Guide to ThermoPic Software – version 3a (2018.01.06)

This document was originally produced as Appendix C of the following report:

Minns, C.K., S. Fung, B. J. Shuter and N. P. Lester (2018). ThermoPic – A Tool for Visualizing the Seasonal Availability of Thermal Habitat in Lakes. Aquatic Research and Monitoring, Ontario Ministry of Natural Resources and Forestry, Peterborough, Ontario, Canada.

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C1. Introduction

A ThermoPic is a picture of thermal habitat in a lake. Given that the seasonal temperature cycle is known or can be predicted (Figure 1), one can calculate for each day of the year how much habitat exists within specified bands of temperature (e.g., 8-12 °C, 12-16 °C, 16-20 °C, etc.). A ThermoPic can then be produced by plotting % volume (or area) of habitat versus day of year (Figure 2). Because fish species differ in terms their preferred temperatures, this plot is a very useful summary of the thermal habitat available for different species.

The ThermoPic software serves three purposes. First, it predicts the seasonal temperature cycle in lakes based on easily measured variables (i.e., lake morphometry and climate). Second, it calculates and reports thermal habitat statistics. Third, it generates a ThermoPic plot. The model used to predict temperature is referred to as the Seasonal Temperature Model (STM). It was created by Minns et al. (2016) based on data from lakes in the province of Ontario (Canada). The STM is based on seven parameters (see Figure 3), each of which can be predicted given the following lake data inputs: location (latitude, longitude, elevation), morphometry (surface area, shoreline length, maximum depth and mean depth), water chemistry (Secchi, DOC), air temperature cycle (monthly means), and precipitation in August. Formulae used to calculate the STM parameters are given in this Guide, including formulae for dealing with missing data (i.e., Secchi, DOC, Shoreline).

Figure 1. Seasonal temperature cycle in a lake.

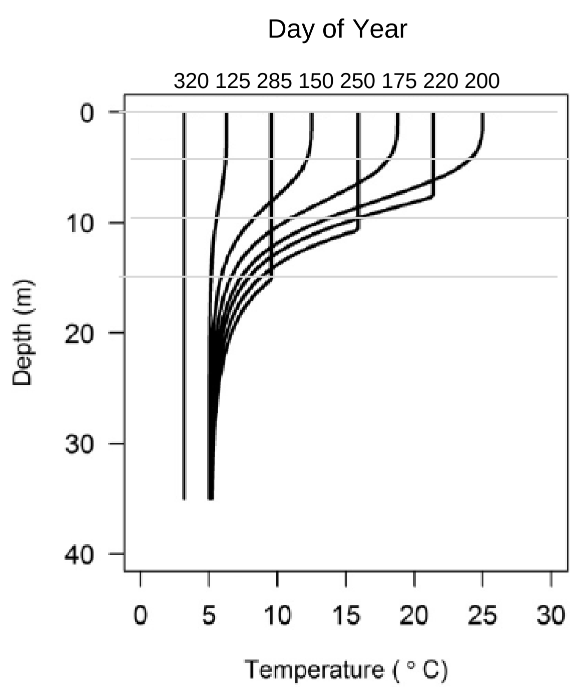


Figure 2. Example of a ThermoPic

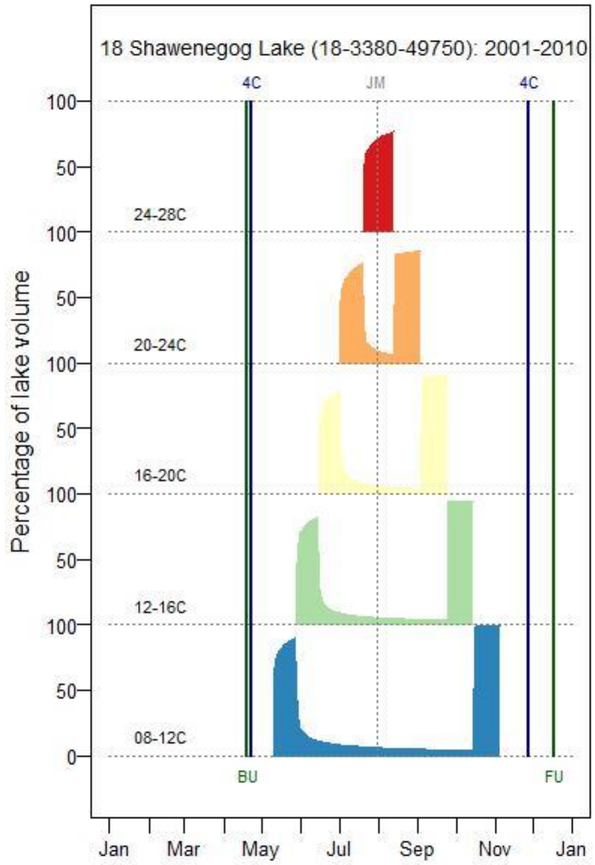
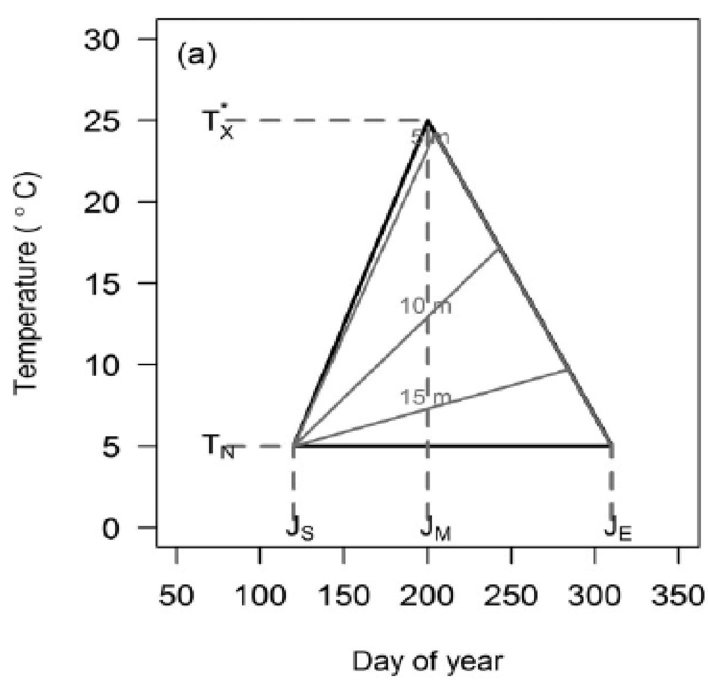


Figure 3. The Seasonal Temperature Model (STM) parameters.



C2. File Organization

ThermoPic software runs in the R environment, uses CSV files for data input and output, and produces JPEG or TIFF files of ThermoPic plots. The package consists of:

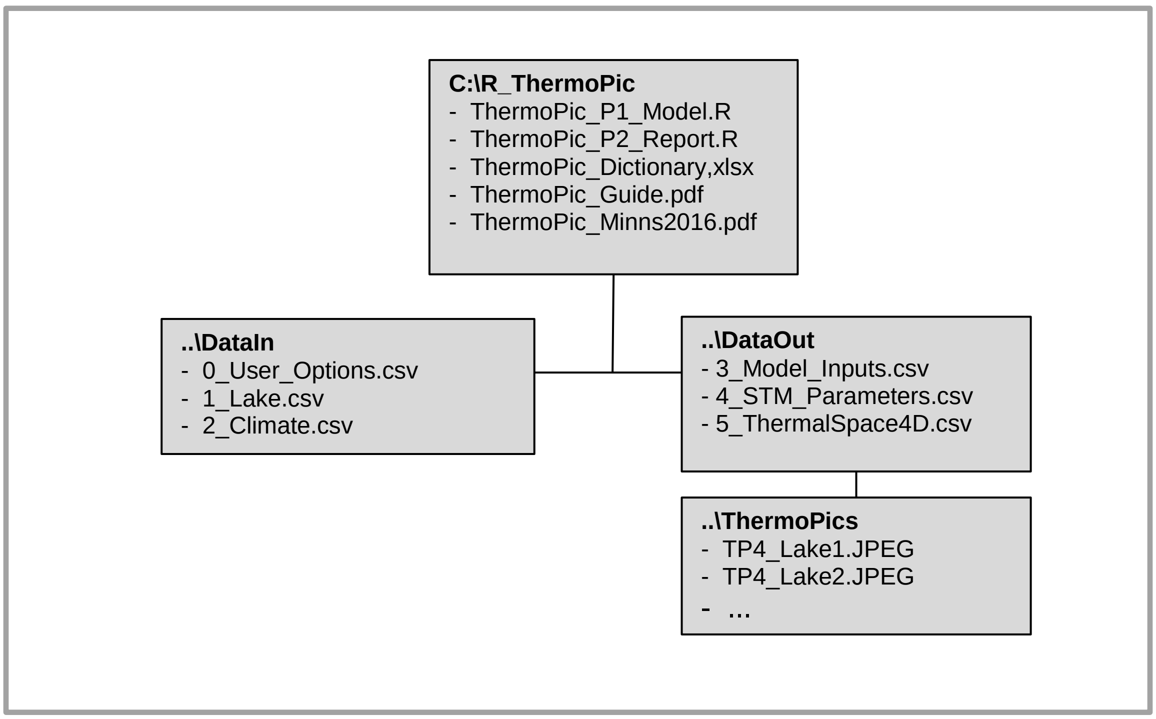
- two R programs (P1_Model, P2_Report)
- a data dictionary (ThermoPic_Dictionary.xlsx)
- 3 CSV data input files (0_User_Options, 1_Lake, 2_Climate)
- 3 CSV output files (3_Model_Inputs, 4_STM_Parameters, 5_Thermal Space4D)
- multiple JPEG files (one for each ThermoPic created)

Program and data files are stored in a main folder (R_ThermoPic) and two sub-Folders (DataIn, DataOut), as illustrated below. ThermoPic plots are stored as JPEG or TIFF files in a sub-folder of DataOut.

The main folder also includes supplementary information:

- ThermoPic_Minns2016 (report by Minns et al. that developed the Seasonal Temperature Model and demonstrates the application of ThermoPics)
- ThermoPic_Guide.pdf (copy of this document, which is Appendix C in Minns2106)

Figure 4. File organization of ThermoPic software.



C3. Running the R Programs

Install ThermoPic by creating a main folder (such as C:\R_ThermoPic) containing the two R programs shown in Figure 1, as well as the ThermoPic_Dictionary and sample data file (ThermoPic_Data). If the main folder is not "C:\R_ThermoPic", change the first line of code in each R program to match the name of your main folder.

Create the sub-folder structure shown in Figure 1 and copy the 3 data files to the sub-folder "..\DataIn":

- 0_User_Options.csv
- 1_Lake.csv
- 2_Climate.csv

Alternatively, if you have other data files in the correct format, copy your data to "..\DataIn".

Set up the R environment so that the following libraries can be accessed:

- Chron
- Plyr
- XLConnect
- rLakeAnalyzer
- rootSolve
- RColorBrewer

Then run the following 2 programs (P1 and P2) in sequence. Results will be stored in sub-folders DataOut and DataOut\ThermoPics. After running the two programs, it is best to copy your results and delete the files in these folders.

ThermoPic_P1_Model

This program calculates parameters that define the Seasonal Temperature Model (STM) using input from "Lake_Climate_Data.xlsx". Parameters are generated for each combination of Lake x Period identified in the climate data file (2_Climate.csv).. The results are stored as csv files in the DataOut folder. These files include:

- 0_User_Options.csv (a copy of the input file)
- 3_Model_Inputs.csv
- 4_STM_Parameters.csv

In addition, two temporary files are created and stored in the DataOut folder:

- tmp_ClimMetrics.csv
- tmp_IceClimMetrics.csv

The file of primary interest is "4_STM_Parameters" – it contains parameters for each lake x climate scenario which is used to report estimate of thermal habitat.

Typically, the code is used to generate a temperature model for a single Period of climatic conditions (e.g. years 2001-2010). But the code can be used to explore how a change in climate affects water temperature in each lake: if the input file includes climate data for several periods (e.g. 1970-1980, 2001-2010), then results are generated for each period.

ThermoPic _P2_Report

This program should be executed after running P1_Model. P2_Report uses outputs from P1_Model to calculate thermal habitat (volume and area) for 5 temperature bands at intervals of 4 °C (8-12, 12-16, 16-20, 20-24, and 24-28). Results are produced for each "Lake x Period" listed in the input file. These results are stored in the file "5_ThermalSpace_4D.csv". In addition, a plot of thermal habitat volume (ThermoPic4D) is produced for each "Lake x Period" listed in the input file. Each plot is stored as a JPEG (or TIFF) file in the 'DataOut\ThermoPics' folder. Production of these plots can be controlled by editing the "0_User_Options" file that is stored in the DataIn folder.

C4. Data Input

0_User_Options.csv

This file allows users to modify several options when reporting thermal space (i.e., when running **P2_Report**). The "Default" column lists default conditions. Edit the "User" column to assign different options.

Option_Name	Default	User
TP_Plots	Yes	Yes
TP_Interval	4	4
TP_Format	JPEG	JPEG
TP_Folder	DataOut/ThermoPics	DataOut/ThermoPics
Nlakes_test	0	0

TP_Plots (Yes or No) indicates whether ThermoPic plots will be produced when running P2_Report. Production of plots for individual lakes can also be controlled by editing the '4_STM_Parameters'file in DataOut (after running P2_Model). By default, "Do_ThermoPic = TRUE" for all records in '4_STM_Parameters'. Setting "Do_ThermoPic" = FALSE will prevent plot production for that case.

TP_Interval specifies the temperature interval used when calculating thermal space. The Default value is 4 ^{o}C, which reports results for the following temperature ranges: 8-12, 12-16, 16-20, 20-24, 24-30. Acceptable values of TP_Interval are 1, 2, 3 and 4. ThermoPic plotting works best when TP_Interval = 3 or 4, because the plot routine has been designed to show the first 6 temperature bands, starting from 8 °C When TP_Interval = 1 or 2, the maximum temperatures shown are 14 and 20, respectively. These plots are not very useful and can be suppressed by setting TP_plots = "No". The setting of "TP_plots" has no effect on the production of the report file (e.g. 5_ThermalSpace_xD.csv). The program will always produce a report with thermal habitat statistics. The default TP_Interval (4 ^{o}C) produces a file whose name ends with the suffix "4D". If other intervals are chosen, this suffix changes accordingly (e.g., "3D" implies a 3 degree temperature interval).

TP_Format specifies the file type for ThermoPic graphs. Acceptable values are 'JPEG' or 'TIFF'.

TP_Folder specifies the sub-folder where ThermPic graphs will be stored.

Nlakes_test allows users to test the **P2_Report** code by processing a small number of lakes, before running the program on all lakes. If **Nlakes_test** = 0, all lakes in the '**1_Lake.csv'** will be processed. Otherwise, the value of **Nlakes_test** specifies how many lakes will be processed.

1_Lake.csv

This file is a list of lakes for which STM parameters will be generated. The data include a unique lake identifier (Wby_Lid) and other variables describing its location, morphometry and water chemistry. Variables used in code calculations include: Latitude, Longitude, Area_ha, Shoreline , Depth_Max, Depth_Mn, Elevation, Secchi and DOC. Missing values are acceptable for Shoreline, Secchi and DOC (see below). Other variables (FMZ, Group) are included for convenience – so they can later be used for organizing the results. These variables can be left empty, but they must not be removed. The column order must not be changed.

Variable List:

Variable	**Description**	**Units**	**Order**
FMZ	Fishery Management Zone (optional)		1
Group	User-defined (optional)		2
Wby_Lid	Waterbody Location ID (Unique identifier)		3
Lake_Name	Lake name		4
Latitude	Laltitude of lake centroid	degrees	5
Longitude	Longitude of lake centroid	degrees	6
Elevation	Elevation above seas level	m	7
Area_ha	Lake area	hectares	8
Shoreline	Shoreline perimeter	km	10
Depth_Max	Maximum lake depth	m	11
Depth_Mn	Mean lake depth	m	12
Secchi	Secchi depth	m	13
DOC	Dissolved organic carbon concentration	mg/l	14

Example:

FMZ	Group	Wby_Lid	Lake_Name	Latitude	Longitude	Elevation	Area_ha	Shoreline	Depth_Max	Depth_Mn	Secchi	DOC
5	0	South Scot Lake	15-3523-55336	49.94	-95.06	343	397	4.4	10.0	3.5	1.45	12.4
5	0	Whitefish Lake	15-3532-55170	49.79	-95.04	366	216	3.4	20.1	7.0	2.50	6.8

Estimating missing values for lakes (based on BsM lakes)

eShoreline = exp(1.39752 + 0.67375*ln(Area) – 0.72932*ln(Depth_Mn) + 0.75298*ln(Depth_Max))
eSecchi (with DOC) = exp(1.878035 + 0.18657*ln(Depth_Mn) – 0.16658*DOC + 0.00376*DOC^2)
eSecchi (without DOC) = exp(-77.0527 – 0.03926*ln(Area) + 0.37082*ln(Depth_Mn) + 3.3899*Latitude – 0.03687*Latitude^2)
eDOC = 2.0409 – 3.009*ln(Depth_Mn) + 18.737*(1/Secchi) – 8.2407*(1/Secchi)^2

2_Climate.csv

This file describes the climate conditions that apply to each lake for a specified period (or several periods). Records are uniquely identified by the combination of *Wby_Lid* x *Period*. *Period* is typically a block of years for which temperature and precipitation norms have been calculated. For example, *Period* = 2001-2010 identifies a recent decadal norm. Climate data for multiple Periods in a lake may be supplied, in which case STM parameters will be produced for each *Lake x Period* combination. Data are required for all temperature variables and the single precipitation variable. The column order must not be changed.

Variable List:

Variable	Description	Units	Order
Wby_Lid	Waterbody Location ID (Unique identifier)		1
Period	Period for which climate norms are given		2
Tjan	Mean air temperature in January for specified Period	°C	3
Tfeb	Mean air temperature in February for specified Period	°C	4
Tmar	Mean air temperature in March for specified Period	°C	5
Tapr	Mean air temperature in April for specified Period	°C	6
Tmay	Mean air temperature in May for specified Period	°C	7
Tjun	Mean air temperature in June for specified Period	°C	8
Tjul	Mean air temperature in July for specified Period	°C	9
Taug	Mean air temperature in August for specified Period	°C	10
Tsep	Mean air temperature in September for specified Period	°C	11
Toct	Mean air temperature in October for specified Period	°C	12
Tnov	Mean air temperature in November for specified Period	°C	13
Tdec	Mean air temperature in December for specified Period	°C	14
Tann	Mean annual air temperature for specified Period	°C	15
Paug	Mean daily precipitation in August for specified Period	mm	16

Example:

Wby_Lid	Period	Tjan	Tfeb	Tmar	Tapr	Tmay	Tjun	Tjul	Taug	Tsep	Toct	Tnov	Tdec	Tann	Paug
15-3523-55336	2001-2010	-15.2	-13.8	-5.7	4.1	10.0	16.3	19.4	18.1	13.4	5.0	-2.8	-12.2	3.2	88.7
15-3532-55170	2001-2010	-15.2	-13.7	-5.7	4.2	10.1	16.3	19.5	18.1	13.4	5.1	-2.7	-12.2	3.2	88.8

C5. Data Outputs

P1_Model Outputs

Results from running P1_Model are stored in several files. Ignore the files with a 'tmp' prefix (used mainly for debugging). Results of primary interest are stored in 2 datasheets (***3_Model_Inputs***, ***4_STM_Parameters).***

3_Model_Inputs,csv

This file contains the input variables needed to calculate the STM parameters. They include lake measurements, as well as climate and ice variables.

4_STM_Parameters.csv

This file contains estimates of the STM parameters which are used to predict temperature at depth throughout the icefree season. These estimates are needed to calculate seasonal thermal habitat. Editing of the columns 'Do_Space' and 'Do_ThermoPic' may be done to control output from P2_ThermoPic.

Variable List:

Variable	Description	Units
Wby_Lid	Waterbody Location ID (Unique identifier)	
Lake_Name	Lake name	
(Other Lake vars)	FMZ, Group, Latitude, Longitude, Elevation, Area_ha, Shoreline, Depth_max, Depth_Mn, Secchi, DOC	
Period	Period for which climate norms are given	
TX	STM parameter - maximum surface temperature (i.e., on day JM)	°C
TN	STM parameter - hypolimnetic temperature at onset of stratification (i.e., JS)	°C
JS	STM parameter - day of onset of stratification	Julian
JM	STM parameter - day of peak surface temperature	Julian
JE	STM parameter - day of end of stratification	Julian
ZTH	STM parameter - thermocline depth on JM (If ZJ=0, ZTH=ZM)	m
ZM	STM parameter - maximum thermocline depth	m
ZJ	STM parameter - number of days after JS when ZTH reaches ZM/2	days
SP	STM parameter - steepness of temperature transition from epi- to hypo-limnion	
IceBU	Ice breakup completion date (Ice free date measured relative to start of year when freeze occurred)	Julian
IceFU	Ice freeze up completion date (date of first complete ice cover)	Julian
Icefree	Duration of icefree (open water) period	days
DataGood	If TRUE then all required STM parameters have assigned values	
LakeNumber	Computed Lake Number based on STM parameters on JM	
Stratified	If TRUE then lake is thermally stratified (based on LakeNumber >= 1)	logical
Do_Space	If TRUE then calculate themal habitat space (volume and area)	logical
Do_ThermoPic	If TRUE then produce ThermoPic plot	logical

Example of 4_STM_Parameters

Wby_Lid	Lake_Name	Period	TX	TN	JS	JM	JE	ZTH	ZM	ZJ	SP	IceBU	IceFU	Icefree
15-3523-55336	South Scot Lake	2001-2010	25.0	8.2	121	218	291	9.7	9.7	0.0	4.5	124	325	201
15-3532-55170	Whitefish Lake	2001-2010	25.3	6.9	125	218	302	8.9	8.9	0.0	4.5	124	331	207

(Continued)	DataGood	LakeNumber	Stratified	Do_Space	Do_ThermoPic
…	True		False	True	True
…	True	12.8	True	True	True

STM Equations:

Parameter	Regression Equations
T_X	$4.81017 - 0.09763*(\ln(Area))^2 + 1.0569*\ln(Elevation) + 0.25207*T_{Ann} + 0.55343*T_{Jul} + 0.14833*T_{Aug}$
T_N	$11.9389 + 0.4687*\ln(Area) + 0.8784*\ln(Depth\_Mn) - 2.0357*\ln(Depth\_Max) - 0.20951*Secchi + 0.09426*T_{Mar}$
J_S (Area >= 8 km^2)	$160 + 5.14*T_{Ann} + 2.49*\ln(Area/Depth\_Mn) - 27$
J_S (Area <8 km^2)	$(160 + 5.14*T_{Ann} + 2.49*\ln(Area/Depth\_Mn))/2 + (91.24 - 5.87*T_{May} - 3.35*DOC + Area + IceBU)/2 - 27$
J_M	$153.592 - 0.93198*Longitude + 3.27394*T_{May} - 4.86477*T_{Jul} + 2.83079*T_{Sep}$
J_E	$219.445 + 9.2161*\ln(Elevation) + 10.6803*\ln(Depth\_Mn) + 2.43965*Secchi + 2.28842*T_{Aug} - 3.97789*T_{JJA} + 5.90576*T_{SON}$
Z_{TH}	$\exp(1.68062 + 0.22536*\ln(Area) - 0.11761*\ln(Shoreline) + 0.04326*T_{JJA} + 0.01575*Lat + 0.02193*Secchi - 0.01663*J_M + 0.00005158*J_M^2 + 0.0300566)$
Z_M	Assumed to equal Z_{TH}
Z_J	Assumed to be 0
SP	$-15.7148 + 0.30155*Latitude + 0.13118*Longitude - 0.15883*T_{Jun} + 0.50025*T_{Jul} + 0.010718*P_{Aug} + 0.04379*J_M$

P2_Report Outputs

The primary output from P2_Report is stored in one file (e.g., ***5_ThermalSpace4D)***. In addition, this module may generate a ThermoPic graph for each Lake x Climate scenario. ThermoPics are stored in a sub-folder of DataOut, whose name is specified in ***0_User_Options.csv*** (default = ThermoPics).

5_ThermalSpace4D
This file contains estimates of thermal space (volume and area) for various temperature ranges (specified by TRange). By default, thermal space is estimated for a 4 ^{o}C temperature interval and the output file is labeled with the suffix '4D'. If P2_Report is run for other TP_Intervals (e.g. 2 or 3), additional files will exist, labeled as ***5_ThermalSpaceXD*** where X equals the temperature interval.

Variable List:

Variable	Description	Units
Wby_Lid	Waterbody Location ID (Unique identifier based on Zone Northing Easting)	
Lake_Name	Lake name	
Lake vars	FMZ, Area_ha, Depth_Max, Depth_Mn	
Period	Period for which climate norms are given	
Stratified	If TRUE then lake is thermally stratified (based on LakeNumber >= 1)	logical
TRange	Temperature range for estimation of thermal area and volume	
PD_year	Proportion of days in year when TRange is present	
PD_icefree	Proportion of days in icefree season when TRange is present	
TSeasons	Number of seasons when TRange is present 0, 1 or 2	
Jstart_Spr	Start date of Spring presence of TRange	Julian
Jend_Spr	End date of Spring presence of TRange (if TSeasons = 2)	Julian
Jstart_Aut	Start date of Autumn presence of TRange (if TSeasons = 2)	Julian
Jend_Aut	End date of Autumn presence of TRange	Julian
PV_JM	Proportion of lake volume where TRange exists on day JM (i.e., midsummer peak)	%
PV_mean	Mean proportion of lake volume where TRange exists for days when TRange is present	%
PV_sd	Standard deviation of PV when TRange is present	%
PV_max	Maximum value of PV when TRange is present	%
PV_min	Minimum value of PV when TRange is present	%
PV_year	Proportion of lake volume where TRange exists for entire year (= PD_year*PV_mean)	%
PA_JM	Proportion of lake area where TRange exists on day JM (i.e., midsummer peak)	%
PA_mean	Mean proportion of lake area where TRange exists for days when TRange is present	%
PA_sd	Standard deviation of PA when TRange is present	%
PA_max	Maximum value of PA when TRange is present	%
PA_min	Minimum value of PA when TRange is present	%
PA_year	Proportion of year-area integral when TRange is present (= PD_year*PA_mean)	%

Example of 5_ThermalSpace4D

Wby_Lid	Lake_Name	Stratified	Period	TRange	PD_year	PD_icefree	TSeasons	Jstart_Spr	Jend_Spr	Jstart_Aut	Jend_Aut
15-3523-55336	South Scot Lake	False	2001-2010	T0812	0.11	0.58	2	121	143	275	291
15-3523-55336	South Scot Lake	False	2001-2010	T1216	0.11	0.58	2	144	166	258	274
15-3523-55336	South Scot Lake	False	2001-2010	T1620	0.11	0.56	2	167	189	240	257
15-3523-55336	South Scot Lake	False	2001-2010	T2024	0.11	0.58	2	190	212	223	239
15-3523-55336	South Scot Lake	False	2001-2010	T2428	0.03	1.00	1	213			222
15-3532-55170	Whitefish Lake	True	2001-2010	T0812	0.45	1.00	1	132			296
15-3532-55170	Whitefish Lake	True	2001-2010	T1216	0.35	1.00	1	152			278
15-3532-55170	Whitefish Lake	True	2001-2010	T1620	0.24	1.00	1	172			260
15-3532-55170	Whitefish Lake	True	2001-2010	T2024	0.14	1.00	1	192			242
15-3532-55170	Whitefish Lake	True	2001-2010	T2428	0.04	1.00	1	212			224

(Continued)	PV_JM	PV_mean	PV_sd	PV_min	PV_max	PV_year	PA_JM	PA_mean	PA_sd	PA_min	PA_max	PA_year
…		100.0	0.0	100.0	100.0	11.0		100.0	0.0	100.0	100.0	11.0
…		100.0	0.0	100.0	100.0	11.0		100.0	0.0	100.0	100.0	11.0
…		100.0	0.0	100.0	100.0	11.2		100.0	0.0	100.0	100.0	11.2
…		100.0	0.0	100.0	100.0	11.0		100.0	0.0	100.0	100.0	11.0
…	100.0	100.0	0.0	100.0	100.0	2.7	100.0	100.0	0.0	100.0	100.0	2.7
…	9.5	30.3	34.4	5.7	100.0	13.7	18.3	34.9	28.5	14.4	99.4	15.8
…	8.3	31.6	33.6	6.0	94.3	11.0	10.6	29.2	27.3	8.9	84.5	10.2
…	9.2	38.5	32.7	6.6	87.2	9.4	10.0	32.5	25.7	7.8	73.9	7.9
…	16.9	55.6	23.5	12.4	78.7	7.8	15.8	43.9	17.9	12.1	63.5	6.2
…	55.4	52.1	10.8	23.0	61.9	1.9	40.9	38.4	8.6	15.7	46.7	1.4

ThermoPic Files

ThermoPic plots are stored in a sub-folder of DataOut (as specified in ***0_User_Options.csv***).

The file name identifies the Lake x Climate scenario, as well as the temperature interval – as illustrated in the following example.

File name = TP4_18_Sand Lake_ 18-3998-49356_P1961-1990.JPEG

TP4	ThermoPic for a 4^{o}C temperature interval
18	FMZ of the lake
Sand Lake	Name of lake
18-3998-49356	Wby_Lid (unique identifier of the lake)
P1961-1990	Label identifying period for which climate data were supplied
JPEG	file type (could also be TIFF).

By default, a TP4 file will be produced for each Lake x Climate scenario indicated by the input files (1_Lake and 2_Climate). Editing the ***0_User_Options*** file allows one to generate ThermoPics for other temperature intervals. For example, after producing the default TP4 plots, one could re-run P2_Report for a TP_Interval = 3. In that case, a similar set of plots would be produced, but with a prefix = TP3.

C6. Data Dictionary

The data dictionary (***ThermoPic_Dictionary.csv***) is stored in the main folder R_ThermoPic. This file is reproduced below. It describes all variables, identifies their units, and indicates their presence in the various input files (1_Lake, 2_Climate) and output files (3_Model_Inputs, 4_STM_Parameters, 5_ThermalSpace). Numbers show the order of variables in each file. If blank, the variable does not exist in the file.

Variable	Description	Units	1_Lake	2_Climate	3_Model_Inputs	4_STM_Parameters	5_ThermalSpace
FMZ	Fishery Management Zone (optional data)		1			1	1
Group	User-defined (optional data)		2			2	
Wby_Lid	Waterbody Location ID (Unique identifier)		3	1	1	3	2
Lake_Name	Lake name		4			4	3
Latitude	Laltitude of lake centroid	degrees	5			5	
Longitude	Longitude of lake centroid	degree	6			6	
Elevation	Elevation above sea level	m	7			7	
Area_ha	Lake area	hectare	8			8	4
Shoreline	Shoreline perimeter	km	10			10	5
Depth_Max	Maximum lake depth	m	11			11	6
Depth_Mn	Mean lake depth	m	12			12	
Secchi	Secchi depth	m	13			13	
DOC	Dissolved organic carbon concentration	mg/l	14			14	
Period	Period for which climate norms are given			2	2		8
Tjan	Mean air temperature in January	°C		3			
Tfeb	Mean air temperature in February	°C		4			
Tmar	Mean air temperature in March	°C		5	3		
Tapr	Mean air temperature in April	°C		6			
Tmay	Mean air temperature in May	°C		7	4		
Tjun	Mean air temperature in June	°C		8	5		
Tjul	Mean air temperature in July	°C		9	6		
Taug	Mean air temperature in August	°C		10	7		
Tsep	Mean air temperature in September	°C		11	8		
Toct	Mean air temperature in October	°C		12			
Tnov	Mean air temperature in November	°C		13			
Tdec	Mean air temperature in December	°C		14			
Tann	Mean annual air temperature	°C		15			
Paug	Mean daily precipitation in August	mm		16	9		
Tjja	Mean air temperature in June, July and August	°C			10		
Tson	Mean air temperature in September, October and November	°C			11		
J_Spr0	Spring date when 30-day smoothed air temperature rose to 0°C	Julian			12		
J_Aut0	Autumn date when 30-day smoothed air temperature dropped to 0°C	Julian			13		
T_Aut0	Mean air temperature for the 3-month period when the central month contains J_Aut0	°C			14		

Ang_Spr0	Angular elevation of the sun above the horizon at noon on J_Spr0	degrees			15		
TX	STM parameter - maximum surface temperature (i.e., on day JM)	°C				15	
TN	STM parameter - hypolimnetic temperature at onset of stratification (i.e., JS)	°C				16	
JS	STM parameter - day of onset of stratification	Julian				17	
JM	STM parameter - day of peak surface temperature	Julian				18	
JE	STM parameter - day of end of stratification	Julian				19	
ZTH	STM parameter - thermocline depth on JM (If ZJ=0, ZTH=ZM)	m				20	
ZM	STM parameter - maximum thermocline depth	m				21	
ZJ	STM parameter - number of days after JS when ZTH reaches ZM/2	days				22	
SP	STM parameter - steepness of temperature transition from epi- to hypo-limnion					23	
IceBU	Ice break up completion date (Ice free date measured relative to start of year when freeze	Julian			16	24	
IceFU	Ice freeze up completion date (date of first complete ice cover)	Julian				25	
Icefree	Duration of icefree (open water) period	days				26	
DataGood	If TRUE then all required parameters have assigned values and thermopic stats computed					27	
LakeNumber	Computed Lake Number based on STM parameters on JM					28	
Stratified	If TRUE then lake is thermally stratified (based on LakeNumber >= 1)	logical				29	7
Do_Space	If TRUE then calculate themal habitat space (volume and area)	logical				30	
Do_ThermoPi	If TRUE then produce ThermoPic plot	logical				31	
Stratified	If TRUE then lake is thermally stratified (based on LakeNumber >= 1)	logical					9
TRange	Temperature range for estimation of thermal area and volume						10
PD_year	Proportion of days in year when TRange is present						11
PD_icefree	Proportion of days in icefree season when TRange is present						12
TSeasons	Number of seasons when TRange is present 0, 1 or 2						13
Jstart_Spr	Start date of Spring presence of TRange	Julian					14
Jend_Spr	End date of Spring presence of TRange (if TSeasons = 2)	Julian					15
Jstart_Aut	Start date of Autumn presence of TRange (if TSeasons = 2)	Julian					16
Jend_Aut	End date of Autumn presence of TRange	Julian					17
PV_JM	Proportion of lake volume where TRange exists on day JM (i.e., midsummer peak)	%					18
PV_mean	Mean proportion of lake volume where TRange exists for days when TRange is present	%					19
PV_sd	Standard deviation of PV when TRange is present	%					20
PV_max	Maximum value of PV when TRange is present	%					21
PV_min	Minimum value of PV when TRange is present	%					22
PV_year	Proportion of lake volume where TRange exists for entire year (= PD_year*PV_mean)	%					23
PA_JM	Proportion of lake area where TRange exists on day JM (i.e., midsummer peak)	%					24
PA_mean	Mean proportion of lake area where TRange exists for days when TRange is present	%					25
PA_sd	Standard deviation of PA when TRange is present	%					26
PA_max	Maximum value of PA when TRange is present	%					27
PA_min	Minimum value of PA when TRange is present	%					28
PA_year	Proportion of year-area integral when TRange is present (= PD_year*PA_mean)	%					29