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Glossary & Examples of: Cooperative Science, Biorepositories & Networks, and Field/Laboratory, Legal, and Metadata Standards	
The lists below are not intended to be comprehensive. Rather, they provide examples for the topics discussed to serve as starting points for further reading.	
Abbreviations, Acronyms, and Glossary	
ABC SG	The IUCN Animal Biobanking for Conservation Specialist Group
abiotic data	Environmental physicochemical variables, s.a. temperature, salinity, etc..
ABNJ	Areas Beyond National Jurisdiction
AMCC	Ambrose Monell Cryo-Collection at the American Museum of Natural History
ANRRC	Asian Network of Research Resource Centers
archaeome	The archaeal portion of a microbiome.
ATCC	American Type Culture Collection

axenic	single-strain, pure, monoculture
bacteriome	The bacterial taxa of a microbiome. (The definition is not universally agreed on.)
BBMRI-ERIC	Biobanking and BioMolecular resources Research Infrastructure - European Research Infrastructure Consortium
BBNJ	Biodiversity Beyond National Jurisdiction
biobank / biorepository	A biobank is a type of a biorepository. Beyond that, opinions diverge. Many authors use the terms "biobank" and "biorepository" interchangeably. Others reserve "biobank" for medical biorepositories, such as collections of tissue samples. Some authors propose distinctions based on services offered, public or private access, or funding models. Many of the authors we cite include museums, databases of metadata, observations, historical records, etc.. The term "biobank" is also sometimes used to signify natural stores of material. For example, plant seeds can lie dormant in soil for years, and have been called "seed banks". Microbes in dormant stages may survive for thousands of years in marine sediments ("sediment archives"), permafrost, and glaciers. Such environments have been called "microbial biobanks" in literature. In this text, we use the term "biobanks" to encompass all human-made repositories of biological material or data. We exclude nature-made archives. Related terms useful for literature searches: biorepository, biological resource centers (BRCs), repository, natural history collection, museum, accessioning, *ex situ* conservation, cryobank, cryorepository, collections, archives.
BioBlitz	A citizen science initiative, usually conducted over a short period of time, such as a day. Participants identify and record biodiversity (or abiotic factors such as pollution) in each participating geographic area.quote: "BioBlitzes are intense periods of biological surveying in an attempt to record all the living species within a designated area."
biocuration	Collecting biological information and making it accessible to humans and search algorithms. Data generation is currently outpacing biocuration.
bioprospecting	Analysis of organisms with the goal of finding bioactive compounds useful in biotechnological, pharmaceutical, and other industries.
Bonn	Bonn guidelines on access to genetic resources and fair and equitable sharing of the benefits
CARE	CARE principles (Collective Benefit, Authority to Control, Responsibility, Ethics)
Cartagena	Cartagena protocol on biosafety
CBD	Convention on Biological Diversity
CBM	Common Biorepository Model Project

citizen/community/crowdsourced/participatory science	A scientific method where data or specimens are collected or analyzed by volunteers. Participants may be subject matter experts, stakeholders such as community activists or educators, or interested public. For more information, visit the websites of the Association for Advancing Participatory Sciences (AAPS) (formerly the Citizen Science Association) and the European Citizen Science Association (ECSA).
CoML	Census of Marine Life
cryodamage	Damage to genetic materials, cell structures, and tissues due to the stresses of toxic, osmotic, and thermal shock during the cryopreservation process.
cryorepository / cryogenic repository / cryobank / cryocollection / cryopreserved collection	An archive of physical specimens, such as tissue samples, gametes, algae, and bacteria that are preserved at ultra-low temperatures. The temperatures are typically either -80°C (in electric freezers) or -196°C (in liquid nitrogen). Liquid nitrogen vapor phase is also a common option, and is typically between -150°C and -165°C. The intent is to keep the material in stasis – living, and with the potential to be later used for cultures, germination, fertilization, etc..
cryopreservation	Cryopreservation is the act of either freezing or vitrifying (super-chilling to a glass-like state that does not form ice crystals) some biological material. In marine science, examples of cryopreserved specimens include: mammalian skin stem cells, fish eggs, coral sperm and larvae, algal cultures, bacterial cultures, and more.
cryoconservation	The act of cryopreservation with the goal of cryoconservation. For example, fish gametes can be cryopreserved to facilitate genetic health interventions in aquacultured. Fish gametes can also be cryopreserved to assist active restoration and rewilding programs (cryoconservation).
DMP	Data Management Plan
digital voucher / e-voucher / virtual voucher	Digital vouchers include photographs, audio and video recordings, etc.. They are a type of secondary vouchers (vouchers that can be used to help identify a species in the absence of conclusive evidence such as a whole physical specimen, which would be the primary voucher).
DNA terminology	(As suggested by Nagler et al. (2018)) eDNA – environmental DNA. Includes iDNA, exDNA. exDNA – extracellular DNA (also called cfDNA – cell-free DNA). Includes esDNA, aDNA, cirDNA, and relic DNA. Estimated to comprise approximately 90% of the total DNA in ocean environments. Includes DNA from dead cells, DNA used in bacterial conjugation, and DNA actively produced by bacteria as structural materials when constructing biofilms. iDNA – intracellular DNA nsDNA – "non-soluble DNA", non-aqueous-extractable. Generally corresponds to iDNA. sDNA – aqueous-extractable, "soluble DNA". Generally corresponds to exDNA.

	aDNA – ancient exDNA. Can remain preserved for thousands of years (perhaps up to a million). relic DNA – Sequences left over from previous ecosystem states. Relic DNA does not represent life that is currently present in the system (cannot be found in the iDNA metagenome). esDNA – extracellular self-DNA. cirDNA – circulating exDNA.
DNA voucher (proposed definition)	Proposed by Astrin et al., (2013) as: "the isolated and preserved, frozen or dried (usu. genomic) DNA. As a derived sample, a DNA voucher should not – if anyhow possible – function as specimen voucher." A type of molecular voucher.
DOI	Digital Object Identifier. Like an RRID, a DOI is globally unique. It may be used to identify persons, datasets, published works, etc. No single identification method has yet been agreed on in the context of biobanking.
DOOS	Deep Ocean Observation System
DwC	Darwin Core Standard
dry shipper / cryoshipper / liquid nitrogen vapor shipper	A portable container with absorbent internal insulation that is chilled down to cryogenic temperatures by pouring in liquid nitrogen and allowing excess nitrogen to evaporate off. Dry shippers are safe to transport by air or ship by courier. They can be used to flash-freeze specimens in the field. Cold temperatures can be maintained in the field for anywhere from a few hours to a few weeks, depending on the size of the container. (Bakker et al., 2020; Corthals and Desalle, 2005; Harvard Campus Services Environmental Health & Safety, 2023)
EBB	European Blue Biobank Network
EBM	Ecosystem-Based Management
EBVs	Essential Biodiversity Variables
ECCO	European Culture Collections' Organization
EMBL	European Molecular Biology Laboratory
EMODnet	European Marine Observation and Data Network
EMP	Earth Microbiome Project
ENVO	Environment Ontology a semantic and ontological standard that describes the environmental variables that may be recorded in monitoring projects. Designed to produce metadata that is both human- and machine-readable. ENVO is part of the Open Biomedical and Biological Ontologies (OBO) set of standards. Is interoperable with other OBO standards.

EOVs	Essential Ocean Variables – recognized metrics of abiotic (temperature, biogeochemistry, etc.) and biological ecosystem factors.
epibiome	The portion of the microbiome that is on the external surfaces or skin of the host.
ESB	Environmental Specimen Bank
ESBB	European, Middle Eastern, and African Society for Biopreservation and Biobanking
EU	European Union
eukaryome	The microeukaryote community within a microbiome.
extended / holistic specimen	A physical specimen accompanied by metadata on provenance, project contributors, field and preparation protocols, analysis data and products, and the specimen's local environmental context. The local environmental context includes links to other specimens from the same location or time, associated behavioral observations and abiotic (physicochemical) measurements, etc.. The extended specimen components generally reside in separate collections or databases, and are linked through metadata. At this time, interlinking databases to create extended specimen aggregates is difficult.
extremophile	An organism that is adapted to life in extreme environments, such sea ice, hydrothermal vents, brines, highly polluted environments, environments under high radiation, etc..
FAIR	Findable, Accessible, Interoperable, and Reusable
Field Information Management System (FIMS)	A database-based application that accepts and stores field data. Can assist the user by presenting prompts and ensuring entry of required metadata.
FRAM	FRAM Microbial Observatory (FRontiers in Arctic marine Monitoring)
Frictionless Data Packages	Frictionless data conforms to specific ontological and semantic standards, such as the Open Biomedical and Biological Ontologies (OBO) standards. Frictionless datasets are interoperable (can be integrated and cross-linked) with other such datasets. They can be read by humans and also parsed, searched, and processed by computer algorithms. Ontological semantic standards are an important step towards the ability to link metagenomic and other biological data to abiotic environmental (physicochemical) datasets that provide contexts for the biological specimens/data records.
GBRCN	Global Biological Resource Centre Network
GCM	The Global Catalogue of Microorganisms data portal.

genomic sample (proposed definition)	Proposed by Astrin et al., (2013) as: "preserved sample containing (isolated or as a constituent) a high percentage of an organism's genome in widely unfragmented form. A type of molecular voucher."
GGBN	Global Genome Biodiversity Network
genophore (proposed definition)	Described by Astrin et al., (2013) as: "specimen vouchers used to produce molecular (sub-)samples".
GOA-ON	Global Ocean Acidification Observing Network
GOODS	Global Open Oceans and Deep Seabed – a classification system for species biogeography in the deep ocean (Canonico et al., 2019).
GOS	Sorcerer II Global Ocean Sampling Expedition
holistic, integrated, place-based, ecosystem-based	Studies of effects in contexts.
holobiont & core microbiome	A "metaorganism", comprised of a host and its microbiome. Holobiont theory is a holistic way of looking at an organism, its long-term associations, and dynamic states. Often, a host has a core microbiome – a set of microbial species that can be expected to be present and may have co-evolved with the host. Their microbiomes participate in the hosts' vital functions, including adaptation, digestion, and immunity. The holobiont's microbial community can be specific to host species, genotype, location, environmental conditions, food sources, etc. Emerging research suggests that captive breeding and other active restoration programs must take microbiomes into consideration. Without the microbial community that is the natural correct match for the host and the environment, a restoration program is less likely to succeed. Core microbiome science is relatively new. Definitions, understanding of their presence, functions and dynamics, and the methodologies to explore and analyze core microbiomes are not yet well understood. We are inspired by Risely (2020), who views host-associated microbiomes as divided into "common core microbiome", "temporal core microbiome", "ecological core microbiome", "functional core microbiome", and "host-adapted core microbiome" to reflect the variations in the host-associated microbiome with host populations, environments, temporal cycles, and functional needs, and to inform ecological and evolutionary models.
hologenophore (proposed definition)	Described by Astrin et al., (2013) as: "specimen voucher from which the molecular sample is directly derived".
HTS	High-Throughput Sequencing
IDA	International Depository/Depositary Authority – an mBRC certified to hold reference patented microbial germplasm under the Budapest Treaty. See McCluskey (2017), WIPO (2024).

iDigBio	Integrated Digitized Biocollections
iDNA	intracellular DNA
INSDC	International Nucleotide Sequence Database Collaboration
IGSN	International Geo Sample Number – a globally unique identifier that can be used to link abiotic data to biosamples.
ITIS	Integrated Taxonomic Identification System
IOM	Integrated Ocean Management – holistic approach to sustainable ecosystem management, balancing economic and conservation needs. When researching further, try also the "systematic conservation planning (SCP)" keywords.
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
ISBER	International Society for Biological and Environmental Repositories
isogenophore (proposed definition)	Described by Astrin et al., (2013) as: "a different specimen with a clonal relationship to the study organism".
JCDP	Joint Cetacean Data Programme
Laboratory Information Management Systems (LIMS)	A database-based application that accepts and stores laboratory workflow data. Can assist the user by presenting prompts and ensuring entry of required metadata.
LN2	liquid nitrogen
macrogenetics	Study of large-scale genetic patterns in data aggregated from multiple large datasets. Analyses generally compare data from multiple species across large spaciotemporal scales.
Malaspina	Malaspina 2010 expedition
MAT	Mutually Agreed Terms
MBON	Marine Biodiversity Observation Network
mBRCs	microbial domain Biological Resource Centers. mBRCs are culture collections that have gained certifications for quality assurance. They hold culturable and viable but non-culturable (VBNC) microorganisms and cells, and other genetic material.
meDNA	microbial environmental DNA

meta-databases, data aggregators, portals, platforms	Digital repositories (databases) that give the user access to external datasets, cross-referenced with each other. For example, GBIF and OBIS contain data submitted by multiple other projects and databases. Through a data aggregator such as GBIF, a research project can access cetacean occurrence observations from all over the world. Another example is the MycoBank portal that allows users to see associations between academic papers and data in biodiversity databases such as GBIF. Finally, the Arctos portal gives the user access to the combined digitized catalogs of member natural history collections.
MGRs	MGR may stand for Marine Genetic Resources or Microbial Genetic Resources.
microbiome	A multispecies community of microorganisms and their products and contexts. Includes bacteria, archaea, microeukaryotes such as yeasts, algae, and protists, viruses, mobile genetic elements such as plasmids, extracellular DNA, metabolites, inorganic molecules and gradients, etc.. The community exists in a dynamic state, with members interacting in a "theatre of activity" (Berg et al., 2020).
microbiome engineering	deliberate manipulation of microbiomes, s.a. use of prebiotics and probiotics in aquaculture or the former plus fecal transplants in captive breeding programs
MIMARKS	Minimum Information about a MARKer gene Sequence specification
MIRCEN	World Federation for Culture Collections Microbial Resource Center (MIRCEN)
MIRRI	MIcrobial Resource Research Infrastructure (www. mirri.org, grant agreement no. 312251) was launched at the end of 2012.
mixed microbial community / complex microbial community	A microbial sample with more than one strain. This can be a microbiome, an artificially constructed mixed culture, or an environmental sample of microbes that are in the same vicinity, but may or may not interact or be expected to be present.
MIxS	Genome Standards Consortium's Minimum Information about Any Sequence data standard.
molecular voucher (proposed definition)	Proposed by Astrin et al., (2013) as: "a sample that is deliberately preserved and curated in a way that will conserve its molecular properties for analysis. A molecular voucher should always be linked to a specimen voucher (which sometimes can be the same object if sufficient characters remain, see tissue voucher). Narrower terms: biobank voucher, DNA voucher, tissue voucher, RNA voucher, protein voucher, genomic sample, etc."
morphological voucher (proposed definition)	Proposed by Astrin et al., (2013) as: "a specimen that allows the inspection of morphological characters." A type of specimen voucher.
MPA	Marine Protected Area
MTA	Material Transfer Agreement
museomics	Multiomic studies of historical specimens, such as are found in museums and herbaria.

mycobiome / fungal microbiome	The microfungal taxa in a microbiome.
NASS	North Atlantic Sightings Survey
NOAA	National Oceanic and Atmospheric Administration (USA)
NSF ADBC	National Science Foundation (NSF) Advancing Digitization of Biodiversity Collections (ADBC) program.
OBIS	Ocean Biodiversity Information System
OECD	Organisation for Economic Cooperation and Development
ontology	Ontologies describe both the data contract and meaning in a database schema. To give an example (extremely simplified for brevity). Let's say Database 1 and Database 2 hold genetic sequences. Each record of a gene is accompanied by metadata. In Database 1, metadata is in the XML format, and dates are recorded in the YYYY-MM-DD format. In Database 2, metadata is in the JSON format, and dates are recorded in plain text, s.a. "June 25, 2025". In addition to the metadata disparities, the two databases use different definitions of the concept of a "gene". An ontology is a contract that defines the differences in the metadata format, data field requirements, and data concept definitions. Defined and compatible ontologies are needed for database integrations. For more information, see Schuurman and Leszczynski (2008).
OSD	Ocean Sampling Day
pan-genome / pangenome / supragenome	All gene variations within a species. In microbes, represents the combined intraspecific diversity of all strains within a clade (Morneau, 2021). Core pangenome is the combined set of genes that are present in all individuals of a species. Shell pangenome is the set of gene variants that are found in two or more strains. And cloud pangenome is the set of gene variants that are only found in one strain each.
PIC	Prior Informed Consent
PID / GUID / UUID	Persistent IDentifier (globally unique identifier, universally unique identifier), a globally unique and permanent id that can be used to cross-reference records in diverse collections. Examples include: ARK, CETAF, DOI, IGSN, ORCID, QID, RRID, URL. Keeping such IDs permanent across the generations of databases and standards is a challenge. Notably, location-dependent IDs such as URLs may not be suitable (Elliott et al., 2020).
PANGAEA	PANGAEA data portal for Earth & Environmental Science
Pangeo	The Pangeo project helps scientists find and learn software and computing infrastructures.
paragenophore (proposed definition)	Described by Astrin et al., (2013) as: "a putatively conspecific specimen voucher collected together with the 'molecular' specimen".

planktonic	Free-living (as opposed to sessile).
PMA Live/Dead stain (viability dye)	Propidium monoazide, a permanent DNA- and RNA-intercalating dye that does not cross cell membranes (is membrane-impermeant) (Emerson et al., 2017). PMA is used to exclude extracellular DNA (such as relic DNA, contaminants, DNA from lysed cells, plasmids, EPS matrix components, etc.) from downstream amplification (techniques tried with PMA include: PCR, LAMP, SMRT, 16S rRNA gene amplicon sequencing, microarrays, microfluidics, etc.). PMA needs to be photoactivated with exposure to UV light (or a strong near-UV/white light). Once photoactivated, PMA forms permanent covalent bonds with the nucleic acids in the DNA or RNA strand, thus "locking" the strand. PMA can be used with bacteria, archaea, viruses, and eukaryotes. Samples can be PMA-pretreated in the field. PMA has also been used on Arctic and Antarctic samples and in aquatic studies (Abdullah Al et al., 2024; Burot et al., 2021; Yun et al., 2023). It should be noted that its effects may not be uniform under certain conditions, and techniques may need to account for turbidity, variability of light sources, and variable responses between taxa (Heise et al., 2016; Joo et al., 2019; Knight et al., 2018; Okada et al., 2022; Wang et al., 2021). Before propidium monoazide gained use, microbiologists used the ethidium monoazide and propidium iodide dyes. Ethidium monoazide is more toxic than propidium monoazide. It is also less reliable – ethidium monoazide has a higher rate of the dye itself damaging cell membranes and entering cells. Propidium iodide is not permanent and will not block PCR amplification.
Precautionary Principle / precautionary approach	Established by international agreement at the Convention on Biological Diversity (CBD), the Principle states: "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat." The precautionary approach is the idea that, in the absence of scientific certainty, policymakers and administrators should choose the conservation-forward approach.
preproducibility	Proposed by Stark (2018), preproducibility is a set of guidelines for communicating experimental processes, including specimen provenance, storage, and handling, tools, raw and processed data, and written code. Preproducibility guidelines set up the necessary contexts for reproducible research.
progenophore (proposed definition)	Described by Astrin et al., (2013) as: "a voucher that is linked to the specimen sampled for molecular analysis by a parent-descendant or sibling relationship".
psychrophilic	An organism that is adapted to cold temperatures.
RRID	Similar to a DOI, an RRID is a globally unique identifier that can be attached to persons, datasets, published works, etc. No single identification method has yet been agreed on in the context of biobanking.
ROI	Returns On Investment – the profit or benefit from an invested sum
SEANOE	SEA scieNtific Open data Edition – marine science open data repository offering citations tracking.
SOI	Schmidt Ocean Institute

syngenophore (proposed definition)	Described by Astrin et al., (2013) as: "a putatively conspecific specimen voucher" "collected at another place or time" from the original 'molecular' specimen.
Tara Oceans	Tara Oceans Expedition
TDWG	Biodiversity Information Standards
TK / TEK	Traditional Knowledge / Traditional Ecological Knowledge
tissue voucher (proposed definition)	Proposed by Astrin et al., (2013) as: "tissue subsampled from a specimen - or the entire specimen -, preserved (usu. frozen) to keep its molecular properties (either fixed tissue or viable cells) for future analysis." A type of molecular voucher.
TOP	Transparency and Openness Promotion guidelines
traceability	Specimens, observations, and research products are traceable when it's possible to determine the item's full history, from collection to present time. A full history includes: - Location, date, time, and circumstances of collection. - Protocols for preparation, storage, transformations, etc.. - Usage in projects, publications, etc., both primary and derivative. - Contributors (local, academic, and industry) to each step.
TREC	Traversing European Coastlines Expedition
type specimen	A type specimen is a vouchered reference specimen that is used to describe a new taxon (usually a species). Type specimens are only collected once per species (and thereafter define that species).
URI	Uniform Resource Identifier. URI, DOI, RRID, ORCID – each provides a way to identify something, uniquely and permanently across global databases. No single identification method has yet been chosen in the context of biobanking.
virome	The viral portion of a microbiome.
voucher / vouchered specimen	A vouchered specimen is the original collected material, well documented to ensure traceability and reproducibility. Vouchers are also sometimes called reference specimens. Unlike type specimens, vouchers are collected in the course of a project, and there can be multiple vouchers per species. Vouchers provide evidence of biodiversity existing at a specific location at a specific time. They can be used to study intraspecies diversity (microdiversity). Vouchers accessioned into a biorepository can be reexamined to verify original study results, answer new questions, or produce fresh analyses with evolving technologies.
WDCM	World Data Centre for Microorganisms – the data center for WFCC and MIRCEN
WFCC	World Federation for Culture Collections

WHO	World Health Organization
WIPO	World Intellectual Property Organisation
WoRDSS	World Register of Deep-Sea Species
WRIMS	World Register of Introduced Marine Species
WoRMS	World Register of Marine Species

Microbiome Cryopreservation Starter Terminology

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Search keywords we found to be helpful in our searches of literature

Cryobanking terminology is a rich tapestry and a search engine nightmare – academic papers use a wide array of terms for the different types of samples, biobanks, and procedures. A search for "marine biobanking" may miss literature on "biorepositories". A search for "microbiome cryopreservation" may miss literature on cryopreservation of raw substrates or mixed microbial communities. Additionally, "microbiome" is often used to refer to just the bacterial portion, making searches for literature on the cryopreservation of novel taxa a challenge. The list of keywords below may help the reader find the literature they need.

microbiome-related keywords: archaeome, bacteriome, co-cultures, complex community, dynamic community, enrichment cultures, environmental microbiome, environmental matrices, environmental sample, epibiome, eukaryome, fungome, holobiont, intact communities, intact microbiome, intact microbiome, metacommunity, microbial consortia, microbial matrix, microbial seedbank/seed bank, microbiome, mixed culture, (mixed) microbial community, mixed sample, mycome, natural communities, non-pure culture, (preserving) community structure and functionality, raw/intact substrate, virome, whole microbiome

cryopreservation-related keywords: chilling, cryobanking, cryoconservation, cryodamage, cryofacility, cryogene bank, cryogenic biorepositories, cryogenic/ultra-low temperatures, cryoinjury, cryopreservation, cryoprotectant, cryo-recalcitrant, cryorepository, isobaric vitrification, isochoric vitrification, freezing, liquid nitrogen, liquid nitrogen gas phase, liquid nitrogen vapor phase, osmotic shock, snap freeze, super-chilling, thawing, thermal shock, toxic shock, vitrification, warming

biobanking-related keywords: accession, active restoration, assisted reproduction, biobank, biological resource centers (BRCs), biocollection, biorepository, biospecimen repository, deaccession, deposit, genetic resources, germplasm, germplasm bank, living collections, living microbiome (collections), natural history collection

Expeditions, Observatories, and Cooperative Fieldwork Projects		Back To Table Of Contents
Name	**Description**	**Citations**
ArcticCBM Atlas	The ArcticCBM Atlas holds an inventory of community-based monitoring (CBM) and Indigenous Knowledge (IK) projects and initiatives in the circumpolar Arctic. The Atlas is a valuable resource for researchers looking to connect with local communities.	(Johnson et al., 2016)
Association of European Marine Biological Laboratories Expanded (ASSEMBLE+ / ASSEMBLE Plus)	An EMBRC-ERIC-led initiative, ASSEMBLE+ is an international consortium of organizations. The project gives scientists access to 30 marine observatories, services, resources, and education. It promotes Open Research and FAIR data. ASSEMBLE+ has coordinated Ocean Sampling Day since 2018. The Cryobanking Research Activity within the project seeks to develop standardized and reproducible cryopreservation protocols for marine macro- and microorganisms. As of 2019, the project has identified cryopreservation methods for over 200 species of algae.	(Assemble+, n.d.; Cryobanking Marine Organisms (JRA2) | Assemble+, n.d.; Ocean Sampling Day | Assemble+, n.d.)
Bio-GO-SHIP (https://biogoship.org/)	Bio-GO-SHIP is part of the GO-SHIP (Global Ocean Ship-based Hydrographic Investigations Program) initiative. Its goals include: - Increasing coverage and consistency of marine planktonic community observations. - Developing and reaching international consensus on standards for observation and collection protocols. - Reconciling EOV protocols and making it easier to integrate biological and abiotic (temperature, pH, etc.) datasets.	(Clayton et al., 2022)
Census of Marine Life (CoML)	A ten-year project with scientists from over 70 nations joining forces to collect, document, cross-reference, and analyze historical records and samples and specimens of marine biodiversity.	(Anderson, 2006)
Coastal Observing System for Northern and Arctic Seas (COSYNA)	Two remotely-operated cabled observatories, available for (assisted) public use. Located in shallow waters off the coast of Svalbard, Norway.	(Fischer et al., 2020)
Earth Microbiome Project (EMP)	EMP acquired 200,000 samples of environmental microbiomes, donated by researchers around the world. Researchers designed standardized protocols for sample collection and requested accompanying metadata in a standardized format. The donations were from around 100 separate studies. The EMP collection covered microbial genetic and functional diversity from a wide range of ecosystems, including marine environments.	(Gilbert et al., 2014; Thompson et al., 2017)
Fram Observatory	An autonomous platform for continuous remote observation of Arctic microbial communities.	(Fadeev et al., 2021; Gilbertson et al., 2022)

Global Ocean Acidification Observing Network (GOA-ON)	Primarily records abiotic (physical and chemical) variables. Is not fully integrated with MBON.	
Greenland Integrated Observing System (GIOS) (https://gios.org/)	A network of remote sensing installations, measuring abiotic environmental data in Greenland.	
Malaspina 2010 Circumnavigation Expedition	A six-year expedition project. Several dozen multi-disciplinary research groups performed studies of marine macro- and micro-organisms.	(Acinas et al., 2021; Catalá et al., 2015; Duarte, 2015; Laiolo et al., 2024)
Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) (https://mosaic-expedition.org/)	A remote observatory capable of recording microbial eDNA over large geographic areas and long time periods.	(Gilbertson et al., 2022; Mock et al., 2022)
North Atlantic Sightings Survey (NASS)	Six multi-national cetacean survey cruises, conducted between 1987 and 2015.	(NAMMCO, 2019)
Ocean Census Expeditions (https://oceancensus.org/expeditions/)	An international alliance that funds, co-organizes, and contributes technology to marine science expeditions. Hosts specialist scientists. Serves both academic institution and citizen science projects.	(Ocean Census, n.d.)
Ocean Sampling Day (OSD) (https://www.microb3.eu/osd.html)	Initiated under the aegis of the Micro B3 (Marine Microbial Biodiversity, Bioinformatics, Biotechnology) project, OSD was a massively parallel citizen science initiative. Professional researchers and ocean-going members of the public were asked to simultaneously collect seawater samples in over a hundred locations worldwide. Collection protocols were standardized, and metadata included environmental variables. Collected samples were sequenced, generating a large standardized microbial dataset.	(Canonico et al., 2019; Kopf et al., 2015; Laiolo et al., 2024; Ocean Sampling Day | Assemble+, n.d.; ten Hoopen et al., 2015)
PARASITE	The PARASITE project links preserved specimens of marine macrofauna, associated parasites, host omic sequences and associated microbial metagenomes, and field observations for integrated genes-to-ecosystems modeling.	(González et al., 2018)
Schmidt Ocean Institute Cruises (SOI)	SOI's ships Falkor (former) and Falkor (too) (current vessel) act as scientific platforms for diverse groups of marine researchers, students, and artists. ROV SuBastian gives researchers access to the sea floor.	(Gauthier et al., 2021; Schmidt, n.d.)

Sea of Change	The Sea of Change project sampled and sequenced microeukaryotes, including microalgae, at a pole-to-pole scale. The results showed unique algal adaptations to polar conditions.	(Gilbertson et al., 2022)
Sorcerer II Global Ocean Sampling (GOS) Expedition (https://www.jcvi.org/research/gos)	A Venter Institute circumnavigation expedition, focusing on studies of marine plankton. Instrumental in the development of omics standards for ocean monitoring.	(Canonico et al., 2019; Laiolo et al., 2024; Nissimov et al., 2022; Rusch et al., 2007)
Svalbard Integrated Arctic Earth Observing System (SIOS) (https://sios-svalbard.org/)	An international remote sensing observatory, focusing on Earth Science-related abiotic measurements.	
Tara Oceans Expedition (https://fondationtaraocean.org/en/home/)	A scientist-led cruise expedition organized by a multidisciplinary consortium of research teams. Tara Oceans takes a holistic view of marine studies, hosting projects in disciplines ranging from meteorology to microbial ecology. Instrumental in the development of omics standards for ocean monitoring.	(Canonico et al., 2019; Karsenti et al., 2011; Laiolo et al., 2024; Nissimov et al., 2022)
Traversing European Coastlines (TREC)	A cruise expedition around European coastlines, with the goal of exploring microbiological responses to environmental changes in microbial communities and select marine organisms.	(EMBL, 2024)

Biorepositories and Biorepository Networks

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For more listings of species identification and occurrence databases, specimen and culture repositories, and repository networks see: Bakker et al. (2020), Boundy-Mills et al. (2020), Chaplow et al. (2021), Corrales and Astrin (2023), Debode et al. (2024), Grenié et al. (2023), Lobanov et al. (2022), Marigomez and Lekube (2017), Martínez-Páramo et al. (2017), McCluskey (2017), Smith et al. (2014), Stephenson (2021).

Name	Description	Citations
Ambrose Monell Cryo Collection (AMCC)	The AMCC cryorepository at the American Museum of Natural History holds and lends tissue samples, provides equipment and expertise, and advances biodiversity cryopreservation standards.	(Corthals and Desalle, 2005)
American Type Culture Collection (ATCC)	ATCC holds strains of over 7600 species of bacteria, fungi, and yeasts. It is ISO-certified to distribute microbial reference cultures, and serves as an International Depository Authority.	(McCluskey, 2017)
Antarctic Environmental Specimen Bank (BCAA)	Part of the International Specimen Bank (IESBs) network, BCAA collects specimens for analyses of environmental pollutants.	(University of Genoa, n.d.)
Arctic Biodiversity Data Service (ABDS)	An online platform for collection and searches of data on biodiversity in the Arctic, featuring an open API and georeferenced datasets.	(Arctic Biodiversity Data Service, n.d.)
Arctos (https://arctosdb.org/) (https://arctos.database.museum/)	A consortium of 236 natural history collections, focusing on universities and museums. Arctos also provides tools and training, and offers a public data portal.	(Arctos, n.d.)
ARS Culture Collection (NRRL)	One of the oldest and largest collections of microbial organisms, with almost 100,000 isolates of bacteria and fungi. Provides "lending" services. Is an IDA. Does not have assured sustainable funding.	(Boundy-Mills et al., 2020; McCluskey, 2017)
Biodiversity Collections Network (BCoN) (https://bcon.aibs.org/)	BCoN promotes the development of a US Extended Specimen Network infrastructure. Its overarching goals are to advance the expansion and connectivity of US biological collections.	(Biodiversity Collections Network, n.d.; Lendemer et al., 2020)
biobanking.org (https://biobanking.org/locator)	Hosts a searchable database of biobanks (mostly medical).	

Biobanking and Biomolecular Resources Research Infrastructure (BBMRI) (BBMRI-ERIC) (https://directory.bbmri-eric.eu/#/catalogue)	BBMRI (Biobanking and Biomolecular Resources Research Infrastructure) is an EU biobank network, focused on medicine. The network maintains a searchable directory of the names and contact details of EU biobanks that are open to service requests. Most members are medical biobanks.	(Holub et al., 2016; Ryan et al., 2021)
Biodiversity Information Standards (TDWG)	A non-profit organization working to improve global biodiversity information management. Develops data standards, including Darwin Core (DwC).	(Collins, J. E., 2021; TDWG, n.d.)
Bionomia (https://bionomia.net/)	A citizen science effort to retroactively give attributions to those who have contributed to natural history collections. The project identifies contributors to accessioned specimens and annotations, and enters their names into linked databases. The project goals are to incentivize biobanking curation and annotations, and to help fund and value those collections by giving incentives.	(Bionomia, n.d.; Mabry et al., 2022)
BirdLife International Seabird Tracking Database (http://www.seabirdtracking.org/)	A large database of seabird data. Open submissions are welcomed and checked by curators. Submitted data is owned and controlled by the submitter. The project mission is to enable conservation and research collaborations.	(Bernard et al., 2021; BirdLife International, 2023; Davies et al., 2021)
CABI (https://www.cabi.org/)	CABI is an international non-profit organization, dedicated to agricultural and environmental research. Among other activities, CABI conducts research on cryopreservation of environmental microbiomes, focusing on the microbiomes of plants of agricultural significance.	(Ryan et al., 2023; Smith et al., 2020)
CCCryo Culture Collection of Cryophilic Algae	Houses hundreds of strains of microalgae from polar environments.	(Leya, 2022)
Common Access to Biological Resources and Information (CABRI) (http://www.cabri.org/)	The CABRI network provides a search portal to 28 partner collections, including CABI, DSMZ, and ECCO. The collections hold about half of Europe's biobanked resources. With partners that include some of the largest mBRCs in the world, CABRI-associated collections hold more than 150,000 specimens (about half of public deposits in Europe), and cover cell lines, prokaryote and eukaryote cultures, plasmids, and viruses. Cultures can be requested for research. The CABRI portal combines the disparate catalogues of member collections into a searchable product.	(Becker et al., 2019; Romano et al., 2005a; Romano et al., 2005b)
CryoArks (https://www.cryoarks.org/)	CryoArks is a UK-based consortium of cryorepositories dedicated to biodiversity conservation. CryoArks partners and affiliates include: Cardiff University, the Natural History Museum of London, National Museums of Scotland, the Royal Zoological Society of Scotland, University of Nottingham, The University of Edinburgh, the Frozen Ark, the European Association of Zoos and Aquaria (EAZA),	(Leigh et al., 2021; Pérez-Espona, 2021)

	the Global Genome Biobanking Network (GGBN), and the CRYOSOCIETIES initiative. One notable CryoArks collection is the Abyssline Deep Sea Collection. CryoArks coordinates specimen donations and maintains an online portal database. Researchers can submit sample requests through the portal.	
Distributed System of Scientific Collections (DiSSCo)	Connects museums, botanic gardens, and universities across 23 countries in the European Union. Works to harmonize curation and data management practices.	(Collins J.E. et al., 2021; Distributed System, n.d.; Hardisty et al., 2022)
European Association of Zoos and Aquaria Biobank (EAZA) (https://www.eaza.net/conservation/research/eaza-biobank)	The EAZA network is dedicated to cryobanking gametes and stem cells of threatened species in zoos and aquaria. The network has members across Europe and in the Middle East. Cryocollections are hosted by the Antwerp Zoo, the Royal Zoological Society of Scotland Edinburgh Zoo, the Institute for Zoo and Wildlife Research, and the Copenhagen Zoo. Collections are expected to be used towards improving genetic diversity in captive breeding programs and towards conservation research. EAZA has set cryopreservation of aquatic species as a priority and has presented a strategy for aquarium biobanking. The organization has also developed standardized protocols for collection of samples from aquatic species.	(EAZA, 2024; Pérez-Espona, 2021)
European Blue Biobank (EBB)	EBB is a consortium initiative under the aegis of EMBRC-ERIC. Its goal is to unite marine biobanks in France, Ireland, Portugal, Spain, UK, and Norway, coordinate ABS infrastructures, facilitate access to collections, develop tools and methods, and educate stakeholders. The EBB project started in 2017, with the final meeting in 2023. The project was the first transnational initiative to coordinate marine biobanks. In 2023, the Marine Research Centre (CIM) of the University of Vigo obtained funding to relaunch and continue the project.	(CIM-UVIGO, 2023; EBB, 2024; EMBRC, 2020)
European Culture Collections' Organisation (ECCO) (www.eccosite.org)	ECCO promotes collaboration and innovation between member mBRCs. Members include non-profit as well as corporate collections from 24 European countries. Aggregated member collections hold over 350,000 specimens.	(ECCO, n.d.)
European Marine Biological Resources Centre (EMBRC)	The MIRRI and the EMBRC infrastructures are products of the European Commission's Open Data Strategy for Europe. The networks' mission is to ensure that public-financed data is publicly available, and generated collections can be used towards innovation. Among other functions, EMBRC coordinates marine stations and sponsors large collaborative field expeditions.	(Rotter et al., 2021)
European, Middle Eastern, and African Society for Biopreservation and Biobanking (ESBB)	Regional biobank network.	(Ryan et al., 2021)

European Molecular Biology Laboratory (EMBL) (https://www.embl.org/)	An intergovernmental organization with 29 member states. EMBL creates databases and software tools for the biobanking industry, runs training programs, and provides life sciences services.	
FishBase (https://fishbase.org/)	Created in the 1980ies, FishBase is now a global network of information databases, and has been cited over 10,000 times in academic literature over its lifetime. FishBase focuses on finfishes, and contains information on 33,000 species. It also hosts a sightings reporting application.	(Canonico et al., 2019; Humphries et al., 2023)
Frozen Ark Project (https://www.frozenark.org/)	In collaboration with zoos, aquaria, museums, and academia, the Frozen Ark cryopreserves the germplasm of threatened animal species. The project mission is to collect and store somatic cells, gametes, and embryos, to be used to enrich genetic diversity in captive breeding programs.	(Clarke, 2009; Pérez-Espona, 2021)
Frozen Zoo® (https://science.sandiegozoo.org/resources/frozen-zoo%C2%AE)	The San Diego Zoo Wildlife Alliance Frozen Zoo® collection contains germplasm of nearly 1,000 taxa. The collection is backed up to a secondary site. The Alliance has set restoration and rescue of threatened, endangered, and even extinct species as its goal.	(Mooney et al., 2023; Pérez-Espona, 2021; San Diego Zoo Wildlife Alliance, 2024)
GenBank (https://www.ncbi.nlm.nih.gov/genbank/)	A genetic sequence database run by the US National Center for Biotechnology Information (NCBI). GenBank is not curated – a proportion of the sequences it contains are annotated with erroneous taxonomic assignments.	(Debode et al., 2024; GenBank Overview, n.d.)
Global Biodiversity Information Facility (GBIF)	The leading meta-database of species occurrence data. GBIF governance and funding are secured through inter-governmental partnerships.	(Costello et al., 2013; GBIF, n.d.)
Global Catalogue of Microorganisms (GCM) (https://gcm.wdcm.org/)	GCM is a data portal into the inventories of 153 microbial culture collections around the world.	
Global Genome Biodiversity Network (GGBN) (https://www.ggbn.org/ggbn_portal/)	An international network of biorepositories dedicated to non-human biodiversity. The GGBN Data Portal provides public access to digitized collections from 23 countries (and counting). GGBN includes the DNA Bank Network - a public portal to DNA samples of micro- and macro-organisms.	(Collins J.E. et al., 2021; Global Genome, n.d.)
Global Natural Products Social Molecular Networking (GNPS)	A crowd-sourced platform for metabolomics analyses that harmonizes microbiome datasets.	(Biteen et al., 2016)
Integrated Digitized Biocollections (iDigBio) (https://www.idigbio.org/)	iDigBio is a data aggregator. It is supported by the US National Resource for Advancing Digitization of Biodiversity Collections (ADBC) initiative, funded by the US National Science Foundation.	(Elliott et al., 2020; Lendemer et al., 2020; Mabry et al., 2022)

	iDigBio coordinates ADBC digitization efforts. As of 2020, the initiative had digitized 62 million specimens in over 700 collections.	
International Environmental Specimen Bank Group (IESB)	IESB provides information on member specimen banks around the globe. It also participates in the development of biobanking standards. (https://www.umweltbundesamt.de/en/topics/chemicals/iesb-specimen-banks/esbs)	(Chaplow et al., 2021; Koschorreck, 2015)
International Nucleotide Sequence Database Collaboration (INSDC)	A consortium consisting of NCBI GenBank, European Nucleotide Archive (ENA), and DNA DataBank of Japan (DDBJ). Hosts a data portal. Participates in the development of metadata standards.	(Colella et al., 2020; Laird et al., 2018; Lofgren & Stajich, 2021; Robert et al., 2013; Vangay et al., 2021)
International Society for Biological and Environmental Repositories (ISBER)	Global network of biobanks. ISBER develops and manages cryopreservation protocol and biobank management standards.	(Ryan et al., 2021)
Irish Cetacean Genetic Tissue Bank (ICGTB)	ICGTB holds skin samples from deceased stranded whales and dolphins found on the Irish coast.	(Cetacean Tissue Bank, n.d.)
Joint Cetacean Data Programme (JCDP)	Joint Cetacean Data Programme aggregates and makes available ship-based and aerial observational data.	(Joint Cetacean, n.d.)
Leibniz Institute DSMZ - German Collection of Microorganisms and Cell Cultures GmbH (https://www.dsmz.de)	One of the few collections that accept microbiome and microbial consortia deposits.	(Debode et al., 2024; DSMZ, 2024)
Lunar Biorepository	Biorepositories are vulnerable to environmental degradation and disasters, political upheavals, institutional and funder changes, owner moves, retirements, and deaths, etc.. Risks can be mitigated by collection backups through specimen sharing and by rescues of orphan collections by absorption into the larger consortia. However, given the importance of Earth's biodiversity heritage, and given the climate and political turmoils that are likely to come this century, a backup off-planet may be in order. Scientists have proposed a backup collection on the dark side of the	(Bakker et al., 2020; Bledsoe et al., 2022; Boundy-Mills et al., 2020; Hagedorn et al., 2024)

	moon. Such a repository would not need active temperature management and would be sufficiently far away from humanity's follies.	
Marbank	Part of the European Blue Biobank network, Marbank is funded by the Norwegian Research Council. Its mission is to facilitate marine academic research and bioprospecting. Marbank coordinates a network of smaller collections in Norway. Marbank collections are a treasure trove of Arctic marine biodiversity. Archived specimens of macrofauna and microbial isolates cover 1,200 species. Most of the specimens were collected in Norwegian waters. Marbank is affiliated with the Marbio bioprospecting platform and the Arctic Biodiscovery Centre. Supported by Marbank collections, Marbio has identified dozens of bioactive compounds and prepared substantial libraries of extracts and assays.	(Rosendal et al., 2016)
Marine Metagenome Metadata Database (MarineMetagenomeDB) (https://web.app.ufz.de/marmdb/)	Manually curated, MarineMetagenomeDB contains the metadata of thousands of microbial metagenomes.	(Laiolo et al., 2024; Nata'ala et al., 2022)
Marine Metagenomics Portal (MMP) (https://mmp2.sfb.uit.no/)	Maintained by the UiT The Arctic University of Norway, MMP provides access to marine microbial reference genomes (MarRef), incomplete genomes (MarDB), a marine fungi database (MarFun), and a database of salmon-associated prokaryotes (SalDB).	(The Arctic University of Norway, n.d.)
Microbiome Centers Consortium (MCC) (https://microbiomecenters.org/)	MCC's mission is to coordinate microbiome centers across the United States. In essence, it is the head node in a newly formed network. Participating microbiome centers are not biorepositories. Rather, they are academic organizations that educate researchers on microbiome science principles and methods, promote holistic microbiome studies, and facilitate "horizontal" knowledge transfer between medical and environmental microbiome specialists. The MCC is also promoting cross-project standardization and modernization of research funding. However, those efforts are at their early stages.	(Lobanov et al., 2022; Martiny et al., 2020)
MIRRI (MIcrobial Resource Research Infrastructure) (https://www.mirri.org/)	European network initiative with the goal of integrating pre-existing mBRC networks. MIRRI members span 10 countries. While non-profit, MIRRI provides accessioning and distribution services to both academic and industry clients. MIRRI also provides education and assistance. At this time, MIRRI collections are limited to axenic culturable strains, and focus on bioprospecting-relevant microbes.	(Becker et al., 2019; Rotter et al., 2021; Schüngel & Stackebrandt, 2015)
Movebank (https://www.movebank.org)	Hosts macrofauna tracking data, including seabirds and marine mammals. Contains The Arctic Animal Movement Archive.	(Bernard et al., 2021)

MycoBank (https://www.mycobank.org/)	A digital portal connecting biodiversity databases s.a. GBIF and EMBL and publication databases s.a. PubMed. MycoBank provides identification services, enables users to suggest specimen annotations, and employs professional mycologists as staff curators.	(Robert et al., 2013)
Nature's SAFE (https://www.natures-safe.com/)	Nature's SAFE is a UK non-profit biobank, dedicated to cryopreservation of gametes and tissue samples from endangered animals. Nature's SAFE partners with EAZA and a number of zoos and organizations.	(Nature's SAFE, 2020; Pérez-Espona, 2021)
NCMA (Bigelow National Center for Marine Algae and Microbiota) (https://ncma.bigelow.org/)	NCMA holds and distributes strains collected across the globe, supporting research and commercialization of algae.	(McCluskey, 2017; NCMA, n.d.)
Ocean Biodiversity Information System (OBIS) (Formerly Ocean Biogeographic Information System) (https://obis.org/)	The global meta-database of marine biodiversity data, containing over 50 million records. The OBIS Network is working to interlink biological and abiotic environmental data repositories, and to develop standards for the inclusion of metadata that describes collecting methods. OBIS uses the Darwin Core metadata standard. OBIS governance and funding are secured through intergovernmental partnerships.	(Costello et al., 2013; Klein et al., 2019; Moudrý & Devillers, 2020)
Pan-Smithsonian Cryo-Initiative (PSCI) (https://www.si.edu/psci)	A network of biobanking projects managed by the Smithsonian (US).	(Comizzoli, 2017)
PANGAEA	An Open Access data platform for georeferenced data. Dataset metadata contain links to principal contributors. Datasets may be uploaded before publication and are given DOIs, to be cited in future publications. The uploads are free of fees, and can be secured by temporary moratoria until data of publishing.	(Felden et al., 2023)
Pangeo	Pangeo creates and shares software tools that make it easier for users to prepare and process scientific data. Thus, it can enable and bolster open science, use of consistent standards, and research reproducibility.	(Pangeo, n.d.; Verwega et al., 2021)
Phaff Yeast Culture Collection	Holds over 6,000 strains, and is a globally important resource of yeast strains. A positive demonstration of the need for collection backups. The Phaff collection has at different times been threatened by wildfires and by the loss of the collection founder. However, collection strains are backed up in cryopreserved state in the NLGRP (National Laboratory for Genetic Resource Preservation) biobank. Unfortunately, while the Phaff Collection receives funding from the US NSF,	(Boundy-Mills et al., 2020; McCluskey, 2017)

	it does not have a long-term sustainable funding commitment.	
Planet Microbe (https://www.planetmicrobe.org/)	A data portal that facilitates metagenomic analyses across multiple marine datasets. The datasets are harmonized through metadata that conforms to OBO ontological semantic standards. Dataset integrations allow for large-scale cross-dataset analyses, bringing exceptional value to users. Planet Microbe does not host data. Rather, it provides data and software tools that help users combine previously incompatible datasets from disparate databases, and export data in a standardized common format. In doing so, platform engineers are developing new metadata standards, designed to handle microbial community sequence data and associated biological and physicochemical (abiotic) ecosystem parameters. The standards are using Frictionless Data Packages that use broad environmental data concepts to produce FAIR and broadly compatible annotations.	(Blumberg et al., 2021; Laiolo et al., 2024)
Polar Data Catalogue (https://www.polardata.ca/)	Run by the Canadian Cryospheric Information Network, the Catalogue is a transdisciplinary repository of Arctic and Antarctic data and metadata. See Bhatia et al. (2021) for an example of such a transdisciplinary dataset.	(Bhatia et al., 2021)
RefSeq (NCBI Reference Sequence Database)	Public database of curated, annotated, and update-able DNA, RNA, and protein sequences. The sequences serve as references for genomic studies.	(Breitwieser et al., 2019; NCBI, n.d.; Pruitt et al., 2005)
SCAR Antarctic Biodiversity Portal (https://www.biodiversity.aq/)	Searchable Antarctic biodiversity datasets,	(SCAR Antarctic Biodiversity Portal, n.d.)
SeaLifeBase (https://www.sealifebase.se/Home/index.php)	Affiliated with FishBase, SeaLifeBase includes non-fish marine fauna. SeaLifeBase contains biological and ecological information on about 240,000 species.	(Canonico et al., 2019)
Swedish Environmental Specimen Bank / Miljöprovbanken (MPB) (https://www.nrm.se/samlingar/miljoprovbanken)	Holds materials from as far back as the 1960ies. Has lending services.	
Umweltprobenbank / German ESB	Due to its continuous and sustainable public funding, the Umweltprobenbank is considered to be the gold standard. It includes Arctic marine specimens in its collection.	(Chaplow et al., 2021)

(https://www.umweltprobenbank.de)		
WikiProfessional Life Sciences (https://www.wikiprofessional.org/)	A citizen science effort to create a searchable index of authors of scientific publications in the PubMed database, and to cross-link author's records with the records of their contributions. The purpose of the project is to improve access to related clusters of biological information and to incentivize open science and comprehensive annotations by assigning reputation credits.	(Howe et al., 2008)
World Data Centre for Microorganisms (WDCM) (https://www.wdcm.org/)	WDCM is the portal for WFCC-MIRCEN, World Data System (WDS), The Asian Consortium for the Conservation and Sustainable Use of Microbial Resources (ACM), Asian Network of Research Resource Centers (ANRRC), and other culture collections. WDCM provides access to microbial strain databases and management and analysis software.	(WDCM, n.d.; Wu et al., 2017)
World Federation for Culture Collections (WFCC) (www.wfcc.info)	Provides the WFCC World Data Centre for Microorganisms (WDCM) searchable database of known mBRCs.	(McCluskey, 2017)
World Register of Deep-Sea Species (WoRDSS)	A taxonomic database of deep-sea species.	(Stefanni et al., 2022)
World Register of Marine Species (WoRMS) (https://www.marinespecies.org/)	A comprehensive taxonomic database of marine species. Annotations are curated by volunteer outside experts, under the oversight of WoRMS editors. WoRMS contributes its data to GBIF and other databases.	(Costello et al., 2018; Stefanni et al., 2022; WoRMS, n.d.)

Standards: Fieldwork and Laboratory Protocols and Tools		Back To Table Of Contents
Name	**Description**	**Citations**
Association for Advancing and Participatory Sciences (AAPS) (formerly the Citizen Science Association (CSA)) (https://participatorysciences.org/)	AAPS provides a wealth of resources to help researchers conduct and communicate ethical and robust research. The resource library is focused on, but is by no means limited to citizen science. Resources include: information on data and collaboration ethics, technical tips, examples of consent and other collaboration-relevant forms, legal and policy resources, research quality measurement tools, educational materials and webinars, and more.	(Association for Advancing and Participatory Sciences, n.d.)
Citizen/Community/Participatory Science platforms (https://participatorysciences.org/resources/platforms-for-hosting-participatory-science-projects/)	The Association for Advancing Participatory Sciences (AAPS) has a list of tech platforms that host / provide functionalities for citizen science projects.	(Platforms for hosting participatory science projects, n.d.)
Cryopreservation: cryoprotection	At temperatures below freezing, formation of ice crystals is a threat to viability, through physical cellular injury or osmotic and other forms of stress. Preventive methodologies most commonly employ cryoprotective agents (CPAs) – additives that affect the structure of aqueous environments. Other cryoprotection methods include manipulation of the physical properties of the sample. For example, keeping constant the sample volume (isochoric vitrification), or employing electromagnetic or ultrasound waves to agitate the aqueous environment. CPAs are often toxic, and different microbial families may have different reactions to a CPA. In general, any given cryoprotectant or cryoprotection mechanism will affect different organisms and/or tissues differently, and there is no "one size fits all" method. Thus, even in samples cryopreserved at -196°C, measurements of post-thaw community structure and function may be biased.	(Best, 2015; Biclot et al., 2022; Carroll et al., 2012; Chang and Zhao, 2021; Corrales & Astrin, 2023; Corthals & Desalle, 2005; Gao & Critser, 2000; Heylen et al., 2012; Junge et al., 2006; Müller et al., 2007; Nakanishi et al., 2012; Prakash et al., 2013; Rain-Franco et al., 2021; Yu et al., 2015)
Cryopreservation: temperature	Common cryopreservation options are electrical freezer storage at -80°C and storage in liquid nitrogen (LN) at -196°C (or in some implementations, its gas phase, at -139°C and below). Electric freezer storage is relatively cost-effective and accessible – many research institutions have -80°C freezers, the freezers don't require special expertise to handle, and only need electricity to run.	(Carroll et al., 2012; Corrales & Astrin, 2023; Corthals & Desalle, 2005; Heylen

	However, at temperatures between 0℃ and -135℃, samples can still contain liquid water, and over time, ice - water fluctuations can damage cells and less stable molecules such as RNA. This is a particular issue for storage of psychrophilic extremophiles, such as bacteria that live in Arctic sea ice. Sea ice-resident microbes are ecosystem engineers – they raise the temperature around themselves, creating channels in the ice. Thus, they may retain some activity at temperatures lower than expected. At temperatures below -135℃, water enters a glass-like state (vitrification), and cannot form ice. Therefore, storage in liquid nitrogen is considered to "freeze" the specimen in time, with a full stop to all metabolism and degradation activities (see Junge et al. (2006) for caveat). Some institutions, such as the AMCC choose to use the gas phase LN to reduce the risk of contamination. While LN storage is more expensive and requires special training and maintenance, specimens preserved in LN can be maintained indefinitely and remain viable on restoration.	et al., 2012; Junge et al., 2006; Müller et al., 2007; Nakanishi et al., 2012; Prakash et al., 2013; Rain-Franco et al., 2021)
Cryopreservation: field cryopreservation and transport under cryogenic conditions	Please see Corrales and Astrin (2023), Harvard Campus Services Environmental Health & Safety (2023), Rüdel et al. (2015), Rüdel and Weingärtner (2008) and Snapes et al. (2023).	
Cryopreservation: preparation for analyses	Since cryoinjured samples may still be sequenced for metagenomic identification, cryopreservation in addition to in the field sequencing immediately after collection offers the widest range of options for follow-up studies. As with in-the-field sequencing, post-cryopreservation sequencing results may be biased by the presence of relic DNA (extracellular DNA from dead cells and living cell excretions). Additionally, the stresses of cryopreservation have variable effects on different taxa, and can exert selective pressures and bias estimations of abundance. To account for possible bias, it can be helpful to exclude nucleic acids from the environment and from dead cells, and to compare sequencing results to those obtained from the same sample prior to storage. One technique that is appropriate for mixed microbial communities and does not require advanced laboratory equipment is live/dead staining with propidium monoazide (PMA). PMA is an intercalating dye that binds permanently to DNA and RNA when activated by UV light. It does not cross cell membranes, and is used to exclude extracellular nucleic acids from amplification. There are other dye-based live/dead assays s.a. techniques based on the SYTOX™ Green nucleic acid stain for fluorescence assays of chlorophyll-bearing organisms, and the LIVE/DEAD™ Fixable Aqua amine-reactive dye for investigations of metabolic activity.	(Best, 2015; Emerson et al., 2017; Müller et al., 2007; Ryan et al., 2021)

	Some studies have found evidence of cryopreservation being associated with increased rate of mutations. Proposed mechanisms include cryoprotectant toxicity and temperature variation damage to proteins affecting the ability of enzymes to repair DNA.	
CyberTracker (https://cybertracker.org/)	Mobile software for biodiversity, farming, forestry, community science and education, and survey data capture, designed with graphical icon-based interfaces for non-literate citizen scientist users.	(CyberTracker, n.d.; Liebenberg et al., 2017)
Earth HoloGenome Initiative (EHI) (https://www.earthhologenome.org/)	EHI works to facilitate microbiome research and promote standardization of practices and metadata. Specimen biobanking is one of the EHI core goals – the initiative aims to develop and implement biobanking strategies that would enable field sample reuse by future researchers.	(Corrales & Astrin, 2023; Earth HoloGenome Initiative, 2024)
Earth Microbiome Project (EMP)	Due to the distributed collection strategy, standardization of collection and handling protocols and of metadata expectations was a need. The EMP committee had designed project standards for their contributors to use in common. For metadata, the EMP framework was a set of data expectations to be recorded in a MIxS- and ENVO-compatible format. The EMP coordinated protocol and metadata standards were a major contribution to the evolution of global standards.	(Gilbert et al., 2014; Thompson et al., 2017)
Field Collecting: marine microbiomes	Patin and Goodwin (2023) is a literature review with best practices recommendations contributing to discussions of collection methods standardization.	(Patin and Goodwin, 2023)
Global Open Oceans and Deep Seabed (GOODS)	GOODS is a classification system for species biogeography in the deep ocean. A globally understood classification system is needed for scientists to be able to mesh observations from disparate monitoring platforms and projects.	(Canonico et al., 2019)
International Environmental Specimen Bank Group (IESB)	IESB coordinates collaborations between specimen biobanks and promotes international development of standards for environmental specimen banking.	(Chaplow et al., 2021; Koschorreck, 2015)
International Society for Biological and Environmental Repositories (ISBER)	ISBER publishes the "ISBER Best Practices" comprehensive handbook that contains cryopreservation methods for a wide array of organisms, materials, and situations, including marine life. It also develops and publishes standards and tools for biorepositories.	(Chaplow et al., 2021; Snapes et al., 2023)
medical biobanks	Most cryobanking research is done in the context of human medicine. Medical applications are widespread and are better funded than conservation cryobanking. This is especially true for novel applications, such as cryobanking of mixed microbial communities, where medical stool banks have early expertise. Medical biobanking communities are developing protocols and technologies, and can be sources of interdisciplinary collaborations and knowledge transfer.	(Carroll et al., 2012; Snapes et al., 2023; West et al., 2019)

MICROBE EU	The new MICROBE EU initiative is an early effort to advance techniques, data standards, and infrastructure plans for preservation of naturally occurring non-human microbiomes. The goals include development of preservation techniques for multi-domain mixed microbial communities, development of standardized collection and preparation methods, and development of plans for future biobanking infrastructures.	(MICROBE, 2023)
Microbiota Vault	The Microbiota Vault is a proposal for a centralized biobank of global human microbiome diversity.	(Corrales & Astrin, 2023; Ryan et al., 2021; Steiger & Heuss, 2020)
Ocean Best Practices (OBP) / Ocean Best Practices System (OBPS)	OBP hosts a document repository for observation protocols, data management methods, community engagement, and other practices in marine research. OBP is a UN Ocean Decade programme, and part of the Ocean Practices Network, which coordinates working groups and communities and hosts user discussion forums, among other activities. OBP employs experts to vet methodologies that are disseminated as Endorsed Practices. It also solicits write-ups on working solutions from the global research and management communities, and facilitates exchange of community knowledge. The OBPS document repository is a treasure trove of information on conducting marine research in the Arctic, working with citizen scientists, integrating with existing monitoring projects in diverse disciplines, etc..	(Collins J.E. et al., 2021; IOC/IODE, 2024)
propidium monoazide (PMA)	PMA is a permanent DNA-intercalating dye that does not cross cell membranes. Thus, PMA excludes extracellular DNA from lysed cells, relic DNA, etc. from downstream amplification. Treatment with PMA is used for Live/Dead testing. Cross-referencing PMA-treated and untreated samples may add insight into the microbial community state at the time of collection, and into the dynamic short-term community fluctuations. It can also be used to ascertain any damage that cells incurred during the cryopreservation and rewarming processes. The technique may be of particular interest in Arctic marine microbiology, where low biomass samples and similarity of Arctic microbes to common PCR contaminants is a problem. Both cryopreservation and PMA treatment can be performed in the field, with portable equipment.	(Edwards et al., 2020; Emerson et al., 2017)
protocols.io (https://www.protocols.io/)	protocols.io supports Open Science by providing a platform for sharing of laboratory, fieldwork, etc. protocols. Authors are encouraged to upload their methods when publishing a paper, to share experience, and to collaborate.	(Springer Nature, 2024)

Standards: Access and Benefit Sharing and Legal and Policy Requirements and Initiatives

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The authors call on funders, publishers, academic institutions, and professional societies to write and uphold codes of conduct and to provide education, assistance, and resources for equitable collaborations with local communities. Inclusive collaboration, comprehensive documentation and transparency, vouchering, and reporting of results back to local stakeholders take time, effort, and money. In the current academic environments, researchers feel pressured to produce and may not have the funds or time resources to expand non-required JEDI (Justice, Equity, Diversity, and Inclusion) practices. Therefore, in addition to expanding and affirming codes of conduct, institutions must provide researchers with the means and supportive encouragement to implement best practices (Mallory et al., 2018). ABS must also be a central consideration for biorepositories and networks, and additional codification of expectations and supportive infrastructures is called for.

Below are examples of some of the legal and project design expectations that may be relevant to Arctic marine studies. We also include select references on the financial stakes in marine exploration in the Arctic – the potential of bioprospecting (looking at nature for biotechnological, pharmaceutical, and nutraceutical innovation).

Regulation and Ethical Requirements	Background and Recommendations	Citations
ABS: Distribution Options	Access and Benefit Sharing includes the sharing of monetary profits derived from exploitation of marine resources, knowledge transfer, and capacity building. We suggest allocations of dedicated funds towards distributing collections between high- and low-income countries, international sharing of biobanking services and expertise, and building up of biobanking capacities in countries with low concentrations of biodiversity biobanks. Additionally, local stakeholders must be included in determinations of research priorities, and governance of environmental impacts. ABS may also be seen through the lens of cost sharing, as well as benefit sharing, as ways to understand global, national, and institutional infrastructure investments and responsibilities.	(Collins J.E. et al., 2021; Haklay et al., 2020; Laird et al., 2018; Rosendal et al., 2016)
Compliance: International and National	These are some of the legal frameworks that are relevant to biobanking-supported research. In some cases the practical definitions and enforcement of international laws, such as the Nagoya Protocol, are left to the individual countries. Due to the complexity of the landscape, researchers need institutional support with compliance paperwork. - Aarhus Convention - Agreement on Enhancing International Arctic Scientific Cooperation - Bonn Guidelines - Budapest Treaty on the deposition of patentable microorganisms - CARE Principles for Indigenous Data Governance - Cartagena Protocol On Biosafety - Convention on Biological Diversity (CBD)	(Bentley et al., 2024; Carcia-Soto & van der Meeren, 2017; Desai and Sidhu, 2020; Fritze, 2009; Goodwin et al., 2017; Haklay et al., 2020; Kraabel, 2020; Laird et al., 2018; Ma et al., 2016; McCluskey, 2017; Moss et al.,

	- Convention on International Trade of Endangered Species (CITES) - International Court of Justice (ICJ) - International Tribunal for the Law of the Sea (ITLOS) - Kunming–Montreal Biodiversity Package - MOSAICC (Micro-organism Sustainable Use and Access Regulation International Code of Conduct - Marine Biodiversity of Areas Beyond National Jurisdiction - Nagoya Protocol on Access and Benefit Sharing - Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) - Rio Declaration on Environment and Development - TRACES - UNCLOS (United Nations Convention on the Law of the Sea) - Canada: Oceans Act, Oceans Strategy - European Union: Marine Strategy Framework Directive (MSFD) - United States: Oceans Act, National Ocean Policy Implementation Plan	2023; Prakash et al., 2013)
Compliance: Corporate and Institutional	These are examples of the types of agreements that are made between individual entities (a research team and a biobank, a corporation and a university, etc.). Researchers need assistance with the legal landscape. - Material Transfer Agreements - Intellectual property (IP) paperwork (subject to local regulations) - Product agreements - Agreements between institutions, funders, research teams, and local contributors such as traditional knowledge holders, local communities, citizen science communities, town councils, tribal leaders, etc.	(Association for Advancing and Participatory Sciences, n.d.; Carcia-Soto & van der Meeren, 2017; Dedeurwaerdere, 2010; Fritze, 2009; Haklay et al., 2020; Laird et al., 2018; McCluskey, 2017; Prakash et al., 2013)
JEDI (Justice, Equity, Diversity, and Inclusion): Local and Indigenous Arctic Communities and Participating Researchers	Local contributors include: external researchers from local academic institutions, local communities, local leaders and councils, Indigenous, traditional, and historical knowledge owners, and more. Local contributors are often inadequately documented in research metadata, and are rarely acknowledged in scientific publications. Documenting local contributions is necessary to acknowledge and reward contributions, inclusion in Access and Benefit Sharing, participation in decision making, and other activities that may be governed by either current or future laws. Indigenous Arctic communities are the traditional ecosystem owners and key stakeholders of local research. In this context, "local" includes coastal and near-shore marine research and research in the adjoining ABNJ and BBNJ areas. While some of the relevant legal and regulatory agreements	(APECS, 2024; Arctic Council, 2019; Association for Advancing and Participatory Sciences, n.d.; Boundy-Mills et al., 2020; Buckner et al., 2021; Buschman, 2022; Carlo, 2020; Collins et al., 2019;

	have not been reached, practitioners should strive to pre-emptively collect and record full provenance and contributor metadata (while following data ethics standards). Such comprehensive metadata, will help ensure near-future usability and help decolonize marine research. Future metadata standards and operating codes of conduct must provide for documentation of: - specimen, sample, and observations provenance - individual and institutional contributions - tracking of secondary use and sharing of research benefits, s.a. marine genetic resource (MGR) sequence data - tracking ABS distributions - associations with available raw sequences (primary data), and analysis products (secondary data), detailed collection protocols and analysis code, vouchered data and specimens, and known associations with outside datasets (s.a. other studies done within the microecosystem) and databases (s.a. associations with databases with physicochemical remote sensing data). The authors call on funders, academic and research institutions, and professional societies to create harmonized codes of conduct and to provide the organizational resources that scientists need for thoughtful and ethical collaborations with local contributors and Indigenous communities. The authors recommend that practitioners follow available standards and maintain awareness of the evolving legal landscapes. Examples of concrete suggestions are provided by Marden et al. (2021) and Laird et al. (2018). Practitioners should also let themselves be guided by the principles outlined by the communities. The Association for Participatory Sciences hosts a library of toolkits, information, and guidance for researchers and practitioners. The Association of Polar Early Career Scientists (APECS) has also created a collection of helpful educational material and resources.	Collins J.E. et al., 2021; Haklay et al., 2020; Greenfield 2022; Johnson et al., 2016; Kraabel 2020; Laird et al., 2018; Marden et al., 2021; Pedersen et al., 2020; Robert et al., 2013; Stephenson, 2021)
Resources: INTERACT	INTERACT (International Network for Terrestrial Research and Monitoring in the Arctic) is a web platform that aggregates information on permits, regulations, and paperwork relevant to research in Arctic Council member states.	(Interact International Network, n.d.)
The Stakes	Marine life has inspired scientific discoveries and is exploited in a wide range of industries. Microbial and other marine biotechnologies contribute to an array of health- environment- and sustainable growth-related UN SDGs.	(Arora et al., 2021; Blockley et al., 2017; Boundy-Mills et al., 2020; Bruno et al.,

	Marine microbes are rich sources of Marine Natural Products (MNPs) – compounds with potential uses in medicine and biotechnologies. Over 20,000 MNPs have been discovered between the 1950ies and 2017, with the majority of those compounds produced by microbes. Of particular interest are mixed microbial communities, such as the microbiomes associated with vertebrate and invertebrate hosts. The complexities of interactions within such communities produce functional adaptations that are often unique. Other areas of bioprospecting focus are extreme microecosystems – areas that may have unusually high or low salinity, temperature, pH, nutrient levels, high concentrations of metals or pollutants, high radiation, or areas at high pressure. Arctic marine environments are rich in extreme microecosystems, such as areas of high temperatures near hydrothermal vents, low temperatures in sea ice, lowered salinities near marine-terminating glaciers, high concentrations of metals and organic pollutants near wastewater treatment plants or glacier meltwater outflows, and oligotrophic environments. Enzymes isolated from extremophiles (microbes adapted to extreme conditions) may be used in biosynthesis reactors, such as for production that saves energy by working at low temperatures. They may also perform in high-temperature conditions where other proteins may denature (such as in PCR reactions). Computational investigations of protein structure changes associated with cold-adapted functions help develop novel enzymes that may act on non-natural industrial substrates. ABS is a dynamic field. In addition to the conversations on equity and distribution options, the very concepts of marine resources are shifting. Bioprospecting can be performed on omic sequences in databases as well as physical samples. Omic sequences may be processed, related and shared. Additionally, strain and epigenetic microdiversity can obfuscate ownership. Thus, ABS depends on multiple parallel conversations on policies, definitions and data ontologies. Benefits: Pharmaceuticals and Medical Research - Novel molecules with medical applications as: antibiotics, antifungals, antivirals, antiplasmodials, analgesics, cancer chemotherapies, antiinflammatories, and antioxidants, as well as compounds with antiosteoporotic, antidiabetic, hypocholesterolemic, and neuroprotective actions. Target diseases include: heart disease, cancer, Alzheimer's, and arthritis. Cryoprotectants for organ cryopreservation research. Benefits: Agriculture and Aquaculture - Thermophilic marine archaea-produced chitinase may be developed to hydrolyze chitin, making it available as feedstock. - Marine-derived food preservatives, stabilizers, and cryoprotectants (allowing food to be frozen or preserved with less spoilage waste and allowing for slower, more sustainable shipping).	2019; Cockell & Jones, 2009; Collins F.W.J. et al., 2021; Collins & Margesin, 2019; Delgado, 2021; Fritze, 2009; Gauthier et al., 2021; Hoag, 2009; Lo Giudice & Rizzo, 2018; Rölfer et al., 2021; Rotter et al., 2021; Segal-Kischinevzky et al., 2022; Timmis et al., 2017)

	Benefits: Biotechnologies - Less toxic antifouling paints for ships' hulls. - Algae-based biofuels, which may be coupled with wastewater valorization. Benefits: Bioremediation - Biorefineries may someday process lignocellulosic waste into biofuels. - Marine microbes from around natural oil seeps may help clean oil spills.	

Standards: Metadata		Back To Table Of Contents
Additional background information may be found in Stephenson (2021). Grenié et al. (2023) provide examples of taxonomy R packages. Damerow et al. (2021) explore and identify gaps in persistent identifier standards and capabilities.		
Name	**Description**	**Citations**
General Notes	One of the uses that currently accepted standards do not fully provide for is Access and Benefit Sharing (ABS) compliance. While some of the requisite schema properties are included, they are not nearly enough. In part, this is because there aren't yet global agreements on how to best do ABS. We know we need to record provenance (collection location, jurisdiction, the collecting team, etc.). We also need to track all legal agreements that were in force when the sample was collected, plus all follow-up agreements that may be reached over the course of the use of the sample. The legal landscape is evolving, for example, the BBNJ agreement was only signed last year. We also need to keep track of how the sample is used by the collecting team, and then how it's used in subsequent research. For example, biotechnology and pharmaceutical projects can be spun off by academic institutions into for-profit startups (what we term "porous academia-industry barriers"). A research team may informally share its cultures with a team across the hall. Or a researcher may download a product of the research that the original sample was a part of. Etc., etc.. At this time, there is no global consensus on how research benefits are to be determined and shared, and no comprehensive implementations. Databases, portals, metadata standards, all will need to be overhauled as the topic develops. Marine researchers may sometimes feel that ABS responsibilities stop at following existing laws and regulations. We feel that bare minimum compliance is shortsighted. We believe that best practice is to make metadata as comprehensive as feasible, in the expectation that laws and standards will be extended and clarified in the future. Some early initiatives include: - European Culture Collections Organisation's: core-MTA standard - Microorganisms Sustainable use and Access regulation International Code of Conduct (MOSAICC) and TRansparent User-friendly System of Transfer (TRUST): standards for legal paperwork relating to microorganisms and the CBD and Nagoya legislation	(Becker et al., 2019; Laird et al., 2018)
Biospecimen Reporting for Improved Study Quality (BRISQ) (https://biobanking.org/we	Designed for biomedical research, this standard describes individual specimen properties, but is not designed to answer biodiversity biobanking needs.	(LaBaer et al., 2018)

bs/brisq)		
Common Biorepository Model Project (CBM)	A metadata model for sharing key specimen information to facilitate inter-repository searches. Does not provide for full data exchange.	(NCIP/common-biorepository-model, 2023)
DwC	Darwin Core Standard, developed by the Biodiversity Information Standards (TDWG) organization. DwC has gained popularity and acceptance in a number of scientific fields, and is used by GBIF. The core DwC specification is designed to accept extensions – specialized DwC standards developed for specialty datasets. Extensions development is in its early stages. For example bioacoustic metadata standards are in discussion.	(Darwin Core Archives – How-to Guide :: GBIF IPT User Manual, n.d.)
Findable, Accessible, Interoperable and Reusable (FAIR)	Findable: Data can be discovered and parsed (understood) by humans and search algorithms. Data are associated by globally unique identifiers. Accessible: Data can be retrieved by a standardized protocol. Interoperable: Datasets can be combined (enriched data), data formats fit within existing workflows. Reusable: Data and metadata are comprehensively described, so that they can be used in novel ways in future studies (converted and calibrated for future formats). Provenance, usage rights, and compliance with community standards are documented in metadata.	(Blumberg et al., 2021; Collins J.E. et al., 2021)
The Global Genome Biodiversity Network (GGBN) Data Standard	Developed by the Global Genome Biodiversity Network to complement the DwC, ABCD, and MIxS data standards.	(Droege et al., 2016)
ISO Standards	Examples of ISO standards and implementation guides describing collection management and IT infrastructure requirements and recommendations for biobanks: ISO/TR 79, ISO/TS 22692, ISO/TR 3985, ISO 9001, ISO/DIS 16677-1, ISO 18209-1, ISO 20184-2, ISO 20387, ISO 20395, ISO/TS 20388, ISO 20658, ISO 20691, ISO 21709, ISO 21710 , ISO 21899, ISO/TR 22758, ISO/TS 23105, ISO/TS 23357, ISO/TS 23494-1, ISO 24088-1, ISO 24190, ISO 24603	(González et al., 2018; ISO, n.d.; Jaroszewska et al., 2023)
Marine Biodiversity Observation Network (MBON)	MBON works to grow monitoring program partnerships, promote best practices for data collection and sharing, and improve interoperability between biological and physicochemical data portals and approaches.	(Canonico et al., 2019)
Marine Microbial Biodiversity, Bioinformatics and Biotechnology (M2B3) standards	A set of standards for contextual metadata associated with marine molecular samples, inspired by the MIxS and Darwin Core. The M2B3 standard is designed to improve interconnectivity between molecular sequence data and environmental data, including physicochemical variables.	(ten Hoopen et al., 2015)
Minimum Information	Designed for human biomedical research, this standard covers information on biobanks,	(LaBaer et al., 2018)

About Biobank Data Sharing (MIABIS) (https://www.bbmri-eric.eu/howtomiabis/)	collections, projects, and individual samples. However, (as of 2018) MIABIS does not cover sample collection, storage, or shipment information.	
Minimum information about any sequence standard (MIxS)	Genome Standards Consortium MIxS metadata standard, which includes the more specific marker genes (mImARKS) and metagenomes (mImS) standards. Some of the data fields are entered as free text, which can cause data divergence. For example, different users may enter different names for the same gene, or use slightly different technical concepts, definitions, or abbreviations, or perhaps describe parameters at different levels of detail. As a result, free text fields can be difficult to parse for search and analysis algorithms. Machine-readable formats are schema with clearly defined fields and allowed parameter values, that can be compared and filtered by algorithms. Standardization initiatives, such as the NMDC initiative, are evolving metadata standards for microbiomes, with successive rounds of MIxS versions beginning to employ machine-readable schema. There are also efforts to find standard ways of connecting sequence data with abiotic data, such as chemical, physical, etc. observations. While major metagenomic data portals use MIxS checklists and ENVO standards, a system of globally unique data object identifiers and centralized identifier directories is needed to integrate biotic and abiotic databases and make marine data FAIR.	(Blumberg et al., 2021; Goodwin et al., 2017; Knight et al., 2018; Vangay et al., 2021; Yilmaz et al., 2011)
Minimum Information for an Omic Protocol (MIOP)	A proposed metadata standard to describe marine omic best practices and protocols. MIOP goals would be to help researchers discover and share fieldwork and laboratory procedures.	(Samuel et al., 2021)
OBIS-ENV-DATA	Building on Darwin Core Archive (DwC-A) and GBIF practices, this data standard is designed to help link the quantitative and qualitative measurements and properties of biodiversity observations with abiotic measurements.	(Pooter et al., 2017)
Open Nomenclature (ON)	ON is a vocabulary of taxonomic terms that is generally used by taxonomists to describe their own data. Term definitions and use are not standardized.	(Sigovini et al., 2016)
ORCID	A global unique identifier, usually used to identify people. Notable use: Bionomia database.	(Bionomia, n.d.)
Public Participation in Scientific Research (PPSR) (https://core.citizenscience.org/)	A set of transdisciplinary data and metadata standards for citizen science.	(PPSR Core | PPSR Core, n.d.)
RRID	A global unique identifier suitable for cross-referencing records residing in separate databases or	(RRID Initiative, n.d.)

	datasets. Notable for being used by a number of publishers.	
SciScore	A tool for reviewing the transparency of methods descriptions in research publications.	(SciScore: The best methods review tool for scientific research, n.d.)
SeqDB	The SeqDB application is built on the Darwin Core and MIxS standards and is used to track workflow and provenance chain from sampling and through genetic sequence analysis. It is available through the EMBL-EBI APIs.	(Bilkhu et al., 2017; Cook et al., 2019)
URI	Specification for the creation of unique identifiers.	(Berners-Lee et al., 2005)

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