**Appendix S1**

**Supporting Information for**

***Scaling of metabolism and maximum consumption with temperature and body size within species of fish***

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# Defining rates to search for

Consumption can relate to different things. (Essington *et al.* 2001) for instance assumed it to be consumption rate, whereas some authors refer to it as maximum consumption rate (consumption rate at food satiation). We choose maximum consumption rates because 1) we control for varying food levels, which can affect optimum temperatures and it makes comparison more meaningful across experiments if the relative food level is the same 2) maximum consumption rate, not realized consumption rate, is an input in dynamical models (or bioenergetics) and is inversely related to handling time in a typical Type II functional response.

Energy expenditure can also be related to metabolic rate or the sum of all activities see which ones in (Essington *et al.* 2001). There is not much data on all of these measurements independently. Moreover, within Wisconsin type models (Kitchell *et al.* 1977), growth is , where . Here has the same size dependence as , because it’s only a proportion of it. ; . Here is an activity factor (2 in the Winberg model). is the temperature scalar and S is SDA. Again, these are either factors or size-independent terms in addition to standard allometric respiration, so the size-dependence can be assumed proportional in the -term. Waste losses: and are assumed to be proportions of . Again, no size-effects here! Thus, the primary components of the model are size and temperature dependent and and the total amount of gains and losses could be assumed to have the same size-dependence as and . Lastly, again, standard metabolic rate, possibly with some activity multiplier, is more easily estimated and is used as input in dynamical models.

* Here I can reiterate the three data sources we have and motivate them (will also describe this in methods).
* Need good motivation for why using exponents and not data! Which is larger sample size...

# Literature search

Prior to starting the actual literature review, we conducted several test-searches on with alternative search-strings on Web of Science Core Collection, basic search. This was done in order to find a manageable number of papers to review and to have a reasonable ratio article titles that passed the first screening, given our pre-defined criteria for when to choose a study.

Cmax comes typically from studies parameterizing bioenergetics models of Kitchell-type, whereas growth rate are generally more aquaculture-type papers. What about ad libitum… sometimes it is % ration of body weight, sometimes they are feed once or twice per day (I assume ad lib, often says so explicitly). But if it’s a reduced ration… are they ever satiated? One idea is to go with ad lib or at least not reduced ration (and this is likely what I’ll write).

As our goal was to get an as extensive as possible view of how these rates scales with size and temperature, we also evaluated papers cited by papers in the literature list, and from published review-type papers, like the Wisonsin model.. How the paper was found is noted in the data-set.

## *Maximum consumption rate*

We choose the following search strings for maximum consumption rate experiments:

*(consumption or feeding$rate or food$intake or bio$energ\* or ingestion or food-intake) AND TOPIC: (mass or weight or size) AND TOPIC: (temperature\*)*

This resulted in 15259 articles (search date: 2018.12.18). We then also applied additional filters on subject (Web of Science Categories). These were: *MARINE FRESHWATER BIOLOGY, FISHERIES, ZOOLOGY, PHYSIOLOGY, ECOLOGY, BIOLOGY, LIMNOLOGY, EVOLUTIONARY BIOLOGY*

Which reduced the number of studies to 3449. However, due to a typo and misunderstanding of search syntax, we had to make a second search:

*(feeding-rate or bio-energ\*) AND TOPIC:(mass or weight or size) AND TOPIC:(temperature\*)*

Which yields 431 additional titles after filtering the following categories: MARINE FRESHWATER BIOLOGY, FISHERIES, ZOOLOGY, PHYSIOLOGY, ECOLOGY, BIOLOGY, LIMNOLOGY, EVOLUTIONARY BIOLOGY

## *Metabolic rate*

We choose the following search strings for metabolic rate experiments:

*(metabolism OR "oxygen-consumption" OR "oxygen consumption") AND TOPIC: (mass OR weight OR size) AND TOPIC: (temperature\*)*

This resulted in 8405 articles (search date: 2019.06.06). We then also applied additional filters on subject (Web of Science Categories). These were: *ZOOLOGY, PHYSIOLOGY, MARINE FRESHWATER BIOLOGY, ECOLOGY, FISHERIES and BIOLOGY.* This reduced the number of studies to 3,458

## *Optimum temperature for growth over size*

We choose the following search strings for optimum growth rate experiments:

*(growth) AND TOPIC: (mass OR weight OR size) AND TOPIC: (temperature\*) AND TOPIC: (optimum)*

This resulted in 3313 articles (search date: 2019.03.22). We then also applied additional filters on subject (Web of Science Categories). These were: *FISHERIES, MARINE FRESHWATER BIOLOGY, ECOLOGY, ZOOLOGY, BIOLOGY, LIMNOLOGY and PHYSIOLOGY*. This reduced the number of studies to 566.

## *Growth data (same protocol though…)*

To find published studies to use data from on body growth rates across a large enough temperature and body size range we searched Web of Science Core Collection on 22/03/19 with the following terms: TOPIC: (*growth*) AND TOPIC: (*mass OR weight OR size*) AND TOPIC: (*temperature*\*) AND TOPIC: (*optim*\*). Further filtering by the Web of Science categories ‘*fisheries’*, *‘marine freshwater biology’*, *‘ecology’*, *‘zoology’*, *‘biology’*, *‘limnology and physiology’*, lead to a subset of 893 studies. First we manually removed studies that did not fulfill all of the following conditions: (1) experimental studies, (2) fish as study organism in life stages older than larval (3) replicates across both size and temperature. Next we evaluated the abstracts and lastly the whole paper. At this stage we also removed studies from which we could not extract (4) growth rates, (5) a single controlled temperature for each growth trial and (6) a clearly defined size class. In addition we ensured that no other treatment (e.g. food limitation) confounded the response variable. In cases where we found more than one study for the same species we selected the study we found most suitable or valuable given pre-defined criteria. While this reduces the number of data points, it ensures that all data within a given species are comparable as measurements of these rates can vary between studies due to e.g. measurement bias or differences experimental protocol. We compiled two separate data sets: (1) raw growth rates (growth\_data.xlsx) and (2) temperature at optimum growth (growth\_data\_Topt.xlsx), where we defined optimum temperature for growth as fitted optimum temperature (in the original study) or in some cases as temperature where the highest growth rate was achieved for a given size-class. All data were extracted from tables or figures using Web Plot Digitizer (Rohatgi 2012), since no study had associated data and authors could not provide it. The optimum growth-temperature data set has 45 data points and the growth data contains X measurements, both spread over the same 13 species. + More info on the spread of data (size ranges, biogeography etc)

# Selection process and criteria

We filtered out articles at three levels of the search: title, abstract and full paper. Appendix **SX** contains lists of paper titles at each of these steps in the filtering process. We also used studies that did not appear in the literature search but that we found by following cited literature in papers to the original source. Such studies are indicated in the data set as an explanation for why they do not appear in Appendix **SX**. When treatments where conducted in the experiment, we extracted data from the control-scenario. When several studies were found for the same species, we did not mix the data but instead chose the study with the largest size and temperature range (in that order), as there can be large differences in absolute values of some physiological parameters between studies (e.g. Armstrong) (did I not write down this protocol somewhere?). See documents I prepared for meeting with Jan and Anna, if I had to take other things into consideration. For cod e.g., we can also cite the other papers essentially showing the same thing!

For metabolic- and consumption rate, we filtered out articles from the full list of article titles if it was evident that: the organism was not a fish, it was not an experimental study or used data from an experiment, not a feeding rate. In the abstract and manuscript, articles where filtered out if: the original reference could not be identified and evaluated, if it was a generic parameter-value based on literature, consumption rate was not ad-libitum or if it was not standard/routine metabolic rate, if there was no acclimation, if multiple rates measured at multiple temperatures where pooled prior to estimating the size-dependence of the rate, if only the fitted equation was only provided in text and not plotted (and we did not acquire the data after asking the authors) (e.g. ref!) and no acclimation was done.

For growth-rate data we are interested in exploring how temperature-optimum depends on body size within species. Therefore, the minimum resolution of the data we extracted from the literature had at least one narrow size range and the optimum growth temperature for that specific size range (note, however, that in theory a study may use a temperature that is not strictly the optimum growth temperature for the species and size range, which still might be closer to the optimum than a study using several discrete temperatures and finding that one of them is highest (!). Note also that this means we don’t need to estimate a size effect within species here, which we do need in the other rates. That is because we don’t need to estimate a growth-exponent within species here, which we do with the other rates – but that’s because we want to predict the growth-exponent (or at least some growth-temp-size patter) from that data. We don’t \*need\* to do that with our growth data, because there we just want to describe it growth. The only issue is then that we could have done the Cmax and Meta plots over temp with only one size-class (or at least mixing intra- and interspecific replication species)! Ideally we want data with a both a temperature and a size range, so that we can estimate an intraspecific slope of how optimum growth temperature depends on size within species, by sharing information across species. In order to relate it to the analysis of metabolic- and maximum consumption rate, we use only *ad libitum* feeding, because feeding level can affect the temperature optimum for growth. In some cases this could be very high ration also. Or ad libitum few times a day. Key is actually not “reduced ration”. And that excess feed existed (because it was removed)

* Say that we took the highest-growth temperature sometimes, or extracted it from a fitted curve, in which case it could be a non-measured temperature
* Say that all growth rates are strictly defined as SGR (% weight increase/day) – see Björnsson for equation
* Size refers to … calculated based on size range in temp experiment closest to optimum/maximum

We used either fitted optimum temperature, or in cases where the effect of temperature on growth rates where not estimated, we took the temperature yielding the highest growth (minimum number of temperatures = 3, and they need to be in or around optimum).

* Did we or did we not collect data for species with single temperature? Better to clean raq data, current some n=1 species, especially for cmax. I did clean the data, so now just say we selected species with more than one temperature in the analysis and that’s what’s online for reproducing the results.

# Data acquisition

* Data, parameters..
* Auxiliary variables. “First of all, we manually checked all temperature-information on Fishbase by looking for the original source.”
  + Body sizes are sometimes taken from length and converted
* Species specific tables on units, temperature, wmax is from length sometines using a and b
* Add that we got weight from Fishase length weight param if only length was given (e.g. for maximum size)

# Data explanation & unit standardization

Table 1 Explanation of metabolic rate & maximum consumption scaling data

|  |  |
| --- | --- |
| **Column** | **Explanation** |
| e.g. temp\_mid\_fishbase | If no info, then used something else |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

# Data exploration

# Statistical analysis

## Maximum consumption rate

## Metabolic rate

# Bibliography

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