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PRELIMINARY ANALYSIS OF BLUEFIN TUNA DEPTH AND TEMPERATURE PREFERENCES REVEALED BY ICCAT GBYP ELECTRONIC TAGS

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SUMMARY

One of the purposes of this exercise was to demonstrate the benefits of having already clean and formatted electronic tags data stored in a relational database in advance of carrying out the analysis. The preliminary analyses performed include fluctuations of mean depth and temperature parameters in relation to time of the day, time of the year, location and maturity level. In-depth analysis of electronic tag datasets is yet to be performed.

RÉSUMÉ

L'un des objectifs de cet exercice était de démontrer les avantages de disposer de données provenant du marquage électronique nettoyées, formatées et saisies dans une base de données relationnelle avant de procéder à l'analyse. Les analyses préliminaires effectuées incluent les fluctuations des paramètres de profondeur et de température moyennes en fonction de l'heure, du moment de l'année, de la localisation et du niveau de maturité. Une analyse approfondie des jeux de données de marques électroniques doit encore être effectuée.

RESUMEN

Uno de los propósitos de este ejercicio era demostrar los beneficios contar con datos de marcas electrónicas ya limpios y formateados almacenados en una base de datos relacional antes de llevar a cabo los análisis. Los análisis preliminares realizados incluían fluctuaciones de los parámetros de profundidad y temperatura medias en relación con el momento del día, el momento del año, la ubicación y el nivel de madurez. Aún deben realizarse análisis en profundidad de los conjuntos de datos de marcas electrónicas.

KEYWORDS

Tagging, Bluefin tuna, Electronic tags, Data collections

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1. Introduction

One of the major research tasks of the ICCAT Atlantic-Wide Research Programme for Bluefin Tuna (GBYP) is to carry out the large, wide and intensive scientific tagging program to address several important biological and ecological topics regarding Atlantic bluefin tuna (*Thunnus thynnus*). According to the GBYP general programme, in Phase 1 (2010-2011) the Tagging Design and the Tagging Manual were adopted and from Phase 2 (2011-2012) onwards, it was proceeded with the tagging activities. At the beginning, the priority was given to the deployment of the conventional tags, but due to low recovery rates, in Phase 4 the Steering Committee decided to focus on the deployment of electronic tags instead, keeping the conventional tagging only as a complementary activity.

GBYP started with electronic tag activities in 2011 when the first few pop-up satellite tags were deployed. Over the course of 7 years, up to 2018, within the framework of this Program, or in joint actions with other institutions, more than 340 electronic pop-up tags were deployed, mostly on adult bluefin tuna (**Table 1**). However, the number of recovered and useful datasets is somewhat smaller because some tags have never transmitted and the others detached prematurely. ICCAT GBYP tagging activities have been reported by Di Natale *et al.* (2015), Di Natale *et al.* (2016), Di Natale *et al.* (2017) and Tensek *et al.* (2017).

All the electronic tags deployed so far by the ICCAT GBYP have been made by the same manufacturer, Wildlife Computers. As a result, the relevant data have homogenous structure and individual tag datasets can be compared. Nevertheless, the original data obtained by electronic tags comprise a series of datasets of different formats which cannot be compiled and subsequently analysed without making a substantial previous effort of data preparation first. In GBYP Phase 7 the first attempt was made by Tensek (2017) towards creating the relational database which would gather all relevant data provided by electronic tags and in this way facilitate their extraction for any further analysis. For that purpose, a code was developed in R which serves for automatic cleaning, formatting and writing the data into the PostgreSQL database.

Currently, GBYP electronic tag datasets are used for feeding the bluefin tuna MSE operating model, and the data haven't been analysed yet. To facilitate their analysis, in Phase 7 a Shiny application was developed for visualisation of individual tag track and temperature and depth parameters (Tensek, 2017). In addition, for facilitating the analysis of bluefin tuna migration patterns, in 2018 other Shiny application was developed (Tensek, 2018, in press), which provides visualisation of electronic tag movements and allows data filtering and grouping according to several criteria.

2. Materials and methods

The dataset received for each tag are comprised of series of spreadsheets which, among other information, contain so-called raw data of depth and temperature and so-called processed data which refer to maximum probable geolocations (track). While raw data consist of direct tag sensor readings, geolocations are estimates obtained by some state-space model using existing values of light intensity, SST and depth.

For the purpose of these analyses, the following datasets were used (see **Figure 1** for the scheme):

1. SERIES – contains time series of temperature and depth readings in a given sample interval.
2. HISTOS – accumulates histogram data i.e. percent of time spent in each bin during the predefined period, including Time At Depth (TAD), Time At Temperature (TAT), definition of TAD limits (bins) and TAT limits (bins)
3. MIXLAYER – contains information about the depth of the mixed layer including the percent of time spent in and out of the layer during the predefined period
4. GEOLOCATIONS – series of maximum probable geolocations (latitude and longitude)
5. Auxiliary table – created for keeping additional information on each tagged bluefin tuna like length and weight

The data were taken directly from PostgreSQL database and although these data have already been compiled, cleaned and formatted, some additional data wrangling needed to be done before performing the analysis. To begin with, tables with values on temperature or depth was combined with other table with geolocations in order to associate values of latitude and longitude to each temperature or depth record. It has to be pointed out that only one geolocation estimate is available per day, while temperature and depth series and histograms include multiple values. In addition, latitude and longitude values were attributed to appropriate area. For the purpose of these analyses, 7 different areas were considered: Gulf of Mexico, Gulf of Saint Laurence, West Atlantic, North Atlantic, South Atlantic, East Atlantic and Mediterranean Sea (**Figure 2**). The polygons were defined in line with spatial definitions currently used for bluefin tuna MSE. Besides, all fish were categorised as juvenile or adult, assuming, for the purpose of this exercise only, adults those fish that measure and/or weight above 115 cm and 30 kg, respectively. The same maturity category was assigned to each value of temperature and depth. Referring to depth of thermocline, the value was taken from spreadsheet on mixed layer, considering daily maximum only. Therefore, series of depth values were considered as “below thermocline” or “above thermocline”. As for the values of time on depth and time on temperature, only the histograms that have same definition of bins were considered and the amount of time at certain depth/time was calculated by summing values of appropriate bins.

It has to be stressed that each tag datasets were individually examined in order to detect the probable moment when the tag detached or fish died. The records that were taken when the tag presumably was not attached to the fish or the fish was not actively swimming were not taken into account in these analyses.

Subsequently, 6 types of analyses were made, 4 including temperature and 2 including depth values, as follows:

1. Diel diving behaviour
2. Percentage of time spent above and below thermocline
3. Depth preferences
4. Percentage of time spent on surface above 10 meter depth
5. Temperature preferences
6. Percentage of time spent on temperatures above 21ºC

For analysing diel diving behaviour, the data from depth series were used, of all tags pulled together. The values of depth were grouped by the hour category and individual means were calculated for each group. Thereafter, they were additionally grouped by maturity class, month and area. Mean depths were also determined in relation to month and for that purpose depth series were also used. Analysis of the percentage of time spent above and below thermocline was made using the mixed layer dataset, using the already provided values for the depth of mixed layer and the percentage of time spent within. The data were grouped by month, area and maturity class and individual mean of percentage of time was calculated for each combination. Additionally, the values of the thermocline depth were combined with depth series dataset in order to categorise each depth value as below or above thermocline. These data were grouped by hour and for each group the percentage of time spent below or above thermocline was computed. For the analysis of percentage of time spent on surface above 10 meters depth the histogram datasets with time on depth were used. The means were calculated per each month, by area and maturity class. Mean temperature by month was calculated using the temperature series, with additional grouping according to area and maturity class. As for the percentage of time spent on temperatures above 21ºC, histograms dataset with time on temperature was used and monthly means were computed. The results of the analyses were represented by barplots, where each vertical bar represents the individual mean of the particular category. To differentiate between the different maturity classes, the bars were coloured respectively.

All analyses were done in R, using “ggplot2” and other packages from “tidyverse”.

3. Results

3.1 Diel diving behaviour

The results of analysis are shown on **Figures 3-11**. They show marked diel behaviour in a way that bluefin tuna spend more time close to surface during the night, while they dive deeper as sunlight intensity increases (around noon). It seems that both adults and juveniles follow the same pattern, although adults dive somewhat deeper. This behaviour seems to be present throughout the year, although it seems to be more pronounced during the colder part of the year and in deeper areas (Atlantic).

3.2 Percentage of time spent above and below thermocline

The plots corresponding to this analysis are given as **Figures 12-15.** There doesn’t seem to be any marked pattern in diving behaviour throughout the year in correspondence to the depth of the thermocline, although it seems that during the hotter part of the year bluefin tuna spend less time in mixed layer, but this effect is probably due to the fact that thermocline is formed closer to the surface. It also has to be taken into consideration that the values of mixed layer depth are taken directly as provided by the tag producer and it is not clear neither how they were calculated nor how reliable they are. Monthly mean thermocline values for each area, along with daily diving means area shown on **Figure 11**.

3.3 Depth preferences

The results of depth preferences in relation to the month are shown on **Figures 16-19**. As concerns this analysis, there doesn't seem to be any pronounced diving pattern, although in average bluefin tuna spends more time closer to the surface during the hotter part of the year. The mean depth juveniles were found was 22.8m, while adults dive deeper and they were found on mean depth of 34.8m. The maximum recorded dives were 1071m for an adult and 785m for a juvenile bluefin tuna. The range of vertical movements per month by area and maturity category is shown on **Figure 20**. Percentage of time spent on each depth category is shown on **Figure 21**.

3.4 Percentage of time spent on surface above 10 meter depth

Considering only the upper layer of the water column from 10 m depth up to the surface, the existence of a specific diving pattern is more obvious. There is a clear pattern indicating more time spent in the upper layer during the summer and less in colder seasons. This behaviour is especially accentuated in the adult bluefin tuna in the Mediterranean. In addition, it seems that juveniles spend more time in the upper layer than adults. The results are shown on **Figures 22-25**.

3.5 Temperature preferences

The results of analysis of temperature in relation to month (**Figures 26-28**) show that the mean temperatures of water column in which bluefin tuna moves are more or less stable throughout the year and follow the seasonal temperature fluctuations. It was again demonstrated that the range of temperatures this species supports is huge. Adults were found on temperatures from -1 to 30.4ºC and juveniles from 11.4 to 29ºC, while the mean temperature for adults was 18.7 and for juveniles 21.6ºC. Minimum, mean and maximum temperatures per month, by area and maturity category are shown on **Figure 29**. Percentage of time spent on each temperature category is shown on **Figure 30**.

3.6 Percentage of time spent on temperatures above 21ºC

The results of analyses, which are shown on **Figures 31-34**, demonstrate the occurrence of bluefin tuna on temperatures above 21ºC not only in the Mediterranean Sea, but also in Atlantic Ocean, especially in Southern part. While in Southern Atlantic bluefin spends in water hotter than 21ºC around 50% of its time during August and September, in the Mediterranean Sea it spends more than 50% of its time on the same temperature from June all the way to September, with peak of 80% in July. Juveniles seem to spend even more time on these temperatures than adults, probably because they don't dive as deep as adults.

4. Discussion

One of the aims of performing this preliminary analysis was demonstrating the benefits of having the electronic tags data stored in a relational database in advance of carrying out any analysis. Data preparation is a tedious and a time consuming and usually takes more effort than the analysis itself. Having all data already cleaned, formatted and stored in an adequate database facilitates any subsequent analysis. Since no effort needs to be put into previous preparation of data, any further analysis becomes more accessible as it is a straightforward process.

Electronic tag data deployed by GBYP are currently stored in a repository on the ICCAT Secretariat Server, but the formal database hasn't been created yet. In 2017 GBYP created PostgreSQL database, but it is kept only on the personal computer and cannot be remotely accessed. The possibility of the integration of the database within the ICCAT Secretariat has already been discussed, but it has to be further evaluated.

References

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Table 1. Number of tags deployed by GBYP up to 2017, by area and year. Tags deployed on juvenile bluefin are indicated in red, while those deployed on adult are indicated in black. Totals are bold.

Deployment Area/Year	2011	2012	2013	2015	2016	2017	Total	Grand total
SKAGERRAK						18	**18**	**18**
BAY_OF_BISCAY		14	7				**21**	**21**
PORTUGAL					24	40	**64**	**64**
MOROCCO	8	24	14	20	14		**80**	**80**
GIBRALTAR		10/11	2/4				**12/15**	**27**
GULF_OF_LION	1	5					**5/1**	**6**
SARDINIA				3/25	5/15		**8/40**	**48**
TYRRHENIAN_SEA				1/4			**1/4**	**5**
MESSINA_STRAIT					15		**15**	**15**
ADRIATIC_SEA			7				**7**	**7**
LEVANTINE_SEA				30	19		**49**	**49**
Total	**9**	**29/35**	**16/18**	**4/79**	**5/87**	**58**	**54/286**	
Grand total	**9**	**64**	**34**	**83**	**92**	**58**		**340**

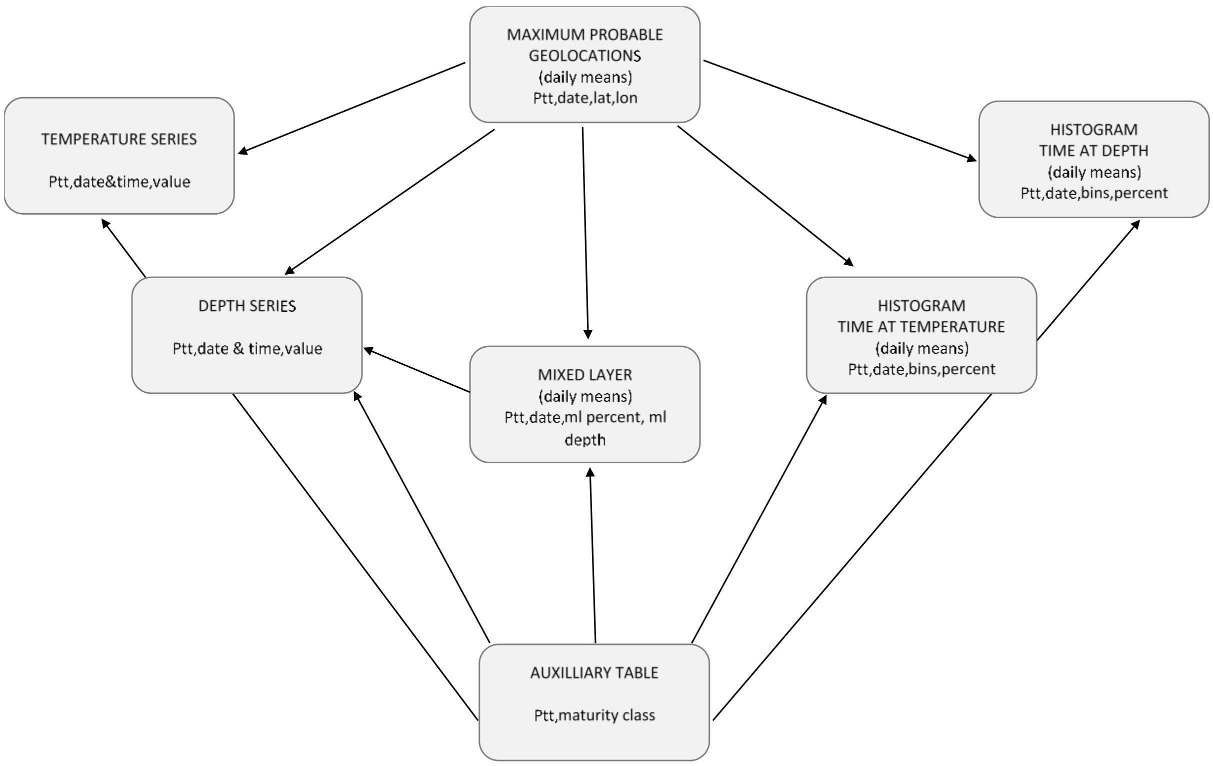

Figure 1. Scheme of different electronic tag datasets used for the analyses with the key information provided by each.

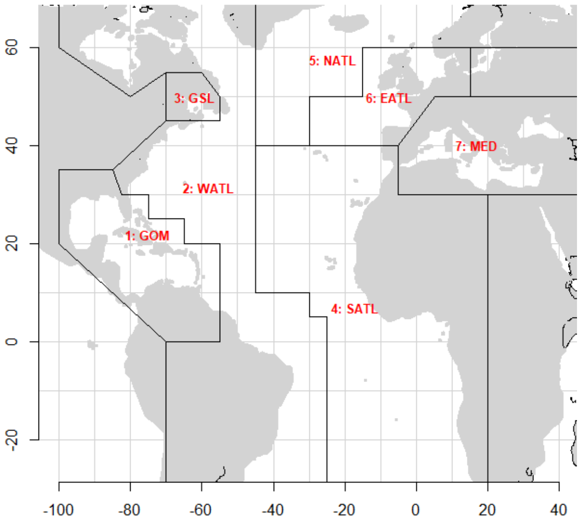

Figure 2. Seven spatial areas used for the analysis, defined in line with current bluefin tuna MSE practice.

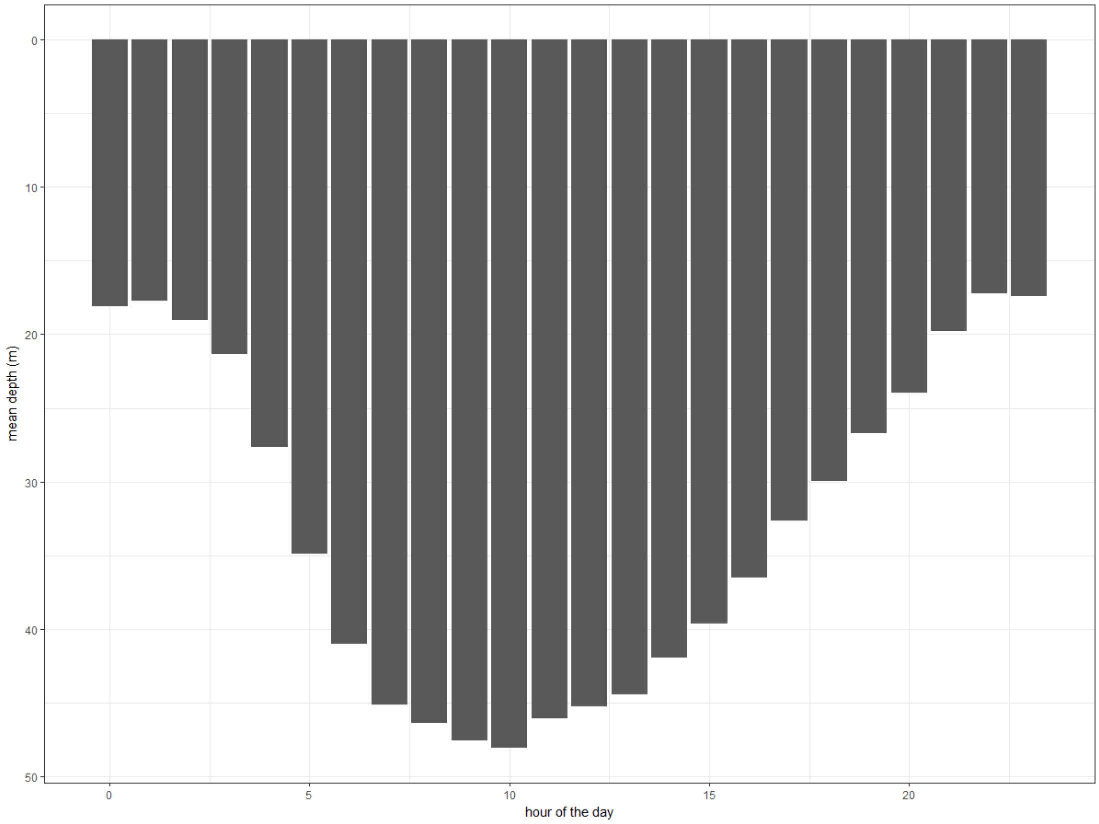

Figure 3. Mean depth per hour of the day.

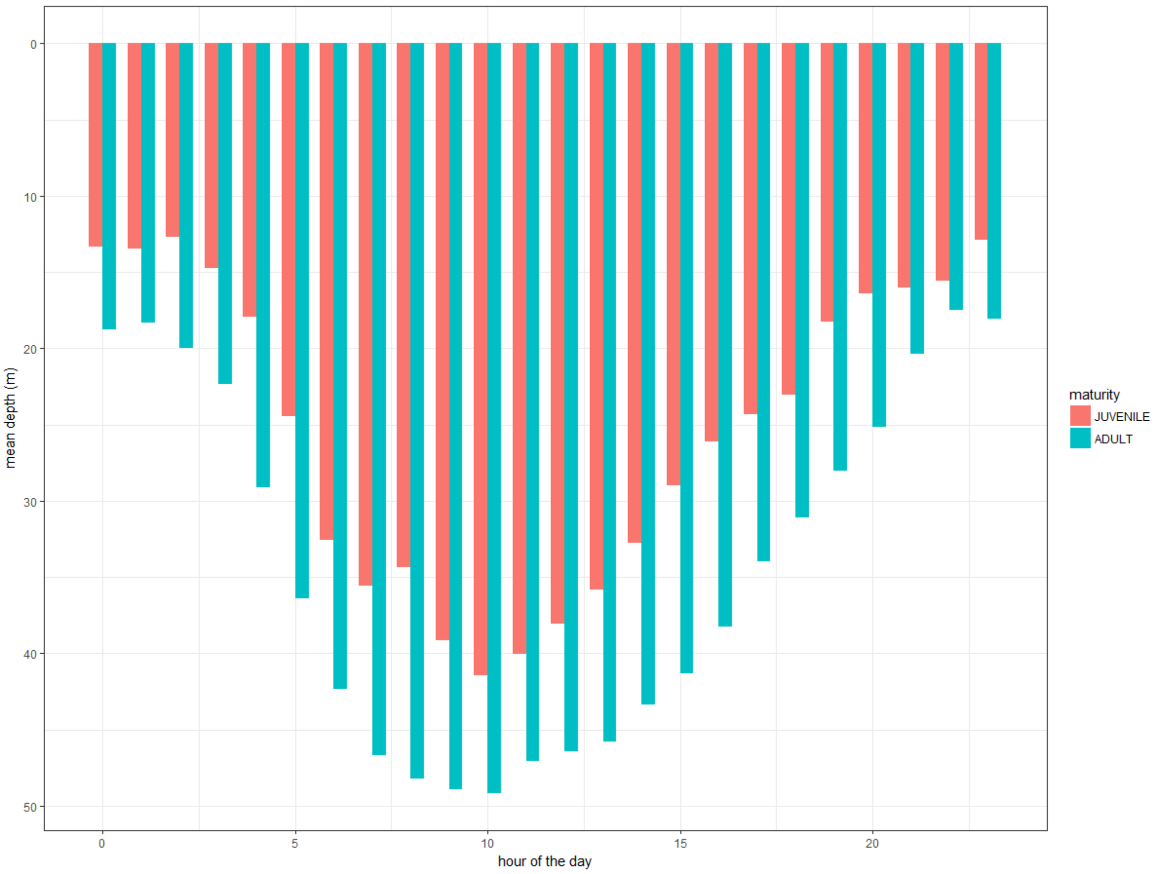

Figure 4. Mean depth per hour of the day, by maturity class.

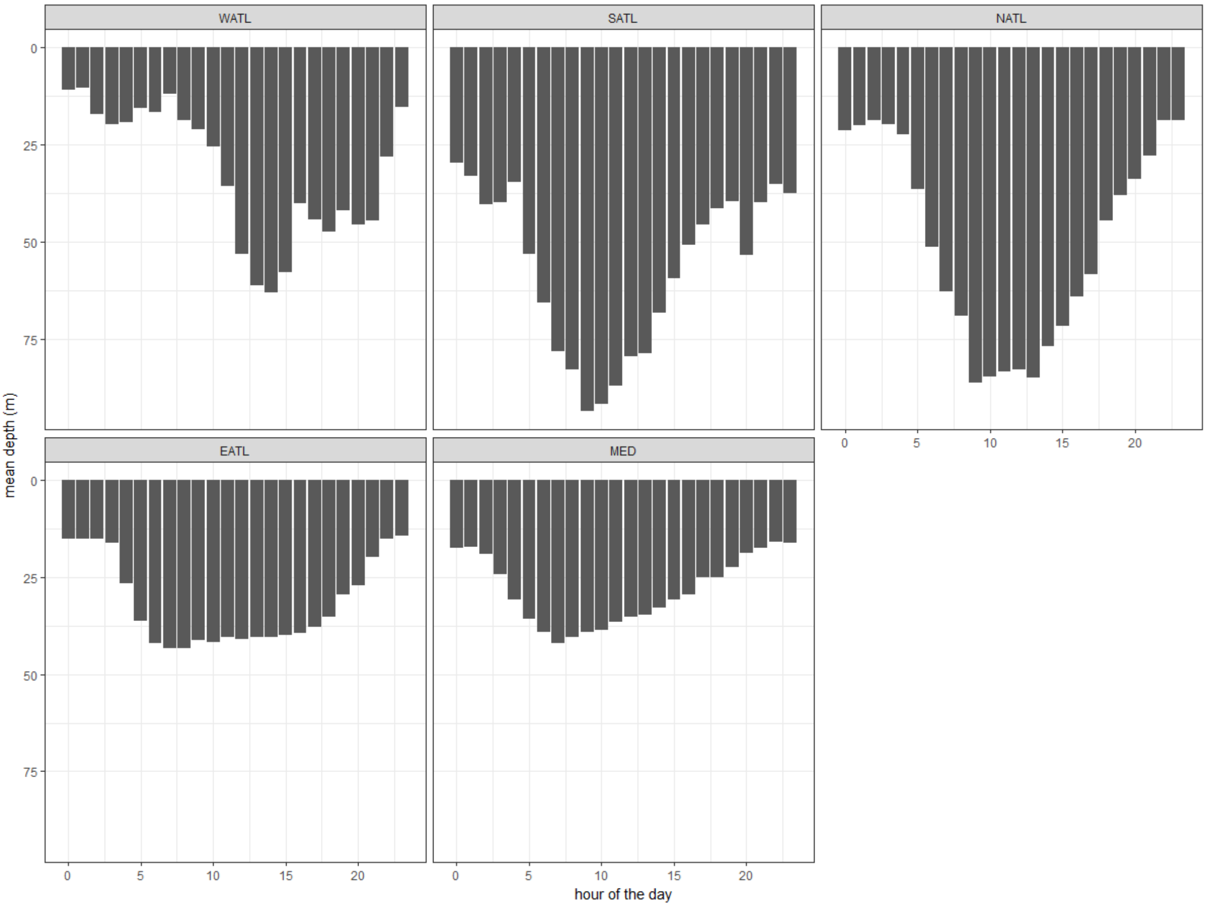

Figure 5. Mean depth per hour of the day, by area.

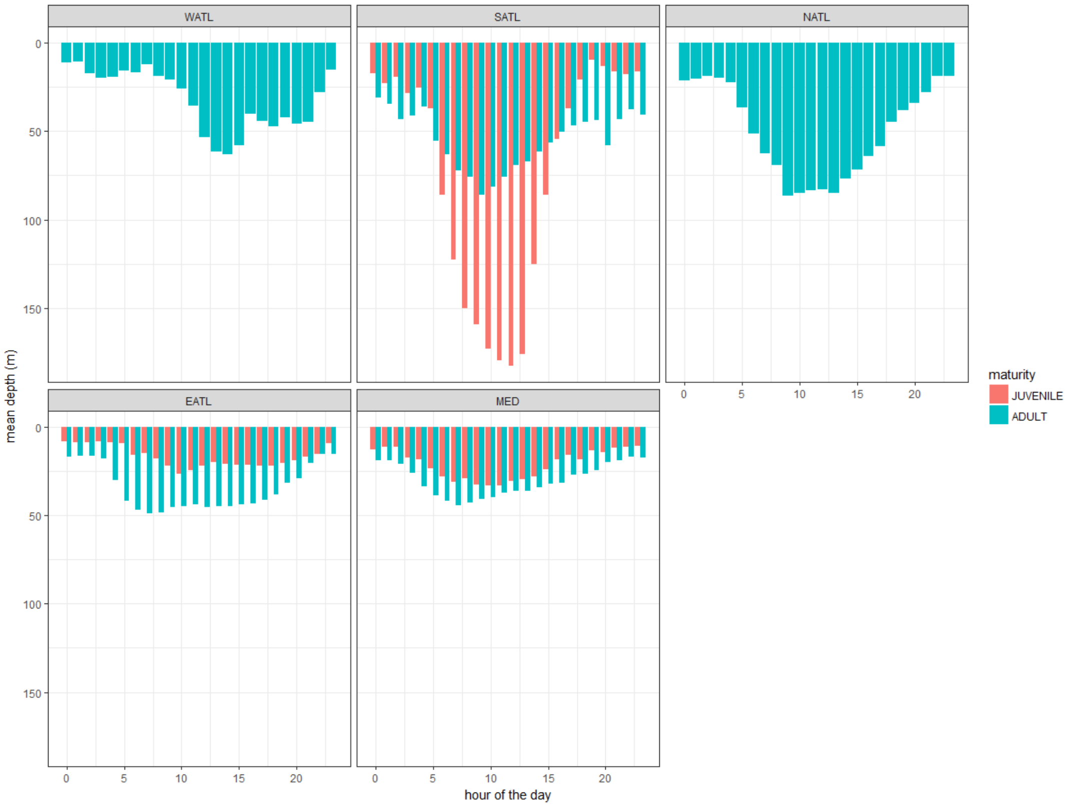

Figure 6. Mean depth per hour of the day, by area and maturity class.

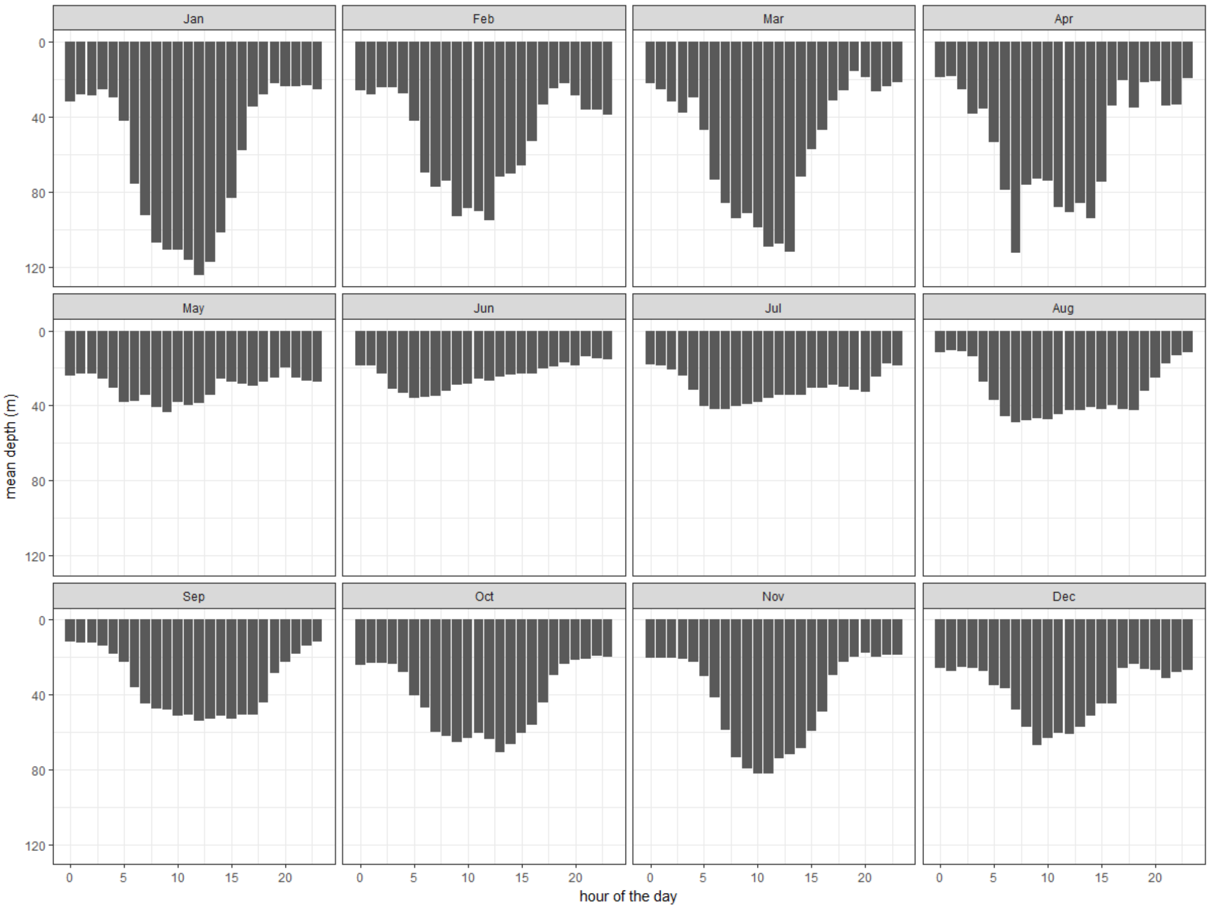

Figure 7. Mean depth per hour of the day, by month.

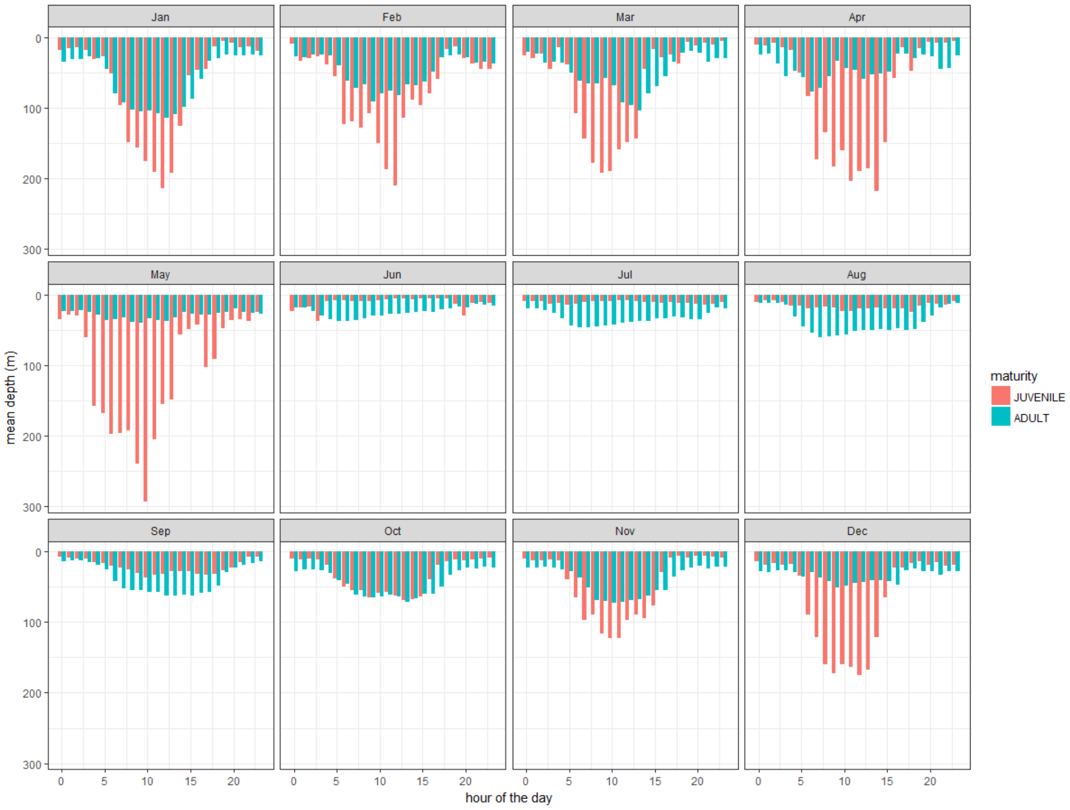

Figure 8. Mean depth per hour of the day, by month and maturity class.

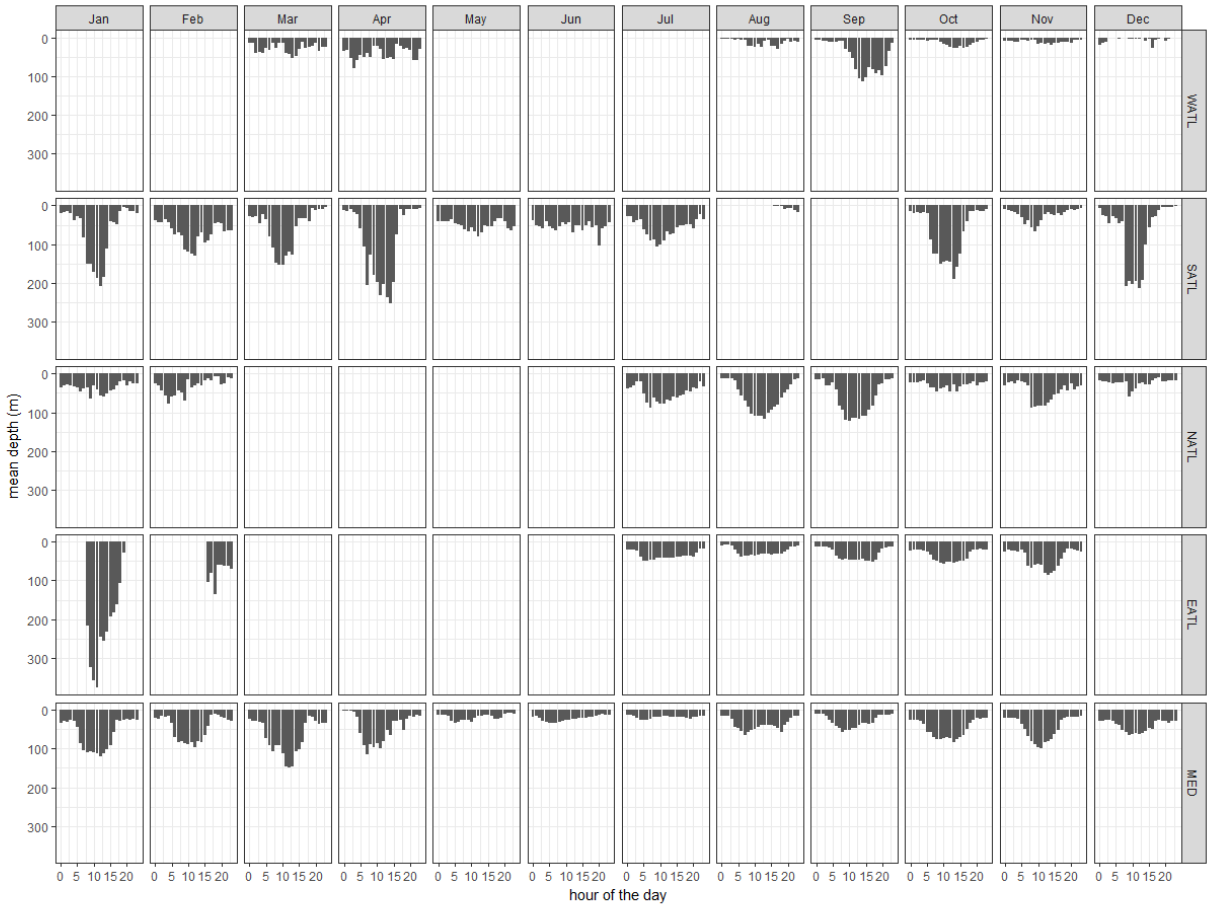

Figure 9. Mean depth per hour of the day, by area and month.

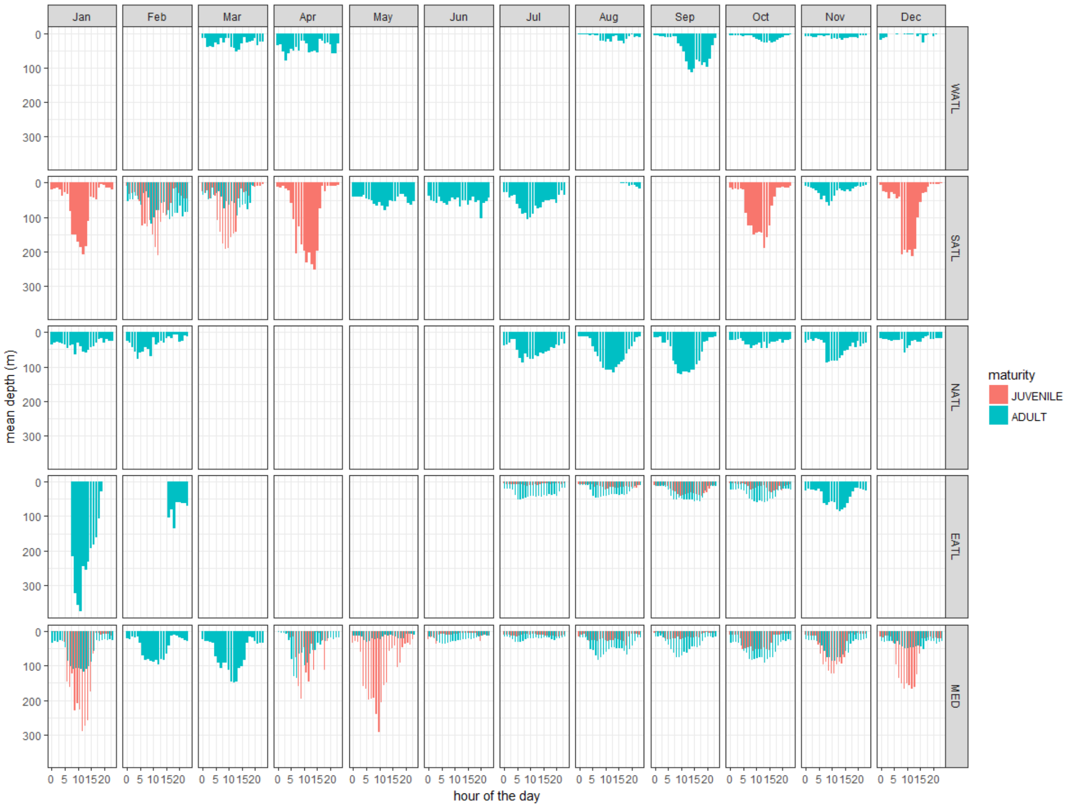

Figure 10. Mean depth per hour of the day, by area, month and maturity class.

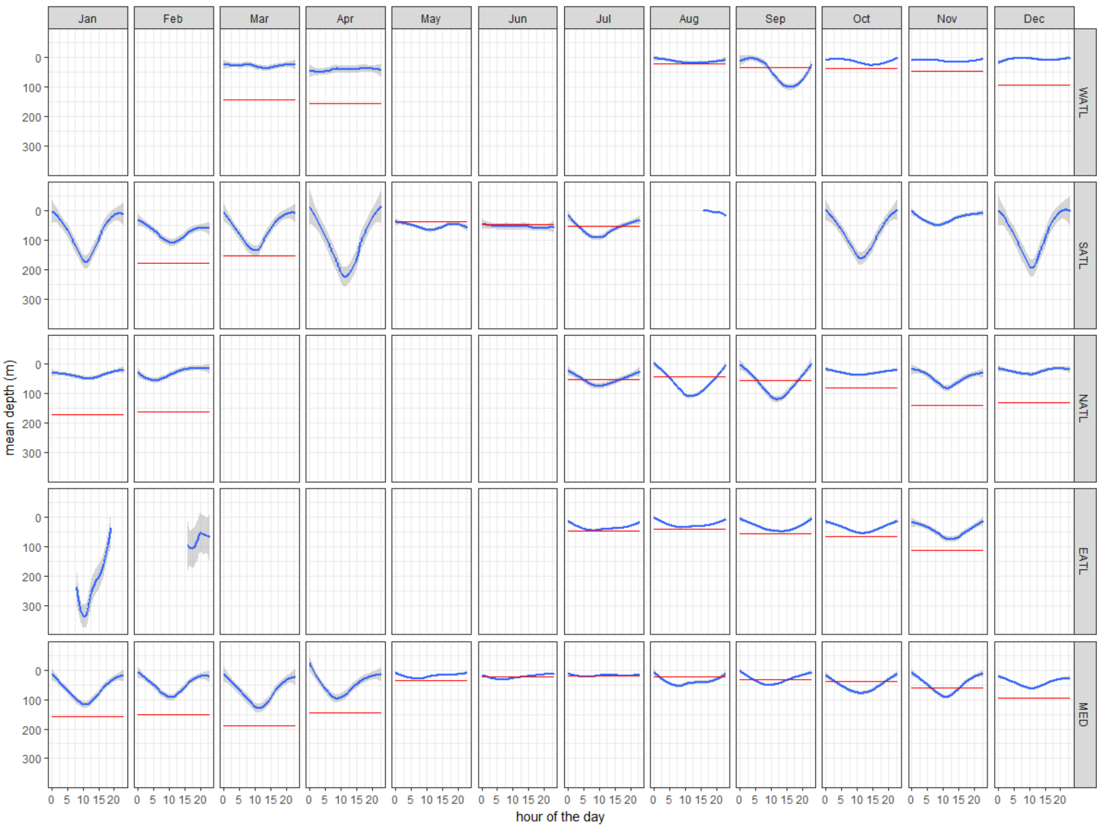

Figure 11. Mean depth per hour of the day (blue) with reference to the thermocline depth (in red).

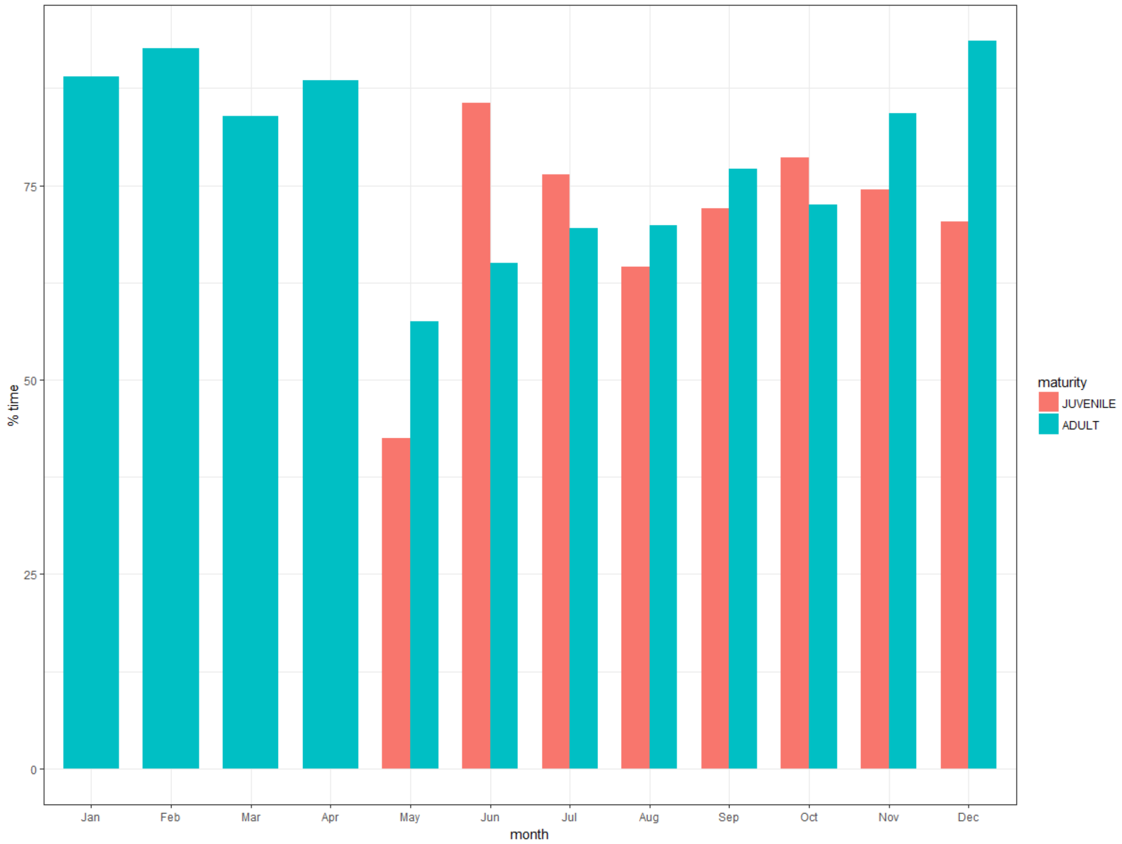

Figure 12. Percentage of time spent in mixed layer per month, by maturity class.

Figure 13. Percentage of time spent in mixed layer per area and month, by maturity class.

Figure 14. Percentage of time spent on depths above and below thermocline per hour of the day, by area and maturity class.

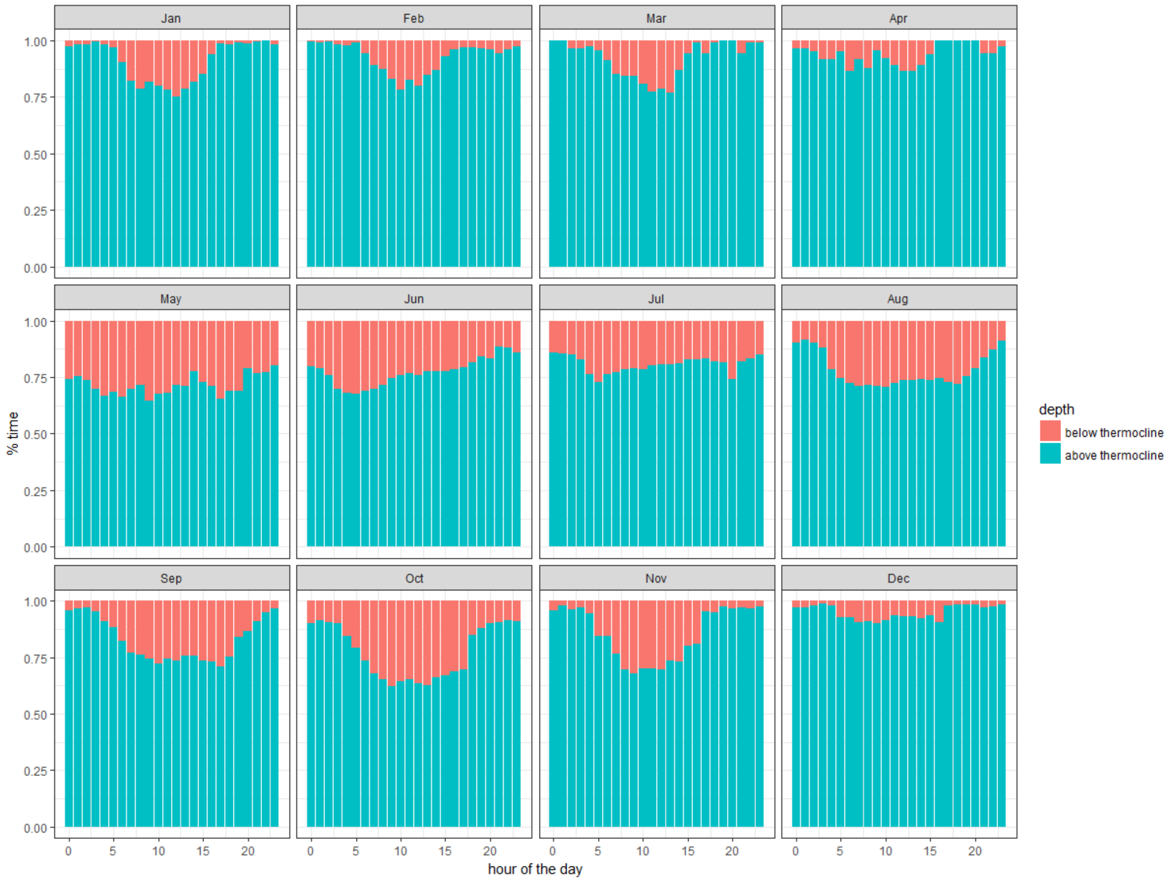

Figure 15. Percentage of time spent on depths above and below thermocline per hour of the day, by month and maturity class.

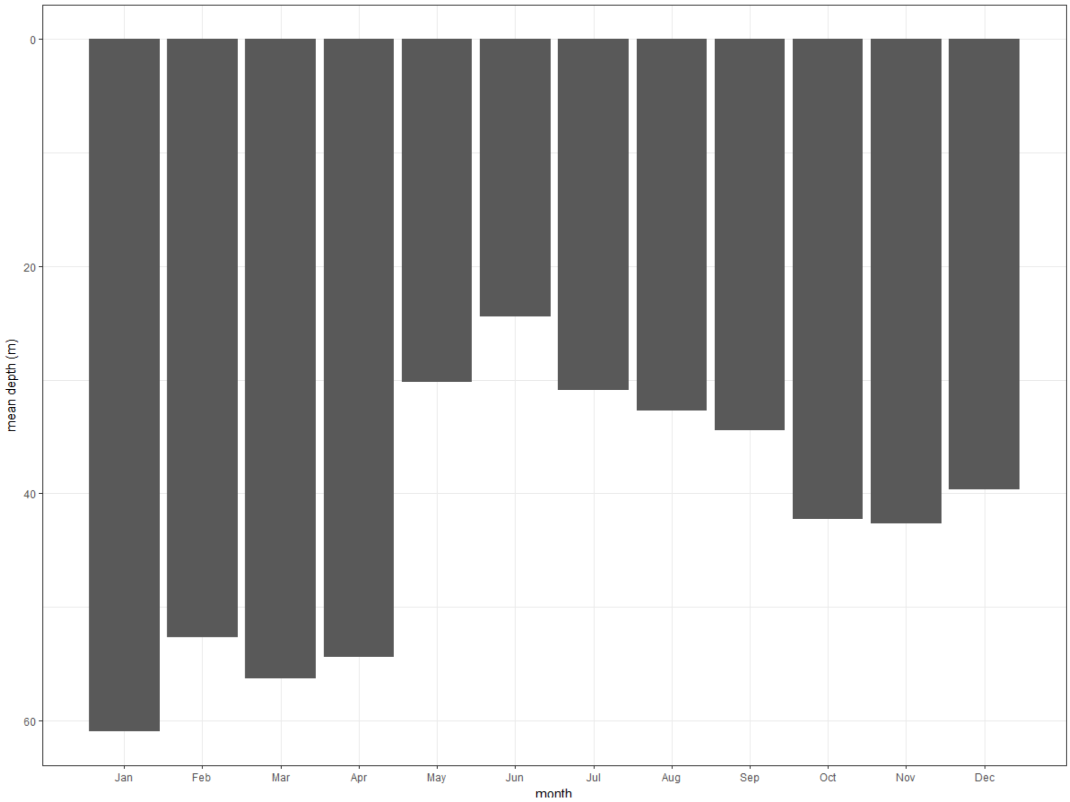

Figure 16. Mean depth per month.

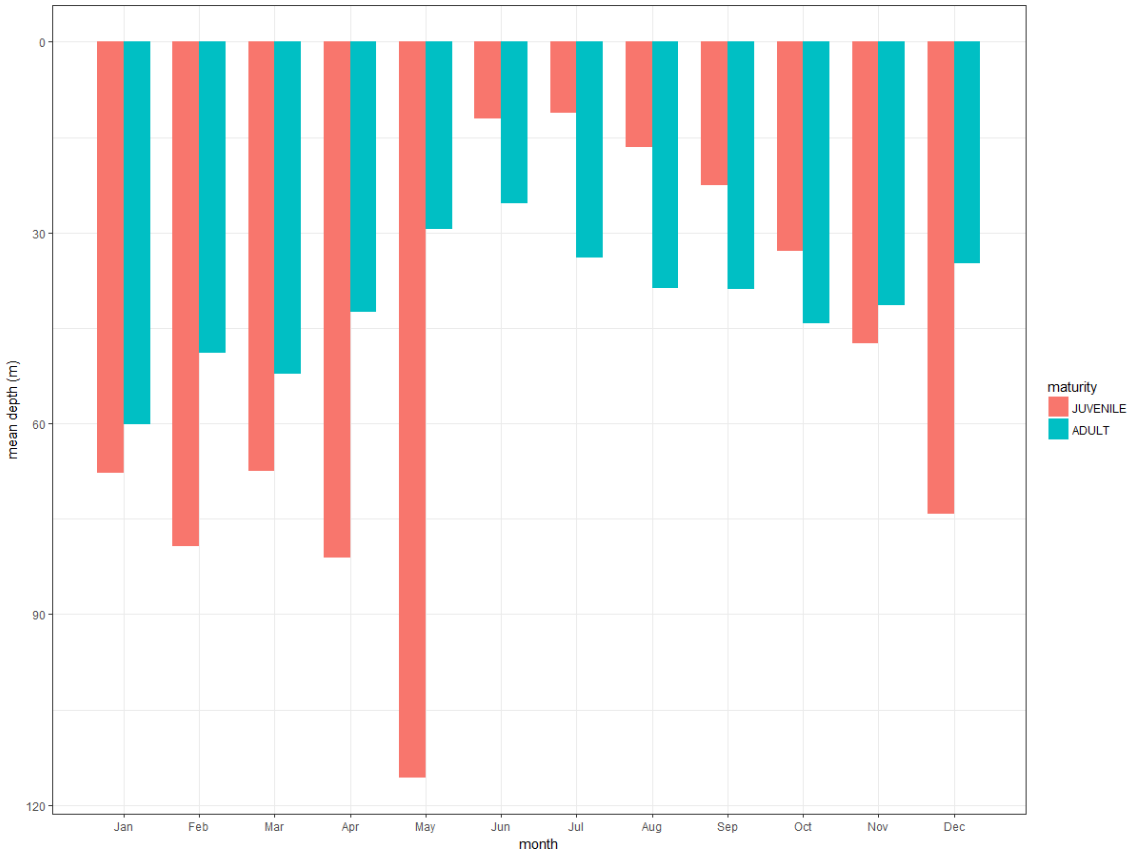

Figure 17. Mean depth per month, by maturity class.

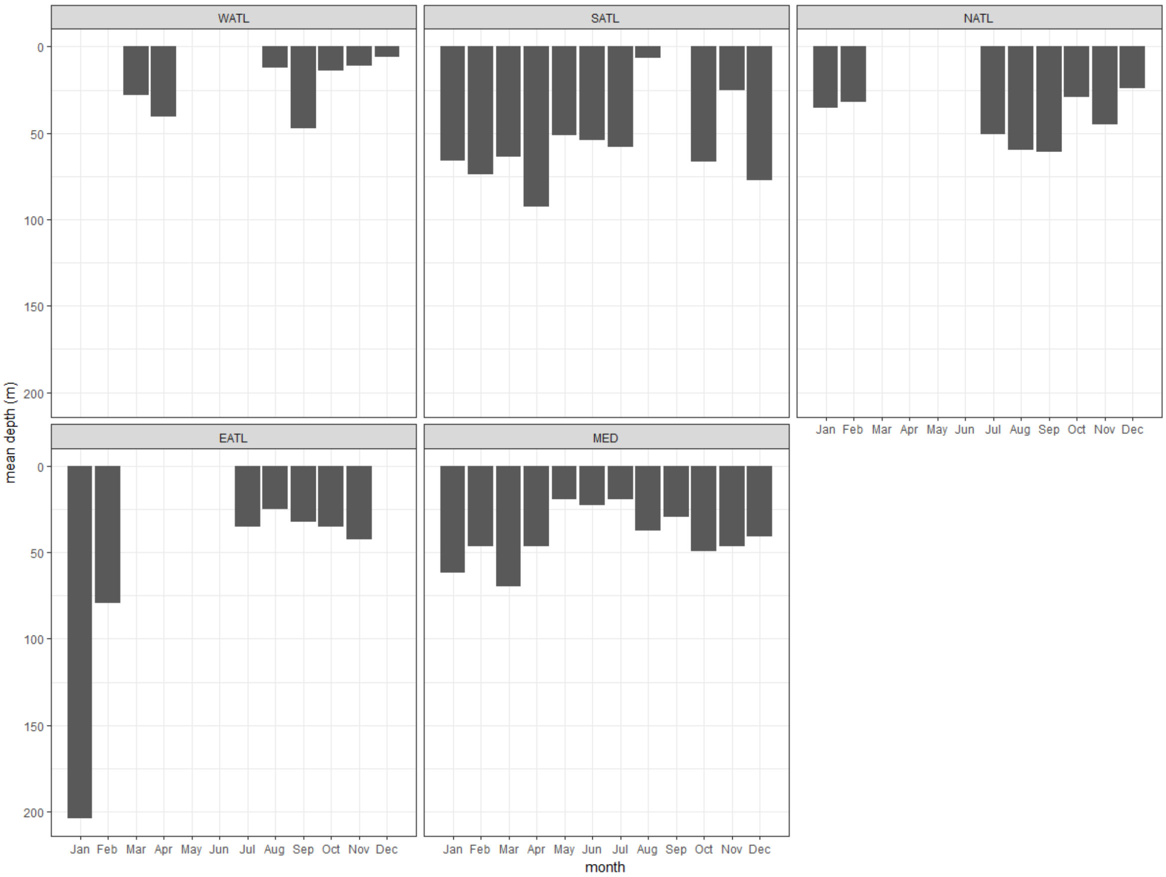

Figure 18. Mean depth per month, by area.

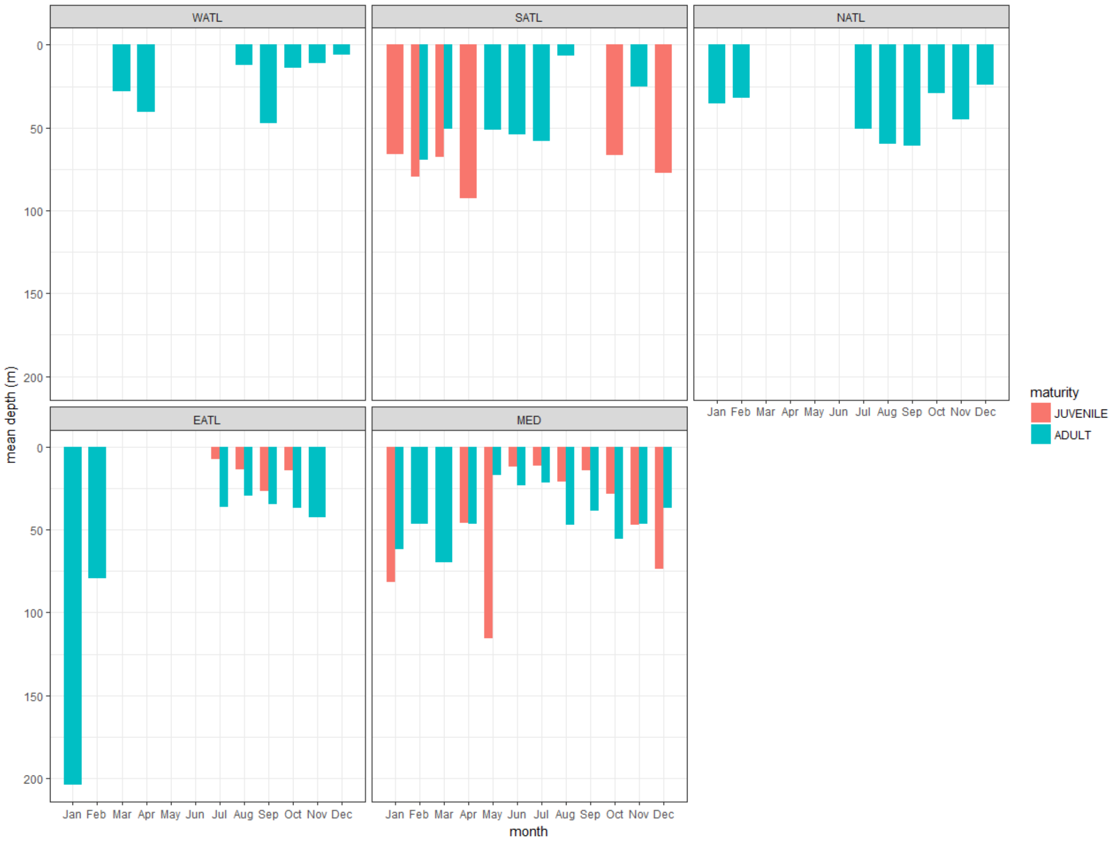

Figure 19. Mean depth per month, by area and maturity class.

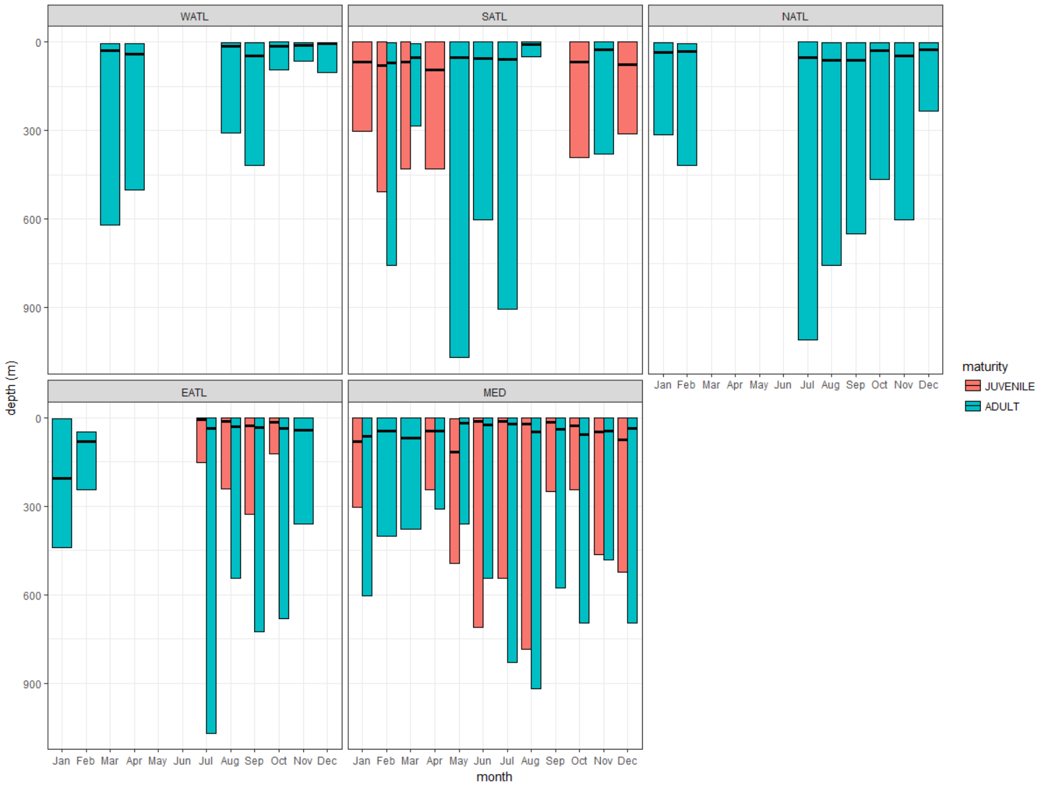

Figure 20. Minimum, mean and maximum depth per month, by area and maturity class.

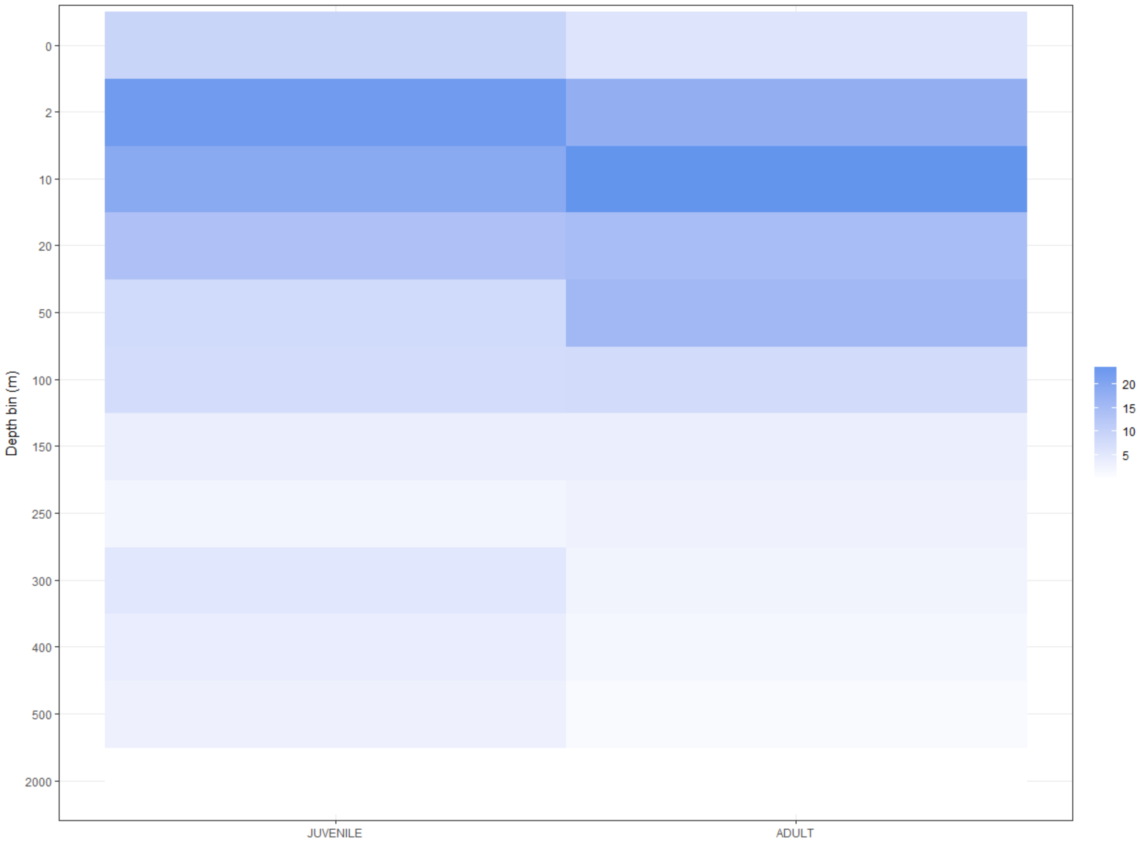

Figure 21. Percentage of time spent on depth category, by maturity class.

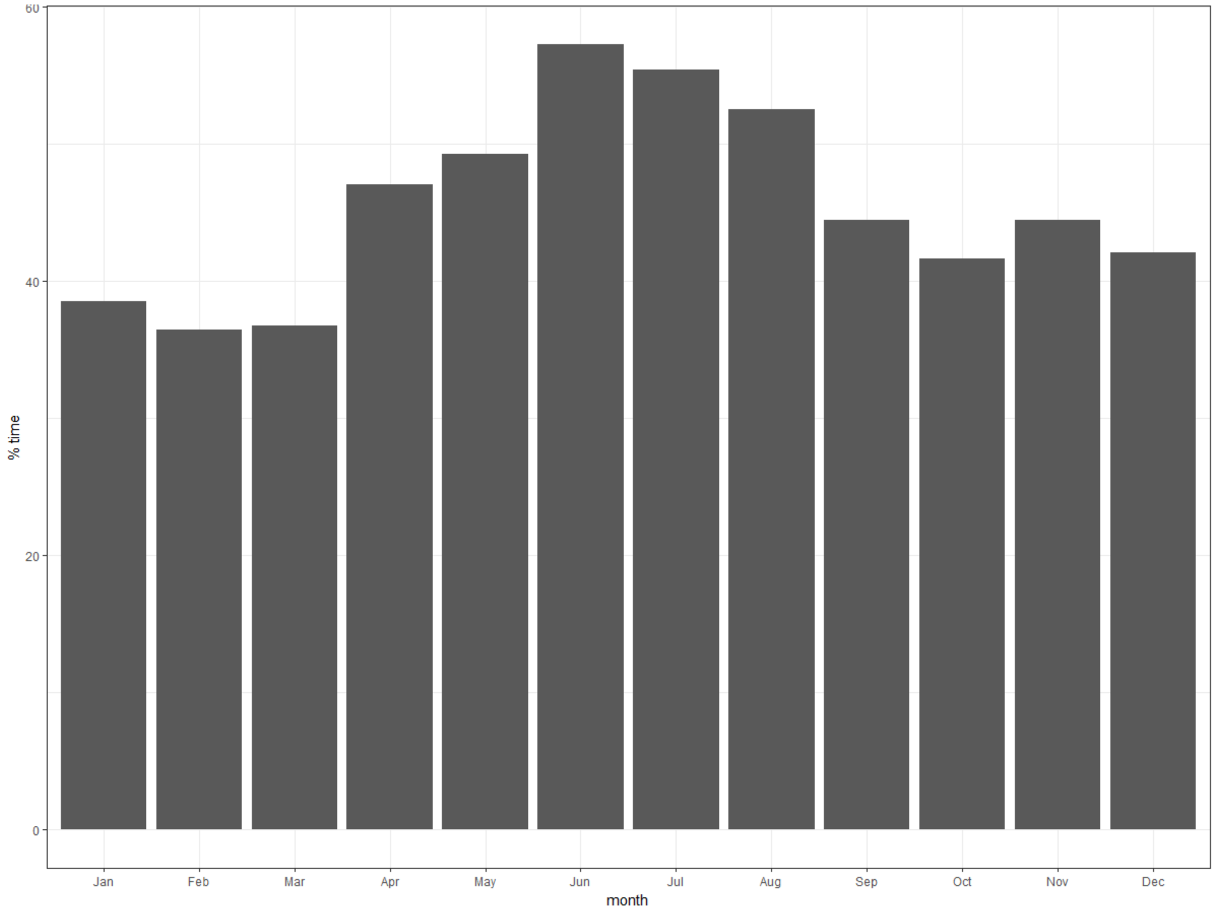

Figure 22. Percentage of time spent on surface above 10m depth per month.

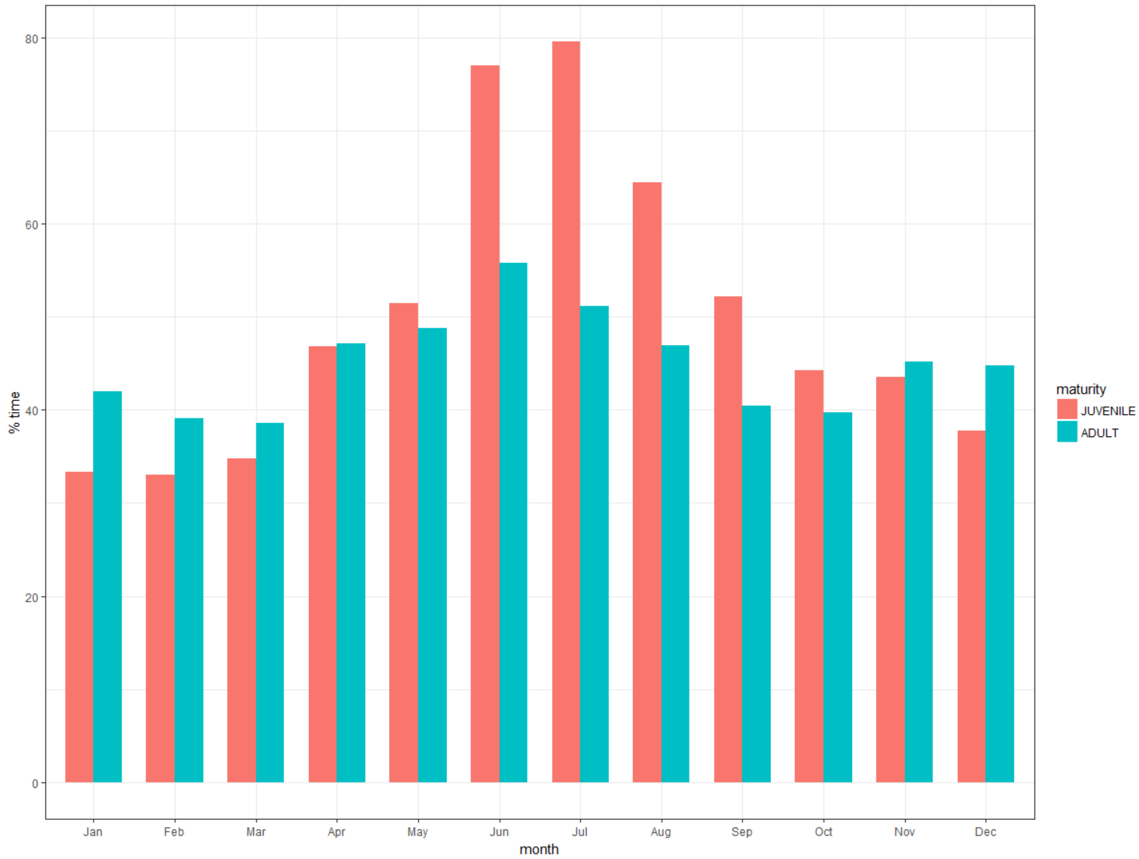

Figure 23. Percentage of time spent on surface above 10m depth per month, by maturity class.

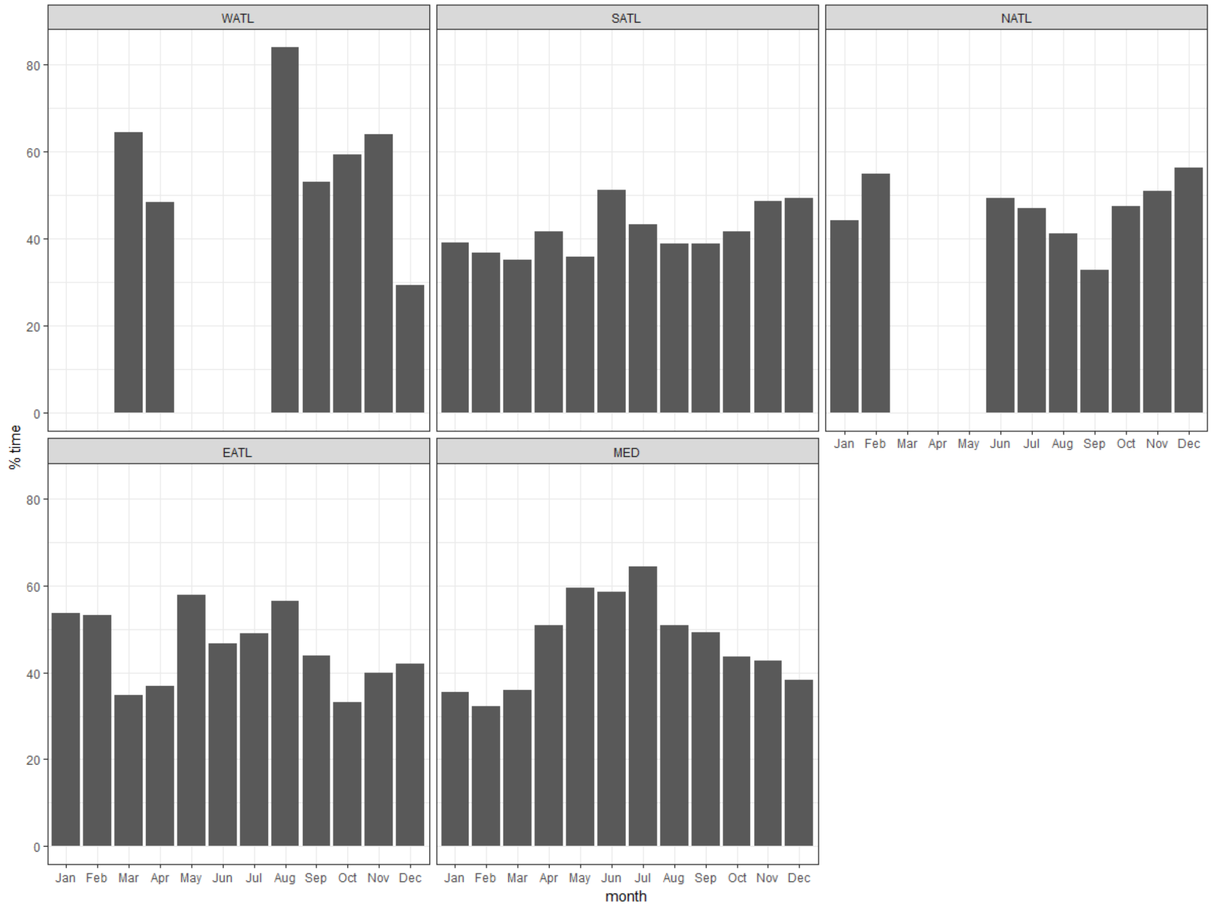

Figure 24. Percentage of time spent on surface above 10m depth per month, by area.

Figure 25. Percentage of time spent on surface above 10m depth per month, by area and maturity class.

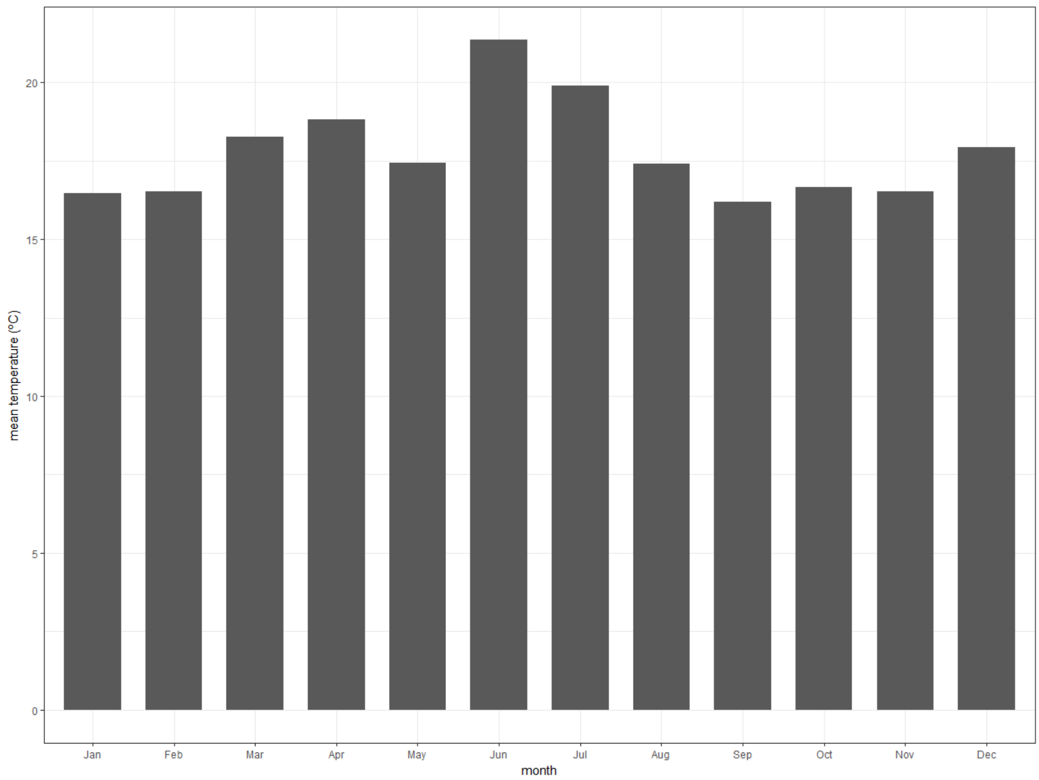

Figure 26. Mean temperature per month.

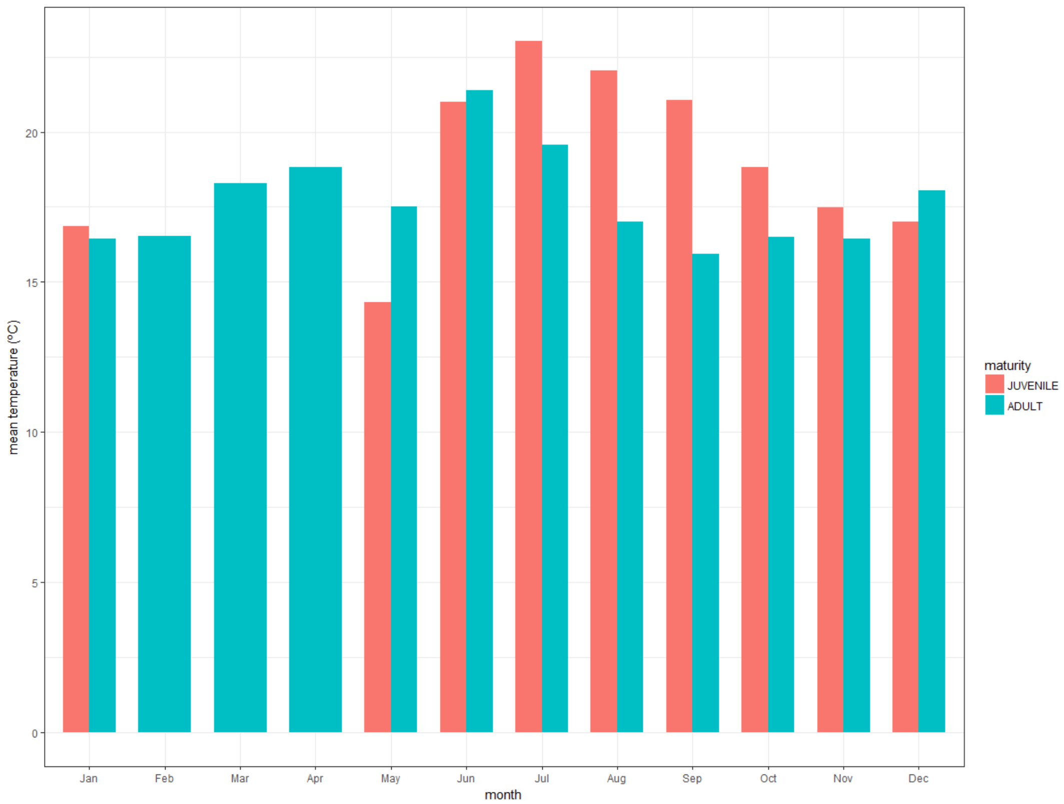

Figure 27. Mean temperature per month, by maturity class.

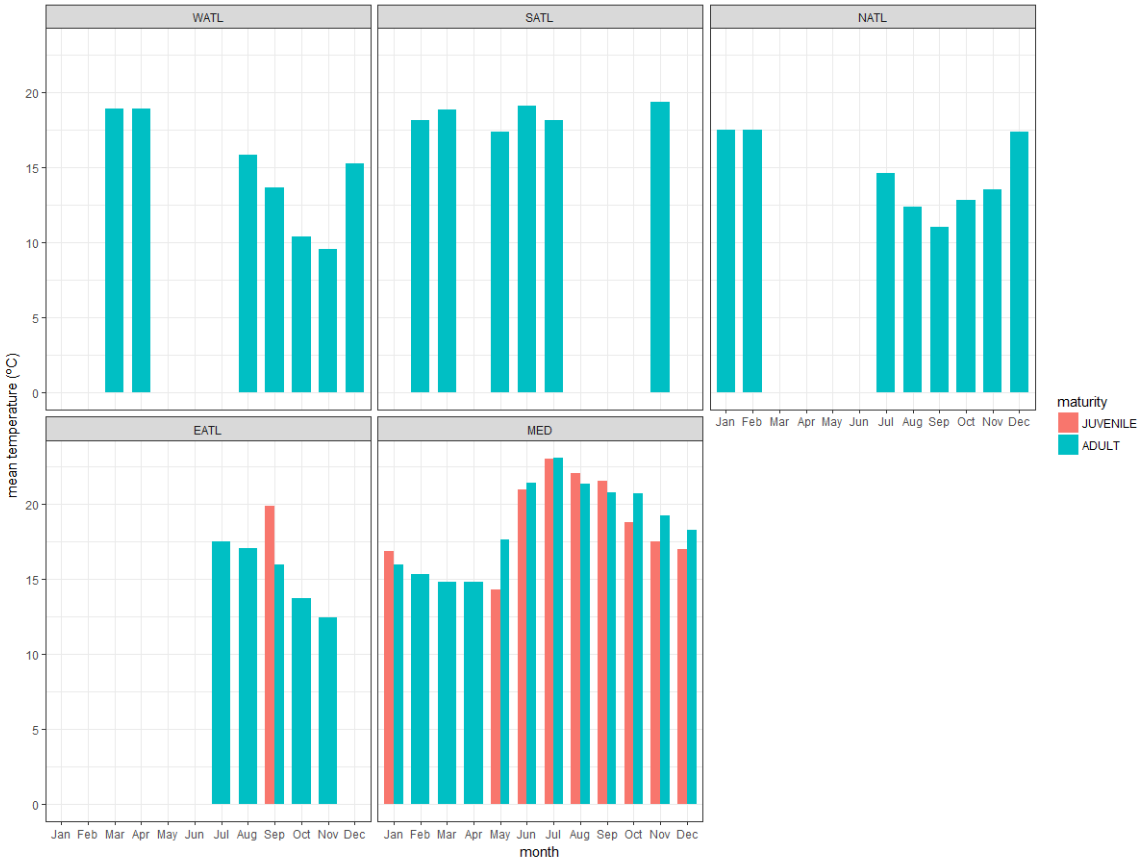

Figure 28. Mean temperature per month, by area and maturity class.

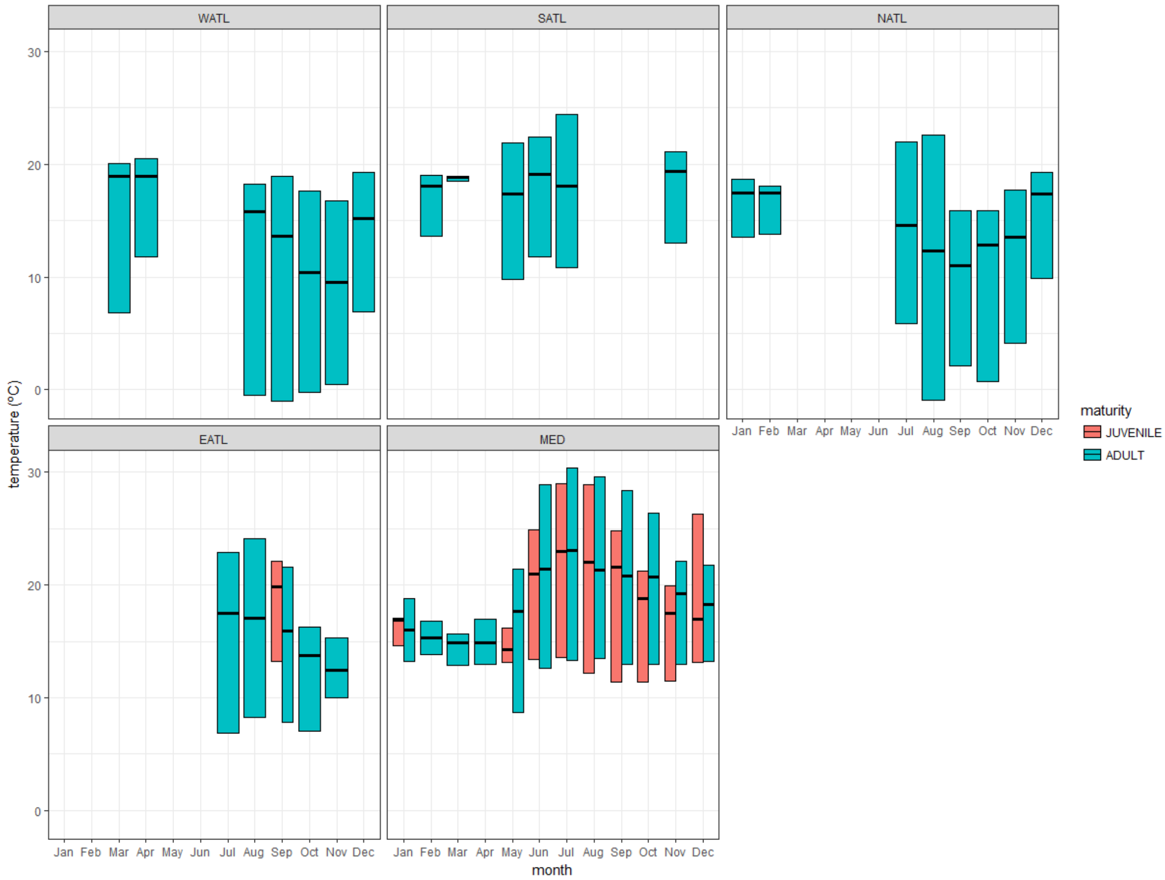

Figure 29. Minimum, mean and maximum temperature per month, by area and maturity class.

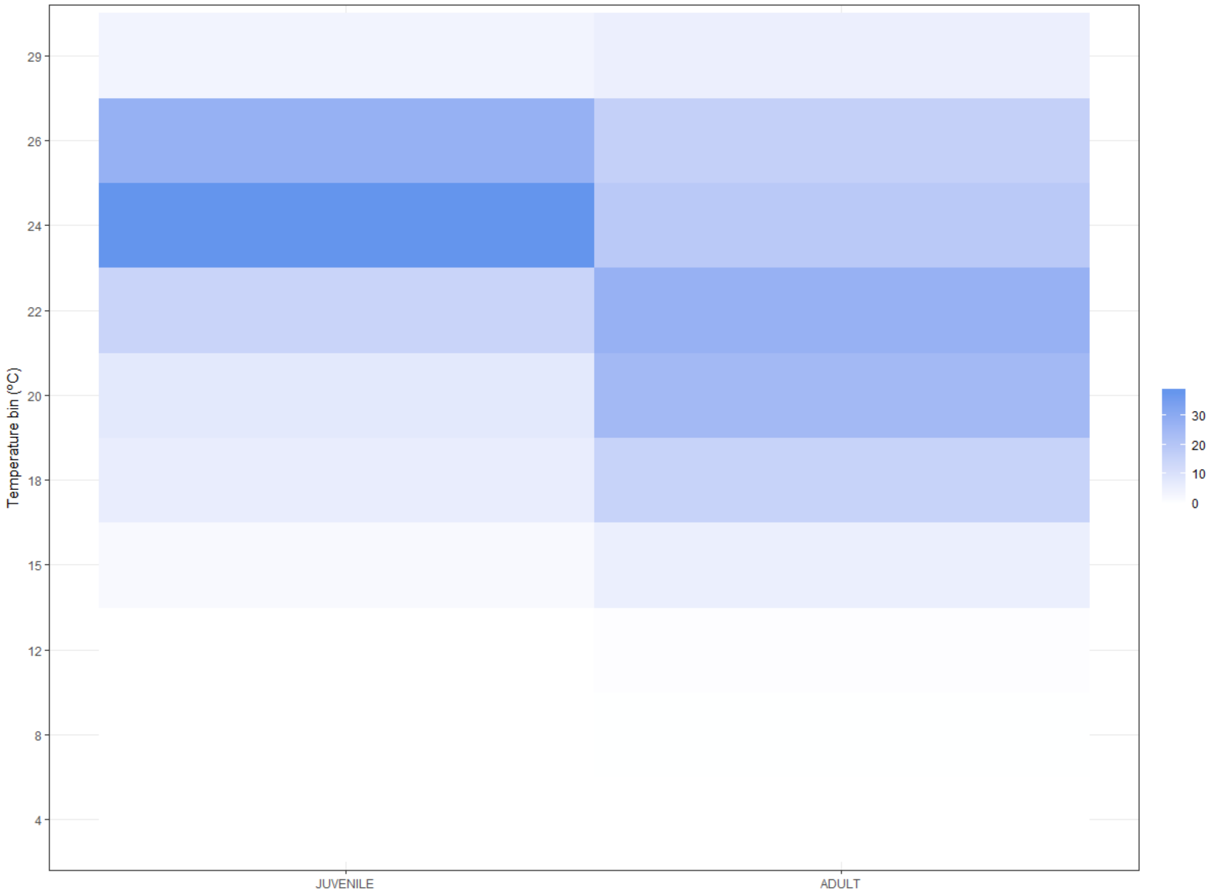

Figure 30. Percentage of time spent on temperature category, by maturity class.

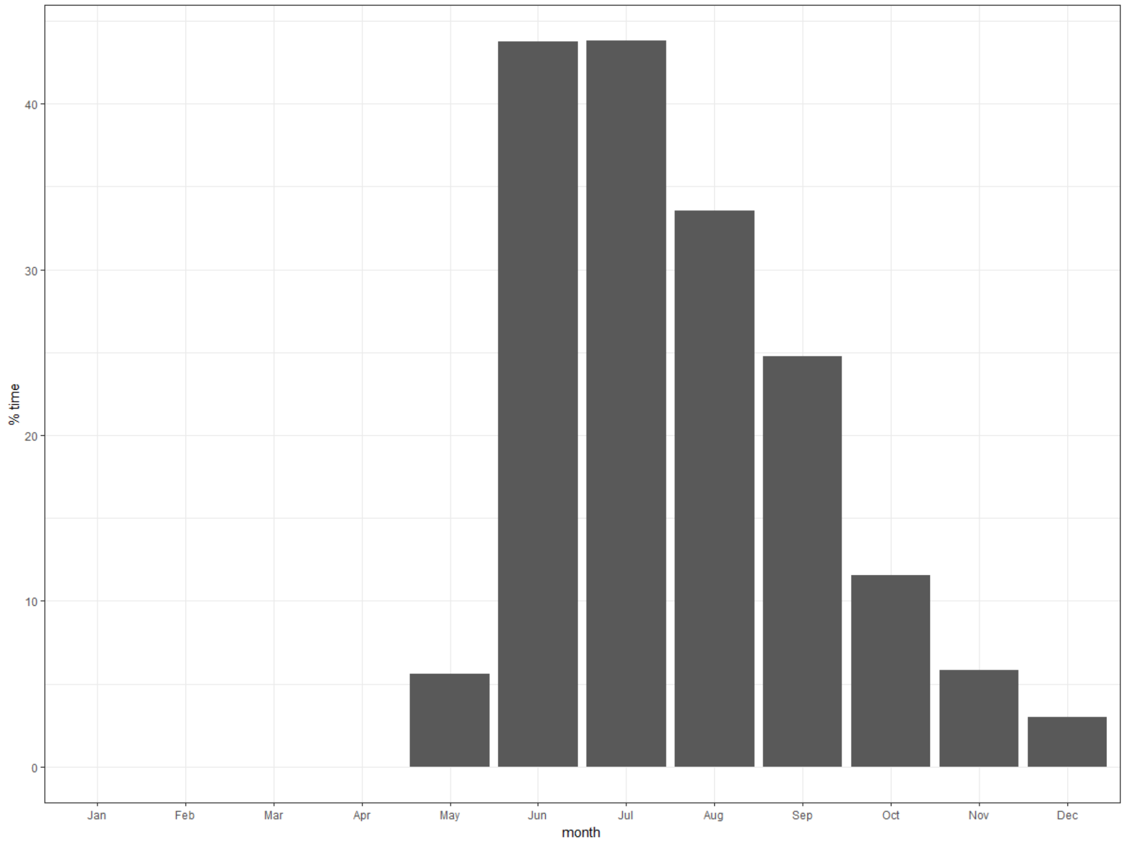

Figure 31. Percentage of time spent on temperatures above 21ºC per month.

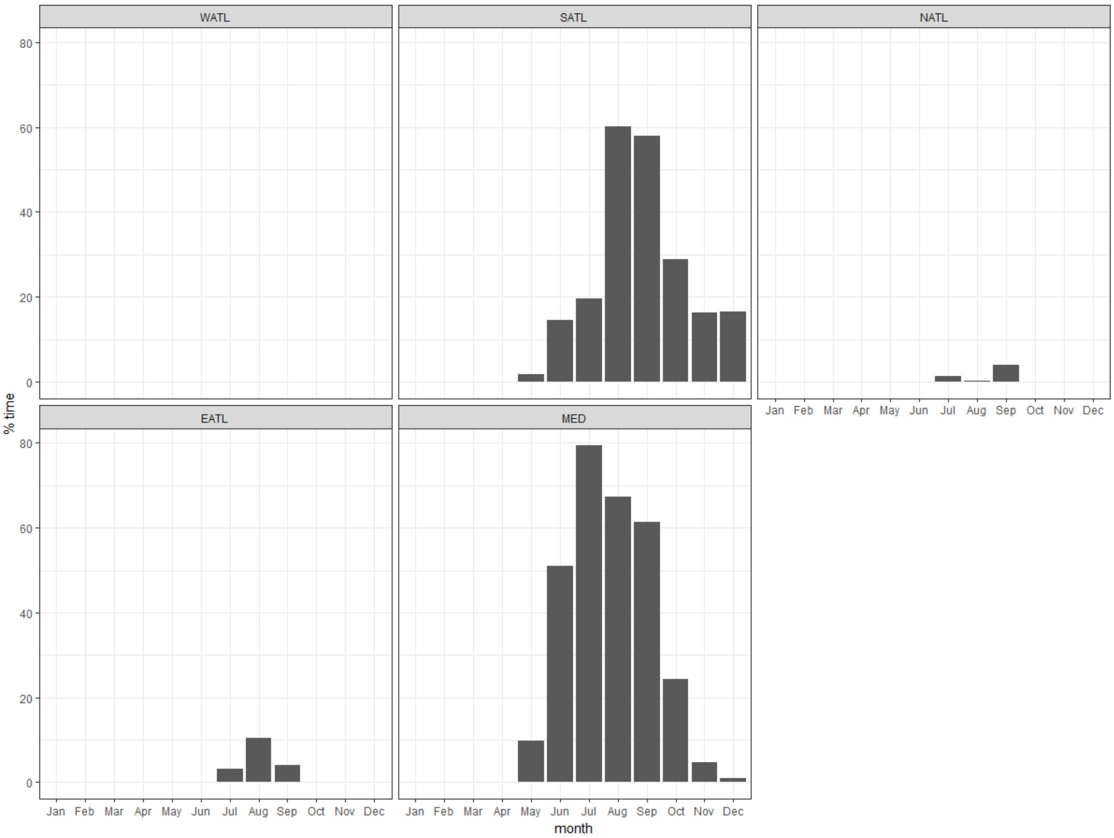

Figure 32. Percentage of time spent on temperatures above 21ºC per month, by area.

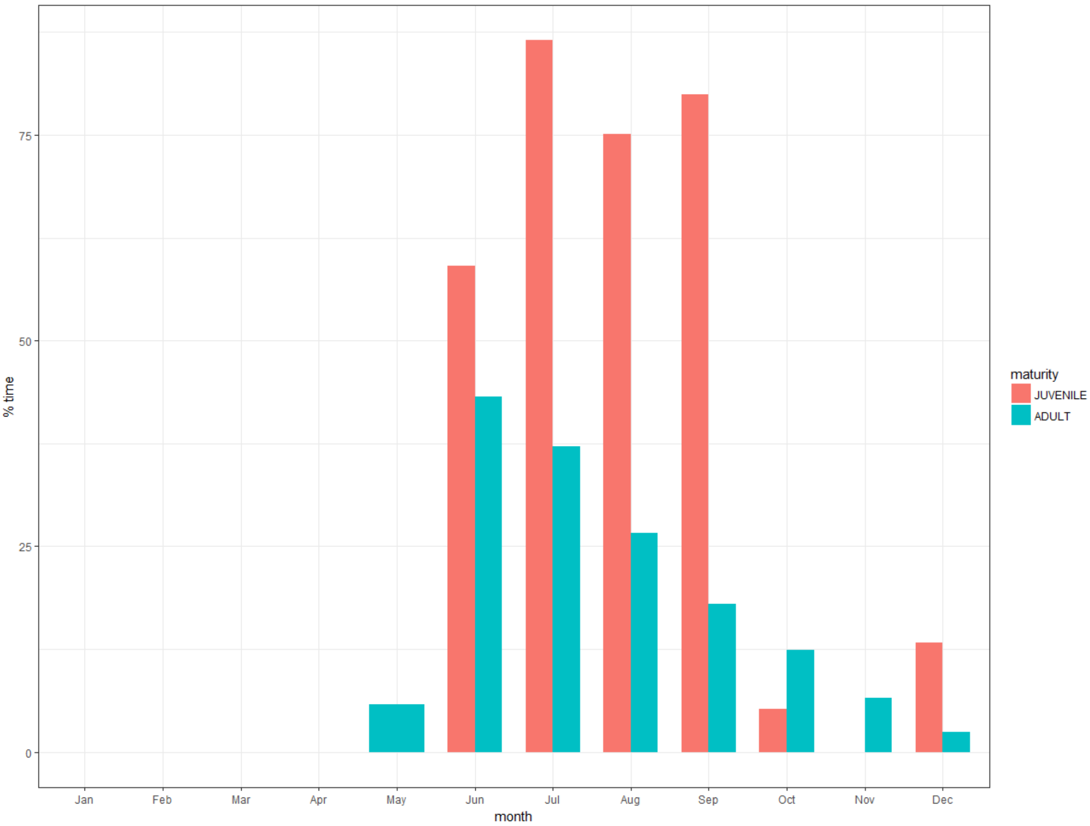

Figure 33. Percentage of time spent on temperatures above 21ºC per month, by maturity class.

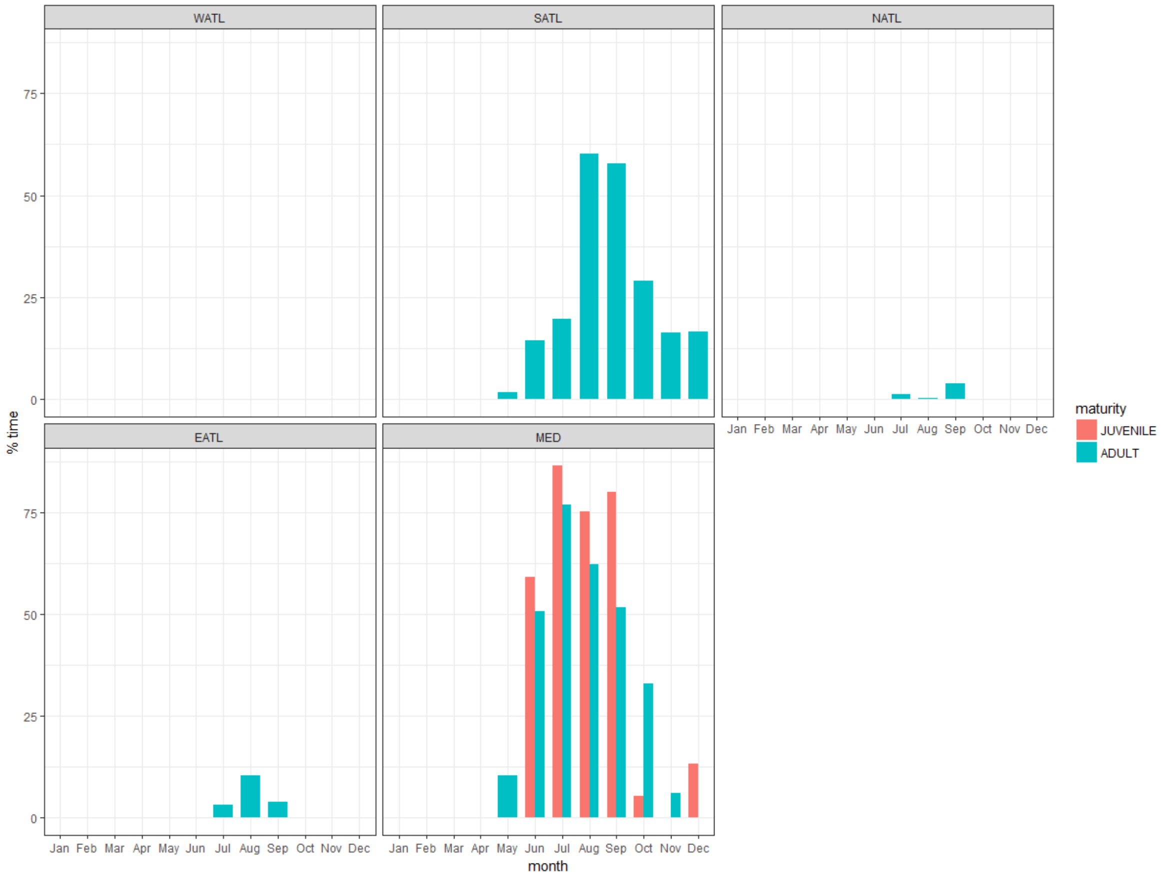

Figure 34. Percentage of time spent on temperatures above 21ºC per month, by area and maturity class.