Author's response

We would like to thank the two anonymous reviewers, whose comments significantly improved our manuscript. Please find our detailed response below. We added numbering to the reviewers comments to easier link to responses that apply several times. Corresponding changes in the manuscript are highlighted in yellow. Line numbers refer to the revised manuscript, attached to this response letter.

Larger changes in manuscript:

- Trait body weight removed from database (see comment 24, reviewer 2).
- All figures, tables and numbers in the text are updated to the latest status of the database.

1) Comments of reviewer 1
   ➔ Response to reviewer 1 in blue
2) Comments of reviewer 2
   ➔ Response to reviewer 2 in green.
3) Revised manuscript
4) Revised supplement

Reviewer 1

Interesting data approach, possibly a useful topic, seems like a good candidate for ESSD. Presentation however leaves much to be desired.

1) Thinking ahead (starting now) to urgent marine issues in the Arctic (loss of snow and ice, change from solid to liquid precip, changing run-off, changing local mixing and large scale circulation, change from predation to grazing, change in primary production / carbon fluxes / nutrient recycling, invasive species, increase in IUU fishing), and of the key role of benthic ecosystems in all the above, I think the authors intend to take an approach that says "document what we have from a functional approach so that we can better anticipate, monitor, detect and model on-going and future changes." Further "here we present a tool that can help our community achieve the functional approach". So far, so good, but how will this tool get used within but particularly beyond the benthos community. What changes, improvements, increased compliance, etc. does this tool need to serve valid research functions for the future Arctic? The authors hint at these directions and questions but give us only bibliometrics and screenshots?
About traits, authors emphasise, particularly in the introduction, usefulness of the trait approach as "indicators of ecosystem functioning" (authors words, page 1 line 30) for which they then elaborate: biodiversity, vulnerability to changing climate, etc. They assume that readers will accept the trait approach as somehow advantageous ("inherent advantage", page 1 line 33). Perhaps, but a reader reaches the end of this paper having encountered almost no examples (on page 11 we get one useful example of how fuzzy coding works for 'motile' species) of how the database, if fully populated, will help us address crucial issues. The authors seem to want to demonstrate a "popular" option while readers want and need to understand how this tool helps us address urgent research questions? Not how popular, how useful!

We understand the reviewers interest in specific applications, however, this is not in the scope of the present paper, nor is it – to our understanding – within the aims and scope of ESSD ("*Any interpretation of data is outside the scope or regular articles*"). RD has a publication that shows some specific applications (building on the data in the database) in preparation (more information can be found on the webpage of the Arctic Traits Project https://sites.google.com/site/arctictraits/home/the-project). But the present manuscript is a data paper. It describes the Arctic Traits Database: how it was developed, the improvements compared to other data repositories, how we tackle standardization issues, what it contains, how it can be used (i.e. how the trait data can be accessed and downloaded). How users proceed from there on is beyond the scope of this work. Trait-based approaches are not new, they are used in marine ecology already since the late 1970ies (as we show in Fig. 1). Consequently a plethora of research questions that can be tackled and applications exists. The only thing they all have in common is that the basic input are traits (see manuscript line 40). Although we cannot go into methodical detail here, we do refer to some concrete examples right at the begin of the introduction (line 28 f) which guide the interested (but yet unaware) reader further. We now added some more references here (Darr et al. 2014, Foden et al. 2013, Hewitt et al. 2016), to further stress the methodical variety. We now also added references of papers that focus specifically on methods (Beauchard et al. 2017, Kleyer et al.2012) in line 40.

Although the main users of our database are (and will be) mainly benthic ecologists, the data is of use also to other disciplines. These include climate researchers, ecosystem modelers, oceanographers, biogeographers, and potentially even geologists.

Further the code package underlying this database is now accessible at figshare via https://doi.org/10.6084/m9.figshare.7491869. This allows scientists to easily build their own trait database for other ecosystem components (e.g. zooplankton, phytoplankton, marine mammals, …). We added this information in part 3.3, line 272f.

2) The Degen et al. 2018 paper in Ecological Indicators (open access, thanks) presents substantial sections on challenges and a specific roadmap. Without repeating verbatim, a précis of that message should find a home here, to set the stage? The authors repeatedly allude to this work meeting community needs and community standards. We could better accept those assurances if we had some tangible examples. Suggest a re-write along the lines of the following outline:
Introduce the trait approach to the earth sciences data community
- briefly justify trait approach compared to taxonomic approach,
- what one can do differently / better in terms of monitoring, ecosystem modelling, carbon or nutrient fluxes, etc.
- what more crucial place than coastal shelves of the Arctic.
Your Arctic Traits database
- goals
- approach
- content
- accessibility
- interoperability
Utility, both as an ingest tool and as a research tool
Contents so far

Example (1 or 2) how to use it
- something about biogeography, invasive or migration
- something about carbon and nutrient fluxes, number and clearance rate of filter feeders, how a benthic ecosystem in the Chukchi might respond to changed carbon imports with changed nitrogen returns, dependence of community structure, feeding activity, reproductive timing, nutrient fluxes on temperature and oxygen, differences Chukchi to Barents, etc. Real example or, if present data prove too limiting, hypothetical example.
What next?
- as an ingest tool and community repository
- as a research tool for a changing Arctic
In the view of this reviewer, the authors have sufficient information to provide, after revision, a much improved description of and guide to this database. Don't show us what we can find ourselves on the web page, show us how we can use this tool!
See response above (1) regarding the specific examples. Regarding the overall structure we follow an outline that is comparable to other database papers in ESSD (e.g. Brun et al. 2017):

1) Introduction & goals
2) Data (choice of taxa and traits)
3) Database (way of structuring and presenting data)
4) Results (current content of the database)

Brief specific comments, assuming the authors make a major revision as recommended:

3) The review apparently treats benthos as independent of water column, but what about sea ice cover, plankton particulate carbon deposition, carbon fluxes, historical depletion of whale and seal populations, continuing harvest of krill, etc. Give us please the valid benthos fully interactive with and essential to water column processes.
Our review paper (Degen et al. 2018 Ecological indicators 91: 722-736) was already reviewed and published in early 2018. At no point it states that benthos is independent from water column processes.

4) Page 2 line 36: Figure 1. Figure 1 not useful nor relevant. Because this reviewer mistrusts any topic where the authors must 'prove' its relevance by starting from bibliometric records, I suggest you simply leave it out.
We understand that figures are always a matter of taste. However, we consider Figure 1 relevant as it clearly shows the increased interest in biological traits, especially in studies from the benthic realm. As such it underlines the current need for sound trait databases that we stress in the introduction.

5) What about Russian source materials. Kedra et al, cited, addresses this issue slightly and these authors reference Laptev Sea Lena R outflow transects work published by Kokarev et al. but, as for plankton, any database of Arctic ecology that does not include overt mechanisms to include Russian language publications will miss a very major fraction of possibly useful information? Does the benthos suffer a similar language barrier? If so, how will the authors address such barriers?
This is definitely an important issue. We are happy to have now (since very recently) Valentin Kokarev on board the editorial team of the Arctic Traits Database, who will in future add information from publications in Russian language.

6) Page 2,3, Table 1: Good list but gets messy and out of order by the bottom entries. Include row demarcation? No diatom or coccolithophore (live or as deposited) databases? As for Figure 1, how useful is this table in a description of the particular Arctic benthic database? Leaving it out would not impact the overall description?
The purpose of this table is to give an overview of existing databases and the ways that data can be accessed, as such it helps to identify the improvements we offer with the Arctic Traits Database (i.e. online browsing + several download options like fuzzy coded trait matrix). We added the coastal phytoplankton trait collection by Riina Klais to the table. We also added row demarcations.

7) Page 3 line 62: “atomised”? A database term? Most readers will not know at this point what you mean by that word. This reviewer knows DarwinCore metadata guidance, but other readers will want a reference?
We changed the sentence in line 64 to “...and provide download of trait data in different tabular formats (i.e. data in columns, once following a database-specific format and once DarwinCore). “ A reference for DarwinCore is added (Wieczorek et al. 2012).

8) Page 3 lines 68 to 70: Agree, and this represents the strong motivation and potential impact of this work. Move this statement earlier, in a more prominent position?
Added now to the abstract in line 18 (“…including for the first time the option to download a fuzzy coded trait matrix”).

9) Reference to a “pan-Arctic” approach and simultaneously, apparent regional focus (Svalbard, Chukchi)? In fact, we get no biogeographic information whatsoever from this database. Why this regional mention here that never gets a follow up?
As stated in line 80: “The regional coverage <u>currently</u> comprises the Chukchi Sea and the Svalbard area”. So this is so far as we got by now, but more data are added successively. This database provides species-specific information, not biogeographic information. For this we we refer to OBIS and GBIS (see line 102f).

10) Page 4 line 93: Costello et al represents a weak and not particularly reliable reference, mostly a self-citation tool for Costello. Fundamentally, Costello et al. recommend following the BIOTIC and FishBase database models. Do the authors not have something stronger on which to base their selections? One of the other marine species databases listed in Table 1, for example? Or other work that satisfies Steps 1 and 2 of the workshop report?
We consider this paper important and the appropriate reference here, as it is the first that clearly states the importance of standardization processes and prioritizes the development of a marine trait database. The authors are all acknowledged experts in the field (along Marc Costello there is e.g. Leen Vandepitte from WoRMS and Harvey Tyler-Walters from BIOTIC).

11) Page 4 line 95 “deep linked”? A database term? Reader does not know what the authors mean here?
Deep linking refers to the use of a hyperlink that links to a specific web content. We changed to “…every species in the database is bidirectionally deep linked (i.e. connected via a hyperlink) to the World register of Marine Species…” in line 100.

12) Page 4 line 97: In GBIF a user can find reported occurrences of species by geographic location. As presented today, the Arctic Traits databases offers zero geographic location

information. Reader will need to copy the species name from Artic Traits into GBIF to find location. I tried that for Nereis Linnaeus, more than 7000 records in GBIF including hundreds in the Arctic, but no zoogreographic information in Arctic Traits? Is this an example, not very successful, of “deep linked”? Should Arctic Traits become traits database linked under GBIF, for all co-listed taxa?
See before (9). We are now linked with WoRMS (in both directions, since January 19 WoRMS provides deeplinks back to us). Traits data is outside the scope of OBIS and GBIF, as these two are biogeographic databases. They do not foresee the integration of trait data.

13) Page 4 line 103 to 108: confusing section! Physiological traits not defined nor well justified. Are they interesting or not interesting, retrievable or not retrievable. Are Arctic species generally eurythermal (which also depends on life history stage) or stenothermal? Reader has no idea what to conclude from this section or about the inclusion or not of physiological traits in the database.
We don’t really see what causes the confusion in this part, as we clearly state why physiological traits (examples thereof are given in brackets in line 111) are excluded. As stated, it relates to the violation of the preconditions for a trait to be included (i.e. being retrievable for most taxa and being usable across a wide geographical area). The preconditions are clearly explained just above (in line 88).

14) Page 10 line 155, 156: Here readers learn that Arctic Traits database includes species with wider biogeographic ranges, not only those species with exclusively Arctic ranges. This inclusion seems to relate to an earlier question of whether the function descriptions in the trait tables referred to only polar or to cosmopolitan species. Apparently the latter? Needs clarification!
We don’t understand this question. In the revised manuscript (according to a comment by Reviewer 2) we added a definition to the trait categories of zoogeography in table 3 – does this solve the issue?

Page 11, 12 fuzzy coding: A necessary inclusion, well described, good use of examples!

15) I don’t know ESSD policy, but most journals do not publish web page screenshots. Give us links instead? Here the authors unfortunately take the approach of showing us the product rather than demonstrating its utility. Walk us through a couple examples, using links in place of screenshots?
To our knowledge screenshots are tolerated in ESSD. Also, the screenshot in Figure 2b and those in the Supplement come from the restricted area of the database (access only for registered users), so this cannot be provided as web link.

16) Tooltip function (dragging cursor across indicator bar) does not work on my machine (MacBook Pro, OS 10.14 Mohave, Safari 12.0).
Fixed that.

17) To get data I need to submit a request. That means that Arctic Traits knows my IP address and can find my user information?
Yes, the user submits a request and the IP is sent to the server. This is however already done when the user only views the site, not only when a request is submitted (normal HTTPS communication). The website is compliant with the European General Data Protection

Regulation (GDPR). While the IP address could theoretically be linked to identifying information, the University of Vienna does not exploit this information or use it in any other way (e.g. marketing) than ensuring the functionality of the servers and IT infrastructure. The University of Vienna, to be compliant with Austrian legislation (Art. 6 Abs. 1 lit. f DSGVO), may retain the information for maximally 30 days. This is already stated on the website at https://www.univie.ac.at/arctictraits/privacy.
Thus, the website, being hosted by an Austrian institution is compliant with Austrian laws and technical specifications are being implemented accordingly by the University of Vienna.

18) Downloaded skeleton file, largest category so far, very detailed, successful download, data access seems good. But, now that I have it, how would I use it? Find all the calcareous species to estimate their role in benthic carbon cycle? I find almost 900 records, out of 2040 total, impressive. After this initial sort I would need to resolve too-numerous species overlaps / redundancies? E.g. 900 records might really only represent 500 or 600 valid independent species. The database won't do this taxonomic clarification step automatically?
We thank the reviewer for highlighting an important aspect, and now include also the rank of a taxon in the download (see also according changes in Table 7 and 8). Apart from that, the common scenario with trait databases is that users have a specific dataset (e.g. benthos abundance data of xy sample stations), for which they want to find trait information. So they upload their specific taxon list and download only the traits of exactly these taxa. Accordingly, for those users a taxonomic "clarification step" is not necessary.

19) I assume in the database as opposed to the .csv file, I can click through to the exact reference and any text excerpts if I desire?
The literature sources and excerpts are also included in the .csv download, so the user is not required to click manually through the database (although this option exists).

20) Next, on the carbon question, I would want to know sea floor population density of these calcareous organisms, carbon fixation rates as a function of season, temperature, O2, POC or DOC fluxes, biogeographic distribution including proximity to, for example, riverine inputs or ice fronts or ocean circulation fronts. I might find helpful information under Body Weight, Living Habit, Reproduction, Feeding Habit, Tolerance, and Depth Range. Zoogeographic here would provide zero useful information. But, in general, I would or would not find useful information here? As an alternative, for a species whose carbon uptake rates I knew from literature, I could go to GBIF to learn its frequency of occurrence in Arctic regions of interest and then do some spatial and physiologic extrapolations? How did the Arctic traits database help me or hinder me in this case? A weak example chosen on my part? If so, give us a stronger more favourable example?
As stated above (1), specific examples are outside the scope of this article type for this journal. But to follow up on the reviewers thought, one idea that comes to mind here are Brey's empirical models that can be used to estimate secondary production or respiration (Brey 2012). Required input are temperature, depth, body mass, and certain traits such as environmental position, mobility, feeding type (traits all included in the Arctic Traits Database). Other large-scale approaches (up to global) use trait information in combination with distribution data from OBIS or the IUCN red list. As one specific example, Foden et al. (2013) followed this approach to identify "The world's most climate vulnerable species"and used traits such as dispersal potential or habitat specialization.

Brey T, 2012. A multi-parameter artificial neural network model to estimate macrobenthic invertebrate productivity and production. Limnology and Oceanography Methods 10: 581-589. DOI: 10.4319/lom.2012.10.581
Brey T, 2001. Population dynamics in benthic invertebrates. A virtual handbook. http://www.thomas-brey.de/science/virtualhandbook/
Foden, W. B., Butchart, S. H. M., Stuart, S. N., Vié, J. C., Akçakaya, H. R., Angulo, A., DeVantier, L. M., Gutsche, A., Turak, E., Cao, L., Donner, S. D., Katariya, V., Bernard, R., Holland, R. A., Hughes, A. F., O'Hanlon, S. E., Garnett, S. T., Şekercioğlu, Ç. H. and Mace, G. M.: Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals, edited by S. Lavergne, PLoS One, 8(6), e65427, doi:10.1371/journal.pone.0065427, 2013.

Reviewer 2

1) Please explain how to work with trait based analyses when some (many) Arctic species/taxons cannot be traitet due to lack of information. In other words: how large part of a database can lack information, but still be possible to analyze? Is it 5%, 15%, 50%?
Most specific software (e.g. R package ade4) can deal with missing trait information, but it remains to the user who interprets the results to decide how many gaps can be tolerated, or whether a trait-based approach might no longer be reasonable. So far, there is no general acknowledged procedure on this. Some papers deal specifically with this issue, e.g. Tyler et al. (2012) or Májeková et al. (2016).

Tyler, E. H. M., Somerfield, P. J., Berghe, E. Vanden, Bremner, J., Jackson, E., Langmead, O., Palomares, M. L. D. and Webb, T. J.: Extensive gaps and biases in our knowledge of a well-known fauna: Implications for integrating biological traits into macroecology, Glob. Ecol. Biogeogr., 21(9), 922–934, doi:10.1111/j.1466-8238.2011.00726.x, 2012.
Májeková, M., Paal, T., Plowman, N. S., Bryndová, M., Kasari, L., Norberg, A., Weiss, M., Bishop, T. R., Luke, S. H., Sam, K., Le Bagousse-Pinguet, Y., Lepš, J., Götzenberger, L. and De Bello, F.: Evaluating functional diversity: Missing trait data and the importance of species abundance structure and data transformation, PLoS One, 11(2), 1–17, doi:10.1371/journal.pone.0149270, 2016.

2) The categorical traits (e.g. body shape, reproduction, larval development, and more) are well suited to be divided into modalities and to be used in fussy coding. Here obligate traceability of literature information is important, but lacking for, as said in the manuscript, many Arctic species and rocky bottom communities. Please explain how to work with trait based analyses when some (many) Arctic species/taxons cannot be traitet due to lack of information. In other words: how large part of a database can lack information, but still be possible to analyze? Is it 5%, 15%, 50%? Or is it so, that the use of the Arctic Trait Database (Degen & Faulwetter) cannot fulfill its purpose before all categorical trait information is in place and with the obligate traceability of literature information?
See above (1).

3) Please explain how the user can work around the problem with categorical trait information that lacks the obligate traceability of literature information.
The Arctic Trait Database does not contain trait information that is not backed up either by literature, database links, or in case of "personal observation" or "expert comment" by a contact that provided the information/observation. See part 2.3, line 152 f.

4) The continuous traits (e.g. body weight, size, height) are measures that are (or could be) obtained during the field work, and are therefore not be limited to "the obligate traceability of literature information". You mention in the manuscript that "Arctic species" can be

deferent than their relatives from lower latitudes". With this, you open for a discussion on species "plasticity" and "adaptation" from area to area. Please explain the difference between a "Trait value" and a "field value" here.

Due to our third precondition for traits to be included in our database ("the traits should be usable across a wide geographical area", part 2.2) we do not account for regional plasticity. Instead we use the maximum body size that we find in literature (or have measured in the field, or are informed of via communication with experts) (as previously suggested by e.g. Costello et al. 2015). To make this more clear to the readers this aspect is now explained more in detail in part 2.2 line 91f ("In order to fulfil this last precondition, the trait body size is provided as "maximum body size as adult" (see also Table 3). While clearly a tradeoff in regard to the detection of intraspecific plasticity, it enables the use of this trait across large spatial scales.").

5) If "field values" are to be lumped into broad categories (see table 3: e.g. body size, body weight, zoogeography – i.e. tolerance of temperatures, and depth range), they might be a tool to compare across areas (if same sampling tool has been used). But if used as a long term monitoring assessment, the "trend" will be "drowning" inside the category, and most likely a catastrophe needs to happen before a signal come forward. With other words, the "early warning signal" will not be available unless the field data are used as detailed as possible.

As the reviewer correctly states, the intraspecific plasticity (e.g. in body size) cannot be tackled with this database (see 4). However, users can still use our database to detect changes or "early warning signals" in their time series community data, as changes in the abundances and/or in the community composition will be reflected in the size spectra (not on species level, but on community level).

6) In the arena of "plasticity" and "adaptation" from area to area, there might be many different values given by a variety of literature references. You have used a "flagging system" to observe this type of "inconsistency". Would it be an idea to simply accept that some values are not consistent and therefore need to be obtained as field values, and not be added to the Arctic Trait Database? If not, please explain what to do with such continuously variable with many different literature-based values – do you trust your field data, or do you need to take the "global plasticity" into consideration? If this depends on your scientific question, please explain this carefully, so the reader will understand the differences between and the usefulness of a "trait-value" and a "field-value".

As stated above (4, 5), we deal with the obvious plasticity in body size by using the max. body size as adult (see Table 3). The "global plasticity" is an issue we briefly discuss in part 2.3 line 159f. Where possible we use literature from the Arctic, but when not available also wider sources are included. As for all traits, literature and/or field measurements are taken into account when available (as explained in part 2.3). For the final coding of the trait, the largest size value is considered (no matter if source is a book or field data). This holds true only on species level, in higher taxonomic levels (e.g. family) the broader range (if applying) is accounted for by coding a "2" over several size classes.

7) Another point that you might bring forward is "species more or less affected by trawling (see Body size in tab 3)". What type of Body size value are you referring to here: the station mean body size of the species, the area mean body size of a species or "the obligate traceability of literature information value" These three values might differ a lot.

See above, 4-6.

8) Please also be aware that a trawl-vulnerable organism (e.g. a sea feather or similar) might evaluated by its "body-size". But, is a small (i.e. young) individual of a species "less vulnerable toward effects from trawling" than a full-grown individual of the same species?
We use max. body size as adult. Juvenile traits are not considered in this database except for larval development. A trade-off in favor to the goal of this database to be applicable across wider geographical areas. Users need to carefully assess which traits and categories that we provide are suitable for their analyses. As the literature reference is given, the user is free to trace back the information and re-evaluate the trait for their analyses, if needed.

9) Is it so that in this type of vulnerability assessment studies a "obligate traceable literature information value" is more correct? Because it is not clear forward when to use field data or when to use "obligate traceable literature information value" it is very important that a pre-evaluation period is made before trait analyses are made.
See before, 4-6.

10) There is an issue of "not all species (particularly Arctic species) being traited" due to the lack of "obligate traceable literature information" on morphological, life history, behavioral traits information. I therefore wonder what type of method need to be used to calculate and finally obtain a result that can be, for example, depicted on a map. Again, I expect that the answer will be that this "depends on the scientific question that is been asked". But could you please explain how to move from an incomplete species-traits database to the most appropriate method, and further to the presentation (be it a map or a figure) that identify the results but also the flaws?
For a study that focuses only on a subset of species or traits, the data we provide may well be complete. And if not, it is up to the user to decide how to deal with the missing data, either by inference from related species, higher taxonomic levels, by using additional direct measurements, by conducting their own literature research to complement the information, or through statistical imputation methods.

General comments:

11) Line 39: what is a species "trait" – please define very clearly.
Modified line 26 (first mention of the term) to make more clear.

12) As clearly stated by the auditors – few (if any) literature proved traits are available for all species – what do you do with a field analyses when you have "missing trait data" because of lacking literature evidence?
See above, 1 and 10.

13) Even if one or more literature references are available for a species Trait – how can we be sure that its correct? –the wording in line 13 "- obligate traceability of information (every entry is linked to at least one source)" seems overemphasized (see also line 157-158).
We emphasize the traceability of information because it is a quality criterion of this database. It is not possible for us to prove that the source is correct. The final choice to use this information or not lies with the user.

14) When a literature based trait is not possible to find for a species, and when a specific trait (for example "size") can vary from one geographic area to another, a "obligate literature traceability" can be misleading information.
See above, 4-6.

15) Line 86-88: traits used in previous studies and databases should be favored to enable comparisons across studies (Degen et al. 2018), and 3) the traits should be usable across a wide geographical area (Bremner et al. 2006). Characteristics such as "body weight", "size", "morphology", "temperature preference", and "depth range", are area depended and subjected to adaptivity/plasticity for existing environment. Do to the "line 13 - obligate traceability of information (every entry is linked to at least one source)" meaning that your species need to be pre-defined with a trait, please explain why changes in "field-based traits" such as "size" cannot be used.
See above, 4-6.

16) Field based characteristics are very important "traits" in monitoring to detect "early warning signals" (see also line 70). These type of field based traits cannot be useful if lumped into large modalities as for example S1-S5 and W1-W5 because a "catastrophe" need to happen before a species will fall from one modality to another. And if literature based evidence shall be given for a trait, such as "size" – how can we detect a change in an area? Please explain why "field-based traits" are not coming into consideration in your choice of traits (line 85-88)?
See above, 4-6.

17) Line 85-88 – says that chosen traits shall be available and applicable to all benthic taxa . .. but still . . . as also stated in the manuscript – not all species (particularly not the Arctic species) can be traitet due to the lack of literature based evidence – so what do you do when you will like to apply traits to a dataset? Does this means that the trait database cannot be used because of this lack of literature based trait evidence? Please explain how to cope with this.
See above, 1 and 10.

18) Traits must be selected in accordance to the scientific question. If a comparison to other areas are important not only same trait and modality has to be used, but also the same type of analyses. Please describe the steps from the fuzzy coding, the analyses and the mapping that can be applied to "all" in order to compare across regions.
It is not the aim of this paper to explain trait-based approaches, and it is also not according to the guidelines of ESSD, which is a data journal. In addition, there is no one single analyses. There are at least as many types of analyses that can be done with traits as can be done with species occurrence data. Every statistical analysis depends on the scientific question in mind, the only thing that changes here is the type of input data (i.e. traits instead of occurrences or biomass or abundances). Nevertheless, in order to guide interested (but yet unaware) readers towards appropriate literature we added even more references now in the introduction, line 29f and 40.

19) Line 115-148: You divide your traits into "indicators of ecosystem functions (effect traits)" and "changes in the environment (response traits)". But it is unclear how you use these two categories in table 3. Can you please mention them specifically here?

This is a common approach, not invented by us. To make this clear we refer now to an older review, Hooper et al. (2005). We decided not to use these categories in Table 3, as traits can be both, effect and response trait, depending on the situation, or neither, which might be more confusing than actually add additional value to this table. Instead we give specific examples, e.g. “Size has a direct effect on productivity …”, or “Long loved animals are more susceptible to disturbance…”. To clarify this we changed the text of the table capture now to “The relation of the respective trait to benthic ecosystem functions or responses (i.e. its role as effect or response trait) are given via specific examples and underlying literature sources are displayed.”

20) Please make it clear in Table 3 if Body Size, BodyWeight, Zoogeography, Depth Range are “Field-based Traits” or if they have to be “obligate traceability of information (every entry is linked to at least one source)”.
See above, 4.

21) Table 3: Please define the “Zoogeography” Trait. What is an Arctic, a Arctic-boreal, and a boreal species defined as. . . what temperature ranges?
This trait relates to the biogeographic distribution (unfortunately we don’t know the temperature preferences of many arctic taxa). Added the following definition into table 3 (and online):
“Definition: Spatial distribution of a species in relation to commonly used zoogeographic regions.
Arctic: Confined to Arctic regions.
Arctic-boreal: Arctic, sub-Arctic and North Atlantic/North Pacific distribution.
Boreal: North Atlantic and/or North Pacific distribution, sub-Arctic regions such as Southern Barents Sea or Bering Sea.
Cosmopolite: Cosmopolite distribution”

22) If lines 149-154 is true, please add them up front in the paper so it is clear that a “trait” have to be both “field-based” and “literature-based” in order to be able to apply a traitbased analyses on all, and not only on a subset of species.
We added this information now also in the introduction in line 41: “… labor intensive survey of literature, databases, field data, and expert knowledge.”

23) Chap 4.2 – it is also obvious that the trait database most efficiently covers macrofaunal species as Annelida, Arthropoda, Mollusca .. It might be written up front in the manuscript that mega-fauna, such as Echinodermata, Sponges are “under development” and therefore not fully operative due to many missing literature based-traits.
Added “At present stage mainly species in the macrofauna size class have been uploaded” in part 2.1, line 81.

24) Line 188: I agree that “Body weight” can be removed from the database because this trait is plastic and variable within and between areas, i.e. not a global constant, and will not be covered efficiently by 1 or 2 literature based references.
We decided to remove this trait because information on max. body weight was rarely found, not because its plasticity (see comments on this topic before, 4-6).

The Arctic Traits Database – A repository of arctic benthic invertebrate traits

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Abstract. The recently increased interest in marine trait-based studies highlights one general demand – the access to standardized, reference-based trait information. This demand holds especially true for polar regions, where the gathering of ecological information is still challenging. The Arctic Traits Database is a freely accessible online repository (https://doi.org/10.25365/phaidra.49; https://www.univie.ac.at/arctictraits) that fulfils these requests for one important component of polar marine life, the Arctic benthic macroinvertebrates. It accounts for 1) obligate traceability of information (every entry is linked to at least one source), 2) exchangeability among trait platforms (use of most common download formats), 3) standardization (use of most common terminology and coding scheme), and 4) user friendliness (granted by an intuitive web-interface and rapid and easy download options, including for the first time the option to download a fuzzy coded trait matrix). The combination of these aspects makes the Arctic Traits Database the currently most sophisticated online accessible trait platform in (not only) marine ecology and a role-model for prospective databases of other marine compartments or other (also non-marine) ecosystems. At present the database covers 19 traits (80 trait categories) and holds altogether 14242 trait entries for 1911 macro- and megabenthic taxa. Thus, the Arctic Traits Database will foster and facilitate trait-based approaches in polar regions in the future and increase our ecological understanding of this rapidly changing system.

1 Introduction

The interest in trait-based approaches – i.e. such that consider the life history, morphological, physiological and behavioral characteristics (i.e. traits) of species – in the marine realm has been growing tremendously in the last decades (reviewed in Degen et al., 2018) (Fig. 1). Reasons for the increasing popularity of these approaches are that they offer a variety of additional options to solely species-based methods: Traits can be analyzed across wide geographical ranges and across species pools (Bernhardt-Römermann et al., 2011), they can be used to calculate a variety of functional diversity indices (Schleuter et al., 2010), to estimate functional redundancy (Darr et al., 2014), or be used as indicators of ecosystem functioning (Bremner et al., 2006). Given the rapid changes we observe in many marine regions of the world, and especially in the Arctic Ocean (Wassmann et al., 2011), the potential to indicate vulnerability to climate change and biodiversity loss, or to estimate climate change effects on ecosystem functions is another inherent advantage of trait-based approaches (Foden et al., 2013; Hewitt et al., 2016).

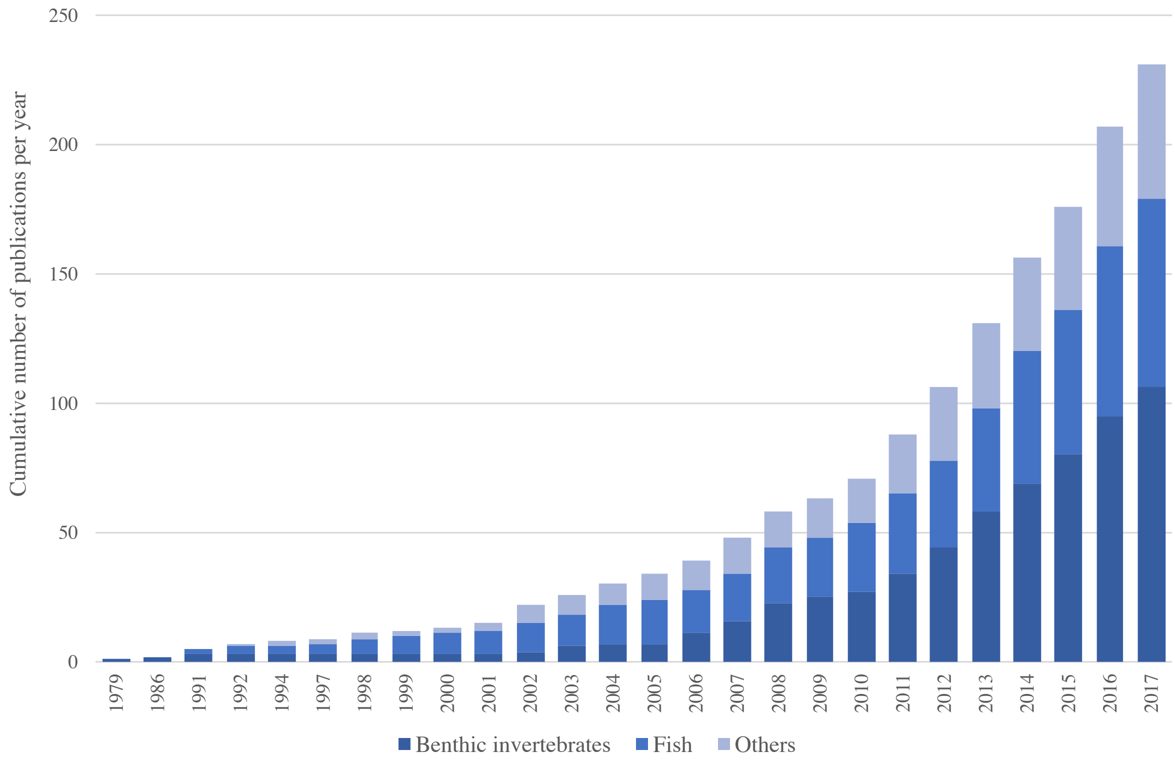

Figure 1. Cumulative number of marine trait-based studies based on the literature review of 233 studies from the marine realm by Degen et al. (2018).

Although the methodical diversity and complexity of trait-based approaches has broadened in the last years (Beauchard et al., 2017; Kleyer et al., 2012), the underlying data are always species traits. Trait information, however, is often not easy to find, and its collation requires a time and labor intensive survey of literature, databases, field data, and expert knowledge. This holds especially true for the polar regions, as ecological information for many polar marine taxa is still scarce, and only few publications supplement traceable resources of trait information (e.g. Kokarev et al., 2017). An additional obstacle is that existing trait repositories focus mainly on species from temperate regions. The increasing variability in terminology that surrounds traits is another challenge, and recent publications stress the importance of standardization in order to facilitate meta-analyses and comparison of results (Costello et al., 2015; Degen et al., 2018). Several online accessible trait databases specialize in specific taxonomic groups such as fish, polychaetes, or copepods, while others cover a wider part of the marine community (Table 1). The number of traits included and the form of access varies considerably among the different repositories. The database for marine copepods (Brun et al., 2017) contains 14 traits, whereas Fishbase (http://www.fishbase.org), polytraits (Faulwetter et al., 2014) and BIOTIC (http://www.marlin.ac.uk/biotic) contain more than 40 traits. Some repositories allow only for online browsing, while others enable different forms of download that range from spread sheets to different matrix formats (Table 1). No traits repository explicitly comprising polar species exists so far.

Table 1. List of marine trait databases or repositories. "Component" indicates the organism group targeted, "Access options" indicates in which forms the data can be accessed. Reference and web links are provided.

Component	Access options	Publication, web links
Copepoda	Download of excel workbook via PANGAEA, traits provided as original values or binary code (0/1), references per trait provided.	Brun et al. (2017) https://doi.pangaea.de/10.1594/ PANGAEA.862968

Polychaeta	Download of full database or specified subsets in various formats (references and partly original quote and page number provided), online via browsing the *Polychaetes Scratchpads*	Faulwetter et al. (2014) http://polytraits.lifewatchgreece.eu http://polychaetes.lifewatchgreece.eu
Benthos	Download of trait information in several matrix formats; as text and for certain traits as binary (0/1) code, also browsing online	Biological Traits Information Catalogue (BIOTIC) http://www.marlin.ac.uk/biotic
Fish	Browse online, programmatically via Application Programming Interface (API) and R package rfishbase	Froese, R. and D. Pauly. Editors. 2018. FishBase. www.fishbase.org, version (02/2018)
Benthos	Browse online	Marine Macrofauna Genus Trait Handbook, http://www.genustraithandbook.org.uk
Corals	Browse online, download as *.csv file, traits provided as original values or text information, references provided.	https://coraltraits.org/
Phytoplankton (coastal)	Download of excel workbook, traits provided as original values or binary code (0/1).	Klais et al. (2017) https://www.riinaklais.com/phytotraits
All marine	Browse online	Marine Species Traits, www.marinespecies.org/traits
All marine	Browse online	Sea Life Base, http://www.sealifebase.org
Fossil groups	Browse online	Neogene Marine Biota of Tropical America (NMiTA) http://eusmilia.geology.uiowa.edu
All biota	Browse online, programmatically via API	Encyclopedia of Life (EoL), http://www.eol.org

With the here presented Arctic Traits Database we aim to bridge some of the above-mentioned issues for one important compartment of marine life: the Arctic macro- and megabenthic invertebrates. In order to fulfil the communities' demand for standardization and comparability only those traits and trait categories are included, that are most frequently used in topical publications or which are already provided in freely accessible trait databases (Table 1). Regarding download options and traceability we follow the successful example given in Faulwetter et al. (2014) and provide download of trait data in different tabular formats (i.e. data in columns, once following a database-specific format and once DarwinCore) (Wieczorek et al., 2012). The use of these formats guarantees that the included trait information can be easily shared between trait repositories and that the content is fully exploitable both by humans and computers. Every trait code is backed up by at least one reference, and where possible the original quote and page number are provided. In addition to above mentioned formats, for the first time trait information is made available also in a fuzzy-coded and ready-to-use matrix format, that can be directly incorporated into appropriate analysis software.

By providing the Arctic Traits Database to the community of benthic ecologists we aim to provide a sound basis for prospective trait-based approaches in polar regions which will in return aid our overall understanding of these unique and rapidly changing ecosystems.

2 Data

2.1 Taxon data

The current taxa in the database are a subset of the dataset compiled in the frame of the "Arctic Traits Project" (Austrian Science Fund FWF, T801-B29), with focus on pan-Arctic benthic invertebrate macro- and megafauna. This dataset comprises species lists from published studies of collaborators (Blanchard et al., 2013a, 2013b; Grebmeier et al., 2015), but also from so far unpublished sampling campaigns (e.g. field courses of the University

Center in Svalbard, UNIS, 2007-2017). The regional coverage currently comprises the Chukchi Sea and the Svalbard area. At present stage mainly species in the macrofauna size class have been uploaded.

2.2 Trait data

Currently we consider 19 traits and 80 trait categories that reflect the morphology, life history, and the behavior of Arctic benthic invertebrates (Table 3). All traits are in categorical format, i.e. belonging to one out of up to six clearly defined trait categories (see Table 3). The three continuous traits included (body size, longevity, and depth distribution) are converted into categories, but the associated text information assures accessibility to users also in their original, numerical or continuous format.

The choice of which traits to include in the database is based on the following considerations: 1) trait information should be available for and applicable to all benthic taxa (Costello et al. 2015), 2) traits used in previous studies and databases should be favored to enable comparisons across studies (Degen et al. 2018), and 3) the traits should be usable across a wide geographical area (Bremner et al. 2006). In order to fulfil this last precondition, the trait body size is provided as "maximum body size as adult" (see also Table 3). While clearly a tradeoff in regard to the detection of intraspecific plasticity, it enables the use of this trait across large spatial scales.

Recent trait-based studies emphasize the importance of standardized traits and trait terminology to ensure that data can be integrated more easily in the future (Costello et al 2015, Degen et al. 2018, Faulwetter et al. 2014). To meet these requirements of the scientific community, the Arctic Traits Database includes seven of the ten traits prioritized in Costello et al. (2015): "depth range", "substratum affinity", "mobility", "skeleton", "diet", "body size" and "reproduction" (Table 3). The remaining three traits emphasized in Costello et al. (2015) – taxonomic identity, environment, and geography – are not included. For taxonomic traits, every species in the database is bidirectionally deep linked (i.e. connected via a hyperlink) to the World register of Marine Species (WoRMS Editorial Board 2017; http://www.marinespecies.org/). For more detailed biogeographic information we refer users to the Global Biodiversity Information System (GBIF; http://www.gbif.org/) or the Ocean Biogeographic Information System (OBIS; http://www.iobis.org). We do include, however, the trait "zoogeography", which enables a differentiation between typical arctic and boreal or cosmopolitan taxa. Of the 19 traits used here, 17 are also identical to those used by the BIOTIC database (MarLIN 2006, Table 1), one of the most comprehensive databases on biological traits of marine organisms. BIOTIC also includes the trait "salinity". We cover salinity preferences within the trait "tolerance", which accounts also for temperature and pollution tolerance (see Table 3 for details). Traits we include in addition are "skeleton", and "mobility" (i.e. the relative degree of movement). Although physiological traits are of high interest in trait-based studies, we do not include them as they are not easily retrieved for many (arctic) benthic taxa (one of the preconditions for inclusion in the database as stated above). In addition, physiological traits (e.g. growth rate, respiration rate, ingestion rate) depend on body mass and temperature (Brown et al., 2004), which can vary tremendously among Arctic regions, contradicting that the provided traits information should be usable across a wide geographical area.

Table 2. Trait terminology as used in the Arctic Traits Database, BIOTIC, Costello et al. 2015, and in "other" marine trait-based studies (i.e. studies reviewed in Degen et al. 2018, list non-exhaustive, see Appendix 1 of Degen et al. 2018 for total trait list and corresponding literature references). Be aware that the Arctic Traits Database and BIOTIC consider only benthic taxa, while Costello et al. (2015) and the studies summarized in "Other" cover all marine groups.

Arctic Traits Database	BIOTIC	Costello et al. (2015)	Other

Body size	Body size	Body size	Body size/length/height, Largest radius, Biovolume, Coverage
Body form	Growth form	–	Body form, Body design, Body shape, Growth form, Growth type, Functional form group, Morphology
Fragility	Fragility	–	Fragility, Structural robustness, Shell strength
Skeleton	–	Skeleton	Skeletal composition/ thickness/material/density
Sociability	Sociability	–	Sociability, Schooling, Gregariousness, Social group size, Social behavior
Reproduction	Reproductive type	Reproduction	Reproduction, Reproduction type, Reproductive method/strategy/type/technique
Larval development	Developmental mechanism	–	Larval development, Larvae type, Larval feeding, Larval development location, Developmental mode/type/mechanism/technique
Life span	Life span	–	Longevity, Age, Life span, Maturity, Life duration, Generation time
Environmental position	Environmental position	–	Environment, Environmental position, Habitat, Vertical distribution, Sediment position, Living position, Life zone
Living habit	Living habit	–	Living habit, Habit, Life habit, Life form, Habitat, Living mode, Habitat structure
Mobility	–	Mobility	Mobility, Relative mobility, Degree of mobility, Mobility within sediment
Adult movement	Mobility/Movement	–	Adult movement, Mobility, Movement method/type, Locomotion
Feeding habit	Feeding habit	–	Feeding habit/behavior/method/type/apparatus, Resource capture method, Trophic mode, Oral gape position/height/surface, Protrusion
Trophic level	Typical food types	Diet	Trophic level, Diet, Food type, Trophic group, Dietary group
Bioturbation	Bioturbation	–	Bioturbation mode/type/potential, Sediment movement/reworking/transport, Direction of sediment transport, Reworking mode, Fecal deposition, Irrigation
Tolerance	Salinity	–	Tolerance, Tolerance limits, Salinity tolerance, Survival salinity/temperature, Temperature optimum, Thermal affinity, Hypoxia tolerance, Tolerance to pollutants, Ecological group, Resilience, Condition index
Zoogeography	Biogeographic range	–	Biogeography, Geographical range/distribution, Range size, Native region, Median latitude
Depth range	Biological zone	Depth range	Depth range/regime, Diving depth
Substratum affinity	Substratum affinity	Substratum affinity	Substratum affinity, Habitat, Habitat preference/type/specifity/complexity, Preferred substrate, Substrate type, Living location

One common approach to use traits is as indicators of ecosystem functions (effect traits) or of changes in the environment (response traits) (Hooper et al., 2005). An overview of how each of the 19 traits that are currently included in the database may relate to ecosystem functions or respond to environmental changes or pressures is given in Table 3.

Table 3. Detailed information on the 19 biological traits currently included in the Arctic Traits Database, clustered into morphology traits (5), life history traits (3), and behavioral traits (11). For every trait and its categories, the definition as used in the Arctic Traits Database is given. Abbreviations of each category are given (e.g. S1, S2) as these are used in files downloaded from the website. The relation of the respective trait to benthic ecosystem functions or responses (i.e. its role as effect or response trait) are given via specific examples and underlying literature sources are displayed.

MORPHOLOGY

Body size			
Definition	Maximum body size as adult given in mm, as individual or colony and excluding appendages. Can be height in rather upright animals (e.g. corals), body width or diameter in rather round animals (e.g. crabs), or body length in elongated animals (e.g. worms).		
Categories	S1	small	< 10 mm
	S2	small-medium	10-50 mm
	S3	medium	50-100 mm
	S4	medium-large	100-300 mm
	S5	large	> 300 mm

Function	Size has a direct effect on productivity, the amount of habitat structuring and facilitation, and is important for the amount of oxygen and nutrient flux across the sediment-water interface. It correlates with food web structure, trophic levels, and energy flow in ecosystems.
Detail	Smaller animals are faster growing, usually show a higher productivity and are less affected by trawling as they are more likely to fit through the net of trawling gear, thus often replacing larger slow-growing fauna in trawl-impacted areas. A clear majority of small-bodied species may be indicative for environments with high instability or be the result of environmental or anthropogenic disturbances. Larger taxa usually show a lower productivity but higher carbon fixation and have a higher effect on fluxes of nutrients, energy and matter. They usually grow slower, reproduce later, and are more affected by trawling and other disturbances.
References	Bolam and Eggleton, 2014; Bremner, 2008; Costello et al., 2015; Emmerson, 2012; Micheli and Halpern, 2005; Norkko et al., 2013; van der Linden et al., 2016

Body form

Definition	The external characteristic of an organism.		
Categories	BF1	globulose	Round or oval (e.g. sea urchin, sponge, some bivalves)
	BF2	vermiform	Wormlike
	BF3	dorso-ventral compressed	Species that are flat, or encrusting (e.g. starfish, sponge)
	BF4	laterally compressed	Thin (e.g. isopods, amphipods, some bivalves)
	BF5	upright	E.g. coral, basket star, sponge
Function	The body form can be indicative for the ecological role of species in an ecosystem (e.g. if it is habitat-forming), and for its vulnerability to mechanical disturbances (e.g. bottom trawling). Species with an upright body form will be more affected than vermiform or flat ones. Sets restrictions to habitat use and migration capability. Vermiform taxa can be a proxy for litter quality/decomposition.		
Remark	Often simply a proxy of taxonomy (e.g. vermiform > polychaetes, laterally compressed > amphipods).		
References	Beauchard et al., 2017; Bolam and Eggleton, 2014; Costello et al., 2015; Törnroos and Bonsdorff, 2012; Wiedmann et al., 2014		

Fragility

Definition	The degree to which an organism can withstand physical impact.		
	F1	fragile	Likely to crush, break, or crack as a result of physical impact (e.g. brittle star, soft worms, smaller crustaceans, mollusks with thin shells)
	F2	intermediate	Liable to suffer minor damage, chips or cracks as result of physical impacts (e.g. mollusks with thicker shells, animals with harder cuticle like some echinoderms)
	F3	robust	Unlikely to be damaged as a result of physical impacts, e.g. hard or tough enough to withstand impact, or leathery or wiry enough to resist impact (e.g. starfish, sponges, tunicates)
Function	Determines sensitivity to physical disturbance (e.g. bottom trawling) and to predatory aggression. Softer/fragile bodies are stronger affected by trawling. Indicative for prey accessibility and ease of ingestion.		
References	Beauchard et al., 2017; Bolam and Eggleton, 2014; Weigel et al., 2016		

Skeleton

Definition	Presence and type of supporting structures in the animal body.		
Categories	SK1	calcareous	Skeleton material aragonite or calcite (e.g. bivalves)
	SK2	siliceous	Skeleton material silicate (e.g. siliceous sponges)
	SK3	chitinous	Skeleton material chitin (e.g. arthropods)
	SK4	cuticle	No skeleton but a protective structure like a cuticle (e.g. sea-squirts)
	SK5	none	No form of protective structure (e.g. sea slugs)
Function	Indicates vulnerability (trawling, ocean acidification), resistance to predation (proxy of palatability), and ecosystem engineering (provision of habitat, increased heterogeneity). Large calcifying taxa contribute most to inorganic carbon sequestration.		
References	Costello et al., 2015; Frid and Caswell, 2016, 2015; Spitz et al., 2014		

Sociability

Definition	The degree to which species aggregate.		
Categories	SO1	solitary	Single individual
	SO2	gregarious	Single individuals forming groups; growing in clusters (e.g. barnacles)
	SO3	colonial	Living in permanent colonies (e.g. stony corals, Bryozoa, Synascidia)

Function	Determines sensitivity to physical disturbance (e.g. bottom trawling) and can indicate if a species can increase habitat heterogeneity or is habitat forming. If yes, then it affects habitat creation, nursery, refuge, facilitation, and sediment oxygenation.
References	Beauchard et al., 2017; Costello et al., 2015

LIFE HISTORY TRAITS

Reproduction			
Definition	The way species reproduce, here including information about where fertilization occurs and whether propagules are released or not.		
Categories	R1	asexual	Budding and fission (e.g. sponges, cnidarians)
	R2	sexual – external	Fertilization external, eggs & sperm deposited on substrate or released into water (broadcast spawners) (e.g. echinoderms, cnidarians)
	R3	sexual – internal	Fertilization internal, but no brooding, eggs deposited on substrate, indirect or direct development (e.g. gastropods)
	R4	sexual – brooding	Fertilization internal or external, Eggs or larvae are brooded, indirect or direct development (e.g. amphipods, isopods, echinoderms)
Function	Indicates the ability of a species to disperse, become invasive, or recover from a population decline. Can indicate if carbon is transported from the benthic to the pelagic realm or stays locally bound. Animals without a planktonic stage that perform brooding and parental care might have a higher tolerance against some forms of stress (e.g. ocean acidification), but may be higher vulnerable to local disturbances (biotic or abiotic).		
References	Bremner, 2008; Costello et al., 2015; Lucey et al., 2015		

Larval development			
Definition	Larval development and feeding type.		
Categories	LD1	pelagic/planktotrophic	High fecundity, larvae feed and grow in water column, generally pelagic for several weeks (e.g. echinoderms, bivalves)
	LD2	pelagic/lecitotrophic	Medium fecundity, larvae with yolk sac, pelagic for short periods (e.g. tunicates)
	LD3	benthic/direct	Larvae have benthic or direct development (no larval stage, eggs develop into miniature adults)
Function	Ability of a species to disperse, become invasive, or recover from a population decline. Indicator for long-term sensitivity (ability to recolonize disturbed areas). Planktonic stages indicate productivity and elemental transport from benthos to pelagos.		
References	Bolam and Eggleton, 2014; Cardeccia et al., 2018; Törnroos and Bonsdorff, 2012		

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Life span			
Definition	The maximum reported life span of the adult stage in years.		
Categories	A1	short	<2 years
	A2	medium	2-5 years
	A3	medium-long	5-20 years
	A4	long	>20 years
Function	Long lived animals are more susceptible to disturbance and need longer to recover (while short-lived species can recover fast and may increase in richness and abundance as disturbance increases). An indicator for population stability over time, carbon fixation, productivity.		
Detail	Indicates the relative investment of energy in somatic rather than reproductive growth and the relative age of sexual maturity. A proxy for relative r- and k-strategy.		
References	Bolam and Eggleton, 2014; Bremner, 2008; Cain et al., 2014; Costello et al., 2015		

BEHAVIORAL TRAITS

Environmental position			
Definition	The position of the animal relative to the sediment.		
Category	EP1	infauna	Lives in the sediment
	EP2	epibenthic	Lives on the surface of the seabed
	EP3	hyper-benthic	Living in the water column, but (primarily/occasionally) feeds on the bottom; bentho-pelagic
Function	Affects carbon fixation and transport within the sediment, between aerobic and anaerobic layers, or from pelagos to benthos. Can indicate facilitation (e.g. for microbial communities in the sediment) and sensitivity to perturbation (e.g. bottom trawling, infauna less affected than epifauna, hyper-benthic taxa might be able to escape). Endobenthic life style effects the sediment biogeochemistry. Epibenthic and shallow sediment-dwelling taxa are more vulnerable to predation. Hyper-benthic taxa are involved in transport of carbon from benthos to pelagos.		

References	Bolam et al., 2014; Bremner et al., 2008; Frid and Caswell, 2016; Törnroos & Bonsdorff, 2012		

Living habit			
Definition	The mode of living, ranging from free over tube or burrow dwelling to permanently attached.		
Categories	LH1	free living	Not limited to any restrictive structure at any time. Able to move freely within and/or on the sediments
	LH2	crevice dwelling	Adults are typically cryptic, inhabiting spaces made available by coarse/rock substrate and/or biogenic species or algal holdfasts
	LH3	tube dwelling	Tube may be lined with sand, mucus or calcium carbonate, tube can also be in a burrow
	LH4	burrowing	Species inhabiting permanent or temporary burrows in the sediment, or are just burrowing in the sediment
	LH5	epi/endo zoic/phytic	Living on or in other organisms
	LH6	attached	Adherent to a substratum
Function	Attached species are more vulnerable to predation and perturbations (e.g. bottom trawling). Burrowing, crevice and tube dwelling taxa affect sediment biogeochemistry, carbon transport, elemental cycling, and are less affected by strong hydrodynamic disturbance, anoxic conditions and water pollution. Tube building can add to local storage of chemicals and waste materials. Microbial processes are facilitated and microbial biomass promoted by deep-dwelling fauna. Burrowing and irrigation generally facilitates life of associates. Burrowing or attached living habit can be related to habitat creation and facilitation.		
References	Aller, 1983; Bolam and Eggleton, 2014; Bremner, 2008; Bremner et al., 2006; Costello et al., 2015; Törnroos and Bonsdorff, 2012; van der Linden et al., 2016		

Mobility			
Definition	Degree or intensity of movement.		
Categories	MO1	none	No movement as adult (sponge, coral)
	MO2	low	Slow movement (e.g. anemones, snails)
	MO3	medium	Medium movement (e.g. starfish, brittle stars)
	MO4	high	High movement, swimmer or fast crawler (e.g. amphipods, shrimp)
Function	Slowly or non-moving species are more vulnerable to predation, perturbations and decrease in food input, while mobile taxa are more flexible and may evade trawl gear or predators. High percentage of non-moving organisms can indicate high amount of food, while high percentage of highly mobile taxa may indicate food patchiness or scarcity. Indicative for dispersal potential and ability to recolonize.		
References	Costello et al., 2015; Micheli and Halpern, 2005; Tyler et al., 2012		

Adult movement			
Definition	Type of movement as an adult.		
Categories	MV1	sessile/none	No movement as adult (sponge, coral)
	MV2	burrower	Movement in the sediment (e.g. annelids, echinoderms, crustaceans, bivalves)
	MV3	crawler	An organism that moves along on the substratum via movements of its legs, appendages or muscles (e.g. crabs, snails)
	MV4	swimmer (facultative)	Movement above the sediment (e.g. amphipods)
Function	Indicates the dispersal and recolonization potential, and the invasiveness of an organism. Related to nutrient cycling (burrowing taxa contribute most to nutrient cycling and regeneration, burrows increase the total sediment surface area available for exchange with the water column), carbon deposition (sessile calcifying taxa), facilitation of microbial and other fauna (either via burrowing or via constructing biogenic habitats), and habitat stability. Swimmers may escape predators and trawling gear.		
Remark	Closely linked to the trait mobility.		
References	Aller, 1983; Bremner, 2008; Bremner et al., 2006; Costello et al., 2015; Frid and Caswell, 2016		

Feeding habit			
Definition	The mode of food uptake.		
Categories	FH1	surface deposit feeder	Active removal of detrital material from the sediment surface. Includes species which scrape and/or graze algal matter from surfaces
	FH2	subsurface deposit feeder	Removal of detrital material from within the sediment matrix (e.g. Echinocardium)
	FH3	filter/suspension feeder	Sponge, coral, hydrozoa, bivalves
	FH4	opportunist/scavenger	An organism that can use different types of food sources/an organism that feeds on dead organic material (e.g. crabs, whelks)

	FH5	predator	An organism that feeds by preying on other organisms (e.g. starfish)
	FH6	parasite/commensal	An organism that lives in or on another living organism (the host), from which it obtains food and other requirements
Function	Can indicate hydrodynamic conditions (suspension feeders in turbulent, deposit feeders in calmer water), carbon transport between pelagos and benthos (suspension feeders) and backwards (predators), and vulnerability (e.g. surface deposit feeders and suspension feeders are more sensitive to trawling). Impacts resource utilization and facilitation (e.g. deposit feeders facilitate microbes that further decompose organic carbon). Effects the depth of oxygen and detritus penetration and can enhance organic matter decomposition and nutrient recycling/regeneration. Control of other species in the assemblage.		
References	Bremner, 2008; Bremner et al., 2006; Dolbeth et al., 2009; Frid et al., 2008; Kröncke, 1994; Oug et al., 2012; Rosenberg, 1995; Tyler et al., 2012; van der Linden et al., 2016		

Trophic level

Definition	Rank of an animal according to how many steps it is above the primary producers at the base of the food web.		
Categories	TL1	1	Primary producer
	TL2	2	Primary consumers – Herbivore / Deposit Feeder /Suspension Feeder
	TL3	3	Secondary consumers – Carnivore
	TL4	4	Tertiary consumers
	TL5	5	Quaternary consumers – Apex predator
Function	Determines the role of an organism in energy transfer within the food web. Control of other species abundance in the assemblage.		
References	Costello et al., 2015; Micheli and Halpern, 2005; Renaud et al., 2011		

Bioturbation

Definition	Biogenic modification of sediments through living, movement and feeding habits of organisms.		
Categories	B1	diffusive mixing	Surficial movement of sediment and/or particles, resulting from movement or feeding activities on the surface
	B2	surface deposition	Deposition of particles at the sediment surface resulting from e.g. defecation or egestion (pseudofaeces) by, for example, surface deposit feeding organisms (e.g. holothuroids, bivalves, tubiculous polychaetes)
	B3	conveyor belt transport (upward)	Translocation of sediment and/or particulates from depth within the sediment to the surface during subsurface deposit feeding or burrow excavation
	B4	downward (reverse) conveyor	The subduction of particles from the surface to some depth by feeding or defecation
	B5	none	No bioturbation (e.g. sessile animals on hoard bottom)
Function	Impacts sediment biogeochemistry (oxygen, pH and redox gradients, elemental carbon), organic matter regeneration, nutrient cycling, sediment granulometry, pollutant release, microbial composition, abundance and diversity and in general provision and maintenance of habitats for other organisms.		
References	Chen et al., 2017; Frid et al., 2008; Gogina et al., 2017; Lacoste et al., 2018; Mermillod-Blondin, 2011; Pearson, 2001; Queirós et al., 2013; Solan et al., 2012		

Tolerance

Definition	Degree to which a species reacts to changes in its environment.		
Categories	T1	low	Species reacts sensitive to changes in the environment like organic enrichment, pollution, temperature or salinity changes; AMBI group I
	T2	intermediate	Species react indifferent or no information available; AMBI group II
	T3	high	Species tolerates organic enrichments, pollution, temperature or salinity changes; AMBI groups III-IV
Function	Indicates vulnerability or resistance/resilience of a species towards pollution or climate change induced changes in water biogeochemistry.		
References	Borja and Franco, 2000; Gusmao, 2017; Marchini et al., 2008; Piló et al., 2016		

Zoogeography

Definition	Spatial distribution of a species in relation to commonly used zoogeographic regions.		
Categories	Z1	arctic	Confined to Arctic regions.
	Z2	arctic-boreal	Arctic, sub-Arctic and North Atlantic/North Pacific distribution.
	Z3	boreal	North Atlantic and/or North Pacific distribution; potentially sub-Arctic regions such as Southern Barents Sea or Bering Sea.
	Z4	cosmopolite	Cosmopolite distribution

Function	Indicates vulnerability (arctic species may be more vulnerable to changes than species with an arctic-boreal or cosmopolite distribution) or potential of a species to become invasive.		
References	Fetzer, 2005; Fetzer and Arntz, 2008; Piepenburg, 2000; Weslawski et al., 2003		
Depth range			
Definition	Species distribution related to water depth.		
Categories	DR1	shallow	0-20 m
	DR2	shelf	20-200 m (some shelves can extend to 500 m)
	DR3	shelf-slope	200-1000 m (sometimes the slope starts deeper, e.g. 500-)
	DR4	slope-basin	> 1000 m
Function	Can be used – along substratum affinity – for habitat classification. Can depict depth distribution of other traits.		
Detail	Shallow water and shelf taxa face a higher exposure to predation of marine mammals and to physical disturbance such as iceberg scouring and to coastal processes and pollution.		
References	Costello et al., 2015; Gutt, 2001		
Substratum affinity			
Definition	Type of substratum that organisms (preferential) live on.		
Categories	SA1	soft	Soft substrata, sand or mud
	SA2	hard	Hard substrata, rock, gravel
	SA3	biological	Epizoic or epiphytic life style
	SA4	none	Species is hyper/supra benthic and has no affinity for a certain substrate, but it might prefer one for hunting/scavenging (this category should not occur too often, as we work with benthos)
Function	Can be used – along depth range – for habitat classification. Can depict potential substrate specificity of other traits.		
References	Costello et al., 2015		

2.3 Sources of trait information

Sources of trait information are research papers, books, databases and online repositories (Table 1), but also grey literature such as cruise reports. Trait information can also result from onsite measurements (e.g. for the trait body size), personal observations, or be transmitted via communication with experts for a specific taxonomic group. In any case, the source is indicated as precise as possible, for published literature with complete reference and DOI (if available), in case of expert communication the name and contact details of the respective expert are given. Wherever possible the original quote from literature and page numbers are given to ensure the traceability of the provided trait information. Although literature sources targeting the Arctic are used preferably (and for exclusively Arctic species are the only option) we do not restrict source information for arctic-boreal or cosmopolite taxa to stem from Arctic regions. This bears the risk that the assigned trait information is not accurate, as polar taxa might differ in their expression of certain traits from their relatives at lower latitudes (Degen et al. 2018). However, this is an issue for now not resolved, as trait information from the high latitudes is often scarce, and we recommend the user to consider the source of trait information when interpreting results.

2.4 Fuzzy coding of traits

The fuzzy coding procedure indicates to which extent a taxon exhibits each trait category (Chevenet et al., 1994). This method has the advantage that it enables us to analyze diverse kinds of biological information derived from a variety of sources (as those included in the Arctic Traits Database, see Sect. 2.3), and that also intermediate scenarios (i.e. when a taxon does not clearly fall into one category or the other) can be accounted for (Chevenet et al. 1994). We use the 0–3 coding scheme (details in Table 4 below) as it is the most widely used (which facilitates comparisons and exchange of trait information) and provides a compromise between binary codes and many not clearly delineated graduations (Degen et al. 2018).

Table 4. Explanation of fuzzy codes as used in the Arctic Traits Database.

Fuzzy code	Explanation
3	Taxon has total and exclusive affinity for a certain trait category, all other categories do not apply and must be coded with “0”.
2	Taxon has a high affinity for a certain trait category, but other categories can occur with equal (2) or lower (1) affinity.
1	Taxon has a low affinity for a certain trait category.
0	Taxon has no affinity for a certain trait category.

Table 5. Two coding examples for the trait “Feeding habit” which has six trait categories (FH1 – FH6, see also Table 3). Species 1 is a surface deposit feeder, but can switch facultative to suspension feeding, while species 2 is an exclusive suspension feeder.

Feeding habit	Abbreviation	Species 1	Species 2
Surface deposit feeder	FH1	2	0
Subsurface deposit feeder	FH2	0	0
Filter/suspension feeder	FH3	1	3
Opportunist/scavenger	FH4	0	0
Predator	FH5	0	0
Parasite/commensal	FH6	0	0

Table 6. This is how the above example would appear in the matrix downloaded from the Arctic Traits Database. In the download matrix format species are rows, trait categories are columns, and the fuzzy codes are the values. Due to the database structure zero codes (“0”) are only displayed when they are backed up by a specific reference (e.g. for the trait category LH3/tube dwelling: “No species within the family Polynoidae is tubiculous”).

	FH1	FH2	FH3	FH4	FH5	FH6
Species 1	2		1			
Species 2			3			

While the coding might for some traits and taxa be pretty straight forward, in some cases a decision might be drawn not so easily. As one of the clearer cases, we point out the coding of the trait “body size” for the star fish *Crossaster papposus*. A literature reference states that the body size can range “Up to 340 mm in diameter” (Hayward and Ryland, 2012, p. 668). This size fits into the category “large” (S5, > 300 mm), thus the taxon is coded “3” for this size class, and “0” for all other categories (S1 – S4). The trait “mobility” is trickier. A literature reference (Himmelman and Dutil, 1991), p. 68) states the following: “*Crossaster papposus* and *Solaster endeca* are highly mobile; large individuals can cover distances of more than 5 meters in 12 hours”. Here we have to keep in mind that the particular reference frame in this publication are subtidal sea stars in the northern Gulf of St. Lawrence (West Atlantic). The reference of the Arctic Traits Database however are all benthic invertebrates, and the trait category “high mobility” is defined here for taxa which are “swimmers or fast crawlers”, such as some amphipods and shrimp (see Table 2). Accordingly, the correct coding for *C. paposus* in the reference system of the Arctic Traits Database is the category “medium” mobility (MO3). Users of the Arctic Traits Database should bear this reference system in mind when downloading only the fuzzy coded trait data and aiming to apply it to another reference system. But as the detailed literature quote that lead to the coding of a trait is always provided (see Sect. 2.3), the trait information can easily be adjusted by the user.

There will always be a certain degree subjectivity related to the fuzzy coding procedure. To find out how strong the coding might differ among scientists a small experiment at the Arctic Traits Workshop in Vienna (December 2016) was performed (Degen et al. 2018). Participants coded 27 trait categories of three common

Arctic benthic species, and found the final trait matrices to be to 83% identical. We are confident that the sophisticated structure of the Arctic Traits Database (see Sect. 3) and the provided information and instructions will support a more consistent coding of benthic traits in the future.

3 Database

In order to collect trait information and to disseminate it among users, a web-based database was created. The database features a public interface (Sect. 3.1) and an entry interface that is accessible only for registered collaborators (Supplement). The public interface (Fig. 2, a) allows to browse the traits and references online ("Data per taxon" in the top menu bar), to view background information ("About" and "Trait definitions") and to download either the entire species, trait and literature information or specified subsets in several formats ("Download data") (see Sect. 3.1). Registered collaborators – i.e. those users that actively contribute trait information to the Arctic Traits Database – can access the interactive part of the database via the log in button on the public page (Fig. 2a). This access offers additional options (Fig. 2b): browsing the existing information also per traits ("Traits" in the top menu bar), uploading new taxa, trait and source information, or adding trait information, references and comments to already existing taxa in the database ("Taxa"). As several users can work on the same taxa, a flagging system is used to highlight and discuss potentially conflicting sources and opinions. The "References", "Statistics", and "Tools" sections are equally accessible only for registered users (Fig. 2, b; Supplement). Every scientist working in the field of Arctic benthic ecology aiming to share trait information can become a registered user by getting in touch with the editor and retrieving a user login. Credit to the registered collaborators is given in the "About" section on the public site and also on taxon pages after each trait entry they conduct. A detailed manual for registered users is provided in the supplementary material to this publication (Supplement), or can alternatively be accessed via the public web interface ("About"). Collaborators who want to share trait information without registering to the database can alternatively be provided with an upload template (.xls).

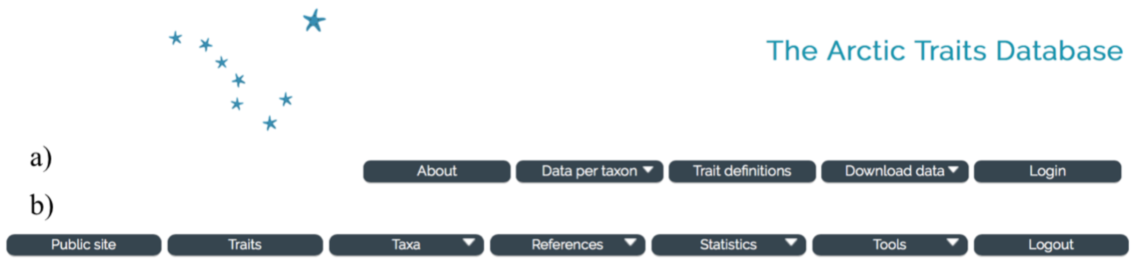

Figure 2. Screenshots of the start page of the Arctic Traits Database. Toolbar of the public page with Login button for the registered user (a), and toolbar in the area for registered users (b).

3.1 Public access and download options

The public access enables to browse the database online and to download the complete set of data as well as the bibliography, or specified subsets. Taxon traits can be visually inspected online via the "Data per taxon" button from the top menu bar and "Browse taxa" or "Search taxa". Taxa can be browsed and selected via the taxonomic tree, as indicated for the asteroid *Crossaster papposus* in Fig. 3. Alternatively, the “Search taxa” panel allows to type in and search a specific taxon.

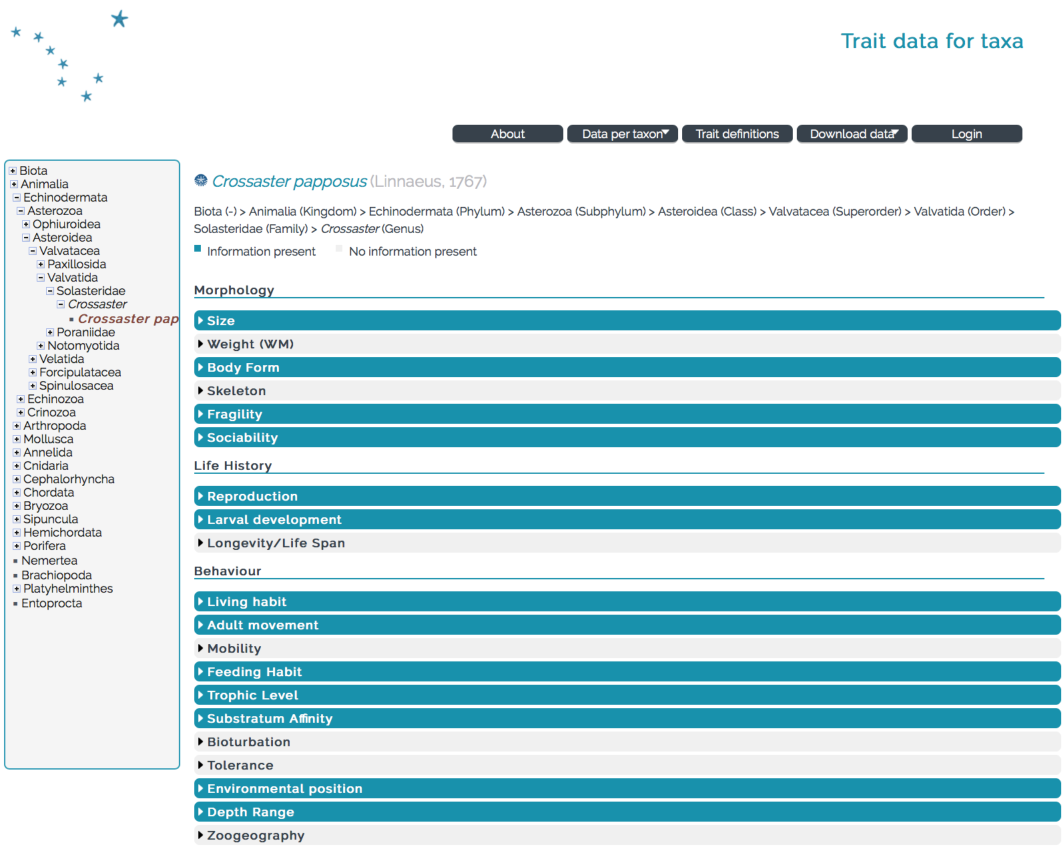

Figure 3. Screenshot of the taxon page of the asteroid *Crossaster papposus* selected from the classification tree on the left.

The completeness of trait information can be inspected via “Data completeness” (Fig. 4), equally accessible via “Data per taxon” on the top menu bar. This option shows an alphabetic list of all taxa in the database for which trait information is available. The bar on the right side indicates the information coverage for each taxon and trait, blue color indicates that trait information is present.

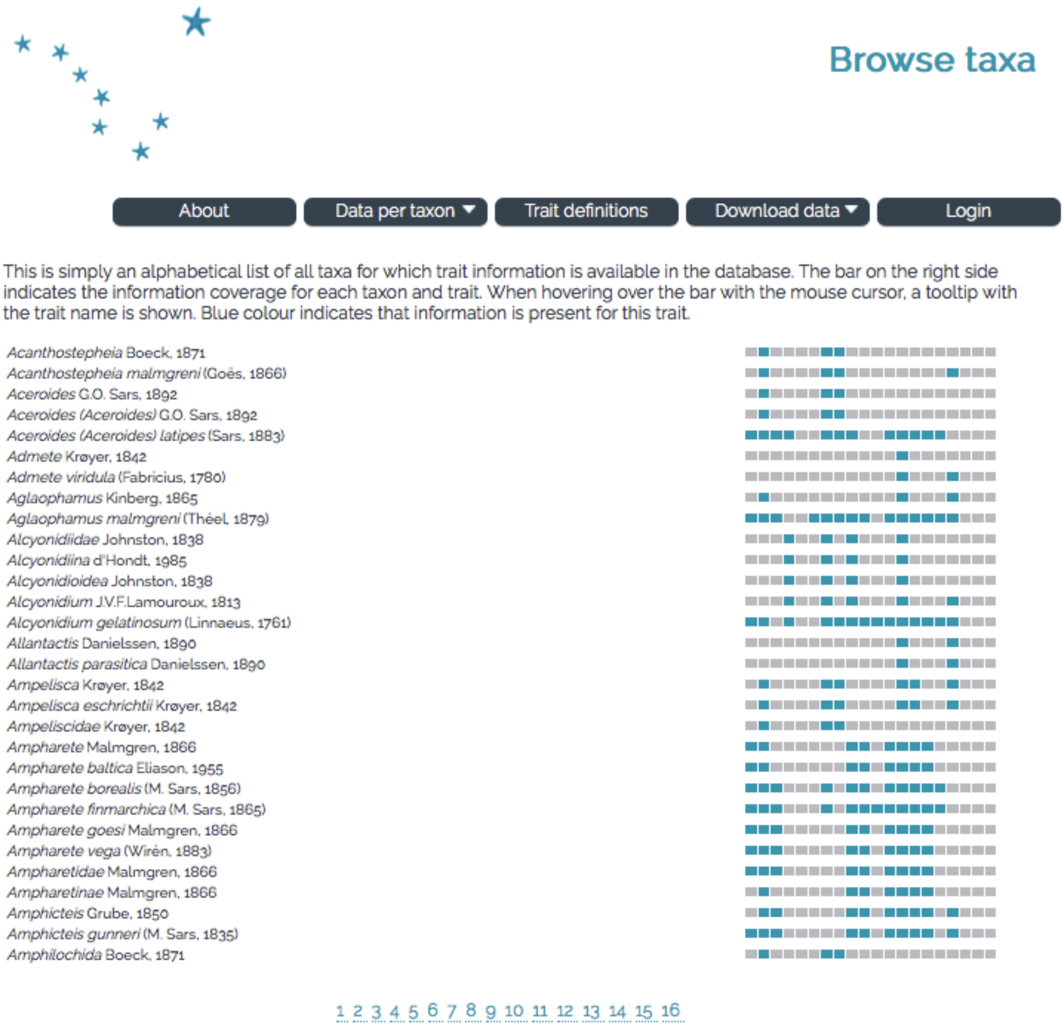

Figure 4. Screenshot of data completeness.

The download section can be accessed via the "Download data" button on the top menu bar (Fig. 2, a; Fig. 3; Fig. 4). Download is enabled in three different computer readable formats: 1) as data in columns (*.csv) (Table 7), 2) in DarwinCore format (Table 8), and 3) as fuzzy coded trait matrix which some users might prefer (see Sect. 2.4 and Fig. 5). Also, the entire bibliography is available for download. Before the download commences the user is asked whether to download a) all data in the database, b) only data for an uploaded list of taxon names, c) only data for an uploaded list of AphiaIDs, or d) only the data selected from a classification tree. In the last option, entire phyla or sub-groups can be easily selected from the tree. By default, all 19 traits are exported, but if the user is interested only in one or a few specific traits, the option to select these from the total list of 19 traits is available. As the fuzzy coded trait matrix (download option 3) contains only the fuzzy codes per trait category but no literature sources, we recommend to also download the "Data in columns" (download option 1) for the same taxa, where the detailed source per species and trait category is included. Details on the structure of the first two download options are given below in Table 7 and Table 8. A clipping from a downloaded fuzzy coded trait matrix is shown in Fig. 5. The database can also be accessed programmatically via a REST API (documented at https://www.univie.ac.at/arctictraits/download-api).

Table 7. List of fields returned by the Arctic Traits Database when "Data as columns" (*.csv) is chosen as an export option from the download section.

Column label	Column description
Taxon	The taxon for which the information was recorded.
Author	The author and year of the *Taxon* for which the information was recorded.
Rank	Rank of the taxon for which the information was recorded.
Valid taxon	Currently accepted name of the *Taxon* (as stored in the Arctic Traits Database - information might not be up to date with the WoRMS or the latest taxonomic literature in some cases). Users should check all taxa against WoRMS before use. If *Taxon* is currently accepted, this field contains the same value as *Taxon*).
Valid author	Currently accepted name of the *Author* (as stored in the Arctic Traits Database - information might not be up to date with the WoRMS or the latest taxonomic literature in some cases). Users should check all taxa against WoRMS before use. If *Taxon* is currently accepted, this field contains the same value as *Author*.
Taxonomic status	The status of the use of the Taxon (e.g. objective synonym, subjective synonym) as stored in the Arctic Traits database.
Source of synonymy	Literature reference for synonymy of taxon (if present).
Parent taxon	The *Taxon*'s direct parent in the taxonomic classification (as stored in the Arctic Traits Database).
Trait	The biological trait for which information is available (e.g. "Feeding habit").
Category	The sub-category of the *Trait* for which information is available (e.g. "Predator").
Category abbreviation	An abbreviated version of the often verbose trait category - useful as a label in further analyses of the data (e.g. "FH(6)").
Traitvalue	Describes the affinity of the *Taxon* to the *Category*. Values range from 0–3: "0"= no affinity for a certain trait category; "1"= low affinity for a certain trait category; "2"= high affinity for a certain trait category, but other categories can occur with equal (2) or lower (1) affinity; "3"= total and exclusive affinity for a certain trait category.
Reference	Literature reference leading to the assignment of the *Traitvalue* to the *Category* for the *Taxon*.
DOI	Digital Object Identifier (where available) of the *Reference*.
Value creator	Person who assigned the *Traitvalue* to the *Category* for the *Taxon*, supported by a *Reference*.
Value creation date	Date and time when the above information was entered into the database.
Value modified by	Person who last modified the Traitvalue. Empty if no modifications were done.
Value modification date	Date and time when the Traitvalue was last modified. If no modification was done since the first entry, this has the same value as Value creation date.
Text Excerpt	A quotation of the original text passage from the literature source that led to the assignment of assignment of the *Category*/*Traitvalue* to the *Taxon*. Empty if information has not been recorded yet.
Text Excerpt creator	Person who entered the *Text excerpt*. Only present if *Text Excerpt* is present.
Text Excerpt creation date	Date and time when the *Text Excerpt* was entered into the database. Only present if *Text Excerpt* is present.
Text Excerpt modified by	Person who last modified the *Text excerpt*. Empty if no modifications were done.
Text Excerpt modification date	Date and time when the *Text Excerpt* was last modified. If no modification was done since the first entry, this has the same value as *Text Excerpt creation date*.

Table 8. List of fields returned by the Arctic Traits Database when "Darwin Core" is chosen as an export option from the download section. DarwinCore does not provide the same granularity as the "Data as columns" format. The output file consequently contains fewer details.

Column label	**Column description**
scientificName	The taxon for which the information was recorded
scientificNameAuthorship	The author and year of the taxon for which the information was recorded
taxonRank	Rank of the taxon for which the information was recorded.
acceptedNameUsage	Currently accepted name and authorship of the *scientificName* (as stored in the *arctictraits* database – information might not be up to date with the latest taxonomic literature in some cases.)
Taxonomic Status	The status of the use of the *scientificName* (e.g. objective synonym, subjective synonym) as stored in the *arctictraits* database. Empty if *scientificName* is the currently accepted name.
MeasurementOrFact	Trait name and trait category, separated by a colon (e.g. Size:small)
measurementValue	Value from 0–3, describing the affinity of the taxon to a trait category. Coding of values as described in Table 7 "Traitvalue".
dcterms:bibliographicCitation	Full literature reference (including Digital Object Identifier (DOI) where present) supporting the trait information for the current taxon.
measurementRemarks	A quotation of the original text passage containing the trait information for the current taxon
measurementDeterminedBy	Person who entered the trait information for this taxon into the database.
measurementDeterminedDate	Date the trait information was entered into the database or last modified.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1	Taxon	Valid_name	S1	S2	S3	S4	S5	W1	W2	W3	W4	W5	BF1	BF2	BF3	BF4	BF5	SK1	SK2	SK3	SK4	SK5	F1	F2	F3	SO1	SO2	SO3	R1	R2	R3	R4	LD1
4	Acanthonotozoma	Acanthonotozoma														3				3												3	
5	Acanthonotozomatidae	Acanthonotozomatidae														3				3												3	
6	Acanthostepheia	Acanthostepheia														3				3												3	
7	Acanthostepheia malmgreni	Acanthostepheia malmgreni														3				3												3	
8	Aceroides	Aceroides														3				3												3	
9	Aceroides (Aceroides)	Aceroides (Aceroides)														3				3												3	
10	Aceroides (Aceroides) latipes	Aceroides (Aceroides) latipes	3													3				3				3		3						3	
11	Acmaeidae	Acmaeidae																3															
12	Actiniaria	Actiniaria																			1	2				3							
13	Adapedonta	Adapedonta																3												3			3
14	Admete	Admete																3															
15	Admete viridula	Admete viridula																3															
16	Admetinae	Admetinae																3															
17	Aglaophamus	Aglaophamus												3								3								2			3
18	Aglaophamus malmgreni	Aglaophamus malmgreni			3									3								3	3							3			3
19	Akanthophoreidae	Akanthophoreidae																		3												3	2
20	Akanthophoreus	Akanthophoreus																		3												3	2
21	Akanthophoreus gracilis	Akanthophoreus gracilis																		3												3	2
22	Alcyonidiidae	Alcyonidiidae																										3					
23	Alcyonidiina	Alcyonidiina																										3					
24	Alcyonidioidea	Alcyonidioidea																										3					
25	Alcyonidium	Alcyonidium																										3					
26	Alcyonidium gelatinosum	Alcyonidium gelatinosum	3												3													3	1			2	
27	Allantactis	Allantactis																															

Figure 5. A clipping from the fuzzy coded trait matrix returned by the Arctic Traits Database when the "Data in matrix format" is chosen as export option from the download section. Species are rows ("Valid_name" refers to the currently accepted taxonomy in WoRMS), abbreviated trait categories are columns. For abbreviations of trait categories see Table 3. Due to the database structure zero codes ("0") are not displayed (see Table 6).

3.3 Database specification

The website runs on an Apache 2.2. server, the database is implemented in MySQL 5. PHP 5 is used as a scripting language. Web technologies used are HTML4, CSS and JavaScript/Jquery. A code package to create such a web-based trait database including a README file with instructions for installation is provided at figshare, https://doi.org/10.6084/m9.figshare.7491869.

4 Results

4.1 Taxonomic data coverage

At present, the database contains 1911 Arctic marine benthic invertebrate taxa. Thereof 686 are on species level, 516 on genus level, and 274 on family level. The remaining 435 taxa are higher taxonomic levels or intermediate ranks. The largest taxonomic group in the database at present stage are the Arthropoda with 557 taxa (186 entries on species level), followed by the Annelida with 489 taxa (218 entries on species level) and the Mollusca with 418 taxa (146 entries on species level) (Fig. 6).

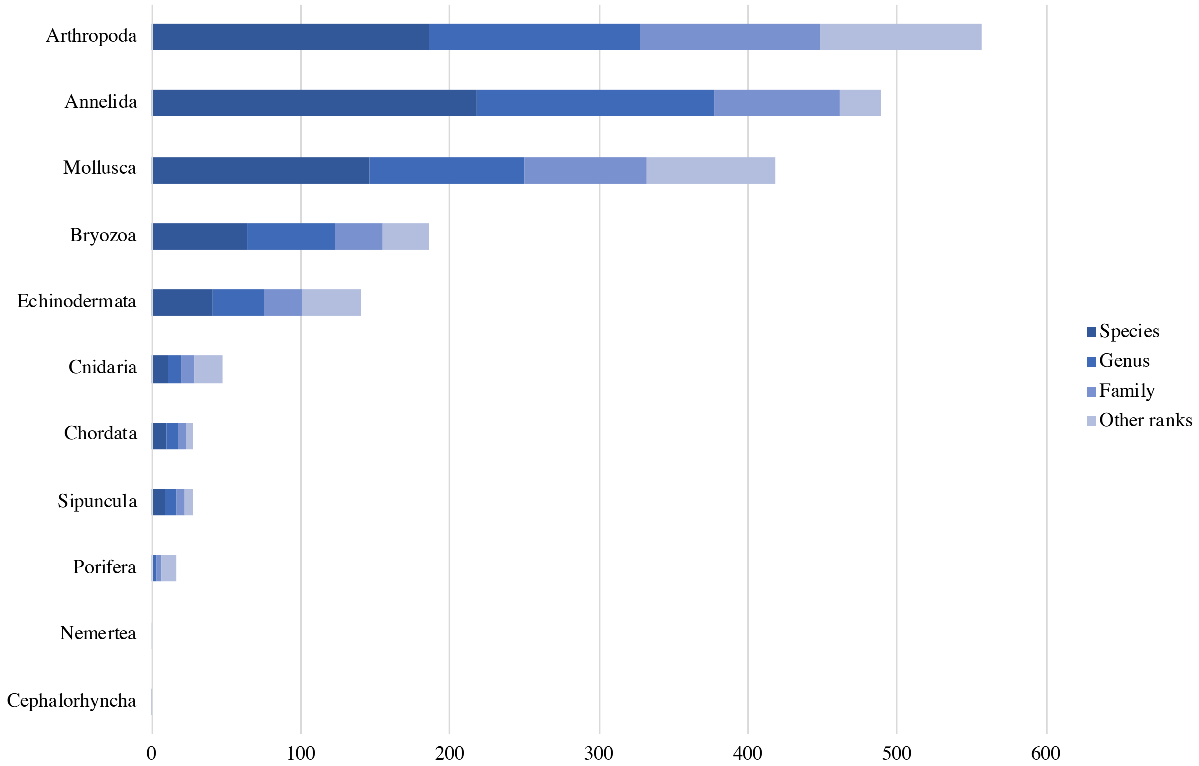

Figure 6. Taxonomic data coverage. "Other ranks" include higher taxonomic levels and intermediate ranks.

4.2 Trait data coverage

At present, the database contains 19 traits and 80 trait categories with in total currently 14242 entries of trait information. The trait for which most entries exist is "Skeleton" (1837 entries), followed by "Reproduction" (1328 entries) and "Body form" (1151 entries) (Fig. 7). The phylum with most entries are the Annelida (6130 entries, 43 %), followed by Arthropoda (2968 entries, 21 %) and Mollusca (2177 entries, 15 %). Regarding the taxonomic level, most trait information was added on the species level (48 %), less on the genus (25 %) and family level (17 %).

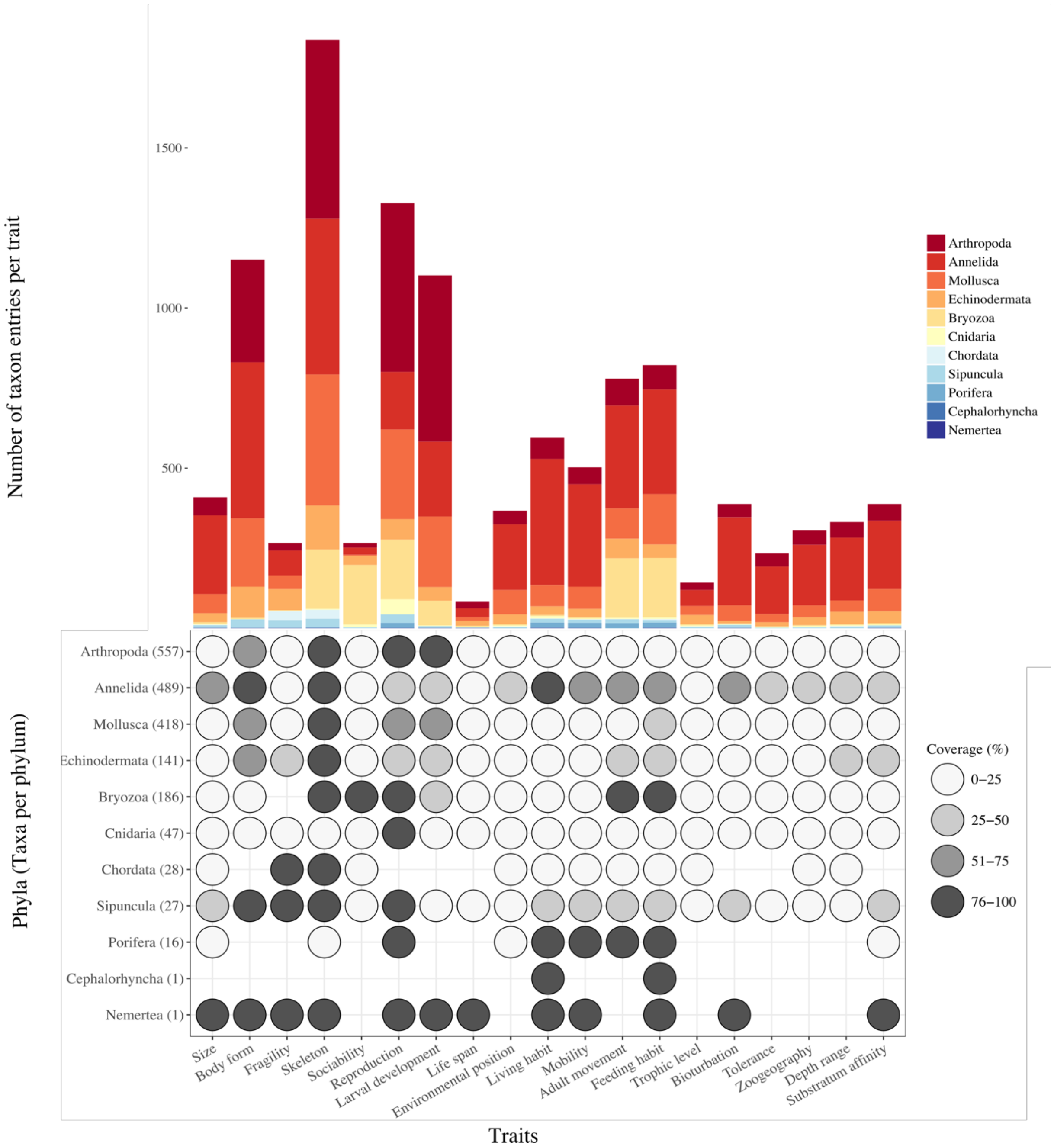

Figure 7. Scheme visualizing the taxon entries per trait (bar chart), the number of taxa per phylum (brackets), and the data coverage per trait per phylum (dot plot).

4.3 Bibliography

The Arctic Traits Database currently includes 394 sources of trait information. Thereof 66 % scientific papers, 11 % are books, 10 % webpages, and 4 % are expert communications and personal observation ("Other"). Theses, book sections, and reports each make up around 3 %. Most sources were used for the phylum Echinodermata and Annelida (33 % each), followed by Arthropoda (29 %).

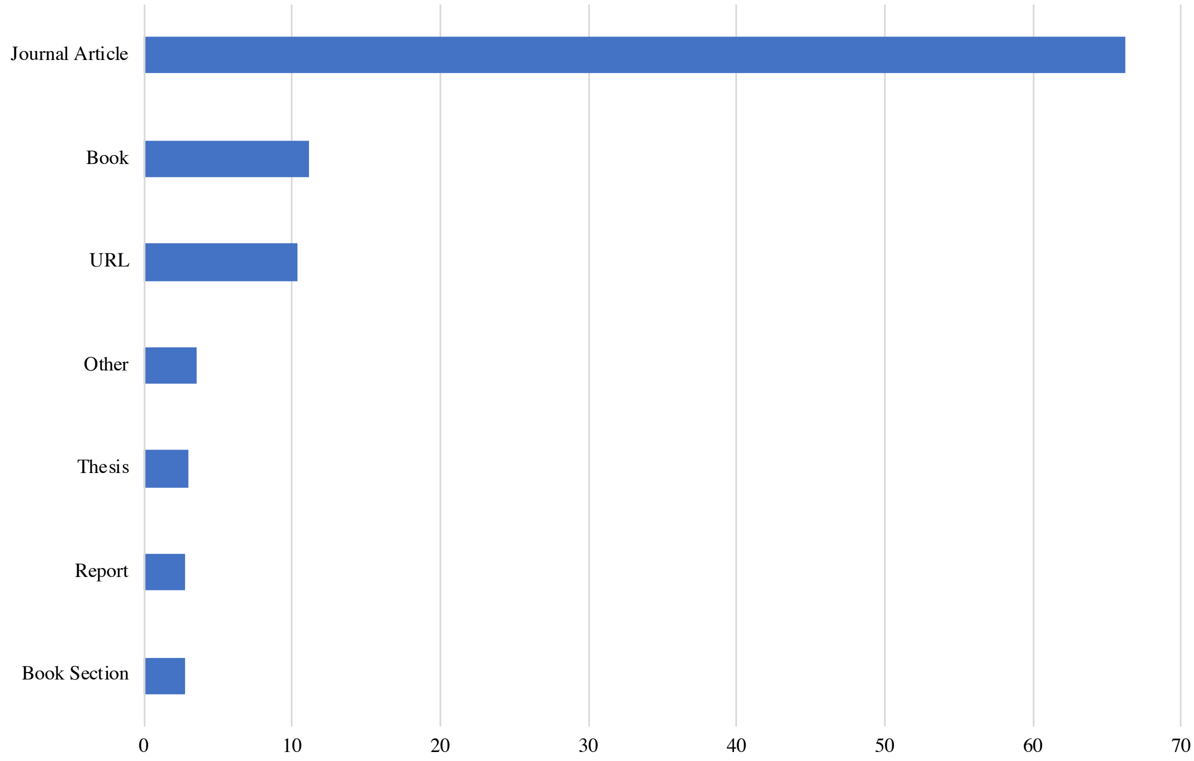

Figure 8. Relative amount (%) of trait source types.

5 Discussion

Although the Arctic Traits Database is still growing as new taxa and trait information are added, certain trends in data completeness or scarceness, respectively, became apparent (Fig. 7). Thus, the database is not only a valuable tool for collecting and providing information, but also for pointing out where more research might be needed. Regarding the 19 traits included at the present stage, it shows that our knowledge on e.g. the live span of many Arctic benthic species is still limited (information only for < 5 % of species). This lack of data on species longevity is astonishing, as polar taxa are traditionally depicted as slow growing and long-lived compared to their relatives from lower latitudes. Accordingly, one might have expected that more studies and measurements are available for a variety of Arctic taxa, which is not the case for many groups. Other traits that are currently underrepresented are trophic level (< 8 %) and tolerance (<13 %).

Regarding our interest to identify knowledge gaps, a special strength of the database is the implemented flagging system (described in detail in the supplement). As registered users continue to upload trait information, also more "conflicts" – i.e. cases where the sources or observations added by different users point towards different trait categories – may arise. Such cases are then indicated by a red flag and can be easily filtered for. Monitoring and statistical evaluation of these cases will grant important information on where conflicts exist and for which taxa or traits future research is needed. Such evaluation will also aid to identify which traits are more robust (i.e. are never flagged), and which show a higher plasticity (frequent flagging). This kind of information is of tremendous value as it can aid the choice as of which traits to include in prospective trait-based studies. Apart from clearly diverging source information, also different levels of experience or customs in fuzzy coding might lead to red flags in the system. Here the editorial team will take care for consistency by solving the conflicts according to the database standard, by that also fostering a standardized way of coding within the community. In addition, repetitively occurring discrepancies in the coding of certain traits might also point towards a need for revision of these trait categories or their definitions, or maybe even the adding of a new trait, in that way improving the quality of the database.

In addition to the above discussed knowledge gaps surrounding certain traits, also the data coverage among taxonomic groups varies considerable (Fig. 7). This potentially mirrors the sampling design of the underlying datasets. Some taxonomic groups such as the polychaetes clearly dominate many benthic soft-bottom communities, while other taxa such as the shrimp/caridea are highly mobile and might be permanently undersampled with sampling gears like grabs, box corers, or bottom trawls (Eleftheriou and McIntyre, 2007). This points toward the need to include also datasets derived from video and still image analysis in the future development of the database. These methods – despite certain disadvantages (discussed in Degen et al. 2018, Supplementary file 3) – have the great benefit that also traits of hard bottom communities can be analyzed, ecosystems which are at present stage underrepresented in the Arctic Traits Database.

6 Data availability

The Arctic Traits Database is hosted at the University of Vienna (Austria) and can be accessed via https://www.univie.ac.at/arctictraits/ (https://doi.org/10.25365/phaidra.49). A code package to create a web-based trait database including a README file with instructions for installation is provided at figshare, https://doi.org/10.6084/m9.figshare.7491869.

7 Conclusions

The Arctic Traits Database provides an easy accessible and sound knowledge base of traits of Arctic benthic invertebrates and will thus facilitate prospective trait-based studies for a variety of benthic ecologists at all career stages. Its sophisticated structure accounts for the most commonly raised demands to contemporary trait databases: 1) obligate traceability of information (every entry is linked to at least one source), 2) exchangeability among platforms (use of most common download formats), 3) standardization (use of most common terminology and coding scheme), and last but not least 4) user friendliness (granted by an intuitive web-interface and rapid and easy download options). The combination of these aspects makes the Arctic Traits Database a cutting-edge tool for (not only) the marine realm and a role-model for prospective databases.

Author contribution

RD designed the project and performed the trait data collection. SF performed database and webpage development and design. RD prepared the manuscript with contributions from SF.

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References

Aller, R. C.: The importance of the diffusive permeability of animal burrow linings in determining marine sediment chemistry, J. Mar. Res., 41(2), 299–322, doi:10.1357/002224083788520225, 1983.

Beauchard, O., Veríssimo, H., Queirós, A. M. and Herman, P. M. J.: The use of multiple biological traits in marine community ecology and its potential in ecological indicator development, Ecol. Indic., 76, 81–96, doi:10.1016/j.ecolind.2017.01.011, 2017.

Bernhardt-Römermann, M., Gray, A., Vanbergen, A. J., Bergès, L., Bohner, A., Brooker, R. W., Bergès, L., Bohner, A., Brooker, R. W., De Bruyn, L., De Cinti, B., Dirnböck, T., Grandin, U., Hester, A. J., Kanka, R., Klotz, S., Loucougaray, G., Lundin, L., Matteucci, G., Mészáros, I., Oláh, V., Preda, E., Prévosto, B., Pykälä, J., Schmidt, W., Taylor, M. E., Vadineanu, A., Waldmann, T. and Stadler, J.: Functional traits and local environment predict vegetation responses to disturbance: a pan-European multi-site experiment, J. Ecol., 99(3), 777–787, doi:10.1111/j.1365-2745.2011.01794.x, 2011.

Blanchard, A. L., Parris, C. L., Knowlton, A. L. and Wade, N. R.: Benthic ecology of the northeastern Chukchi Sea. Part I. Environmental characteristics and macrofaunal community structure, 2008-2010, Cont. Shelf Res., 67, 52–66, doi:10.1016/j.csr.2013.04.021, 2013a.

Blanchard, A. L., Parris, C. L., Knowlton, A. L. and Wade, N. R.: Benthic ecology of the northeastern Chukchi Sea. Part II. Spatial variation of megafaunal community structure, 2009–2010, Cont. Shelf Res., 67, 67–76, doi:10.1016/j.csr.2013.04.031, 2013b.

Bolam, S. G. and Eggleton, J. D.: Macrofaunal production and biological traits: Spatial relationships along the UK continental shelf, J. Sea Res., 88, 47–58, doi:10.1016/j.seares.2014.01.001, 2014.

Borja, A., Franco, J. and Pérez, V.: A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments, Mar. Pollut. Bull., 40(12), 1100–1114, 2000.

Bremner, J.: Species' traits and ecological functioning in marine conservation and management, J. Exp. Mar. Bio. Ecol., 366(1–2), 37–47, doi:10.1016/j.jembe.2008.07.007, 2008.

Bremner, J., Rogers, S. I. and Frid, C. L. J.: Methods for describing ecological functioning of marine benthic assemblages using biological traits analysis (BTA), Ecol. Indic., 6(3), 609–622, doi:10.1016/j.ecolind.2005.08.026, 2006.

Brown, J. H., Gillooly, J. F., Allen, A. P., Van Savage, M. and West, G. B.: Toward a metabolic theory of ecology, Ecology, 85(7), 1771–1789, 2004.

Brun, P., Payne, M. R. and Kiørboe, T.: A trait database for marine copepods, Earth Syst. Sci. Data, 9(1), 99–113, doi:10.5194/essd-9-99-2017, 2017.

Cain, M. L., Bowman, W. D. and Hacker, S. D.: Ecology, Third Edit., Sinauer Associates., 2014.

Cardeccia, A., Marchini, A., Occhipinti-Ambrogi, A., Galil, B., Gollasch, S., Minchin, D., Narščius, A., Olenin, S. and Ojaveer, H.: Assessing biological invasions in European Seas: Biological traits of the most widespread non-indigenous species, Estuar. Coast. Shelf Sci., 201, 17–28, doi:10.1016/j.ecss.2016.02.014, 2018.

Chen, X., Andersen, T. J., Morono, Y., Inagaki, F., Jørgensen, B. B. and Lever, M. A.: Bioturbation as a key driver behind the dominance of Bacteria over Archaea in near-surface sediment, Sci. Rep., 7(1), 1–14, doi:10.1038/s41598-017-02295-x, 2017.

Chevenet, F., Dolédec, S. and Chessel, D.: A fuzzy coding approach for the analysis of long-term ecological data, Freshw. Biol., 31(3), 295–309, doi:10.1111/j.1365-2427.1994.tb01742.x, 1994.

Costello, M. J., Claus, S., Dekeyzer, S., Vandepitte, L., Tuama, É. Ó., Lear, D. and Tyler-Walters, H.: Biological and ecological traits of marine species., PeerJ, 3, e1201, doi:10.7717/peerj.1201, 2015.

Darr, A., Gogina, M. and Zettler, M. L.: Functional changes in benthic communities along a salinity gradient- a western Baltic case study, J. Sea Res., 85, 315–324, doi:10.1016/j.seares.2013.06.003, 2014.

Degen, R., Aune, M., Bluhm, B. A., Cassidy, C., Kędra, M., Kraan, C., Vandepitte, L., Włodarska-Kowalczuk, M., Zhulay, I., Albano, P. G., Bremner, J., Grebmeier, J. M., Link, H., Morata, N., Nordström, M. C., Shojaei, M. G., Sutton, L. and Zuschin, M.: Trait-based approaches in rapidly changing ecosystems: A roadmap to the future polar oceans, Ecol. Indic., 91(April), 722–736, doi:10.1016/j.ecolind.2018.04.050, 2018.

Dolbeth, M., Teixeira, H., Marques, J. C. and Pardal, M. Â.: Feeding guild composition of a macrobenthic subtidal community along a depth gradient, Sci. Mar., 73(2), 225–237, doi:10.3989/scimar.2009.73n2225, 2009.

Eleftheriou, A. and McIntyre, A.: Methods for the Study of Marine Benthos: Third Edition, Blackwell Science Ltd., 2007.

Emmerson, M. C.: The importance of body size, abundance, and food-web structure for ecosystem functioning, in Marine Biodiversity and Ecosystem Functioning: Frameworks, methodologies, and integration, edited by M. Solan, R. J. Aspden, and D. M. Paterson, p. 240, Oxford University Press, Oxford., 2012.

Faulwetter, S., Markantonatou, V., Pavloudi, C., Papageorgiou, N., Keklikoglou, K., Chatzinikolaou, E., Pafilis, E., Chatzigeorgiou, G., Vasileiadou, K., Dailianis, T., Fanini, L., Koulouri, P. and Arvanitidis, C.: Polytraits: A database on biological traits of marine polychaetes, Biodivers. Data J., 2, e1024, doi:10.3897/BDJ.2.e1024, 2014.

Fetzer, I.: Reproduction strategies and distribution of larvae and juveniles of benthic soft-bottm invertebrates in the Kara Sea (Russian Arctic), Universtiy of Bremen., 2005.

Fetzer, I. and Arntz, W. E.: Reproductive strategies of benthic invertebrates in the Kara Sea (Russian Arctic): Adaptation of reproduction modes to cold water, Mar. Ecol. Prog. Ser., 356(1878), 189–202, doi:10.3354/meps07271, 2008.

Foden, W. B., Butchart, S. H. M., Stuart, S. N., Vié, J. C., Akçakaya, H. R., Angulo, A., DeVantier, L. M., Gutsche, A., Turak, E., Cao, L., Donner, S. D., Katariya, V., Bernard, R., Holland, R. A., Hughes, A. F., O'Hanlon, S. E., Garnett, S. T., Şekercioğlu, Ç. H. and Mace, G. M.: Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals, edited by S. Lavergne, PLoS One, 8(6), e65427, doi:10.1371/journal.pone.0065427, 2013.

Frid, C. L. J. and Caswell, B. A.: Is long-term ecological functioning stable: The case of the marine benthos?, J. Sea Res., 98, 15–23, doi:10.1016/j.seares.2014.08.003, 2015.

Frid, C. L. J. and Caswell, B. A.: Does ecological redundancy maintain functioning of marine benthos on centennial to millennial time scales ?, Mar. Ecol., 37(2), 392–410, doi:10.1111/maec.12297, 2016.

Frid, C. L. J., Paramor, O. A. L., Brockington, S. and Bremner, J.: Incorporating ecological functioning into the designation and management of marine protected areas, edited by J. Davenport, G. Burnell, T. Cross, M. Emmerson, R. McAllen, R. Ramsay, and E. Rogan, Hydrobiologia, 606, 69–79, doi:10.1007/978-1-4020-8808-7_7, 2008.

Gogina, M., Morys, C., Forster, S., Gräwe, U., Friedland, R. and Zettler, M. L.: Towards benthic ecosystem functioning maps: Quantifying bioturbation potential in the German part of the Baltic Sea, Ecol. Indic., 73, 574–588, doi:10.1016/j.ecolind.2016.10.025, 2017.

Grebmeier, J., Bluhm, B., Cooper, L., Denisenko, S., Iken, K., Kedra, M. and Serratos, C.: Time-Series Benthic Community Composition and Biomass and Associated Environmental Characteristics in the Chukchi Sea During the RUSALCA 2004–2012 Program, Oceanography, 28(3), 116–133, doi:10.5670/oceanog.2015.61, 2015.

Gusmao, J. B.: Sediments and Functional Traits : Applying a Functional Trait Approach To Assess Marine Macrobenthic Function, Univeridade Federal do Parana., 2017.

Gutt, J.: On the direct impact of ice on marine benthic communities, a review, Polar Biol., 24(8), 553–564, doi:10.1007/s003000100262, 2001.

Hayward, P. J. and Ryland, J. S.: Handbook of the marine fauna of North-West Europe, edited by P. J. Hayward and J. S. Ryland, Oxford University Press, Oxford, New York, Tokyo., 2012.

Hewitt, J. E., Norkko, J., Kauppi, L., Villnäs, A., Norkko, A. and Peters, D. P. C.: Species and functional trait turnover in response to broad-scale change and an invasive species, Ecosphere, 7(3), doi:10.1002/ecs2.1289/supinfo, 2016.

Himmelman, J. H. and Dutil, C.: Distribution, population structure and feeding of subtidal seastars in the northern Gulf of St. Lawrence, Mar. Ecol. Prog. Ser., 76, 61–72, doi:10.3354/meps076061, 1991.

Hooper, D. U., Chapin, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., Lodge, D. M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A. J., Vandermeer, J. and Wardle, D. A.: Effects of biodiversity on ecosystem functioning: A consensus of current knowledge, Ecol. Monogr., 75(1), 3–35, doi:10.1890/04-0922, 2005.

Klais, R., Norros, V., Lehtinen, S., Tamminen, T. and Olli, K.: Community assembly and drivers of phytoplankton functional structure, edited by E. Carrington, Funct. Ecol., 31(3), 760–767, doi:10.1111/1365-2435.12784, 2017.

Kleyer, M., Dray, S., Bello, F., Lepš, J., Pakeman, R. J., Strauss, B., Thuiller, W. and Lavorel, S.: Assessing species and community functional responses to environmental gradients: Which multivariate methods?, edited by O. Wildi, J. Veg. Sci., 23(5), 805–821, doi:10.1111/j.1654-1103.2012.01402.x, 2012.

Kokarev, V. N., Vedenin, A. A., Basin, A. B. and Azovsky, A. I.: Taxonomic and functional patterns of macrobenthic communities on a high-Arctic shelf: A case study from the Laptev Sea, J. Sea Res., 129(April), 61–69, doi:10.1016/j.seares.2017.08.011, 2017.

Kröncke, I.: Macrobenthos composition, abundance and biomass in the Arctic Ocean along a transect between Svalbard and the Makarov Basin, Polar Biol., 14(8), 519–529, doi:10.1007/BF00238221, 1994.

Lacoste, É., Piot, A., Archambault, P., McKindsey, C. W. and Nozais, C.: Bioturbation activity of three macrofaunal species and the presence of meiofauna affect the abundance and composition of benthic bacterial communities, Mar. Environ. Res., 136, 62–70, doi:10.1016/j.marenvres.2018.02.024, 2018.

van der Linden, P., Marchini, A., Dolbeth, M., Patrício, J., Veríssimo, H. and Marques, J. C.: The performance of trait-based indices in an estuarine environment, Ecol. Indic., 61, 378–389, doi:10.1016/j.ecolind.2015.09.039, 2016.

Van Der Linden, P., Borja, A., Rodríquez, J. G., Muxika, I., Galparsoro, I., Patrício, J., Veríssimo, H. and Marques, J. C.: Spatial and temporal response of multiple trait-based indices to natural- and anthropogenic seafloor disturbance (effluents), Ecol. Indic., 69, 617–628, doi:10.1016/j.ecolind.2016.05.020, 2016.

Lucey, N. M., Lombardi, C., DeMarchi, L., Schulze, A., Gambi, M. C. and Calosi, P.: To brood or not to brood: Are marine invertebrates that protect their offspring more resilient to ocean acidification?, Sci. Rep., 5(January), 12009, doi:10.1038/srep12009, 2015.

Marchini, A., Munari, C. and Mistri, M.: Functions and ecological status of eight Italian lagoons examined using biological traits analysis (BTA), Mar. Pollut. Bull., 56(6), 1076–1085, doi:10.1016/j.marpolbul.2008.03.027, 2008.

Mermillod-Blondin, F.: The functional significance of bioturbation and biodeposition on biogeochemical processes at the water–sediment interface in freshwater and marine ecosystems, J. North Am. Benthol. Soc., 30(3), 770–778, doi:10.1899/10-121.1, 2011.

Micheli, F. and Halpern, B. S.: Low functional redundancy in coastal marine assemblages, Ecol. Lett., 8(4), 391–400, doi:10.1111/j.1461-0248.2005.00731.x, 2005.

Norkko, A., Villnäs, A., Norkko, J., Valanko, S. and Pilditch, C.: Size matters: implications of the loss of large individuals for ecosystem function., Sci. Rep., 3, 2646, doi:10.1038/srep02646, 2013.

Oug, E., Fleddum, A., Rygg, B. and Olsgard, F.: Biological traits analyses in the study of pollution gradients and ecological functioning of marine soft bottom species assemblages in a fjord ecosystem, J. Exp. Mar. Bio. Ecol., 432, 94–105 [online] Available from: http://apps.webofknowledge.com/full_record.do?product=CCC&search_mode=GeneralSearch&qid=7&SID=W29TQeqCuCsBtQBk9hp&page=1&doc=9 (Accessed 28 April 2016), 2012.

Pearson, T. H.: Functional group ecology in soft-sediment marine benthos: the role of bioturbation, Oceanogr. Mar. Biol. Annu. Rev., 39(1), 78–94, 2001.

Piepenburg, D.: Arctic Brittle Stars (Echinodermata: Ophiuroidea), Oceanogr. Mar. Biol. Annu. Rev., 38, 189–256, 2000.

Piló, D., Ben-Hamadou, R., Pereira, F., Carriço, A., Pereira, P., Corzo, A., Gaspar, M. B. and Carvalho, S.: How functional traits of estuarine macrobenthic assemblages respond to metal contamination?, Ecol. Indic., 71, 645–659, doi:10.1016/j.ecolind.2016.07.019, 2016.

Queirós, A. M., Birchenough, S. N. R., Bremner, J., Godbold, J. A., Parker, R. E., Romero-Ramirez, A., Reiss, H., Solan, M., Somerfield, P. J., Van Colen, C., Van Hoey, G. and Widdicombe, S.: A bioturbation classification of European marine infaunal invertebrates., Ecol. Evol., 3(11), 3958–85, doi:10.1002/ece3.769, 2013.

Renaud, P., Tessmann, M., Evenset, A. and Christensen, G.: Benthic food-web structure of an Arctic fjord (Kongsfjorden, Svalbard), Mar. Biol. Res., 7(1), 13–26, doi:10.1080/17451001003671597, 2011.

Rosenberg, R.: Benthic marine fauna structured by hydrodynamic processess and food availability, Neth. J. Sea. Res., 34(4), 303–317, 1995.

Schleuter, D., Daufresne, M., Massol, F. and Argillier, C.: User's guide to functional diversity indices., Ecol. Monogr., 80(3), 448–469, doi:10.1890/08-2225.1, 2010.

Solan, M., Aspden, R. J. and Paterson, D. M.: Marine biodiversity & ecosystem functioning, First edit., edited by M. Solan, R. J. Aspden, and D. M. Paterson, Oxford University Press, Oxford., 2012.

Spitz, J., Ridoux, V. and Brind'Amour, A.: Let's go beyond taxonomy in diet description: Testing a trait-based approach to prey-predator relationships, J. Anim. Ecol., 83(5), 1137–1148, doi:10.1111/1365-2656.12218, 2014.

Törnroos, A. and Bonsdorff, E.: Developing the multitrait concept for functional diversity: Lessons from a system rich in functions but poor in species, Ecol. Appl., 22(8), 2221–2236, doi:10.1890/11-2042.1, 2012.

Tyler, E. H. M., Somerfield, P. J., Berghe, E. Vanden, Bremner, J., Jackson, E., Langmead, O., Palomares, M. L. D. and Webb, T. J.: Extensive gaps and biases in our knowledge of a well-known fauna: Implications for integrating biological traits into macroecology, Glob. Ecol. Biogeogr., 21(9), 922–934, doi:10.1111/j.1466-8238.2011.00726.x, 2012.

Wassmann, P., Duarte, C. M., Agustí, S. and Sejr, M. K.: Footprints of climate change in the Arctic marine ecosystem, Glob. Chang. Biol., 17(2), 1235–1249, doi:10.1111/j.1365-2486.2010.02311.x, 2011.

Weigel, B., Blenckner, T. and Bonsdorff, E.: Maintained functional diversity in benthic communities in spite of diverging functional identities, Oikos, 125(10), 1421–1433, doi:10.1111/oik.02894, 2016.

Weslawski, J., Wlodarska-Kowalczuk, M. and Legezynska, J.: Occurrence of soft bottom macrofauna along the depth gradient in High Arctic, 79 N, Pol. Polar Res, 24(1), 73–88 [online] Available from: http://polish.polar.pan.pl/ppr24/ppr24-073.pdf, 2003.

Wieczorek, J., Bloom, D., Guralnick, R., Blum, S., Döring, M., Giovanni, R., Robertson, T. and Vieglais, D.: Darwin core: An evolving community-developed biodiversity data standard, PLoS One, 7(1), doi:10.1371/journal.pone.0029715, 2012.

Wiedmann, M., Aschan, M., Certain, G., Dolgov, A., Greenacre, M., Johannesen, E., Planque, B. and Primicerio, R.: Functional diversity of the Barents Sea fish community, Mar. Ecol. Prog. Ser., 495, 205–218, doi:10.3354/meps10558, 2014.

Web links / Trait databases

Encyclopedia of Life: http://www.eol.org/, last access: 29 June 2018.

Froese, R. and D. Pauly. Editors. 2018. FishBase. World Wide Web electronic publication. www.fishbase.org, version (02/2018).

Functional trait compilation for marine phytoplankton: https://www.riinaklais.com/phytotraits, last access: 28 January 2019.

GBIF.org (2018), *GBIF Home Page*: https://www.gbif.org/, last access: 29 June 2018.

Marine Macrofauna Genus Trait Handbook: http://www.genustraithandbook.org.uk/, last access: 27 June 2018.

MarLIN, 2006. *BIOTIC - Biological Traits Information Catalogue.* Marine Life Information Network. Plymouth: Marine Biological Association of the United Kingdom: www.marlin.ac.uk/biotic/, last access: 18 April 2018.

Marine Species Traits editorial board (2018). Marine Species Traits: http://www.marinespecies.org/traits/, last access: 27 June 2018.

Neogene Marine Biota of Tropical America (NMiTA): http://eusmilia.geology.uiowa.edu/, last access: 29 June 2018.

Ocean Biogeographic Information System (OBIS): http://www.iobis.org/, last access: 27 June 2018.

Sea Life Base: http://www.sealifebase.org/, last access: 29 June 2018.

The Polychaetes scratchpad: http://polychaetes.lifewatchgreece.eu/, last access: 27 June 2018.

WoRMS Editorial Board (2017). World Register of Marine Species: http:// www.marinespecies.org/, last access: 27 June 2018. doi:10.14284/170.

Supplement

The Arctic Traits Database was originally designed as an interactive tool for benthologists working in the field of (arctic) trait-based ecology, in order to facilitate the exchange and the discussion of biological trait information within the community. The final goal is to provide sound and easy accessible trait information to the entire scientific community. While trait information that is added to the database is immediately visible and accessible online via the public page (http://www.univie.ac.at/arctictraits/), the restricted, interactive area of the database offers several benefits solely to the registered user:

1) A well-structured and user-friendly interface to get trait information organized and obligatory linked to source information and to taxonomy (via the World Register of Marine Species, WoRMS).
2) A working environment that facilitates knowledge exchange and discussion among collaborators.
3) Additional options to inspect, organize, and analyze the entire dataset included in the database.
4) Traceable credit, as every collaborator is listed as board member on the public page and right after every trait entry performed.

The following manual for registered users explains in detail and via screenshots how species and trait information can be entered in the Arctic Traits Database. It is also provided in the “About” section of the Arctic Traits Database (via the public access).

Database manual for registered users

1 Login

Once a user entry is received from the editor, the restricted area of the database can be accessed via the “Login” button on the public page (Fig. S1).

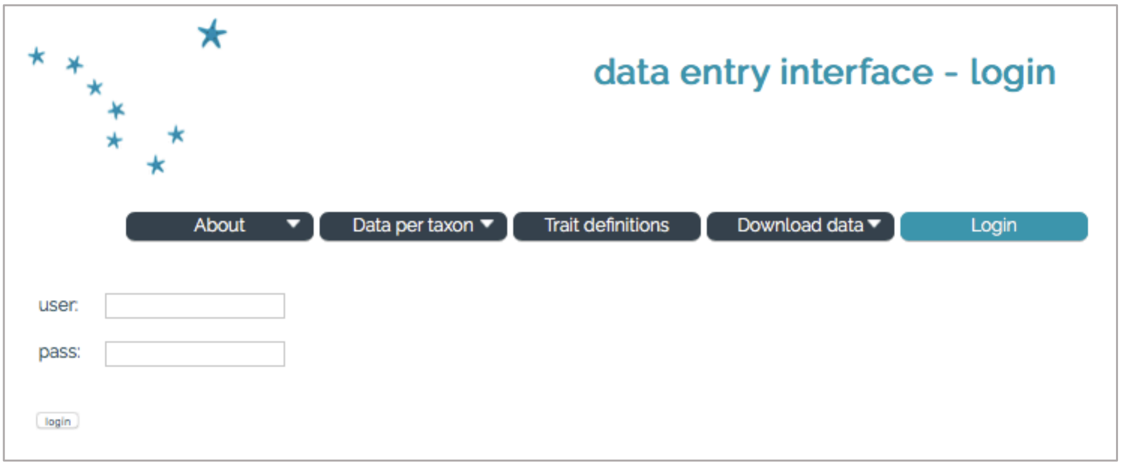

Fig. S1. User entry interface.

2 Getting started

After signing in the user is transferred to a starting page with a top menu bar of seven headers (Fig. S2, Table S1). In addition, an alphabetic list of all taxa in the database is displayed (grouped in species/genus/family level taxa). The taxon list can be filtered for datasets (see Sect. 4) or phyla. Each taxon name links directly to the respective taxon page (see Sect. 5). Alternatively, a taxon can be searched for by typing its name into the input panel.

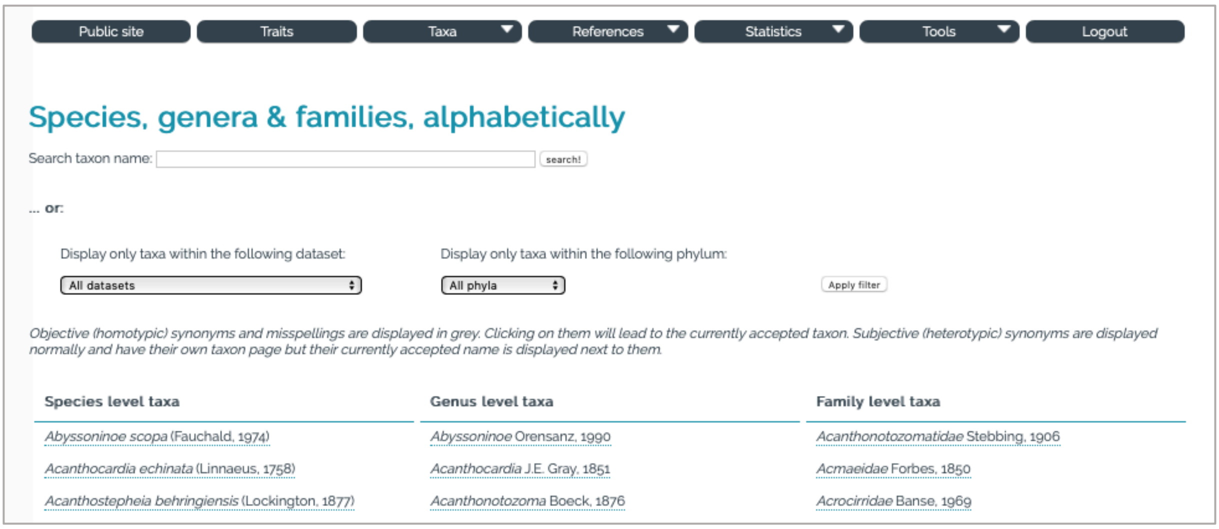

Fig. S2. Clip of the starting page for registered users.

Table S1. Brief summary of the options behind each header in the top menu bar

Header	Function		
Public site	Transfer back to the public page.		
Traits	Shows a list of the traits included in the database. Each trait links to all those taxa for which information on this specific trait are existing.		
Taxa	Taxa alphabetically	Alphabetic list of taxa, same than starting page.	
	Classification	Classification tree, branches can be expanded per mouse click and taxa selected.	
	Add new taxon	Manual entry of taxa (see 3.1).	
	Aphia batch entry	Batch entry of up to 50 taxa via their Aphia IDs (see 3.2).	
	Manage synonyms	This page allows you to change the status of synonyms (and add references for synonymies).	
References	List of references	Show total list of included sources (see Sect. 5).	
	Add new reference	Entry window for new reference or observation (see Sect. 5).	
Statistics	Data per user	Overview of all entries of the respective user.	
Tools	Dataset management	Add a new dataset.	see Sect. 5
		Remove an existing dataset.	see Sect. 5
		Add taxa to an existing dataset.	see Sect. 5
		Remove taxa from an existing dataset.	see Sect. 5
	Data with conflicts	Lists all taxa for which conflicts exist (see Sect. 5).	
	User management	List of registered users with options for account management.	
Logout	Logs the user out of the system and leads back to the public site (Fig. 1).		

3 Adding taxa to the Arctic Traits Database

As trait information is always connected to specific taxa, in a first step the respective taxon (Sect. 3.1) or a whole list of taxa (Sect. 3.2) hast to be entered or uploaded. Optionally, the taxa can be organized into specific datasets, e.g. linking to a specific sampling campaign and location (see Sect. 4 “Dataset management”).

3.1 Manual entry of taxa

The system allows data entry at different taxonomic levels, from species to phylum. Via the “Taxa” dropdown in the top menu and “Add new taxon” (Fig. S3, Table S1) taxon names can be entered one by one manually. In that case, the system will query the World Register of Marine Species (WoRMS Editorial Board, 2018; http://www.marinespecies.org/) for the taxon, may correct for misspellings, and then enter the taxon and its higher classification automatically. In the event that taxon names have changed ("unaccepted" in worms), we recommend to stick to the original taxon name as information might end up attached to the wrong taxon if the classification changes again at any point in the future. In the database synonyms are displayed and deep-linked to WoRMS in the taxonomic tree on the taxon page (Fig. S5). If the taxon is already included in the database, a message is displayed and the taxon is not entered, thus avoiding duplicates. The user can of course still add trait information to the already existing taxon.

Fig. S3. Screenshot of the manual taxon entry.

3.2 AphiaID batch entry

Adding of multiple taxa at once is possible via the "AphiaID batch entry" function in the "Taxa" dropdown menu (Fig. 4). This function allows to enter up to 50 AphiaIDs at the same time. The system will query WoRMS for the taxa for these AphiaIDs and enter them automatically. In this case, the taxon names have first to be matched to WoRMS by the user (see taxon match tutorial at http://www.marinespecies.org). In the event that AphiaIDs have changed ("unaccepted" taxa in worms), we recommend to stick to the original AphiaID (see Sect. 3.1). Again, if a taxon is already included in the database, a message is displayed and the taxon is not entered.

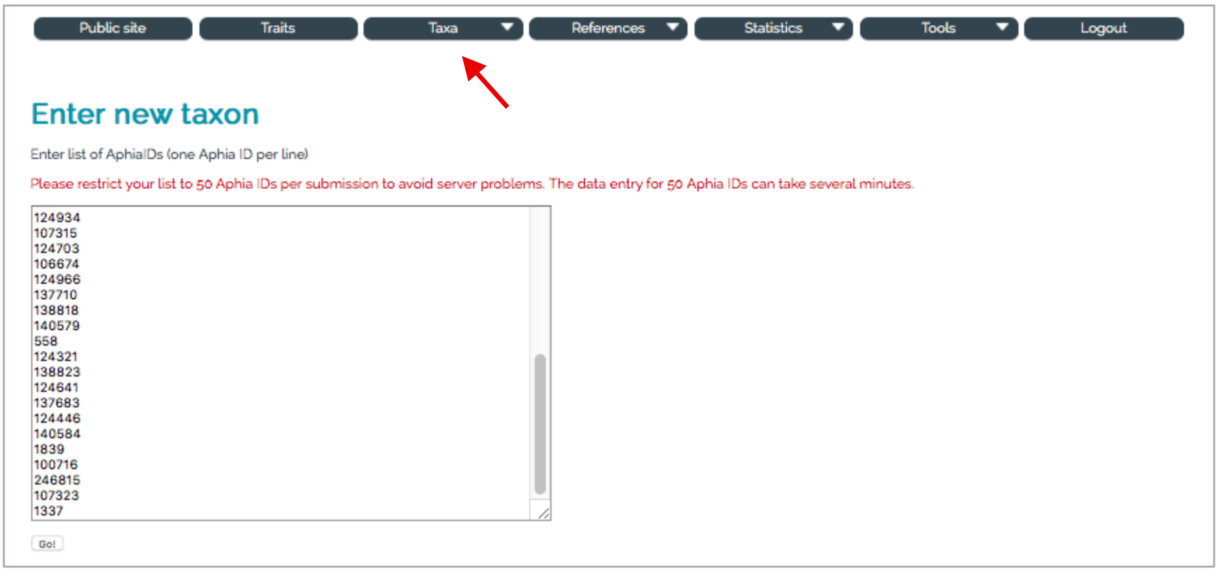

Fig. S4. Screenshot of the AphiaID batch entry. The AphiaIDs can be entered simply via copy-paste.

4 Dataset management

In the "Tools" section taxa can be allocated to one or more specific datasets via the "dataset management" function. This can be done either to organize a user's working process, to ensure a certain degree of traceability to the original data source and to the region where the taxon was sampled, or to be able to export only pre-defined subsets of data. As one specific example, the echinoderm species *Crossaster papposus* is one of 350 taxa from a dataset named "RUSALCA 2012" provided by Jaqueline Grebmeier, sampled on the RUSALCA cruise 2012 (Grebmeier et al. 2015). If another dataset is uploaded including *C. papposus*, the taxon is not entered again, but also the second dataset linked to the taxon. There is no limitation in the number of datasets to which a taxon can be linked. In case the connection of a taxon to a specific dataset is no longer desired, it can – again via the "dataset management" function – easily be removed from the dataset ("Remove taxa from an existing dataset"), or added to another ("Add taxa to an existing dataset"). In any case, the taxon or the trait information tied to this taxon is thereby not affected.

5 Adding trait and source information

Once a taxon is added to the database, it has its own taxon page (Fig. S5) and trait information to each of the 19 traits and 80 trait categories can be added. Below the taxon (and author) name the taxonomic tree (derived from WoRMS) is displayed. The WoRMS logo (left of the taxon name) directly links to the WoRMS taxon page of – in this example – *Crossaster papposus*. 17 traits are highlighted in blue, indicating that information was already entered. 2 traits are highlighted in light grey color, here – so far – no trait information was entered for this taxon.

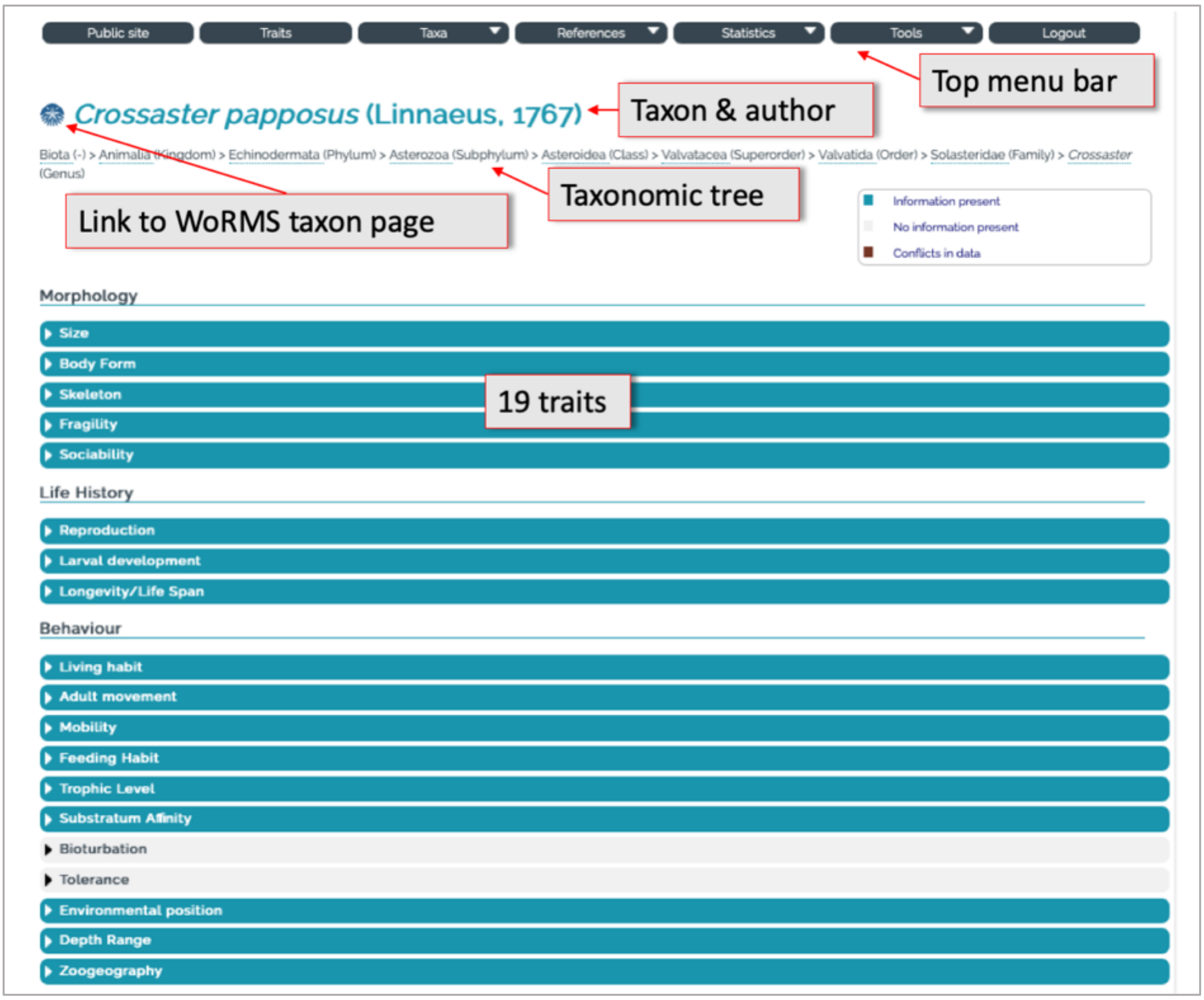

Fig. S5. Screenshot of the taxon page of *Crossaster papposus*.

The data in the database are organized in the format of taxon – trait – trait categories – fuzzy codes – references (Fig. S6). When moving the mouse cursor over a trait category (e.g. LD3 "benthic/direct" in Fig. S6), the trait definition is shown in a small window ("Larvae have benthic or direct development [no larval stage, eggs develop into miniature adults]"). For each trait category, a fuzzy value from 0 to 3 (see Sect. 2.4 of main text or the "About" section of the public page) can be checked per mouse click and must be supported by at least one reference. This guaranties that no trait information in the entire database is without a source information. In the example below (Fig. S6) two users checked the fuzzy code "3" and added references to the trait category LD2 ("pelagic/lecitotrophic"). Once information is added the color of the respective trait changes from light grey to blue (after the page is reloaded).

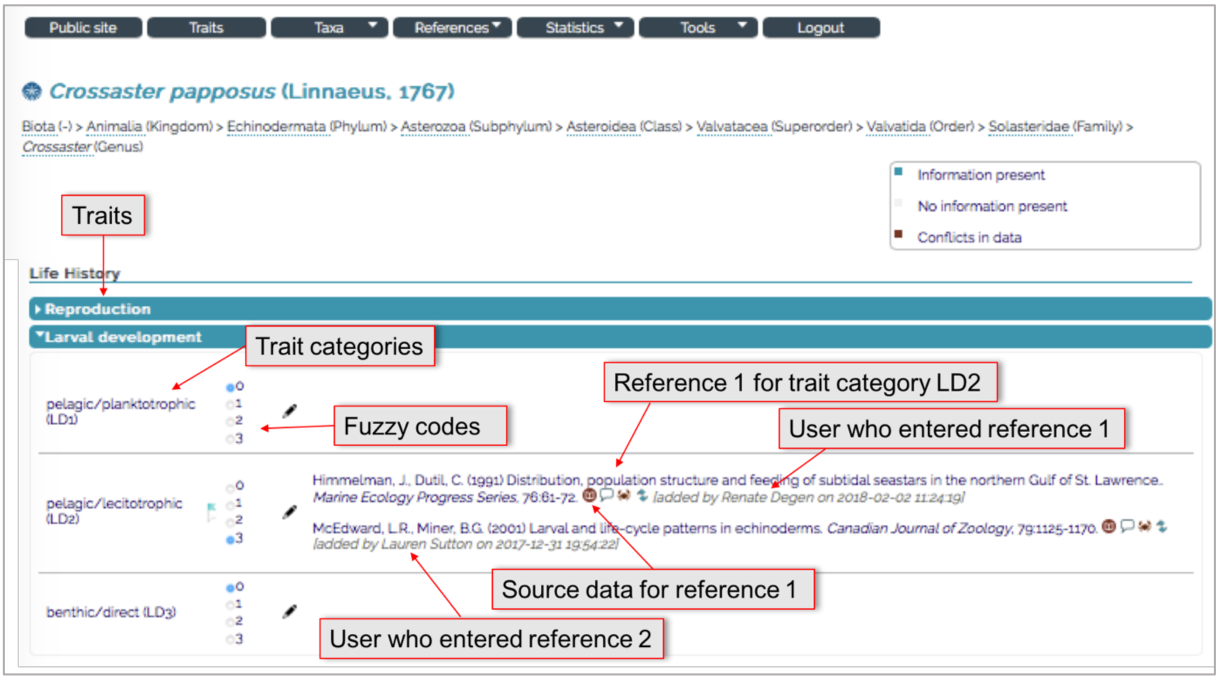

Fig. S6. Screenshot of the taxon page of *Crossaster papposus*. For the trait Larval development two references were entered by two different users in the trait category LD2 (pelagic/lecithotrophic). The fuzzy code "3" is checked for this category.

The exact reference needs to be chosen from the database bibliography via a window that opens automatically once a fuzzy code is entered (Fig. S7, left). The search options are "author", "title", "year", "journal", "DOI", "url", and "other". The option "other" is included because trait information does not always stem from published literature, but from communication with experts. In such cases the name of the taxonomic expert that passed on the information can be entered in the "Enter new publication" window (Fig. S7, right). In such cases the reference type "Other" needs to be selected. Also, the event of a "Personal observation", i.e. when the user personally observed or measured a certain trait, is included in the option "other". The "enter new publication" window is needed in any case when the respective reference (published or communicated) is not yet included in the database bibliography. Then the entire bibliographic information (reference type, authors, year, title, journal, …) needs to be entered. The use of the "Lookup data from DOI" option speeds up the process, as then manual entry is no longer required. Additional references can be added at any time via the "References" section in the top menu bar (Fig. S2, Table S1).

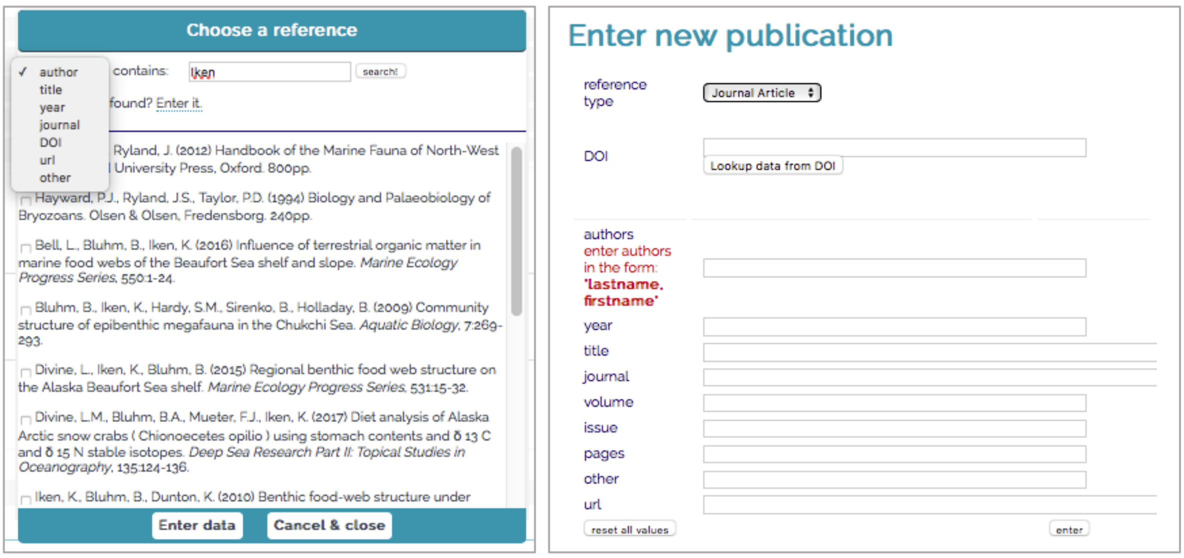

Fig. S7. Screenshots of the reference entry interface. Once a fuzzy code is entered, a reference has to be assigned from the bibliography (left), or a new reference has to be entered (right).

Once a reference is selected, the exact source information (raw data, quote of the text that led to the choice of the fuzzy value, table or page number) can be entered in another popup window via the **"source"** symbol (book icon, Table S6) (Fig. S8). This allows other users to understand which information led to the assignment of the taxon to a specific trait category. It also provides a means for quality control and for the re-using of the information in different contexts (Faulwetter et al. 2014). This is especially helpful if a specific research question might require different trait categories than those that have been chosen in the Arctic Traits Database. In the example in Fig. S8, text information from Lambert (2000), p. 77, is entered to support the coding of the trait category LD2 ("pelagic/lecitotrophic").

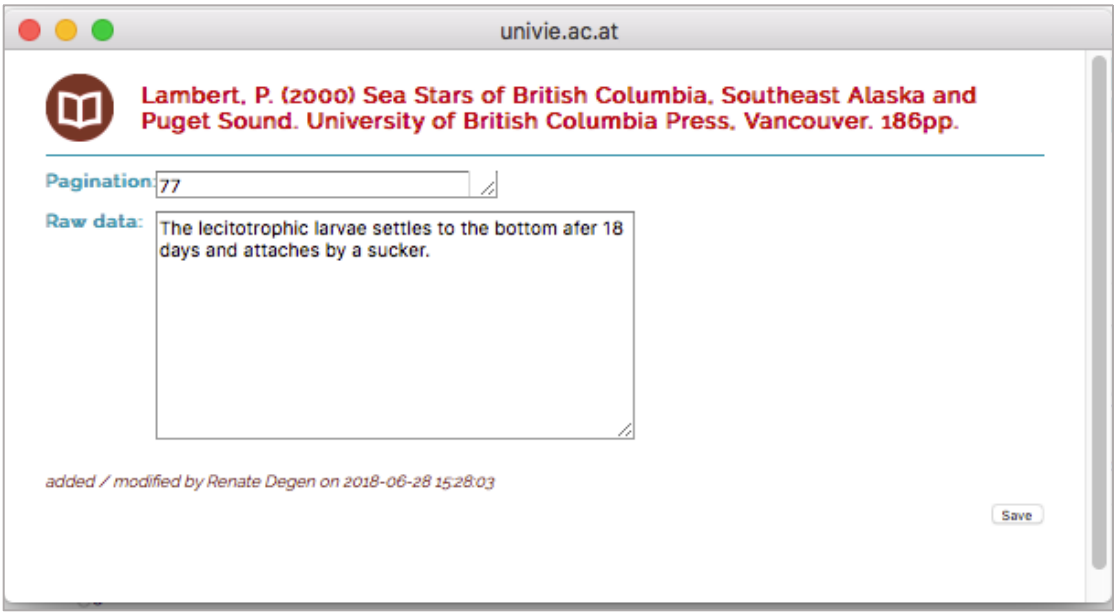

Fig. S8. Screenshot of the source entry window.

The **"comment"** symbol (speech bladder icon, Table S2) allows to add a personal comment to the entered trait information, or to the information entered by other users.

The **"taxonomy"** symbol (crab icon, Table S2) allows to copy or shift the trait information to another taxon, allowing for rapid entry of characteristics and references that are valid for several taxa. In general, the information is always assigned to the most specific taxon possible. As an example, the information "*Crossaster papposus* is a predator and scavenger" was assigned to *C. papposus*, while the information "most sea stars are predators of attached or buried animals" is assigned to the class Asteroidea.

The **"move"** symbol (two arrows icon, Table S2) allows to move or copy the entered trait information and reference to another trait category. This is useful when the quote is appropriate for several categories of one trait, to avoid repeating working steps and to save time. As one specific example, the quote "15-200 m" regarding the depth distribution of *Crossaster papposus* is appropriate for the first category in the trait "depth range" which is "shallow (DR1)", as well as for the second category which is "shelf (DR2)".

If data is entered for a taxon that has child taxa (i.e. on genus level or higher), also the **"child taxa"** symbol (down-looking arrow icon, Table S2) is visible. It allows to copy the entered fuzzy code, reference, detailed trait information and comments to all child taxa (e.g. all members of the current family) of the specific taxon. This function has to be used very carefully, as – in case the copied information proved later to be wrong – potentially dozens of wrong entries have to be deleted manually.

Once a reference is entered, a **"blue flag"** symbol (Table S2) shows up next to the fuzzy codes (Fig. S6). If users disagree concerning the fuzzy coding or the underlying reference, the color of the flag can be changed to red (Table S2) via mouse click, indicating a **"conflict"** (Fig. S10). The reason for the disagreement can be entered in a window, thus enabling a discussion among users (Fig. S11). A list of all data with conflicts can be accessed via the "tools" section in the top window (Fig. S2). Conflicts can only be resolved by the editor of the database after sound evaluation of the comments and suggestions by the users. In this event, the flag will then be changed back to blue. Unsolved conflicts will keep the red flag and the respective trait will not be included in the download in order to avoid transporting disputable information.

Other conflicts may appear due to bias in entering data. Cases where a reference is present but all fuzzy codes are "0" will be marked by the **"zero"** symbol (Table S2). Cases where the entered fuzzy codes are conflicting (e.g. "3" is entered twice for one trait, or a "2" and a "3" are entered, see Sect. 2.4 in main text) will be marked by the **"crash"** symbol (meeting arrows icon, Table S2). Such conflicts can be filtered for from the total dataset in the "Tools" section and resolved by the editor or registered users.

If a code, a reference or source information are changed, the grey **"modified by"** symbol appears next to the fuzzy codes (Table S2). This allows to track changes in the database.

Table S2. Explanations of icons in the interface for registered users.

Symbol	**Action/Interpretation**
	Source – original quote from reference, page number.
	Comment – e.g. to explain your choice of coding (not mandatory).
	Taxonomy – Move or copy trait information to other taxa.
	Move or copy trait information to another trait or trait category.
	Copy trait information to all child taxa.
	Trait information is present and not conflicting
	Conflict – disagreement among users.
0	Conflict – All fuzzy codes are set to "0".
	Conflict – Fuzzy codes are conflicting (e.g. codes "2" and "3" in one category)
	Modified by – Trait information was modified by a user; name and date are given.

Once trait information and references have been entered, the appearance of the respective taxon page changes (Fig. S9). Registered users will see that traits where no information is currently present are highlighted in light grey, traits with information are highlighted in blue, and traits where any of the conflicts mentioned above exist are now highlighted in brown. Once a conflict is resolved, the color will change from brown to blue after the page is reloaded. The taxon page visible via the public access shows only those traits that have complete information in blue, while absent traits are highlighted in light grey and conflicts are not visible at all.

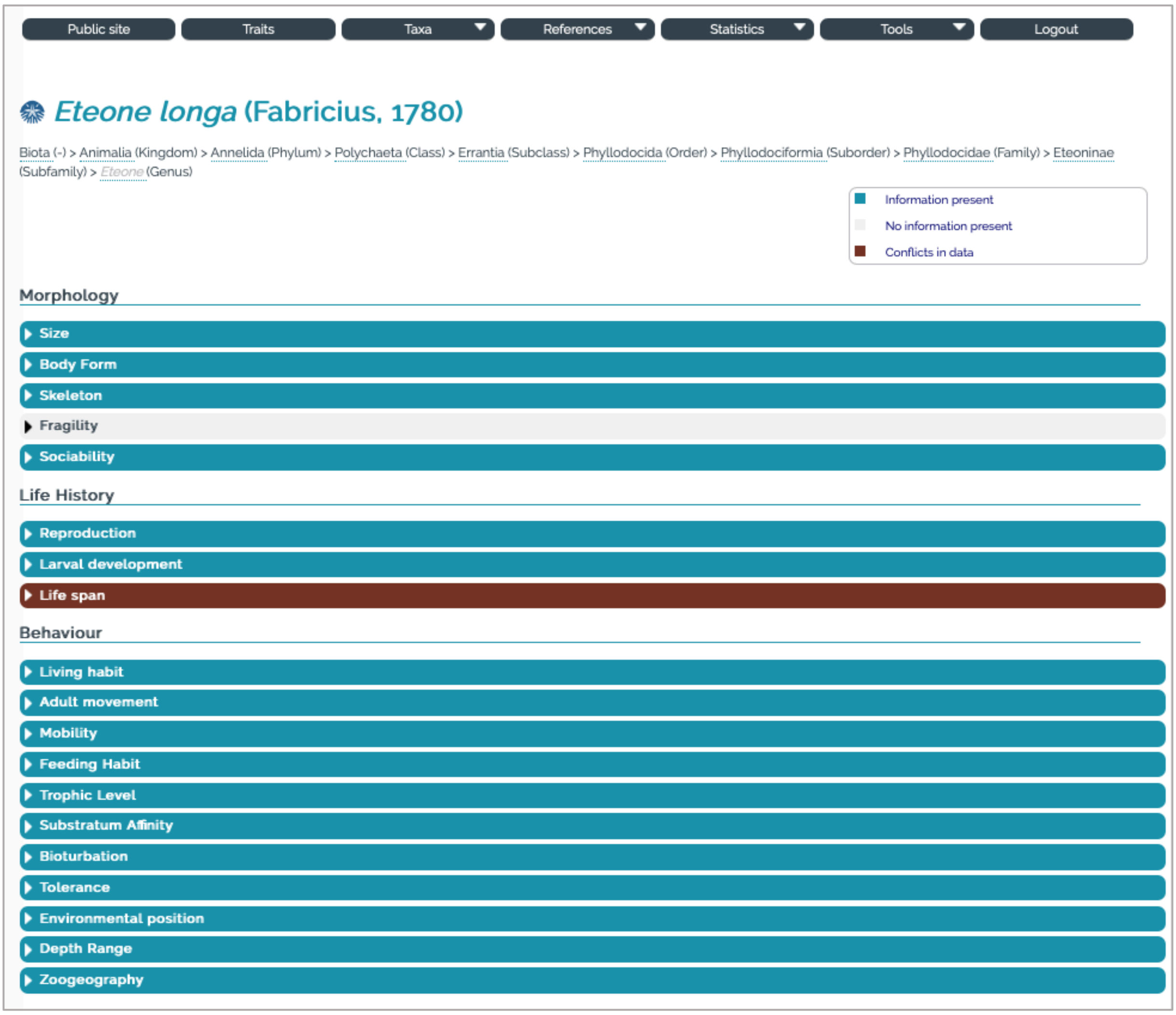

Fig S9. Screenshot of the taxon page of the polychaete *Eteone longa*. 18 traits contain information, 17 traits are highlighted blue, one conflict is indicated for the trait “Life span” (highlighted in brown).

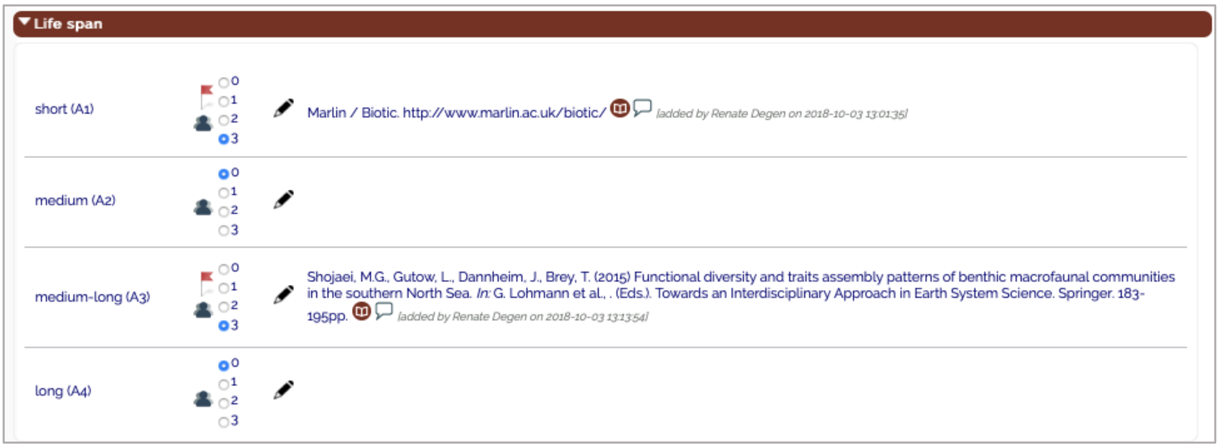

Fig. S10. Detail on the conflicting trait “Life span” in the polychaete *E. longa*. The first literature reference led to the coding of 3 for the trait category “short (A1)”, the second reference led to a coding of 3 for the category “medium-long (A3)”.

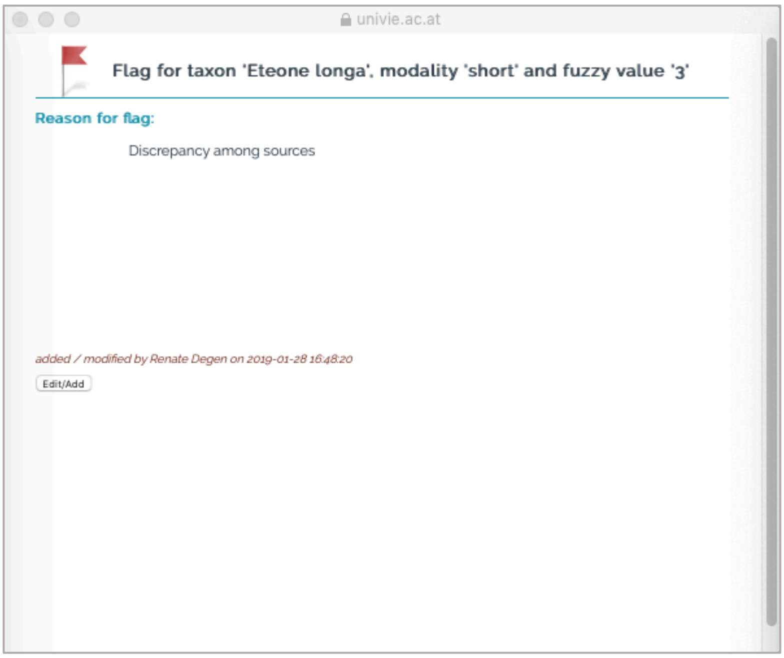

Fig. S11. Reason for the red flag/conflict in the trait category "short (A1)".

6 References

Faulwetter, S., Markantonatou, V., Pavloudi, C., Papageorgiou, N., Keklikoglou, K., Chatzinikolaou, E., Pafilis, E., Chatzigeorgiou, G., Vasileiadou, K., Dailianis, T., Fanini, L., Koulouri, P., Arvanitidis, C., 2014. Polytraits: A database on biological traits of marine polychaetes. Biodivers. Data J. 2, e1024. https://doi.org/10.3897/BDJ.2.e1024

Grebmeier, J., Bluhm, B., Cooper, L., Denisenko, S., Iken, K., Kedra, M., Serratos, C., 2015. Time-Series Benthic Community Composition and Biomass and Associated Environmental Characteristics in the Chukchi Sea During the RUSALCA 2004–2012 Program. Oceanography 28, 116–133. https://doi.org/10.5670/oceanog.2015.61

Lambert, P. (2000) Sea Stars of British Columbia, Southeast Alaska and Puget Sound. University of British Columbia Press, Vancouver. 186pp.