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A SYSTEMATIC REVIEW OF TROPICAL TUNA PREFERENCES FOR MOVEMENT MODELS

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SUMMARY

The objective of this study was to extract parameter information from multiple sources and quantify parameter uncertainty for model application. Following PRISMA methods, we searched Scopus, reviewed titles and abstracts in AbstrackR, and extracted tropical tuna movement parameters from relevant articles. We quantified parameters and uncertainty for four drivers affecting tuna movement: speed, temperature preferences, oxygen preferences, and associations of tuna with Fish Aggregation Devices (FADs). Bigeye, yellowfin, and skipjack, move at about 1 m/s. Bigeye prefer a wider and colder range of temperatures (14.7°C-23.2°C) than yellowfin (20.3°C-25.5°C) and skipjack (19.3°C-27.9°C). Bigeye dives into less oxygenated waters than yellowfin (1.4 ml/L, 3.1 ml/L), but oxygen information on skipjack is lacking (n=1). The continuous residence time of bigeye and yellowfin on FADs (7.7 days, 6.8 days) is double the residence times of skipjack (2.6 days). All species sense a FAD from 5.4 nautical miles away and take 23.8 days to colonize it. We hope that this systematic review can inform movement models and encourage others to fill gaps in the literature to improve tropical tuna management.

RÉSUMÉ

L'objectif de cette étude était d'extraire les informations sur les paramètres à partir de sources multiples et de quantifier l'incertitude des paramètres pour l'application du modèle. En suivant les méthodes PRISMA, nous avons effectué des recherches dans Scopus, examiné les titres et les résumés dans AbstrackR, et extrait les paramètres de mouvement des thonidés tropicaux des articles pertinents. Nous avons quantifié les paramètres et l'incertitude pour quatre facteurs affectant le mouvement du thon : la vitesse, les préférences en matière de température, les préférences en matière d'oxygène et les associations des thonidés avec les dispositifs de concentration de poissons (DCP). Le thon obèse, l'albacore et le listao se déplacent à environ 1 m/s. Le thon obèse préfère une gamme de températures plus large et plus froide (14,7°C-23,2°C) que l'albacore (20,3°C-25,5°C) et le listao (19,3°C-27,9°C). Le thon obèse plonge dans des eaux moins oxygénées que l'albacore (1,4 ml/L, 3,1 ml/L), mais les informations sur l'oxygène en ce qui concerne le listao font défaut (n=1). Le temps de séjour continu du thon obèse et de l'albacore sur les DCP (7,7 jours, 6,8 jours) est le double du temps de séjour du listao (2,6 jours). Toutes les espèces détectent un DCP à 5,4 miles nautiques de distance et mettent 23,8 jours à le coloniser. Les auteurs espèrent que cet examen systématique pourra alimenter les modèles de mouvement et encourager d'autres personnes à combler les lacunes de la littérature afin d'améliorer la gestion des thonidés tropicaux.

RESUMEN

El objetivo de este estudio era extraer información sobre los parámetros a partir de múltiples fuentes y cuantificar la incertidumbre de los parámetros para la aplicación del modelo. Siguiendo los métodos PRISMA, se realizaron búsquedas en Scopus, se revisaron los títulos y resúmenes en AbstrackR y se extrajeron los parámetros de movimiento del atún tropical de los artículos pertinentes. Cuantificamos los parámetros y la incertidumbre de cuatro impulsores que afectan al movimiento de los túnidos: la velocidad, las preferencias de temperatura, las preferencias de oxígeno y la asociación de los túnidos con los dispositivos de concentración de peces (DCP). El patudo, el rabil y el listado se mueven a aproximadamente 1 m/s. El patudo prefiere un rango de temperaturas más amplio y frío (14,7°C-23,2°C) que el rabil (20,3°C-25,5°C) y el listado (19,3°C-27,9°C). El patudo se sumerge en aguas menos oxigenadas

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que el rabil (1,4 ml/L, 3,1 ml/L), pero se carece de información sobre el oxígeno en el listado (n=1). El tiempo de residencia continuo del patudo y el rabil en los DCP (7,7 días, 6,8 días) es el doble que el del listado (2,6 días). Todas las especies perciben un DCP a 5,4 millas náuticas de distancia y tardan 23,8 días en colonizarlo. Esperamos que esta revisión sistemática pueda servir de base a los modelos de movimiento y anime a otros a llenar las lagunas de la bibliografía para mejorar la ordenación de los túnidos tropicales.

KEYWORDS

Behavior, Habitat, Environmental Effects, Surface Temperature, Dissolved Oxygen, Floating Structures, Systematic Review, Tropical Tunas

Introduction

As ICCAT and other RFMOs, move toward spatially explicit stock assessment models incorporating migration patterns, seasonal trends, and habitat-dependent scenarios, a review of movement model parameters is necessary. This systematic review identifies relevant papers, extract numbers, and summarize those numbers for use in movement models.

Modeling tropical tuna movement and migrations relies on speed and habitat preference assumptions. Base tuna speeds are required for selecting time and space scales of models; the tuna must be able to migrate between areas in a reasonable amount of time. When examining seasonal or habitat dynamics, it is useful to know the relationship between tuna and environmental features such as temperature and oxygen. Fish Aggregation Devices may drastically alter fish movement behaviors as an ecological trap or a generally productive area (Marsac et al. 2000). So, knowing both the distance that tuna can sense FADs and the amount of time spent at FADs is useful to modeling movement.

These assumptions typically come from the literature and are selected based on location, recency, and quality. Choosing a paper that is too specific to a study area, has a small sample size, or is outdated can result in model misspecification. This would likely lead to skewed outputs by using mis-matched inputs. Using more than one reference to define a model parameter reduces uncertainty and can improve evidence surrounding policy decisions (Myers and Mertz 1998; O'Leary et al. 2015). Additionally, larger sample size and emergent trends from the cumulation of multiple sources can produce stronger averaged parameters.

The objective of this study was to extract parameter information from multiple sources and quantify parameter uncertainty for model application. We completed a systematic review within the SCOPUS database following PRISMA standards for each parameter (Page et al. 2021). A summary of the parameters for speed, temperature preferences, oxygen preferences, and behavior around FADs for each species of tropical tuna are presented below.

1. Data and methods

This project followed Preferred Reporting Items for Systematic reviews & Meta-Analyses (PRISMA) methodology (Page et al. 2021). We used the Boolean statements listed in **Table 1** to search the Scopus database. The titles and abstracts were reviewed for relevance in AbstrackR (Wallace et al. 2012). We defined relevance as any paper pertaining to tropical tuna or "large pelagic species" and by type of driver including habitat, environmental effects, or tagging studies. If a paper was retained after review, it would be confirmed as relevant by reading in detail, and relevant numbers would be extracted to a database. The PRISMA flow charts for each section are presented as **Figures 1-4** and demonstrate the number of papers eliminated at each round of review.

Once collected, the extracted data were summarized using R version 4.0.5 (R Core Team, 2021). A series of bar charts describing the number of papers by locations, species, methods, and the type of data extracted are available in **Figures 5-7**. Statistical analysis for each driver was completed based on the available data for that driver and any unique trends discovered during the systematic review process. Below are each of the analyses summarized by driver.

2. Analysis

2.1 Speed analysis

Speed was reported in either body lengths per second (BL/s) or meters per second (m/s). When possible, the speed was converted to both units to allow for a comparison of all studies. We averaged the mean, minimum, and maximum speeds by species and reported the number of papers that contributed to those means. If a mean had standard deviations, we used the following equation, adapted from Borenstein et al. (2009), to weight the mean speed for all species:

$$\frac{\sum(speed * \sum\frac{1}{sd})}{\sum\frac{1}{sd}} = Mean\ Speed\ weighted\ by\ sd$$

$$\frac{1}{\sum\frac{1}{sd}} = sd\ of\ Weighted\ Mean$$

We calculated the weighted mean overall (n=12) and by species, however there were only 4 means reported with standard deviations for skipjack (n=2) and bigeye tunas (n=2).

2.2 Temperature analysis

Tropical tuna temperature preferences were reported as either ambient or sea surface temperatures and all analysis for temperature was split between those two categories. Following the same methods as speed, we took the mean of the mean temperatures reported in the literature and calculated the standard deviation. There were enough means reported (n=31) to do this calculation for both ambient (n=22) and sea surface (n=9) temperatures, but there were not enough reported standard deviations (n=1, n=8) to do a weighted mean.

Most temperatures were reported as a preferred range (n=84). The mean of the upper limit and the lower limit of the ranges were calculated with standard deviation. We calculated the mean range of temperature by method (remote sensing and electronic tags) and by species to account for possible covariates.

We recorded the absolute minimum and maximum reported temperatures for each tuna species in the literature. The mean was not calculated for these numbers as they represented the lethal or extreme temperatures for each species.

2.3 Oxygen analysis

Oxygen preferences were reported the least consistently in the literature, so the results were limited. We calculated the mean of the upper and lower limits of oxygen tolerance. The means were also calculated by species; however no analysis was completed for skipjack because only one data point was available.

2.4 FAD analysis

The target statistics for tuna behaviors around FADs were Continuous Residence Time (CRT), colonization time, and attraction distance. CRT, defined as the total time an individual continuously stayed at a FAD excluding short excursions (< 24 hours), was the most common statistic (n=57). We took the Mean of the collected CRTs and categorized by species.

We defined colonization time as the total soak time before tuna gather on a FAD. There were two methods, in situ and fisher interviews, and we calculated a mean colonization time for both. We were unable to calculate the mean colonization time by species due to the limitations in the literature.

We defined attraction distance as the maximum distance that a tuna can sense and move towards a FAD. This was typically determined by tuna leaving and returning to a FAD or a tuna changing trajectory to move toward a FAD. Some papers reported much shorter attraction distances which were likely indicative of a tuna that was “associated” with a FAD rather than where the tuna first sensed the FAD. The mean attraction distance could be calculated for yellowfin, skipjack, and mixed schools but not for bigeye.

3. Results and conclusions

3.1 Speed

A summary of 18 papers suggested that tropical tuna all move at the same speed of approximately 1 m/s. All means in m/s and BL/s are provided in **Table 2**. The mean speed of all species combined was 0.0929 ± 0.012 m/s. The weighted means of each species 0.863 ± 0.015 m/s, 1.14 ± 0.073 m/s, and 1.28 ± 0.23 m/s, for yellowfin, bigeye, and skipjack respectively. When weighted, there was a clearer trend that skipjack tended to swim slightly faster than bigeye and yellowfin. Yellowfin were seen to reach the lowest and highest speeds at .322 m/s and 5.4 m/s and had the largest sample size which may have contributed to their lower weighted mean. **Figures 8 and 9** illustrate the speeds reported in the literature by paper and the final means for both unweighted and weighted treatments.

Magnuson (1970, 1973, 1978) are the most referenced speed articles but are based on anatomical models and swim tunnels instead of in situ behaviors (Dewar and Graham 1994). The results ended up most similar to Magnuson (1973) reporting speeds of 1.5-2.2 L/sec for skipjack, 1.3 L/sec for yellowfin, and 1.08 l/sec for bigeye. We recommend using the weighted means by species in m/s for parameterizing movement models.

3.2 Temperature

The types of papers used for the temperature analysis are in **Tables 3-5**. Papers were evenly divided between species even when split into ambient and sea surface temperatures (**Table 3**). Most of the research was conducted in the Pacific Ocean (n = 52) however there was representation from all three major oceans and three global studies (**Table 4**). Additional research on tropical tuna temperature trends in the Atlantic Ocean would be beneficial to ICCAT initiatives, but the global data is sufficient for analysis. The most prominent method in the papers was remote sensing (n = 42), closely followed by electronic tagging (n = 29) (**Table 5**). Remote sensing papers examined sea surface temperature by comparing tag locations to temperature models or satellite maps. Electronic tagging papers were more focused on ambient temperature since electronic tags can sense the temperature around the fish. Thus, most of the results ended up being split between these two methods. We calculated separate means, minimums, and maximums for SST and ambient temperature.

Most of the temperatures were reported as ranges with an upper and lower limit (n=84), in a few cases only an upper limit or lower limit was reported. The means and histograms of the upper and lower limits for each species and the two major methods are presented in **Table 6** and **Figure 10**. Bigeye tuna preferred colder waters than yellowfin and skipjack in both ambient and sea surface conditions.

Means represented 32 of the extracted numbers. The nine SST means and 22 ambient means are illustrated in **Figure 11** by species and by method. None of the ambient temperatures had standard deviations while 8 of the 9 sea surface temperatures had standard deviations. Due to the lack of standard deviations overall, we reported the unweighted means by species in **Table 7**.

Since we extracted data from all types of tropical tuna temperature studies, we captured the lethal extremes of their temperature ranges. 21 minimum temperatures were recorded with the absolute minimum being 2.0 in an electronic tag study on diving yellowfin tuna (**Table 8**). The minimum temperature for bigeye was 2.5 and 7.7 for skipjack. There were 9 maximum temperatures recorded. Dizon et al. (1977) found the lethal maximum for skipjack was 34 degrees in a lab study. Bigeye and yellowfin were found at 31.9 and 32.2 degrees C (Evans et al. 2008, Aoki et al. 2020). These numbers were not included in any temperature preference range analyses to avoid bias from the extremes.

In 9 cases a preferred isotherm was reported. The mean isotherms preferred by bigeye, yellowfin, and skipjack were 19, 17.75, and 24.5 respectively. A future analysis examining isotherms or depth relationships in the literature could benefit three-dimensional models and lead to an improved understanding of ambient temperature effects on tuna movement.

Another 9 studies were recorded because they reported a relationship between tropical tuna and temperature. Power and May (1991) found no relationship between temperature and yellowfin tuna CPUE. The remaining 8 papers found that SST has a strong relationship with tropical tuna catches. In 3 of the papers Chlorophyll-a and SST were the best predictors of tuna catch.

3.3 Oxygen

Papers on the relationship between oxygen and tropical tuna were the hardest to extract information from resulting in the smallest database of oxygen-related numbers (n=41). Many papers looked at metabolic processes which mention internal tolerances but not the external oxygen level (Blank et al. 2007). Bushnell and Brill (1991), Lowe et al. (2000) and Bach et al. (2003) reported oxygen preferences in incomparable units (partial pressures, gradients, etc.). Arrizabalaga et al (2015) and Hu et al. (2018) found that oxygen explained some of the deviance in their CPUE GAMs. The highest reported percent of explained deviance was 31.19% for Yellowfin tuna CPUE in a univariate GAM. However, some papers including Bigelow and Maunder (2007) and Brill et al. (1999) argued that oxygen was less important than temperature and thus excluded oxygen analysis from their paper. This belief that oxygen is less important than temperature for tropical tuna distribution may have influenced the infrequency of oxygen reports in the literature.

There were 8 upper limits and 15 lower limits of oxygen preference ranges extracted from the literature. Unlike temperature, the upper limits referred to the low oxygen zones where the fish were observed and not the lethal or stressful upper limit as well-oxygenated waters are preferred by tuna. The extracted upper and lower limits by paper and by species are in **Figure 12**. The mean lower and upper limits for each species are reported in **Table 9**. There was not sufficient data for skipjack analysis for either mean lower or upper limits. The lowest oxygen level bigeye tuna were seen diving into was 1 ml/L. Bigeye were seen in lower oxygen levels than Yellowfin tuna at 1.4 ml/L and 3.1 ml/L respectively.

3.4 Fish Aggregation Devices

We extracted 153 statistics related to tropical tuna and FADs from 33 papers. Most papers studied Yellowfin tuna, but there were at least 10 papers studying each species (**Figure 7**). 11 papers focused on school relationships with FADs and did not specify the species within the schools. As expected, most studies were conducted in the Pacific Ocean and Indian Ocean with many studies in FAD systems in Hawaii and the Maldives (**Figure 5 and 7**).

Most papers used ultrasonic or acoustic transmitters to track fish around floating objects, boats, or buoys (n= 25, **Figure 7**). 4 studies interviewed purse seine fishers from Spain, France, and China to determine fisher knowledge on Tuna-FAD relationships. There was 1 study using a small-scale fishery, 1 study using mark-recapture data, and 2 studies using archival tags.

The most common statistic extracted was CRT. The mean CRT was 6.2 days, but when categorized by species the CRTs were 6.8 days, 7.7 days, and 2.6 days for yellowfin, bigeye, and skipjack respectively (**Figure 13, Table 10**). There was also a separate mean of 8.6 days calculated for all the papers that reported CRT without specifying the species (n = 4).

Only 10 papers reported colonization times which fell into two categories: interviews and *in situ*. The mean colonization time of the *in situ* papers (n=4) was 23.8 days which was very similar to 32.3 days the mean colonization time of the interview papers (n=6). The minimum colonization times were reported by Schaefer et al. 2021 suggesting that tuna could start gathering at FADs as early as 1.5 days after setting. Schaefer et al. 2021 looked at 150 FADs instead at specific tunas which may have resulted in the lowest colonization time.

The extracted attraction distances to FADs are displayed in the forest plot on **Figure 14**. There are a mix of short and long distances because the "attraction distance" definition varied too much. Trygonis et al. 2016, Moreno et al. 2007b, and Cillaurren et al. 1994 all used echosounders attached to the FAD or a nearby buoy with a limited range, so this may be more accurately defined as the "association distance" or how far away tuna stay from a FAD when considered associated with it. Other papers investigated how far away a tracked fish could travel to and from a FAD or change trajectory to find another FAD. There were no reported FAD attraction distances for bigeye tuna. The mean attraction distance was 10,074.4 m or 5.4 nm for all tuna species excluding the shorter reports from different methods.

3.5 Limitations and applications

This systematic review was only comprehensive for the Scopus database. The speed study was conducted in 2 databases: Scopus and Web of Science. Web of Science added only one unique paper to the collected information and was subsequently not worth the additional time needed to search it. Now that the methods have been refined by repeated execution, it would be easier to complete this analysis in additional databases to better capture the entire breadth of the literature.

During the search process, many papers used parameters referenced from other papers. Papers describing models have references to the speeds, temperatures, oxygen, and FAD parameters used in their model descriptions. Some of these secondary references were noted during the collection process, but those references were rarely back checked unless they came up as a paper in the search. A future study on connected papers, including those referenced by models would be interesting to compare to the parameters proposed in this paper.

These collected parameters will be used in an agent-based model of tropical tuna movement in the Atlantic Ocean. We encourage anyone who is interested in this data for use in their own models or who wishes to expand this systematic review contact the authors.

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Table 1. Boolean statements used for searching Scopus database. SPECIES represents the scientific name and COMMON NAME represents the common name, these fields were changed for each search in order to search each species one at a time.

Database	Boolean Statement
Speed WoS	((“tropical tuna” OR skipjack OR yellowfin OR bigeye) AND (speed OR velocity))
Speed Scopus	(("tropical tuna" OR "skipjack" OR "yellowfin" OR "bigeye") AND ("speed" OR "velocity")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j"))
Temperature Scopus*	("SPECIES") AND ("temperature*") AND NOT ("bone") AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (EXCLUDE (EXACTSRCTITLE , "Food Chemistry"))
Oxygen Scopus	("SPECIES" OR "COMMON NAME") AND ("oxygen*" OR "aerobic*" OR "respiration") AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar"))
FAD Scopus	("SPECIES") AND ("FAD" OR "Fish Aggregation Device*" OR "Association" OR "Seamount" OR "Aggregation" OR "FAD-Associated" OR "log" OR "floating object" OR "Fish Aggregating Device" OR "Fish Attracting Device") AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar"))

*”AND NOT (“bone”) was added to eliminate a strange abundance of bone related papers and (EXCLUDE (EXACTSRCTITLE , "Food Chemistry") was added because of a high number of Food Chemistry papers that had nothing to do with live tuna. This exclusion was not added to later searches due to capacity improvements.

Table 2. The maximum, minimum, and average speed of each tropical tuna species in m/s and BL/s. The total number of papers used for the average analysis and the total number of papers recorded in the database are included.

m/s

species	min	average	max	number of papers included in average	total papers
YFT	0.322	0.988	5.4	8	26
BET	0.88	1.07	1.91	2	4
SKJ	0.6	1.09	2.06	7	11
All	0.322	1.041	5.4	17	41

BL/s

species	min	average	max	number of papers included in average	total papers
YFT	0.65	0.929	3.7	8	16
BET	NA	NA	NA	0	0
SKJ	1.1	NA	10	0	6
All	0.65	0.929	10	8	22

Table 3. Number of papers with temperature data by species and by data type.

Species	Ambient	Sea Surface	Total
Bigeye	21	12	33
Yellowfin	14	22	37
Skipjack	12	15	27

Table 4. Number of papers with temperature data by ocean and by data type.

Ocean	Ambient	Sea Surface	Total
Pacific	36	17	52
Atlantic	5	9	14
Indian	4	8	11
Global	0	3	3

Table 5. Number of papers with temperature data by method and by data type.

Method	Ambient	Sea Surface	Total
Remote Sensing	12	30	42
Electronic Tagging	28	5	31
Lab	3	0	3
Fishing	2	2	4

Table 6. Ranges of temperature preferences by species and by method for ambient and sea surface temperatures with standard deviation.

		Ambient		SST	
Species	Methods	lower	upper	lower	Upper
Bigeye	All	14.7±4.6	23.2±5.4	20.8±7.0	25.2±6.5
	Selected	15.1±4.19	24.3±4.8	24.2±2.4	28.5±082
Yellowfin	All	20.3±3.3	25.3±4.0	23.6±5.0	28.6±2.0
	Selected	21.4±3.1	26.7±3.0	24.4±5.0	28.6±2.2
Skipjack	All	19.3±2.7	27.9±2.1	23±3.6	28.3±2.2
	Selected	19.2±3.4	28±2.31	23±3.6	28.3±2.2

Table 7. Mean of the tropical tuna mean temperature preferences in the literature by species with standard deviation.

Species	Ambient	Sea Surface	Total
Bigeye	18.07±5.7	27.4±0.14	19.2±6.2
Yellowfin	23.59±0.79	23.9±5.7	23.7±3.6
Skipjack	24.34±1.4	23.3±3.6	23.9±2.5

Table 8. Extreme temperatures experienced by tropical tuna in the literature with citations.

Species	Minimum	Citation	Maximum	Citation
Bigeye	2.5	Evans et al. 2008	31.9	Evans et al. 2008
Yellowfin	2	Aldana-Flores 2018	32.2	Dagorn et al. 2006
Skipjack	7.7	Schafer and Fuller 2007	34	Dizon et al. 1977

Table 9. Mean oxygen ranges preferred by tropical tuna with standard deviation and sample size.

Species	Lower Limit	Upper Limit	n
Bigeye	1.4±0.5	1.8±0.79	8
Yellowfin	3.1±1.5	4.6±1.4	7
Skipjack	1	NA	1
All	2.2±1.4	3.2±1.9	16

Table 10. Mean Continuous Residence time by species with standard deviation.

Species	Lower Limit	n
Bigeye	7.7±8.7	13
Yellowfin	6.8±6.3	28
Skipjack	1	12
Unspecified	8.6±3.1	4
All	6.2±6.4	57

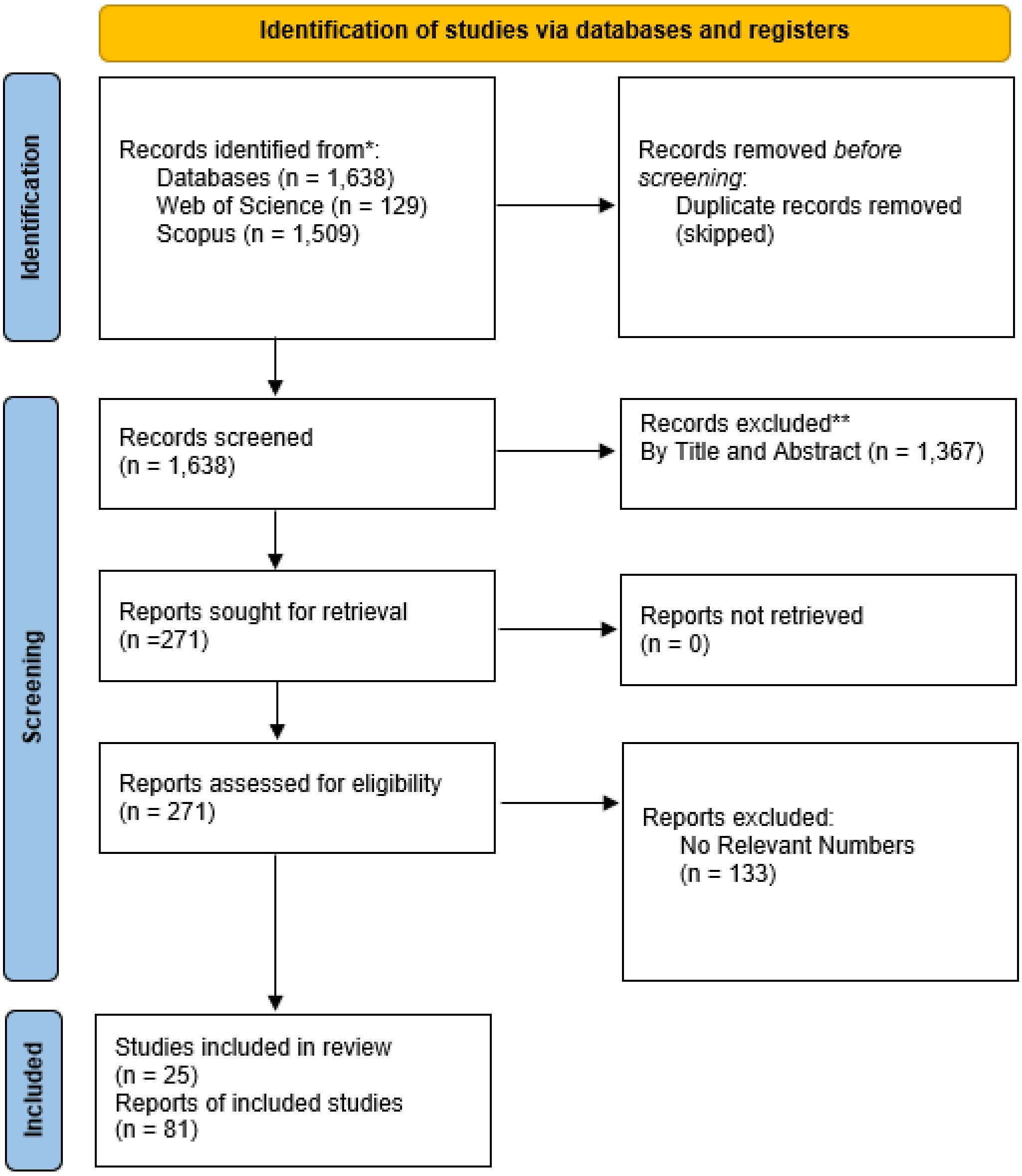

Figure 1. PRISMA 2020 flow diagram of Tropical Tuna Speed. A Boolean search of tropical tuna speeds started with 1,638 papers, after screening 271 papers were skimmed for relevant numbers, 81 numbers from 25 papers were included in the final analysis.

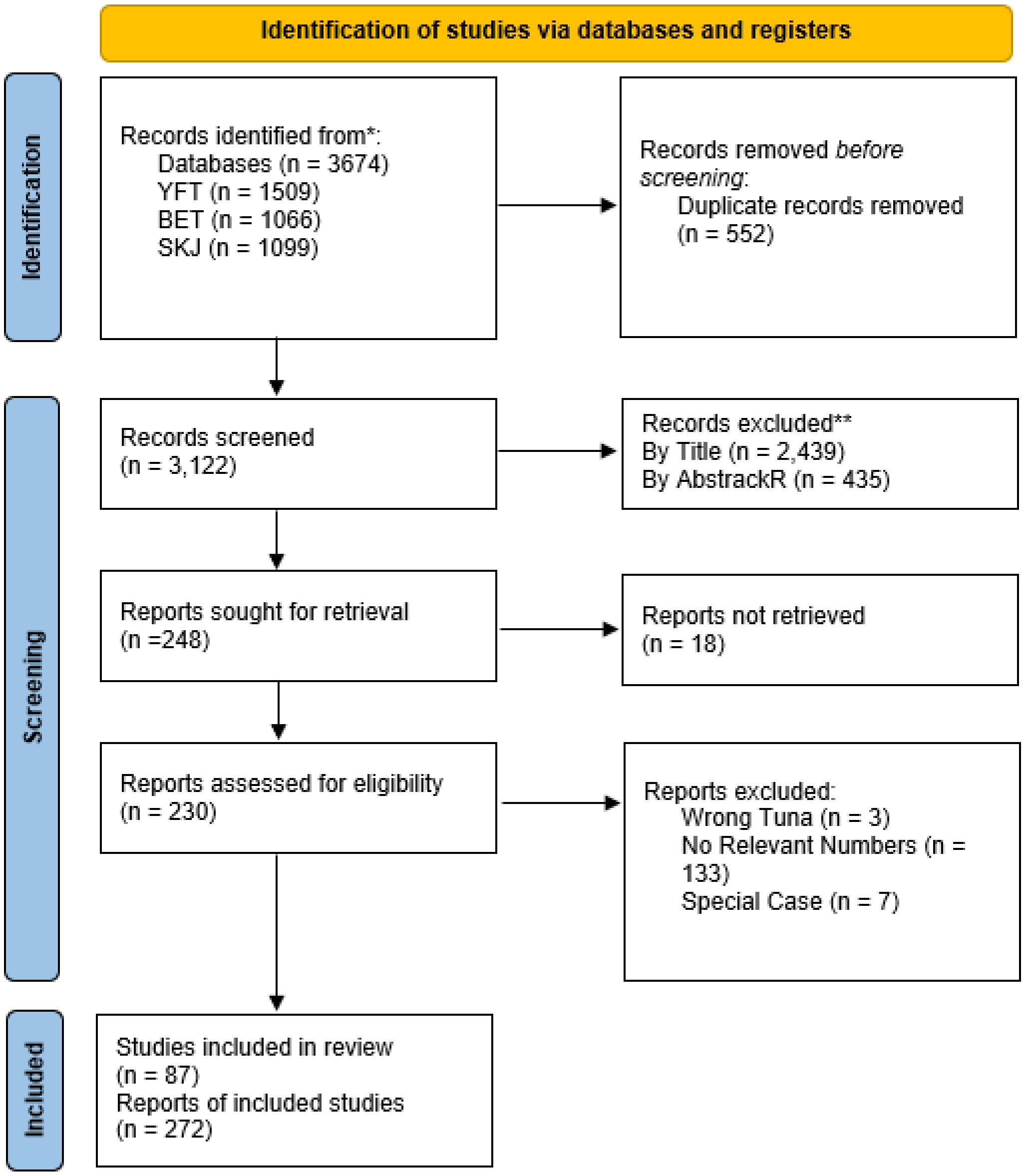

Figure 2. PRISMA 2020 flow diagram of Tropical Tuna Temperature preferences. A Boolean search of tropical tuna temperature started with 3,674 papers, after screening 230 papers were skimmed for relevant numbers, 272 numbers from 87 papers were included in the final analysis.

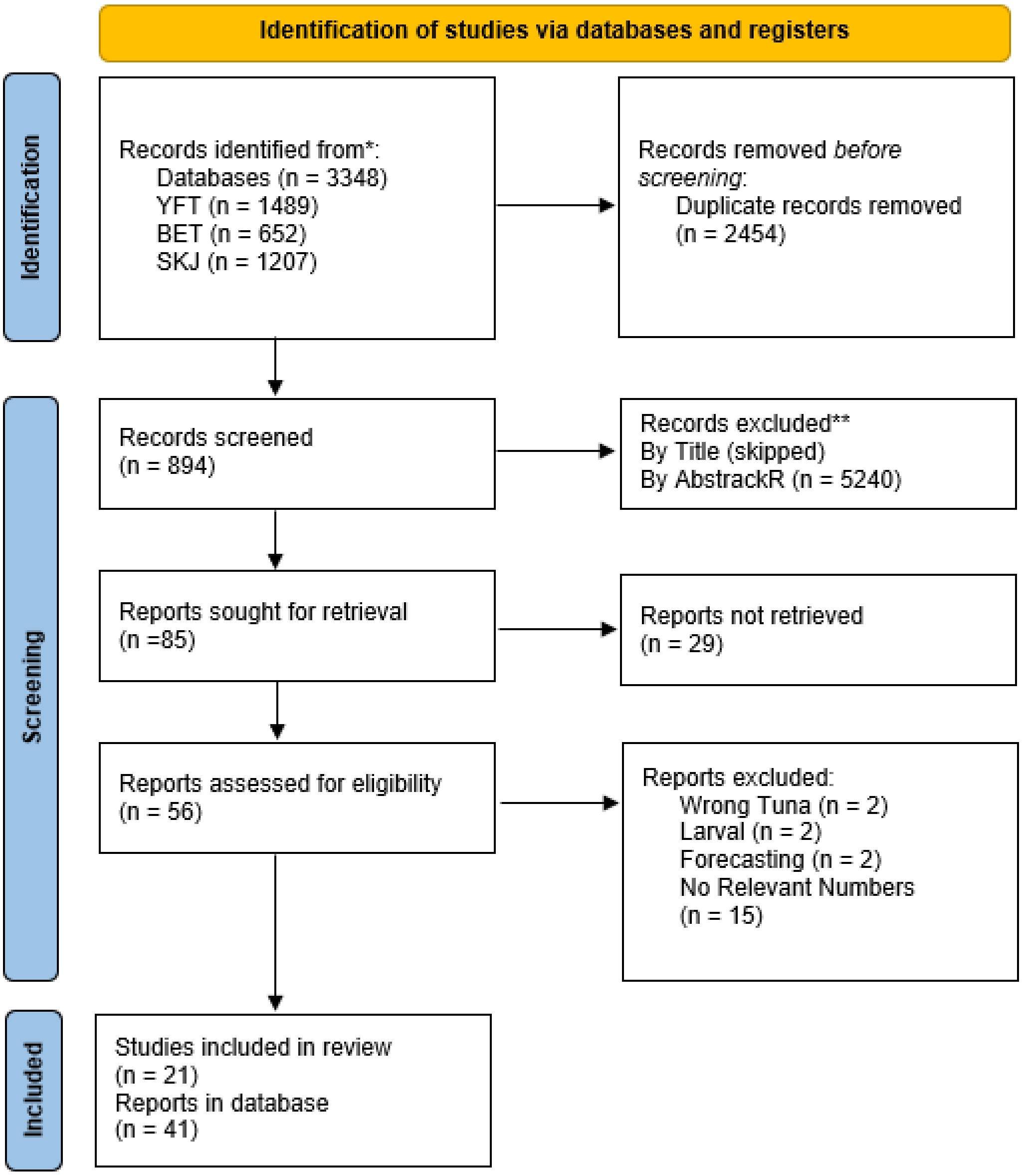

Figure 3. PRISMA 2020 flow diagram of Tropical Tuna Oxygen preferences. A Boolean search of tropical tuna oxygen started with 3,348 papers, after screening, 56 papers were skimmed for relevant numbers, 41 numbers from 21 papers were included in the final analysis.

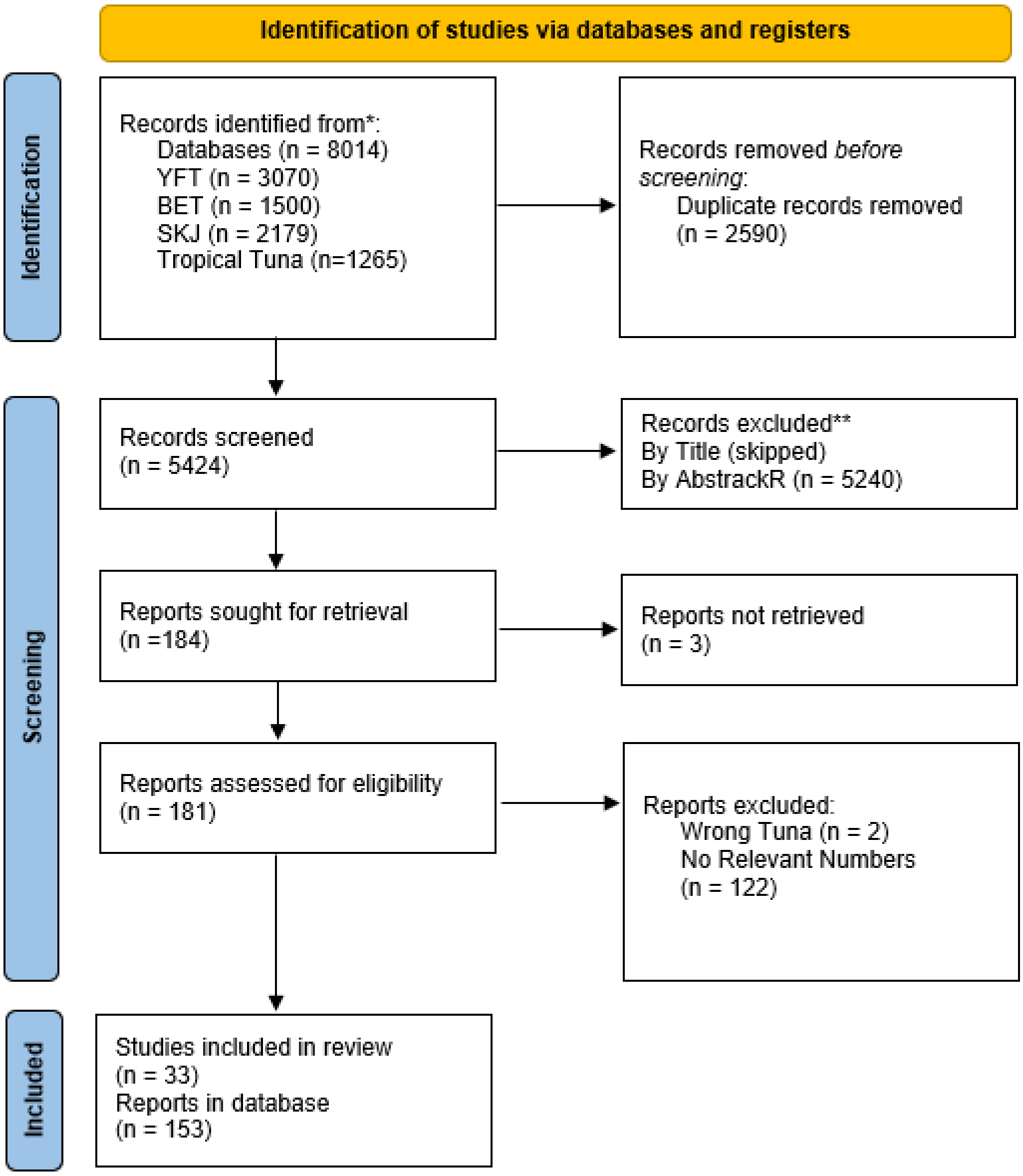

Figure 4. PRISMA 2020 flow diagram of Tropical Tuna FAD relationships. A Boolean search of tropical tuna and FADs started with 8,014 papers. After screening, 181 papers were skimmed for relevant numbers, 33 numbers from 153 papers were included in the final analysis.

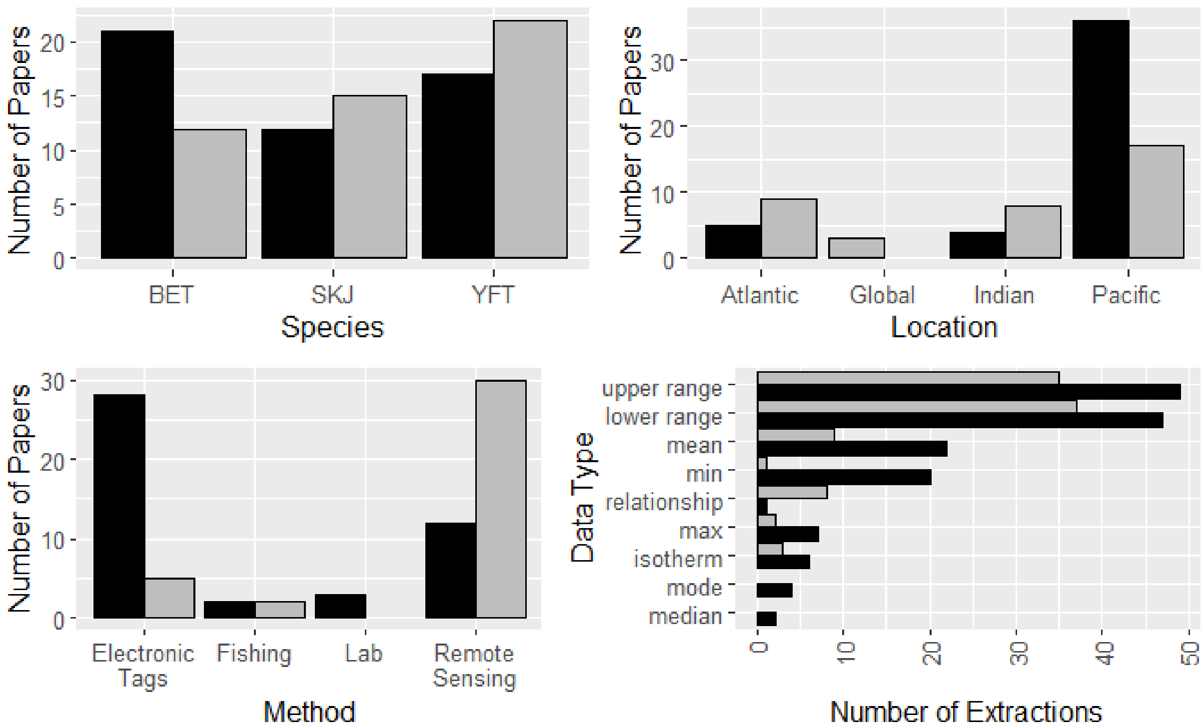

Figure 5. The distribution of temperature information related to each species, location, method, and statistics type. Grey represents the number of papers related to ambient temperatures and the black represents the number of papers related to sea surface temperatures.

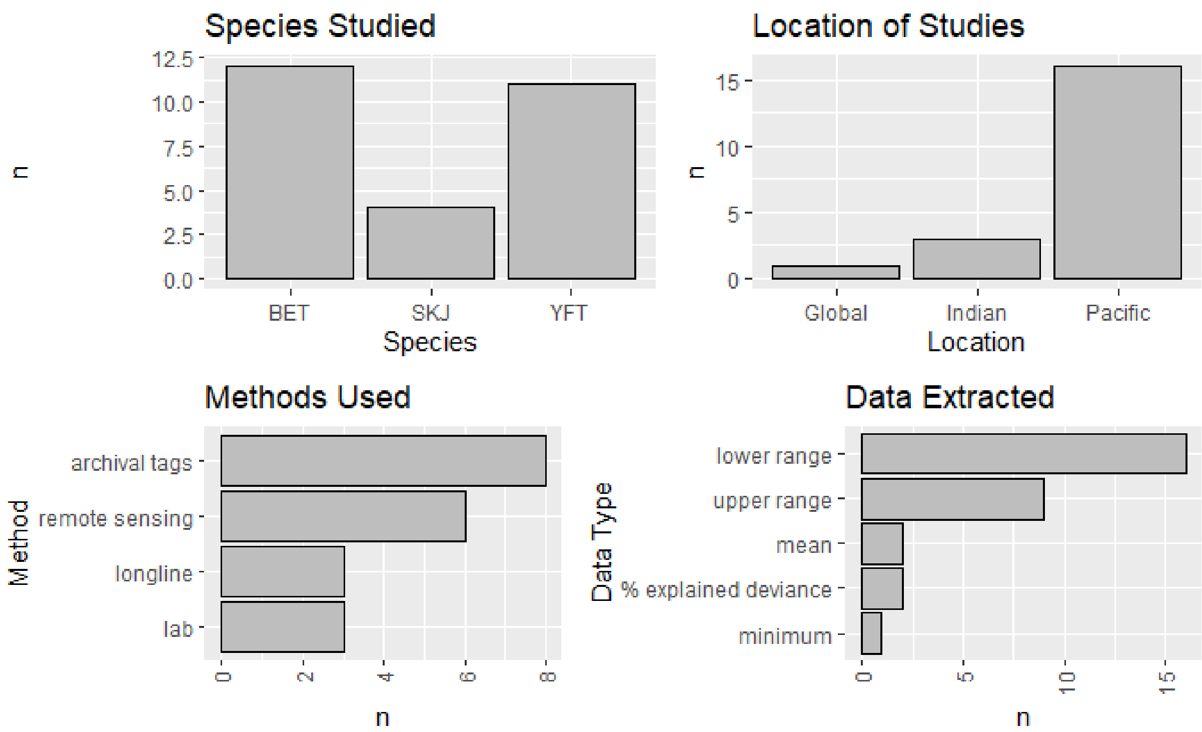

Figure 6. The distribution of oxygen information related to each species, location, method, and statistics type.

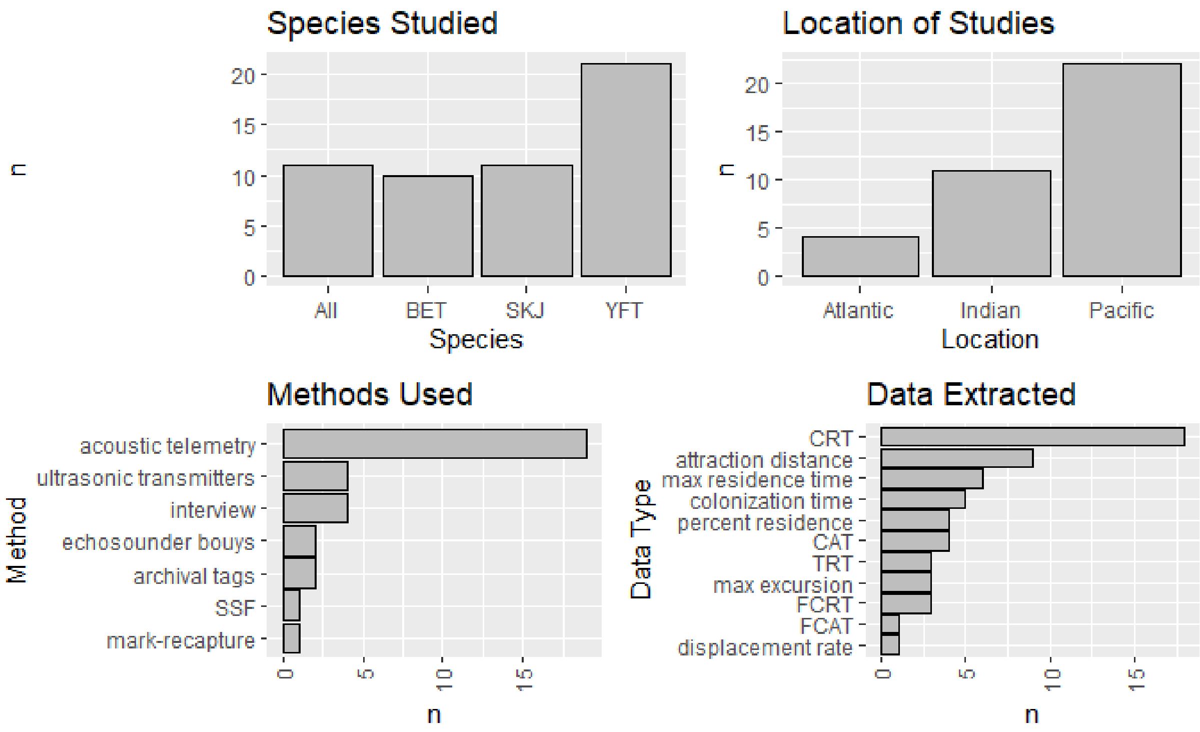

Figure 7. The distribution of FAD information related to each species, location, method, and statistics type.

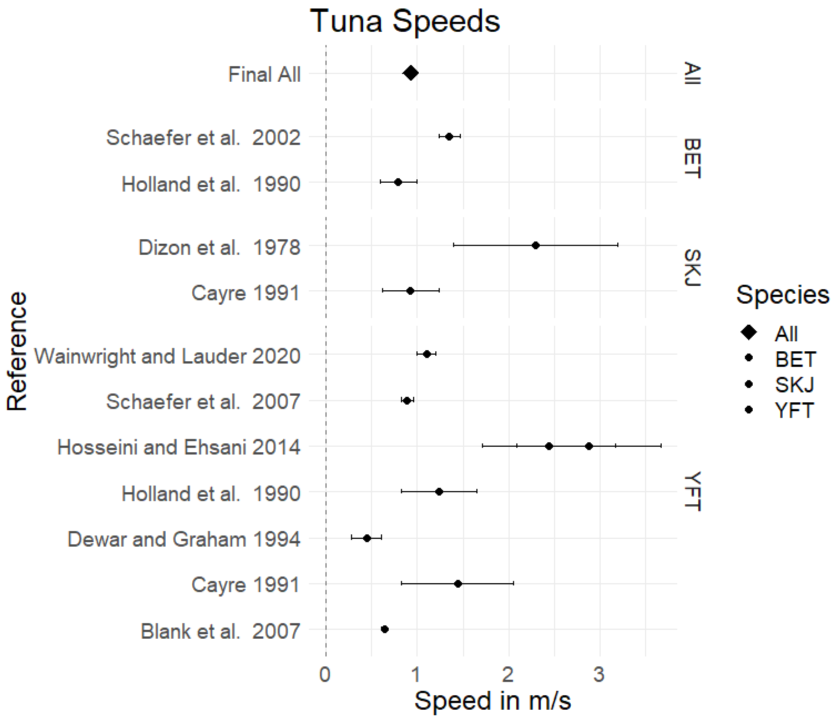

Figure 8. A forest plot of Mean tropical tuna speeds by species with standard deviations. The mean of all data is Final All valued at 0.929 + 0.012.

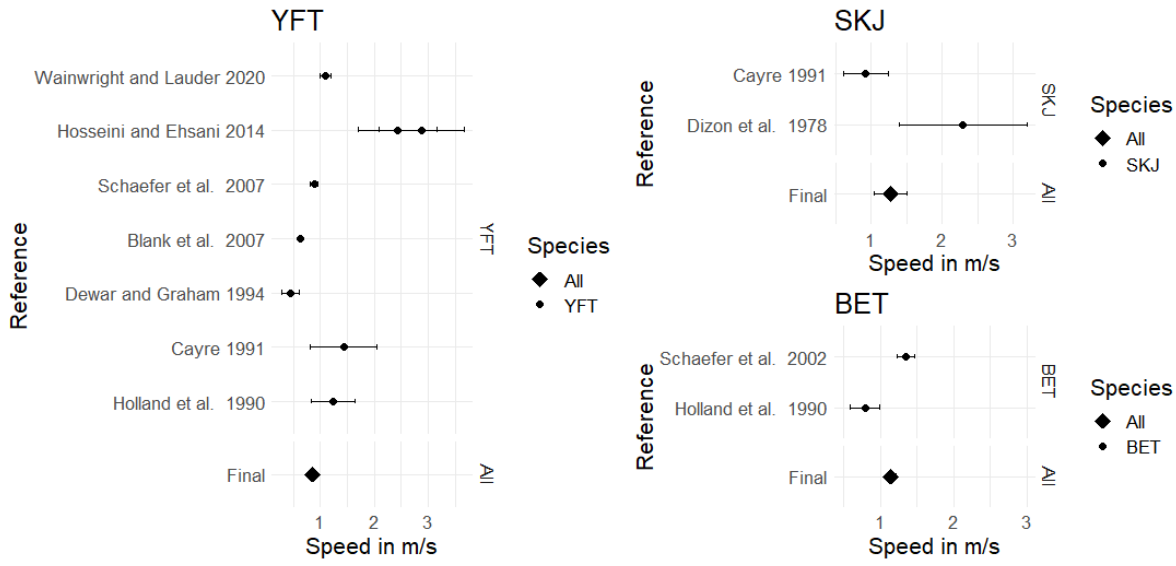

Figure 9. Mean tropical tuna speeds weighted by standard deviations sorted by species.

A. Ambient B. Sea Surface

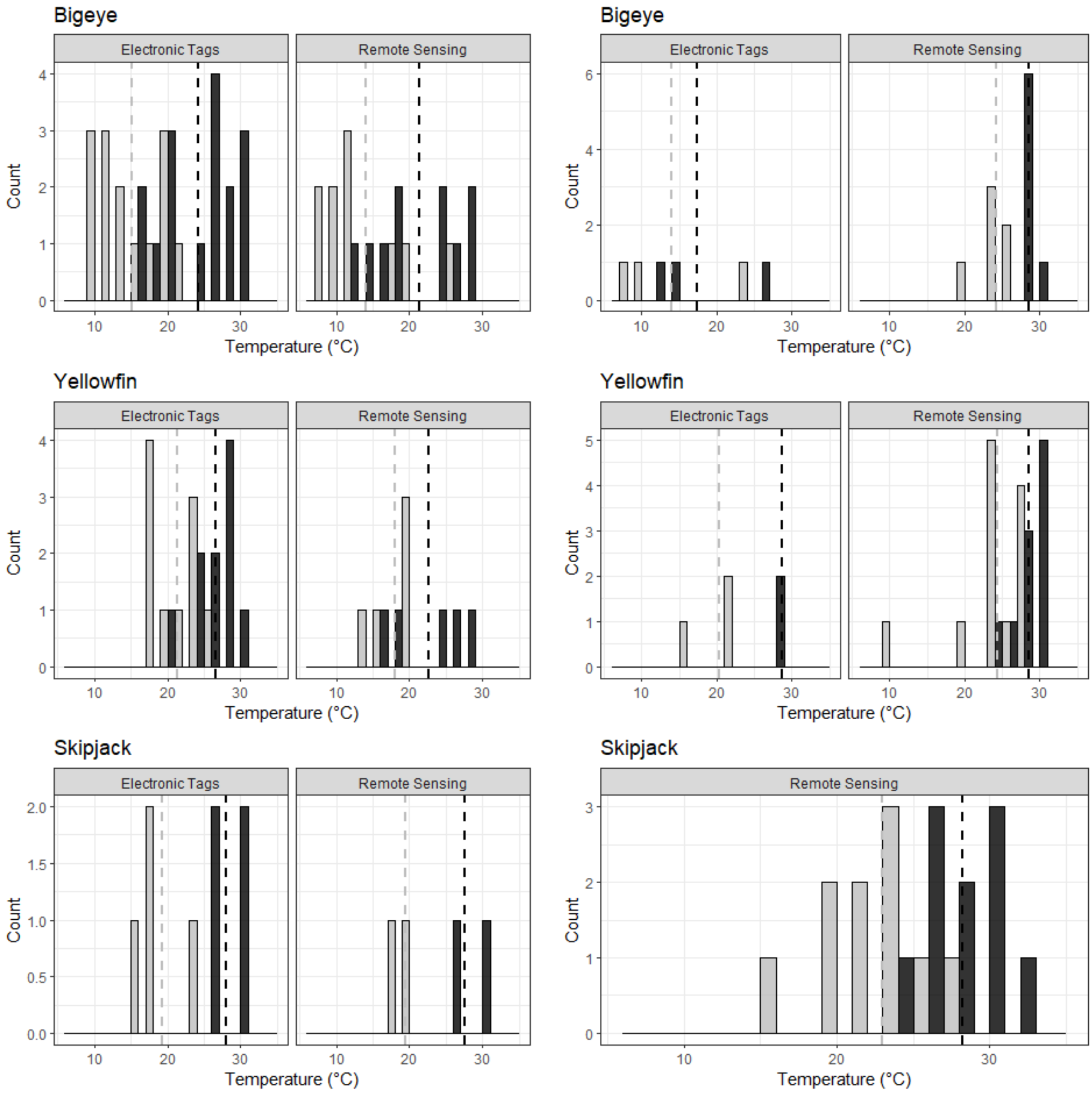

Figure 10. The upper and lower limits of temperature preferences divided by species and method. The black bars represent the upper limits of the extracted ranges, and the white bars represent the lower limits. Figure A includes the papers where the ambient temperature was reported, and Figure B includes the papers where the sea surface temperature was reported.

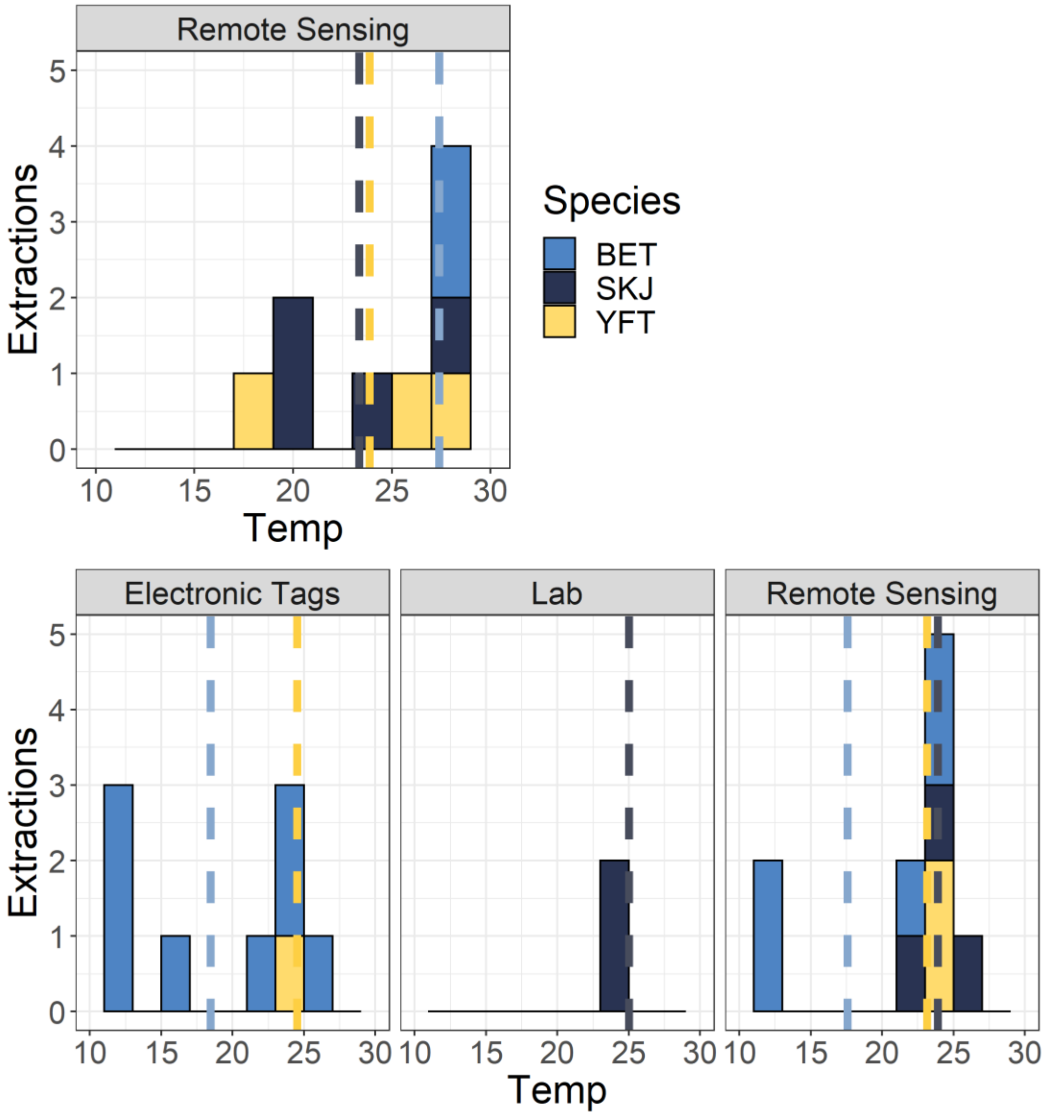

Figure 11. The mean temperature preferences for each species sorted by method. The dotted lines represent the mean temperature for each species within each method.

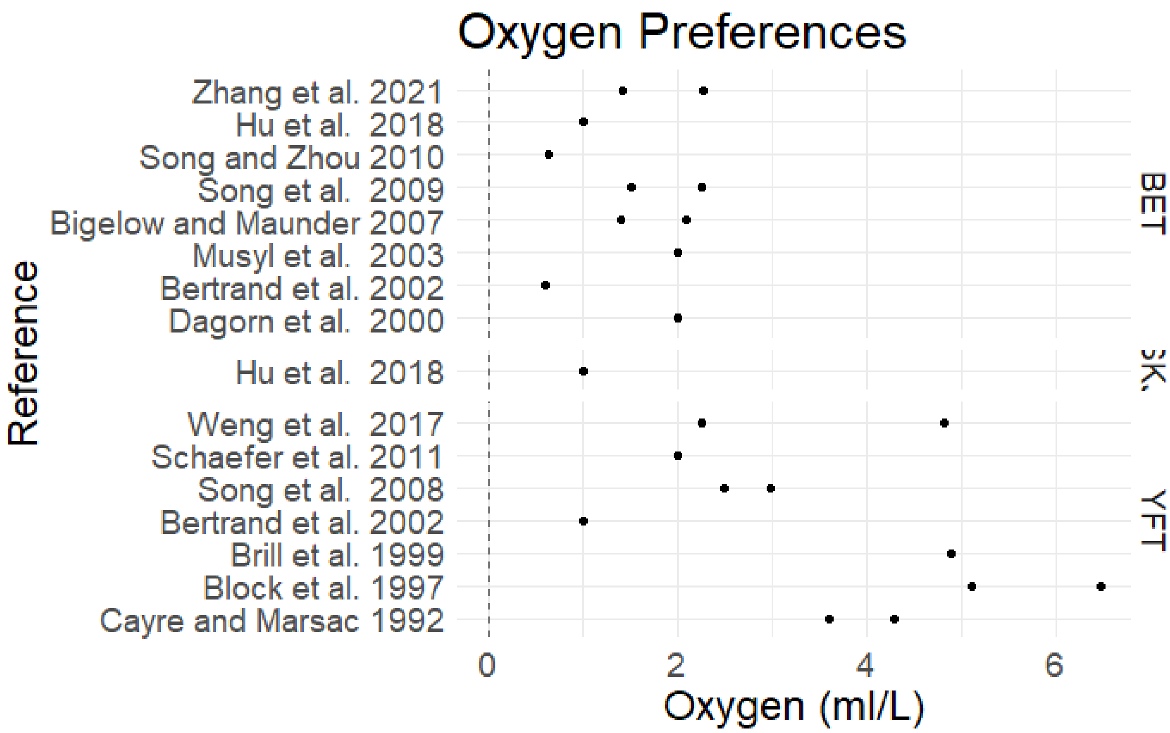

Figure 12. A forest plot of the minimum and maximum oxygen preferences for each paper by species.

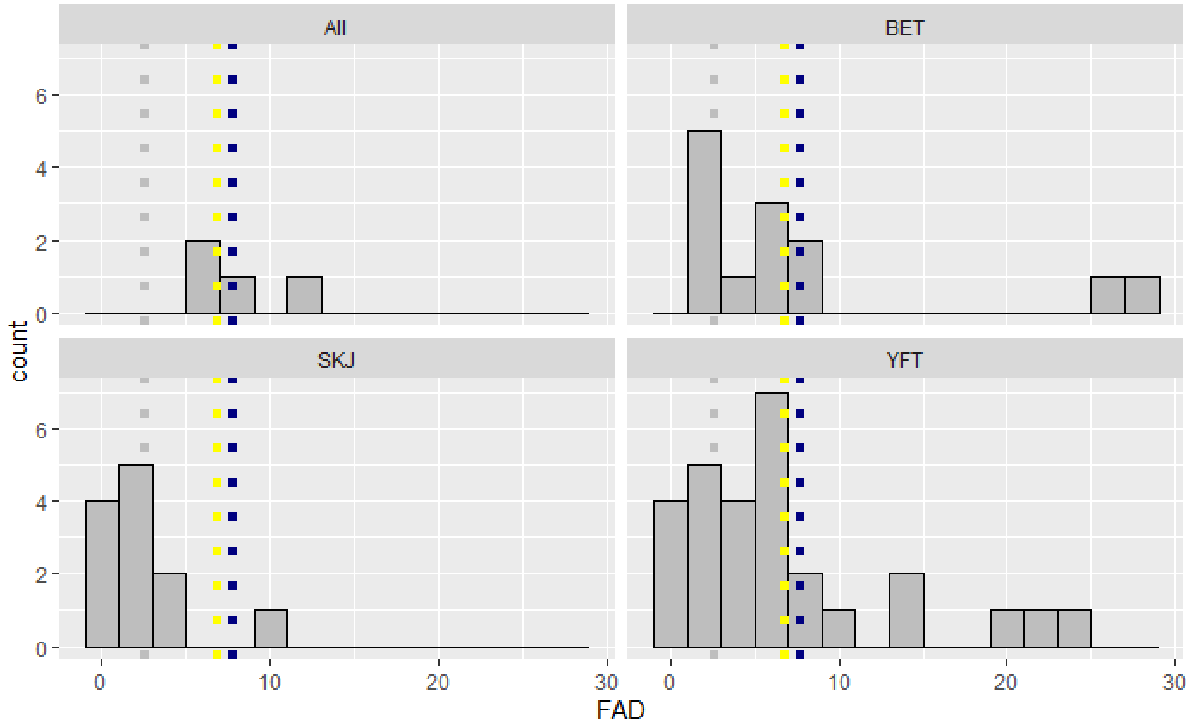

Figure 13. Continuous Residence Time distributions by species with the mean lines for bigeye tuna in navy, yellowfin tuna in yellow, and skipjack in grey.

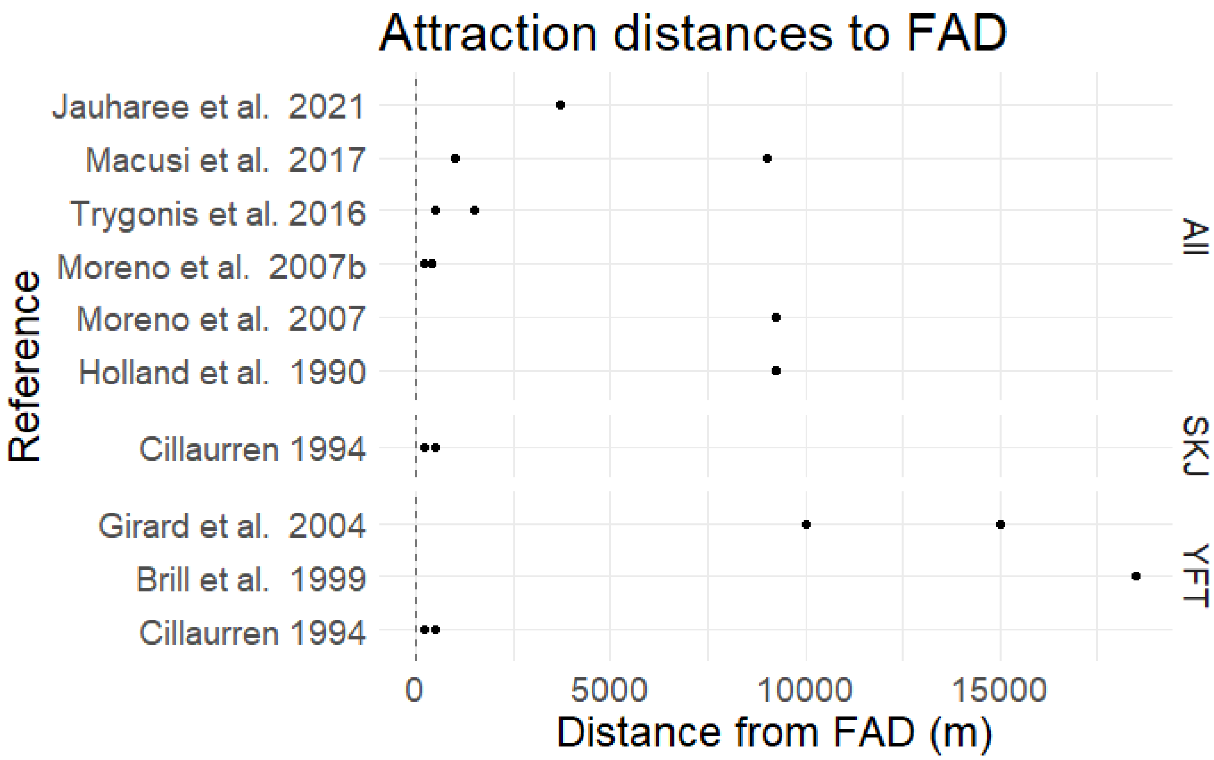

Figure 14. A forest plot of the minimum and maximum attraction distances to FADs by species.