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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, last access: 20 February 2019) 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, for the first time including 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 14 242 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), and 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 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).

Although the methodical diversity and complexity of trait-based approaches have 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

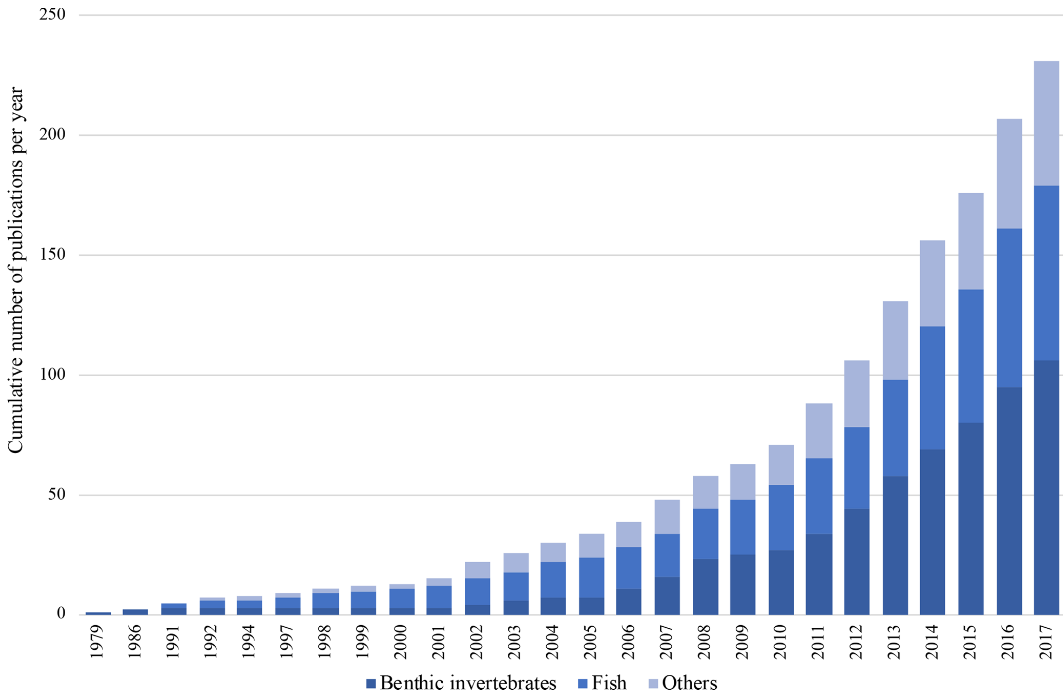

Figure 1. Cumulative number of marine trait-based studies based on the literature review of 233 studies from the marine realm by Degen et al. (2018).

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, last access: 20 February 2019), polytraits (Faulwetter et al., 2014) and BIOTIC (MarLIN, 2018, http://www.marlin.ac.uk/biotic, last access: 20 February 2019) contain more than 40 traits. Some repositories allow only for online browsing, while others enable different forms of download that range from spreadsheets to different matrix formats (Table 1). No traits repository explicitly comprising polar species has existed so far.

With the Arctic Traits Database presented here we aim to investigate 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 following Darwin Core format) (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 the above-mentioned formats, for the first time trait information has also been made available 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 a focus on pan-Arctic

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. References 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 Scratchpad	Faulwetter et al. (2014); http://polytraits.lifewatchgreece.eu (last access: 20 February 2019) http://polychaetes.lifewatchgreece.eu (last access: 20 February 2019)
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); MarLIN (2018), http://www.marlin.ac.uk/biotic (last access: 20 February 2019)
Fish	Browse online, programmatically via an application programming interface (API) and R package rfishbase	Froese and Pauly (2018) http://www.fishbase.org, version (02/2018) last access: 20 February 2019
Benthos	Browse online	Marine Macrofauna Genus Trait Handbook; http://www.genustraithandbook.org.uk (last access: 27 June 2018)
Corals	Browse online, download as *.csv file, traits provided as original values or text information, references provided.	https://coraltraits.org/ (last access: 20 February 2019)
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 (last access: 20 February 2019)
All marine	Browse online	Marine Species Traits; http://www.marinespecies.org/traits (last access: 27 June 2018)
All marine	Browse online	SeaLifeBase; http://www.sealifebase.org (last access: 29 June 2018)
Fossil groups	Browse online	Neogene Marine Biota of Tropical America (NMiTA); http://eusmilia.geology.uiowa.edu (last access: 29 June 2018)
All biota	Browse online, programmatically via an API	Encyclopedia of Life (EoL); http://www.eol.org (last access: 29 June 2018)

benthic invertebrate macro- and megafauna. This dataset comprises species lists from published studies of collaborators (Blanchard et al., 2013a, b; Grebmeier et al., 2015) but also from sampling campaigns that are so far unpublished (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, mainly species in the macrofauna size class have been uploaded.

2.2 Trait data

Here, 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., they belong to one out of up to six clearly defined trait categories (see Table 3). The three continuous traits included (body size, life span and depth distribution) are converted into categories, but the associated text information also assures accessibility to users in their original numerical or continuous format.

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 only consider 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/specificity/complexity, preferred substrate, substrate type, living location

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) is given via specific examples, and underlying literature sources are displayed.

MORPHOLOGY			
Body size			
Definition	Maximum body size as adult given in millimeters, 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 it 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 nets of trawling gear, thus often replacing larger slow-growing fauna in trawl-impacted areas. A clear majority of small-bodied species may be indicative of 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	Worm-like
	BF3	dorsoventrally 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 of the ecological role of species in an ecosystem (e.g., if it is habitat-forming) and of 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 for 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 a 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 more strongly affected by trawling. Indicative of prey accessibility and ease of ingestion.		
References	Beauchard et al. (2017), Bolam and Eggleton (2014), Weigel et al. (2016)		

Table 3. Continued.

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 for 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 (2015, 2016), 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 and 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 more 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 of 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)		

Table 3. Continued.

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			
Living habit			
Definition	The mode of living, ranging from free-living to 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-/endozoic or epi-/endophytic	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 and 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 is promoted by deep-dwelling fauna. Burrowing and irrigation generally facilitate 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)		
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 trait mobility.		
References	Aller (1983), Bremner (2008), Bremner et al. (2006), Costello et al. (2015), Frid and Caswell (2016)		

Table 3. Continued.

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	Slow- 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 of dispersal potential and ability to recolonize.		
References	Costello et al. (2015), Micheli and Halpern (2005), Tyler et al. (2012)		
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). Affects 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)		
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 lifestyle
	SA4	none	Species is hyper-/suprabenthic 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 – alongside depth range – for habitat classification. Can depict potential substrate specificity of other traits.		
References	Costello et al. (2015)		

Table 3. Continued.

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., Holothuroidea, 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 et al. (2000), Gusmao (2017), Marchini et al. (2008), Piló et al. (2016)		
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	hyperbenthic	Living in the water column but (primarily/occasionally) feeds on the bottom; benthopelagic
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; hyperbenthic taxa might be able to escape). Endobenthic lifestyle affects the sediment biogeochemistry. Epibenthic and shallow-sediment-dwelling taxa are more vulnerable to predation. Hyperbenthic 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 and Bonsdorff (2012)		
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., 500–1000 m)
	DR4	slope basin	> 1000 m
Function	Can be used – alongside 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, to physical disturbances such as iceberg scouring and to coastal processes and pollution.		
References	Costello et al. (2015), Gutt (2001)		

Table 3. Continued.

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, subarctic and North Atlantic/North Pacific distribution.
	Z3	boreal	North Atlantic and/or North Pacific distribution; potentially subarctic 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 (2004), Fetzer and Arntz (2008), Piepenburg (2000), Weslawski et al. (2003)		

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 the "maximum body size as adult" (see also Table 3). While clearly a trade-off 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 7 of the 10 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/, last access: 20 February 2019). For more detailed biogeographic information we refer users to the Global Biodiversity Information System (GBIF; http://www.gbif.org/, last access: 29 June 2018) or the Ocean Biogeographic Information System (OBIS; http://www.iobis.org, last access: 27 June 2018). 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 also accounts 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 the consideration that the trait information provided should be usable across a wide geographical area.

One common approach to the use of 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.

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 on-site measurements (e.g., for the trait body size) or personal observations or be transmitted via communication with experts for a specific taxonomic group. In any case, the source is indicated as precisely as possible, for published literature with a complete reference and DOI (if available), and in the 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 ac-

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 from 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			

curate, 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 that is not resolved for now, as trait information from the high latitudes is often scarce, and the user is recommended to consider the source of trait information when interpreting results.

2.4 Fuzzy coding of traits

The fuzzy coding procedure indicates to what 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 above) as it is the most widely used (which facilitates comparisons and exchange of trait information) and provides a compromise between binary codes and many graduations that are not clearly delineated (Degen et al., 2018).

While the coding might be pretty straightforward for some traits and taxa, in some cases a decision might not be drawn so easily. As one of the clearer cases, we point out the coding of the trait "body size" for the starfish *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 is subtidal sea stars in the northern Gulf of St. Lawrence (west Atlantic). The reference of the Arctic Traits Database however is the entire community of 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. papposus* 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 only downloading the fuzzy coded trait data and aiming to apply it to another reference system. But as the detailed literature quote that leads 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 of subjectivity related to the fuzzy coding procedure. To find out how strong the coding might differ among scientists, a small experiment was performed at the Arctic Traits Workshop in Vienna (December 2016) (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 information and instructions provided will support a more consistent coding of benthic traits in the future.

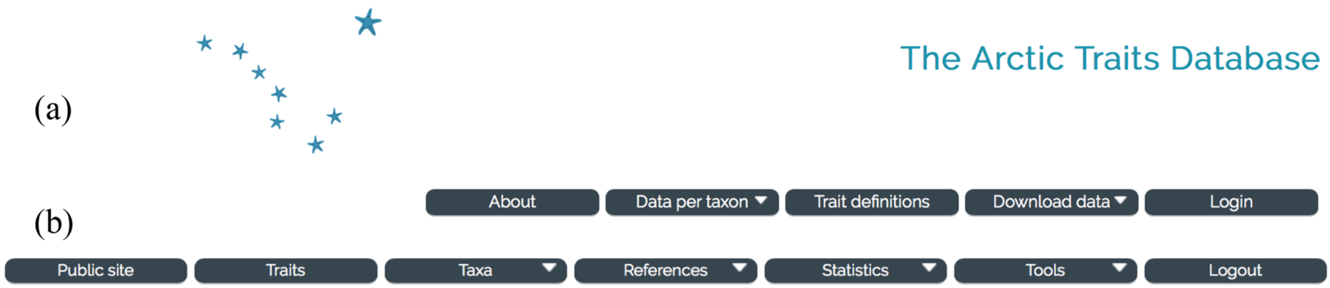

Figure 2. Screenshots of the start page of the Arctic Traits Database. Toolbar of the public page with the login button for the registered user **(a)** and toolbar in the area for registered users **(b)**.

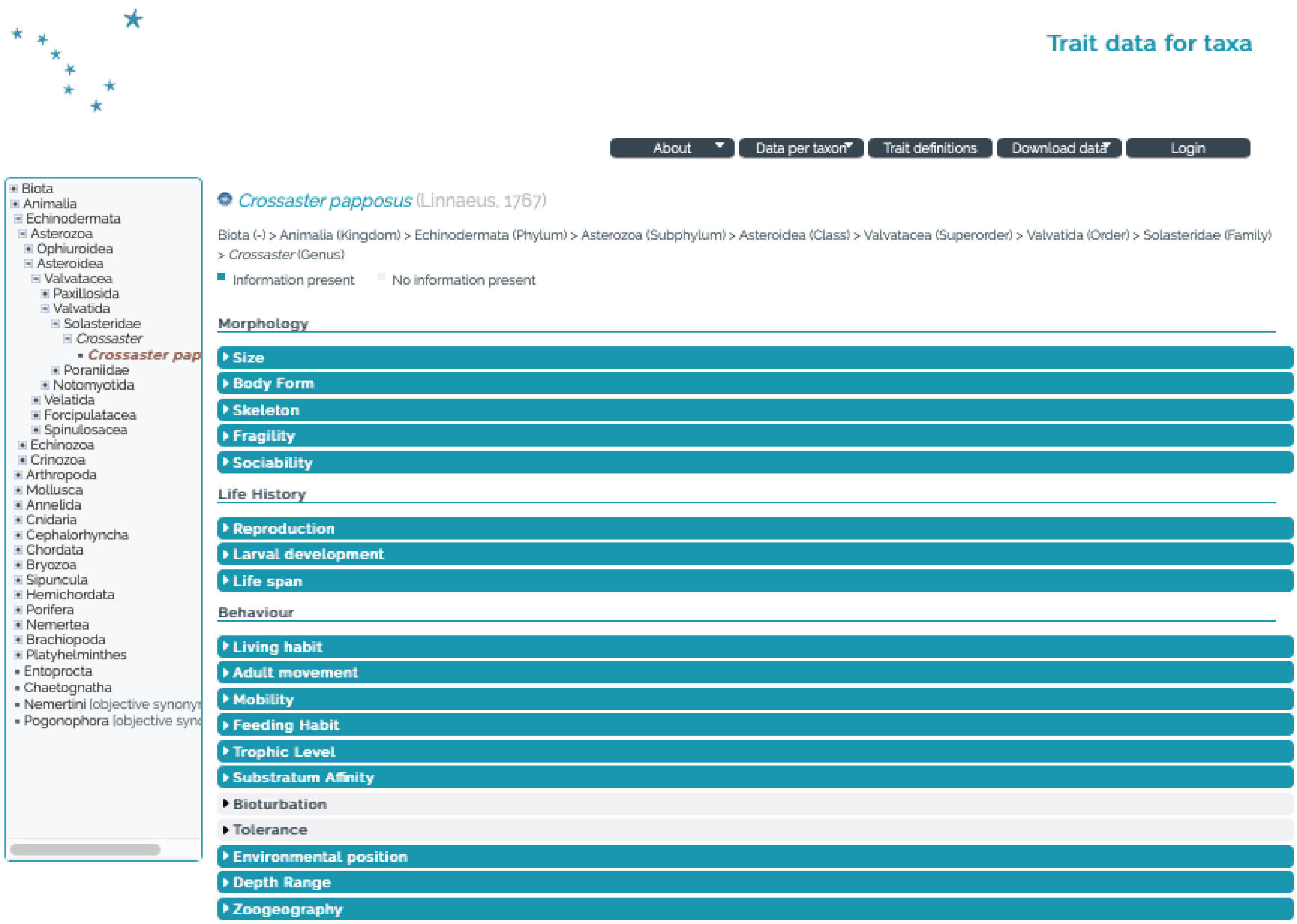

Figure 3. Screenshot of the taxon page of the asteroid *Crossaster papposus* selected from the classification tree on the left.

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 only accessible for registered collaborators (Supplement). The public interface (Fig. 2a) allows the traits and references to be browsed online ("Data per taxon" in the top menu bar), background information to be viewed ("About" and "Trait definitions") and either the entire species, trait and literature information or specified subsets to be downloaded 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 login button on the public page (Fig. 2a). This access offers additional options (Fig. 2b): browsing the existing infor-

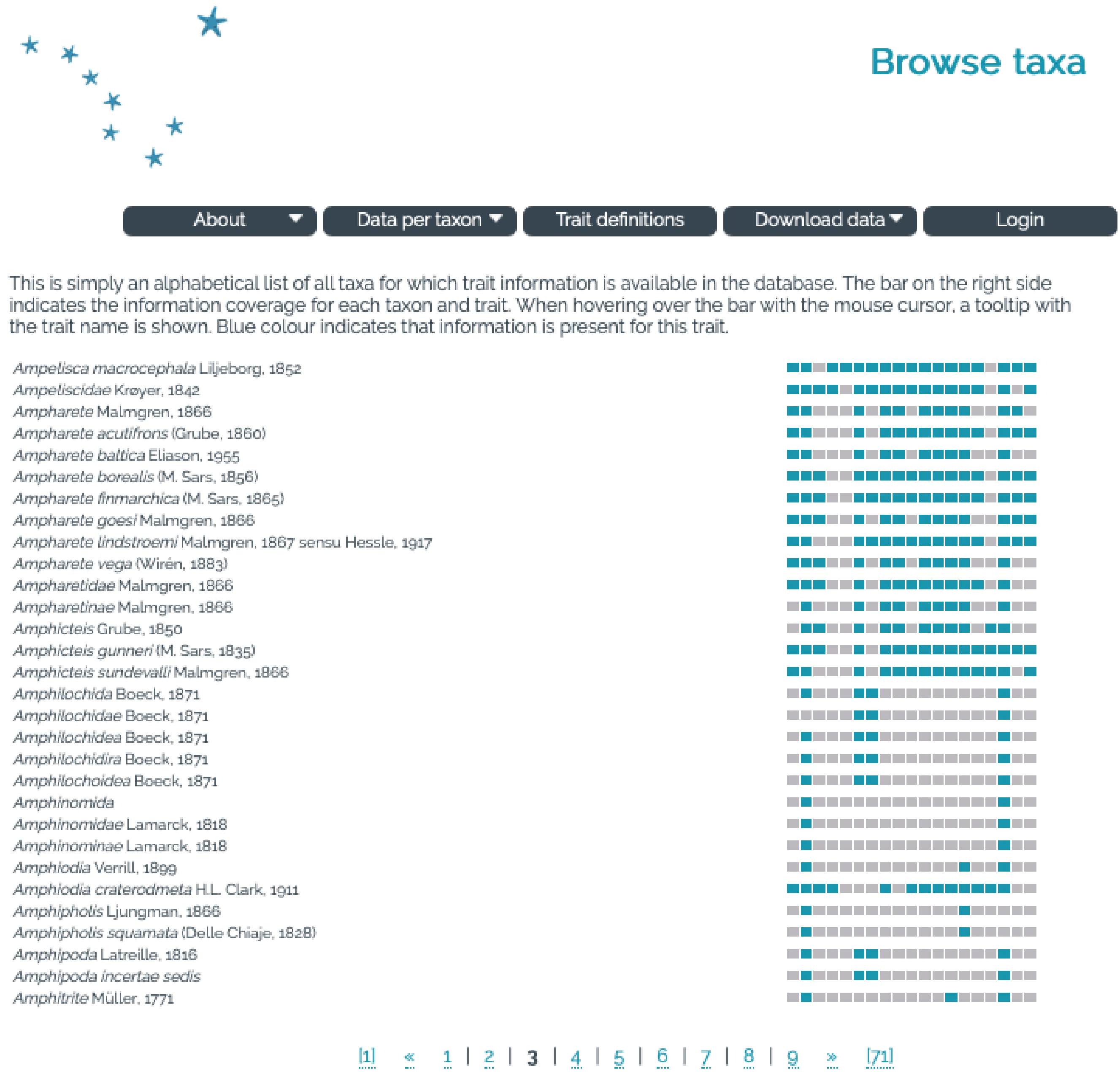

Figure 4. Screenshot of data completeness.

mation also by trait ("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 only accessible for registered users (Fig. 2b; 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 Supplement to this publication or can alternatively be accessed via the public web interface ("About"). Collaborators who want to share trait information without registering on the database can alternatively be provided with an upload template xls.

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 subcategory 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., FH6).
Traitvalue	Describes the affinity of the *Taxon* to the *Category*. Values range from 0 to 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 has been 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. Darwin Core 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 Arctic Traits 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 Arctic Traits 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 to 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 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	AH	AI
1	NOTE: Subjective synonyms are listed as separate rows in this file as they may have conflicting data. It is recommended that you manually merge the data for these taxa, resolving conflicts on a case-by-case basis.																																		
2	Taxon	Valid_name	Rank	S1	S2	S3	S4	S5	BF1	BF2	BF3	BF4	BF5	SK1	SK2	SK3	SK4	SK5	F1	F2	F3	SO1	SO2	SO3	R1	R2	R3	R4	LD1	LD2	LD3	A1	A2	A3	A4
3	Ampelisca	Ampelisca	Genus			3						3				3							3					3			3	3			
4	Ampithoe	Ampithoe	Genus		3							3				3												3			3	3			
5	Brachiopoda	Brachiopoda	Phylum	2	2	2								3								3			0	2		2	2	2		2	2	2	
6	Golfingia margaritacea	Golfingia (Golfingia) margaritacea	Species				3			3							3			3						3				3		3			
7	Heteromastus	Heteromastus	Genus			3				3								3								3			3			3			
8	Idoteidae	Idoteidae	Family	2	2						3					3												3			3	3			
9	Leucon nasica	Leucon (Leucon) nasica	Species		3						3					3												3			3	0	1		
10	Ampelisca eschrichtii	Ampelisca eschrichtii	Species		3							3				3							3					3			3		3		
11	Anonyx	Anonyx	Genus		3							3				3				3		2	1					3			3		3		
12	Ascidiacea	Ascidiacea	Class		2	2	2										3				3	2	0	2	2	2	2	2		2	2		3		
13	Byblis	Byblis	Genus		3							3				3												3			3		3		
14	Byblis robustus	Byblis robustus	Species		3							3				3												3			3		3		
15	Diastylis goodsiri	Diastylis goodsiri	Species		3						3					3					3							3			3		3		
16	Eudorella emarginata	Eudorella emarginata	Species	3							3					3												3			3		3		
17	Levinsenia gracilis	Levinsenia gracilis	Species		3					3								3	3									3			3		3		
18	Astarte borealis	Astarte borealis	Species		2	1						3		3							3					3				3				2	2
19	Astarte montagui	Astarte montagui	Species		3							3		3							3		3			3				3				3	
20	Cerianthidae	Cerianthidae	Family		3																	3			2	2			3					3	
21	Cerianthus	Cerianthus	Genus				3															3			2	2			3					3	
22	Echinoidea	Echinoidea	Class		2	2	2		2		1			3												2		2	2		2			3	
23	Macoma calcarea	Macoma calcarea	Species			3						3		3					3							3			3					3	
24	Actiniaria	Actiniaria	Order		2	2	2		2				2				1	2				3			2	2		2	2	2					3
25	Clinocardium ciliatum	Ciliatocardium ciliatum	Species			3						3		3							3					3			3						3
26	Hiatella arctica	Hiatella arctica	Species		3							3		3							3		3			3			3						3
27	Amphiuridae	Amphiuridae	Family	2							3			3					3							2	2		2	2	2				
28	Bathymedon	Bathymedon	Genus	3								3				3												3			3				
29	Chone	Chone	Genus			2	2			3								3								2		2		3					

Figure 5. A screenshot 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), and 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).

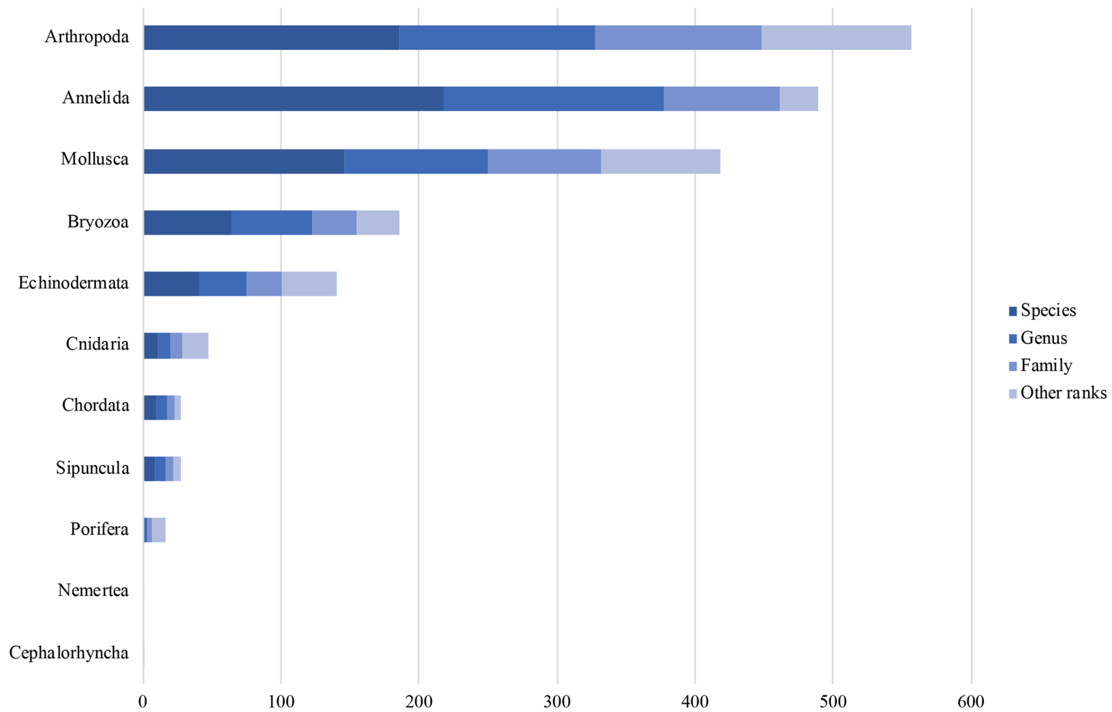

Figure 6. Taxonomic data coverage. "Other ranks" include higher taxonomic levels and intermediate ranks.

3.1 Public access and download options

The public access enables the database to be browsed online and the complete set of data as well as the bibliography or specified subsets to be downloaded. 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 a specific taxon to be typed in and searched.

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; the blue color indicates that trait information is present.

The download section can be accessed via the "Download data" button on the top menu bar (Figs. 2a, 3, 4). Download is enabled in three different computer readable formats: (1) as data in columns (*.csv) (Table 7), (2) in Darwin Core format (Table 8) and (3) as a 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 also downloading the data in columns (download option 1) for the same taxa, for which the detailed source per species and trait category is included. Details on the structure of the first two download options are given above in Tables 7 and 8. A screenshot 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, last access: 20 February 2019).

3.2 Database specification

The website runs on an Apache 2.2. server, and the database is implemented in MySQL 5. PHP 5 is used as the 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.

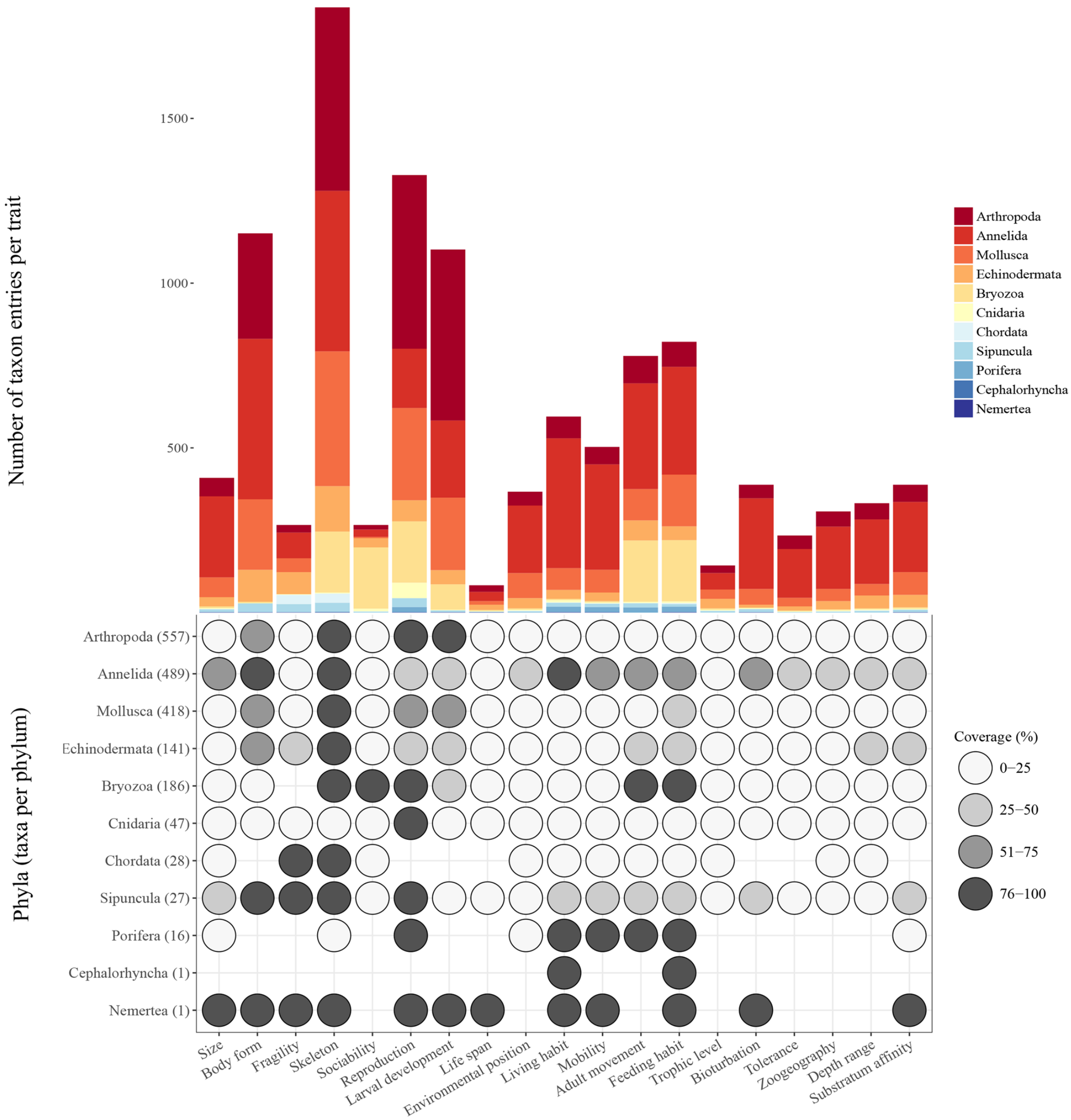

Figure 7. Scheme visualizing the taxon entries per trait (bar chart), the number of taxa per phylum (brackets) and the data coverage per trait per phylum (dot plot).

4 Results

4.1 Taxonomic data coverage

At present, the database contains 1911 Arctic marine benthic invertebrate taxa. Thereof 686 are on species level, 516 are on genus level and 274 are 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).

4.2 Trait data coverage

At present, the database contains 19 traits and 80 trait categories, with currently 14 242 entries of trait information in total. 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 is the Annelida (6130 entries, 43 %), followed by Arthropoda (2968 entries, 21 %) and Mollusca (2177 en-

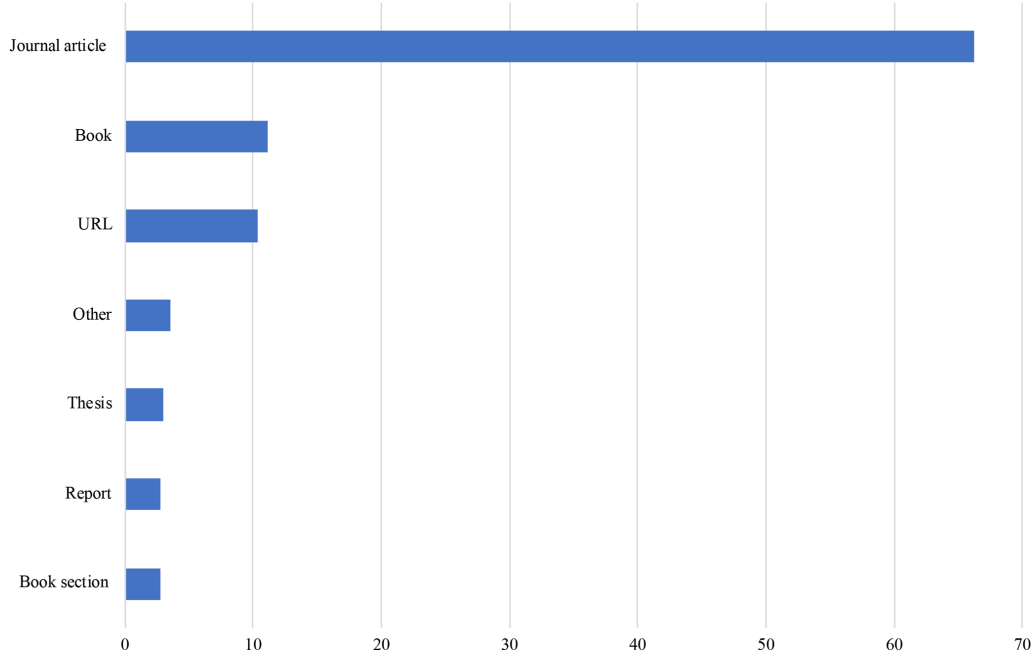

Figure 8. Relative amount (%) of trait source types.

tries, 15 %). Regarding the taxonomic level, most trait information was added on the species level (48 %), less on the genus (25 %) and family level (17 %).

4.3 Bibliography

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

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, have become apparent (Fig. 7). Thus, the database is not only a valuable tool for collecting and providing information but also for pointing out in which areas more research might be needed. Regarding the 19 traits included at the present stage, it shows that our knowledge on, e.g., the life 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 in identifying 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, more "conflicts" – i.e., cases in which the sources or observations added by different users point towards different trait categories – may also arise. Such cases are then indicated by a red flag and can be easily filtered. 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 in identifying 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 to which traits to include in prospective trait-based studies. Apart from clearly diverging source information, different levels of experience or customs in fuzzy coding might also lead to red flags in the system. Here the editorial team will take care of consistency by solving the conflicts according to the database standard and through 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 knowledge gaps surrounding certain traits discussed above, the data coverage among taxonomic groups also 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 gear like grabs, box corers or bottom trawls (Eleftheriou and McIntyre, 2007). This points toward the need of also including 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, their supplementary material, file 3) – have the great benefit that traits of hard-bottom communities can also be analyzed, ecosystems which are at present 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/ (last access: 20 February 2019) (https://doi.org/10.25365/phaidra.49; Degen and Faulwetter, 2018). 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 (Faulwetter and Degen, 2018).

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 for 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.

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