**Guide to ThermoPic Software – version 3b (2018.01.28)**

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 Predicting and 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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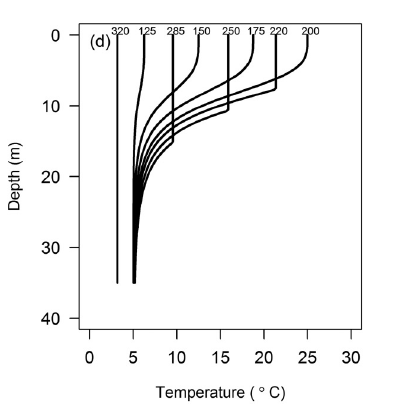
C6. Data Dictionary

**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).

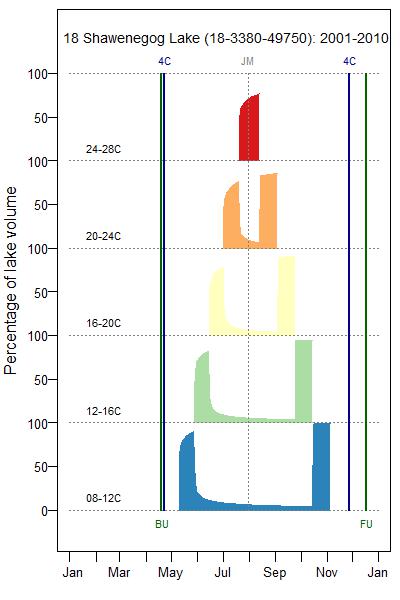
**Figure C1**. Seasonal temperature cycle in a lake.



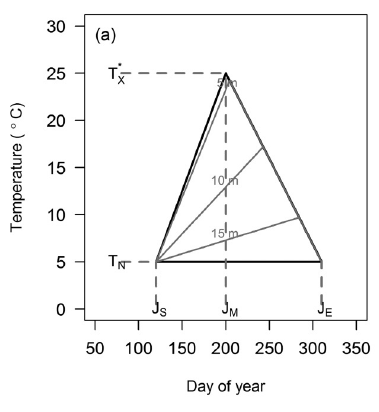
320 125 285 150 250 175 220 200

Day of Year

**Figure C2.** Example of a ThermoPic



**Figure C3.** The Seasonal Temperature Model (STM) parameters.



**C2. File Organization**

The thermopic R package provides functions for creating and modifying a project directory with a particular structure. The setup\_directory function automatically imposes this structure on a chosen directory and populates it with CSV files to be used as input. The thermopic\_model and thermopic\_report functions modify and create files within this structure and produces JPEG or TIFF files of ThermoPic plots. Once all three functions are called, the project directory structure consists of:

* a data dictionary (ThermoPic\_Dictionary.csv)
* 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)

The data dictionary is stored in a main folder for reference, 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\_TechReport (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 ThermoPic\_TechReport.pdf)

Figure 4. File organization of a ThermoPic project.

**C:\R\_ThermoPic**

- ThermoPic\_Dictionary.csv

- ThermoPic\_Guide.pdf

- ThermoPic\_TechReport.pdf

**..\DataIn**

- 0\_User\_Options.csv

- 1\_Lake.csv

- 2\_Climate.csv

**..\DataOut**

- 3\_Model\_Inputs.csv

- 4\_STM\_Parameters.csv

- 5\_ThermalSpace4D.csv

**..\ThermoPics**

- TP4\_Lake1.JPEG

- TP4\_Lake2.JPEG

- ...

**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 programcalculates 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 oC, 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 oC) 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(1.39494 + 0.69596\*ln(Area) – 0.68779\*ln(Depth\_Mn) + 0.65994\*ln(Depth\_Max) + (0.3772^2)/2)

eSecchi (with DOC) = exp(2.19226 + 0.179978\*ln(Depth\_Max) - 0.720734\*ln(DOC) + (0.3617^2)/2)

eSecchi (without DOC) = exp(0.277336 – 0.08618\*ln(Area) + 0.11680\*ln(Depth\_Mn) + 0.36719\*ln(Depth\_Max) + (0.4582^2)/2)

eDOC = exp(2.7215 – 0.0734\*ln(Depth\_Max) - 0.1276\*ln(Secchi) – 0.1469\*Secchi + (0.3070^2)/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** |
| TX | 4.81017 - 0.09763\*(ln(Area))2 + 1.0569\*ln(Elevation) + 0.25207\*TAnn + 0.55343\*TJul  + 0.14833\*TAug |
| TN | 11.9389 + 0.4687\*ln(Area) + 0.8784\*ln(Depth\_Mn) - 2.0357\*ln(Depth\_Max) - 0.20951\*Secchi + 0.09426\* TMar |
| JS  (Area >= 8 km2) | 160 + 5.14\*TAnn + 2.49\*ln(Area/Depth\_Mn) - 27 |
| JS  (Area <8 km2) | (160 + 5.14\*TAnn + 2.49\*ln(Area/Depth\_Mn))/2 + (91.24 - 5.87\*TMay  - 3.35\*DOC + Area + IceBU)/2 - 27 |
| JM | 153.592 - 0.93198\*Longitude + 3.27394\*TMay  - 4.86477\*TJul + 2.83079\*TSep |
| JE | 219.445 + 9.2161\*ln(Elevation) + 10.6803\*ln(Depth\_Mn) + 2.43965\*Secchi + 2.28842\*TAug - 3.97789\*TJJA + 5.90576\*TSON |
| ZTH | exp (1.68062 + 0.22536\*ln(Area) - 0.11761\*ln(Shoreline) + 0.04326\*TJJA + 0.01575\*Lat + 0.02193\*Secchi - 0.01663\*JM + 0.00005158\*JM2 + 0.0300566 ) |
| ZM | Assumed to equal ZTH |
| ZJ | Assumed to be 0 |
| SP | -15.7148 + 0.30155\*Latitude + 0.13118\*Longitude - 0.15883\*TJun + 0.50025\*TJul + 0.010718\*PAug + 0.04379\*JM |

**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 oC 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\_ThermalSpace****X****D*** where X equals the temperature interval.

**Variable List:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **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 occurred) | 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\_ThermoPic | 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 |
| TSeasons | Number of seasons when TRange is present 0, 1 or 2 |  |  |  |  |  | 12 |
| PD\_season1 | For unstratified lakes (i.e., TSeasons=2), proportion of days when TRange is present in the Spring season relative to Spring and Fall; for stratified lakes (i.e., TSeasons=1), PD\_season1 = 1.0 |  |  |  |  |  | 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 | Percent of lake volume where TRange exists on day JM (i.e., midsummer peak) | % |  |  |  |  | 18 |
| PV\_mean | Mean percent 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 | Percent of lake volume where TRange exists for entire year (= PD\_year\*PV\_mean) | % |  |  |  |  | 23 |
| PA\_JM | Percent of lake area where TRange exists on day JM (i.e., midsummer peak) | % |  |  |  |  | 24 |
| PA\_mean | Mean percent 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 | Percent of year-area integral when TRange is present (= PD\_year\*PA\_mean) | % |  |  |  |  | 29 |

**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 4oC 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 occurred) | 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\_ThermoPic | 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 |