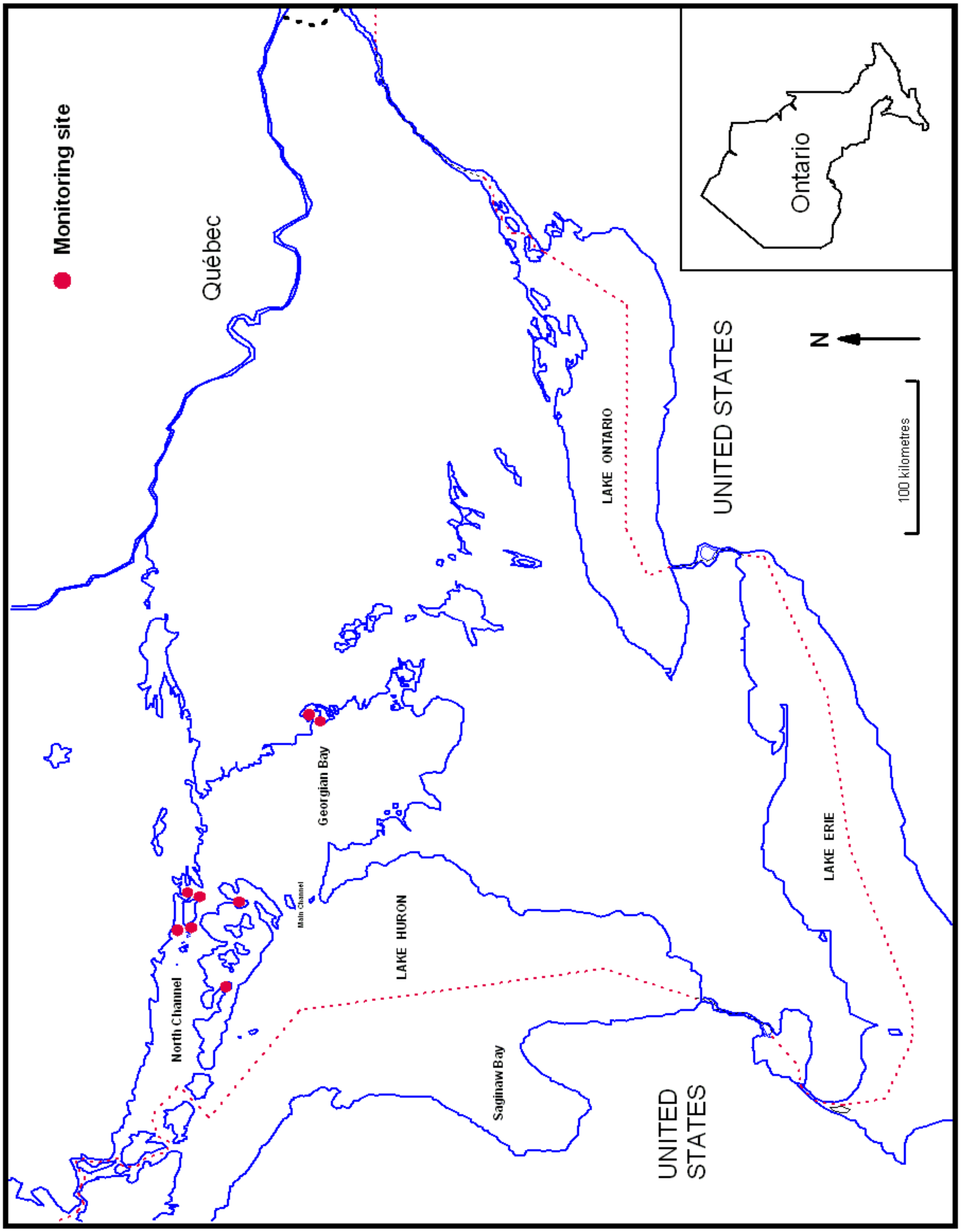
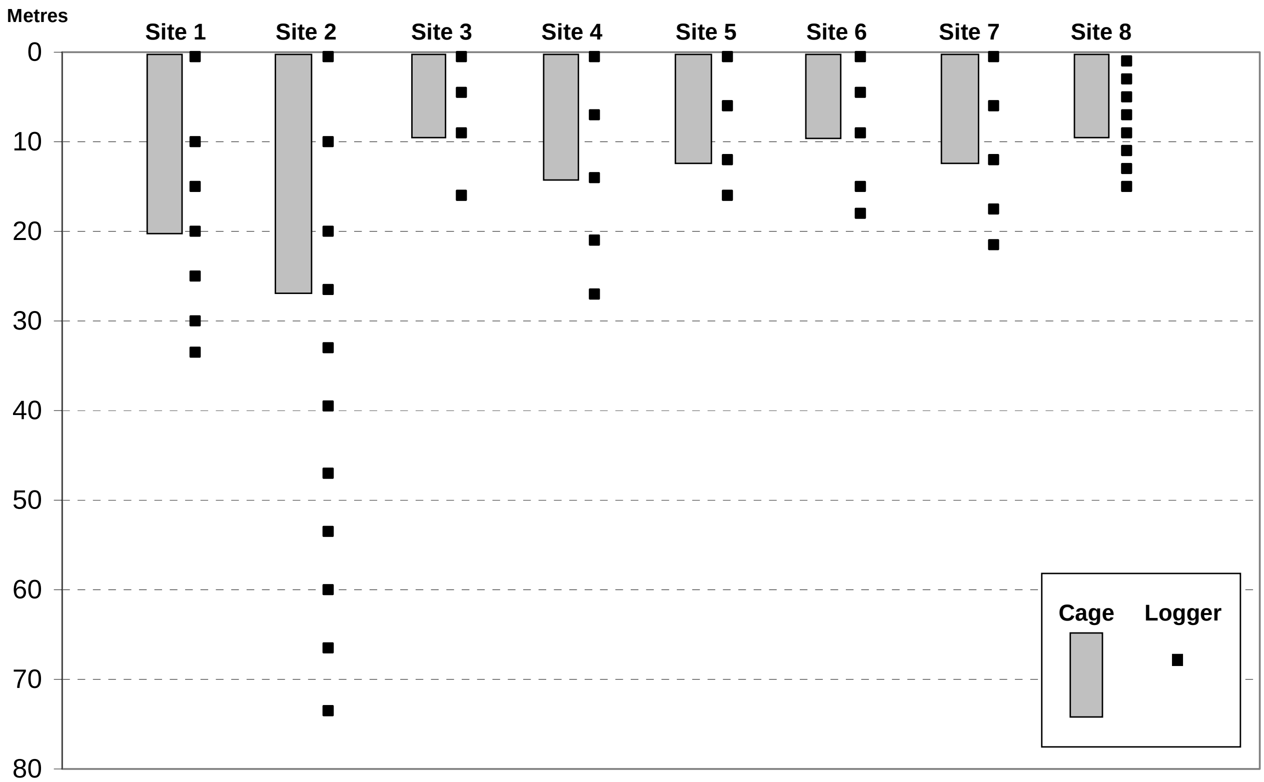


Figure 2. Schematic of the cages and the depths of individual loggers at each monitored site.



3. RESULTS

The temperature loggers were successfully deployed and recovered and temperature profiles were determined for all eight sites from May through December 2007 (Figure 2). During this period, the cage environment temperature varied from 4.0 to 25.9°C, with an overall average temperature of 14.7°C. A similar range was observed for the whole water column (3.9 to 25.9°C), reflecting the complete mixing of the water column towards the end of the recording period. Differences between the sites were observed, with the average cage environment water temperature ranging from 11.8°C at Site 2 to 16.4°C at Site 6. Similarly, the range of temperature within the cage environment varied from 18.0°C at Site 5 to 21.7°C at Site 2.

In May, the water column was already stratifying and the temperatures, though highly fluctuating, were steadily increasing. During the mid-summer period, June through July, the surface water temperatures were generally above 20ºC with strong temperature stratification existing at most sites. By the end of August and early September, the surface water temperatures began to decline and the surface and bottom water started to mix and destratify. By the end of December, the entire water column at most sites was mixed to within approximately 0.1ºC, termed fall turnover (Table 4). No fall turnover was observed at Site 6 during the recording period, 23rd May – 11th December, 2007.

During the mid-summer period, water temperature fluctuations within the cages were often very short in duration, generally less than 1.0 °C over 15 minutes, although 2 – 3°C changes over 15 minutes and 10°C over several hours were recorded. At the extreme, a 10°C change over 15 minutes was observed! Analysis of the periodicity of the temperature fluctuations suggests that regular fluctuations exist at several of the sites monitored.

Figure 2.a. Site 1 temperature profile of cage environment (0.5 & 20m) and maximum depth (33.5m) from May through December 2007.

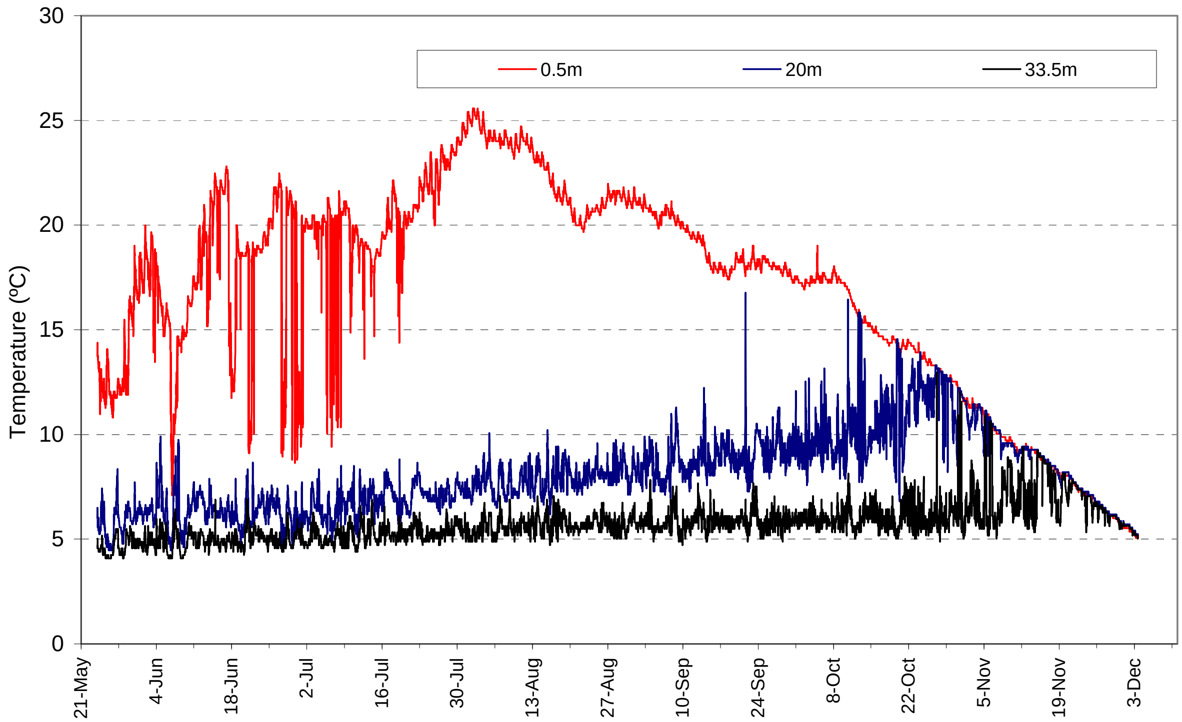


Figure 2b. Site 2 temperature profile of cage environment (0.5 & 26.5m) and maximum depth (73.5m) from May through December 2007.

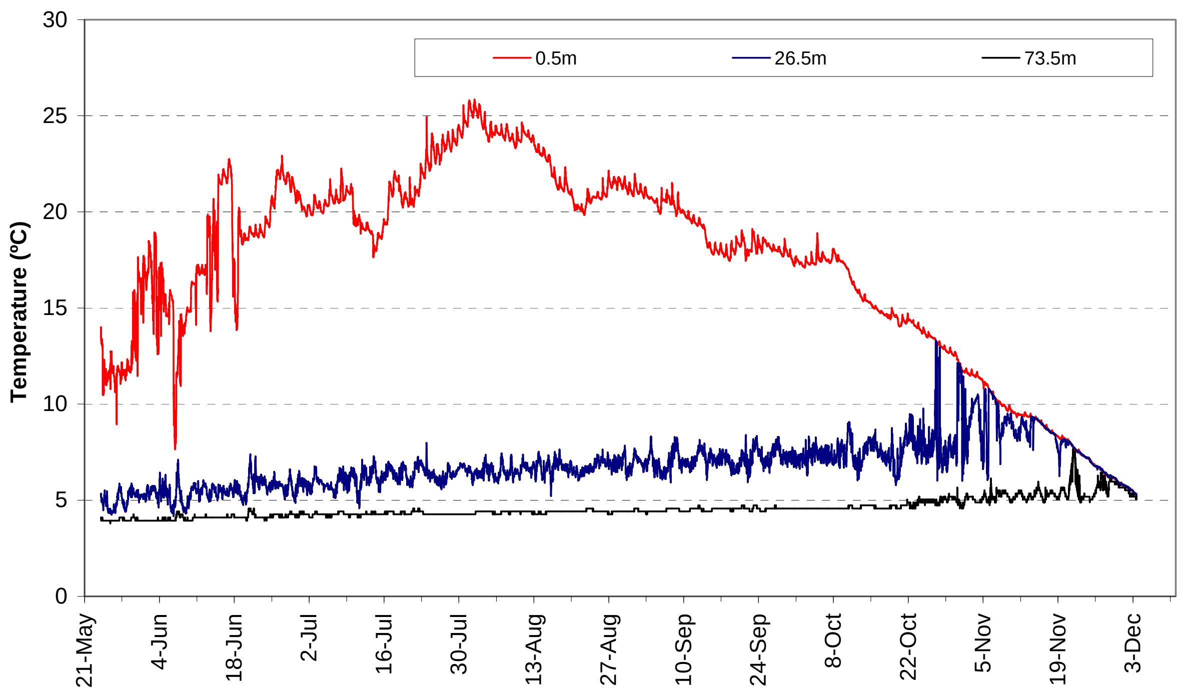


Figure 2.c. Site 3 temperature profile of cage environment (0.5 & 9m) and maximum depth (16m) from May through December 2007.

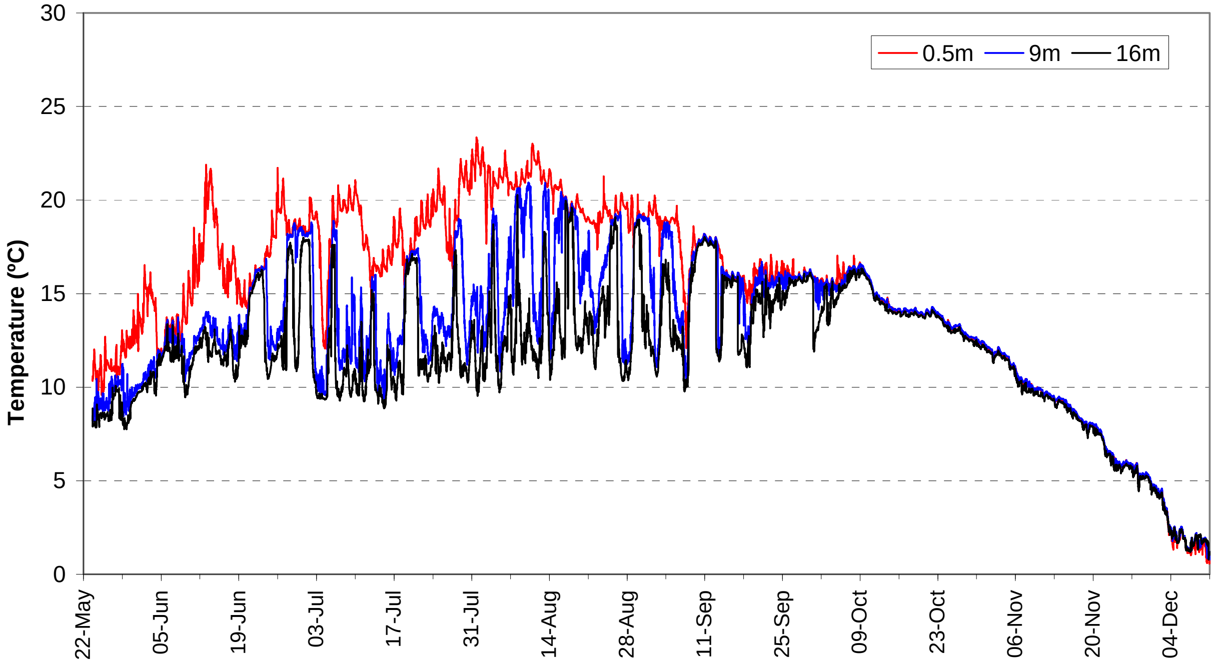


Figure 2.d. Site 4 temperature profile of cage environment (0.5 & 14m) and maximum depth (27m) from May through December 2007.

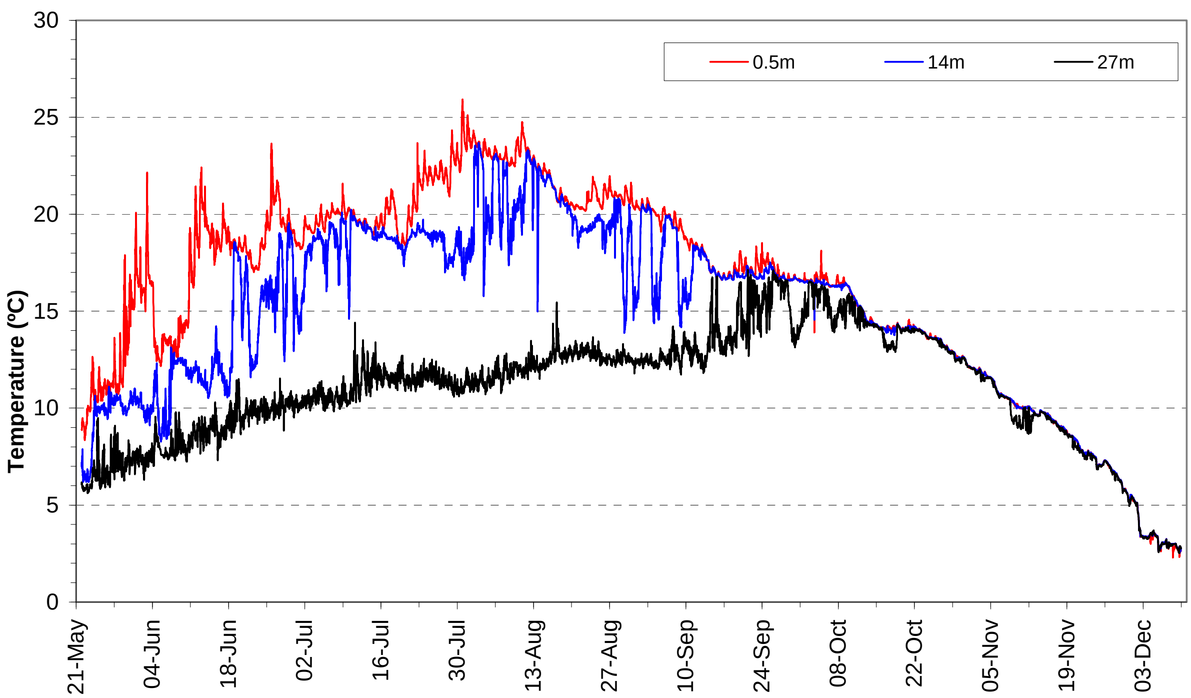


Figure 2.e. Site 5 temperature profile of cage environment (0.5 & 12m) and maximum depth (16m) from May through December 2007.

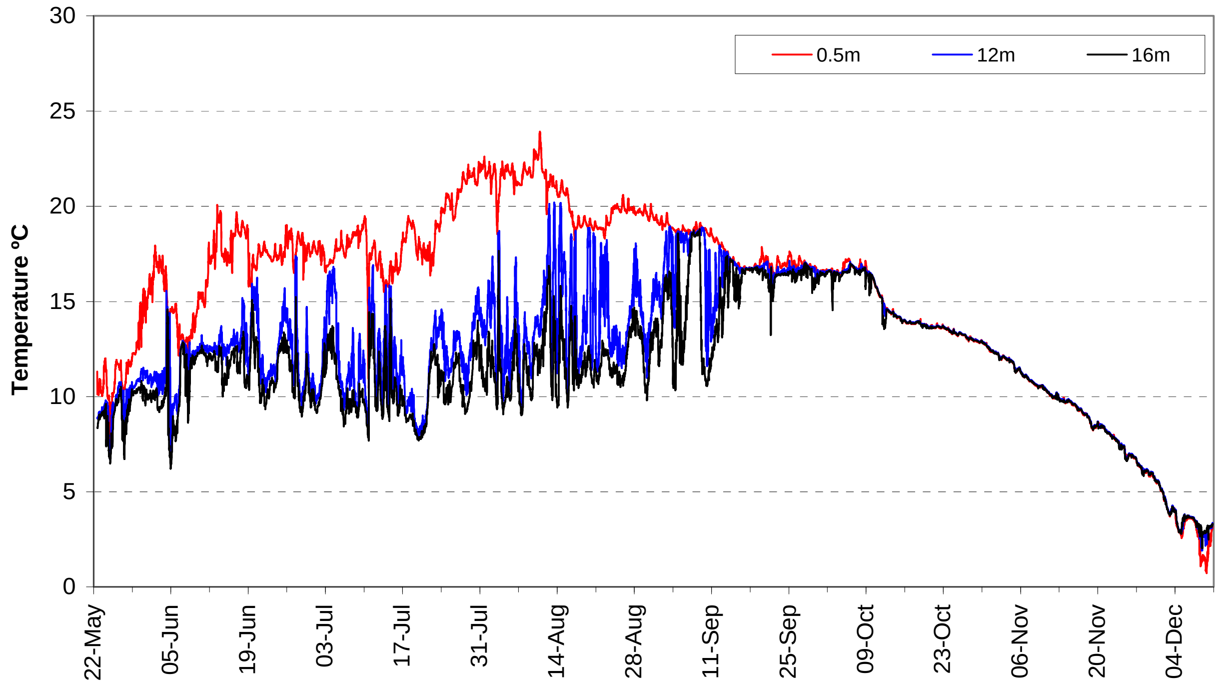


Figure 2.f. Site 6 temperature profile of cage environment (0.5 & 9m) and maximum depth (18m) from May through December 2007.

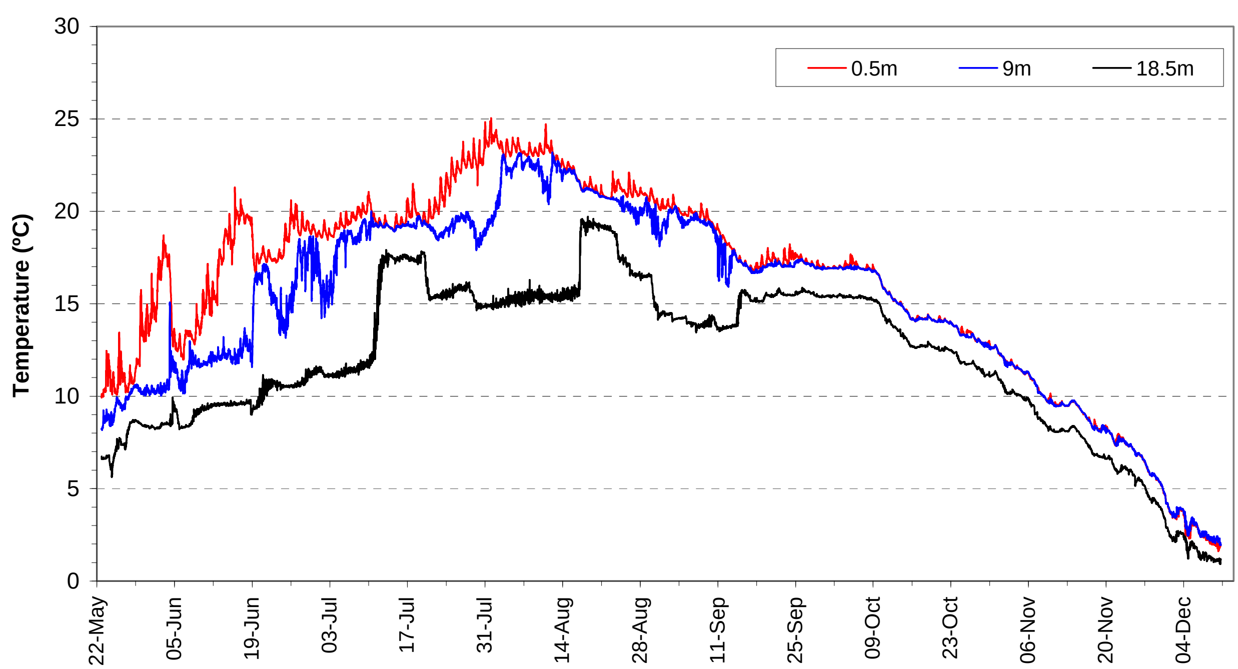


Figure 2.g. Site 7 temperature profile of cage environment (0.5 & 12m) and maximum depth (21.5m) from May through December 2007.

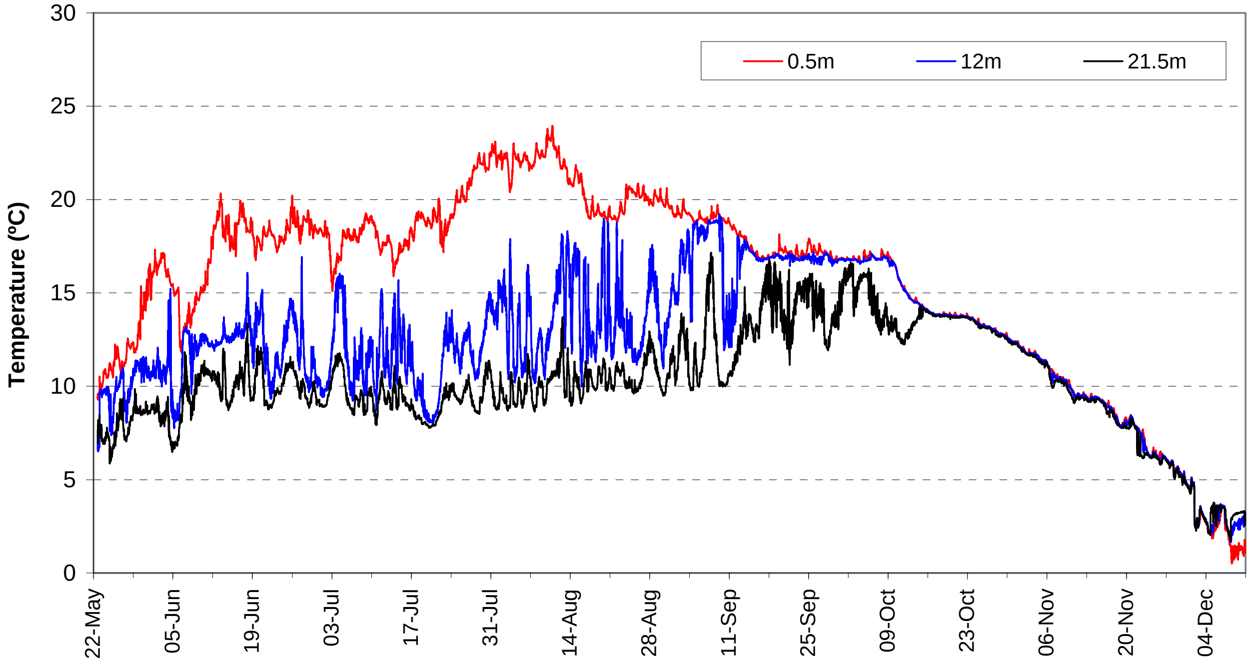


Figure 2.h. Site 8 temperature profile of cage environment (1 & 9m) and maximum depth (15m) from May through December 2007.

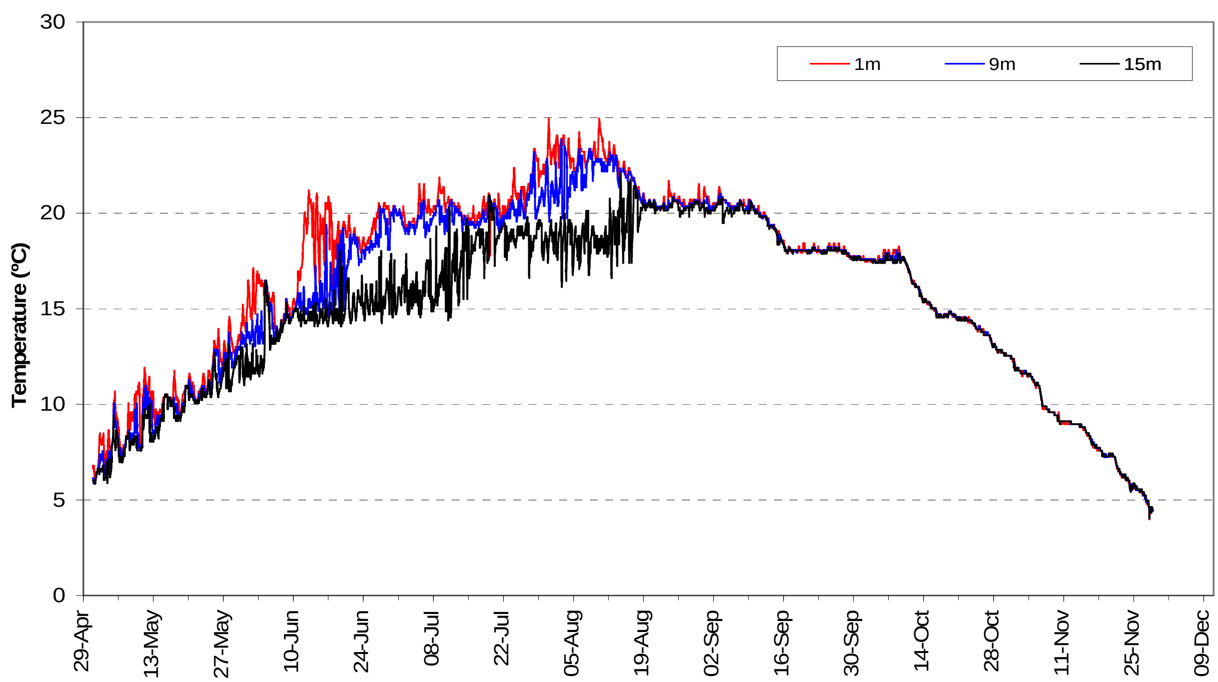


Table 1. Summary statistics of temperature data recorded from May 25 – November 28 at the 8 aquaculture sites, with 3 depth zones; whole water column (WWC), cage environment (CE), below cage environment (BCE).

Site	Depth zone	Mean °C	Median °C	Mode °C	Range °C	Max. °C	Min. °C	1st Quartile °C	3rd Quartile °C
1	WWC	9.87	7.88	5.80	21.56	25.58	4.02	6.17	12.37
	CE	12.55	11.30	8.81	21.11	25.58	4.47	8.33	17.08
	BCE	6.32	6.11	5.80	9.25	13.27	4.02	5.49	6.91
2	WWC	7.47	5.41	4.57	22.18	25.84	3.66	4.59	7.65
	CE	11.80	9.44	8.10	21.67	25.84	4.17	7.09	17.23
	BCE	4.97	4.78	4.57	7.70	11.36	3.66	4.43	5.35
3	WWC	14.25	14.19	15.92	18.92	23.35	4.43	11.69	16.70
	CE	14.87	15.37	15.92	18.59	23.35	4.77	12.39	17.82
	BCE	12.39	12.17	11.69	15.84	20.27	4.43	10.49	14.36
4	WWC	14.75	14.24	16.63	20.09	25.91	5.82	11.47	18.31
	CE	16.30	16.87	16.63	19.41	25.91	6.51	12.97	19.63
	BCE	12.42	12.46	12.56	17.08	22.90	5.82	10.17	14.30
5	WWC	14.15	13.83	16.77	18.03	23.93	5.90	11.25	16.89
	CE	14.85	15.29	16.77	17.98	23.93	5.95	12.12	17.49
	BCE	12.06	11.81	16.53	12.90	18.79	5.90	10.05	13.69
6	WWC	15.36	15.70	16.96	20.82	25.04	4.22	11.76	19.06
	CE	16.39	17.15	16.92	19.37	25.04	5.67	12.97	19.70
	BCE	13.81	14.22	15.37	18.58	22.80	4.22	10.66	16.92
7	WWC	13.41	12.97	16.82	18.34	23.95	5.62	10.17	16.77
	CE	14.89	15.20	16.82	18.18	23.95	5.77	11.88	17.87
	BCE	11.19	10.66	13.76	13.08	18.70	5.62	9.34	12.94
8	WWC	15.80	17.54	20.33	21.02	24.95	3.93	11.92	19.97
	CE	16.13	17.75	20.33	20.98	24.95	3.97	12.36	20.33
	BCE	15.09	15.97	18.03	18.94	22.87	3.93	11.6	18.83

Figure 3a. Whisker box-plot of whole water column (WWC) temperature range at the 8 monitored sites from May 25 – November 28, 2007, yellow box represents 50 percent of the data points between the 1st and 3rd quartiles, whiskers mark the total range of temperatures.

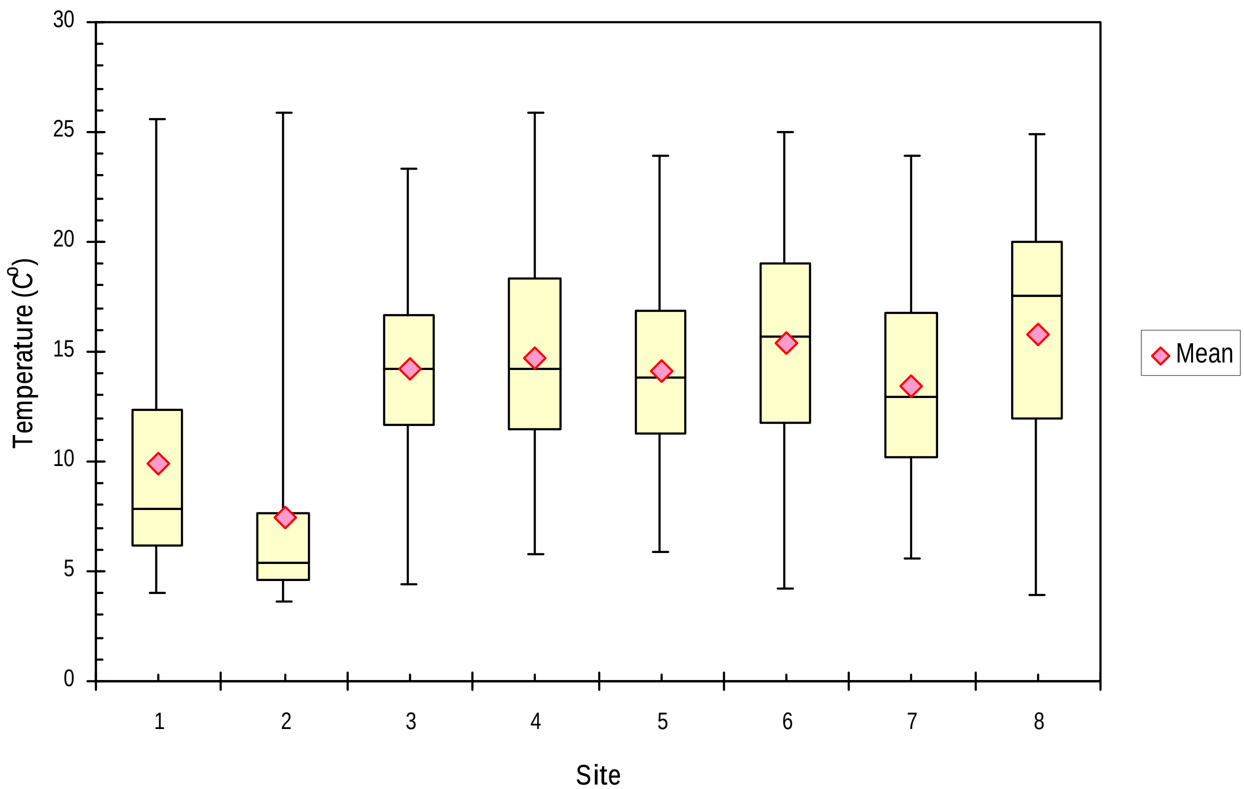


Figure 3b. Whisker box-plot of the cage environment (CE) temperature range at the 8 monitored sites from May 25 – November 28, 2007, yellow box represents 50 percent of the data points between the 1st and 3rd quartiles, whiskers mark the total range of temperatures.

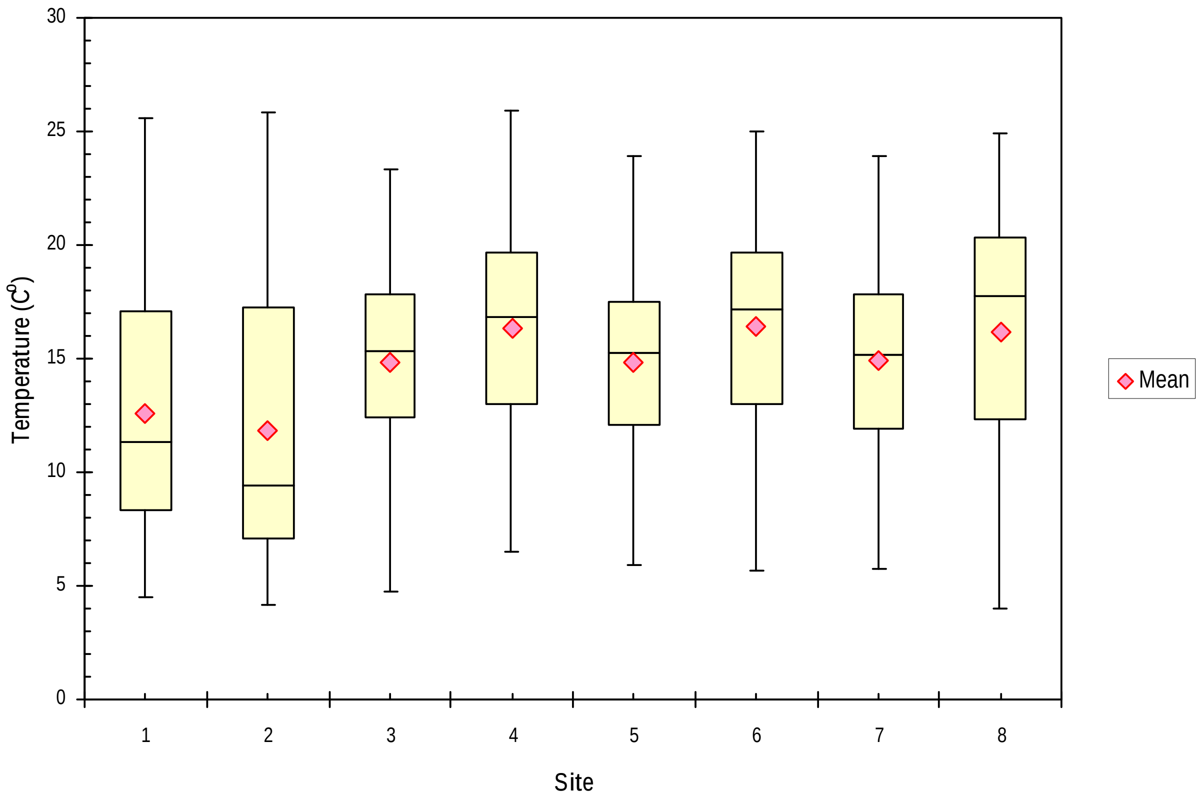


Figure 3c. Whisker box-plot of below cage environment temperature range at the 8 monitored sites from May 25 – November 28, 2007, yellow box represents 50 percent of the data points between the 1st and 3rd quartiles, whiskers mark the total range of temperatures.

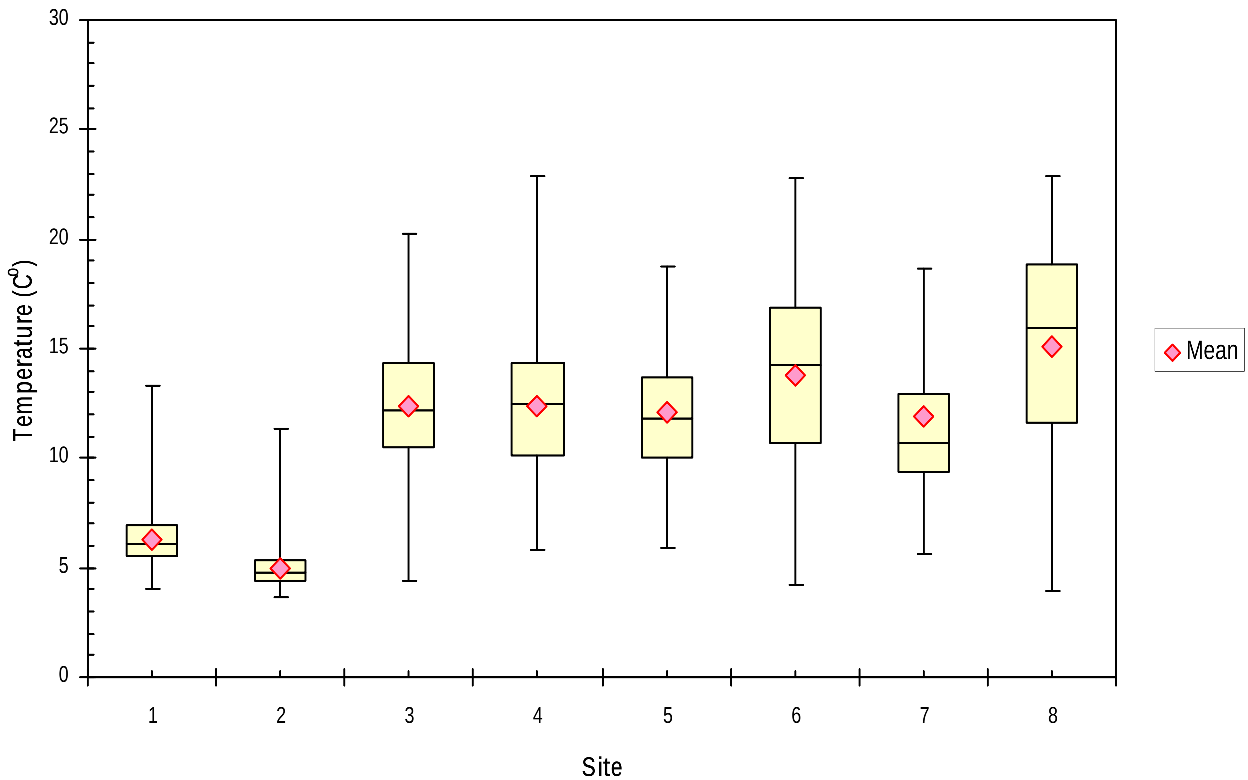


Table 4. Estimated fall turnover dates for each site during 2007.

Site	Fall turnover date
1	20th November
2	28th November
3	9th October
4	15th October
5	17th September
6	No turnover
7	15th October
8	19th August

4. DISCUSSION

To fully appreciate the temperature profiles recorded at the eight sites, it is useful to understand the driving forces responsible for establishing these temperature regimens. Lake Huron is made up of four interconnected water bodies, the North Channel, Georgian Bay, Saginaw Bay and the main Lake Huron (Sheng and Rao 2006). The principle inflows of water into Lake Huron are from Lake Superior, via the St. Mary’s River into the North Channel and from Lake Michigan via the Straits of Mackinac into the main lake. Water leaves Lake Huron via the St. Clair River in the south. As a result of the high inflow via the St. Mary’s River, with corresponding outflow, the North Channel can be regarded as a flow-through system with a complete exchange every two years (Weiler 1988). The larger Georgian Bay water body water is exchanged every 8.5 years (Weiler 1988). The exchange that occurs at the Main Channel between Georgian Bay and Lake Huron is responsible for the oligotrophic status of Georgian Bay by providing cooler surface waters to offset summer solar heating, while allowing nutrient-rich bottom waters from the bay to flow out into the main water body of Lake Huron (Bennett 1988).

The main driving force of the temperature distributions observed in the Great Lakes region is the climate, which including a long, cold winter and a hot, humid summer with strong winds and frequent storms throughout the year (Weiler 1988). In addition, the irregular shoreline and highly varying basin morphology contribute to changes in current flow and wave action (Sheng and Rao 2006). The temperature profiles at all the sites (except Site 6) show an important hydrodynamic feature of seasonal changes in the thermal structure; from a completely vertically mixed water column in early spring and late fall to a highly stratified water column in the summer. As a result of reduced solar input and wind cooling, the surface water cools and as it approaches 4 ºC, the maximum water density, this water sinks and begins mixing with deeper waters to form a vertically homogenous water column . As winter cooling progresses, the surface waters continue to cool below 4 ºC mark, becoming less dense at 0 – 3 ºC, forming a weak inverse stratification near the surface, with denser 4 ºC water lying under the cold surface layer. The process then reverses during late winter and early spring, as temperatures near the surface warm up to 4 ºC, again forming a vertically mixed water column before the onset of summer stratification due to increased solar heating (Wetzel 1975). During the summer stratification period, the water column can be divided into three main bodies of decreasing temperature from surface to bottom: the epilimnion, metalimnion and hypolimnion. The epilimnion is the most turbulent and heated layer, the bottom hypolimnion layer is the densest and coldest layer, making it the most stable and isolated. The metalimnion is the layer of thermal discontinuity between these two layers, characterized by a steep thermal gradient, where the largest decrease in temperature with regard to depth and is often referred to as the thermocline (Wetzel 1975).

Rainbow trout (*Oncorhynchus mykiss*) are poikilothermic and consequently have their metabolic rate, growth, energy expenditure and feed intake are regulated by water temperature. An aquaculture manager can accurately predict final product weight by knowing the average environmental rearing temperature, growth period (days), initial weight and thermal growth coefficient of the fish species (Cho, 1992). Such information is useful in determining stocking density based on desired final product weight, initial fingerling weight, known temperature regime and length of production cycle. Rainbow trout prefer a temperature range between 10-15 ºC (Lund and Tufts 2003); however, they can acclimate to higher temperatures of 18 – 19 ºC (Werner, Smith, Felciano and Johnson 2005).

The lower and upper lethal temperatures for rainbow trout, depending on acclimation temperature, are approximately 0 – 1 ºC and 26 – 29 ºC, respectively (Moloney 2001). The maximum observed temperature within the cage environment ranged from 23.4 ºC at Site 3 to 25.9 ºC at Site 4. Over winter monitoring at Site 7, showed that the minimum cage environment temperature was 0.1ºC at 0.5m and 0.3 ºC at 12m for a brief period during January 2007.

In addition to the temperature extremes, the sites showed high-frequency, large-amplitude fluctuations in temperature on the order of 5 ºC over 60 minutes. Examples include: Site 2, during the periods 18th June – 2nd July and 13th – 27th August (Figure 4a and Appendix II, Figures 5a & 5b); and Site 4, during the period 30th July – 13th August (Figure 4b and Appendix II, Figure 5c). This spatial heterogeneity of mixing is usually attributed to turbulent mixing of water layers, e.g. wind action. However, recent studies suggest that oscillating baroclinic currents along the lake bottom, causing shear-driven turbulence along with high-frequency internal waves breaking up on sloping boundaries at the depth of the metalimnion, are also responsible for water mixing (Boegman, Imberger, Ivey and Antennuci 2003). It has been shown that high-frequency internal waves exist in narrow, discrete frequency bands, and some common mechanisms for their formation have been proposed: shear instability, nonlinear steepening of basin-scale internal waves, internal hydraulic jumps, excitation by intrusion and gravity currents, and flow interaction with boundaries (Boegman et al. 2003). Internal waves are of great significance to both aquaculture managers and monitoring agencies due to their role in sediment resuspension, dissolved and particulate phosphorous levels and the release of methane from the bottom sediment at the end of the stratification period (Saki, Murase, Sugimoto, Okubo and Nakayama 2002).

Figure 4a. Site 2 daily average water temperature within cage environment and bottom level.

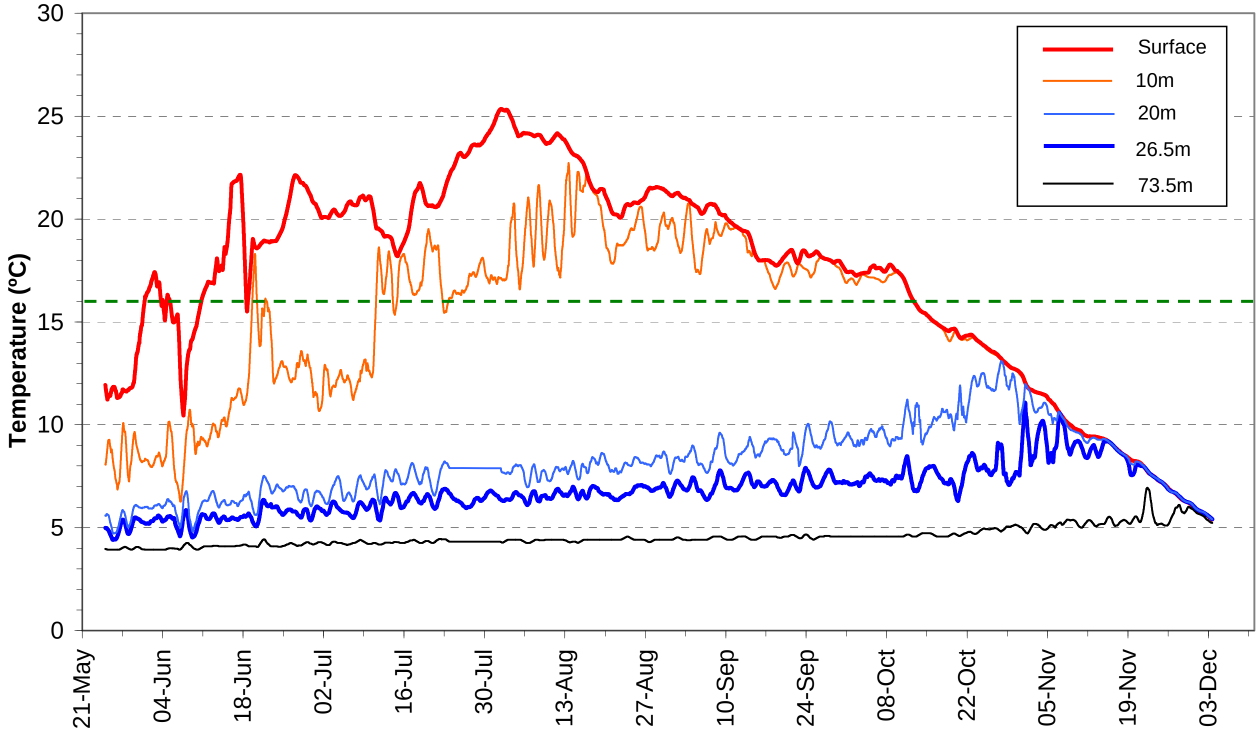
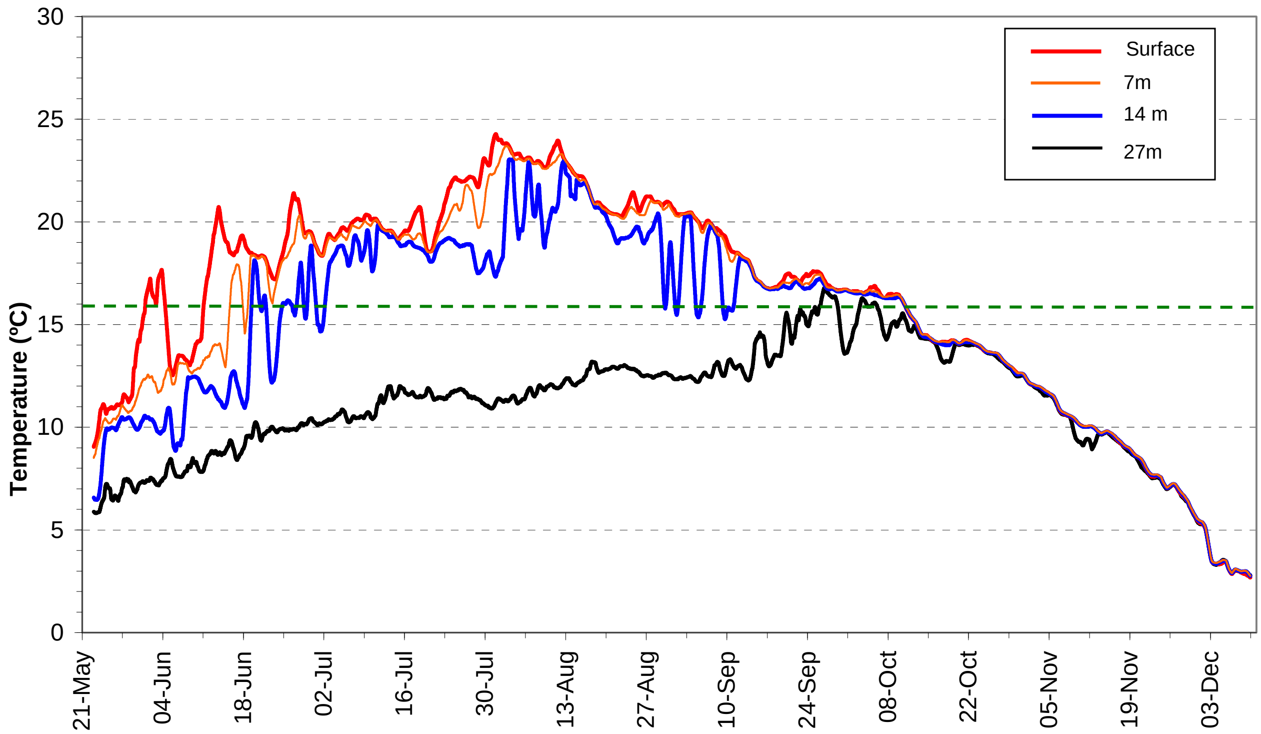


Figure 4b. Site 4 daily average water temperature within cage environment and bottom level.



Fish, given the opportunity to move between water bodies with temperatures ranging from optimal to near lethal limits, will seek refuge in thermally optimal waters (Mathews and Berg 1997). This is of importance at sites where optimal temperatures occur below the cages while near lethal temperature's occur within the cages, as seen at all eight sites in this study. The use of either deeper cages and/or pumping the deeper cold water up through the cages are options to consider. Furthermore, stocking density should be reconsidered if elevated temperatures in the upper cage region results in fish seeking deeper refuge causing overcrowding.

Temperature stress can also increase the risk of disease in fish exposed to many pathogens. Schisler et al. (2000) found that elevated temperature from 12.5 ºC to 17 ºC contributed significantly to mortality of fingerling rainbow trout when exposed to *Myxobolus cerebralis* (whirling disease) and *Flavobacterium psychrophilum* (bacterial coldwater disease). Taking this into account, it is clear that fish exposed to an environmental stressor such as temperature, as is the case at all the aquaculture sites in this study, are at risk of disease outbreak and management strategies to minimize the stress must be observed.

Rainbow trout also respond to extreme temperature conditions with the "heat shock protein response," an important mechanism used to repair denatured cellular proteins and prevent further damage from thermal cellular stress (Werner et al. 2005). Upon exposure to thermal stress, there is a rapid induction and expression of heat shock proteins whose roles are to correct folding, repair, translocate intracellular proteins, suppress protein aggregation and reactivate denatured proteins (Werner et al. 2005). Heat shock protein expression has also been linked to cellular signalling molecules and receptors controlling development and growth (Werner et al. 2005). Werner et al.

(2005) found that *Onchorynchus mykiss* (steelhead) acclimated to 15 ºC but chronically exposed to 20 ºC were associated with a decrease in high-energy compounds in liver and muscle tissue. Thermal stress is thus considered to cause energy diversion from growth to maintenance, minimizing thermal damage by using heat shock proteins to reorganize plasma membranes, particularly in fish with chronic exposure at 20 ºC (Viant, Werner, Rosenblum, Gantner, Tjeerdema and Johnson 2003). It is also suggested that energy repartitioning, due to heat shock protein induction within tissues of juvenile rainbow trout, results in a 20 percent decrease in growth, appetite, food conversion efficiency, protein turnover and accretion when exposed to 24 – 26 ºC for 30 days (Reid, Dockray, Linton, McDonald and Wood, 1995). In addition to causing a heat shock response, higher temperatures also reduce haemoglobin oxygen affinity, thus further raising the basic metabolic cost for the fish (Lund and Tufts 2003). Considering the effects of thermal stress and the cage environment, temperature distributions at Sites 4, 6 and 8, which have the highest averages, all above the upper optimal range of 15 ºC at approximately 16 ºC, frequently fluctuating and exceeding 20 ºC, it can be inferred that the fish are experiencing considerable thermal stress. The first and third quartile temperature marks for these sites are above the lower and upper optimal range values at approximately 12.5 and 20 ºC, respectively, meaning that 50 percent of the time the temperatures are found within this range and beyond it reach maximums of approximately 25 ºC. Sites 3, 5 and 7 have a similar first quartile mark of around 12 ºC; however, the third quartile mark is 2 ºC cooler and so are the maxima at just below 24 ºC. This cooler upper temperature regime probably coincides with a markedly reduced heat shock response, thus drawing less energy away from growth.

Important factors determining an open water cage site are the dissolved oxygen profile and assimilative capacity of a site. Oxygen is responsible for driving the chemical and biological degradation of deposited organic material on the lake bottom by affecting the biological diversity and abundance responsible for it (Wetzel 1975). Water at the sediment-water interface, where oxygen demand is highest due to bacterial breakdown of organic compounds, will consequently lose oxygen quickest (Wetzel 1975). Since the temperature differences between the hypolimnion and overlying waters prevent mixing, the oxygen in the hypolimnion can be completely used up by organic degradation (Wetzel 1975). Complete anoxia in the hypolimnion leads to production of toxic sulphur gas, hydrogen sulphide and methane gas (Wetzel 1975). Furthermore, a change from hypoxic to anoxic conditions brings the redox potential to 0mv and creates a reducing environment in the sediment (Wetzel 1975). This condition, along with the presence of deposited aquaculture waste with further reducing properties, can lead to metal enrichment by complexing and adsorption to the acid molecules within the waste (Wetzel 1975). Since aquaculture feed contains trace metals copper, zinc, iron and manganese as dietary requirements for salmonids (Chou 2002), their accumulation in long-term deposited sediments may have significant effects under anoxic conditions. Chou et al. (2002) found high concentrations of copper and saturation levels of zinc in marine sediments related to the inputs of fecal and metabolic waste metals and organic carbon originating from salmon aquaculture feed. In such cases of hypolimnetic anoxia and organic waste loading, spring and fall turnovers become important mechanisms in restoring oxygen levels in the hypolimnion and bringing nutrients/waste to the surface to be utilized/assimilated by primary producers. Observing the lower depth temperature profiles, it is evident that a pronounced stable hypolimnion is found only at the deeper Sites 1 and 2 and at the more wind-sheltered Site 6 site, located between two islands. However, Site 6 is the only one of the three sites with a pronounced hypolimnion that does not show a full turnover in the fall, suggesting an anoxic hypolimnion with high anaerobic hydrogen sulphide and methane gas by-products of the aquaculture waste degradation. Sites 3, 4, 5, 7 and 8 show weak hypolimnetic stratification, with temperatures in the hypolimnion often fluctuating in the metalimnetic and even epilimnetic temperature ranges, suggesting adequate mixing with overlying water. This may be attributable to the higher wind exposure and relatively shallow depths of these sites where, as a result, solar heating of the hypolimnion occurs and sufficient winds cause turbulent vertical convection mixing during the stratification period. This can be clearly seen at Site 8's profile, with no evidence of a hypolimnion, weak stratification, no natural wind barriers and, consequently, the earliest fall turnover of August 19, 2007. Correspondingly, the latest turnover date occurs at the deepest site, Site 2, over three months later on November 27, 2007. With regard to assimilative capacity of a site, summer stratification, along with spring and fall turnovers, are some of the fundamental determinants and complete seasonal temperature profiles are necessary for their identification.

In conclusion, the sustainability and future development of Ontario aquaculture will in part depend upon the continued prudent management of existing sites and development of new sites. Water temperature is a fundamental criterion for site selection and this study shows the dynamic range that exists in the Lake Huron water body. The development of a database and map of expected temperature and current profiles would be a useful "first-stage" in assisting future site selection.

Acknowledgments:

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6. APPENDIX I

Table 5. Site location and logger deployment details.

Site	Max. Depth (m)	# Loggers per String	Logger Depths (m)	Logging Interval (minutes)
1	34	7	0.5,10,15,20,25,30,33.5	15
2	74	11	0.5,10,20,26.5,33,39.5, 47,53.5, 60, 66.5, 73.5	15
3	16.5	4	0.5, 4.5,9,16	15
4	27.5	5	0.5,7,14,21,27	15
5	16.5	4	0.5,6,12,16	15
6	18.5	5	0.5, 4.5,9,15,18	15
7	22	5	0.5,6,12,17.5,21.5	15
8	15.5	8	1,3*,5,7,9,11,13,15	10-12*

Table 6. Initial data logging start, offloading and final logging dates at the 8 aquaculture sites:

Site	Start date	Offloading/relaunch dates	Final date
1	May 24, 2007	June 15, August 2	December 4, 2007
2	May 24, 2007	TempProV2 all loggers*: July 24 *Surface logger: June 15, July 24 Tidbits**: July 24, relaunched August 2 **No logging July 24 – August 2	December 4, 2007
3	May 24, 2007	June 15, July 22, October 4	December 12, 2007
4	May 22, 2007	June 14, July 23, October 4	December 10, 2007
5	May 23, 2007	June 14, July 23, October 5	December 11, 2007
6	May 23, 2007	June 14, July 24, October 5	December 11, 2007
7	May 23, 2007	June 14, July 23, October 5	April 28,2008
8	May 1, 2007	August 22	November 29, 2007

APPENDIX II:

Figure 5a. Wire frame chart showing temperature profile at Site 2 from June 18 – July 2, 2007.

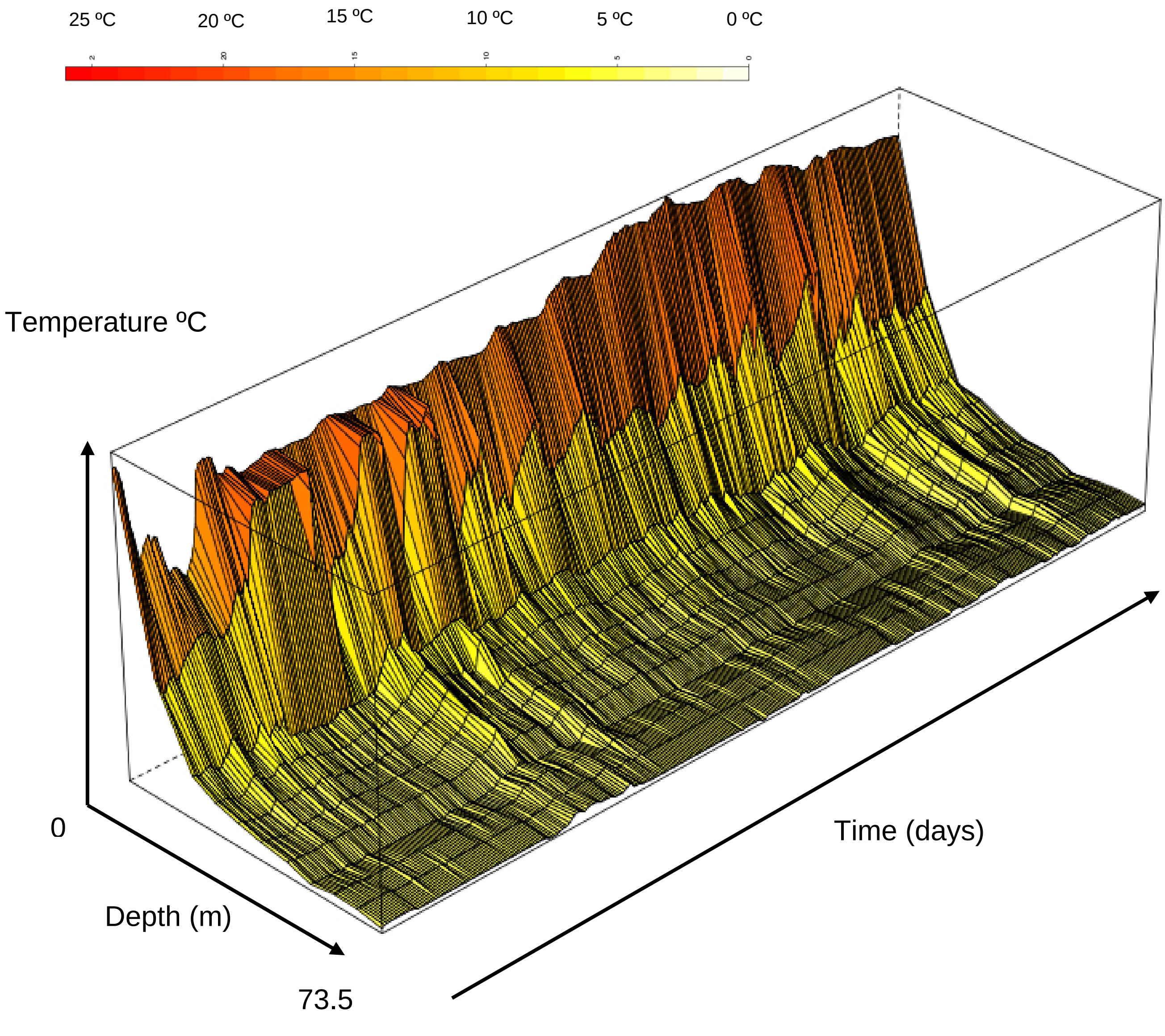

Figure 5b. Wire frame chart showing temperature profile at Site 2 from August 13-27, 2007.

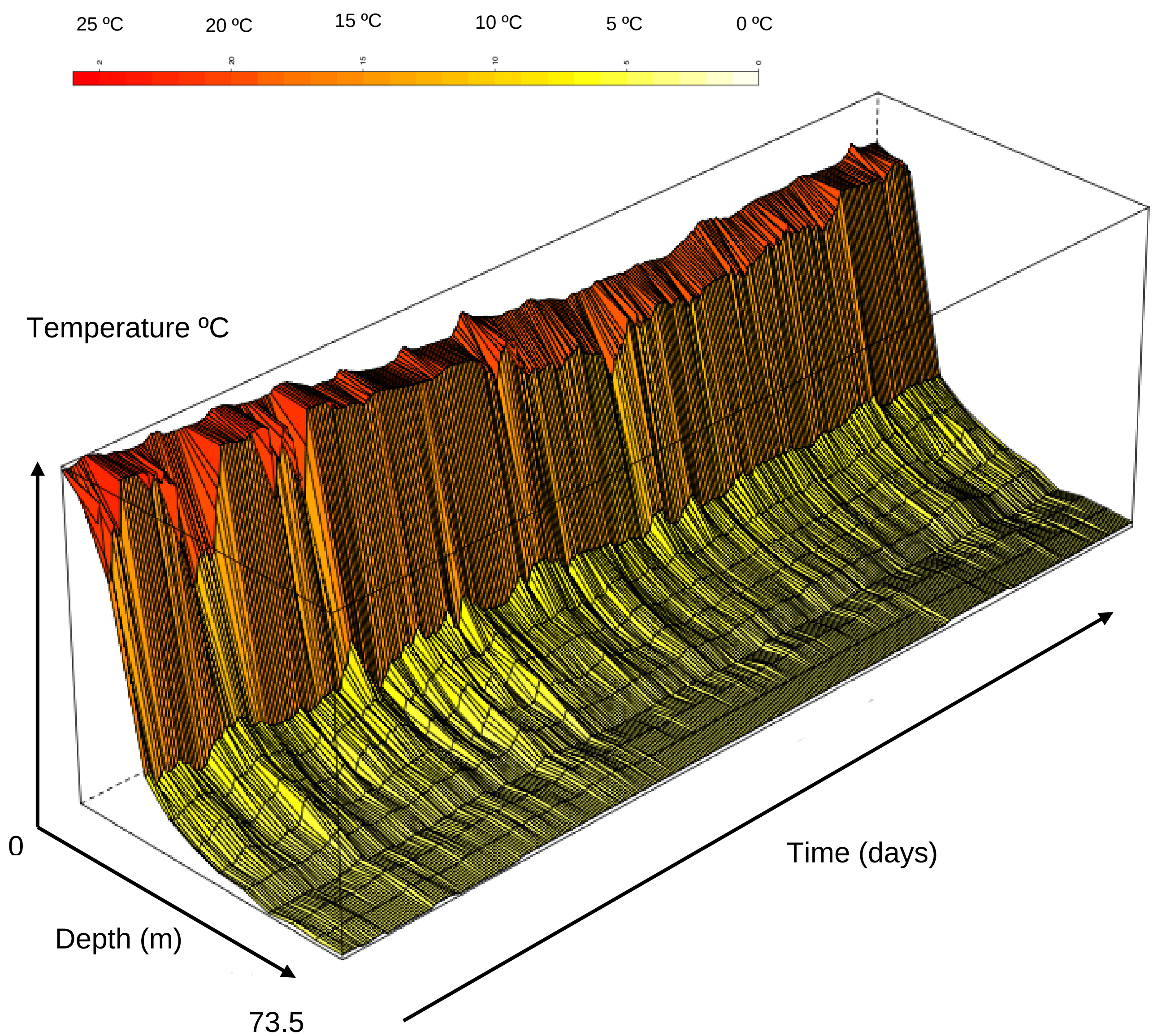

Figure 5c. Wire frame chart showing temperature profile at Site 4 from July 30 – August 13, 2007.