EuropaBON EBV workflow templates

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Description

The information provided here represents the EBV workflow templates collected during the EuropaBON online workshop on Essential Biodiversity Variable (EBV) workflows from 22–24 February 2023. The templates were designed to capture comprehensive descriptions about the three workflow components (data collection and sampling, data integration, and modelling) that are typical for generating EBVs. Recognising the potential value of those EBV templates for European biodiversity monitoring, our objective is to share them for enhancing transparency, knowledge exchange and collaboration, and promoting the operationalisation of EBVs across Europe.

EuropaBON (https://europabon.org/) is a Horizon 2020 research and innovation action funded by the European Commission that seeks to co-design a European Biodiversity Observation Network. This network aims to bridge the gap between the biodiversity data needs of policy-makers and authorities on the one hand and the existing reporting streams and available data sources on the other hand, considering both present obligations and forthcoming policy needs. Essential Biodiversity Variables (EBVs) are a central concept of EuropaBON as they provide a standardised framework for biodiversity monitoring and reporting. In 2023, EuropaBON had identified 70 EBVs (Junker et al., 2023) that are policy-relevant for the EU, and measurable with available and existing technologies and with a proven track record of feasibility in ongoing initiatives. EBVs require workflows to process the raw data (primary observations) through data integration and modelling into spatially-explicit EBV data products (Kissling et al., 2018; Schmeller et al., 2017). These workflows can be broken down into three main components (data collection and sampling, data integration, and modelling), with additional aspects of data interoperability and IT infrastructure being recognised as crucial for transnational data streams (Kissling & Lumbierres, 2023).

To capture information about the EBV workflows, an online workshop was held on 22–24 February 2023 with 520 registered participants from 49 countries, covering a large range of expertise (Lumbierres & Kissling, 2023). Participants contributed information on EBV workflow components and advanced monitoring techniques, discussed initiatives, and identified tools and requirements for implementing 70 proposed EBVs. The information from the workshop participants was collected through pre-defined EBV workflow templates (provided as Google Docs). Templates were organised into rows representing the workflow components (‘Data collection and sampling’, ‘Data integration’, and ‘Modelling’) and columns reflecting the levels of maturity ('Current initiatives', 'Emerging tools and projects' or 'Future needs'). Prior to the workshop, some information on existing workflows was pre-filled based on previous EuropaBON deliverables, namely an assessment of the current biodiversity monitoring gaps in the EU (Santana et al., 2023) and an assessment of current EU monitoring workflows and bottlenecks (Morán-Ordóñez et al., 2023).

After the workshop, the EBV workflow templates were processed to ensure the accuracy and relevance of the information. Each listed initiative was verified to be part of an active biodiversity monitoring scheme and pertinent to the specific EBV under consideration, cross-referencing with

the initiative's websites and other data collected by the EuropaBON deliverables (Morán-Ordóñez et al., 2023; Santana et al., 2023). Moreover, we ensured correct alignment of each initiative and listed requirements and needs with the appropriate workflow components and maturity levels.

The EBV workflow templates provide insights into the current biodiversity monitoring landscape in Europe and how EBV production could be operationalized at the EU level. They offer detailed information about ongoing initiatives and projects, methodologies, and technologies that can be used to generate EBVs at a continental scale. Nevertheless, it is important to note that they do not encompass an exhaustive list of all ongoing or proposed initiatives of biodiversity monitoring in all member states of the EU. It is suggested to use them as a starting point and baseline for the further development of EBVs in a European context.

Keywords

Essential Biodiversity Variables, Biodiversity monitoring, EBV workflows, European Biodiversity Observation Network, Monitoring initiatives, Data collection, Data integration, Biodiversity modelling

References

Junker, J., Beja, P., Brotons, L., Fernandez, M., Fernández, N., Kissling, W. D., Lumbierres, M., Solheim, A. L., Maes, J., Morán-Ordóñez, A., Moreira, F., Musche, M., Santana, J., Valdez, J., & Pereira, H. (2023). D4.1. List and specifications of EBVs and EESVs for a European wide biodiversity observation network. *ARPHA Preprints*, *4*, e102530.

Kissling, W. D., Ahumada, J. A., Bowser, A., Fernandez, M., Fernández, N., García, E. A., Guralnick, R. P., Isaac, N. J. B., Kelling, S., Los, W., McRae, L., Mihoub, J. B., Obst, M., Santamaria, M., Skidmore, A. K., Williams, K. J., Agosti, D., Amariles, D., Arvanitidis, C., … Hardisty, A. R. (2018). Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale. *Biological Reviews*, *93*(1), 600–625.

Kissling, W. D., & Lumbierres, M. (2023). Essential Biodiversity Variable workflows: Designing the freshwater, marine and terrestrial EBV workflows from data collection to modeling. *ARPHA Preprints*, *4*, e101949.

Lumbierres, M., & Kissling, W. D. (2023). Important first steps towards designing the freshwater, marine and terrestrial Essential Biodiversity Variable (EBV) workflows for the European Biodiversity Observation Network. *Research Ideas and Outcomes*, *9*, e109120.

Morán-Ordóñez, A., Beja, P., Fraixedas, S., Herrando, S., Junker, J., Kissling, W. D., Lumbierres, M., Solheim, A. L., Miret, G., Moe, J., Moreira, F., Pereira, H., Santana, J., Villero, D., & Brotons, L. (2023). D3.3 Identification of current monitoring workflows and bottlenecks. *ARPHA Preprints*, *4*, e103765.

Santana, J., Porto, M., Brotons, L., Junker, J., Kissling, W. D., Lumbierres, M., Moe, J., Morán-Ordóñez, A., Pereira, H., Solheim, A. L., Villero, D., Moreira, F., & Beja, P. (2023). D3.2 Report on gaps and important new areas for monitoring in Europe. *ARPHA Preprints*, *4*, e103657.

Schmeller, D. S., Mihoub, J.-B., Bowser, A., Arvanitidis, C., Costello, M. J., Fernandez, M., Geller, G. N., Hobern, D., Kissling, W. D., Regan, E., Saarenmaa, H., Turak, E., & Isaac, N. J. B. (2017). An operational definition of essential biodiversity variables. *Biodiversity and Conservation*, *26*(12), 2967–2972.

List and overview of EBV workflow templates

Freshwater EBVs

Marine EBVs

Terrestrial EBVs

Genetic diversity of selected freshwater taxa			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building		Taxonomic diversity of Eukaryotes and Fungi in lakes at different depths and seasons (https://www.biodiversa.eu/2023/04/19/funaction/ Genetic diversity of freshwater mussels using different techniques(Cost Action Confremus: https://www.cost.eu/) **G-bike** is an initiative to develop monitoring tools and standardised protocols and formats for genetic diversity in wild populations. Not only restricted to the marine realm.	Better biogeographic cover. For example, a better cover of the glacial refugia (Iberia, Italy, Balkans) Increase temporal trends in genetic diversity monitoring to understand the risk of genetic erosion in relation to fragmentation (dams and other obstacles) and other threats. Capacity building in low-income countries. Harmonisation in methods
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	Reference sequences databases (e.g. **BOLD**) for metabarcoding of freshwater taxa (though not dealing with genetics but on taxonomic diversity) **The International Nucleotide Sequence Database Collaboration** repositories	GBIF (see https://www.gbif.org/dna)	Establish clear metadata (see pubs below) Data standardisation for interoperability (e.g. linking morpho-taxonomic and genetic databases for the study of biodiversity)

	Angiosperm Phylogeny Group (APG) megatree combined with more detailed phylogenies, fossil record (for dating nodes), combined phylogeny coded in Newick format.		Incomplete sequence database references for metabarcoding coverage of many taxa Calibration of methods to better link molecular data (eDNA reads) with the abundance of species Experiments (lab and natural ecosystems) link molecular data and abundance of species.
Modelling Types of models Predictors Estimation & uncertainty Software			Better understanding of how spatial and temporal features may change this relationship
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • GEOBON, the Coalition of Conservation Genetics, IUCN SSC Conservation Genetics Specialist Group and EU COST Action Network G-BIKE (Genomic BIodiversity Knowledge for Resilient Ecosystems) can be consulted/contacted for input. • Cost Action on conservation of freshwater mussels: https://www.cost.eu/actions/CA18239/ • Hoban, S., Archer, F.I., Bertola, L.D., Bragg, J.G., Breed, M.F., Bruford, M.W., Coleman, M.A., Ekblom, R., Funk, W.C., Grueber, C.E., Hand, B.K., Jaffé, R., Jensen, E., Johnson, J.S., Kershaw, F., Liggins, L., MacDonald, A.J., Mergeay, J., Miller, J.M., Muller-Karger, F., O'Brien, D., Paz-Vinas, I., Potter, K.M., Razgour, O., Vernesi, C. and Hunter, M.E. (2022), Global genetic diversity status and trends:			

towards a suite of Essential Biodiversity Variables (EBVs) for genetic composition. Biol Rev, 97: 1511-1538. https://doi.org/10.1111/brv.12852

- Hvilsom et al. 2022. Selecting species and populations for monitoring of genetic diversity. https://doi.org/10.2305/IUCN.CH.2022.07.en
- Crandall, E. D., Toczydlowski, R. H., Liggins, L., Holmes, A. E., Ghoojaei, M., Gaither, M. R., Wham, B. E., Pritt, A. L., Noble, C., Anderson, T. J., Barton, R. L., Berg, J. T., Beskid, S. G., Delgado, A., Farrell, E., Himmelsbach, N., Queeno, S. R., Trinh, T., Weyand, C., … Toonen, R. J. (2023). The importance of timely metadata curation to the global surveillance of genetic diversity. *Conservation Biology*, 00, 00– 00. https://doi.org/10.1111/cobi.14061
- Andres, K. J., Sethi, S. A., Lodge, D. M., & Andrés, J. (2021). Nuclear eDNA estimates population allele frequencies and abundance in experimental mesocosms and field samples. *Molecular Ecology*, *30*(3), 685-697.
- Tsuji, S., Maruyama, A., Miya, M., Ushio, M., Sato, H., Minamoto, T., & Yamanaka, H. (2020). Environmental DNA analysis shows high potential as a tool for estimating intraspecific genetic diversity in a wild fish population. *Molecular Ecology Resources*, *20*(5), 1248-1258.
- Cabello-Yeves, P.; D. J. Scanlan, C. Callieri, A. Picazo, L. Schallenberg, P. Huber, J. J. Roda-García, M. Bartosiewicz, O. I. Belykh, I. V. Tickhonova, A. Torcello-Requena, P. M. De Prado, A. D. Millard, A. Camacho, F. Rodriguez-Valera, R. J. Puxty. (2022). α-cyanobacteria possessing form IA RuBisCO globally dominate aquatic habitats. *ISME Journal* 16: 2421-2432. Doi: 10.1038/s41396-022-01282-z
- Weitemier, K., Penaluna, B. E., Hauck, L. L., Longway, L. J., Garcia, T., & Cronn, R. (2021). Estimating the genetic diversity of Pacific salmon and trout using multigene eDNA metabarcoding. *Molecular Ecology*, *30*(20), 4970-4990. https://doi.org/10.1111/mec.15811

Species abundances of wetland birds			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**IWC (International Waterbird Census)** - Bird counts at waterbodies conducted by volunteers (winter censuses) **Nacional and regional initiatives** **Doñana monitoring program** - Aerial bird censuses (link) **Norway and Sweden Citizen Science program** The citizen science presence data from citizen science reporting systems of Norway and Sweden are good examples (i.e. https://www.artportalen.se/). **BMS:** - Biodiversity Monitoring South Tyrol, started in 2019, uses standardized protocols in 320 permanent plots across South Tyrol, Italy - Plots are surveyed every 5 years, with visual/acoustic counts	**UAVs to Map Aquatic Bird Colonies** - Counting of breeding birds of aquatic birds using drones (ref1, ref2) **eLTER** Monitoring protocolssa: eLTER Plus Discussion paper on key standard observation variables	Aerial censuses with drones Clear guidelines on data collection and sampling for non-experts working on biodiversity / wetland-bird research Develop guidelines for new projects involving non-experts on Essential Biodiversity Variables (EBVs).

	conducted for 10 minutes during the breeding season. - Each site is surveyed three times per season, with Alpine sites surveyed twice.		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**International Waterbird Census (IWC)** - Data aggregated at the national level - Standardized excel format - Standard protocols (Guidance on waterbird monitoring methodology: Field Protocol for waterbird counting) -IWC online platform **The European Bird Portal** **-** Data aggregated from number and diversity of web portals dedicated to the collection of bird observations from simple standardized protocols (e.g. complete lists), or in some cases even no protocol (casual observations), https://eurobirdportal.org/ebp/en/#home/HIRRUS/r52weeks/CUCCAN/r52weeks/ **Second European Breeding Bird Atlas (EBBA2):** targeted surveys (breeding period; 10 km2	**Biodiversity Information Standards** At TDWG, we are developing a standard to capture and share biodiversity surveys (currently called Humboldt Extention). This provides a useful vocabulary (terms) that is standardized for multiple sampling protocols). It does not only apply to birds, it is more general for biodiversity data, but worth mentioning here since you already have a comment about standardized Excel formats	Advise on required metadata and data standards. Open data for initiatives/projects to improve their modeling (e.g., our BirdWatch project would need data to help us with species distribution modeling) Information on data sources which can be used to support biodiversity / wetland-bird research including for non-experts Information on data repositories which can be supplemented by biodiversity / wetland-bird research; including for non-experts

	squares); standardized protocol (time surveys 60–120 min, 2013–2017) **Regional repositories** Regional repositories (e.g. PlutoF) can also be checked for more data on this taxon group		
Modelling Types of models Predictors Estimation & uncertainty Software	**TRIM models** eLTER to estimate trends R package rtrim - Modeling using abiotic and biotic explanatory variables for occurrence and abundance (under the framework of eLTER Plus WP8 project) **Multiple imputations** of missing data at the site level. Then aggregating the augmented data in totals per year and month which we model to get indices per year. The full analysis is documented in a public git repo. The relevant raw data is extracted from the database and stored in a private git repo. The analysis always runs from the data in the private git repo. This is required to make the analysis reproducible. **The European Bird Portal**	Work currently being done in Task 5.2 of EuropaBON could be relevant here, although it's not focused on wetland birds.	Improve the imputation of missing data by taking the spatio-temporal autocorrelation and relevant covariates into account. (https://link.springer.com/article/10.1007/s10336-016-1404-9, https://doi.org/10.1007/s10336-016-1404-9)

	https://eurobirdportal.org/ebp/en/#home/HIRRUS/r52weeks/CUCCAN/r52weeks/		

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Data available on request after paying a fee
- Metadata standards: Humboldt Extension currently under development can be applied. See https://tdwg.github.io/hc/terms/

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

Single central repository (global IWC database) managed by the Wetlands International

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Hilpold, A., Anderle, M., Guariento, E., Marsoner, T., Mina, M., Paniccia, C., Plunger, J., Rigo, F., Rüdisser, J., Scotti, A., Seeber, J., Steinwandter, M., Stifter, S., Strobl, J., Suárez-Muñoz, M., Vanek, M., Bottarin, R., & Tappeiner, U. (2023). Handbook Biodiversity Monitoring South Tyrol. https://doi.org/10.57749/2QM9-FQ40

Species distributions of freshwater fishes			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** Composition, abundance and age structure of fish fauna at the waterbody level Fish data on river site for WFD reporting (Composition, abundance and age structure of fish fauna) **Habita Directives 92/43** Species composition in the water body level in Natura2000 sites and distribution maps (Habita Directives 92/43) **National programs** **Norway and Sweden Citizen Science program** The citizen science presence data from citizen science reporting systems of Norway and Sweden are good examples (i.e. https://www.artportalen.se/).	**REFCOND-VOLGA monitoring program**, project 'Monitoring Aquatic Biodiversity in the Headwaters of the Volga River using eDNA.' Monitoring of species distribution using eDNA tools (e.g. Lecaudey et al. 2019; Schenekar et al. 2020)	Expand the geographical coverage of data sampling to more countries and waterbodies (especially southern and eastern countries) Use of Internet ecology and culturomics more often Assess deep rivers and lakes to link WFD with Natura 2000 Directives. Design concrete sampling protocols in time and space for eDNA to best optimize and harmonise outputs from such efforts. Focus on species in decline rather than just HD species. Include species that act as hosts for rare and endangered MIV species. Harmonisation of the monitoring

			design and data collected for the WFD and the Habitats Directive Standardisation & harmonization of a unified sampling protocol framework in rivers and lakes across EU (standardised sampling designs and data collection methods)
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EQR monitoring WFD:** - Standardize data collection for fish EQR - Excel template for data entry **National databases on freshwater** fish (including raw data on length/weight etc.) are available and collect data from the WFD, but should be integrated into one database to make Europe-wide analysis possible/easier. **Swedish national fish databases** NORS (gillnet sampling) and SERS (electrofishing) are data providers at www.analysportal.se. They are then linked to GBIF.	**European Tracking Network ETN** https://europeantrackingnetwork.org/en **OpenBioMaps**, a free database service aimed at data collection and management (https://openbiomaps.org/index.php) **Report to SLU Aqua**, Swedish University of Agricultural Sciences report data on observations of alien species, lobster, eel, invasive species, crayfish and tagged fish (https://www.slu.se/institutioner/akvatiska-resurser/forskning/rapportera-till-slu-aqua/)	Unified, free and open-access data cloud services focused on species distribution and composition in a multi-national scale. Use existing data from national databases that are not currently made openly available. A lot of this data is collected through public funding, but not made available. E.g. Fisheries Research Institute of Slovenia manages such a database for the Slovenian Ministry of Environment There is data on species occurrences on GBIF. Assessment of local/traditional ecological knowledge

		The Freshwater Information Platform: freshwater data from information about datasets (metadata) to occurrence and species data from Europe. It has been set up by BOKU in cooperation with a number of research institutes. http://freshwaterplatform.eu/	Establishment of a modelling-oriented fish distribution community of experts. Similar initiatives would fulfil theoretical and technical gaps in the fields of additional EBVs as well.
Modelling Types of models Predictors Estimation & uncertainty Software	SDMs (MaxENT), GAMs, ANNs (Artificial Neural Networks) Climate drivers (temperature, pluviosity, etc), AMBER (European barrier atlas), functional traits (www.freshwaterecology.info) GLMs using beta diversity	Wallace Ecological Model v 2.0: An R-based GUI app focused in bioclimatic SDMs through the integration of MaxEnt modelling and environmental drivers for the estimation of suitable environmental conditions under different climate scenarios (i.e., https://wallaceecomod.github.io/wallace/articles/tutorial-v2.html). Nature-FIRST project: developing a digital twin, real-time distribution predictions based on observations made with Cluey, for the sturgeon in the Danube Delta	Integration to High Performance Computing (HPC) environments. Workflow adequation to HPC requirements. Future modelling exercises (SDMs for example) need to more often include biotic interactions (predator - prey interactions, parasites, diseases, etc) Include the importance of connectivity (presence of dams and other obstacles) - at least for future predictions taking into account climate change, for example Look for habitat connectivity between populations. Migration routes

			Simplified standardised tools for automatic calculation of geospatial information related to species distribution (i.e. http://geocat.kew.org/). These hands-off-based tools can be hosted either on a web-site or programming package environment (i.e., R/Python).

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Free database with species occurrences from WFD and Habitats Directive reporting needed
- The templates for data products should ideally use non-proprietary formats, to cope with the FAIR principles.
- See: Home - Swedish Biodiversity Data Infrastructure
- Promoting Open Data policies and the use, re-use and citation of data stored in repositories such Zenodo (https://zenodo.org/) , Dryad (https://datadryad.org/) , movebank (https://www.movebank.org/), FigShare (https://figshare.com/) and etc.
- Add robust metadata and follow the up to date ontologies (Darwin Core, DataCite, etc)

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- Maybe use the existent Research Infrastructures (e.g. GBIF, iNaturalis, eLTER, etc) as a possibility to join efforts and take advantage of workflows already in place.
- An European based on Natura2000/WFD database repository for freshwater fish, all information related to fish traits (like NABIA database)
- Integration with HPC clusters. Workflow adaptation to plug-in on super computers.
- SBDI Tools Swedish Biodiversity Data Infrastructure SBDI Tools start - SBDI Tools (biodiversitydata.se)

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Jarić, I., Correia, R. A., Brook, B. W., Buettel, J. C., Courchamp, F., Di Minin, E., ... & Roll, U. (2020). iEcology: harnessing large online resources to generate ecological insights. *Trends in Ecology & Evolution*, *35*(7), 630-6no39.
- Jarić, I., Roll, U., Arlinghaus, R., Belmaker, J., Chen, Y., China, V., ... & Correia, R. A. (2020). Expanding conservation culturomics and iEcology from terrestrial to aquatic realms. *PLoS Biology*, *18*(10), e3000935.

- Lecaudey L.A., Schletterer M., Kuzovlev V.V., Hahn C. Weiss S.J. (2019). Fish diversity in the headwaters of the Volga River using environmental DNA metabarcoding. Aquatic Conservation: Marine and Freshwater Ecosystems 29: 1785-1800. https://doi.org/10.1002/aqc.3163
- Schletterer M., Kuzovlev V.V., Zhenikov Y.N., Tuhtan J.A., Haidvogl G., Friedrich T., Górski K., Füreder, L. (2018): Fish fauna and fisheries of large European rivers: examples from the Volga and the Danube. Hydrobiologia 814: 45–60. https://doi.org/10.1007/s10750-017-3370-5
- Schenekar T., Schletterer M., Lecaudey L.A., Weiss S. (2020): Reference databases, primer choice, and assay sensitivity for environmental metabarcoding: Lessons learnt from a re-evaluation of an eDNA fish assessment in the Volga headwaters. River Research and Applications 36: 1004-1013. https://doi.org/10.1002/rra.3610

Species distributions of amphibians and freshwater reptiles			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Reptile and Amphibian Conservation Europe (RACE)** network of European, non-governmental amphibian and reptile conservation organisations - Distribution and abundance surveys coordinated by NGO partners **National initiatives** (e.g. Spain, France, Netherlands, etc.) In some EU countries, there are ongoing monitoring programs of common species based on citizen science, but international initiatives to integrate national monitoring outcomes are lacking. **AHE Spanish amphibian and reptile monitoring programs** **Romania** uses for amphibian and reptile species monitoring a mix of presence data from the field, from recent publications and recent EU-funded projects for management plan drafting /	**New protocols for the National Amphibian Survey in the UK**: https://amphibian-survey.arc-trust.org/pages/protocol ArcGIS Survey123 app data collection within the National Amphibian and Reptile Monitoring Programme **PONDERFUL** project: eDNA data of amphibians from over 7 countries (30 ponds per country)	Structure monitoring Standardize European sampling of amphibians in freshwater spatial units (eg CCM2). Assessing effective population sizes with genetic methods Capacity building: Training for volunteer surveyors Finding a way to integrate and validate herp species occurrence and impact data from citizen science, inventory studies, EIA studies and structured monitoring programmes

	setting up conservation measures / monitoring conservation measures effectiveness. **Norway and Sweden Citizen Science Program** The citizen science presence data from citizen science reporting systems of Norway and Sweden are good examples (i.e. https://www.artportalen.se/) **Monitoring the Effectiveness of Habitat Conservation in Switzerland** (www.biotopschutz.wsl.ch) - Long-term monitoring program since 2011 - Collects occurrences and population size estimates of pond-breeding amphibians in 258 sites of national importance - Each site visited every six years, with four visits in the year of visiting to account for detectability - Trends analyzed for individual species, with future consideration for occupancy models and breeding population trends **UK National Amphibian and Reptile Monitoring Programme**: - Program for collecting		

	conservation data on amphibians and reptiles across the UK. - Combines professional research with citizen science efforts. - National Amphibian Surve employs standardized protocols and digital resources to track abundance and distribution trends of native amphibians. - Regular surveys, using various observation techniques, are conducted at different waterbodies multiple times annually. - Specific focus on the Natterjack toad monitoring, aiming at consistent monitoring of the *Epidalea calamita* population in Britain - PondNet, coordinated by Freshwater Habitats Trust **RAVON Dutch amphibian monitoring programmes** **Ornitho.it** Citizen science platform holding data on presence of many taxa in Italy. This includes amphibians (and reptiles) data that are managed by the Italian herpetological society (Societas Herpetologica Italica –		

	Atlas des reptiles et amphibiens de France Data are given to the SINP (Système d'Information de l'iNventaire du Patrimoine naturel, established to support the design, implementation and evaluation of decentralized inventories in France)		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Reporting on Art.17 (HD)** In EU countries there are monitoring programmes for reporting on Art.17 (Habitats Directive), supported by EU or national level funding. **New Atlas of Amphibians and Reptiles of Europe (NA2RE, 2014)** - No structure monitoring - Presence data compiled from publications, atlases, herpetological societies, and opportunistic occurrence data. - mapped distributions, 50 x 50 km grid, 218 taxa (145 species of reptiles) updated as of 2014 - no information about temporal dynamics - data not from systematic monitoring programs		Collation of trend data from multiple European countries to understand EU wide trends Assessing population trends by merging structured monitoring, occurrence data, and citizen science contributions. Atlas data available, but no raw data available Support the creation of integration nodes at European level, e.g. involving the SEH https://www.seh-herpetology.org Ensure dedicated personnel for managing and updating national databases and secure funding Funding dedicated to the

	- temporal snapshot (2014) - data centralized and harmonized from different sources using different standards - data streams not automated - raw data not openly available **Reporting on Art.17 (HD)** Data aggregated at 10x10 km (presence/absence) to produce distribution and range maps for 34 herp species **National initiatives** **OpenHerpMaps (Romania)** **-** Database of herpetological data with 98 species. - Combines expert and amateur contributions. - Over 544,000 data points from varied collection methods.		coordination and operation of monitoring programs.
Modelling Types of models Predictors Estimation & uncertainty Software	Range tool was a modelling tool available on Eionet portal for ArcGIS in the reporting time frame 2013-2018 for reporting on Art.17 Habitat Directive No modeling to predict species distribution across areas not covered by data No open code or user-friendly	SDM like Maximum Enthropy (MaxEnt) could better capture distribution dynamics, leading to better reporting on Art.17 (HD) (Sousa-Silva et al., 2014) Use of citizen science data to estimate population trends (e.g., Kery et al., 2010; van Strien et al., 2013)	Mapping of important herpetofauna areas at EU and national scales Improved access to maps on waterbodies

	software	Bayesian dynamic occupancy or abundance models (e.g., Falaschi et al. 2021, 2022) implemented through R and nimble (de Valpine et al., 2017)	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- National Amphibian and Reptile Monitoring Programme - https://monitoring.arc-trust.org
- National Amphibian Survey - https://amphibian-survey.arc-trust.org
- Monitoring the Effectiveness of Habitat Conservation in Switzerland (www.biotopschutz.wsl.ch)
- Biggs et al. 2015. USing eDNA to develop a national citizen science-based monitoring programme for the great crested newt (*Triturus cristatus*). *Biological Conservation*, 183, 19-28
- Cruickshank, S. S., Bergamini, A., & Schmidt, B. R. (2021). Estimation of breeding probability can make monitoring data more revealing: a case study of amphibians. *Ecological Applications*, *31*(6), 1–12. https://doi.org/10.1002/eap.2357
- de Valpine, P., Turek, D., Paciorek, C. J., Anderson-Bergman, C., Lang, D. T., & Bodik, R. (2017). Programming With Models: Writing Statistical
- Algorithms for General Model Structures With NIMBLE. Journal of Computational and Graphical Statistics, 26(2), 403–413. https://doi.org/10.1080/10618600.2016.1172487
- Falaschi, M., Giachello, S., Lo Parrino, E., Muraro, M., Manenti, R., & Ficetola, G. F. (2021). Long-term drivers of persistence and colonization dynamics in spatially structured amphibian populations. Conservation Biology, 35(5), 1530–1539. https://doi.org/10.1111/cobi.13686
- Falaschi, M., Muraro, M., Gibertini, C., Delle Monache, D., Lo Parrino, E., Faraci, F., … Ficetola, G. F. (2022). Explaining declines of newt abundance in northern Italy. Freshwater Biology, 67(7), 1174–1187. https://doi.org/10.1111/FWB.13909
- Ficetola, G. F., Romano, A., Salvidio, S., & Sindaco, R. (2018). Optimizing monitoring schemes to detect trends in abundance over broad scales. Animal Conservation, 21(3), 221–231. https://doi.org/10.1111/acv.12356

- Kéry, M., Royle, J. A., Schmid, H., Schaub, M., Volet, B., Häfliger, G., & Zbinden, N. (2010). Site-occupancy distribution modeling to correct population-trend estimates derived from opportunistic observations. Conservation Biology, 24(5), 1388–1397. https://doi.org/10.1111/j.1523-1739.2010.01479.x
- Sousa-Silva, R, Paulo Alves, João Honrado, Angela Lomba. 2014. Improving the assessment and reporting on rare and endangered species through species distribution models. Global Ecology and Conservation, Volume 2, Pages 226-237.https://doi.org/10.1016/j.gecco.2014.09.011. https://www.sciencedirect.com/science/article/pii/S235198941400047X
- Spanish Herpetological Society - https://herpetologica.es
- Santini, L., Isaac, N. J. B., & Ficetola, G. F. (n.d.). TetraDENSITY: A database of population density estimates in terrestrial vertebrates. *Global Ecology and Biogeography*, *0*(0). doi: 10.1111/geb.12756
- Svenningsen, A. K. N., Pertoldi, C., & Bruhn, D. (2022). EDNA Metabarcoding Benchmarked towards Conventional Survey Methods in
- Amphibian Monitoring. *Animals*, *12*(6), 763. doi: 10.3390/ani12060763
- https://freshwaterhabitats.org.uk/projects/pondnet/
- OpenHerpMaps http://openherpmaps.ro/
- Van Strien, A. J., Van Swaay, C. A. M., & Termaat, T. (2013). Opportunistic citizen science data of animal species produce reliable estimates of distribution trends if analysed with occupancy models. Journal of Applied Ecology, 50(6), 1450–1458. https://doi.org/10.1111/1365-2664.12158
- http://lashf.org/popamphibien-2/ Les protocoles POPAmphibien : des outils pour la surveillance nationale des populations d’amphibiens
- https://ponderful.eu/

Species distributions of freshwater mammals			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Reporting on Art.17 (HD)** **I**ntegration of information on key freshwater mammals such as *Lutra lutra*, *Galemys pyrenaicus*, among others. It's not perfect, but it's potentially useful. **National initiatives** **Norway and Sweden Citizen Science Program** The citizen science presence data from citizen science reporting systems of Norway and Sweden are good examples (i.e. https://www.artportalen.se/)	**eDNA tools** Monitoring of aquatic and terrestrial mammals can be made using eDNA tools (metabarcoding, metagenomics), including Nanopore sequencing for rapid detection (Egeter et al., 2022). DNA/RNA probes to detect aquatic and terrestrial mammals in real-time (e.g., Seeber et al. 2019). Freshwater mammals eDNA metabarcoding,	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Second Atlas of European Mammals (EMMA2)** - No structured monitoring - Presence data compiled from publications, atlases, and opportunistic occurrence data. - Data aggregated at 50x50 km - Data is submitted via email in CSV format following Darwin Core		Assess the need for a European coordinated effort at sampling the distribution of freshwater mammals in the CCM2 sampling units.

Modelling Types of models Predictors Estimation & uncertainty Software		**Geostatistical modeling framework** Freshwater mammals inhabiting stream networks should be modelled using geostatistical modeling frameworks that account for the hierarchical dendritic structure of rivers. The only example that I'm aware of is the work of Quaglietta et al. 2018 on *Galemys pyrenaicus*	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Metadata standards are defined (Darwin Core)

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Quaglietta, L., Paupério, J., Martins, F. M. S., Alves, P. C., & Beja, P. (2018). Recent range contractions in the globally threatened Pyrenean desman highlight the importance of stream headwater refugia. *Animal Conservation*, *21*(6), 515-525.https://doi.org/10.1111/acv.12422
- Egeter, B., Veríssimo, J., Lopes-Lima, M., Chaves, C., Pinto, J., Riccardi, N., ... & Fonseca, N. A. (2022). Speeding up the detection of invasive bivalve species using environmental DNA: A Nanopore and Illumina sequencing comparison. *Molecular Ecology Resources*, *22*(6), 2232-2247.
- Seeber, P. A., McEwen, G. K., Löber, U., Förster, D. W., East, M. L., Melzheimer, J., & Greenwood, A. D. (2019). Terrestrial mammal surveillance using hybridization capture of environmental DNA from African waterholes. *Molecular ecology resources*, *19*(6), 1486-1496.
- Vogt, J. V., Soille, P., Jager, A. D., Rimavičiūtė, E., Mehl, W., Haastrup, P., … Bamps, C. (2007). Developing a pan-European Database of Drainage Networks and Catchment Boundaries from a 100 Metre DEM. Proceedings 10th AGILE Int. Conference on Geographic Information Science, 8–11.
- Jamwal, P. S., Bruno, A., Galimberti, A., Magnani, D., Krupa, H., Casiraghi, M., & Loy, A. (2021). First assessment of eDNA-based detection approach to monitor the presence of Eurasian otter in southern Italy. *Hystrix, the Italian Journal of Mammalogy*, *32*(2).

- Cianfrani, C., Le Lay, G., Hirzel, A. H., & Loy, A. (2010). Do habitat suitability models reliably predict the recovery areas of threatened species?. *Journal of Applied Ecology*, *47*(2), 421-430.
- Russo, L. F., Fernández-González, Á., Penteriani, V., Delgado, M. D. M., Palazón, S., Loy, A., & Di Febbraro, M. (2023). The Different Fate of the Pyrenean Desman (Galemys pyrenaicus) and the Eurasian Otter (Lutra lutra) under Climate and Land Use Changes. *Animals*, *13*(2), 274.

Software

- SSN: Spatial Modeling on Stream Networks - https://cran.r-project.org/web/packages/SSN/SSN.pdf
- SSN & Stars: Tools for Spatial Statistical Modeling in Stream Networks https://www.fs.usda.gov/rm/boise/AWAE/projects/SpatialStreamNetworks.shtml

Links

- Rivers and Catchments of Europe - Catchment Characterisation Model (CCM) - https://data.jrc.ec.europa.eu/dataset/fe1878e8-7541-4c66-8453-afdae7469221

Species distributions of freshwater invertebrates			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** - Pollution-sensitive benthic invertebrates in rivers, lakes, transitional and coastal waters - Composition and abundance of pollution-sensitive benthic invertebrates - biased to lakes and rivers **Dragonfly** monitoring well-developed in many countries **Monitoring of the phenology** of different species of freshwater invertebrates **eLTER** Use the data and information from Research Infrastructures, such as eLTER. **<u>Regional initiatives</u>** **South Tyrol (Italy) monitoring of benthic macroinvertebrates**	**CONFREMU** Cost Action on freshwater bivalves (https://www.cost.eu/actions/CA18239/) **IberRios:The Iberian River Observatory** (https://tanogutierrezcanovas.weebly.com/iberrios.html) **DNAquaPlan** (New EU horizon) **PONDERFUL:** Macroinvertebrates sampling in 8 countries (30 ponds in each) by using 25x18cm conical sampling net with a mesh size 500 µm. Sampling 20 sweeps of 1 m in each pond. Sweep-net sampling is conducted by striking the net in the open water area, among the submerged macrophytes, floating-leaved macrophytes, and in the littoral vegetation (sampling the different mesohabitats). Samples are fixated at 70% EtOH.	Expand the taxonomic coverage to dragonflies and bivalves. All species need to be included, not just HD species. Develop structured freshwater biodiversity monitoring across Europe Include Coleoptera for the pollution-sensitive species (and maybe other selected species) @WFD sampling: is biased towards impacted sites; for proper monitoring, the sampling of reference sites would be needed, and more sites need to be included (e.g. in <10km2 catchments and sources) WFD focuses on large lakes and rivers, but small and temporary waters are completely missing and harbor most of the freshwater biodiversity.

	Monitoring of benthic macroinvertebrates related to stream type categories (origin, elevation, discharge, geology) and substrate composition (BMS) (https://doi.org/10.1016/j.dib.2022.108648) **Swedish Malaise Trap Project** (Swedish Museum of Natural History / Swedish Biodiversity Institute (SBI)) **LTER (IT25)** Long-term macroinvertebrate monitoring in the glacier-fed Saldur stream: monthly samplings from April to September started in 2010	**EUROPONDS**: Welcome to our Webpage - europonds website! (jimdofree.com) **FLOW- germany citizens science** Citizen Science project to complement WFD sampling https://www.flow-projekt.de/	Monitoring of deep rivers and lakes Long-term assessments that also include hydrological variables Proper invertebrate monitoring needs to include not only HD species or so-called “pollution sensitive” species, and it needs a proper taxonomic backbone; freshwater taxonomy on GBIF, for example, does not represent state-of-the-art WFD sampling is biased towards spring sampling and taxa that can be properly identified in spring samples. Summer/Autumn samples would provide supplementary info on species/taxa with late emergence. Concrete and specific habitat preferences and suitabilities need to be identified to better target general river and lake improvement initiatives towards the taxa that actually have declining population sizes and numbers.

			Use of internet Ecology and Culturomics more often
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**WFD - Water Information System for Europe - Biology data (WISE-2, EEA)** (Pollution-sensitive benthic invertebrates) - Standardized data collection for benthic invertebrates EQRs (but not including any species data) - Excel templates for data entry -Standardised online data entry for WFD data (including protocols and metadata) are e.g. provided in Austria and Germany and could be adapted to a European level **IUCN European Red Lists of Dragonflies** (using a combination of data analysis and expert opinion)	**New version of Freshwater Biodiversity Data Portal** (http://www.freshwaterplatform.eu) allows easy data input by data providers and can be equipped with API to e.g. feed into EEA databases; GBIF connection is included; metadata are stored; it will have powerful visualization tools	Harmonization of identification (and taxonomic) level is needed; for EPT species level is absolutely needed WFD monitoring includes the collection of a lot of invertebrate species/taxa; it is absolutely necessary that these taxa are also collected on EU level and feed into one (interoperable) database; with that we would have a good starting point for biodiversity monitoring Assessment of local/traditional ecological knowledge Easy to use app for transect counts (e.g. amphibians,

	Atlas of the European dragonflies and damselflies. - Data aggregate at 50x50 km. - Data source: platforms that contain data on species biodiversity (e.g. GBIF, WORMS), on climate variables (e.g. worldclim, chelsa, GEBCO, google earth engine, etc) - Data available at https://doi.org/10.1007/s10750-017-3495-6 **Distribution Atlas of European Trichoptera** **European Red List of Odonata** Data on distribution (presence/absence) of dragonflies and damselflies at the European scale (new European Red List of Odonata, in prep) **Unionida** Data on distribution (presence/absence) of freshwater mussels (order Unionida) at the European scale		dragonflies) during short time interval that can be used everywhere in Europe No raw data available Follow data publication standards Darwin core files to record the occurrences of species
Modelling Types of models	**Occupancy modeling** - Some attempts to calculate European trends of dragonflies	**SDM and sp live cycle** Joint species distribution modelling for certain species that	Optimize SDM-modeling, there is room for improvement with more and more data becoming

Predictors Estimation & uncertainty Software	are made using list-length and occupancy modeling. - Climate drivers (temperature, pluviosity, than others) **Changes in species composition** Assessment of long-term changes in species composition, abundance, and population structure of freshwater mussels (**SDM** Correlative and mechanistic species distribution models with Maxent, biomod2 in R **Structural Equation Modelling** Structural Equation Modelling to assess pond macroinvertebrates' importance in the trophic cascade **Diversity indices and/or abundances** Correlations between environmental variables and diversity indices and/or abundances (GLM, LMM, GAM models in R)	depend on biotic interactions to complete their life-cycle. For exemple freshwater mussels need suitable fish hosts to complete the life cycle. So, modelling exercises need to account for these biotic interactions besides the usual environmental factors (Silva et al., in press). **Species Flying Propensity** (Sarremejane et al., 2017; Peredo Arce et al. 2021)	available, especially for less sampled regions Future modeling exercises (SDMs, for example) need to more often include biotic interactions (see for example Silva et al. 2022). At least for species such as freshwater mussels or similar that rely on a host. Include the importance of connectivity - at least for future predictions taking into account climate change, for example Moving from distribution to abundance as distribution does not reflect what is going on accurately, it misses the loss of biomass and is not sensitive enough when used on a large scale such as a catchment or lake. If a species is gone you're too late. This needs to be a combination of counts and something like N-mixture abundance models. Mapping of future refuge areas in relation to climate change and other human disturbances

			Improve the spatial and temporal resolution of environmental, climate, and satellite variables in polar and subpolar zones Since rivers are linear systems do not make much sense to use 10 x10 km grids or something like that. A possible approach is to pass the sampling points to level 10 (or other ot be decided) in the Hydrobasins. Anyway, in the different taxonomic groups we may use different levels … see Silva et al. (2022)

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- No raw data available
- For dragonflies data is scattered over countries but many have collaborated on projects such as the IUCN EU Red-List.
- Follow data publication standards
- Darwin core files to record the occurrences of species

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- Encourage one specific database that can be adopted by journals (to make data available) as well as EU organisations like the EEA for making raw (EQR) data available. GBIF would be an option - willing to adjust/design a template for e.g. species abundance incl methodology.
- Currently EEA centralizes (CDR - Central Data Repository) the EQRs
- Freshwater Information Platform (http://www.freshwaterplatform.eu) (currently updated)
- Species occurrence data stemming form WFD monitoring should be made available
- Funding of existing infrastructures to be maintained after projects; or option to host these infrastructures on European infrastructures
- Pangaea data publisher (generally open data portal for archiving, publishing and re-usage of data): https://www.pangaea.de/

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Cost Action on conservation of freshwater mussels: https://www.cost.eu/actions/CA18239/
- Karlsson, Dave & Forshage, Mattias & Holston, Kevin & Ronquist, Fredrik. (2020). The data of the Swedish Malaise Trap Project, a countrywide inventory of Sweden's insect fauna. Biodiversity Data Journal. 8. 10.3897/BDJ.8.e56286.
- Kalkman V. J., Boudot J.-P., Bernard R., De Knijf G., Suhling F. & Termaat T. 2018. Diversity and conservation of European dragonflies and damselflies (Odonata). *Hydrobiologia* 811: 269-282. https://doi.org/10.1007/s10750-017-3495-6:
- Termaat, T., van Strien, A. J., van Grunsven, R. H., De Knijf, G., Bjelke, U., Burbach, K., ... & WallisDeVries, M. F. (2019). Distribution trends of European dragonflies under climate change. *Diversity and Distributions*, *25*(6), 936-950.
- Kalkman, V. J., Boudot, J. P., Futahashi, R., Abbott, J. C., Bota-Sierra, C. A., Guralnick, R., ... & Belitz, M. W. (2022). Diversity of Palaearctic Dragonflies and Damselflies (Odonata). *Diversity*, *14*(11), 966. (on SDM for dragonflies)
- Jarić, I., Correia, R. A., Brook, B. W., Buettel, J. C., Courchamp, F., Di Minin, E., ... & Roll, U. (2020). iEcology: harnessing large online resources to generate ecological insights. *Trends in Ecology & Evolution*, *35*(7), 630-639.
- Jarić, I., Roll, U., Arlinghaus, R., Belmaker, J., Chen, Y., China, V., ... & Correia, R. A. (2020). Expanding conservation culturomics and iEcology from terrestrial to aquatic realms. *PLoS Biology*, *18*(10), e3000935.
- Schletterer Martin, Steven J. Weiss, Vyacheslav V. Kuzovlev, Simon Vitecek, Florian Borgwardt, Wolfram Graf (2021): The rare and enigmatic mayfly Prosopistoma pennigerum (Müller, 1785): Habitat characteristics, recent records from the Volga (Russia) and Vjosa (Albania) rivers, and a proposal for flagship species status. Aquatic Conservation 31: 3636-3643, https://doi.org/10.1002/aqc.3748
- Silva J., Gonçalves D., Lopes-Lima M., Anastácio P., Banha F., Frimpong E., Gama M., Miranda R., Reis J., Filipe A.F. & Sousa R. (2022) - Predicting climatic threats to a critically endangered freshwater mussel in Europe: the need to account for fish hosts. Freshwater Biology 67, 842-856.
- Silva J., Gonçalves D., Garcia-Raventós A., Lopes-Lima M., Varandas S., Froufe E., Teixeira A., Hui F.K.C., Filipe A.F. & Sousa R. (in press) - Joint Species Distribution Models unveil co-occurrences between freshwater mussels and their fish hosts. Journal of Biogeography.
- Sousa, R., Nogueira, J. G., Miranda, F., & Teixeira, A. (2020). Time travelling through local ecological knowledge regarding an endangered species. *Science of the Total Environment*, *739*, 140047.
- von Gönner, J., Bowler, D. E., Gröning, J., Klauer, A. K., Liess, M., Neuer, L., & Bonn, A. (2023). Citizen science for assessing pesticide impacts in agricultural streams. Science of the Total Environment, 857, 159607. https://doi.org/10.1016/j.scitotenv.2022.159607
- Hilpold A., Anderle M., Guariento E., Marsoner T., Mina M., Paniccia C., Plunger J., Rigo F., Rüdisser J., Scotti A., Seeber J., Steinwandter M., Stifter S., Strobl J., Suarez-Muñoz M., Vanek M., Bottarin R., Tappeiner U., Handbook – Biodiversity Monitoring South Tyrol, Bozen/Bolzano, Italy: Eurac Research, 2023, https://doi.org/10.57749/2qm9-fq40

Species distributions of freshwater macrophytes			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** **-** WISE-2 provides access to Ecological Quality Ratios (EQRs) but lacks the availability of raw biological and environmental data, hindering the application of Water Framework Directive (WFD) data for broader biodiversity research. **-** Surveys on the composition and abundance of macrophytes are conducted in lakes for WFD and Habitats Directive compliance, with some EU countries extending surveys to river macrophytes. **National Initiatives** **Norway** macrophyte analysis to assess hydromorphological impacts, developing a water level index. **Norway and Sweden** Citizen science platforms in (e.g., Artportalen) provide valuable species presence data, demonstrating effective public	**eDNA Pilot Studies - DNA-AquaNet**: Pilot studies focus on eDNA for detecting rare, small, and invasive species like Elodea under the **DNA-AquaNet initiative (NIVA).** A new Horizon EU project, DNAquaplan, is dedicated to advancing aquatic DNA research and applications. **Species Traits - NIVA:** Exploration of biological species traits for aquatic vascular plants, distinct from ecological traits, with NIVA utilising a European database (Willby et al. 2000, Freshwater Biology). **Dated Phylogeny for Aquatic Vascular Plants - NIVA**: Developing a dated phylogeny for aquatic vascular plants in North West Europe through an ensemble of molecular phylogenies and fossil records (Durka W. & Michalski S.G. 2012, Ecology).	Expand the geographical coverage of data sampling to more countries Make citizen science data trustable to report to directives Historical changes using lake sediment core using macrofossils, pollen and e-DNA(complementary list of species in some cases) e.g. Parducci L., et al. (2019) Frontiers in Ecology and Evolution, 7. Make use of optical satellite data to better resolve some species of floating invasive plants Broad range of models and R workflows at their disposal, as shown in Norberg's 2019 review of 33 SDMs, but there's a need for larger datasets to enhance analyses, particularly for studying phylogenetic diversity across multiple species and locations.

	involvement in biodiversity monitoring.	Remote Sensing for Invasive Plant Species: Utilisation of remote sensing for emergent (reedbeds) and floating invasive plants, with drones required for precise species identification. **IberRios - Iberian River Observatory:** IberRios focuses on macrophyte diversity, especially bryophytes, macroalgae, pteridophytes, and vascular plants, following a slightly modified version of the WFD protocol and conducting annual summer sampling since 2022. **Remote Sensing and In Situ Sampling - Doñana LTSER Platform:** Remote sensing to identify spatiotemporal signatures of dominant helophytes and macrophytes, validated through in situ sampling as part of the Doñana LTSER Platform.	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation	**EQR monitoring WFD:** - Standardized data collection for macrophyte EQRs - still need harmonisation of raw data such as species list (taxonomy), spatial and environmental variables, etc	**EuropaBON WP5.3** data harmonisation for Norway, Sweden and Finland using lake data collected by national organisations	To refine biodiversity studies using GBIF and atlas data, better evaluation of sampling efforts is necessary, with a potential to link specific surveys to larger

Integration nodes (national or EU) Automated data streams	- Excel templates for data entry - Water Information System for Europe - Biology data (WISE-2, EEA) (macrophytes in lakes)		geographical grids, as indicated by NIVA. Developing terms of references and workflows Need time to curate past data (thousands or surveys in grey literature across Europe), some need geographical coordinates (only include a map or location description for now).
Modelling Types of models Predictors Estimation & uncertainty Software	**Niche Modeling and Uncertainty Analysis:** Utilization of Generalized Linear Models (GLM) to determine species' ecological optimum and realized niche breadth, incorporating uncertainties into environmental indices (Demars & Tremolieres 2009; Demars et al 2012). **Biological Trait Analyses:** Conducting multivariate data analyses integrating species traits with environmental and spatial data to explore biological traits over ecological preferences, enhancing causality confidence and predictive capability (RLQ	The ecological uncertainty (species optimum and tolerance) derived from GLM could easily be propagated to EQRs using simple Monte Carlo simulations. Nice graphic (mapping) interface for GDM in R (Mokany 2022 Global Ecology & Biogeography) - Could try this in EuropaBON WP5.3 if time allow	From the perspective of an applied ecologist, there are a lot of models (see Norberg 2019 Ecological Monographs for a comparison of 33 SDMs), and existing workflows (see books cited on the left with applications in R) catering for a wide range of data type, it remains to harvest larger datasets on which data analyses would also be more meaningful, e.g. a wide range of species in many sites are necessary to study phylogenetic diversity Biodiversity work using GBIF and atlas data, needs to better assess sampling effort, and opportunity to

	Doledec 1996; Legendre et al 1997; Lavorel et al 1998). **Temporal Community Change Analysis:** Analyzing temporal dynamics in plant communities in aquatic environments to understand species turnover and community autocorrelation, and applying joint species distribution models (Baselga 2012; Demars et al 2014; Garcia-Giron 2021). **Species Distribution Models (SDMs):** Implementing individual SDMs with uncertainty estimation through Generalized Additive Models (GAM), following established workflows in R for habitat suitability and distribution modeling (Heikkinen et al 2009; Guisan et al 2017; Ovaskainen 2020).		link point surveys (lake, rivers, …) to grid square (NIVA, maybe Enhancement of remote sensing classification techniques to map aquatic vegetation avoiding spectral confusion with water characteristics (water depth, turbidity, colour, etc.) Continue developing approaches to fill in gaps in species traits (imputation methods) so we can run phylogenetic analyses Biodiversity work using GBIF and atlas data, need to better assess sampling effort, and opportunity to link point surveys (lake, rivers, …) to grid square (NIVA, may be EuropaBON WP5.3 if time allow)

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Major issue is to make data open access and develop European / Global databases

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- Data storage would not take much space, need to develop pipelines for current data harvest across countries (raw data, not just EQRs)
- Bayesian models applied to large datasets to propagate uncertainties will require cloud services

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Sources of data are everywhere: data stream from botanical societies (involving citizen), natural history museum, conservation agencies, environmental agencies, institute, universities, IUCN Freshwater Plant Specialist Group IUCN SSC Freshwater Plant Specialist Group | IUCN
- https://ponderful.eu/

Species distributions of invasive alien freshwater taxa of European concern			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** **Norway and Sweden** - Presence data from citizen science reporting systems for Norway and Sweden (https://www.artportalen.se/). **Portugal and Spain** - **Aquatic invasive species in Iberia** https://lifeinvasaqua.com/pt-pt/ -	**eDNA Tools** - Utilization of environmental DNA (eDNA) techniques such as metabarcoding and metagenomics, complemented by Nanopore sequencing for swift detection of invasive species - Implementation of DNA/RNA probes for the real-time identification of key aquatic invasive species (Seeber et al. 2019). **Citizen Science and Remote Sensing** The European Citizen Science application (EASIN) enables public reporting of invasive aquatic species sightings, supporting validation efforts for SDM and remote sensing	Build an structured monitoring system Consistent monitoring of aquatic invasives across Europe, using standardised sampling designs and data collection methods. Make citizen science data trustable to report to directives Long-term assessments Use of internet Ecology and Culturomics more often
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata	**EASIN (European Alien Species Information Network):** **- Data Aggregation:** EASIN aggregates data at a spatial resolution of 10 x 10 km or by	**Biotope vulnerability workflow** LifeWatch ERIC Internal Joint Initiative. The incidence version of the workflow uses data cube analysis to estimate the incidence	For rivers and streams, data should be aggregated considering stream segments or small catchments, rather than grid cells (10x10km, or other). A useful

Way of data aggregation Integration nodes (national or EU) Automated data streams	river basin for comprehensive coverage. **- Data Broker System:** Utilizes a sophisticated system to collect species occurrences and related data (date, source) from various sources, integrating them into a normalized database for streamlined access. **- NOTSYS Platform:** Serves as the official platform for EU Member States to fulfill their notification obligations under Regulation 1143/2014 on Invasive Alien Species (IAS), facilitating communication with the Commission and other Member States. **- Capacity Building:** EASIN enhances surveillance and monitoring capabilities by offering support for the development of surveillance systems, citizen science initiatives, and educational programs for teachers, detailed at https://easin.jrc.ec.europa.eu/easin. **IUCN** - ISSG Invasive Species Specialist Group	of alien species on biotopes. The Virtual Research Environment can be accessed at: https://www.lifewatch.eu/internal-joint-initiative/workflows/ **Trait database** Biological and ecological trait databases already available for many species (see www.freshwaterecology.info) **Non-Native Bivalve Species Distribution Data Compilation:** - An organized effort under the Cost Action on freshwater bivalves to compile distribution data about non-native bivalve species (https://www.cost.eu/actions/CA18239/).	basis for aggregation is provided for instance by the CCM2 model (Vogt et al., 2007) Same rationale as the above comment: Since rivers are linear systems do not make much sense to use 10 x10 km grids or something like that. A possible approach is to pass the sampling points to level 10 (or other ot be decided) in the Hydrobasins. Assessment of loca//traditional ecological knowledge Harmonization of management actions Database on management initiatives (including failure attempts). Some data exist but need to be extended. In fact many information is available in grey literature and need to be resurrect Improve communication and coordination among administrative level

	- GISD Global Invasive Species Database - EICAT standards classification invasive species **DAISIE GBIF** - Delivering Alien Invasive Species Inventories for Europe. **GRIIS** - Global Register of Introduced and Invasive Species		
Modelling Types of models Predictors Estimation & uncertainty Software	**Geostatistical Modeling and Spatial Analysis of Invasive Species in Stream Networks** - Studies by Filipe et al. (2017) and Mota-Ferreira & Beja (2020) explore the geostatistical modeling of invasive species distributions across dendritic stream networks. - The SSN (Spatial Modeling on Stream Networks) framework is employed for detailed spatial analysis within these aquatic ecosystems.	**EASIN** Test Habitat suitability model for *Elodea nuttallii* using **MaxENT** algorithm	Future spatial modeling of invasives in rivers need to consider the dendritic hierarchical structure of stream networks, rather than using SDMs borrowed from terrestrial environments. Ecological and economic Impact mapping based on distribution, abundance/biomass and functional traits Vulnerability mapping using predictive modeling Rapid assessment surveys linked with citizen science initiatives and key stakeholders The templates for data products should ideally use non-proprietary

			formats, to cope with the FAIR principles.

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- AS GeoDatabase is open access

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- AS GeoDatabase (the central repository of EASIN curated by the Joint Research Centre of the European Commission)

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Egeter, B., Veríssimo, J., Lopes-Lima, M., Chaves, C., Pinto, J., Riccardi, N., ... & Fonseca, N. A. (2022). Speeding up the detection of invasive bivalve species using environmental DNA: A Nanopore and Illumina sequencing comparison. *Molecular Ecology Resources*, *22*(6), 2232-2247.
- Mota-Ferreira, M., & Beja, P. (2020). Combining geostatistical and biotic interaction model to predict amphibian refuges under crayfish invasion across dendritic stream networks. *Diversity and Distributions*, *26*(6), 699-714.
- Filipe, A. F., Quaglietta, L., Ferreira, M., Magalhães, M. F., & Beja, P. (2017). Geostatistical distribution modelling of two invasive crayfish across dendritic stream networks. *Biological Invasions*, 19, 1– 14.
- Seeber, P. A., McEwen, G. K., Löber, U., Förster, D. W., East, M. L., Melzheimer, J., & Greenwood, A. D. (2019). Terrestrial mammal surveillance using hybridization capture of environmental DNA from African waterholes. *Molecular ecology resources*, *19*(6), 1486-1496.
- Vogt, J. V., Soille, P., Jager, A. D., Rimavičiūtė, E., Mehl, W., Haastrup, P., … Bamps, C. (2007). Developing a pan-European Database of Drainage Networks and Catchment Boundaries from a 100 Metre DEM. Proceedings 10th AGILE Int. Conference on Geographic Information Science, 8–11.
- BROCHURE IAS OF UNION CONCERN 2022. Circabc (europa.eu)
- Jarić, I., Bellard, C., Correia, R., Courchamp, F., Douda, K., Essl, F., ... & Roll, U. (2021). Invasion culturomics and iEcology. *Conservation Biology*, *35*(2), 447-451.

Software

- SSN: Spatial Modeling on Stream Networks - https://cran.r-project.org/web/packages/SSN/SSN.pdf
- SSN & Stars: Tools for Spatial Statistical Modeling in Stream Networks https://www.fs.usda.gov/rm/boise/AWAE/projects/SpatialStreamNetworks.shtml

Links

- Rivers and Catchments of Europe - Catchment Characterisation Model (CCM) - https://data.jrc.ec.europa.eu/dataset/fe1878e8-7541-4c66-8453-afdae7469221
- LifeWatch ERIC Internal Joint Initiative: https://www.lifewatch.eu/internal-joint-initiative/

Phenology of migration of wetland birds			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EuroBirdPortal (EBP)** Standardised protocols (complete lists) and opportunistic data EBP data collected through mobile apps in near-real time **EURING** The data consist of bird ringings (when a ring was first added to a bird), recaptures (recaptures of ringed birds by ringers) and recoveries/resighting (ringed birds reported by the public.	Possibly weather radar can be used to identify nights and areas with high migratory fluxes (see aerial biomass EBV) Nocturnal migration (BIOACOUSTICS) https://trektellen.org/static/doc/Protocol_for_standardised_nocturnal_flight_call_monitoring_v01.pdf **Nature-FIRST** project: Data collection application for training areas for ecosystem classification (Sensing Clues Wildlife Tool Suite). To be tested in 5 field sites (Bulgaria, Romania, Spain and Ukraine). Digital twin for Crane migration was created by WUR and Sensing Clues Foundation researchers (Crane radar). It is integrating data from Waarneming.nl.	Expand taxonomic coverage Expand geographical coverage Combining radar data (EBV aerial biomass) with species counts and atmospheric data
Data integration Standardisation & harmonisation	**EuroBirdPortal (EBP)**		There is still limited integration across the different possible sources of information.

Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	Aggregated observations at weekly at 30 x 30 km and 10 x10 km EBP data is automatically transferred from the app to the centralised EBP on a daily basis. **EURING** EURING Exchange Code standard Data centralised at EURING databank **Movebank** (www.movebank.org) - database with animal tracking data (incl. licenses, DOIs) - data entry standards - standardised data model (Kays et al. 2022)		EBP data is available upon request
Modelling Types of models Predictors Estimation & uncertainty Software		Eurasian African Migration Atlas for 300 bird species are mapped and analysed drawing on data gathered by EURING. Migration seasons of hunted species, binomial conditional autoregressive (CAR) mixed models	

		Combining radar data with atmospheric data (Doren et al. 2018) **Nature-FIRST** project: Data collection application for training areas for ecosystem classification (Sensing Clues Wildlife Tool Suite). To be tested in 5 field sites (Bulgaria, Romania, Spain and Ukraine). Digital twin for Crane migration was created by WUR and Sensing Clues Foundation researchers (Crane radar). It is integrating data from Waarneming.nl.	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- EBP data is available upon request

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- Central repository curated by the European Bird Census Council

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Kays, R., Davidson, S.C., Berger, M., Bohrer, G., Fiedler, W., …,Wikelski, M. 2022. The Movebank system for studying global animal movement and demography. Methods in Ecology and Evolution 13: 2, 419-431.
- Doren, B. M. V., & Horton, K. G. (2018). A continental system for forecasting bird migration. *Science*, *361*(6407), 1115–1118.
- Nature-FIRST project: Forensic Intelligence and Remote Sensing Technologies for nature conservation. CORDIS URL. (Crane radar website)

Ecological Quality Ratio (EQR) of phytoplankton in lakes			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** - Conduct integrated sampling in the epilimnion/euphotic zone of various lakes, analysing samples under an inverted microscope to determine species and their abundance (biovolume). - Ensure sampling covers a diverse range of lake types, geographical regions, and impact levels, aligning with the WFD-CIS guidance and implemented by National Environmental Agencies. - Compile a comprehensive list of phytoplankton species, noting the biovolume of each in samples. - Emphasize taxonomic training and proficiency testing to ensure standardised approaches across different lake surveys. - Implement two distinct monitoring programs: Surveillance and Operational monitoring. <u>Surveillance Monitoring</u>:		Expand the geographical coverage of data sampling to more water bodies. Expand the number of monitoring sites in large lakes to include also the near-shore areas where blooms can develop in otherwise pristine lakes.. Increase the sampling frequency in many countries from 1-2 samples per year to monthly during summer (June-September). Comparison of species lists derived from conventional microscopy to e-DNA. Comparison of total biovolume from microscopy to remote sensing, drones and sensors. Training of more taxonomists is needed.

	- Aims for representativeness in river and lake types, geographic distribution, and status classes. - Frequency is relatively low (1-2 times a year, every six years). - Includes all biological quality elements. <u>Operational Monitoring:</u> - Targets water bodies with moderate to poor ecological status. - Focuses on the most sensitive biological quality element under human pressure. - Conducted more frequently than surveillance monitoring for trend analysis and assessing mitigation impacts.		The lakes selected for reporting in each country should be more representative to cover all lake types and all geographic regions in each country.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EQR monitoring WFD:** - Standardization in Phytoplankton Data Collection: Development of standardised sampling and analysis procedures for phytoplankton in lakes, based on CEN standards. Harmonisation of taxonomy across different data sets. - Water Information System for Europe (WISE-2) Workflow: The European Environment Agency (EEA) organises a workflow for		Organise more dialogue meetings with data providers to convince more countries to report their EQR data. Specific meetings are needed with France, Germany and Finland to find solutions to problems preventing them from reporting. Further meetings with the countries are needed to discuss

	State-of-Environment reporting, requiring annual EQRs data to assess deviation from pristine conditions. Development of various tools for WISE-2 reporting, including a data dictionary, common data repository (CDR), Reportnet, an online helpdesk, and annual webinars. Application of similar processes for all EQR EBVs. - Data Entry and Visualization: Utilization of Excel templates for data entry. Creation of interactive dashboards to visualise the collected data. **eLTER-RI** - eLTER-RI focuses on monitoring phytoplankton abundance and composition at selected freshwater sites across Europe. - Creation of guidelines for data sharing and metadata formats, including information on sites, sampling stations, and sensors, available at https://deims.org. - Standardization of raw data variable names using specific vocabularies like SKOS. - Collected data are made publicly available in repositories such as Zenodo and GBIF.		options for getting access to the underlying species lists. (this applies to all the EQR EBVs) Webinars with data providers are held once per year to solve technical problems with reporting.

Modelling Types of models Predictors Estimation & uncertainty Software	**R script(s)** for analyze raw data **LUPLES** method to relate Land Uses to Pressure Level, then to Ecological Status (Morant et al, 2021, and Restore4Cs Horizon project). Can be used to relate pressure levels with impacts detected by any BQE used in the WFD	**Restore4Cs Project** (HORIZON-CL5-2021-D1-01-08) ETC-BE task is ongoing to link the EQR data to abiotic stressors and land use. This will be based on ECRINS.	Spatially explicit models are needed for the estimation of metrics values for waterbodies not covered in the monitoring. This valid for all BQEs used in the WFD.
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): • These exists already: WISE-2, CDR (Central data repository), Interactive dashboards for vizualisations.			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • WISE-2 Biology data: reporting system, data dictionary, other reporting guidance https://cdr.eionet.europa.eu/help/WISE_SoE/wise2 • Quality-checked WISE-2 Biology data published in EEA's Waterbase: https://www.eea.europa.eu/data-and-maps/data/waterbase-biology-1 • WISE-2 Biology statistics tables with further post-processing of data (e.g. spatial aggregation and gap-filling of missing years by interpolation), published in Discodata: https://discomap.eea.europa.eu/App/DiscodataViewer/?fqn=[WISE_Indicators].[v3r2].[BiologyData_Indicator] • Moe, S.J., S. Mentzel, S. A. Welch and A. Lyche Solheim. From national monitoring to transnational indicators: reporting and analysis of aquatic biology data under the European Environment Agency's State of the Environment data flow. Frontiers in Environmental Science • Morant, D.; C. Perennou, and **A. Camacho**. 2021. Assessment of the pressure level over lentic waterbodies through the estimation of land uses in the catchment and hydro-morphological alterations: the LUPLES method. *Applied Sciences* 11(4): 1633. Doi: 10.3390/app11041633			

Ecological Quality Ratio (EQR) of freshwater macrophytes			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** In-situ collection of freshwater macrophyte composition and abundance at the water body level **National initiatives:** **Norway and Sweden** The presence of data from citizen science reporting systems in Norway and Sweden are good examples (i.e. https://www.artportalen.se/).	**National initiatives:** **Germany** Citizen Science project of macrophytes in lakes (https://www.nabu-naturschutztauchen.de/)	Expand the geographical coverage of data sampling to more countries and more water bodies Expand the taxonomic coverage Expand temporal coverage The lakes selected for reporting in each country should be more representative to cover all lake types and all geographic regions in each country. Evaluate the suitability of citizen science data for reporting to directives, ensuring its reliability and adherence to required standards for trusted use.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation	**EQR monitoring WFD:** - Standardized data collection for freshwater macrophytes EQR - Excel templates for data entry - Water Information System for Europe - Biology data (WISE-2,		Organise more dialogue meetings with data providers to convince more countries to report their EQR data.

Integration nodes (national or EU) Automated data streams	EEA) (see info on the phytoplankton EQR Google sheet).		Include species lists of macrophytes when reporting EQR values.
Modelling Types of models Predictors Estimation & uncertainty Software			
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of the expert who provided information for this template, literature, online sources, web pages of EU project):			

Ecological Quality Ratio (EQR) of freshwater phytobenthos			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** - In-situ collection of phytobenthos composition and abundance at the water body level, with a primary focus on diatoms to represent overall phytobenthos abundance. - Widespread use of diatoms as a proxy for phytobenthos in EU-wide Water Framework Directive (WFD) monitoring. - Intercalibrated methods and indices, adhering to EU standards EN13946:2014 and EN 14407:2014 for freshwater benthic diatoms. - Collection of raw data as lists showing relative abundances (%) of morphotaxa, applicable to both river catchments and lakes	**DNAqua-Net's diatom working group** - DNA Metabarcoding for Benthic Diatoms - The rbcL barcode, with its curated reference database (Diat. barcode), is primed for implementation in identifying benthic diatoms. - The 18S V4 barcode is also a potential candidate, though it currently has less developed reference databases. - One European country has already transitioned from traditional microscopy to metabarcoding for diatom taxonomic identification. - Efforts are ongoing to establish EU-wide DNA standards for this methodology.	Expand the geographical coverage of data sampling to more countries and more water bodies. Expand the taxonomic coverage Expand temporal coverage DNA reference databases still have large gaps regarding diatom taxa and coupling species-sequence is not sufficiently studied. ASVs could be used as stable units meanwhile, and taxa names could be coupled later when known. Infrastructure for DNA data hosting and bioinformatics are however not established yet. At least in the countries I know, no central hub has all responsibility for DNA monitoring, and capacity is not focused on monitoring samples.
Data integration	**EQR monitoring WFD:**	**National initiative Swedish Miljodata MVM**	Regarding DNA data, portals are focused on research data, not

Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	- Implement a standardised process for collecting phytobenthos data in lake EQR assessments using Excel templates for data entry. - Data harmonisation and flow to the EU level through the Water Information System for Europe - Biology data (WISE-2, EEA), with emphasis on national or normalised Ecological Quality Ratios (EQRs). Raw data are not accessible at the EU level. - Data retrievable for specific sampling sites from data hosts. Uncertainty exists in the extent of data hosting, especially for benthic diatoms. - While taxa are currently used in indices, biodiversity information is not yet aggregated for comprehensive use but holds potential for both species population monitoring and ecosystem monitoring. **National initiatives** **Sweden** Miljödata MVM https://miljodata.slu.se/mvm/ Swedish national data host for phytoplankton and benthic	Harvesting of benthic diatom data from Swedish Miljodata MVM to GBIF is in preparation (by SLU). Swedish Biodiversity Data Infrastructure (SBDI) is involved in this harvesting, and developing open APIs to deliver raw data to ENA, and taxa data to GBIF.	dedicated to monitoring. WFD data portals, on the other hand, are not adapted to deliver biological taxa data Underlying data is essential; EQRs tell very little about the actual biodiversity. There is no focus at all on diatom taxa harmonisation. There is an urgent need for expert workshops to discuss how the different traditions of identifying diatoms morphologically, resulting in different names, could be handled. Regarding DNA units, it would be very good if we could agree to use stable ASVs as the EU-wide unit. Taxa names could be coupled nationally if wished, but AVSs would enable us to harmonise diatom taxa easily and automatically. There is an urgent need to include all kinds of experts in the planning of how taxa data are handled in different ways. Provide and integrate not only the indices (EQR values) but also the biodiversity information

	diatoms for all traditional freshwater monitoring. Is harvested regularly for plankton taxa data to be delivered to GBIF. Actually, MVM is hosting also large mussels, which could be used for biodiversity reporting.		(relative abundances of morphotaxa)
Modelling Types of models Predictors Estimation & uncertainty Software		There is at least 1 initiative to use models to establish taxa-specific indicator values for monitoring (Switzerland, Pawlowski et al.) dedicated for WFD use, not for species monitoring though. The initiative is only on national level.	Freshwater phytobenthos collected for the WFD is currently not included in any biodiversity monitoring, assessment or indices, other than the EQRs are included to state good habitat quality (at least in Sweden).

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): the FWBON has currently a survey on this aspect where Sweden has delivered information about the freshwater national datahost “Miljödata MVM” which is located at my Department of Aquatic Sciences and Assessment, SLU, Sweden. I guess you are connected to this ongoing work? Or shall I copy the info I gave here again?

The main integration challenge for microorganisms to be used for EU- or global-wide biodiversity modelling is the harmonisation of taxa units, as I see it (and others put it). “In terms of extracting species data from existing biodiversity data portals, a reliable taxonomy with clear tagging of freshwater and freshwater-dependent species is necessary” (FADA, Balian et al. 2007). However, I really think that organism experts should be part of this work, as agreement is not reached yet! For microorganisms, there are methods to e.g. find synonyms, and the Darwin code is accepted, but I have not seen that the major challenges with problematic taxa-complexes are targeted at all by this: For morphological data, we need to merge taxa complexes to be able to make distribution maps. This is because microalgal taxa (incl. e.g. diatoms, and bluegreens) are difficult to identify, and different laboratories have their own tradition of handling difficult taxa complexes, leading to different names in many cases. But if we merge taxa, we could actually use the WFD EBVs for microorganisms (both plankton and benthos) also for taxa (maybe not species for many of them, still valuable as we do not know much about microtaxa distribution on EU level which is based on hard data) population analysis, both for trends and spatial distributions. I see even a much bigger chance to integrate DNA data, as this could be done automatically, and then on a much finer level, as the ASVs (amplicon sequence variants) in part separate also cryptic taxa.

Raw data (relative abundance of morphotaxa for a sampling site) need to be requested from local or national data hosts because only national or normalized EQR values (indices) are reported to EU level
Some raw data are delivered to GBIF, but it is unknown from how many data hosts, and sometimes only plankton raw data are delivered, not benthic diatom information

Taxonomic names for microalgal taxa (incl. e.g. diatoms, and bluegreens) and problematic taxa-complexes are insufficiently harmonized

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): see previous comment

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): Name:

- I will contact the diatom experts of the EU COSt network DNAqua-Net who all are familiar with both the traditional and the metabarcoding method for freshwater benthic diatoms, and with WFD monitoring, but not with the HD, or with biodiversity. I am sure they can contribute to this EBV with a lot of expert information, especially on sampling and upcoming/future methods in the different countries, as the details of the species collections of the WFD are on national level, not on EU. On EU there are only the integrated EQR results, which are not species lists, but based on them.
- European network DNAqua-Net (COST Action CA15219): roadmap for implementing DNA-based methods with a focus on inland waters assessed by the EU Water Framework Directive. Blancher, P., et al. (2022). "A strategy for successful integration of DNA-based methods in aquatic monitoring." Metabarcoding and Metagenomics 6. https://doi.org/10.3897/mbmg.6.85652
- Rimet, F., et al. (2021). "Metadata standards and practical guidelines for specimen and DNA curation when building barcode reference libraries for aquatic life." 5.https://doi.org/10.3897/mbmg.5.58056
- Rimet, F. (2020). "Diat.barcode: a curated barcoding database." Retrieved 21 Jan, 2020, from https://www6.inrae.fr/carrtel-collection/Barcoding-database.
- Rimet, F., et al. (2019). "Diat.barcode, an open-access curated barcode library for diatoms." Scientific Reports 9(1): 15116. https://doi.org/10.1038/s41598-019-51500-6
- Keck, F., et al. (2019). "A ready-to-use database for DADA2: Diat.barcode_rbcL_312bp_DADA2, https://doi.org/10.15454/HNI1EK, Portail Data Inra, V1."
- Kahlert, M., et al. (2009). "Harmonization is more important than experience-results of the first Nordic-Baltic diatom intercalibration exercise 2007 (stream monitoring)." Journal of Applied Phycology 21(4): 471-482. DOI10.1007/s10811-008-9394-5 https://link.springer.com/article/10.1007/s10811-008-9394-5

- Suggestion to merge diatom taxa from different sources (CAFF work): Table S2 from Kahlert et al. (2020). Kahlert, M., K. M. Rühland, I. Lavoie, F.Keck, E. Saulnier-Talbot, D. Bogan, R. B. Brua, S. Campeau, K. S. Christoffersen, J. M. Culp, S. M. Karjalainen, J. Lento, S. C. Schneider, R.
- Shaftel, and J. P. Smol. 2020. Biodiversity patterns of Arctic diatom assemblages in lakes and streams: Current reference conditions and historical context for biomonitoring. Freshwater Biology 67:116–140. https://onlinelibrary.wiley.com/doi/full/10.1111/fwb.13490
- EU COST Action DNAqua-Net (https://dnaqua.net/)
- Barcoding database Diat.barcode (https://www6.inrae.fr/carrtel-collection/Barcoding-database)
- WISE-2 (https://cdr.eionet.europa.eu/help/WISE_SoE/wise2)
- Swedish iljödata MVM (https://miljodata.slu.se/mvm/)

Ecological Quality Ratio (EQR) of benthic freshwater invertebrates			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** - Geographical coverage: Extensive monitoring in various EU Member States - Temporal coverage: Consistent time-series data available since 2004. - Regular monitoring every 2 or 3 years. - Taxonomic coverage: It includes all freshwater benthic invertebrate species with indicator values. - Data on species composition and abundance at specific locations. - Standardized and intercalibrated metrics for consistent EU-wide monitoring.	**eDNA**	Expand the geographical coverage of data sampling to more countries and more water bodies Include reference sites into the monitoring (WFD monitoring is biased towards bad sites) Expand the taxonomic coverage (to only monitor HD and pollution sensitive species is not enough!) Implement regular long-term biomonitoring programs Expand temporal coverage - define content of needed time series (e.g. how often sampling, water body types, pressure representativeness, supporting parameters (abiotic) Expand WFD sampling to small catchments as well Expand on traits

			For some specific species (e.g. freshwater mussels) that need a host to complete their life cycle we need the integration of these biotic interactions (distribution on hosts) besides the usual environmental factors. Harmonise eDNA data with in situ monitoring data (WFD) (e.g. the use of number of reeds as proxy of taxa abundance) - alternatively test presence-absence based indicator tools based on meta-barcoding To improve cross boundary comparison of EQRs, a more similar methodology should be used, e.g. use of MHS sampling, core sampling, one specific taxon level, (preferred species), one harmonized EU taxon list. Implement EU-protocols for eDNA - if sufficient evidence exists that this could provide a valuable supplement
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata	**EQR monitoring WFD:** - Established protocols and standards.	**Freshwater trait database**	Mobilize the raw data of the EQRs (i.e. all the species distribution and abundance data) Free access data

Way of data aggregation Integration nodes (national or EU) Automated data streams	- Raw data to produce EQR restricted, requiring formal requests for access. - Excel templates for data entry - Database: Water Information System for Europe - Biology data (WISE-2, EEA)		Data policy and sharing For proper biodiversity monitoring it is essential to know the identification level behind the EQRs; this should ideally be species level. And this data should be used, not just the EQR if we want to say something about biodiversity instead of ecological water quality. Development of indices using species-level information, for other type of stressors than eutrophication (go beyond ASPT) Harmonization of taxonomic nomenclature Improve web portals facilitating local access data (especially for national environmental agency)
Modelling Types of models Predictors Estimation & uncertainty Software	No models available for EQRs	**Machine Learning** approach (random forest) to assess anthropogenic alterations based on a-priori impact classification and taxonomic or functional macroinvertebrate information in R (ongoing study, not yet published)	Development of indices macroinvertebrate-based for assessment of flow alterations Joint species distribution models for some specific species such as freshwater mussels that need a suitable fish species to complete their life cycle

			Include multiple stressor effect on diversity (derived from in situ experiments)

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- EQR's are available, but not the raw data and how each EQR is formed, making cross-boundary comparisons difficult.
- Need for certification for taxon ID to harmonize ID standard across EU?
- For metadata, using Darwin core

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

Long-term maintenance for existing infrastructures

Encourage one specific database that can be adopted by journals (to make data available) as well as EU organizations like the EEA for making raw (EQR) data available. GBIF would be an option - willing to adjust/design a template for e.g. species abundance incl methodology.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- da Silva, J. P., Gonçalves, D. V., Garcia-Raventós, A., Lopes-Lima, M., Varandas, S., Froufe, E., ... & Sousa, R. Joint species distribution models unveil co-occurrences between freshwater mussels and their fish hosts. *Journal of Biogeography*.

Ecological Quality Ratio (EQR) of freshwater fish			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EQR monitoring WFD:** In-situ collection of fish composition and abundance at the water body level Fish data on river site for WFD reporting (Composition, abundance and age structure of fish fauna) **National monitoring initiatives** Spain national protocol fish monitoring: EFI+ index on fish (Spain) Different national fish indices (FIA in Austria,...)	**National initiatives** New protocols for data collection EFI + is about to be implemented as the main protocol in the different Spanish catchments	Expand the geographical coverage of data sampling to more countries and more water bodies (especially smaller ones) Expand the taxonomic coverage. Expand temporal coverage Standardization & harmonization of a unified sampling protocol framework in rivers across the EU (standardised sampling designs and data collection methods) WFD is based on a network of sites and “loses” data on sensitive or rare species, and for sure, species with high functional diversity, focusing on species traits rather than on taxonomic species will be valuable Age structure and abundance based on eDNA
Data integration	**EQR monitoring WFD:**	**National Initiative Spain and Portugal**	Georeferenced data are often not easily accessible or traceable,

Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	Water Information System for Europe - Biology data (WISE-2, EEA) Standardized data collection for fish EQR Excel templates for data entry	POCTEP Albufeira - Integration of WFD and Habitats Directive objectives on water management ((https://poctepalbufeira.org/objetivos-ambientales/) -> Creation of species databases for each catchment, detailed pool of “umbrella” species database for each water body, depending on fish traits.	and there is significant variation across EU countries in terms of monitoring guidance, as well as the spatial scale and level of detail in reporting. Methods to continuously (or at any time) combine relevant data from ongoing programmes in different countries, i.e. not as static as the collation of common datasets as was previously done within intercalibration coordinated by ECOSTAT Central repository needed with free access Access to raw data on the site level Communication between reporting countries Improve communication and coordination among administrative level.
Modelling Types of models Predictors Estimation & uncertainty		EQRfishes: R package to calculate the EQR. Still under development. A first stable version is expected by the end of this year.	Go beyond EQR and look at other ways of assessing trends of communities of freshwater fishes (not assuming "good condition" reference).

Software			
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Free database with species occurrences from WFD and Habitats Directive reporting needed			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): European based on Natura2000/WFD database repository for freshwater fish			
References and sources (e.g. name and institution of an expert who provided information for this template, literature, online sources, web pages of EU project):			

Ecological Quality Ratio (EQR) of freshwater zooplankton			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building		**PONDERFUL** project about pond biodiversity - Manually data collection over 7 countries (30 ponds per country) across Europe and Uruguay - Rotifers, cladocera and copepods at the species level (in combination with phytoplankton, macroinvertebrates, macrophytes and eDNA data - Data collection on databases across Europe, from private sources - Samples collected on Different lakes on a monthly-biweekly schedule **TheZooCAM** (in-flow imaging for fast counting)	Requirement for Long-Term Assessment: Establishment of long-term assessment protocols to monitor changes and trends over time.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU)		**PONDERFUL:** Data integration on row data together with European database, mainly focused on zooplankton. For metadata, using Darwin core	Harmonisation of taxonomic nomenclature Need for Automated Data Collection: Development of automated methods for the collection and identification of

Automated data streams			small macroinvertebrates and zooplankton.
Modelling Types of models Predictors Estimation & uncertainty Software		**PONDERFUL:** Modeling of row data for different climate change scenarios to predict areas of conservation (pondscapes)	Modelling of long-term monitoring
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Colas, F., Tardivel, M., Perchoc, J., Lunven, M., Forest, B., Guyader, G., ... & Romagnan, J. B. (2018). The zoocam, a new in-flow imaging system for fast onboard counting, sizing and classification of fish eggs and metazooplankton. *Progress in Oceanography*, *166*, 54-65. https://doi.org/10.1016/j.pocean.2017.10.014 • Cuenca-Cambronero, M., Blicharska, M., Perrin, JA. *et al.* Challenges and opportunities in the use of ponds and pondscapes as Nature-based Solutions. *Hydrobiologia* (2023). https://doi.org/10.1007/s10750-023-05149-y • https://ponderful.eu/			

River Connectivity/Free river flow			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** **Ireland** **Irish National Barriers Programme** (SNIFFER protocol adapted to Irish waters - **Spain** **Spanish Hydromorphology protocols for shared water catchments** - Variability in Barrier Measurement Protocols: Current barrier assessment protocols vary, encompassing measurements like depth, length, width, fish passability, site-specific river width, barrier structure and type, degree of use or abandonment, leap distance, and pool depth. **-** Hydromorphological Assessment of River Fragmentation: Utilization of	**AMBER** Barrer location in Europe: Transects Barrier Tracker Citizen science phone application	Expand the geographical coverage of data on barriers. Use telemetry to understand connectivity in the field and the different requirements of different species (both spatially and periodically) Expand the data type about barriers (include location, width, height, material, photo, crest width, pool depth, depth at the crest, etc.) Long term of hydrological and biological data Improve indicators species and indices based on macroinvertebrates to assess E-flows, flow and morphological alterations (i.e. disconnections due to hydropower plant and barriers)

	indices such as the compartmentalisation index (IC) and the longitudinal continuity index (ICL) to quantify river segmentation and assess river continuity. The IC index specifically evaluates barrier suitability for fish passage of different Iberian species. **Austria** Local inventory Austrian barriers assessment for WFD/RBMP		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**National initiatives:** **Ireland** Irish interactive map on barriers **Spain** Inland Fisheries Ireland - National Barriers Programme (National Barriers Programme Dataset - /tinyurl.com/rcnyvvs9) Spanish Duero Catchment 'Mírame' portal: Inventory on barriers in rivers.	**AMBER project** - Standardized data sampling protocols - Barrier Atlas: Centralized at EU - Data available in the AMBER data portal - AMBER database, user-friendly app, web interface for visualization	Standardise method for calculating passibility for as many species as possible. Define a free-flowing river/river connectivity and assessment method/criteria Data policy and sharing
Modelling Types of models Predictors		**Aber project modelling:** - Machine learning (random forest) models	Should be created a modelled barrier density map on each catchment of interest, in order to prioritize the rivers with the

Estimation & uncertainty Software		- Land cover, population density, elevation and roads Barrier density **Madrid modeling** - Modelling and high spatial resolution research done in C. de Madrid on barriers density	highest density of barriers and risk of fragmentation for fish. (http://dx.doi.org/10.5209/OBMD.79518) The free-flowing river initiative in EU appeals to both longitudinal and lateral "freedom". We need to understand more about the role of lateral connectivity on everything from carbon fluxes to biodiversity and EQ improvements in relation to longitudinal connectivity. This also to best prioritise the river stretches or systems that could/should become embedded in the 25,000 km initiative.

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Irish interactive map on barriers (National Barriers Programme Dataset (tinyurl.com/rcnyvvs9)
- Spanish Duero Catchment 'Mírame' portal: (https://mirame.chduero.es/DMADuero_09_Viewer/viewerShow.do?action=showViewer)

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- AMBER database, user-friendly app, web interface for visualization
- More detailed AMBER data input, in order to collect more detailed information on barriers passability for fish.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

Ecosystem distribution of freshwater EUNIS Habitats			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building		**RIPARIANET (Biodiversa+ 2023-2026):** - A project under the Biodiversa+ program focusing on riparian ecosystems from 2023 to 2026. **Spain's EUNIS Freshwater Habitat Mapping Project:** -National mapping project of EUNIS freshwater habitat types led by MITECO in Spain. **Transboundary Habitat Integration (Spain-Portugal):** - Integrating Habitat Natura2000 across the Spain-Portugal border	Systematic mapping of EUNIS habitats and their status of conservation Mapping of wetland habitats other than lakes and rivers (i.e. marshes, peatlands, etc) Lack of satellite technologies to identify small water bodies <1ha Ground-truth of remote sensing data
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams		**ETC-BE's** EUNIS updated classification of inland waters habitat types is harmonised with the wide classifications of the WFD and would also facilitate cross-walks to comparable habitats reported under the HD.	Access to local data

Modelling Types of models Predictors Estimation & uncertainty Software		**ETC-BE's Support for EUNIS Habitats Mapping:** - Collaboration with the EEA for mapping EUNIS habitats. **Habitat quality modelling** Variables vs pressures levels correlation, e.g. LUPLES method - Morant et al., 2021 (for habitat quality, but not for habitat distribution) - DEM, Climatic data,WFD waterbody type	Vegetational maps

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- BIODIVERSA+ (RIPARIANET) - the project will start in April 2023 - https://www.biodiversa.eu/2022/10/07/2021-2022-joint-call/
- JRC surface water: https://global-surface-water.appspot.com/
- Doña, C.; N-B. Chang, V. Caselles, J. M. Sánchez, L. Pérez-Planells, M.M. Bisquert, V. García-Santos, S. Imen and **A. Camacho**. 2016. Monitoring hydrological patterns of temporary lakes using remote sensing and machine learning models: Case study of la Mancha Húmeda Biosphere Reserve in central Spain. *Remote Sensing* 8: 618.
- Doña, C.; D. Morant, A. Picazo, C. Rochera, J.M. Sánchez, and A. Camacho. 2021. Estimation of water coverage in permanent and temporary shallow lakes and wetlands by combining remote sensing techniques and genetic programming. Application to the Mediterranean basin of the Iberian Peninsula. *Remote Sensing* 13(4): 652. Doi: 10.3390/rs13040652
- Morant, D.; C. Perennou, and A. Camacho. 2021. Assessment of the pressure level over lentic waterbodies through the estimation of land uses in the catchment and hydro-morphological alterations: the LUPLES method. *Applied Sciences* 11(4): 1633. Doi: 10.3390/app11041633
- https://poctepalbufeira.org/objetivos-ambientales/].

Structural complexity of riparian habitats			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Copernicus Land Monitoring Service - Riparian Zones** (RZ) The Riparian Zones product offers standardised precise land cover and used maps across Europe, aiding in monitoring floodplains and sensitive ecosystems and informing policy on waterways and freshwater ecosystem restoration, with updates every six years covering 2012-2018. **LiDAR data from national programs** Land use and land cover map, in combination with (airborne, terrestrial, UAV-based) LiDAR data. drone-based surveys - orthoimages and photogrammetric analyses QField field mapping surveys - citizen science	**RIPARIANET** (BIODIVERSA+, 2023-2026): - Six catchments, Sweden, Germany, Italy, Spain, and Portugal, aims to provide tools for stakeholders to identify and prioritise areas of high conservation value for biodiversity preservation. - Use of remote sensing to map ecological values and their spatial connections, integrating fieldwork on riparian vegetation to pinpoint key areas for nature protection, Sentinel-2 data Drones and UAVs	Copernicus Land Monitoring Service - Riparian Zones (RZ) do not cover all the stream network (especially 1st and 2nd order) In Sweden, existing protocols cover only a small portion of the entire watercourse network. To achieve sufficient coverage, there is a need to integrate detailed inventories with satellite data. Utilise indicative species to assess habitat structure, as they are more sensitive and provide more accurate information compared to satellite data. Include non-riparian wetland vegetation. Advance the use of LIDAR-based sampling techniques.

Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	Spanish protocol for the assessment of hydromorphological indicators in freshwater systems (Riparian zone structure) (https://www.miteco.gob.es/es/agua/temas/estado-y-calidad-de-las-aguas/aguas-superficiales/programas-seguimiento/Protocolos-caracterizacion-y-calculo-metricas-en-hidromorfologia.aspx)		Improve accessibility to LIDAR data (e.g. local data)
Modelling Types of models Predictors Estimation & uncertainty Software	Coregistration of different datasets Fusion of point clouds and aerial imagery structure-from-motion Predictors (Vegetation maps EUNIS Habitat,DEM, Climatic (precipitation), River networks)	RIPARIANET (BIODIVERSA) https://riparianet.eu/index.html	Implement a model for the characterisation of RZ for all the stream network. Models for detection of hydroclimatic effect on Riparian Vegetation (phenology, productivity, health) - using Sentinel 2 data Analyze climatic effect on phenology (e.g. broadleaved) - how can change CPOM input on rivers change due to climate?
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): Copernicus - Land services (RZ)			

Sentinel HUB, SNAP (NDVI, etc)
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Riedler, B., Lang, S., 2018. A spatially explicit patch model of habitat quality, integrating spatio-structural indicators. Ecological Indicators 94, 128-141. • Schmölz et al. 2022 - https://doi.org/10.1016/j.scitotenv.2021.151886 • Strasser, T., Lang, S., 2015. Object-based class modelling for multi-scale riparian forest habitat mapping. International Journal of Applied Earth Observation and Geoinformation 37, 29-37. • G Pace, C Gutiérrez-Cánovas, R Henriques, F Boeing, F Cássio, C Pascoal (2021). Remote sensing depicts riparian vegetation responses to water stress in a humid Atlantic region. Science of the Total Environment 772, 145526 • Pace, G., Gutiérrez-Cánovas, C., Henriques, R., Carvalho-Santos, C., Cássio, F., Pascoal, C. (2022). Remote sensing indicators to assess riparian vegetation and river ecosystem health. Ecological Indicators 144,109519. http://dx.doi.org/10.1016/j.ecolind.2022.109519. • FP7 SPACE project MS.MONINA (Multi-scale Service for Moni-toring Natura 2000 Habitats of European Community Interest). Grant agreement No. 263479 • BIODIVERSA+ (RIPARIANET) - the project will start in April 2023 - https://www.biodiversa.eu/2022/10/07/2021-2022-joint-call/

Harmful freshwater algal blooms			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**In situ collection** **Water Framework Directive - WISE 6** - Monitoring of Cyanobacteria is part of the routine lake phytoplankton evaluations. - Measurements include Cyanobacteria biovolume (mg L-1 or mm3 L-1) and its percentage of total phytoplankton biovolume in lakes. - Water Quality Standard Protocols encompassing nutrients, organic matter, chlorophyll-a, hazardous substances, and physicochemical parameters in water, sediment, and biota. - Reports 5 MS, annually in some water bodies - Capacity building efforts are part of the WISE-6 initiative - The collected data serve the objectives of both the Water Framework Directive (WFD) and the Bathing Water Directive.	***Citizens Science*** **Bloomin' Algae app** Presence/absence of blooms judged by experts on photographic evidence (location, date). Available in real-time through an API from iRecord. Currently used in 5 European countries (4 languages). ***Remote sensing*** **CyanoAlert app** Remote sensing data Space-based Cyanobacteria information and Services are an example of what is possible. **GeoAquaWatch** - Develop and build the global capacity and utility of Earth Observation-derived water quality data, products and information to support effective monitoring, management and decision-making.	Ensure sampling diversity by including lakes from various regions, types, and impact levels to create a comprehensive dataset that reflects varying status classes Compile comprehensive lists of cyanobacterial species, including biovolume measurements for each species within samples, to enhance taxonomic resolution. Establish clear guidelines on acceptable data formats for member states to report to EU directives, accommodating the diverse nature of data types. Promote the use of hyperspectral satellite imagery to differentiate between various algal bloom types, with emphasis on understanding the limitations in optically diverse water bodies.

	-Water sample collection by drones for early warning - Remote sensing indicators for early detection - In situ proximal sensing of areas prone to algal blooms	- Observed presence and intensity of algal blooms derived from satellite imagery **Lake Water Quality | Copernicus Global Land Service** - Satellite monitoring provides essential data on water quality and temperature for over 4,200 medium and large-sized lakes globally, aiding in ecological status assessment under directives like the EU's WFD -Monitored water quality parameters, including turbidity, indicating water clarity and seasonal changes due to river discharge and phytoplankton, and the trophic state index, reflecting phytoplankton productivity and eutrophication levels. - Lake surface reflectances offer insights into water color for scientific analysis and algorithm development, with visual wavebands enabling true-colour image production.	Provide taxonomic training and conduct proficiency tests to standardize identification and reporting methodologies among different stakeholders Develop and standardize validated remote sensing products specifically for detecting cyanobacteria using hyperspectral data, and improve understanding of their effectiveness across different lake optical types, including those with high humic content. Integrate citizen science with satellite remote sensing to increase the frequency and scope of Harmful Algal Blooms (HABs) monitoring across European lakes, implementing cross-calibration methods to improve data reliability. Promote the adoption of novel monitoring technologies, including e-DNA, satellites, and drones
Data integration Standardisation & harmonisation Pre-processing	**Water Framework Directive - WISE 6** - Excel templates for data entry to ReportNet	**GLORIA** A globally representative hyperspectral in situ dataset for optical sensing of water quality	Increase the participation of EU countries in reporting cyanobacterial data to WISE-6,

Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	- Automatic quality control (QC) process at the Central Data Repository, to check the structure and content of the data file(s) uploaded by each member state. - Data store: Water Information System for Europe - Water Quality (WISE-6) as part of the Water Framework Directive lake phytoplankton monitoring - European State-of-Environment level workflow organised by EEA requesting annual reporting of cyanobacteria based on: In-situ collection of cyanobacteria biovolume (in mg L-1 or mm3 L-1) or the % of total biovolume in lakes	**Global remotely sensed phenology of Blue-Green Ecosystems** -Comparison of the phenology between more than 4000 lakes and their watersheds	aiming to expand beyond the current five contributing countries. Develop a European spatial database to record and share occurrence events of cyanobacteria
Modelling Types of models Predictors Estimation & uncertainty Software		**Cyanobacteria abundance model** Modeled cyanobacteria density in European lakes based on lake type, climate and water quality (total phosphorus) data is possible using published statistical models (Richardson et al., 2018) **Opt4Cyan;** Develop a regional early-detection algorithm for cyanobacterial blooms through visible and near-	Implement a unified and strategic approach for in situ sampling to calibrate and validate remote sensing products for chlorophyll and cyanobacteria detection.

		infrared optical radiometry, leveraging automatic data from the Doñana National Park's TriOS RAMSES network.	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Better inter-operability of satellite EO products			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):			

Freshwater primary productivity			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	Primary production is measured by 13C uptake biweekly at different depths (where?) Photosynthetic efficiency measured by PAM biweekly at different depths Biomass sampling for herbaceous aquatic plants in mesotrophic temporary wetlands Eddy Covariance flux towers to validate GPP/NPP remote sensing models	**IberRios:** The Iberian River Observatory - Chlorophyll measurements and macrophyte biomass once per year -Creates a comprehensive observatory for studying the effects of stressors on river ecosystems, tracking a wide array of organisms and ecological processes. - Its goals include improving long-term monitoring techniques, analysing trends in river ecosystems under stress, and understanding the changing dynamics of ecosystem functions - Standardized protocol from IberRios (standardised timing?- every year in summer, started in 2022) **Copernicus data** (Sentinel 2) Remote sensing for almost continuous Chl-a monitoring in large enough waterbodies	Establish a long-term assessment. Really need for remote sensing exercises at meaningful spatial and temporal scales

		Copernicus data (Sentinel 2) sweet for lakes and reservoirs (maybe for large rivers) **eLTER** Plus, a Discussion paper on key standard observation variables (link) **Lacs Sentinelles** (France but with collaboration with Italy/Alcotra) : monitoring of alpine lakes in natural reserves / flexible monitoring of different parameters	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams			Calibration and validation of emerging remote sensing algorithms to derive NPP
Modelling Types of models Predictors Estimation & uncertainty Software	Productivity models based on nutrients/Light availability and Chl-a stocks Riparian Vegetation Fragmentation (for rivers) Hydroclimatic data (discharge, current velocity, Temperature)	Bio-optical modelling and remote sensing data (Sentinel-3 Ocean and Land Colour Instrument), see Soomets ref below.	Improvement of GPP/NPP models based on remote sensing data for freshwater systems

	For reservoirs (TSS, in situ data and satellite data)		

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
https://earth.esa.int/eogateway/tools/snap

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- VH Neves, G Pace, J Delegido, SC Antunes (2021). Chlorophyll and Suspended Solids Estimation in Portuguese Reservoirs (Aguieira and Alqueva) from Sentinel-2 Imagery. Water 13 (18), 2479
- Michael J. Sayers, Gary L. Fahnenstiel, Robert A. Shuchman & Karl R. Bosse (2021) A new method to estimate global freshwater phytoplankton carbon fixation using satellite remote sensing: initial results, International Journal of Remote Sensing, 42:10, 3708-3730,
- Soomets, T.; Uudeberg, K.; Kangro, K.; Jakovels, D.; Brauns, A.; Toming, K.; Zagars, M.; Kutser, T. Spatio-Temporal Variability of Phytoplankton Primary Production in Baltic Lakes Using Sentinel-3 OLCI Data. Remote Sens. 2020, 12, 2415.
- Doña, C.; N.B. Chang, V. Caselles, J. M. Sánchez, A. Camacho. J. Delegido, B. and W. Vannah. 2015. Integrated satellite data fusion and mining for monitoring the lake water quality status of the Albufera de Valencia in Spain. *Journal of environmental management* 151: 416-426.

Genetic diversity of selected marine taxa			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Regional initiatives** **ICES Working group on the application of genetics in fisheries and aquaculture** https://www.ices.dk/community/groups/Pages/Wgagfa.aspx eDNA, Microbiomes, Transcriptomics, Adaptive Diversity, Population Sizes, Metabarcoding, Epigenetics **Genetic fish stock identification** (e.g. prolific literature for the Atlantic herring) **LifeWatch observatory data**: genomic observations in the Belgian Part of the North Sea (https://www.vliz.be/en/imis?dasid=5188&doiid=603)	At least three Horizon Europe projects are dealing with monitoring and assessing genetic diversity at sea as part of the project. These are: OBAMA-NEXT, BiOCEAN5D and GES4SEAS **OBAMA-NEXT:** delivering information products for marine biodiversity**.** WP3: Task 3.3: Evaluating molecular methods for benthic species and habitat detection	Continuity of any monitoring activity beyond the duration of a research project. The common agreed pool of data (some mentioned in the papers below)
Data integration Standardisation & harmonisation Pre-processing		**EMODnet** Biology is currently working on integrating genetic data with EurOBIS - follow up with bio@emodnet.eu	

Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams		**G-bike** is an initiative to develop monitoring tools, standardised protocols, and formats for genetic diversity in wild populations. Not only restricted to the marine realm. **National monitoring in Sweden** has recently included intraspecific genetic diversity of some marine species. About that work is being done on data formats.	
Modelling Types of models Predictors Estimation & uncertainty Software			Four EBV cover the components of Wright genetic variation and together provide a comprehensive description of the impacts of environmental change on genetic composition: 1) genetic diversity in terms of richness and He, 2) genetic differentiation in terms of number of genetic units and distance genetic units, 3) inbreeding and 4) Ne
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): We lack standardized formats for the curation and sharing of primary data underlying the EBV metrics. Primary data involves relevant metadata regarding sampling, preparation and and analysis methods but also how to express the genetic composition of the individuals. There exist plenty of formats for genetic data, but it is unclear which of these should be applied for different types of genetic data, e.g. from different markers or whole genome sequencing.			

In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): There exist different global data portals for storing genetic sequences and genetic experts could best describe which to use for different types of data. However, it is not clear where to store information about the EBV metrics that are calculated from those primary data? Should decentralized data distribution be used or a central data repository for EBV metrics?

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

https://www.g-bikegenetics.eu/en

- Old book: Genetic diversity of marine fisheries resources https://www.fao.org/3/v4865e/v4865e00.htm , particularly the (old) methods to measure here https://www.fao.org/3/v4865e/V4865E03.htm#ch3.1
- Baltic Sea genetic biodiversity, multiple taxa and groups: https://doi.org/10.1002/aqc.2771
- Hoban et al 2022 (doi: 10.1111/brv.12852)
- Hvilsom et al. 2022. Selecting species and populations for monitoring of genetic diversity. https://doi.org/10.2305/IUCN.CH.2022.07.en

Species distributions of marine fishes			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**International Council for the Exploitation of the Sea (ICES)** - Surveys undertaken through trawls of commercial fish. (mainly for Baltic and NE Atlantic) - Data types: Coordinates of the shooting and hauling locations, species ID, and information on the age disaggregated abundance of fish species - Including International Bottom Trawl Survey Working Group MEDITS: - trawl survey for both commercial species and biodiversity components in the Mediterranean - acoustic small pelagic fish survey in the Mediterranean - abundance indices of target species **National initiatives:** - Spanish Tracking Network	**STRAITS (HORIZON INFRA)** Strategic Infrastructure for improved Animal Tracking in European Seas (STRAITS) will leverage ongoing acoustic tracking projects across the four corners of Europe (i.e. North Channel, Danish Straits, Straits of Gibraltar and the Bosporus/Dardanelles) by expanding efforts to connect initiatives on species-based biodiversity management while developing data management plans and networking channels to deliver data to national and international governing bodies. **QUAMPO** project (finished): eDNA citizen-science monitoring of fish species in Corsican ports **MOVE**	Expand geographical coverage (MediterranSea sea, Macaronesia and the Black Sea) Expand taxonomic coverage Apart from the geographical coverage, the species coverage is sometimes an issue since only the most valuable and well-known commercial species are monitored, and they may represent less than half of the commercially exploited species. Conduct fish monitoring campaigns in a broad sense, not only focusing on species of commercial interest. Increase the coverage (number) of acoustic receivers, particularly in key areas (bottlenecks such as Straits and passages and/or relevant areas such as EFHs)

	Portugues Tracking Network (https://coastnet.pt/news/portuguese-tracking-network-alentejo/) Belgian Tracking Network (https://www.lifewatch.be/en/fish-acoustic-receiver-network) **ICCAT** - large pelagic (mainly tuna species) tagging (East Atlantic and Mediterranean)	(Biodiversa+ project; IP: Esben Moland Olsen from IMR Norway) has just started, and it will be monitoring the multi-scale movement behaviour of predatory fish across three countries in Europe (Spain, Norway, and Portugal) with the possibility of recording movements in other countries as part of the ETN. There is no website for the project yet.	Integrate acoustic receivers into already existing (or to be deployed) oceanographic observation platforms which will increase coverage in an easy and cost-effective way. Using epigenetics data to determine the distribution of species and also to link it with the structure of the population, currently, some results show that the methylation allows to distinguish between the eel from the France region and other UE areas. An investigation on epigentics from eDNA may be a potential tools to estimate the biomass, biodiversity and the population structure.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**European Tracking Network (ETN)** - Presence of fish tagged with electronic transmitters (mainly acoustic transmitters but also PIT, radio, archival and satellite tags). A wide array of acoustic receivers, spread throughout Europe enables the detection of tagged fish.	**DEVOTES** Nested Environmental status Assessment Tool (NEAT)**;** To integrate information, coming from different sources of data and different indicators. https://www.azti.es/en/productos/neat/ There are plenty of papers published using this tool, which allows integrating multiple indicators. Although primarily	Ensure interoperability within acoustic tracking networks (see also note under “**Interoperability aspects”** about Open Protocols)

	- Data includes detection date, time and location (coordinates). All data (from all partners) is in a quality controlled centralized database. Some transmitters include sensors that measure depth, activity, temperature, etc… **European Tracking Network** The data generated within the is centralized in a data platform (https://www.lifewatch.be/etn/) with standardized protocols, quality controls, etc.. There are R packages that can be used to upload, access, and have a preliminary visualization of the data (https://github.com/inbo/etn) **EMODnet-Biology data portal** Standardisation to Darwin-Core. Data harvest via VLIZ IPT QC automatically via LW/EMODnet BioCheck tool Publication: Direct download, OGC web services. **Data Collection Framework (DCF-STECF)** The largest and most consistent fish monitoring data source in Europe is generated through the reporting obligations of the	developed for marine systems, it can be used in any realm **GES4SEAS** www.ges4seas.eu building on NEAT (Nested Environmental status Assessment Tool), to develop a tool able to assess multiple pressures, the status of the sea (including multiple ecosystem components), and the ecosystem services delivered. This will include different ways of integration Dataflow from the European Tracking Network (ETN) to OBIS/EMODnet Biology will be improved in the **DTO-Bioflow** project (approved, but not started yet). eDNA fish community data in the information system WISE (open and FAIR)	

	Common Fisheries Data and collected in the https://datacollection.jrc.ec.europa.eu/ **International Council for the Exploitation of the Sea (ICES)** - Regional integration initiatives Northeast Atlantic, the Norwegian Sea, the North Sea, the Baltic Sea, Mid-Atlantic Ridge, and the Skagerrak - Standardized survey protocols, but differ across regions (e.g. between the Baltic and the Western and Southern Areas) - Worksheets in .csv format are submitted to the DATRAS online database via the ICES platform. **Ocean Tracking Network (OTN)** - global aquatic research, data management and partnership platform **NAFO (Northwest Atlantic Fisheries Organization)** Need to consider data collection and integration, monitoring and modelling occurring under		

	regional fisheries agreements such as - responsible for regional cooperation on the conservation and management of fish stocks in the north-west Atlantic, NEAFC (North-East Atlantic Fisheries Commission) - focusing on regional cooperation on the conservation and management of fish stocks in the north-east Atlantic, NASCO (North Atlantic Salmon Conservation Organisation) - responsible for regional cooperation to protect wild salmon in the north Atlantic, CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) - pursuing the aim of conserving the marine life of the Southern Ocean; - the Agreement to prevent unregulated high seas fisheries in the Central Arctic Ocean, and future impacts of the High Seas Treaty just agreed to (see note below).		
Modelling Types of models	**Acoustic telemetry data** (ETN-type) provides presence data potentially at a very large spatial	AQUAMAPS (aquamaps.org; https://en.wikipedia.org/wiki/AquaMaps	

Predictors Estimation & uncertainty Software	scale which can be used in species distribution modelling. Acoustic telemetry data is also analyzed using mixed-effect models to identify trends over time, drivers of behaviour, plasticity and intraspecific variation in behaviour although these methods do not directly apply to this EBV. However I see no other EBVs based on behavioural variables where those modelling methods could apply (so I´m leaving a general comment under the Marine EBV Reporting document to flag this). There are several R packages commonly used to analyze telemetry data and calculate behavioural variables including ACTEL, GLATOS, ATT, adehabitat Species distribution modelling-statistical modelling: EwE -food web Atlantis-End to End modelling Osmose-multispecies modelling Strat to E - multispecies Individual Based modelling (IBM) Piroddi et al 2015 (Ecological Indicators)		

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Data can be freely downloaded from DATRAS
- Data can be requested by web services from EMODnet Biology.
- Statement from the ETN about interoperability in acoustic telemetry protocols: https://europeantrackingnetwork.org/en/open-protocol
- In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
DATRAS online database of trawl surveys with access to standard data products Data Network (EMODnet) standard data products

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- https://europeantrackingnetwork.org/en
- https://trackingfish.com/
- https://cordis.europa.eu/project/id/101094649
- https://animalbiotelemetry.biomedcentral.com/articles/10.1186/s40317-021-00253-z
- Clémence Epinoux, Marine Barbarin, Justine Castrec, Carine Churlaud, Mathilde Dabrowski, et al. 2022. Water Interdisciplinary Biology and Ecology database “WIBE”: Towards FAIR, open and interdisciplinary data on biomarkers to monitor the ecological status of coastal waters. urn:node:PNDB. Urn:uuid:99abf52c-b271-4b66-ae50-c504e492bc4c.
- https://doi.org/10.1186/s40317-018-0156-0
- https://doi.org/10.1111/gcb.16343
- https://doi.org/10.1016/j.ecolind.2015.05.037

Species abundances of marine commercial fish species and long-distance migratory fishes			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	No information is available on long-distance migratory fishes **International Council for the Exploitation of the Sea (ICES)** - Surveys undertaken through trawls of commercial fish. (mainly for Baltic and NE Atlantic) - Data types: Coordinates of the shooting and hauling locations, species ID, and information on the age disaggregated abundance of fish species - Including International Bottom Trawl Survey Working Group **ICES WGNAS (Working Group on North Atlantic Salmon)** - Catch data available in annual reports. This also includes biological sampling in some commission areas, for example, East and West Greenland **Arctic Indigenous and local peoples knowledge**	**STRAITS (HORIZON INFRA)** Strategic Infrastructure for improved animal Tracking in European Seas (STRAITS) will leverage ongoing acoustic tracking projects across the four corners of Europe (i.e. North Channel, Danish Straits, Straits of Gibraltar and the Bosporus/Dardanelles) by expanding efforts to connect initiatives on species-based biodiversity management while developing data management plans and networking channels to deliver data to national and international governing bodies. **QUAMPO** project (finished): eDNA citizen-science monitoring of fish species in Corsican ports **MOVE** (Biodiversa+ project; IP: Esben Moland Olsen from IMR Norway) has just started, and it will be monitoring multi-scale movement behaviour of predatory fish across three countries	Expand geographical coverage (Mediterranean sea, Macaronesia and the Black Sea) Expand taxonomic coverage to Mediterranean, Macaronesia and the Black Sea species and long-distance migratory fishes. The species coverage is sometimes an issue since only the most valuable and well-known commercial species are monitored, and they may represent less than half of the commercially exploited species. Estimate abundances from eDNA or metabarcoding, acquiring additional data from various regions .

	Traditional knowledge, subsistence harvesting, commercial harvesting, and participation in data collection and monitoring. https://www.sciencedirect.com/science/article/pii/S2590332221006680 https://www.sciencedirect.com/science/article/pii/S0959378022000073 **MEDITS**: - trawl survey for both commercial species and biodiversity components in the Mediterranean - acoustic small pelagic fish survey in the MedMediterranean **ICCAT** - large pelagic (mainly tuna species) tagging (East Atlantic and Mediterranean) **Arctic Council** Other work on data collection and monitoring is occurring on fish stocks and population shifts at the Arctic Council https://arctic-council.org/explore/topics/arctic-peoples/our-changing-home/shifting-food-stocks/	in Europe (Spain, Norway and Portugal) with the possibility of record movements in other countries as part of the ETN. There is no website for the project yet.	

Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**PAN-EUROPEAN INFRASTRUCTURE FOR OCEAN & MARINE DATA MANAGEMENT** https://www.seadatanet.org/ - SeaDataNet is a comprehensive marine data infrastructure managing vast and diverse in situ data sets from seas and oceans, with a network of professional data centres across Europe providing standardised, high-quality, integrated databases. - It offers online access to in-situ data, metadata, and products through a unified portal, ensuring interoperability through the adoption of common communication standards and technologies for data quality and compatibility. - The infrastructure supports various applications, including research, model initialisation, industrial projects, education, and marine environmental assessments, and is a key component of the European marine data management landscape alongside EMODnet and Copernicus CMEMS.	**IUU fisheries** Given concerns with illegal and, unregulated and unreported fisheries (IUU fisheries), there is extensive data collection, monitoring, and commercial tracking of vessels and fishes harvested. Some of the fish tracking is monitored commercially and on a voluntary basis. **DEVOTES** Nested Environmental status Assessment Tool (NEAT)**;** To integrate information, coming from different sources of data and different indicators. https://www.azti.es/en/productos/neat / There are plenty of papers published using this tool, which allows integrating multiple indicators. Although primarily developed for marine systems, it can be used in any realm **DTO-Bioflow** project (approved, but not started yet). eDNA fish community data in the information system WISE (open and FAIR)	Public access to VMS data (Vessel monitoring system) Consider international fisheries treaties. - The Atlantic -NAFO and NASCO for data collection. - Ciircum-Arctic and polar regions continue to be considered. Arctic right now limits commercial fishing in the central Arctic Ocean due to the initiative of key states - Commission for the Conservation of Antarctic Fishing in marine waters of Antarctica has been contentious, and the scientific body of treaty organisation - Consider the impact of High Seas Treaty discussed below

	International Council for the Exploitation of the Sea (ICES) - Regional integration initiatives Northeast Atlantic, the Norwegian Sea, the North Sea, the Baltic Sea, Mid-Atlantic Ridge, and the Skagerrak -Standardized survey protocols, but differ across regions (e.g. between the Baltic and the Western and Southern Areas) - Worksheets in .csv format are submitted to the DATRAS online database via the ICES platform. **Ocean Tracking Network (OTN)** - global aquatic research, data management and partnership platform **European Tracking Network** The data generated within the is centralized in a data platform (https://www.lifewatch.be/etn/) with standardized protocols, quality controls, etc.. There are R packages that can be used to upload, access, and have a preliminary visualization of the data (https://github.com/inbo/etn) **Arctic Council Working Groups such as CAFF, PAME, AMAP**		

	Within the Arctic, monitoring and modelling occurs under Arctic Council Working Groups such as CAFF, PAME, AMAP and under biodiversity monitoring initiatives and programs. **Circumpolar Biodiversity Monitoring Program (CBMP)** . For the Antarctica, this may occur under the Antarctic Treaty, but seem to be limits on this effectiveness of this, so a gap that could be remedied here, given large number of EU states active in the southern oceans. **MSFD assessment guidance** https://www.aquabiota.se/wp-content/uploads/european-commission-2022.-msfd-cis-guidance-document-no.-19-article-8-msfd-may-2022.pdf Descriptor 3 **Data Collection framework (DCF-STECF)** The largest and more consistent fish monitoring data source in Europe is generated through the reporting obligations of the Common Fisheries Data and collected in the		

	https://datacollection.jrc.ec.europa.eu/		
Modelling Types of models Predictors Estimation & uncertainty Software	**Fish Population Monitoring & Modelling in Arctic Waters:** **- Monitoring Efforts:** Continuous scientific monitoring and modelling, despite no commercial fishing in certain Arctic waters. **- Climate Change Impact Studies:** Canadian-led models predict fish population changes due to climate impacts, contributing to wider regional and global assessments. **Incorporating Indigenous Knowledge:** **- Model Design:** Emphasis on integrating indigenous and traditional knowledge into Arctic fish population models. **Advanced Modelling Techniques:** **- Machine Learning in Biomass Estimation:** Utilization of Machine Learning, specifically Gaussian Process Regression (GPR), for biomass estimation of species like Atlantic cod, based on eDNA and environmental parameters.	AQUAMAPS (aquamaps.org; https://en.wikipedia.org/wiki/AquaMaps **GES4SEAS** www.ges4seas.eu building on NEAT (Nested Environmental status Assessment Tool), to develop a tool able to assess multiple pressures, the status of the sea (including multiple ecosystem components), and the ecosystem services delivered. This will include different ways of integration Dataflow from the European Tracking Network (ETN) to OBIS/EMODnet Biology will be improved in the	Fitting computational models effectively necessitates incorporating extra data from diverse regions. Modelling, in particular, is starting to look at future changes to fish populations due to climate changes and impacts on marine waters. Improvement in the assessment of individual species abundance from stock to species from an ecosystem point of view

	- Model Validation: Correlation between model predictions and trawl data validates the approach. **Diverse Modeling Frameworks:** **- Individual Stock Assessments:** Focus on specific fish stock evaluations. **- Ecosystem and Multispecies Modeling:** Implementation of various models like EwE, Atlantis, Osmose, Strat to E, and IBM for comprehensive ecosystem and multispecies analysis.		

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Data can be freely downloaded from DATRAS
- Look to various regional seas conventions and all the monitoring and modelling that occurs under them with country support, particularly for the Atlantic. Within the Arctic, monitoring and modelling occurs under Arctic Council Working Groups such as CAFF, PAME, AMAP and under biodiversity monitoring initiatives and programs. Circumpolar Biodiversity Monitoring Program (CBMP) .
- For the Antarctica, this may occur under the Antarctic Treaty, but seem to be limits on this effectiveness of this, so a gap that could be remedied here, given large number of EU states active in the southern oceans. More to be provided subsequently.
- There are some initiatives to make this data compatible and open source.
- Data integration of migratory fishes/animals through aquatic tracking: the European Tracking Network (ETN). https://europeantrackingnetwork.org/en Data will flow from ETN to OBIS. (and is shared with the Ocean Tracking Network).
- In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): • DATRAS online database of trawl surveys with access to standard data products • Data Network (EMODnet) standard data products • European Tracking Network: https://europeantrackingnetwork.org/en aquatic tracking data (management & sharing) platform.
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • https://portal.azores.gov.pt/web/drp/monico - monitoring program in the Azores (contact person: Pedro Afonso - pafonsopim@gmail.com) • Genetic Informed Fisheries Assessment for improved Management (2021-2024). European Project (contact person: Naiara Rodriguez-Ezpeleta (nrodriguez@azti.es) • Díaz-Arce, N.; Fraile, I.; Abid, N.; Addis, P.; Deguara, S.; Sow, F.N.; Hanke, A.; Karakulak, F.S.; Lino, P.G.; Macias, D.; Nøttestad, L.; Oray, I.K.; Rodriguez-Marin, E.; Tsukahara, Y.; Varela, J.L.; Arrizabalaga, H.; Rodriguez-Ezpeleta, N. Insights in the Stock Mixing Dynamics of Atlantic Bluefin Tuna in the North Atlantic †. *Biol. Life Sci. Forum* **2022**, *13*, 30. https://doi.org/10.3390/blsf2022013030 (contact person: Naiara Rodriguez-Ezpeleta (nrodriguez@azti.es) • See links provided below to start: • https://www.nafo.int/Science/Science-Advice/Stock-advice • https://nasco.int/ices-2/scientific-research-fishing/

Species distributions of marine birds			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Regional initiatives** **OSPAR** collects abundance data on breeding seabird colonies, breeding waterbirds, and wintering and passage water birds in countries of the Northeast Atlantic **HELCOM** collects abundance data for six marine bird species of the Baltic Sea. **Migres Programme.** (Strait of Gibraltar) Citizens science project with standard daily counties of marine species Citizen science projects: https://www.fundacionmigres.org/programa-migres/ **RAM: Red de observación de Aves y Mamíferos marinos** (Spain and Portugal) Citizens science project with standard daily counties of marine bird and mammal species	**SeaBee** is a Norwegian infrastructure for drone-based research, mapping and monitoring in the coastal zone (including seabird monitoring). **LifeWatch Belgium (INBO/VLIZ)** Bird tracking by various tracking sensors is part of: https://www.lifewatch.be/en/gps-tracking-network-large-birds **UNEPMAP-Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast** - Program established to monitor environmental conditions in the Mediterranean, focusing on biodiversity, pollution, and marine litter - Operates within a framework aligned with various international environmental agreements, and adhering to a set of common indicators	Expand geographical coverage (Mediterranean Sea) Expand taxonomic coverage Homogenisation of surveys from different countries (with special attention to coastal monitoring)

	http://redavesmarinas.blogspot.com/ **Arctic Council working group CAFF-** The ***Arctic Migratory Birds Initiative (AMBI)*** Improve the status and secure the long-term sustainability of declining Arctic breeding migratory bird populations. There is specific work on the following flyway and on specific issues of plastics and seabirds. (African Eurasian Flyway, Americas Flyway, Central and East Asian Flyways, Circumpolar Flyway, Plastics and Seabirds)	- Common Indicator 3: Species distributional range	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	No EU-level initiatives focussed on marine birds however regional/partial initiatives exist: ESAS, HELCOM-OSPAR, Baltic seabirds transects survey, OBIS Standardised monitoring protocols for each program, but not standardised between programs. **European Seabirds At Sea (ESAS)** aggregates offshore monitoring data on seabirds (e.g., from ship-based surveys) across the North Sea	**Joint OSPAR/HELCOM/ICES Working Group on Seabirds (JWGBIRD)**: focusing on developing Ecological Quality Objectives and common bird indicators under the EU's Marine Strategy Framework Directive, with annual meetings set to balance participant interests and OSPAR needs, driven by pre-established objectives. **DTO-Bioflow** - standard for bird biologging networks, optimize the dataflow	Need for integration initiative at the EU level

	EMODnet-Biology data portal Standardization to Darwin-Core. Data harvest via VLIZ IPT QC automatically via LW/EMODnet BioCheck tool Publication: Direct download, OGC web services **MSFD assessment guidance** **MovebankTracking** movement data integration. From Movebank, there is a data flow to OBIS (and GBIF): https://github.com/inbo/bird-tracking **The European Breeding Bird Atlas (EBBA2)** includes 63 marine and coastal species. Uses targeted surveys (during breeding period; 10 km2 squares) with standardised protocols (time surveys 60–120 min, years 2013–2017)	towards EMODnet Biology/EurOBIS, as well as create relevant data products.	
Modelling Types of models Predictors Estimation & uncertainty Software	**TRIM**: Marine Bird Abundance indicator integrates species trends	ML techniques for Localization/Classification of Birds. Already methodes for terrestrial birds are available (DeViSe)Machine learning techniques for developing spatio-temporal predictive models from	

		environmental open-datasets: Martin, Beatriz & Onrubia, Alejandro & González Arias, Julio & Vicente-Vírseda, Juan. (2020). Citizen science for predicting spatio-temporal patterns in seabird abundance during migration. PLOS ONE. 15. e0236631. 10.1371/journal.pone.0236631 **Environmental status Assessment Tool** (NEAT,H2020 project DEVOTES) - To integrate information, coming from different sources of data and different indicators, - Plenty of papers published using this tool, which allows integrating multiple indicators.	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):
In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
In the future EDITO- the European Digital Twin of the Ocean should provide data and resources to calculate and model indicators.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Dierschke, V., A. Kreutle, N. Häubner, C. Magliozzi, S. Bennecke, L. Bergström, A. Borja, S. T. Boschetti, A. Cheilari, D. Connor, F. Haas, M. Hauswirth, S. Koschinski, C. Liquete, J. Olsson, D. Schönberg-Alm, F. Somma, H. Wennhage, A. Palialexis, 2021. Integration methods for Marine Strategy Framework Directive' s biodiversity assessments. EUR 30656 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-79-33990-8, doi:10.2760/4751, JRC124613: 45 pp.
- DeViSe, Fraunhofer IDMT, Menno Müller: https://www.idmt.fraunhofer.de/en/institute/projects-products/projects/devise.html
- Arctic Migratory Birds Initiative (AMBI) Revised Work Plan 2019-2025 (Revised May 2021)
- https://www.caff.is/strategies-series/all-strategies-documents/563-arctic-migratory-birds-initiative-ambi-revised-work-plan-2019-2023

Species distributions of marine mammals			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Regional initiatives** **HELCOM (Baltic Marine Environment Protection Commission) - EG MaMa Expert Group on Marine Mammals** - Marine mammals health status - Seal abundance - Harbour porpoise abundance **OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) - CEMP (OSPAR's Coordinated Environmental Monitoring Programme)** - ***Seal abundance*** and distribution Guidelines for data collection, reporting and modeling the Common Indicator: Seal abundance and distribution (M3) https://www.ospar.org/documents?v=38980	**Marine drones** - The Guarda Costiera and Tethys Research Institute are conducting a pilot study using marine drones to monitor dolphins (like Bottlenose Dolphin) and whales (such as Fin whales) within the Pelagos Sanctuary. - CIMA is utilizing drone surveys to study Cuvier's beaked whales in the Tyrrhenian Sea. **Digital sensors** - Hydrophones incorporated to gliders (Uzan&Pellet, 2019). - LifeWatch Belgium marine acoustic data - Infrared cameras (e.g. for near-miss detection) **Citizen sciences** Citizen-science data collection in French Marine Mammal Sanctuary AGOA (French Caribbeans): Kakila	Passive acoustic monitoring: Marine observatories connected to the land (cable, radio or satellite)

	- *Cetaceans* **European Atlantic:** SCANS, SCANS-II, SCANS-III (Small Cetacean Abundance in the North Sea; Hammond et al., 2002, 2013, 2021) CODA (Cetacean Offshore Distribution and Abundance in the European Atlantic; CODA, 2009) Ship and aircraft surveys ACCOBAMS (Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area) **ACCOBAMS Survey Initiative (ASI Project)** both aerial and boat surveys same timescale and geographical coverage 2019 ASCOBANS **Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas** FLT Mediterranean Monitoring Network (FLT Med Net): Transect counts of mega and macro marine fauna (cetaceans, sea turtles, seabirds)	OS4DOM project - eDNA, aerial drone surveys, and glider bioacoustic data to detect cetaceans in the Balearic Sea. Monitoring and impact assessment of human activities using AIS data. SeaBee is a Norwegian infrastructure for drone-based research, mapping and monitoring in the coastal zone (including seabird monitoring). **UNEPMAP-Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast** - Program established to monitor environmental conditions in the Mediterranean, focusing on biodiversity, pollution, and marine litter - Operates within a framework aligned with various international environmental agreements, and adhering to a set of common indicators	

	eDNA **RAM: Red de observación de Aves y Mamíferos marinos** (Spain and Portugal) Citizens science project with standard daily counties of marine bird and mammal species http://redavesmarinas.blogspot.com/ **National projects** **CETUS** Portugal, project (CIIMAR / UPorto): cetacean monitoring programme using platforms of opportunity in the Eastern North Atlantic (routes between mainland Portugal and Macaronesia) - occurrence data (abundance and distribution, habitat modelling). Non-funded project. (Correia AM) **LifeWatch Belgium** CPOD data from local observatory		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation	No EU-level initiative, regional/partial initiatives exist Marine Strategy Framework Directive (MSFD)	**IMPEL Marine Transborder Transect**: link together the two networks (Mediterranean and Atlantic) expanding the networks to the southern countries of the Mediterranean Region in order to	Need for integration initiatives at the EU level

Integration nodes (national or EU) Automated data streams	Common Implementation Strategy Article 8 MSFD Assessment Guidance HELCOM (Baltic Marine Environment Protection Commission) - EG MaMa Expert Group on Marine Mammals OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) ACCOBAMS (Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area) ASCOBANS Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas FLT Mediterranean Monitoring Network (FLT Med Net) OBIS Ocean biodiversity information system is a global open-access data and	strengthen the implementation of environmental law in Europe.Standardizing and integrating projects collecting data from large vessels across long-routes. Initiatives included: ORCA, CETUS and FLT Med **DTO-Bioflow** - improve the protocols and standards for cetacean passive acoustic observation networks, optimize the data flow as well as create relevant data products.	

	information clearing-house on marine biodiversity OBIS mapper National initiatives Open and FAIR database in the French National Biodiversity Repository (PNDB): Kakila		
Modelling Types of models Predictors Estimation & uncertainty Software	**Habitat modelling** - Integration of digital terrain, AIS data, and in-situ/satellite habitat data for enhanced spatial analysis. - Examination of marine mammal and shipping interactions using factors like bathymetry, temperature, and shipping metrics. **SDM and Climate Impact Analysis:** - Deployment of advanced models to study species distribution, leveraging EMODnet Biology data for regional focus. - Assessment of climate change effects on habitat using dynamic environmental variables. **Predictive Ecological Modelling:**	**Modeling** Machine Learning for acoustic detection/localisation of marine mammals CKMR modelling to estimate the biomass and the structure of the population **Environmental status Assessment Tool** (NEAT,H2020 project DEVOTES) - To integrate information coming from different sources of data and different indicators, - Plenty of papers have been published using this tool, which allows for the integration of multiple indicators. **GES4SEAS** (Horizon Europe project) -NEAT to develop a tool able to assess multiple pressures, the	Collision and near-miss database Acoustic map of European Waters By-catch distribution

	- Implementation of EwE and Atlantis models for food web and holistic ecosystem analysis. - Utilization of AQUAMAPS for global fishery distribution predictions, supporting regional assessments.	status of the sea (including multiple ecosystem components), and the ecosystem services delivered. This will include different ways of integrating	

- **Interoperability aspects** (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Open-access CETUS dataset (cetacean occurrence data in the Eastern North Atlantic) at OBIS / GBIF, through VLIZ: https://dx.doi.org/10.14284/547
- Open-access Kakila database: https://data.pndb.fr/view/doi%3A10.48502%2F8bb5-pk85 EML metadata, controlled vocabularies, license CC-BY4
- In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): Bénédicte Madon (University of Sevilla):

- Lorraine Coché, Elie Arnaud, Bouveret Laurent, Romain David, Eric Foulquier, et al. 2021. Kakila database of marine mammal observation data around the French archipelago of Guadeloupe in the AGOA sanctuary - French Antilles. Urn:node:PNDB. doi:10.48502/8bb5-pk85.
- Madon et al., 2022. Pairing AIS data and underwater topography to assess maritime traffic pressures on cetaceans: Case study in the Guadeloupean waters of the Agoa sanctuary": https://www.sciencedirect.com/science/article/pii/S0308597X2200207X
- Assessing bias in CETUS dataset: Oliveira-Rodrigues, C., Correia, A.M., Valente, R. *et al.* Assessing data bias in visual surveys from a cetacean monitoring programme. *Sci Data* 9, 682 (2022). https://doi.org/10.1038/s41597-022-01803-7

- Habitat modelling with CETUS dataset: Correia AM, Sousa-Guedes D, Gil Á, Valente R, Rosso M, Sousa-Pinto I, Sillero N and Pierce GJ (2021) Predicting Cetacean Distributions in the Eastern North Atlantic to Support Marine Management. Front. Mar. Sci. 8:643569. doi: 10.3389/fmars.2021.643569
- Garcia-Baron, I. et al. 2019. Modelling the spatial abundance of a migratory predator: A call for transboundary marine protected areas. Diversity and Distributions 25:346-360.
- M. Louzao et al., Understanding the 3D environment of pelagic predators from multidisciplinary oceanographic surveys to advance ecosystem-based monitoring. Marine Ecology Progress Series 617, 199-219 (2019).
- Astarloa et al., Identifying main interactions in marine predator-prey networks of the Bay of Biscay. ICES Journal of Marine Science 76, 2247-2259 (2019).
- Dierschke, V., A. Kreutle, N. Häubner, C. Magliozzi, S. Bennecke, L. Bergström, A. Borja, S. T. Boschetti, A. Cheilari, D. Connor, F. Haas, M. Hauswirth, S. Koschinski, C. Liquete, J. Olsson, D. Schönberg-Alm, F. Somma, H. Wennhage, A. Palialexis, 2021. Integration methods for Marine Strategy Framework Directive' s biodiversity assessments. EUR 30656 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-79-33990-8, doi:10.2760/4751, JRC124613: 45 pp.
- IMPEL MTT: https://www.impel.eu/actions/download-file/files/1ebabb86-773b-4375-b7f0-0c32fd004432/202017_FR_FLT%20Europe%20State%20of%20the%20art.pdf
- BSoundH, Fraunhofer IDMT, Menno Müller: https://www.idmt.fraunhofer.de/en/institute/projects-products/projects/bsh.html
- Uzan&Pellet, 2019. A NEW ACOUSTIC PAYLOAD FOR GLIDERS. https://www.uaconferences.org/docs/2019_papers/UACE2019_776_Uzan.pdf
- Gliders and PAM (contact person: Anna Rubio (arubio@azti.es)

Distributions of marine turtle species nesting grounds			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Regional initiatives** FLT Med Net: Transect count of mega and macro marine fauna (cetaceans, sea turtles, seabirds) Satellite tracking of nesting females and stranded and recovered individuals (young, adults, males and females).	**EuroTurtles and MedTurtle** LIFE Use of drones and small aircrafts to search for and identify marine turtles and marine mammals both near-shore and more off-shore.	Need to develop an EU monitoring system
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	No EU-level initiatives. **Global data aggregation system**: OBIS https://mapper.obis.org/ **MSFD assessment guidance** https://www.aquabiota.se/wp-content/uploads/european-commission-2022.-msfd-cis-guidance-document-no.-19-article-8-msfd-may-2022.pdf, in particular D1-reptiles **Regional initiatives**		Need for extended integration initiative at the EU level Improve data access though Ocean Data and Information System (ODIS)

	FLT Mediterranean Monitoring Network (FLT Med Net): Standardized protocols Regional initiatives exist for *Caretta caretta,* the Mediterranean (FLT Med Net) and with sub-national level monitoring programs run by eleven European countries, across the North East Atlantic (FAO 27), Northern Bay of Biscay, ICES Subarea7, parts of the Mediterranean Sea, Channel Islands, Cyprus, United Kingdom and Ireland coasts.		
Modelling Types of models Predictors Estimation & uncertainty Software	Species distribution modelling-statistical modelling EwE -food web Atlantis-End to End modelling Piroddi et al 2015 (Ecological Indicators) **AQUAMAPS:** modeling tool designed for large-scale prediction of marine species occurrences, leveraging environmental preferences like depth, temperature, salinity, and more to generate species' environmental envelopes based on data from GBIF, OBIS, FishBase, and SeaLifeBase	**LIFE TURTLENEST Project:** nesting range expansion of *Caretta caretta* in the Western Mediterranean	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

Species distributions of benthic marine invertebrates			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building		**EMO BON** European Marine Omics Biodiversity Observation Network [regular sampling of macrofauna and meiofauna from soft substrates & passive sampling using Autonomous Reef Monitoring Structures (ARMS); sampling protocols (EMO BON handbook & ARMS Handbook); sampling design (handbook); genomic data (macro- & meio-benthos); genomic and imaging data (ARMS)] **ARMS-MBON** -Autonomous Reef Monitoring Structures to monitor marine biodiversity in near-coastal areas using genetic and visual methods, contributing to the GEO BON's MBON initiative. - Insights and methodologies of ARMS-MBON's approach to marine biodiversity monitoring are detailed in a publication in Frontiers in Marine Science.	Deep-Sea is (near) totally absent from monitoring at European level Increase the coverage (number) of acoustic receivers, particularly in key areas (bottlenecks such as Straits and passages, relevant areas such as EFHs). Operational omics approaches Improve usability of citizens' science Phone APP also for MAC users; DNA methods standardization is absolutely necessary (now, it is difficult to compare results from different laboratories) .. Integrate acoustic receivers into already existing (or to be deployed) oceanographic observation platforms which will increase coverage in an easy and cost-effective way.

		Hidden Deserts Project Citizen science program monitoring underwater deserts. Compiles data on macroalgal cover and sea urchin densities by means of diving techniques (transect/quadrat), species, size classes. Involves dive clubs. **The Reef Check Mediterranean Sea** - Citizen science project focused on conducting visual censuses of 43 selected taxa, including algae, invertebrates, and vertebrates, with emphasis on noting the presence/absence, abundance, and depth range of these taxa. - Data collection also records the prevailing habitat, estimated underwater visibility, and precise geographic coordinates (WGS84) of each observation site. **OBAMA-NEXT (2022-2026)** Drones, submarine drones, eDNA, DNA metabarcoding, etc. Many of these methods are going to be developed. **MARBEFES, ANERIS** Emerging eDNA methods & protocols	

		STRAITS (HORIZON INFRA) Strategic Infrastructure for improved animal Tracking in European Seas (STRAITS) will leverage ongoing acoustic tracking projects across the four corners of Europe (i.e. North Channel, Danish Straits, Straits of Gibraltar and the Bosporus/Dardanelles) by expanding efforts to connect initiatives on species-based biodiversity management while developing data management plans and networking channels to deliver data to national and international governing bodies.	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Data repositories and standards:** OBIS, GBIF, TDWG Darwincore **EMODnet-Biology data portal** - Standardization to Darwin-Core. - Data harvest via VLIZ IPT - QC automatically via LW/EMODnet BioCheck tool - Direct download - OGC web services **FathomNet**	**EMO BON** Data Management (here Genomic Data FAIRification (data &metadata standardisation & harmonization; metadata forms; data integration; automated metadata QC) **DEVOTES** Nested Environmental status Assessment Tool (NEAT)**;** To integrate information, coming from different sources of data and different indicators. https://www.azti.es/en/productos/	Richer reference libraries for genomic data ETN: Ensure interoperability within acoustic tracking networks (see also note under "**Interoperability aspects"** about Open Protocols). Add the capability to have other biotelemetry data in the ETN database.

	Seabed photography (e.g. Ocean Floor Observation System, ROV's, AUV's) **BIIGLE 2.0 -** Browsing and Annotating Large Marine Image Collections **EN ISO 16665. Edition: 2014-08-01.** Water quality — Guidelines for qualitative sampling and sample processing of marine soft-bottom macrofauna. EN ISO 19493. Edition: 2007-09-01. Water quality — Guidance on marine biological surveys of hard-substrate communities. **European Tracking Network (ETN)** - Presence of animals tagged with electronic transmitters (mainly acoustic transmitters). A wide array of acoustic receivers, spread throughout Europe enables the detection of tagged fish. Marine invertebrates such as lobsters, crabs, and cephalopods have been tagged in the past. - ETN data encompasses detection date, time, and location, alongside measurements such as depth and temperature, all	neat/ There are plenty of papers published using this tool, which allows integrating multiple indicators. Although primarily developed for marine systems, it can be used in any realm	Procedures/workflows to get the analysed data to policy and decision-making Increase the number of volunteers across the Mediterranean Sea;

	centralized in a quality-controlled database. - ETN also offers training programs on aquatic telemetry basics, available at their website https://europeantrackingnetwork.org/en/training-school-aquatic-telemetry-basics		
Modelling Types of models Predictors Estimation & uncertainty Software	**Acoustic telemetry data** (ETN-type) provides presence data potentially at a very large spatial scale which can be used in species distribution modelling. Acoustic telemetry data is also analyzed using mixed-effect models to identify trends over time, drivers of behaviour, plasticity and intraspecific variation in behaviour although these methods do not directly apply to this EBV. There are several R packages commonly used to analyze telemetry data and calculate behavioural variables including ACTEL, GLATOS, ATT, adehabitatHR **EMODnet Biology Data Products** - Presence/Absence maps of benthic species in the North Sea: GitHub, Product	**Reef Check Mediterranean Sea** - uses citizen science to model species distribution, tracking presence, absence, and abundance, with sampling effort gauged by time. - Implements the MedSens Index, a biotic index assessing the sensitivity of 25 taxa to pressures outlined in MSFD Annex III, using a QGIS plugin for area and timeframe analysis. - Data collection is streamlined via the RCMed APP for Android, facilitating uploads from field activities. - Time series analysis, combined with citizen science data and CMEMS oceanographic models, aims to develop an early warning system for mortality events correlated with heatwaves	

	- Probability maps for different benthos species in the North Sea. GitHub, Product - Benthic occurrences, habitat maps, and species traits GitHub - Presence/absence data of macrozoobenthos in the European Seas. GitHub	**MOVE (Biodiversa+**) has just started and it wil be monitoring multi-scale movement behaviour of predatory fish across three countries in Europe (Spain, Norway and Portugal) with the possibility to record movements in other countries as part of the ETN. There is no website for the project yet.	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):
Reef Check Mediterranean Sea (citizen science initiative): data findability; proprietary WEBGIS/EMODnet/GBIF/OBIS/Zenodo, peer-rewieved articles published OA, QGIS plugin, free APP, data reusability CC-BY 4.0 (by attribution)
In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

Statement from the ETN about interoperability in acoustic telemetry protocols: https://europeantrackingnetwork.org/en/open-protocol

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
European Tracking Network database - https://www.lifewatch.be/etn/

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- CEAB-CSIC (Hidden Deserts): www.hiddendeserts.com, www.observadoresdelmar.es, www.ceab.csic.es

- EMO BON Sampling and Procedures Document in OBPS: Santi, I., Casotti, R., Comtet, T., Cunliffe, M., Koulouri, Y., Macheriotou, L., et al. (2021). European Marine Omics Biodiversity Observation Network (EMO BON) Handbook. Paris: EMBRC-ERIC doi: 10.25607/OBP-1653.
- EMODnet Biology data products
- **Reef Check Mediterranean Sea** (citizen science initiative): www.reefcheckmed.org

Species distributions of invasive alien marine taxa of European concern			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** **BE/NL, MARE Madeira monitoring** - Monitoring with **SERC** protocol (e.g. Smithsonian Institute, University of Pavia (IT), **Gimariis ARMS** (Smithsonian Institute)	**UseIt** Italian CNR Project. The project aims to hharmonisemonitoring strategies at the national level by taking into account European sampling standards. Raw data mostly consists of distribution and abundance data. **EMO BON** European Marine Omics Biodiversity Observation Network [regular sampling of macrofauna and meiofauna from soft substrates & passive sampling using Autonomous Reef Monitoring Structures (ARMS); sampling protocols (EMO BON handbook & ARMS Handbook); sampling design (handbook); genomic data (macro- & meiobenthos); genomic and imaging data (ARMS)] **ARMS-MBON** -Autonomous Reef Monitoring Structures to monitor marine	No structured monitoring programs. Develop a standardised monitoring program. Better training to monitor and collect alien/invasive/range expanding species. Expand geographical and taxonomic coverage (Mediterranean Sea) Sampling methods for passive and active (mobile) sampling Increase the coverage of acoustic receivers, particularly in key areas (bottlenecks such as Straits and passages and/or relevant areas such as EFHs) Integrate acoustic receivers into already existing (or to be deployed) oceanographic observation platforms, which will increase coverage in an easy and cost-effective way.

		biodiversity in near-coastal areas using genetic and visual methods, contributing to the GEO BON's MBON initiative. - Insights and methodologies of ARMS-MBON's approach to marine biodiversity monitoring are detailed in a publication in Frontiers in Marine Science. **<u>Citizen science projects:</u>** - Malta: “Spot the Alien” Campaign (https://www.aliensmalta.eu/) - Citizen science campaigns in the Mediterranean, e.g. Greece, Italy - Portugal: invasoras.pt	Having good/effective means of identification (i.e. genetic barcoding, species sometimes not available on Genbank) It would be ideal also to hold stable isotope analysis to determine where the individual organisms could be coming from (e.g. aquarium release, brought with oil rigs or ships, etc)
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EASIN** **-** European Alien Species Information Network is a comprehensive platform for monitoring and managing invasive alien species (IAS) within the European Union, including three marine species of Union concern. - Aggregates data from various sources, including citizen science projects, to compile detailed records on invasive species. - Offers a Catalogue of Alien Species, an Alien Species	**LifeWatch ERIC** **-** Focuses on investigating biodiversity and ecosystem functions through specialized workflows. **- Biotope Vulnerability Workflow:** Integrates various data sources into datacubes to assess biotope vulnerability. **- ARMS Workflos:** Utilizes bioinformatics to analyze DNA metabarcoding data from the ARMS project. Capable of identifying both native and alien	Ensure interoperability within acoustic tracking networks (see also note under “**Interoperability aspects”** about Open Protocols) Consider relevance of and incorporation of monitoring, data integration and modelling for ship based transport of invasive species and movement of invasive species through ballast water spillage. Need to consider efforts and information from or under UNCLOS, WMO, IMO given

	Geodatabase, and a specific Protocol for data handling. - Utilizes the EASIN Data Broker system to collect and standardize species occurrence data and related information from diverse data sources. **European Tracking Network (ETN)** Presence of fish (including alien species) tagged with electronic transmitters (mainly acoustic transmitters but also PIT, radio, archival and satellite tags). A wide array of acoustic receivers, spread throughout Europe enables the detection of tagged fish. Data includes detection date, time and location (coordinates). All data (from all partners) is in a quality controlled centralized database. Some transmitters include sensors that measure depth, activity, temperature, etc. The ETN organizes training schools: **WRiMS** The World Register of Introduced Marine Species records which marine species in the World Register of Marine species	species by consulting WoRMS and WRiMS databases. **EMO BON** Data Management (here Genomic Data FAIRification (data &metadata standardisation & harmonization; metadata forms; data integration; automated metadata QC) **National iniciatives** - UseIt Italian CNR Project. The project aims at providing guidelines for harmonisation, standardisation, and integration by following existing international standards including a data schema based on DwC and other controlled vocabularies and EML standards for metadata. Data and associated metadata will be uploaded on the central national repositories of data and metadata developed by LifeWatch Italy and that will be shortly available on the LW Ita website.	international nature of shipping, particular given climate impact and increased marine shipping in previously isolated or remote areas such as the Arctic and Antarctic.

	(WoRMS) have been introduced deliberately or accidentally by human activities to geographic areas outside their native range. WoRMS offers web services, and WoRMS taxon lists can be easily linked to EMODnet Biology/OBIS occurrences. **IUCN** - ISSG Invasive Species Specialist Group - GISD Global Invasive Species Database - EICAT standards classification invasive species **GISD** GLOBAL INVASIVE SPECIES DATABASE (GISD (iucngisd.org)) **EMODnet** Biology has a data workflow to compare harbour invasive species from the HELCOM/OSPAR ballast water database with occurrences in the EurOBIS database:		
Modelling Types of models Predictors Estimation & uncertainty	**National/Regionl initiatives** **Aegean Sea**		Assess the effectiveness of MPAs (Marine Protected Areas) regarding the introduction of invasive species

Software	Cumulative IMPacts of invasive ALien species (**CIMPAL**) (Katsanevakis et al 2016) Cumulative impact scores are estimated on the basis of the distributions of invasive species and ecosystems, and both the reported magnitude of ecological impacts and the strength of such evidence		Improves artificial Intelligence to identify found species

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):
In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.
Statement from the ETN about interoperability in acoustic telemetry protocols: https://europeantrackingnetwork.org/en/open-protocol
Suggestions from Magdalena Muir and can provide more information about international treaty based science processes as need to consider efforts and information from or under UNCLOS, WMO, IMO given international nature of shipping and ballast water spills for invasive species:
1) WMO has monitoring programs that could be considered across the marine EBVs, with summary from website below:
https://public.wmo.int/en/programmes/marine-meteorology-and-oceanography-programme
“The Marine Meteorology and Oceanography Programme (MMOP) coordinates, develops and recommends standards and procedures for a fully integrated marine observing, data management and services system using state-of-the-art technologies and capabilities. The Programme maximizes the benefits to Members through the projects, programmes and activities that it coordinates in their interest and in aid of the global marine community.
The Programme responds to the evolving needs of users of marine data and products, and includes an outreach programme to enhance the national capacity of all maritime countries. While safety at sea is its primary priority, coastal area management, disaster risk reduction and climate service applications have been integrated into the Programme.”

2) The International Maritime Organization does extensive work on the marine environment and ballast water issues, as well as creating a regulatory framework under the UN Convention on the Law of the Sea (Article 196) provides the global framework by requiring States to work together to prevent, reduce and control pollution of the marine environment including the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes
After more than 14 years of complex negotiations between IMO Member States, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was adopted by consensus at a Diplomatic Conference held at IMO Headquarters in London on 13 February 2004.
https://www.imo.org/en/OurWork/Environment/Pages/Default.aspx
https://www.imo.org/en/OurWork/Environment/Pages/BallastWaterManagement.aspx

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
Need to share and integrate data across multiple sources and particularly European and global regulation and treaties for shipping, ballast water management such as ballast water regulations by the International Maritime Organization.
https://www.aliensmalta.eu/
https://oceania.research.um.edu.mt/jellyfish/stats.html
https://harmony-italiamalta.eu/GIS.html

Phenology of migration of marine birds and mammals			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** **Migres Programme** Standardised long-term monitoring (i.e., visual count record) at a bottleneck area (the Strait of Gibraltar) targeting soaring birds but also for passerines and seabirds. Over this site, almost all the migratory seabird birds moving between the Mediterranean Sea and the Atlantic Ocean can be observed. Monitoring is mainly conducted by volunteers. There are other initiatives along the coast through the migratory route.	**Trektellen** Nocturnal migration (BIOACOUSTICS) https://trektellen.org/static/doc/Protocol_for_standardised_nocturnal_flight_call_monitoring_v01.pdf **STRAITS (HORIZON INFRA)** Strategic Infrastructure for improved Animal Tracking in European Seas (STRAITS) will leverage ongoing acoustic tracking projects across the four corners of Europe (i.e. North Channel, Danish Straits, Straits of Gibraltar and the Bosporus/Dardanelles) by expanding efforts to connect initiatives on species-based biodiversity management while developing data management plans and networking channels to deliver data to national and international governing bodies.	Increase the coverage (number) of acoustic receivers, particularly in key areas (bottlenecks such as Straits and passages, relevant areas such as EFHs). Integrate acoustic receivers into already existing (or to be deployed) oceanographic observation platforms, which will **increase coverage** in an easy and cost-effective way. There is not enough **spatially explicit** knowledge of migration habits and corridors to analyse phenology. Anyway, only local case studies (e.g. pelicans in the Gulf of Ambrakikos) can be analysed. European (and actually global) coverage would be very difficult, at least for mammals.
Data integration	**European Tracking Network (ETN)**	**European Tracking Network (ETN)**	Ensure interoperability within acoustic tracking networks (see

Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	Presence of animals tagged with electronic transmitters (mainly acoustic transmitters but also PIT, radio, archival and satellite tags). A wide array of acoustic receivers, spread throughout Europe enables the detection of tagged fish. Data includes detection date, time and location (coordinates). All data (from all partners) is in a quality controlled centralized database. Some transmitters include sensors that measure depth, activity, temperature, etc… A data platform to manage aquatic tracking data. There is a workflow to convert datasets to OBIS. **Movebank** Moveapps for analysing tracking data from movebank (https://www.moveapps.org/) https://www.movebank.org/cms/movebank-main	Increasing the coverage of the European Tracking Network database. It currently includes acoustic telemetry data but it is being expanded to also include archival tags data. Other technologies, such as PIT tags, radio tags and satellite tags could also be included.	also note under "**Interoperability aspects"** about Open Protocols). Add the capability to have other biotelemetry data in the European Tracking Network database. Ensure interoperability within acoustic tracking networks
Modelling Types of models Predictors Estimation & uncertainty Software	**Machine learning techniques** for development of predictive models based on environmental open-data: Martin, Beatriz & Onrubia, Alejandro & González Arias, Julio & Vicente-Vírseda, Juan. (2020).	**MOVE** (Biodiversa+ project; IP: Esben Moland Olsen from IMR Norway) has just started, and it will be monitoring the multi-scale movement behaviour of predatory	Machine Learning methods for classification

	Citizen science for predicting spatio-temporal patterns in seabird abundance during migration. PLOS ONE. 15. e0236631. 10.1371/journal.pone.0236631. **Acoustic telemetry data** (ETN-type) provides presence data potentially at a very large spatial scale which can be used to understand timing of migration in fish and aquatic invertebrates. There are different modelling options. One of them is to use mixed-effects models to investigate timing o departure or arrival (for instance using binomial family distributions). Survival models are sometimes used too. There are several R packages commonly used to analyze telemetry data and calculate behavioural variables including ACTEL, GLATOS, ATT, adehabitatHR . Residence indices are commonly used to analyze length of stay in fish and this can be estimated with the above packages or with custom made software.	fish across three countries in Europe (Spain, Norway, and Portugal) with the possibility of recording movements in other countries as part of the ETN. There is no website for the project yet.	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			

Statement from the ETN about interoperability in acoustic telemetry protocols: https://europeantrackingnetwork.org/en/open-protocol
In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
European Tracking Network database - https://www.lifewatch.be/etn/ and https://europeantrackingnetwork.org/en. The data system is set-up and maintained by LifeWatch Belgium.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- https://doi.org/10.1186/s40317-018-0156-0
- https://doi.org/10.1111/gcb.16343

Functional composition of marine phyto/zooplankton			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**eLTER-RI** Monitoring of phytoplankton and zooplankton abundances and composition at selected marine and transitional water sites across Europe **MSFD** and WFD implementation by the National Environmental Agencies (see Ponis et al., 2019) **National initiatives** **NIMRD** Local sampling, across transect, along the Romanian Black Sea coast; Samples are collected mainly 2 times/year from different depths with Niskin Bottle; Raw data: phytoplankton composition, phytoplankton abundance (cell/L) and phytoplankton biomass (mg/m3). **HELCOM** Sampling in the Baltic Sea. Swedish plankton data (both morfotaxa and DNA) are stored at	**EMO BON** European Marine Omics Biodiversity Observation Network [regular sampling of macrofauna and meiofauna from soft substrates & passive sampling using Autonomous Reef Monitoring Structures (ARMS); sampling protocols (EMO BON handbook & ARMS Handbook); sampling design (handbook); genomic data (macro- & meio-benthos); genomic and imaging data (ARMS)] **BOOMS** Phytoplankton functional types from remote sensing have been investigated in oceanic waters (BOOMS)	In situ radiometers for RS integration and modeling of functional groups based on spectral characteristics Standardisation of protocols Increasing spectral resolution on reflectance data can provide additional information useful to separate among different functional types In situ probes would speed the taxa/functional recognition for monitoring purposes without the need of waiting for the sequencing and data processing Operational omics approaches Increase data collection. Data limitation is the main barrier to advancing the state of the art of plankton diversity.

	https://sharkdata.smhi.se/about/ and harvested to GBIF already. **LifeWatch** Sampling stations at Belgian part of the North Sea.		Seascape definition can also be used to support modelling with zooplankton species distribution models using satellite remote sensing data project BOOMS
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EMODnet Biology/EurOBIS/OBIS** Darwin Core standards, NERC/BODC vocabularies, WoRMS taxonomy **eLTER-RI** Developing guidelines for data sharing and metadata format of sites/sampling stations, sensors and dataset (DEIMS-SDR - https://deims.org) **EcoPortal** Semantic resources is the LifeWatch ERIC repository of semantic resources for ecology and related domains (https://ecoportal.lifewatch.eu/) documentation: https://github.com/lifewatch-eric/documentation/wiki **National initiatives** **NIMRD**	**EMO BON** Data Management (here Genomic Data FAIRification (data &metadata standardisation & harmonization; metadata forms; data integration; automated metadata QC) **H2020 project DEVOTES** To integrate information, coming from different sources of data and different indicators, within the project DEVOTES, we developed the Nested Environmental status Assessment Tool (NEAT), **GES4SEAS** Now, in a Horizon Europe project (www.ges4seas.eu) we are building on NEAT, to develop a tool able to assess multiple pressures, the status of the sea (including multiple ecosystem components), and the ecosystem services delivered. This will	Data harmonization Integration of sleeping/historical datasets Increase data sharing between organizations, administrations and countries Enrichment of reference omics databases Procedures/workflows to get the analysed data to policy and decision making

	Phytoplankton Historical data from the Romanian Black Sea coast was standardised. **LifeWatch Italy** The Italian node of the e-science European infrastructure for biodiversity and ecosystem (LifeWatch ERIC) aims to support the scientific community providing e-science tools and digital services such as data portals, semantic resources, workflows, virtual research environments, in order to facilitate the ecological research in all its phases. We promote the collection, integration, interoperability, analysis and sharing of biodiversity and environmental data and metadata, through the application of FAIR and Open principles (DwC standards and other controlled vocabularies and EML standards for metadata) (https://www.lifewatchitaly.eu/)	include different ways of integration **Jerico-S3** Developing guidelines for data integration of plankton imagery data **DTO-Bioflow** Improve the standards and procedures for plankton imaging observation networks, optimize the dataflow towards EMODnet Biology/EurOBIS, as well as create relevant data products. **LifeWatch Italy's Semantic Tools**: - Develops thesauri for phytoplankton and zooplankton traits to support biodiversity research. - Data Standardization: Introduces a Phytoplankton Data Template based on Darwin Core and specific trait thesauri for harmonized data collection. - Semantic Search Platform: Tests a semantic platform designed for enhanced access to LifeWatch Italy's resources using enriched semantic queries.	

Modelling Types of models Predictors Estimation & uncertainty Software	**OceanParcels** (a set of Python classes and methods to create customisable particle tracking simulations using output from Ocean Circulation models. Parcels can be used to track passive and active particulates such as water, plankton, plastic and fish. **Copernicus models** are mostly biogeochemical and include phytoplankton and zooplankton functional groups. **FABM model** is a model set up than links ecological, biogeochemical and physical models together. Has been used for forcing ecological models that use EBV with biogeochemistry and physics. FABM has been used for monitoring HABs and as a policy advice tool for coastal regions in the North Sea (e.g., Kemiroglu et al., 2023). **Seapodym** is a global ecosystem model with good spatial resolution for European seas. Has good projections for micronekton and is being further developed for increasing the zooplankton and micronekton diversity to better link	**Continuous Plankton Recorder (CPR):** Enhances plankton monitoring with the integration of omics and new imaging data. **PlanktoScope:** Offers frugal, high-quality in-situ imaging tools accessible to both scientists and the general public. **BGC Argo Program:** Integrates physical, biogeochemical, and biological observations of plankton with innovative sensors and imaging tools. **Acoustic Monitoring (MarcoBolo):** Applies acoustics to study meso/macrozooplankton and micronekton. **Phytoplankton Virtual Research Environment (Phyto VRE) by LifeWatch Italy:** Provides computational and analytical services for phytoplankton research, including species identification and trait analysis. **Blue-Cloud EOV Demonstrators:** Features a virtual lab for analyzing nutrient and plankton dynamics, offering	Using a high resolution hydrodynamic model would provide better insight into small scale hydrodynamic processes that can influence particle distribution.

	lower and higher trophic levels. Some applications: projecting habitat suitability and as advice for MPAs and studying the effect of extreme events on zooplankton.	mechanistic models and neural network analyses for phytoplankton and zooplankton. **EcoTaxa:** An AI-assisted platform for the classification and validation of plankton images, with capabilities to export data to OBIS Darwin Core format.	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):
Remote sensing data are in netCDF usually
In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
In the future EDITO- the European Digital Twin of the Ocean should provide data and resources to calculate and model indicators.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Mortelmans, J.; Goossens, J.; Amadei Martínez, L.; Deneudt, K.; Cattrijsse, A.; Hernandez, F. (2019). LifeWatch observatory data: zooplankton observations in the Belgian part of the North Sea. *Geoscience Data Journal 6(2)*: 76-84. https://dx.doi.org/10.1002/gdj3.68
- European Commission, Joint Research Centre, Ponis, E., Pagou, K., Giovanardi, F., et al., Transitional waters Mediterranean geographic intercalibration group : phytoplankton ecological assessment methods, Publications Office, 2019, https://data.europa.eu/doi/10.2760/239940

- Martin-Cabrera, P., Perez Perez ,R., Irisson, J-O., Lombard, F., Möller, K.O., Rühl, S., Creach, V., Lindh, M., Stemmann, L. and Schepers, L. (2022) Best practices and recommendations for plankton imaging data management: Ensuring effective data flow towards European data infrastructures. Ostend, Belgium, Flanders Marine Institute, 31pp. DOI: http://dx.doi.org/10.25607/OBP-1742
- Biodiversity in the Open Ocean: Mapping, Monitoring and Modelling (BOOMS) European Space Agency precursor project
- I am a co-author in these publications. Happy to connect you with other co-authors from those papers if you need their expertise (Maria Grigoratou)
- *Grigoratou et al. 2022: The Marine Biodiversity Observation Network (MBON) plankton workshops: "Plankton ecosystem function, biodiversity, and forecasting - research requirements and applications", L&O Bulletin, https://doi.org/10.1002/lob.10479*
- *Ratnarajah, L., Abu-Alhaija, R., Atkinson, A. et al. Monitoring and modelling marine zooplankton in a changing climate. Nat Commun 14, 564 (2023). https://doi.org/10.1038/s41467-023-36241-5*
- *Acevedo-Trejos E, Cadier M, Chakraborty S, Chen B, Cheung SY, Grigoratou M, Guill C, Hassenrück C, Kerimoglu O, Klauschies T, Lindemann C, Palacz A, Ryabov A, Scotti M, Smith SL, Våge S and Prowe F (2022) Modelling approaches for capturing plankton diversity (MODIV), their societal applications and data needs. Front. Mar. Sci. 9:975414. doi: 10.3389/fmars.2022.975414*
- *Kerimoglu, O., Pahlow, M., Anugerahanti, P., and Smith, S. L.: FABM-NflexPD 2.0: testing an instantaneous acclimation approach for modeling the implications of phytoplankton eco-physiology for the carbon and nutrient cycles, Geosci. Model Dev., 16, 95–108, https://doi.org/10.5194/gmd-16-95-2023, 2023.*
- BiOcean5D Horizon project: MARINE BIODIVERSITY ASSESSMENT AND PREDICTION ACROSS SPATIAL, TEMPORAL AND HUMAN SCALES: https://www.azti.es/en/proyectos/understanding-marine-biodiversity-for-a-sustainable-ocean/
- EMO BON Sampling and Procedures Document in OBPS: Santi, I., Casotti, R., Comtet, T., Cunliffe, M., Koulouri, Y., Macheriotou, L., et al. (2021). European Marine Omics Biodiversity Observation Network (EMO BON) Handbook. Paris: EMBRC-ERIC doi: 10.25607/OBP-1653.
- Garate L *et al.* (2022) Shared and contrasting associations in the dynamic nano- and picoplankton communities of two close but contrasting sites from the Bay of Biscay. *Environ Microbiol* 24, 6052--6070.https://doi.org/10.1111/1462-2920.16153
- OceanParcels - a Lagrangian Ocean Analysis toolbox
- Frontiers | Computing marine plankton connectivity under thermal constraints (frontiersin.org)
- Ilaria Rosati et al., 2017 A thesaurus for phytoplankton trait-based approaches: Development and applicability,Ecological Informatics,Volume 42,2017,Pages 129-138,ISSN 1574-9541,https://doi.org/10.1016/j.ecoinf.2017.10.014.
- Rosati et al. (2017). LifeWatch Italy Thesauri Documentation, Version 1.0. Roma, CNR Pubblicazioni 2017, pp.18, ISBN 978-88-8080-249-5
- Stanca, E., Fiore, N., Rosati, I., Vaira, L., Cozzoli, F., Basset, A,Case Study: LifeWatch Italy Phytoplankton VRE.*Towards Interoperable Research Infrastructures for Environmental and Earth Sciences* (2020).https://doi.org/10.1007/978-3-030-52829-4_18
- Cabrera, Patricia, & Drago, Federico. (2022). Zoo- and Phytoplankton Essential Ocean Variable products. Zenodo. https://doi.org/10.5281/zenodo.7229886 (Short description of the Blue-Cloud EOV demonstrator).

Ecosystem distribution of hard corals habitats			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building			Design an EU structure sampling design.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EMODnet** Broad-scale seabed habitat mapping for Europe (e.g. EUSeaMap 2021) **Habitats Directive** Data reporting (habitat "reefs"), different monitoring programs (e.g. maps of threatened and/or declining habitats hard corals developed by the OSPAR convention) **Regional initiatives** **OSPAR Status Assessment 2022** - *Lophelia pertusa* reefs: https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/lophelia-pertusa-reefs/	**The Sustainable Seabed Knowledge Initiative** (SSKI) of the International Seabed Authority (ISA) https://isa.org.jm/sski/) **National initiatives** Presentation on benthic imagery workflows (in UK) towards OBIS: https://data.jncc.gov.uk/data/73ded805-d741-4f24-aff0-595bdfef6293/bp2-day-2-03-b.pdf	

	ICES Vulnerable Marine Ecosystem database (for N-Atlantic): https://www.ices.dk/data/data-portals/Pages/vulnerable-marine-ecosystems.aspx		
Modelling Types of models Predictors Estimation & uncertainty Software	**EMODnet maps** Vector format for the Atlas of Marine Life in Europe. **Habitat suitability models** for several coral species in the Atlantic in the iAtlantic project:	**Mission Atlantic** AI/ML classification of acoustic multibeam data to derive suitable (habitat) maps. (e.g. MissionAtlantic project)	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project)			

Ecosystem distribution of marine macroalgae canopy cover (more info)			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building		SeaBee is using Machine Learning Methods (Convolutional Neural Network CNN) combined with in situ Ground Truth data to map coastal vegetation. SeaBee is developing a protocol for collecting in situ ground truth data (using Leica high precision GPS) and annotation (using ArcGIS Pro) for this. **Bicome** Biodiversity of the Coastal Ocean Satellite Remote sensing and drones Bicome **OBAMA-NEXT Project** This Horizon Europe project (2022-2026) focuses on developing innovative monitoring methods and technologies for mapping and monitoring marine ecosystems, including benthic habitats like macroalgae. **Hidden Deserts Project** A citizen science effort monitoring	Including hyperspectral and high spatial-resolution data More effective and precise methods for in situ ground truthing to train algorithms. One way is to use unmanned surface vehicles equipped with different sensors (both acoustic and optical). Biomass of macroalgae (as a proxy of carbon content, perhaps) may be measured using LIDAR or acoustics. Standards in situ that can be compared with remote sensing measures of habitat diversity

		underwater deserts, gathering data on macroalgal cover and sea urchin densities using diving techniques and engaging dive clubs.	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EMODnet** Broad-scale seabed habitat mapping for Europe (e.g. EUSeaMap 2021) **National initiatives** **CEAB-CSIC** A Remote Sensing Lab that integrates classic marine ecology sampling techniques with remote sensing platforms to map underwater vegetated habitats (seaweed meadows and macroalgal forests). We use drones and satellites to collect imagery and take advantage of ongoing monitoring programs at the centre gathering in-situ validation data. **SeaBee** is a Norwegian infrastructure for drone-based research, mapping and monitoring in the coastal zone. They are mapping coastal vegetation, including seagrass and	**DEVOTES Project:** Utilizes the Nested Environmental Status Assessment Tool (NEAT) to integrate diverse data sources and indicators for comprehensive environmental status assessments.	Standards in situ that can be compared with remote sensing measures of habitat diversity

	macroalgae with preliminary models that separate between these.		
Modelling Types of models Predictors Estimation & uncertainty Software	**EMODnet maps** Broad-scale seabed habitat mapping for Europe (e.g. EUSeaMap 2021)**.** Data form Habitats Directive reporting, different monitoring programs (e.g. maps of threatened and/or declining habitats hard corals developed by the OSPAR convention) and others **Bio-Oracle** Marine data layers for ecological modelling. Serves as a baseline for Species Distribution Modelling in macroalgae and future predictions under climate change scenarios **National initiatives** **Norwegian Institute for Water Research** (NIVA) has modelled kelp density for the whole coast of Norway at a 25x25m resolution. Available here.	**SeaBee** is using Machine Learning Methods (Convolutional Neural Network CNN) combined with in situ Ground Truth data to map coastal vegetation. SeaBee is developing a protocol for collecting in situ ground truth data (using Leica high precision GPS) and annotation (using ArcGIS Pro) for this. **GES4SEAS Project** A Horizon Europe initiative aimed at developing a tool under the GES4SEAS project for assessing multiple pressures, sea status, ecosystem components, and delivered services using diverse integration methods.	Separate between different coastal vegetation types using machine learning (SeaBee is working on this). OBAMA-NEXT and SeaBee are looking into the possibilities to upscale local algorithms/models (based on drone data) to larger regions using satellite data.

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Bicome: Biodiversity of the Coastal Ocean: Monitoring with Earth Observation European space Agency (ESA) project : https://www.bicome.info/
- https://www.restoreseas.net/
- 10.1038/s41598-022-26439-w
- 10.1111/geb.13515
- 10.1038/s41597-020-0459-x

Ecosystem distribution of marine seagrass habitats			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** **German TMAP-,WFD-Monitoring**: Yearly mapping of intertidal eelgrass beds by aerial photos (area covered, density) and biomass sampling in respective beds (Wadden Sea); depth limit assessment, density assessment and biomass sampling in (subtidal) eelgrass beds (only) in the Baltic Sea.	**SeaBee** Norwegian infrastructure for drone-based research, mapping and monitoring in the coastal zone. They are mapping coastal vegetation using in-situ ground truth data together with drone imagery, including seagrass and macroalgae with preliminary models that separates between these. **BiCOME project** Using remotely sensed reflectance close to the shoreline (e.g. global ocean colour satellite datasets), also preparing for the advent of operational hyperspectral satellite imagers. **CEAB-CSIC** Developing a Remote Sensing Lab that integrates classic marine ecology sampling techniques with remote sensing platforms to map underwater vegetated habitats (seaweed meadows and macroalgal forests). We use	More effective and precise methods for in-situ ground truthing to train algorithms. Use Unmanned Surface Vehicles equipped with different sensors (both acoustics and optical) SeaBee. Use citizen science (OBAMA-NEXT) Given shared but limited sea grasses species across the Atlantic, it is suggested that consider North America and Arctic work in this area. Many more researchers will be willing to support this EBV framework, but are not aware of its existence Use forthcoming hyperspectral satellite imagers

		drones and satellites to collect imagery and take advantage from ongoing monitoring programs at the center gathering in-situ validation data. **OBAMA-NEXT** The EU-project is looking at new technologies to map and monitor marine ecosystems (including benthic habitats such as seagrass). **Seabee** Developing a protocol for collecting in situ ground truth data (using Leica high precision GPS) and annotation (using ArcGIS Pro) for this.	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Habitats Directive** Data form Habitats Directive reporting, different monitoring programs (e.g. maps of threatened and/or declining habitats hard corals developed by the OSPAR convention). **EMODnet** Broad-scale seabed habitat mapping for Europe (e.g. EUSeaMap 2021): Aligning of classification systems: Europe-wide (EUNIS habitat classification 2007, EUNIS marine	**OBIS - GBIF** Darwin Core standards for in situ validation data.	Align standards and classification systems of in-situ data with remote sensing measures of habitats Integrate past in-situ data collected in the framework of many different research projects, to be available for the RS community. Consider work on similar or related seagrass species on both sides of the Atlantic, given more

	habitat classification 2019 and MSFD Benthic Broad Habitat Types), and two regional classifications (HELCOM Underwater Biotopes in the Baltic and Barcelona Convention habitat types in the Mediterranean).		limited species present in Atlantic and potential future need to transplant species between regions, given changes in water temperature and other factors due to climate shifts.
Modelling Types of models Predictors Estimation & uncertainty Software	**EMODnet** Broad-scale seabed habitat mapping for Europe (e.g. EUSeaMap 2021), based on habitat point data, geology, substrate etc.	**SeaBee** Using Machine Learning Methods (Convolutional Neural Network CNN) combined with in situ Ground Truth data to map coastal vegetation.	Restoration activities for some specific species; proper mapping; presence/absence of disease signs Upscale local algorithms/models (based on drone data) to larger regions using satellite data. Separate between different coastal vegetation types using machine learning Modelling required for sea grasses as area of carbon mitigation and use for climate adaptation. Several seagrass bed quality parameters/indices should/could be developed using drones (coverage/distribution, density, shoot length, turf algae coverage, biomass, etc.) (SeaBee is aiming for this). Relevant for instance for the WFD.

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):
In the ocean domain, yhe IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
Harmonization of data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- EUSeaMap 2021: https://emodnet.ec.europa.eu/en/euseamap-2021-emodnet-broad-scale-seabed-habitat-map-europe
- BiCOME: Biodiversity of the Coastal Ocean: Monitoring with Earth Observation European space Agency (ESA) project : https://www.bicome.info/
- OBAMA-NEXT: https://obama-next.eu/
- SeaBee: https://seabee.no/
- Ocean Data and Information System (ODIS): https://oceaninfohub.org/odis/
- Ocean InfoHub (OIH): https://oceaninfohub.org/
- Documentation of Ocean InfoHub: https://book.oceaninfohub.org/index.html
- Ocean Biodiversity Information System (OBIS): https://obis.org/
- European Marine Observation and Data Network (EMODnet): https://emodnet.ec.europa.eu/en
- ODIS specifications for sharing Essential Ocean Variables (EOVs): https://book.oceaninfohub.org/thematics/variables/index.html
- GOOS BioEco Metadata Portal: https://bioeco.goosocean.org/
- https://www.restoreseas.net/
- 10.1038/s41597-020-0459-x

Ecosystem distribution of oyster reef habitats			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** **TMAP** National monitoring on blue mussel and Pacific oyster beds in the Wadden Sea, aerial photos, acoustic imaging (multibeam) and core sampling in respective beds	**TAO** Coastal monitoring technologies Implementation of a technological platform consisting of mobile and fixed monitoring stations with low environmental impact and low cost for the investigation of littoral and supra / sub-littoral areas. It will be accompanied by autonomous surface vehicles equipped with ad-hoc instruments that will allow the implementation of seabed 3D models based on morpho-bathymetric surveys, surface stratigraphy, and distribution of the sediments in the area.	Need for an EU-coordinated monitoring system
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**OSPAR Status Assessment 2020** European flat oyster and Ostrea edulis beds: https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-assesments/european-flat-oyster/		

Modelling Types of models Predictors Estimation & uncertainty Software	**Delft3D** To assess the impact of the bottom shear stress on oyster reefs https://www.deltaexpertise.nl/images/3/35/Oyster_reefs_in_inter_tidal_areas_-_RAAKPRO.pdf		

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):
In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g. this query for corals data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
ODIMS: OSPAR Data and Information Management System. http://odims.ospar.org/ (this information system actually hosts all kind of marine environmental information).

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- https://qsr.waddensea-worldheritage.org/reports/subtidal-habitats
- Ricklefs, K., Büttger, H., Asmus, H. (2020) *Occurrence, stability, and associated species of subtidal mussel beds in the North Frisian Wadden Sea (German North Sea Coast)*. Estuarine, Coastal and Shelf Science 233, 106549
- A couple of studies have been made at Deltares for suitability maps for potential locations for oysters, particularly in the context of European projects as FORCOAST (https://doi-org.tudelft.idm.oclc.org/10.1093/conphys/coac034), UNITED or ULTFARMS and other studies, see for example https://doi.org/10.3390/su10113942. TAO project website: www.tao.consorzioproambiente.it/en/about-project-2/

Degree of seabed disturbance			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building			Need to have data collection and sampling expanded to address future seabed disturbance from new sources such as seabed mining, additional marine cables, including high voltage electric cables or fibre optic or telecommunications cables. Deep-sea data is absent
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EMODnet** Broad-scale gathering of human activities for Europe. **MSFD assessment guidance** https://www.aquabiota.se/wp-content/uploads/european-commission-2022.-msfd-cis-guidance-document-no.-19-article-8-msfd-may-2022.pdf,in particular D6 MSFD Descriptor 6. All reported information can be accessed via WISE-Marine https://water.europa.eu/marine/da	**GES4SEAS** In a Horizon Europe project (www.ges4seas.eu), we are building on NEAT, to develop a tool able to assess multiple pressures, the status of the sea (including multiple ecosystem components), and the ecosystem services delivered. This will include different ways of integration.	Harmonisation in protocols between different data portals/repositories, e.g. data on pressures human activities are uploaded to national repositories, HELCOM and EMODnet repositories with different protocols

	ta-maps-and-tools/msfd-reporting-information-products **Regional initiatives** **HELCOM Core Indicator CumI** Cumulative impact from physical pressures on benthic biotopes (CumI) integrating impacts of bottom trawling fishery, mariculture, extraction and disposal of sediments, pipelines and cables, platforms and windfarms, coastal protection, shipping HELCOM Data and map portal Dublin Core metadata **OSPAR Common indicator:** Condition of benthic habitat communities (BH2)		
Modelling Types of models Predictors Estimation & uncertainty Software		**H2020 project DEVOTES** To integrate information coming from different sources of data and different indicators, within we developed the Nested Environmental Status Assessment Tool (NEAT), freely available here: https://www.azti.es/en/productos/neat/	Need to have data modelling be expanded to address future seabed disturbance from new sources such as seabed mining, additional marine cables, including high voltage electric cables or fibre optic or telecommunications cables

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):
In the ocean domain, the IOC-UNESCO Ocean Data and Information System (ODIS) is creating generic interoperability architecture for all domains, including biodiversity, and implementing knowledge bases through Ocean InfoHub (OIH). Documentation here. OBIS is already connected to OIH/ODIS, as is EMODNet (e.g., this query for coral data sets with spatial metadata), and more biodiversity data providers will follow. ODIS specifications for sharing EOV data have been created, and will be refined for the Biology and Ecosystem EOVs (which overlap with the EBVs) to allow the BioEco EOV portal to interoperate more impactfully. **Future need:** Harmonise the data flows between ODIS and emerging GEO BON data systems (e.g. GBiOS, BiaB) such that EOV/EBV data can flow or at least be discovered simultaneously and frictionlessly.

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
HELCOM Data and map service
Consider whether useful to have integrated marine spatial planning and mapping that includes specific information of disturbances on geospatial basis, where parties can either have references to or drill down to that data. This already tends to be done for hydrocarbon, waters and minerals and could also be done for sea bed disturbances.
There is much data in gray literature, commercial sources, or to support specific projects or initiatives, given the commerciality of seabed disturbance. There may be further information that available through military monitoring and sources.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- HELCOM (2022) Cumulative impact from physical pressures on benthic biotopes. HELCOM indicator report. Online. [Date Viewed], [Web link]. ISSN 2343-2543
- Berg T, Murray C, Carstensen J, Andersen JH (2016): NEAT – Nested Environmental status Assessment Tool. Manual – Version 1.2. Project: DEVOTES: DEVelopment Of innovative Tools for understanding marine biodiversity and assessing

Phenology of marine spring phytoplankton bloom			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiative** **Belgian LifeWatch observatory on phytoplankton:** https://www.lifewatch.be/en/local-observatory-data-phytoredplankton-4		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**MSFD** MSFD competence centre for descriptor 5 https://mcc.jrc.ec.europa.eu/main/dev.py?N=23&O=398&titre_chap=D5%20Eutrophication&titre_page=Monitoring%20&%20Assessment Under the MSFD, each Regional Sea Convention has a programme and compilation about “eutrophication” that normally covers nutrients, Chlorophyll a, algal blooms and primary productivity **EMODnet**		

	Catalogue for MSFD descriptor 5 (pdf version: https://marine.copernicus.eu/news/new-catalogue-support-msfd-joint-copernicus-marine-and-emodnet-initiative but better online) **National initiative** LifeWatch Belgium has developed some RShiny applications to explore and download data on phytoplankton from its local observatory: https://rshiny.lifewatch.be/flowcam-data/		
Modelling Types of models Predictors Estimation & uncertainty Software	**EMODnet Biology data** Aim to tackle the distribution of phytoplankton distribution and temporal variations. Some examples: - 'Proof of concept' product: Fraction of mixoplankton (photo-phagotrophic) species in the Greater North Sea and Celtic Seas - Presence/Absence maps of phytoplankton in the Greater North Sea	**Blue Cloud Phytoplankton EOV demonstrator**: Global open ocean three-dimensional (3D) gridded products of (1) chlorophyll a concentration (Chla), which is a proxy of the total phytoplankton biomass, and (2) Phytoplankton Functional Types (PFT), as a proxy for phytoplankton diversity, based on vertically-resolved *in situ* data of ocean physical properties (temperature and salinity) matched up with satellite products of ocean color and sea level anomaly. Copernicus	

	- Presence/Absence maps of phytoplankton in the Greater Baltic Sea - Probability maps for different phytoplankton species in the North Sea	product with DOI http://doi.org/10.48670/moi-00046	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): Racault, Marie-Fanny, Trevor Platt, Shubha Sathyendranath, Ertuğrul Ağirbaş, Victor Martinez Vicente, and Robert Brewin. 2014. “Plankton Indicators and Ocean Observing Systems: Support to the Marine Ecosystem State Assessment.” Journal of Plankton Research 36 (3): 621–29. Biodiversity in the Open Ocean: Mapping, Monitoring and Modelling (BOOMS) European Space Agency precursor project			

Marine primary productivity			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	COPERNICUS (datasets available but hidden in the catalogue)	HR Copernicus coastal initiatives - SeaCras uses high-resolution satellite data, especially from Sentinel missions, to advance coastal water monitoring for the Mediterranean. - The project develops AI models with in-situ data to improve water quality - SeaCras aids coastal parks like Croatia's Brijuni in making informed decisions for marine protection and sustainable use,	Extend to coastal areas Increase of in situ validation data collection is needed
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	MSFD Member States should focus their monitoring on nutrients levels and on those direct effects (e.g. Chl-a concentration, phytoplankton abundance and composition, water transparency) and indirect effects (e.g. oxygen concentration, macrophytes) that are closely linked to nutrient enrichment and relevant to their marine region or sub-region	Copernicus Marine & EMODnet catalogue New catalogue form Copernicus Marine & EMODnet catalogue to support European Member States with the implementation of the Marine Strategy Framework Directive (MSFD).	

Modelling Types of models Predictors Estimation & uncertainty Software	**Primary production models from remote sensing** (basically all biogeochemical model has a PP component): 1. **NASA** 2. **Environmental Marine Information System (EMIS)** 3. **JRC MSFD Modelling Framework implementation** **4. Copernicus**	**Biological Pump and Carbon Exchange Processes (BICEP) project** - Phytoplankton primary production from satellite remote sensing Bicep project productivity. - Synthesize existing knowledge to identify scientific requirements and create key RS products - Generate the BICEP dataset for a new satellite-based analysis of the ocean's biological carbon pump, detailing carbon pools and fluxes and their spatiotemporal variations - Compare satellite-based estimates with ocean model predictions and integrate findings into broader Earth System carbon cycle models.	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): Kulk, Gemma, Trevor Platt, James Dingle, Thomas Jackson, Bror F. Jönsson, Heather A. Bouman, Marcel Babin, et al. 2020. “Primary Production, an Index of Climate Change in the Ocean: Satellite-Based Estimates over Two Decades.” *Remote Sensing* 12 (5): 826. https://doi.org/10.3390/rs12050826.			

Genetic diversity of selected terrestrial taxa			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building		**G-Bike** aims to enable standard and routine tools for assessing, monitoring and managing the genetic resilience and related adaptive potential of wild and captive populations **G-bike** is an initiative to develop monitoring, tools and standardized protocols and formats for genetic diversity in wild populations. Not only restricted to the marine realm. Population monitoring by genetic analyses under **IPA project** framework (Implementation of the National Action Plan for brown bear conservation in Romania) **LIFEPLAN** is a global initiative by the University of Helsinki. It is a six-year-long projecinon 83 global locations (including Europe). It consists on the continuous monitoring of soil fungi, airborne fungi and insects (captured	Improvement and increasing accessibility to novel technologies for massive sampling and monitoring (eDNA, metabarcoding) Add temporal trends in genetic monitoring to understand the risk of genetic changes in extinction risk. Determine which species are important to be monitored at the population level to measure genetic diversity within species.

		through Malaise traps) through metabarcode.	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Biodiversity Information Standards (TDWG)** https://www.tdwg.org/community/dwc/ which includes the Darwincore Maintenance Group and Interest Group Observations & Specimens Databases: Gbif, BOLD, NCBI, Darwin Tree of Life **Metadata:** GEOME https://geome-db.org/ **National Initiatives** Biobank at LIB - Museum Koenig, Germany https://bonn.leibniz-lib.de/en/biobank Comprises not only Natural-History-collection materials but also the national GBOL 1-3 projects (counts also for data integration)	**B-cubed** (https://doi.org/10.3030/101059592): creating data cubes on species occupancy from data mobilised by GBIF. Evaluating standards for publication and analysis of aggregated biodiversity data, developing data aggregation algorithms to reduce bias. **Biodiversity Genomics Europe (BGE)project:** Brings together BIOSCAN (DNA barcoding) and ERGA (European Reference Genome Atlas) **ERGA** initiative (European Reference Genome Atlas) as European node of the Earth Biogenome project aims to sequence reference genomes of all European biodiversity.	Integration of data from different genetic 'markers' (e.g. microsatellites vs. SNPs and genomic data) Transferability tools For standardization, Determining minimum number of markers and samples needed to estimate genetic diversity parameters and trends Provide automatic workflows producing biodiversity indicators Establish database for reference genomes, which provide highly contiguous, accurate, and annotated genome assemblies to provide a solid, quantitative, and comparable foundation for biodiversity assessments, conservation, management, and restoration. Access to reference libraries for barcodes and genomes which include not only the raw data, but

			important associated data as the coordinates, date etc A main requirement for monitoring genetic diversity is the availability of whole sequenced genomes. For those flagship taxa that are going to be monitored such information is required as a reference. Open access to all the row data
Modelling Types of models Predictors Estimation & uncertainty Software			Determine the level of genetic diversity that should be maintained to optimize conservation efforts Four EBV to cover the components of Wrights genetic variation and together provide a comprehensive description of the impacts of environmental change on genetic composition : 1) genetic diversity in terms of richness and He, 2) genetic differentiation in terms of number of genetic units and distance genetic units, 3) inbreeding and 4) Ne

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Provide automatic workflows producing biodiversity indicators. Databases that can host all types of data, including proxy and DNA based data. Aim for FAIR sharing of data

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- EBV data portal for genetic data
- Databases that can host all types of data, including proxy and DNA based data. Aim for FAIR sharing of data.
- An important aspect of monitoring genetic diversity is also the requirement of storing DNA samples. Future synthesis might make it necessary to re-analyze stored DNA, which requires DNA repositories.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- GEOBON, the Coalition of Conservation Genetics, IUCN SSC Conservation Genetics Specialist Group and EU COST Action Network G-BIKE (Genomic BIodiversity Knowledge for Resilient Ecosystems) can be consulted/contacted for input.
- Hoban et al 2022 (doi: 10.1111/brv.12852)
- Hvilsom et al. 2022. Selecting species and populations for monitoring of genetic diversity. https://doi.org/10.2305/IUCN.CH.2022.07.en
- Landscape genetics analysis: Fedorca et al. (2019) Inferring fine-scale spatial structure of the brown bear (Ursus arctos) population in the Carpathians prior to infrastructure development (https://doi.org/10.1038/s41598-019-45999-y)
- IPA project Romanian brown bear official website (http://www.ursulbrunsinoi.ro/pagini/date-despre-proiect), Bear National Action Plan (http://www.editurasilvica.ro/carti/jurj1/integral.pdf)
- https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903/sp.efsa.2022.EN-7766
- ERGA: Formenti et al. 2022 https://www.sciencedirect.com/science/article/pii/S016953472100313X, Theissinger et al. 2023 https://www.sciencedirect.com/science/article/pii/S0168952523000203

Species distributions of terrestrial birds			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Second European Breeding Bird Atlas (EBBA2):** targeted surveys (breeding period; 10 km2 squares); standardised protocol (time surveys 60–120 min, 2013–2017) **Pan-European Common Bird Monitoring Scheme (PECBMS)**: yearly bird count data for common birds, 170 bird species, during breeding **EuroBirdPortal (EBP):** citizen science data collected all year around, unstructured but intensive sampling, standardised and non-standardized protocols **EURING:** standardised fieldwork protocols to collect count data seasonally during breeding, wintering and migration, ongoing long-term time-series updated annually **National initiatives**	**LIFEPLAN** is a six-year global initiative led by the University of Helsinki. It spans 83 locations worldwide, including Europe. The project involves continuous monitoring of bats, birds, insects, amphibians, and reptiles using camera and audio traps. Within the project's scope, advanced modeling and AI tools will be developed for species identification.	**EBP:** improve spatial coverage density **EBBA2:** replicate sampling intensity/effort with higher frequency (less than 5 years) for all species; **EBBA2:** continue sampling after atlas publication Pan-European Common Bird Monitoring Scheme (PECBMS): improve taxonomic coverage **EuroBirdPortal (EBP)**: increase number of species covered **EURING:** make spatial distribution of sampling sites more even Provide training regarding the EBV to non-experts

	BMS: - Biodiversity Monitoring South Tyrol, started in 2019, uses standardised protocols in 320 permanent plots across South Tyrol, Italy - Plots are surveyed every 5 years, with visual/acoustic counts conducted for 10 minutes during the breeding season. - Each site is surveyed three times per season, with Alpine sites surveyed twice. **National monitoring of birds (Israel):** Ongoing since 2012, this project monitors terrestrial birds across Israel to assess ecosystem health. Using point count methods, data is collected, analyzed, and published annually for public and decision-maker use in managing biodiversity and landscapes		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EBBA2:** EU-level integration of multiple sources for mapping species distributions. Designed metadata standards for data reporting and aggregation; developed tools to harmonize and centralize data at EU-level; huge effort to automate data flows; data	**B-cubed**: creating data-cubes on species occupancy from data mobilized by GBIF. Evaluating standards for publication and analysis of aggregated biodiversity data, developing data aggregation algorithms to reduce bias.	**EuroBirdPortal (EBP)**: improve data structure **EBBA2:** match products fully to EBV definition with regards to taxonomic completeness and temporal/spatial resolution;

	is either open access or upon request **PECBMS:** metadata standards to facilitate data harmonization, flows, counts in a central repository - Automated data flows from national coordinators to European integration node - Raw data only available upon request and subject to agreement by national coordinators **EuroBirdPortal (EBP)**137 species maps in viewer aggregated by week and 30 x 30 km; data in central repository aggregated at 10 x 10 km - time series data since 2003 updated weekly - data streams automated - data access requires authorization from national data owners **EURING Data Bank** (EDB): - Digitized according to standard protocols - Data only partially available		Provide guidelines, resources, contacts, and more to advise on necessary data and metadata standards, data integration standards, etc., to make project results available to the EBV community **EBBA2:** improve the availability of specific data from the observation process Open data for initiatives/projects to improve their modelling **EBBA2:** automate data flows from sampling plots to national coordinators

Modelling Types of models Predictors Estimation & uncertainty Software	**EBBA2:** statistical modeling to generate continuous predictions of distributions of all birds across Europe (probability of occurrence/site occupancy) **EBBA Live Farmland initiative:** model combining PECBMS and EBP datasets; output: maps of breeding distribution at a high temporal resolution (< 5 years)	**EBBA2:** EBBA Live Farmland distribution maps will be produced for 50 European bird species, especially focusing on farmland species. The goal is to assess the feasibility and constraints of updating these maps every five years **BirdWatch** is an upcoming Horizon Europe Project focused on Farmland Bird Biodiversity. The project aims to combine satellite remote sensing data from Copernicus with species distribution modeling to create a habitat suitability monitoring service. It will also optimize habitat structures in line with farmer requirements to enhance habitat suitability. This work is linked to SDMs integrating remote sensing-derived structure indicators by Camille Van Eupen at KU Leuven**.** **Joint Species Distribution Modelling** (https://doi.org/10.1017/9781108591720;https://doi.org/10.1111/2041-210X.13345): models that integrate community ecology data with data on environmental	**EBBA2:** advance technical programming skills and modelling knowledge **EBBA2:** make code used to fit models openly available;

		covariates, species traits, phylogenetic relationships and the spatio-temporal context **DeViSe:** Machine Learning Methods for Detection and Localization of birds based on acoustic data. Especially for *Crex crex* and *Scolopax rusticola*. **Guarden**: improving species distribution models using species-interaction data EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species.	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): **Biodiversity Information Standards (TDWG)** https://www.tdwg.org/community/dwc/ which includes the Darwincore Maintenance Group and Interest Group Observations & Specimens			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Keller, V., Herrando, S., Voříšek, P., Franch, M., Kipson, M., Milanesi, P., ... & Foppen, R. P. B. (2020). European breeding bird atlas 2: Distribution, abundance and change. European Bird Census Council and Lynx Editions, 967 pp.			

- Hilpold A., Anderle M., Guariento E., Marsoner T., Mina M., Paniccia C., Plunger J., Rigo F., Rüdisser J., Scotti A., Seeber J., Steinwandter M., Stifter S., Strobl J., Suarez-Muñoz M., Vanek M., Bottarin R., Tappeiner U., Handbook – Biodiversity Monitoring South Tyrol, Bozen/Bolzano, Italy: Eurac Research, 2023, https://doi.org/10.57749/2qm9-fq40
- https://pecbms.info/
- https://eurobirdportal.org/ebp/en/about/
- DeViSe, Fraunhofer IDMT, Menno Müller: https://www.idmt.fraunhofer.de/en/institute/projects-products/projects/devise.htm

Species abundances of terrestrial birds			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Second European Breeding Bird Atlas (EBBA2):** targeted surveys (breeding period; 10 km2 squares); standardised protocol (time surveys 60–120 min, 2013 – 2017) **Pan-European Common Bird Monitoring Scheme (PECBMS)**: yearly bird count data for common birds, 170 bird species, during breeding; standardised sampling; variable spatial distribution **EuroBirdPortal (EBP):** citizen science data collected all year around, unstructured but intensive sampling; simple standardised or non-standardized protocols; spatial coverage sufficient for modelling at 10x10km resolution for a subset of species **EURING:** standardised fieldwork protocols to collect count data seasonally during breeding, wintering and migration; ongoing		Improve spatial coverage in some countries Improve monitoring for rare and priority species. Increase taxonomic coverage

	long-term time series updated annually; sampling points unevenly distributed; 300 species **National initiatives** **Flanders**: unified data entry portal for all species abundance data for all species monitored for the report on the state of the habitat directive **BMS:** - Biodiversity Monitoring South Tyrol, started in 2019, uses standardized protocols in 320 permanent plots across South Tyrol, Italy - Plots are surveyed every 5 years, with visual/acoustic counts conducted for 10 minutes during the breeding season. - Each site is surveyed three times per season, with Alpine sites surveyed twice. **Israel national monitoring of birds:** Ongoing since 2012, this project monitors terrestrial birds across Israel to assess ecosystem health. Using point count methods, data is collected, analysed, and published annually for public and		

	decision-maker use in managing biodiversity and landscapes		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EBBA2:** EU-level integration of multiple sources for mapping species distributions. Designed metadata standards for data reporting and aggregation; developed tools to harmonize and centralize data at EU-level; huge effort to automate data flows; data is either open access or upon request **PECBMS:** metadata standards to facilitate data harmonization, flows, counts in a central repository - Automated data flows from national coordinators to European integration node - Raw data only available upon request and subject to agreement by national coordinators **EuroBirdPortal (EBP):** 137 species maps in viewer aggregated by week and 30 x 30 km; data in central repository aggregated at 10 x 10 km - time series data since 2003 updated weekly - data streams automated	**SPI-Birds:** Summary data in the process of being made available via GBIF.	**General:** standardized protocols for different workflow steps (+ tools that help with easy implementation thereof) need to be developed and adopted by relevant actors **EBP:** improve data access; **PECBMS:** Reinforce national integration nodes

	- data access requires authorization from national data owners **EURING Data Bank** (EDB): - Digitized according to standard protocols - Data only partially available **SPI-Birds:** standardization service and database for nest box monitoring schemes and mark-recapture programmes at specific locations throughout Europe. - Most data is not available without filing a request.		
Modelling Types of models Predictors Estimation & uncertainty Software	**TRIM model** (TRends and Indices for Monitoring data): single- and multi-species indicator trends at European level - RTRIM-shell R package: open code **Bayesian models** - **Bayesian mixed models with R and INLA**. The source code of the analysis is freely available. -**SPI-Birds data workflow for Bayesian integrated analysis of mark-recapture and nest survey data** from nestbox monitoring	**EBBA2:** EBBA Live Farmland distribution maps will be produced for 50 European bird species, especially focusing on farmland species. The goal is to assess the feasibility and constraints of updating these maps every five years EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species.	Species abundance models for continuous spatially explicit estimates **General:** standardized protocols and best practices guidelines for modelling need to be developed and adopted by relevant actors.

	schemes (data): Code and code manual for setting up, running, and analysing **National initiative Norwegian breeding bird survey** Estimation of species-specific national abundance indices from structured monitoring data	**Integrated distance sampling models** Models for analyzing data collected using distance sampling (line transect) over large spatial scales. Example for Norwegian data in “Hønsefuglportalen”: Hønsefuglportalen (nina.no) s://github.com/NINAnor/NI_lirype **Integration with citizen science observations**: Integrated distribution modelling to estimate the national population size of an alpine bird (ecoevorxiv.org)	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Keller, V., Herrando, S., Voříšek, P., Franch, M., Kipson, M., Milanesi, P., ... & Foppen, R. P. B. (2020). European breeding bird atlas 2: Distribution, abundance and change. European Bird Census Council and Lynx Editions, 967 pp. • Hilpold A., Anderle M., Guariento E., Marsoner T., Mina M., Paniccia C., Plunger J., Rigo F., Rüdisser J., Scotti A., Seeber J., Steinwandter M., Stifter S., Strobl J., Suarez-Muñoz M., Vanek M., Bottarin R., Tappeiner U., Handbook – Biodiversity Monitoring South Tyrol, Bozen/Bolzano, Italy: Eurac Research, 2023, https://doi.org/10.57749/2qm9-fq40 • https://pecbms.info/ • https://eurobirdportal.org/ebp/en/about/ • https://wlandau.github.io/targetopia/packages.html • https://rstudio.github.io/renv/			

Species abundances of terrestrial migratory birds			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EuroBirdPortal (EBP):** citizen science data collected all year around; unstructured but intensive sampling; simple standardised or non-standardized protocols; spatial coverage sufficient for 10 x 10 km resolution for a subset of species **EURING:** standardised fieldwork protocols to collect count data seasonally/annually; ongoing long-term time-series updated annually; sampling points unevenly distributed but with exact location; 300 species **National initiatives** **Migres Programme**: standardised long-term monitoring (i.e., visual count record) at a bottleneck area (the Strait of Gibraltar) targeting soaring birds but also for passerines and seabirds. Over this site, almost all the migratory soaring birds breeding in Northern and Western	Bioacoustics and automatic classification as a complement to actual data collected.	Improve spatial resolution Long-term financial sustainability of the ongoing programmes to avoid gaps in time series Increase taxonomic coverage

	Europe can be observed due to flight constraints in these species. There are other similar initiatives across European migratory routes (at other bottleneck areas: e.g., Falsterbo, Pyrennes, Bosphorous) with a similar methodological approach. Volunteers mainly conduct monitoring.		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EuroBirdPortal (EBP):** maps in viewer aggregated by week and 30 x 30 km; data in central repository aggregated at 10 x 10 km - data streams are automated - data access requires authorization from national data owners - only data for 137 species - data harmonized, managed, and stored in central repository curated by European Bird Census Council **EURING Data Bank (EDB,** https://euring.org/node/4): digitized according to standard protocols **Migres Programme**:https://www.fundacionmigres.org/en/programa-migres/	EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species. See also Digital Twin models below.	Improve data access Need for the integration of visual count record at migratory bottleneck areas initiatives at the EU level. Needs to develop workflows to integrate bioacoustic species list and abundance estimates to current workflows.

Modelling Types of models Predictors Estimation & uncertainty Software	**EBP:** Data already been used to produce weekly models of relative abundance at necessary spatial resolution for some species; the process not automated **Migres Programme**: Martín, B., Onrubia, A., De la Cruz, A., & Ferrer, M. 2016. Trends of autumn counts at Iberian migration bottlenecks as a tool for monitoring continental populations of soaring birds in Europe. Biodiversity and Conservation, 25(2):295-309.	**Digital Twin models** for biodiversity monitoring. A way to combine movement ecology models with citizen science observations to make real-time predictions on migratory birds: https://cranes.sensingclues.org/cranes/	Automate modeling process Generate open code and user-friendly software Better link modelling building with data collection people and IT infrastructures (i.e. evaluating the role of errors and decisions made during modelling).
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): Data sharing for visual migration count records through data management platforms (e.g., CKAN) that include all bottleneck migration areas and programmes			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): Panuccio, M., Martín, B., Morganti, M., Onrubia, A. & Ferrer, M. 2017. Long-term changes in autumn migration dates at the Strait of Gibraltar reflect population trends of soaring birds. Ibis, 159(1): 55-65.			

Species abundances of selected terrestrial mammals			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Second European Mammal Atlas (EMMA2):** - No structured data collection and monitoring (only voluntary contributions) - Observations (records) in three classes (species present 1999–2023, species present 1970–1998, species presence presumed) - subset of countries and particular taxa (Carnivora, Artiodactyla, Chiroptera species) - Chiroptera abundance time series data available for cave-dwelling bats yearly/seasonally - based on verified data from national databases **National initiatives** **Norwegian Large Predator Monitoring Program (AK)** **-** Monitoring of Eurasian lynx, wolverine, brown bear, wolf, and golden eagle.	**ENETWILD project and European Observatory of Wildlife (EOW)** - Hunting statistics, roadkill information, density data, occurrence points (presence/absence), radio-tagging, and camera trapping - Guidance to estimate population density with different methods **Mammalnet** Citizen science initiative associated to ENETWILD based mainly in Mammalweb and iMammalia apps to collect camera trap and occasional records, respectively **Scandobs**, is an internet service and mobile app where everyone can report observations of bears, lynx, wolf and wolverine. **National initiatives** Iberconejo Life project. Rabbit status in Spain and Portugal.	Collects density, abundance, or relative abundance data of all the suitability range of the species. Incorporate new protocols to improve species with reduced information Monitored common (non-threatened) species that may be early indicators of new covenants. Collection of accurate high-resolution density data Expansion of camera trapping network across Europe **EMMA2:** Increase country coverage Improve sampling frequency Generate time series data **Bat monitoring:** Increase number of species monitored

	-Harmonized with Sweden's Naturvårdsverket.. **BMS: Biodiversity Monitoring South Tyrol** **-** Professional bioacoustic monitoring of bats. - Protocol: 320 plots throughout South Tyrol, 5-year survey interval for each plot. Data collected includes species list, activity, feeding buzzes, and social calls. **Step Change Slovenia** - Wildlife monitoring for ungulates and small carnivores. - Camera traps, citizen science app, and genetic sampling. **Flanders**: - Monitoring of hibernating bats and bats roosting in large attics. - Unified data entry portal available at https://meetnetten.be for species abundance data, which contributes to the report on the state of the habitat directive. I**srael National Monitoring of Large Mammals**:	setting up standardized monitoring systems **Bat Monitoring Programme:** Spain only; started 2019; year round; based on standard protocols; data collected by professionals and volunteers (citizen science) SAFE (Stop atropellos fauna en españa). Spanish project about wildlife road-kills. Carried out by volunteers, structured sampling. **IPA project**: Non-invasive genetic sampling, at the national scale in Romania, collecting faeces and hair from brown bear population. Integral monitoring within bear suitable habitat areas.	Bias factors considering species/ population level behaviour when collecting data, sample design

	- Monitors medium to large mammals across Israeli ecosystems. - Provides annual public reports to guide informed biodiversity management. - Uses camera traps; initiated in 2012 and ongoing.		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EMMA2**: - Observations are aggregated at 50 km x 50 km grid cell resolution and mapped across Europe - Products generated do not match EBV definition - Defined metadata standards - European Mammal Foundation central repository - Coordinators harmonize and integrate data - Data flows not automated - Majority of records freely accessible in national/regional atlases	**European Observatory of Wildlife (EOW) and ENETWILD** project: a framework for comparable, interoperable, and openly accessible data at the European level; special focus on mammals - Harmonization protocols for data collection and reporting - Portals and platforms for managing or sharing wildlife images (e.g. MammalWeb and Agouti) - Data exchange formats for camera trap data (e.g. Camtrap DP) - **Wildlife Data Model** (WLDM) to aggregate distribution and abundance data on wild boar, ungulates and other mammals species	Expand the use of data models (e.g. Wild Boar Data Model (WBDM)) Develop flexible data integration models to combine different data sources (e.g. hunting data, roadkill data, and conventional abundance data) Improve data standardisation between administrations and organisations Improve data transfer mechanisms and exchange formats Develop (and promote/incentivise) a standard format for relevant data (ideally highly compatible with other formats, e.g. Darwin Core format used on GBIF and elsewhere)

		-Incorporating eDNA protocols for diseases associated pathogen (pilot phase) **EUROMAMMALS**: Collaborative network of > 100 research institutes in Europe sharing European mammals movement data and other large sets of ancillary information in a common harmonised database	Provide more information about sampling unit and frequency Make raw data available Increase data sharing between organizations, administrations and countries Automate EMMA2 data flows Improve coordination at a European scale through trans-disciplinary authority
Modelling Types of models Predictors Estimation & uncertainty Software	**SCR model** to estimate bear demographic parameters, movement trend and gene flow - Software: MARK, STRUCTURE, Rpackage 'Capwire', LDNe from NeEstimator **RovQuan**t integrated SCR model for estimating large carnivore abundance: rovQuant | NMBU using Bayesian software package **Prototype European Hibernating Bat Indicator**: aggregates monitoring data	- **Agouti, Conservation AI**: Emerging AI models for automated mammal identification from images **ENETWILD ,Spain Road-kills Study**: Uses hierarchical modeling to estimate abundance from road-kills, accounting for observational processes such as sampling biases. **Random Encounter Model (REM)**: Determines animal density using camera trap data. **Hunting yields and citizen science species**	Improve accuracy of AI models for automated mammal identification (maybe even recognizing individuals, and combining this information with the location data of where the photos were taken) from images (Experimental) study/investigation of detection/reporting biases for data commonly available at large geographical scales (e.g. roadkills) → accounting/correcting for in models mentioned in above point

	collected by national programs via standardized protocols 1993-2011	**Distribution/Abundance**: Combines various data sources like hunting yields and citizen science to model abundance on a large scale. Examples include hunting bags with camera trap data in the USA, and hunting bags combined with citizen science in Ireland. **Close-Kin-Mark-Recapture**: A novel method to estimate abundance using genetic samples from sources such as hunted animals or hair snares. More information can be found in the ICES Journal of Marine Sciences Nature-FIRST project: developing a digital twin, real-time distribution predictions based on observations made with Cluey, for the bear in Bulgaria, Romania and Spain	Easy-to-use tools for integrated species distribution/abundance modeling (the most of current tools are just programing languages to program your own model, but see spOccupancy R package)
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Develop (and promote/incentivize) a standard format for relevant data (ideally highly compatible with other formats, e.g. Darwin Core format used on GBIF and elsewhere) Data from European Mammal Atlas (EMMA2) is made available through GBIF (https://www.gbif.org/), using the Darwin Core (DwC) metadata standard Emerging data exchange formats for camera trap data (e.g. Camtrap DP) Need for legal data-sharing agreements			

Need for open data or data that are free from restrictions on use, modification and sharing
Need for a common standard format in which to share data (ideally compatible with other datastreams, e.g. Darwin Core standard compliant)

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
Centralized (cloud) computing infrastructure (e.g. for processing camera trap images)
Centralized data repository for data sharing
Centralized (cloud) computing infrastructure (e.g. for processing bio-acoustic data)

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- EMMA2 Steering Group (2020): Selecting and preparing data for the Atlas of European Mammals, 2nd edition. https://www.european-mammals.org/public-documents?task=download.send&id=81&catid=2&m=0
- MammalWeb, a "citizen science" platform intended to collate, validate and curate camera trap data: https://www.mammalweb.org/en/
- Agouti, an AI powered solution for managing wildlife camera-trapping projects: https://www.agouti.eu/
- Camtrap DP Development Team (2022): Camera Trap Data Package (Camtrap DP). https://tdwg.github.io/camtrap-dp
- ENETWILD-consortium et al. (2022): Update of model for wild ruminant abundance based on occurrence and first models based on hunting yield at European scale. EFSA Supporting Publications 19: 7174E.
- IPA project: Fedorca et al. 2019 (https://doi.org/10.1038/s41598-019-45999-y); http://www.ursulbrunsinoi.ro/pagini/date-despre-proiect; http://www.editurasilvica.ro/carti/jurj1/integral.pdf
- ENETWILD-consortium et al. (2022): Wild boar density data generated by camera trapping in nineteen European areas. EFSA Supporting Publications 19: 7214E.
- https://discovermammals.org/projects/the-2nd-european-mammal-atlas/ European Mammal Foundation (the successor of the Societas Europaea Mammalogy that published the first Atlas)
- Mitchell-Jones et al. (Eds) 1999 The Atlas of European Mammals
- Hilpold A., Anderle M., Guariento E., Marsoner T., Mina M., Paniccia C., Plunger J., Rigo F., Rüdisser J., Scotti A., Seeber J., Steinwandter M., Stifter S., Strobl J., Suarez-Muñoz M., Vanek M., Bottarin R., Tappeiner U., Handbook – Biodiversity Monitoring South Tyrol, Bozen/Bolzano
- Biodiversity Monitoring South Tyrol BMS (https://biodiversity.eurac.edu)
- StepChange Slovenia: https://stepchangeproject.eu/citizen-science-initiatives/wildlife-conservation/
- Nature-FIRST project: Forensic Intelligence and Remote Sensing Technologies for nature conservation. CORDIS URL.

Species distributions of all terrestrial mammals			
Workflow components			
	Current initiatives	**Emerging products and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** **Norwegian Large Predator Monitoring Program (AK)** **-** Monitoring of Eurasian lynx, wolverine, brown bear, wolf, and golden eagle. -Harmonized with Sweden's Naturvårdsverket.. **BMS: Biodiversity Monitoring South Tyrol** **-** Professional bioacoustic monitoring of bats. - Protocol: 320 plots throughout South Tyrol, 5-year survey interval for each plot. Data collected includes species list, activity, feeding buzzes, and social calls. **Step Change Slovenia** - Wildlife monitoring for ungulates and small carnivores. - Camera traps, citizen science app, and genetic sampling.	**Citizen science** **Mammalnet** EFSA initiative uses the apps iMammalia and Mammalweb apps to allow a record of occasional and camera trap surveys reported by citizens. Active in different European countries. **Scandobs** is an internet service and mobile app where everyone can report observations of bears, lynxes, wolves, and wolverines. **National programs** **Bat Monitoring Programme:** Spain only; started 2019; year round; based on standard protocols; data collected by professionals and volunteers (citizen science)	Improve spatial resolution. In most cases, it limits the modelisation potential Increase country coverage Improve sampling frequency Generate time series data. Improve long-term and ongoing monitoring. Improve accessibility of registration devices (e.g. acoustic or visual) Reinforces the role of citizens' participation (especially in some countries or groups with economic constraints). Capacity building

Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Second European Mammal Atlas (EMMA2):** - Distribution and abundance data for specific taxa (Carnivora, Artiodactyla, Chiroptera species) sourced from national/regional databases, literature, and data portals. - Yearly/seasonal distribution data for cave-dwelling bats (Chiroptera) based on abundance time series. -Verified data, both standardized and opportunistic, including citizen science contributions. - Web portals for observation uploads in some countries. - Atlases updated with a frequency greater than 10 years. - coordinators harmonise and integrate data - products generated do not match EBV definition - defined metadata standards - European Mammal Foundation central repository - data flows not automated **Biodiversity Information Standards (TDWG)** https://www.tdwg.org/community/dwc/ which includes the Darwincore Maintenance Group	**European Observatory of Wildlife** (EOW) and ENETWILD project: a framework for comparable, interoperable, and openly accessible data at the European level; special focus on mammals **B-cubed**: creating data-cubes on species occupancy from data mobilized by GBIF. Evaluating standards for publication and analysis of aggregated biodiversity data, developing data aggregation algorithms to reduce bias.	Make raw data available Make records freely accessible at higher resolution Provide more information about sampling unit and frequency Automate data flows at European scale Support national coordinators

	and Interest Group Observations & Specimens **Biodiv' Occitanie**, South-West of France. - Data portal and biodiversity atlas. - Data provided to SINP for decentralised inventories in France.		
Modelling Types of models Predictors Estimation & uncertainty Software		See proposals included for abundance estimation of mammals. In most cases, the proposal integrates both approaches, occurrence and abundance - **ENETWILD:** European habitat suitability (MaxEnt) models for wild boar, red deer and roe deer, with topography, bioclimatic data, and land cover as predictors **TrapTagger by WildEye:** open source; combination of artificial intelligence and manual annotation for processing camera trap data; detect, count, classify species of animals and identify individuals -**Guarden** (https://guarden.org): improving species distribution	

		models using species-interaction data EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species. Will be integrating TrapTagger in camera-trap data processing and add functionality such as automatically generating subsets of images which would benefit the model the most if they are manually annotated	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Mitchell-Jones et al. (Eds) 1999 The Atlas of European Mammals. Academic press, p 484. • TrapTagger | WildEye (wildeyeconservation.org) and their repository at GitHub - WildEyeConservation/TrapTagger: AI-Powered Camera-Trap Image Processing			

Species distributions of terrestrial reptiles			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Reporting on Art.17 (HD)** In EU countries there are monitoring programmes for reporting on Art.17 (Habitats Directive), supported by EU or national level funding. **Reptile and Amphibian Conservation Europe (RACE)** network of European, non-governmental amphibian and reptile conservation organisations - Distribution and abundance surveys coordinated by NGO partners **National initiatives** In some EU countries there are ongoing monitoring programs of common species based on citizen science, but international initiatives to integrate national monitoring outcomes are lacking. **UK National Amphibian and Reptile Monitoring Programme:**	New protocols for the National Reptile Survey in the UK: https://reptile-survey.arc-trust.org/pages/protocol Tailored standardised data collection forms (including use of mobile apps - Survey123) using ESRI ArcGIS hub platform https://reptile-survey.arc-trust.org	Adequate spatial coverage for monitoring programs Ongoing timely updates to monitoring programs Standardized monitoring methods and protocols Finding a way to integrate and validate herp species occurrence and impact data from citizen science, inventory studies, EIA studies and structured monitoring programmes Capacity building: Training for volunteer surveyors

	- Program for collecting conservation data on amphibians and reptiles across the UK. - Combines professional research with citizen science efforts. **National Reptile Survey** (UK): - Structured with standardized protocols - Digital tools for data collection & review - Covers all species' abundance and distribution trends - Uses visual surveys & artificial cover methods on repeat visits - Make the Adder Count - coordinated by ARGUK **National monitoring of reptiles (Israel):** Monitors terrestrial reptiles across various Israeli ecosystems since 2012 - Aims to evaluate ecosystem states and guide science-based landscape management - Utilizes various monitoring methods - Yearly public report to inform decision-making and the general populace. **AHE Spanish amphibian and reptile monitoring programs**		

	RAVON **Dutch amphibian monitoring programmes**		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**New Atlas of Amphibians and Reptiles of Europe (NA2RE, 2014)** - No structure monitoring - Presence data compiled from publications, atlases, herpetological societies, and opportunistic occurrence data.- mapped distributions, 50 x 50 km grid, 218 taxa (145 species of reptiles) updated as of 2014 - no information about temporal dynamics - data not from systematic monitoring programs - temporal snapshot (2014) - data centralized and harmonized from different sources using different standards - data streams not automated - raw data not openly available https://montobeo.shinyapps.io/NA2RE/ **Reporting on Art.17 (HD)** Data aggregated at 10x10 km (presence/absence) to produce distribution and range maps for 34 herp species.	Integration of opportunistic and structured data sources for trend analysis (see Becky Turner PhD DICE, CEH) **B-cubed** (https://doi.org/10.3030/101059592): creating data-cubes on species occupancy from data mobilized by GBIF. Evaluating standards for publication and analysis of aggregated biodiversity data, developing data aggregation algorithms to reduce bias.	Better collation of fragmented data, with standardised metadata Collation of trend data from multiple European countries to understand EU-wide trends Ensure dedicated personnel for managing and updating national databases and secure funding Funding dedicated to the coordination and operation of monitoring programs.

	IUCN European Red List of Reptiles - expert-based assessments, including distribution maps, but not linked to monitoring program - temporal snapshot, no temporal replication **The Reptile Database** **(**maintained by Peter Uetz**)** **-** Covers snakes, lizards, turtles, amphisbaenians, tuataras, and crocodiles. - Over 10,000 species and 2,800 subspecies listed. - Focuses on taxonomic data, including names, distribution, and literature references. - Relies on volunteers and published sources **Biodiversity Information Standards (TDWG)** https://www.tdwg.org/community/dwc/ which includes the Darwincore Maintenance Group and Interest Group Observations & Specimens **National initiatives** **OpenHerpMaps (Romania)**		

	- Database of herpetological data with 98 species. - Combines expert and amateur contributions. - Over 544,000 data points from varied collection methods.		
Modelling Types of models Predictors Estimation & uncertainty Software	Range tool was a modelling tool available on Eionet portal for ArcGIS in the reporting time frame 2013-2018 for reporting on Art.17 Habitat Directive No modeling to predict species distribution across areas not covered by data No open code or user-friendly software	SDM like Maximum Enthropy (MaxEnt) could better capture distribution dynamics, leading to better reporting on Art.17 (HD) (Sousa-Silva et al., 2014) -Guarden (https://guarden.org): improving species distribution models using species-interaction data Modelling of *Coronella austriaca*, *Vipera berus* and *Lacerta agilis* across heathlands in southern England as part of the Snakes in the Heather project. Final model outputs expected this year (ensemble models in Biomod2, looking at landcover classes, DEM-derived variables and geology as predictors) EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species.	Occupancy and n-mixture modelling to provide occupancy and abundance estimates whilst accounting for detection. Has been used in multiple studies but has further applications. Defining Favourable Conservation Status for individual species and ensuring surveillance returns relevant metrics at different required scales Access to soil data and certain primary data sources is restricted for non-academic users due to high licensing costs. The UK lacks consistent availability of aerial maps and LIDAR data on a national scale. Platforms like ESRI ArcGIS have data sharing capabilities, but current licensing terms limit its full utilization, especially concerning

			affordability and definitions of non-commercial use.

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- National Amphibian and Reptile Monitoring Programme - https://monitoring.arc-trust.org
- National Reptile Survey - https://reptile-survey.arc-trust.org
- Spanish Herpetological Society - https://herpetologica.es
- Ficetola et al. 2017 Optimizing monitoring schemes to detect trends in abundance over broad scales. *Animal Conservation*, 21 (3), 221-231
- http://lashf.org/popreptile/ Le programme POPReptile, un programme national de suivi des populations de reptiles
- Sousa-Silva, R, Paulo Alves, João Honrado, Angela Lomba. 2014. Improving the assessment and reporting on rare and endangered species through species distribution models. Global Ecology and Conservation, Volume 2, Pages 226-237.https://doi.org/10.1016/j.gecco.2014.09.011. https://www.sciencedirect.com/science/article/pii/S235198941400047X
- Sos, Tibor (Milvus Group) - OpenHerpMaps http://openherpmaps.ro/

Species abundances of butterflies			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**European Butterfly Monitoring Scheme (eBMS)** -Transect counts (weekly during the butterfly season, depending on the regions), standardized protocols - abundance data for > 312 butterfly and moth species - Standardized sampling protocols for transect counts **National initiatives** **Flanders:** unified data entry portal for all species abundance data for all species monitored for the report on the state of the habitat directive **Biodiversity Monitoring South Tyrol** (BMS) - data are available for South Tyrol (Italy); the project started in 2019 and is based on standard transect (50m) and time-area counts 4x per site (1000m2) by professionals - - around 320 plots all over South Tyrol	**eBMS App** - Citizen science phone application for 15-min full counts and 15-min single species counts - Massive collection of opportunistic observations **DECIDE** App citizen science Adaptive sampling approaches	- Increase the number of transects - Field guides and sampling protocols for other regions in Europe

	- Each plot is surveyed every 5 years **Biodiversity Monitoring scheme of Switzerland (BDM)** Surveyed along a 2.5-kilometer transect that follows existing trails. The transect routes, the number of field trips (four to seven, depending on elevation), and the time intervals between field trips are predefined for each sampling area. Every species fieldworkers find is electronically registered on the spot. Transects are resurveyed every 5 years.		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Butterfly Conservation Europe** - EU-wide integration node - Standardized sampling protocols for transect counts - Field guides for different regions in Europe - Different methods of data entry depending on the county - Data streams not fully automated eBMS database; review of the uploaded data - Raw data freely available upon request with license agreement, only for the countries officially covered by eBMS	**ABLE project: 'Assessing Butterflies in Europe'** Data inclusion and data harmonization for new European countries- Extended EU-wide data integration through Butterfly Conservation Europe	- Integration of transect count data (eBMS) and data from the 15-min counts (eBMS App) - Interfaces between decentralized national databases of butterfly monitoring systems - Further development of app usability, including new local adaptations (translation and species guides) - Increase the number of coordinators, volunteers and paid

			experts to monitor sensible areas and species across Europe - Need to improve data accessibility beyond request-only, and for all member states. - Development of legal data sharing agreements - Metadata forms should be made available in machine-readable formats, not just Excel.
Modelling Types of models Predictors Estimation & uncertainty Software	**European Butterfly Monitoring Scheme (eBMS)** - Species flight curves with splines and generalised additive models (GAMs) - Trend estimation with Generalized Abundance Index (GAI) - Combined site index with a generalised linear model (GLM) - Uncertainty estimation with bootstrapping **R packages** - R-package 'rtrim' - R-package rGAI - R-package rbms: https://retoschmucki.github.io/rbms/ - R-package Hmsc (see reference HMSC and Ovaskainen et al., 2017)	- European-wide occupancy models - Integrated modeling of species distributions and abundance through combining different data sources (transect counts, 15-minute counts and opportunistic observations)	- Models to estimate abundance continuously (wall-to-wall) across Europe - Automated calculation of butterfly indicators

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Data is currently only available upon request (and only for 17 EU member states)
- No legal data sharing agreements in place
- Metadata forms only available as Excel files (not machine-readable)

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- Expanded and improved centralized eBMS database with greater functionality
- Centralized (cloud) computing infrastructure for automated calculation of butterfly indicators

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Expert input from Roy van Grunsven, Elia Guariento, Simon Rolph, Ward Langeraert, Pablo Denti, Martin Musche
- eBMS (https://butterfly-monitoring.net/, Flanders (https://meetnetten.be), Switzerland (https://www.biodiversitymonitoring.ch), South Tyrol (https://biodiversity.eurac.edu)
- HMSC package: https://www.helsinki.fi/en/researchgroups/statistical-ecology/software/hmsc#:~:text=Hierarchical%20Modelling%20of%20Species%20Communities,a%20matrix%20of%20environmental%20covariates.
- Ovaskainen et al. (2017) https://doi.org/10.1111/ele.12757
- Butterfly Conservation Europe (https://www.vlinderstichting.nl/butterfly-conservation-europe/)
- Dennis, E. B. et al. (2016): A generalized abundance index for seasonal invertebrates. Biometrics 72:1305-1314.
- Sevilleja, C. G. et al. (2019): Butterfly transect counts: manual to monitor butterflies. https://butterfly-monitoring.net/sites/default/files/Publications/Manual_Butterfly_Monitoring%20(English).pdf
- ABLE project (https://butterfly-monitoring.net/able), DECIDE (https://decide.ceh.ac.uk)
- Biodiversity Monitoring South Tyrol BMS (https://biodiversity.eurac.edu)
- Hilpold A., Anderle M., Guariento E., Marsoner T., Mina M., Paniccia C., Plunger J., Rigo F., Rüdisser J., Scotti A., Seeber J., Steinwandter M., Stifter S., Strobl J., Suarez-Muñoz M., Vanek M., Bottarin R., Tappeiner U. (2023): Handbook – Biodiversity Monitoring South Tyrol, Bozen/Bolzano. DOI - Handbook Biodiversity Monitoring South Tyrol (eurac.edu)

Species distributions of terrestrial priority invertebrates and key pollinators			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**European Butterfly Monitoring Scheme (eBMS)** -Transect counts (weekly during the butterfly season depending on the regions), standardized protocols - abundance data for > 312 butterfly and moth species - Standardized sampling protocols for transect counts European Stag beetle Monitoring Network Network of population monitoring transects. **National initiatives:** Large heterogeneity in sampling terrestrial invertebrates and pollinators across Europe, e.g. 76 pollinator monitoring schemes across Europe using different sampling methods. **UK Initiatives:** **BeeWalk Survey Scheme** offers potential for pan-EU citizen	**European Pollinator Monitoring scheme (EU PoMS)**: Pilot EU PoMS monitoring developed by the SPRING project for all key pollinator species. - 2022-2023 UK pilot; 2023-2024 all countries - several sampling rounds per year, expected to continue on an annual basis - Methods are being refined further through a second working group - eBMS App allows volunteers to record species observations and abundances, direct upload to **SPRING** project to strengthen taxonomic and citizen science capacity (pollinating insects) and trial the methods proposed by the EU PoMS across Europe. **Digital sensors:** **BE-HIVE**: Project funded by RIF Cyprus to create smart beehives,	Improve spatial coverage density Long-term data Specific lists of “key pollinators” (based on traits) as the taxa can vary between regions, ecosystems and crops. Improve taxonomic coverage Need to balance distribution/abundance techniques with population/genetic diversity approaches, particularly for social species Greater engagement from citizen scientists, especially in eastern and southern Europe. Ideally, this should be supported with targeted initiatives. Capacity building, i.e. taxonomic resources and experts.

	science standardisation as part of the UK Pollinator Monitoring Scheme. **UKBMS** monitors butterfly populations in the UK. **Other Monitoring schemes** Comprehensive list of various national invertebrate tracking programs. **Italy Initiatives:** **InNat**; captures occurrence data from citizens focusing on protected beetle, butterfly, cricket, and crayfish species. **LIFE ESC360** oversees the monitoring of protected insect species in Italian State Nature Reserves, engaging young volunteers with standardised protocols. **BeeNet** is a national scheme assessing the agro-environment quality through honey bee and wild bee monitoring networks. **Germany Initiatives:** **LTER-D** Malaise trap program utilises metabarcoding to study biodiversity.	monitoring bees' behaviour and population numbers in real-time, examining in real-time potential threats to their colonies (bee and beehive analytics). **3Bee** Combining remote sensing with satellite images with bioacoustics and remote monitoring of bees **Faunaphotonics** Remote monitoring of flying insects with a technology based on light beams Protocols for the time-lapse camera-based monitoring of flowers and pollinators https://doi.org/10.1098/rsbl.2022.0187 **MAMBO project** building on the use of cameras to count insects and moth and bumblebee visitation in the mountains **AgriSound**: (Uk company) capture insect species on the fly by specialised acoustic sensor automated pollinator monitoring	Recommended: permanent positions for taxonomists. Field guides and sampling protocols for other regions in Europe.

	MonVia is a farmland biodiversity project by the Thünen Institute, aimed at monitoring and assessment. **France Initiatives:** **Biodiv' Occitanie** offers a data portal and Atlas detailing biodiversity in the South-West of France, with data contributing to the SINP for decentralised inventories.	**The World Bee Project**: UK non-profit company, private initiative that uses AI and advanced technologies to monitor pollinator and biodiversity declines from a global perspective to help find long-term solutions to benefit both nature and people, not one at the cost of the other. **Citizen science** **eBMS App** - Citizen science phone application for 15-min full counts and 15-min single species counts - Massive collection of opportunistic observations **SPIPOLL**: French citizen science project to improve research results on pollinators (set-up by the French national museum of natural history) **DECIDE** App citizen science Adaptive sampling approaches **eDNA** **LIFEPLAN** has global biodiversity monitoring scheme with passive samplers (e.g.,	

		malaise trap for invertebrates) combined with eDNA. It has a Finnish sister project that applies similar methods in National Forest Inventory plots	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Butterfly Conservation Europe** - EU-wide integration node - Standardized sampling protocols for transect counts - Field guides for different regions in Europe - Different methods of data entry depending on the county - Data streams not fully automated eBMS database; review of the uploaded data - Raw data freely available upon request with license agreement, only for the countries officially covered by eBMS **World Spider Trait database** online open-access database of phenotypic traits of spider species at a global scale	**EU PoMs pilot proposal:** central data repository at EEA, European Commission (DG ENV), JRC or Eurostat. **Butterfly Conservation Europe:** - Data inclusion and data harmonisation for new European countries (ABLE project: 'Assessing Butterflies in Europe') - Extended EU-wide data integration through Butterfly Conservation Europe **Taxonomic information** **ORBIT:** EU-funded project to develop resources for European bee inventory and taxonomy (e.g. centralised taxonomic EU facility for wild bee identification) **Taxo-FLY**: EU-funded project to gather taxonomic information for all European hoverfly species **B-cubed**: creating data-cubes on species occupancy from data mobilised by GBIF. Evaluating	Restoring and digitising national public collections Linking of data repositories Improved data availability Implement metadata standards to facilitate data integration Further development of app usability, including new local adaptations (translation and species guides) Increase number of paid experts

		standards for publication and analysis of aggregated biodiversity data, developing data aggregation algorithms to reduce bias. **Safeguard** produces a central data repository for European wild pollinators that standardises the data input, including metadata, format, data-processing toolset, data exchange protocol, data aggregation and linking toolset - Uses standardised XML metadata adapted from Darwin Core, EML, and PANGAEA. - Implements standardised sampling protocols across 12 European countries. - Offers standardised data structure, upload, versioning, and sharing procedures. - Provides online data tools for outlier detection, aggregation, statistics, etc. - Sampling is study design-based, not time-based.	
Modelling Types of models Predictors Estimation & uncertainty	**eBMS:** - TRIM model to estimate population trends and calculation of trend indices/products at national level on annual basis	TumblingDice: (UK company) develop image recognition software, movement-based image capture that only films	Develop models to make spatially-explicit predictions of community abundance and taxonomic diversity

Software	- training courses and materials available **Occupancy models** for occurrence records are widely used for trend estimation & biodiversity indicators in UK (C4b & D1c) & Netherlands (van Strien et al 2016). **Temporal beta diversity in species composition** (Matthews, T., Sadler, J.P., Carvalho, R., Nunes, R. & Borges, P.A.V. (2019). Differential turnover rates and temporal beta-diversity patterns of native and non-native arthropod species in a fragmented native forest landscape. *Ecography,* 42: 45–54. DOI: 10.1111/ecog.03812)	when it detects movement, and maps topographical change over time	Ensure that code for integration and modelling will be shared; Ensure that software will be user-friendly Better understanding and integration of data on common pressures (e.g. pesticide use). Better access to habitat and crop data across countries (e.g. IACS data on crop use).

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Improved data availability
- Implement metadata standards to facilitate data integration
- Darwin core is the main way to prepare data.
- Data of individual species should be stored in GBIF and in Data Papers (e.g. Biodiversity Data Journal. - Example of a Collection of data at https://bdj.pensoft.net/topical_collection/58)
- **Biodiversity Information Standards (TDWG)** https://www.tdwg.org/community/dwc/ which includes the Darwincore Maintenance Group and Interest Group Observations & Specimens
- Legal implication unclear regarding images on platforms to train Artificial Intelligence (the legislation is not clear at the moment on which image can be used, and platforms like iNaturalist could provide licenced images to train AI for academic and commercial purposes, as

several companies are getting into the smart monitoring field and could provide devices or services to citizens, local agencies and farmers, with research cooperations through partnerships)

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

- We use Zenodo as repository for datasets
- For most distribution data we use GBIF IPT

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Boyd R, August T, Cooke R, et al. An operational workflow for producing periodic estimates of species occupancy at large scales. 2022. doi:10.32942/OSF.IO/2V7JP
- Costa, R. & Borges, P.A.V. (2021). SLAM Project - Long term ecological study of the impacts of climate change in the natural forest of Azores: I - the spiders from native forests of Terceira and Pico Islands (2012-2019). *Biodiversity Data Journal*, 9: e69924. DOI:10.3897/BDJ.9.e69924 https://bdj.pensoft.net/article/69924/
- van Strien AJ, Meyling AWG, Herder JE, et al. Modest recovery of biodiversity in a western European country: The Living Planet Index for the Netherlands. Biol Conserv. 2016;200:44-50. doi:10.1016/j.biocon.2016.05.031
- Lhoumeau, S., Cardoso, P., Boieiro, M., Ros-Prieto, A., Costa, R., Lamelas-Lopez, L. Leite, A., Amorim, I.R., Gabriel, R., Malumbres-Olarte, J., Rigal, F., Santos, A.M.C., Tsafack, N., Ferreira, M.T. & **Borges, P.A.V.** (2022). SLAM Project - Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores: V - New records of terrestrial arthropods after ten years of SLAM sampling. *Biodiversity Data Journal,* **10**: e97952. DOI: 10.3897/BDJ.10.e97952 https://bdj.pensoft.net/article/97952/
- L. Zapponi, A. Cini, M. Bardiani, S. Hardersen, M. Maura, E. Maurizi, L. Redolfi De Zan, P. Audisio, M.A. Bologna, G.M. Carpaneto, P.F. Roversi, G. Sabbatini Peverieri, F. Mason, A. Campanaro, 2017. Citizen science data as an efficient tool for mapping protected saproxylic beetles, Biological Conservation 208: 139-145, https://doi.org/10.1016/j.biocon.2016.04.035
- Thomaes A, Barbalat S, Bardiani M, Bower L, Campanaro A, Fanega Sleziak N, Gonçalo Soutinho J, Govaert S, Harvey D, Hawes C, Kadej M, Méndez M, Meriguet B, Rink M, Rossi De Gasperis S, Ruyts S, Jelaska LŠ, Smit J, Smolis A, Snegin E, Tagliani A, Vrezec A. The European Stag Beetle (*Lucanus cervus*) Monitoring Network: International Citizen Science Cooperation Reveals Regional Differences in Phenology and Temperature Response. *Insects*. 2021; 12(9):813. https://doi.org/10.3390/insects12090813
- Powney et al (2019) https://www.nature.com/articles/s41467-019-08974-9

Species distributions of terrestrial plants			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**eLTER Europe** 500 sites all over Europe **National initiatives** **UK National Forest Inventories (NFI)** - Standardized protocols with 768,228 sites on a 1km grid. - Sampling every 6-10 years with species variance among countries. - Different parameters collected by countries. **UK National Plant Monitoring Scheme** - Indicator species recording in ~5 plots per 1km square in semi-natural habitats. **Monitoring the Effectiveness of Habitat Conservation in Switzerland** - Initiated in 2011 with around 6000 plots (10 m^2 each) covering various ecosystems.	**ReSurveyEurope** http://euroveg.org/eva-database-re-survey-europe - initiative within EVA to mobilize vegetation-plot data with repeated measurements over time - started 2021 by EVA - seeks to compile temporal series data - important source of information on habitat quality - smaller spatial and temporal coverage than EVA Cost Action Bottoms-Up Gathering knowledge of European multi-taxonomic forest biodiversity through the collaboration of research groups that collect data locally. Deadwood spatial distribution, type and decay.	**EVA:** - Increase temporal resolution; - promote generation of time series data from vegetation plots; - increase spatial coverage; **ENFIN:** - Increase taxonomic coverage; - increase sampling frequency More data outside (semi) natural ecosystems: e.g. urban and agricultural ecosystems Increase the sampling coverage of other plant growth forms such as shrubs, herbs and lianas, for example. Currently, there are very few datasets (eg. vegetation surveys), compared to standard sampled plots for tree inventory, where all plant growth forms are sampled. EVA & ResurveyEurope data is not suitable for meeting the

	- Surveyed every 6 years, listing vascular plants and bryophytes. **Biodiversity Monitoring scheme of Switzerland** - 2.5km transect surveys for vascular plants, with bryophytes and snails on ~1500 permanent 10 m^2 plots. - Resurveyed every 5 years. **Biodiversity Monitoring South Tyrol (BMS)** - Launched in 2019, covering around 320 plots in different habitat types. - 5-year survey intervals, detailing vascular plants, bryophytes, and lichens. **German Agriculture: Crop Type Classifications** - Maps based on remote sensing, detailing different land cover classes with varying resolutions and years. **France & Spain Snowbed monitoring in the Pyrenees** - Yearly resurveys since 2012 and decadal since 2003 on pasture to snowbed vegetation.		t1arget temporal resolution (see the GitHub sheet https://github.com/EuropaBON/EBV-Descriptions/wiki/Terrestrial-Species-distributions-of-terrestrial-plants), therefore in-situ systematic monitoring approaches need to be installed and integrated. Further explore and capitalize on new methods of monitoring (such as remote sensing) see eg. IPBES assessment (just before release) that would complement laborious field monitoring **ICP Forests Lev. II:** increase sampling frequency (from 5 to 1 year) Monitoring species traits (changing along time at community level, species level and also at individual level). Selection of most importants traits depending on ecosystem/species. Assessment of the, e.g., environmental representativeness & consequent uncertainty of current monitoring schemes. Gap-filling via new surveys, multi-

	France & Spain High-mountain mire vegetation database - Resurveys of plots with environmental metrics and elevation gradient vegetation studies. Includes livestock exclusion monitoring since 2018. **Nature Census, Latvia** - Habitat type mapping with standardized data protocols. - Various species data collection in different habitats. **Denmark Initiatives Habitats Directive Annex I Monitoring** - Significant plant data collection within monitored regions. **Israel Initiatives** **National monitoring of woody plants** - Aims to assess diverse ecosystems since 2012. - Annual public reports showcasing the health of Israel's landscapes.		source data integration and/or modelling approaches.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata	**European Vegetation Archive (EVA)** **-** Integrates 99 national /supranational databases, totalling	Cost Action Bottoms-Up Gathering knowledge of European multi-taxonomic forest biodiversity through the collaboration of research groups that collect data	link habitat quality trends from ReSurveyEurope to trends in spatial extent derived from remote sensing.

Way of data aggregation Integration nodes (national or EU) Automated data streams	1,804,985 vegetation plots from 53 countries. **-** Uneven sampling across countries with plots typically sampled once. - Systematic Sampling Protocols; may not cover all targeted terrestrial vascular species. - Semi-automated data flow. - Harmonized via TurboVeg3 software with set metadata standards. **- Data Access**: Partially restricted; custodians determine data availability for their contributions. **LOTVS long-term vegetation surveying** - Vegetation database of resurveyed plots around the world. - Each plot has a minimum of 6 years and plots come from different authors and databases. - Around 90 databases standardized. - Abundance and presence/absence data **Crop Wild Relative Global Occurrence Database**	locally. Deadwood spatial distribution, type and decay. **B-cubed** creating data-cubes on species occupancy from data mobilized by GBIF. Evaluating standards for publication and analysis of aggregated biodiversity data, developing data aggregation algorithms to reduce bias.	- Fully automate data flows: develop apps or other software (i.e. digital sampling tool) to automatically transfer data from the field to IT infrastructure - Make data fully available - Complement with GBIF occurrence data

	- A downloadable database with occurrence data on crop wild relatives. The information was gathered from multiple sources: genebanks, herbaria, researchers and other data providers. - 5,647,442 records in total representing records from germoplasma, herbarium samples and other sources. - 322,735 records georeferenced. - 96 % of the world 's countries are covered. **Atlas of Flora Europea:** A long-running, long-term programme for mapping the current and past distribution of 25% of vascular plants - AFE Editor software for electronic data entry into database - LUMOUS centralizes data - data not freely available - low spatial resolution - taxonomically incomplete - no temporal replication **European National Forest Inventory Network (ENFIN)** - data custodian of *in-situ* tree species occurrences, 241 species		

	- provides data and support to European Forest Data Centre and Forest Information System For Europe (FISE) - defined metadata standards to harmonize data across National Forest Inventories - data used for modeling and for European Atlas of Forest Tree species - ENFIN data not available; NFI data open or available upon request in many countries; raw data not available or unknown availability for some countries		
Modelling Types of models Predictors Estimation & uncertainty Software	**EVA:** - Use of models (machine-learning, presence-background Maxent) to predict ecosystem distributions - user-friendly interface - could be applied to model individual single species **General modelling options (not specific to any current inventory initiative)** for predicting species distributions (or probabilities of occurrence) from presence-absence or abundance data - in addition to those listed elsewhere here - include various	- Integration of all available data sources for European-wide occupancy models - Integrated modeling of species distributions and abundances - Generalized dissimilarity models, biodiversity samples (species diversity per area) and combined with EO spatial covariates, predicted compositional dissimilarity (beta diversity), gdm R package - Joint species distributional models (JSDMs) are another	Make model code publicly available Workflows (including modelling scripts) should also ideally be open and easy to update, e.g., when new data are added. Selection of comprehensive suites of 'biodiversity metrics' to represent various dimensions of spatial and temporal change in modelling plant species/communities. (There is an enormous literature on the topic, not a simple task).

	regression approaches for binary or continuous data.	option for entire community data matrices (species x sites, as a function of, e.g., environmental covariates), as implemented in, for example, the Hmsc R package. Spatial predictions of species distributions and emergent community-level properties for mapping are possible outputs. Uncertainty is represented by the credible intervals of predictions. Note: Hmsc is computationally heavy (slow) for large datasets (several hundreds of taxa and/or sites), may require supercomputer access. See also https://www.helsinki.fi/en/research groups/statistical-ecology/software/hmsc - Guarden (https://guarden.org); improving species distribution models using species-interaction data	Fine-scale environmental data for effective local scale modelling of the distribution of terrestrial plant species over large extents. The plant data is there to some degree through EVA, but e.g. coverage of satellite data, lidar data, soil data etc. tends to either be missing from large parts of Europe or to be in too coarse a resolution to enable modelling of this EBV at spatial scales required for management. Extend information about past plant species distributions (e.g., with palaeodata) to obtain reference baselines Adapted AI tools to analyze field (citizen science) smartphone camera photos may be able to support EBV variables data gaps. We for example use an adapted AI model approach to classify arable crops in the field of agricultural monitoring
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): Centralized cloud for data storage			

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Preidl et al. (2020): https://doi.pangaea.de/10.1594/PANGAEA.910837
  Blickensdörfer et al. (2022): https://zenodo.org/record/6451848
  MonViA: National Monitoring of Biodiversity in Agricultural Landscapes in Germany: https://www.agrarmonitoring-monvia.de/
- LOTVS database (https://lotvs.csic.es/) - Victor Lecegui (UB) Gaia Sperandii, M., de Bello, F., Valencia, E., Gotzenberger, L., Bazzichetto, M., Galland, T., ... & Leps, J. (2022). LOTVS: A global collection of permanent vegetation plots. *Journal of Vegetation Science*, *33*(2).
- High-Mountain Mire Vegetation - Aaron Pérez and Eulàlia Pladevall (UB). https://www.givd.info/ID/EU-ES-001.
- Pyrenean Snowbed Monitoring (https://www.opcc-ctp.org/en/proyecto/florapyr-avance) Estela Illa (UB). Masclaux, T., Largier, G., Cambecèdes, J., Fallour-Rubio, D., Hamdi, E., Komac, B., ... & Papuga, G. (2022). Large-scale diachronic surveys of the composition and dynamics of plant communities in Pyrenean snowbeds. *Plant Ecology*, *223*(9), 1103-1119.
- Küchler et al. 2023. Vegedaz - a program for recording and analysing vegetation data. https://www.wsl.ch/en/services-and-products/software-websites-and-apps/vegedaz.html
- Tillé, Y., & Ecker, K. (2014). Complex national sampling design for long-term monitoring of protected dry grasslands in Switzerland. *Environmental and Ecological Statistics*, *21*, 453–476.
- Bergamini, A., Ginzler, C., Schmidt, B. R., Bedolla, A., Boch, S., Ecker, K., Graf, U., Küchler, H., Küchler, M., Dosch, O., & Holderegger, R. (2019). Biotope von nationaler Bedeutung: Zustand und Veränderungen. *WSL Berichte*, *85*, 1–104.
- Monitoring the Effectiveness of Habitat Conservation in Switzerland (www.biotopschutz.wsl.ch)
- Hilpold A., Anderle M., Guariento E., Marsoner T., Mina M., Paniccia C., Plunger J., Rigo F., Rüdisser J., Scotti A., Seeber J., Steinwandter M., Stifter S., Strobl J., Suarez-Muñoz M., Vanek M., Bottarin R., Tappeiner U., Handbook – Biodiversity Monitoring South Tyrol, Bozen/Bolzano, Italy: Eurac Research, 2023, https://doi.org/10.57749/2qm9-fq40
- Bruelheide, H., Jansen, F., Jandt, U., Klenke, R., Sperle, T., Grescho, V., Bonn, A., Winter, M., 2022. Mindestanforderungen an ein Monitoring von
- Gefäßpflanzenarten auf den bundesweit repräsentativen Stichprobenflächen. NuL 97, 289–299. https://doi.org/10.19217/NuL2022-06-03
- Rocchini, D., Thouverai, E., Marcantonio, M., Iannacito, M., Da Re, D., Torresani, M., ... & Wegmann, M. (2021). rasterdiv—An Information Theory tailored R package for measuring ecosystem heterogeneity from space: To the origin and back. *Methods in ecology and evolution*, *12*(6), 1093-1102.
- Burrascano, S., & Trentanovi, G. (2022). Handbook of field sampling for multi-taxon biodiversity studies in European forests. *Handbook of field sampling for multi-taxon biodiversity studies in european forests*, 1-114.

Species distributions of main trees			
Workflow components			
	Current initiatives	**Emerging products and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National Forest Inventories (NFI)** - follow standardised monitoring protocols - 768,228 sampling sites - data registered in 1 km geographical grid - sampling frequency: varies and is low (6-10 years) - species sampled differ among countries; absences are highly uncertain for some species in some countries - not all countries collect same parameters **ICP Forests** 8000 Lev. I plot on 16x16 km grid sampling frequency yearly. **National initiatives**	**International Co-operative Program on Assessment and Monitoring of Air Pollution Effects on Forests (ICP - Forest)**: established network of sample points in major forest ecosystems - large-scale and intensive monitoring follows harmonised and standardised survey methods - measurement parameters: tree crown condition, foliar chemistry, tree growth, soil chemistry, etc. https://www.uni-goettingen.de/en/wp4+remote+sensing+and+machine+learning/636253.html Digital Forest: remote sensing and machine learning, automates satellite data processing into data cubes, also connected to the project: https://rsc4earth.de/	Increase sampling frequency to be able to provide modelled tree species distributions at 3-6 year resolution. Increase capacity building Increase taxonomic coverage to include secondary species; taxa growing only in part of the continent; smaller trees, alien and rare species; and species for agroforestry or short-rotation forestry. Harmonise the collected parameters

	Ongoing tree health monitoring web-based app via satellite remote sensing (Germany only): ForestWatch, the data shows changes in tree vitality relative to a reference year (2017, due to availability of Sentinel-data) the	**Forgenius**: -genetic, phenotypic (in situ collecting data on growth, phenology, fecundity…) and environmental data (remote sensing) of Genetic Conservation Units in EU	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**European National Forest Inventory Network (ENFIN)** - combines field-based sample plots and remote-sensing products - was set up in 2003 - data custodian of *in-situ* tree species occurrences, 241 species - provides data and support to European Forest Data Centre and Forest Information System For Europe (FISE) - defined metadata standards to harmonize data across National Forest Inventories - data used for modeling and for European Atlas of Forest Tree species - ENFIN data not available; NFI data open or available upon request in many countries; raw	**International Co-operative Program on Assessment and Monitoring of Air Pollution Effects on Forests (ICP - Forest)**: - available online platform for forest data storage and exchange - geo-database: 42 countries and 165 tree species **Dataset** Diameter, height and species of 42 million trees in three European counties. ALS data: https://open-research-europe.ec.europa.eu/articles/3-32 **B-cubed** (https://doi.org/10.3030/101059592): creating data-cubes on plant occupancy from data mobilized by GBIF. Evaluating standards for publication and analysis of aggregated biodiversity data,	Improve data availability within project partners before publications. Increase availability of spatial explicit information on tree species presence, capitalizing on available data products such as Small Woody Features (Copernicus) etc Advocate for the implementation of an open data policy to ensure that detailed national forest inventories, funded by public money and covering forest composition, structure, production, etc., are accessible to academia and the public across the EU, where current availability is limited. Aim to develop a harmonized EU-wide forest data product,

	data not available or unknown availability for some countries **Forgenius**: integrating genetic, phenotypic and environmental data. **Euforgen** European Information System on Forest Genetic Resources (EUFGIS) **Biodiversity Information Standards (TDWG)** https://www.tdwg.org/community/dwc/ which includes the Darwincore Maintenance Group and Interest Group Observations & Specimens	developing data aggregation algorithms to reduce bias. EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species.	matching the detail of existing national-level collections and, ideally, including historical data to provide insights into both current and past forest states. Add the UK to the NFI group
Modelling Types of models Predictors Estimation & uncertainty Software	Model and map distribution of > 250 tree species across Europe using ENFIN data -Predictive models on adaptability and evolvability of populations **Euforgen** development of the distribution maps of European forest trees Predictors: evolvability, Ne, adaptability	- Guarden (https://guarden.org): improving species distribution models using species-interaction data	Implement routine modelling within framework of ENFIN initiative More detailed species distribution models, taking intraspecific genetic diversity and phenotypic plasticity into account Open data for initiatives/projects to improve their modelling (e.g. for tree health, early warning systems for disease outbreaks, drought stress, etc.). A project on the

	ML to produce distribution maps for Europe 2000 - 2020 (Bonannella et al., 2022)		(early) identification of tree damage in Germany is FirSt, which would benefit from open-source data.
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Mauri, A., Strona, G., and San-Miguel-Ayanz, J. (2017). EU-Forest, a high-resolution tree occurrence dataset for Europe. Scientific data, 4(1), 1-8. • https://www.forgenius.eu/the-project/overview • https://www.euforgen.org/ • https://zenodo.org/record/5524611#.Y_dEtR_MLmF • https://open-research-europe.ec.europa.eu/articles/3-32			

Species distributions of lichens (as indicators of pollution)			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Dutch lichen monitoring program (NEM)**	**The Lichens of Italy;** project on iNaturalist: a tool for citizen science and lichens. Experts assess the taxonomic correctness of iNaturalist records.	Include other groups of indicator species, especially Bryophytes In addition to the occurrence of indicator species, chemical analysis of widespread species allows monitoring of air quality (example: https://www.umweltbundesamt.de/daten/luft/bioindikation-von-luftverunreinigungen#moose-als-bioindikator)
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**National initiatives** **ITALIC 7.0** - information system on Italian lichens - data retrieved from Checklist of the Lichens of Italy by Nimis (2016) and 13 lichen herbaria in Italy - herbaria with georeferenced data downloadable (Darwin Core) - not specific for lichens as indicators for pollution, but contains information on species' ecological indicator values of		

	interest (such as eutrophication and poleotolerance) - dot-maps for each taxon (presence data) - spatial scope: Italy **DRYADES project - Biodiversity databases** Project Dryades, started in the late 90s, gathers the results of all the initiatives coordinated by the Department of Life Sciences of the Trieste University in the field of Biodiversity Informatics The Dryades website allows access to interactive identification tools devoted to plants, fungi and animals, to archives of digital images, and to important databases on the biodiversity of Italy. **British Lichen Society**		
Modelling Types of models Predictors Estimation & uncertainty Software		British Lichen Society**:** **Occupancy models** have been used for national trends in bryophytes in UK (Outhwaite et al. 2019, 2020)	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- For DRYADES and ITALIC 7.0 project contact the lichen expert Juri Nascimbene (juri.nascimbene@unibo.it - Univ. Bologna). Check also the Italian Lichen Society website for further details
- Nimis P.L. 2016. The Lichens of Italy. A Second Annotated Catalogue. EUT, Trieste, 739 pp.
- Nimis P.L. (2022) ITALIC - The Information System on Italian Lichens. Version 7.0. University of Trieste, Dept. of Biology, (https://dryades.units.it/italic)
- Outhwaite CL, Powney GD, August TA, et al. Annual estimates of occupancy for bryophytes, lichens and invertebrates in the UK, 1970-2015. Sci data. 2019;6(1):259. doi:10.1038/s41597-019-0269-1
- Outhwaite CL, Gregory RD, Chandler RE, Collen B, Isaac NJB. Complex long-term biodiversity change among invertebrates, bryophytes and lichens. Nat Ecol Evol. 2020;4:384–392. doi:10.1038/s41559-020-1111-z
- https://www.blwg.nl/mossen/korstmossen/landelijk_meetnet_korstmossen.aspx
- Lichen expert might be contacted to help for EVBs: Univ.-Prof. Dr. Roman Türk (retired), University of Salzburg, Lichen expert
- For Bryophytes and lichens experts contact Bryologisch-lichenologische Arbeitsgemeinschaft für Mitteleuropa e. V.

Species distributions of invasive alien terrestrial taxa of European concern			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiative** **UseIt** is an Italian CNR Project. The project aims to harmonise monitoring strategies at the national level by taking into account European sampling standards. Data collection methods include DNA metabarcoding, stable isotope analysis, remote sensing and citizen science data. All data are geo-referenced.	**Citizen science** **EASIN** "IAS Europe" smartphone App for citizen science; data integrated into EASIN GeoDatabaseMonitoring data from other initiatives can potentially be used. Citizen science initiative for monitoring invasive terrestrial planarians across Europe	Develop EBV-specific monitoring network with adequate taxonomic, spatial and temporal coverage of European invasive species Develop further the remote sensing-assisted monitoring tools to complement labour field campaigns. Standardise and coordinate data collection tasks
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EASIN (European Alien Species Information Network):** **- Data Aggregation:** EASIN aggregates data at a spatial resolution of 10 x 10 km or by river basin for comprehensive coverage. **- Data Broker System:** Utilizes a sophisticated system to collect species occurrences and related data (date, source) from various sources, integrating them into a	**B-cubed** Creates data-cubes on invasive species occupancy from data mobilised by GBIF. Evaluating standards for publication and analysis of aggregated biodiversity data, developing data aggregation algorithms to reduce bias. https://doi.org/10.3030/101059592	Improve communication and data integration between national coordinators & EU funded projects working on alien invasive species in a country Improve communication and coordination among national admin bodies in charge of monitoring alien invasive species Facilitate data flows and integration at federal and regional levels

	normalised database for streamlined access. **- NOTSYS Platform:** Serves as the official platform for EU Member States to fulfil their notification obligations under Regulation 1143/2014 on Invasive Alien Species (IAS), facilitating communication with the Commission and other Member States. **- Capacity Building:** EASIN enhances surveillance and monitoring capabilities by offering support for the development of surveillance systems, citizen science initiatives, and educational programs for teachers, detailed at https://easin.jrc.ec.europa.eu/easin. **IUCN** - ISSG Invasive Species Specialist Group - GISD Global Invasive Species Database - EICAT standards classification invasive species **DAISIE GBIF** - Delivering Alien Invasive Species Inventories for Europe.		Develop API and apply metadata standards

	GRIIS - Global Register of Introduced and Invasive Species **National initiatives** **Distribution of invasive terrestrial species in Romania**: https://zenodo.org/record/6832794		
Modelling Types of models Predictors Estimation & uncertainty Software	**Species distribution models** - Machine-learning - MaxEnt models - Bayesian SDMs - Joint species distribution models	**EO4diversity** Invasive Species model derived from remote sensing data (https://www.eo4diversity.info/) **Biotope vulnerability workflow** (LifeWatch ERIC Internal Joint Initiative). The incidence version of the workflow uses data cube analysis to estimate the incidence of alien species on biotopes. The Virtual Research Environment can be accessed at: https://www.lifewatch.eu/internal-joint-initiative/workflows/ **Guarden** (https://guarden.org) Improving species distribution models using species-interaction data. **Nature-FIRST**	Methods for the generation of information about past distributions of alien species (e.g., palaeodata for plants) to establish baselines Make model code open, provide user-friendly software

		EU Horizon project: Develop predictive, proactive and preventative capabilities for nature conservation stakeholders based on Digital Twins	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): API, metadata standards (DwC is great on giving us a good and maintained standard), open science in general should be welcome

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- https://easin.jrc.ec.europa.eu/easin/
- Boon, P. J., Clarke, S. A., & Copp, G. H. (2020). Alien species and the EU Water Framework Directive: A comparative assessment of European approaches. *Biological Invasions*, *22*(4), 1497-1512. URL.
- BROCHURE IAS OF UNION CONCERN 2022. Circabc (europa.eu)
- LifeWatch ERIC Internal Joint Initiative: https://www.lifewatch.eu/internal-joint-initiative/

Species abundances of selected terrestrial disease vectors			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building		**ENETWILD-EFSA** -Establishing a pilot study to assess the use of eDNA to monitor wildlife-associated pathogens within the EOW. - Immamalia app (https://mammalnet.net/es/imammalia) -Mammalnet (www.mammalnet.com) is an Enetwild associated citizen science project, which developed app iMammalia (https://mammalnet.net/es/imammalia), useful for communicating the presence of wildlife carcasses (wildlife disease surveillance) **Iberconejo LIFE project**. Monitoring program for demographic and health status of wild rabbit populations in the Iberian Peninsula. Interested specifically in Myxomatosis and viral haemorrhagic disease. They are carrying out health	# Systematic monitoring for identifying new occurrences (mosquitoes)

		surveillance about these two diseases. **INF-ACT Foundation** is a NextGenerationEU-funded project that studies arthropod vectors and emerging vector-borne pathogens.	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**VectorNet** is a joint initiative by ECDC and EFSA designed to enhance readiness and response to vector-borne diseases using a 'One-Health' approach. The database offers details on the distribution of various European mosquitoes, ticks, sandflies, and biting midge species, potential carriers of pathogens impacting human and animal health. **GBIF-health** GBIF plays its role in supporting **One Health dataset** **WAHIS** is the global animal health reference database of the World Organisation for Animal Health (WOAH). Just including new	**ENETWILD-EFSA** **-** mapping of the existing structures and systematic initiatives and academic activities for surveillance in the EU for zoonoses - Applying the Darwin Core data standard to wildlife disease ENETWILD-EFSA	# Automated workflows for standardisation and harmonisation - Mapping/overview of national monitoring of disease vectors/prevalence (this will probably hinge on collaboration with public health sectors, veterinary institutes, etc.) see # Automated workflows for collecting data from different online sources, namely citizen science initiatives and Apps (specifically mosquitoes)

Modelling Types of models Predictors Estimation & uncertainty Software	- Local-/national scale integrated modelling of vector and disease abundance (several including data from hunting/culling programmes)		A harmonised early warning system for mosquitoes across Europe
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): data portal, central repositories, scalable computing, cloud services, to develop and maintain an harmonized early warning system across Europe (referring to mosquitoes)			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Ceia-Hasse A., Sousa C.A., Gouveia B.R., Capinha C. (2022) Forecasting the numbers of disease vectors with deep learning. bioRxiv 2022.11.22.517519. https://doi.org/10.1101/2022.11.22.517519 • Cardoso, B., **García-Bocanegra, I**., Acevedo, P., Cáceres, G., Alves, P. C., & **Gortázar, C**. (2022). Stepping up from wildlife disease surveillance to integrated wildlife monitoring in Europe. *Research in Veterinary Science*, *144*, 149-156. https://doi.org/10.1016/j.rvsc.2021.11.003 • Braks, M., Schaffner, F., Medlock, J. M., Berriatua, E., Balenghien, T., Mihalca, A. D., ... & Wint, W. (2022). VectorNet: Putting vectors on the map. *Frontiers in Public Health*, 549. 10.3389/fpubh.2022.809763			

Species abundances of selected terrestrial crop pests			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National initiatives** Several national projects (LIB) https://bonn.leibniz-lib.de/en/zbm#info working on insect diversity on agro-ecosystems also covering crop pests (often crop-specific) All projects have standardised monitoring methods. Structured species lists with spatial information.	Med4Pest: MED4PEST is PRIMA-Med funded project. It aims to develop proven, effective Ecologically Based Rodent Management (EBRM) methods and products, which are readily integrated into local pest /invasive rodent management systems in Mediterranean countries, contributing to the shift from synthetic pest control to biological and ecological pest management, ultimately leading to eco-sustainable farming systems, higher quality and quantity crop production and optimization of input use for ecosystem health. MED4PEST objectives and goals will produce new knowledge through scientific research that will be pursued with the collaborative research of the consortium partners from 2 Universities, 2 Research Institutes, and one company Terra 4 project. Civil UAVs	EU monitoring Fine-resolution monitoring of pest effects on vegetation through RS

		Initiative: Regional project (NW Spain). Module 3.- **Forest** Pests. Module aimed at detecting trees symptomatic of a forest disease or pest. Based on the analysis of very high resolution multispectral images (RPAs, WorldView). Detection of trees with a decline in photosynthetic activity within the forest stand, facilitating damage assessment and treatment planning. Machine learning model. Eg. *Bursaphelenchus xylophilus*	
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**European Food Safety Authority** (EFSA) Monitoring of foodborne diseases: monitors and analyses the situation on zoonoses, zoonotic microorganisms, antimicrobial resistance, microbiological contaminants and foodborne outbreaks across Europe. The Authority is assisted by the Network for zoonoses monitoring data, a pan-European network of national representatives and international organisations that assist EFSA by gathering and sharing information on zoonoses in their respective countries.	New EU-project Biomonitor4CAP www.BioMonitor4CAP.eu (2022-2026) Task: Methods comparison, standardisation and new developments for CAP (common agricultural policy)	Develop public databases, including time-stamped and accurately geolocated/delineated observations designed to train and validate algorithms based on remote sensing data

Modelling Types of models Predictors Estimation & uncertainty Software		FORDEAD: A python package providing a method for detection of forest dieback resulting from bark beetles attacks on spruce stands using remote sensing (Sentinel-2 time series analysis): https://fordead.gitlab.io/fordead_package/	Spatiotemporal models of pest prevalence of EU priority pests
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Legal implication unclear regarding images on platforms to train Artificial Intelligence (the legislation is not clear at the moment on which image can be used, and platforms like iNaturalist could provide licenced images to train AI for academic and commercial purposes, as several companies are getting into the smart monitoring field and could provide devices or services to farmers, with research cooperations through partnerships)			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Terra 4 project. Civil UAVs Initiative. (Boris Hinojo. 3edata ingeniería ambiental) • https://www.efsa.europa.eu/en/science/tools-and-resources			

Phenology of fructification of mushrooms and wild fruits			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**National Initiatives** **Network for the Study of Mycological Diversity**. ISPRA has a national network that works on Fungi, collecting data on all fungal species (not only mushrooms). Fungal data are collected by mycologists, i.e., citizens who are experts in mycology because they are certified as mycologists. Data is sent to ISPRA by a mobile App implemented by ISPRA. Data regard not only fungal species but also the specific habitat in which they live.	**Project LifePlan** (https://www.helsinki.fi/en/projects/lifeplan) has many passive samplers, including fungal spore traps that can be used for fungal phenology and species communities.	Identify the species that are more important economically and for recreation across Europe, but also if there are country specificities Censused fungal species present in Europe
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams			Automated workflows Standardisation and harmonisation We would like to have a European database of all fungal species in European habitats. Better communication of

			procedures and tools among European countries that are interested in Fungi. Automated workflows for collecting data from different online databases Collect historical data from museums or, private associations, or single mycologists.
Modelling Types of models Predictors Estimation & uncertainty Software		**EuropaBON WP5** Forecasts of mushroom fructification across Europe currently being developed.	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): data are free, the Information System is open to all citizens			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): all the examples would help develop and run in a stable (long-term) way the mentioned forecasts, as well as compiling, keeping and sharing the monitoring results, especially at the European scale			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • System of Fungi: https://sinacloud.isprambiente.it/portal/apps/webappviewer/index.html?id=a39bdb095c5b42318cf283e0bb21ee1f • Italian Network: https://www.isprambiente.gov.it/en/activities/biodiversity/network-for-the-study-of-mycological-diversity/network-for-the-study-of-mycological-diversity?set_language=en			

Phenology of flowering and leaf senescence			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Satellite signal and products** **MODIS NDVI/EVI time series** product MOD/MYD13Q1 iNaturalist dataset **MODIS phenology product MCD12Q2** **Copernicus High-Resolution Vegetation Phenology and Productivity** **Ground truth data** GLORIA (Global Observation Research Initiative in Alpine Environments): - global long-term observation network in alpine areas. - Permanent plot sites for consistent data collection. - Collects vegetation and temperature data from these sites. - Protocols and standards for data collection	**Ground truth data** **Phenocams** Digital cameras use to monitor ecological phenomena. They capture periodic images to provide detailed, high-resolution data on ecosystem changes over time, particularly phenological shifts.	More observations/higher temporal coverage from satellite observations to improve phenological stages accuracy More in-situ observations in the European Southernmost Regions

	National initiatives **LifeWatch-University of Granada and the Global Change Observatory of Sierra Nevada** have been monitoring flowering phenology in the field for 20 years and in herbarium specimens over 100 years https://obsnev.es/en/		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**DEIMS-SDR eLTER-R** (Dynamic Ecological Information Management System - Site and dataset registry**)** is developing guidelines for data sharing and metadata format of sites/sampling stations, sensors and dataset	**PEP725** observations network (Pan-European phenological database)	A platform especially for sharing image time series focussed on small areas with e.g. flowers and pollinators - our data don't naturally fit on platforms for camera traps for large vertebrates
Modelling Types of models Predictors Estimation & uncertainty Software	**PROSAIL** Estimation of vegetation biophysical properties (LAI, leaf pigment content, LMA, equivalent water thickness) from remote sensing optical images (multi & hyperspectral) based on physical model inversion **Wekeo** platform to access Sentinel-2 times series analysis tools	**PhenoApp** (developed under eLTER Plus and SUMHAL projects). - Dynamic map for site selection with phenological information. - Uses Ndvi2Gif and PhenoPY libraries for Sentinel-2 image metrics. - Integrates MODIS and Copernicus Sentinel 2 HR VPP phenology products.	Upscaling of Earth Observation Phenology products Validation products using in situ data like Phenocams and other observations.

	Phenofit R Package: An R package for extracting vegetation phenology from time series remote sensing - Adopted 'TIMESAT' and 'phenopix'. - Whittaker-based snow elimination. - 7 curve fitting methods and 4 phenology extraction methods. - Parameter boundaries set for ecology. - Used 'optimx' for optimization.		

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

- Plant Phenology task group at TDWG that discusses the amendment of Darwin Core to accommodate phenology data: https://www.tdwg.org/community/osr/phenology/
- Plant Phenology Ontology: https://obofoundry.org/ontology/ppo.html

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

Very high computational needs for satellite based time series analysis for high resolution phenology maps

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Francesco Chianucci, Sofia Bajocco, Carlotta Ferrara, Continuous observations of forest canopy structure using low-cost digital camera traps, Agricultural and Forest Meteorology, Volume 307, 2021, 108516, ISSN 0168-1923, https://doi.org/10.1016/j.agrformet.2021.108516.

Phenology of migration of terrestrial birds			
Workflow components			
	Current initiatives	**Emerging products and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EURING:** standardised fieldwork protocols to collect count data seasonally/annually; ongoing long-term time-series updated annually; sampling points unevenly distributed but exact location; 300 species **National initiatives** **Migres Programme**: standardised long-term monitoring (i.e., visual count record) at a bottleneck area (the Strait of Gibraltar) targeting soaring birds but also for passerines and seabirds. Over this site, almost all the migratory soaring birds breeding in Northern and Western Europe can be observed due to flight constraints in these species. There are other similar initiatives across the European migrations route (at other bottleneck areas, e.g., Falsterbo, Pyrennes, Bosphorous) with a similar methodological approach.	**Trektellen** Nocturnal migration (BIOACOUSTICS) https://trektellen.org/static/doc/Protocol_for_standardised_nocturnal_flight_call_monitoring_v01.pdf	Improve spatial resolution Increase taxonomic coverage Strive to have all data collected with standardised monitoring protocols. Update data more frequently so the EBV could be generated more frequently than once a year Possibly, weather radar can be used to identify nights and areas with high migratory fluxes (see aerial biomass EBV)

	Monitoring is mainly conducted by volunteers.		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**EuroBirdPortal (EBP):** - maps in viewer aggregated by week and 30 x 30 km; data in central repository aggregated at 10x10km - data streams automated - data access requires authorisation from national data owners - only data for 137 species - data harmonised, managed, and stored in a central repository curated by European Bird Census Council **EURING Data Bank (EDB,** https://euring.org/node/4): digitized according to standard protocols - data available upon request - mostly updated once per year, although each record retains temporal resolution **Movebank** (www.movebank.org) - database with animal tracking data (incl. licenses, DOIs) - data entry standards - standardized data model (Kays et al. 2022)	**Eurasian African Migration Atlas** (Spina et al. 2022) **Migration Mapping Tool 2022:** combines EURING connectivity information with EBP observational data; joint initiative by EURING, EBP, EFSA	Standardized protocols for data integration Improve data access Coordination (e.g., data sharing) among bottleneck migration areas and programmes

	Migres Programme: https://www.fundacionmigres.org/en/programa-migres/ **Convention on the Conservation of Migratory Species of Wild Animals** (CMS): https://www.cms.int/en		
Modelling Types of models Predictors Estimation & uncertainty Software	**Climate-window analysis** (10.1371/journal.pone.0167980; 10.1111/gcb.14746): a statistical approach that identifies and quantifies climate/weather signals and their critical time window for traits (often applied in phenology research)	**Full-annual-cycle models** Full-annual-cycle (FAC) models integrate seasonal demographic and environmental processes to elucidate the factors that limit and regulate animal populations. (https://doi.org/10.1642/AUK-14-211.1; https://doi.org/10.1111/conl.12933 **Moveapps** for analysing tracking data from movebank (https://www.moveapps.org/)	Generate open code and user-friendly software
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): Crane radar: Data obtained and integrated from Waarneming.nl.			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Spina, F., Baillie, S.R., Bairlein, F, Fiedler, W. and Thorup, K. (Eds) (2022) The Eurasian African Bird Migration Atlas. https://migrationatlas.org. EURING/CMS.			

- Kays, R., Davidson, S.C., Berger, M., Bohrer, G., Fiedler, W., …,Wikelski, M. 2022. The Movebank system for studying global animal movement and demography. Methods in Ecology and Evolution 13: 2, 419-431. DOI: 10.1111/2041-210X.13767.
- Hostetler, J.A., Sillett, T.S., Marra, P.P. 2015. Full-annual-cycle population models for migratory birds. The Auk 132: 2, 433-449. DOI: 10.1642/AUK-14-211.1.
- Marcacci, G., Briedis, M., Diop, N., Diallo, A.Y., Kebede, F., Jacot, A. 2022. A roadmap integrating research, policy, and actions to conserve Afro-Palearctic migratory landbirds at a flyway scale. Conservation Letters. DOI: 10.1111/conl.12933.

Phenology of the emergence of butterflies			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**European Butterfly Monitoring Scheme (eBMS)** -Transect counts (weekly during the butterfly season depending on the regions), standardised protocols - abundance data for > 312 butterfly and moth species - Field guides for different regions in Europe	**eBMS 15-min Counts** New methodology of opportunistic counts in areas currently uncovered by fixed transects, e.g. areas of difficult accessibility **ABLE project**. Massive collection of opportunistic observations. Geographic coverage was enlarged via the	Long term data Increased sampling frequency Improved spatial coverage density Increase the number of transects across Europe. Field guides and sampling protocols for other regions in Europe
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Butterfly Conservation Europe** - EU-wide integration node - Metadata standards for harmonisation across countries - Standardised sampling protocols for transect counts - Different methods of data entry depending on the county - Data streams not fully automated - eBMS App allows volunteers to record species observations and abundances; directly upload to	ABLE project: 'Assessing Butterflies in Europe' Data inclusion and data harmonisation for new European countries	Improve data availability Integration of transect count data (eBMS) and data from the 15-min counts (eBMS App) Increase the number of coordinators, paid experts and volunteers across Europe. Further development of app usability, including new local adaptations

	eBMS database; review the uploaded data -Raw data freely available upon request with license agreement, only for the countries officially covered by eBMS		
Modelling Types of models Predictors Estimation & uncertainty Software	**TRIM model** to estimate population trends and calculation of trend indices/products at national level on an annual basis - training courses and materials available - models not routinely used to generate phenology products		Routinely model butterfly phenology for priority butterfly species
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of an expert who provided information for this template, literature, online sources, web pages of EU project):			

Community biomass of selected functional groups of terrestrial arthropods			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Land Use/Cover Area Frame Statistical Survey (LUCAS):** - change in the relative abundance of living components of soil organic matter, including Eukaryotes (18S rDNA), Microfauna (nematodes), Mesofauna (arthropods) with DNA metabarcoding; start in 2018 across all EU-MS, every 3 years - minimum sampling unit likely adequate for 1 x 1 km spatial resolution **eLTER** LTSER site Matschertal_Val Mazia, Italy Pitfall traps and soil core sampling for studying soil macrofauna **National initiatives** **LIB** https://bonn.leibniz-lib.de/en/zbm#info working on insect diversity on agro-ecosystems covering also	**Automatic image-based identification and biomass estimation of invertebrates** Upscaling across projects possible and follow-up synthesis - New monitoring methods - Cameras in the lab https://doi.org/10.1111/2041-210X.13428 **Mambo project** https://www.mambo-project.eu/ building on use of cameras to quantify biomass **Biomonitor4CAP** www.BioMonitor4CAP.eu (2022-2026) Task: Methods comparison, standardization and new developments for CAP (common agricultural policy)	Temporal extension (extend time period covered (i.e. prior to 2018) Implement this in several forest ecosystems throughout Europe Find partners that are keen to perform long-term monitoring with SLAM traps, Deployment of in-field cameras at scale to build a diverse training dataset for “minifauna”. Standardized protocols for deployment of cameras and image annotation

	biomass. All projects with standardized monitoring methods. Structured species lists with spatial information. **SLAM** (Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores) (https://bdj.pensoft.net/article/97952/) (data from 2012 to 2022 and ongoing) - collect long-term ecological data - identify the spatial and temporal invasion patterns of exotic arthropod species;		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**LUCAS** - Standardized sampling procedure & central laboratory - Raw data freely available and downloadable after registration - Metadata standards: surveyors use same forms and instructions to integrate data - Data standardized and integrated into central repository via Data Management Tool Automatic quality control		Fully automated data flows Data of individual species can be stored in GBIF and in Data Papers (e.g. Biodiversity Data Journal. - Example of a Collection of data at https://bdj.pensoft.net/topical_collection/58) A platform especially for sharing image time series focussed on small animals, especially arthropods.

			Increasing the number of transects, coordinators, and volunteers across Europe.
Modelling Types of models Predictors Estimation & uncertainty Software	**Biomass Modelling using Maximum Entropy Theory of Ecology (METE)** (Brush, M., Matthews, T.J., Borges, P.A.V. & Harte, J. (2022). Land use change through the lens of macroecology: insights from Azorean arthropods and the Maximum Entropy Theory of Ecology. *Ecography*, **5**: e06141. DOI: 10.1111/ecog.06141		
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): The use of DARWIN CORE is essential			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): We use for SLAM project GBIF IPT Portal. A good example: Borges P A V, Lhoumeau S (2022): Long-term monitoring of Azorean forest arthropods. v1.3. Universidade dos Açores. Dataset/Samplingevent. http://ipt.gbif.pt/ipt/resource?r=arthropods_slam_azores&v=1.3			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): https://esdac.jrc.ec.europa.eu/projects/lucas • Brush, M., Matthews, T.J., Borges, P.A.V. & Harte, J. (2022). Land use change through the lens of macroecology: insights from Azorean arthropods and the Maximum Entropy Theory of Ecology. *Ecography*, **5**: e06141. DOI: 10.1111/ecog.06141 • Costa, R. & Borges, P.A.V. (2021). SLAM Project - Long term ecological study of the impacts of climate change in the natural forest of Azores: I - the spiders from native forests of Terceira and Pico Islands (2012-2019). *Biodiversity Data Journal*, 9: e69924. DOI:10.3897/BDJ.9.e69924 https://bdj.pensoft.net/article/69924/			

- Emerson, B.C., Casquet, J., López, H., Cardoso, P., Borges, P.A.V., Mollaret, N., Oromí, P., Strasberg, D. & Thébaud, C. (2017). A combined field survey and molecular identification protocol for comparing forest arthropod biodiversity across spatial scales. *Molecular Ecology Resources,* **17**: 694-707. DOI:10.1111/1755-0998.12617.
- Emerson, B., Borges, P.A.V., Cardoso, P., et al. (2022). Collective and harmonised high throughput barcoding of insular arthropod biodiversity: toward a Genomic Observatories Network for islands. *Molecular Ecology*. DOI: 10.1111/mec.16683
- Lhoumeau, S., Cardoso, P., Costa, R., Boieiro, M., Malumbres-Olarte, J., Amorim, I.R., Rigal, F., Santos, A.M.C., Gabriel, R. & **Borges, P.A.V.** (2022). SLAM Project - Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores: IV - The spiders of Terceira and Pico Islands (2019-2021) and general diversity patterns after ten years of sampling. *Biodiversity Data Journal,* **10**: e96442. DOI: 10.3897/BDJ.10.e96442 https://bdj.pensoft.net/article/96442/list/8/
- Lhoumeau, S., Cardoso, P., Boieiro, M., Ros-Prieto, A., Costa, R., Lamelas-Lopez, L. Leite, A., Amorim, I.R., Gabriel, R., Malumbres-Olarte, J., Rigal, F., Santos, A.M.C., Tsafack, N., Ferreira, M.T. & Borges, P.A.V. (2022). SLAM Project - Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores: V - New records of terrestrial arthropods after ten years of SLAM sampling. *Biodiversity Data Journal,* 10: e97952. DOI: 10.3897/BDJ.10.e97952) https://bdj.pensoft.net/article/97952/
- Matthews, T., Sadler, J.P., Carvalho, R., Nunes, R. & Borges, P.A.V. (2019). Differential turnover rates and temporal beta-diversity patterns of native and non-native arthropod species in a fragmented native forest landscape. *Ecography,* 42: 45–54. DOI: 10.1111/ecog.03812

Community biomass of soil microbes			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Land Use/Cover Area Frame Statistical Survey (LUCAS):** **-** over ~20000 soil sampling points across all EU member states revisited every 3 years (starting in 2009) - currently small fraction (885 plots) of samples are used to measure microbial biomass, started in 2018 across all EU-MS, sampled every 3 years - Microbial biomass measured from topsoil samples with substrate-induced respiration; units [µg Cmic g soil dw-1]. - Other related measurements: Respiratory quotient, basal respiration. - organic content (microbial carbon and general organic carbon combined) could potentially be used; started in 2009 - minimum sampling unit likely adequate for 1 x 1 km spatial resolution		Microbial biomass varies through the year, but current initiatives don't take into account this seasonal variation. I**ncreasing the temporal resolution** by sampling several times during the year could improve our understanding on the seasonality of microbial biomass across Europe. - **Increase the taxonomic resolution** of the current microbial biomass monitoring protocols to include the measurement of the bacteria-to-fungal ratio, and gain insights into the relative abundance of these two major microbial groups in soils. This additional information can contribute to a more comprehensive understanding of soil microbial communities and their potential ecological functions.

	<u>National initiatives</u> **RMQS: French Soil Quality Monitoring Network** - The network covers the entire French territory and soils are sampled at 2240 sites along a systematic grid (16 km x16 km) across different land uses in continental France and overseas territories. - Each site is sampled every 15 years, since 2000 (2nd campaign started in 2016) - 12 sub-contracted teams in France doing the fieldwork, based on a common manual - Organize and store soil samples and soil information, give access to soil information and samples and support public policies -The soil DNA extracted is expressed in terms of soil molecular microbial biomass and related to other soil and land-use data over French territory. **DSQN: Dutch Soil Quality Network** - Random stratified grid design across ~ 300 locations comprising stringent combinations of land use		Use molecular technologies, e.g. by using qPCR in the already sampled specific primers for bacteria and fungi (16S and ITS), or using other traditional protocols, such as PLFA Analysis (Phospholipid Fatty Acid Analysis)

	and soil type. Represents ~75% surface area of the Netherlands. - Categories comprises conventional farms, organic farms (dairy or arable), nature, parks - All locations sampled in a six-year cycle. - The measurements are combined in the Biological Indicator of Soil Quality (BISQ), comprising average values for biomass, abundances and taxonomic diversity of various soil dwelling organisms (including microbial biomass and Fungal:bacterial biomass ratio).		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Land Use/Cover Area frame statistical Survey (LUCAS):** - standardized sampling procedure & central laboratory - microbial biomass is measured in the lab once and data is further provided to the users. -Database creation on European Soil Data Center (ESDAC) available and downloadable after registration. https://esdac.jrc.ec.europa.eu/projects/lucas		

Modelling Types of models Predictors Estimation & uncertainty Software	Types of models: - Structural equation models have been used to produce maps of the EBV at the European scale (https://onlinelibrary.wiley.com/doi/full/10.1111/geb.13371) - Machine learning models (RF, XGBoost) for current and future prediction of microbial biomass in Europe, from LUCAS topsoil survey (2018). Predictors: land use and land cover, climatic variables, topographic variables, soil physical-chemical variables (LUCAS), soil threats (e.g. erosion, compaction, from LUCAS). Most of the predictors useful for modelling this EBV are available in the European Soil Data Center (ESDAC).	SoilTemp Project - soil temperature and moisture for the globe, but much well covered in Europe. Relevant data to modeling soil biota as several of the environmental covariates currently used are measured at a relevant scale for microorganisms and other dwelling soil organisms.	Some of the main soil predictors of microbial biomass are available at the European scale for the present time. Yet, if we want to make predictions for future scenarios of microbial biomass we would first need to **model these predictors** (e.g., soil organic matter, pH, nitrogen, etc) based on future climatic scenarios to use them as predictors for microbial biomass then. **Implementing hierarchical modeling** would help to do both at the same time (e.g. neuroal network SEM).
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): https://esdac.jrc.ec.europa.eu/projects/lucas			

Community abundance and taxonomic diversity of pollinator insects			
Workflow components			
	Current initiatives	**Emerging products and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	European Butterfly Monitoring Scheme (eBMS) -Transect counts (weekly during the butterfly season, depending on the regions), standardised protocols - abundance data for > 312 butterfly and moth species **National or subnational programs** Large heterogeneity in sampling terrestrial invertebrates and pollinators across Europe, e.g. 76 pollinator monitoring schemes across Europe using different sampling methods	European Pollinator Monitoring scheme **(EU PoMS)**: Pilot EU PoMS monitoring developed by the SPRING project for all key pollinator species. - 2022-2023 UK pilot; 2023-2024 all countries - several sampling rounds per year, expected to continue on annual basis - Methods are being refined further through a second working group SPRING project: to strengthen taxonomic and citizen science capacity (pollinating insects) and trial the methods proposed by the EU PoMS across Europe. **Digital sensors:** BE-HIVE: Project funded by RIF Cyprus to create smart beehives, monitoring bees' behaviour and population numbers in real-time,	Improve spatial coverage density and distribution. Currently, these are based on power analyses at a whole European scale but with an initially biased dataset (due to limited raw data availability when generating the records) and do not include a proper estimate of how these samples should be distributed to capture trends at a national level given the size and diversity of pollinator fauna in each country. Long-term data Improve taxonomic coverage Improving record validation and data entry processes for citizen science initiatives. These should be based on the idea of a consistent output but maybe with bespoke inputs per taxa.

		examining in real-time potential threats to their colonies (bee and beehive analytics). **3Bee** Combining remote sensing with satellite images with bioacoustics and remote monitoring of bees **Faunaphotonics** Remote monitoring of flying insects with a technology based on light beams Protocols for time-lapse camera based monitoring of flowers and pollinators https://doi.org/10.1098/rsbl.2022.0187 **MAMBO project** building on use of cameras to count insects, and moth and bumblebee visitation in mountains	Capacity building, i.e. taxonomic resources and experts. Priorities for these are outlined in the EU PoMS report.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams		**EU PoMs pilot proposal:** central data repository at EEA, European Commission (DG ENV), JRC or Eurostat. **Taxonomic information** **ORBIT:** EU-funded project to develop resources for European bee inventory and taxonomy (e.g. centralized taxonomic EU facility for wild bee identification)	Many project repositories contain valuable pollinator data that is often overlooked. There is a great need for better management of metadata of data repositories and for more effective linking between different repositories. E.g. "Single Sign-On" (SSO) to an alliance of repositories would be very attractive (also enable further collaborations between projects)

		Taxo-FLY: EU-funded project to gather taxonomic information for all European hoverfly species	Implement metadata standards to facilitate data integration Make raw data freely available A platform especially for sharing image time series focussed on small animals, especially arthropods. Current options are either for focussed images of individual specimens, or camera trapping of large animals. We need datasets to train models that can detect insects in a variety of complex scenes
Modelling Types of models Predictors Estimation & uncertainty Software	- R-package Hmsc (see reference HMSC and Ovaskainen et al., 2017) → hierarchical modelling of species communities Poll4Pop (Haussler et al., 2017; Gardner et al., 2020) - a spatially explicit process based model of bee population abundance, based on the INVEST model. This has been developed and validated for the UK and Sweden. The model is available online here https://github.com/yclough/poll4pop	**Safeguard** Expanding species distribution and process based models of pollinating insects to capture the influence of pressures better and to expand the Poll4Pop model into different countries. **BeeHAVE:** an agent based model for assessing the populations of 8beehives. This has been developed for honeybees and common bumblebee species. It is openly available and has a specific use interface https://beehave-model.net/	Develop models to make spatially-explicit predictions of community abundance and taxonomic diversity (e.g. combining Poll4Pop and SDMs) Expanding the temporal aspects of process-based models. Expanding models to capture a wider range of specific bee species. At the moment Poll4Pop and other INVEST derived models only covers broad taxonomic groups which can include a lot of different species. This makes validation and prediction difficult.

			Expanding models to cover non-bee pollinator species and particularly hoverflies which are included in the EU PoMS and are key pollinators. Better understand the impact of climate change (and other pressures) on pollinators As pollinator monitoring is linked with pollination services, a better understanding of the functional role of pollinators within different ecosystems and crop systems at a local scale is important to link pollinators with pollination services (i.e. who is a pollinator, of what and where). Access to mapping (e.g. IACS data on crops) and pressure data for developing SDMs and running abundance models- very fine scale data is needed to accurately estimate populations and communities of pollinators but often CORINE is too course and misses important habitat features. Ensure that code for integration and modeling will be shared

			Ensure that software will be user-friendly Improved data validation methods, including tools for training taxonomists and automated validation processes of common pollinators.

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
long term data archive centre (not only for large-scale monitoring data, but also individual based data e.g. from master thesis or phd studies, these data are often not preserved in open access repositories; also would be a good destination for data in project repositories that lacks the long term preservation plan after funding phase, APIs between project repositories and data archive centre can greatly streamline the data management cycle)

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Potts, S.G., Dauber, J., Hochkirch, A., et al. (2021) Proposal for an EU Pollinator Monitoring Scheme, EUR 30416 EN, Publications Office of the European Union, Ispra, 2021, ISBN 978-92-76-23859-1, doi:10.2760/881843, JRC122225.
- HMSC package: https://www.helsinki.fi/en/researchgroups/statistical-ecology/software/hmsc#:~:text=Hierarchical%20Modelling%20of%20Species%20Communities,a%20matrix%20of%20environmental%20covariates.
- Ovaskainen et al. (2017) https://doi.org/10.1111/ele.12757
- Gardner et al (2020) https://doi.org/10.1111/2041-210X.13483
- Haussler et al (2017) https://doi.org/10.1002/ece3.2765
- Twiston-Davies et al (2021) https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/2041-210X.13673

Aerial biomass of migrating birds, bats and insects			
Workflow components			
	Current initiatives	**Emerging products and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Operational Programme for the Exchange of Weather Radar Information in Europe** (OPERA), the radar program of EUMETNET Network of meteorological offices from 35 European countries that collect polar volume weather radar data, typically every 5-15 minutes. Data are centralised near-real time, but **not publicly accessible** and increasingly optimised/filtered for meteorological applications. ENRAM/GloBAM members get access to the data via a license agreement. Some meteo offices (e.g. the Netherlands) provide direct and **open access** to their polar volume data (Den Helder radar, Herwijnen radar).	Weather radar data have been recognised as a European High-Value Datasets directive. This means data will become more openly available, but it is unclear if this is also going to cover unfiltered data.	
Data integration	**2013-2017:** European Network for the Radar Surveillance of Animal	INBO is maintaining an automated pipeline that:	Ensure archival and availability of unfiltered polar volume data for all

Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	Movement (ENRAM) **2019-2022**: Monitoring, understanding and forecasting global biomass flows of aerial migrants (GLOBAM) These radar aeroecology initiatives extract biological signals (**mainly birds**) from polar volume data. Typically results in "vertical profile" data. Done with open source software (vol2bird, bioRad, Dokter et al. 2019), but requires advanced technical knowledge to use.	1. Copies vertical profile created by BALTRAD from OPERA polar volume data to an Amazon S3 bucket 2. Packages the data in a more easily accessible CSV format 3. Provides **open access** to the data via https://aloftdata.eu/browse GloBAM consortium is seeking funding to maintain this pipeline, seek collaborations with weather offices to get access to unfiltered data and create more data products. Machine learning approaches exist for identifying biological signals in US radar data (different frequency band). Currently, at the University of Amsterdam initiatives are underway to develop an algorithm that can also be applied to Dutch radar data. The goal is to have the algorithm be transferable between countries allowing it to be more broadly more used across Europe. This allows the calculation of higher resolution	countries via a central repository (Shamoun-Baranes et al. 2022) Harmonise data across radars.

		products (different from vertical profile data).	
Modelling Types of models Predictors Estimation & uncertainty Software	Models of animal movement, estimates of aerial biomass of birds and insects, forecasts of bird migration peaks GLoBAM project uses standard tools, e.g. R package “bioRad”.	Interpolation methods being developed to create 10 km resolution products (Nussbaumer et al. 2019) Initial work on separating taxonomic groups (birds from insects) within polar volume data is going on, but this is still in its very early stages. Explorations on the accuracy and general application are required, possibly integration of local radars is helpful.	Improve models for bats and insects. Especially bats will require extra work. Improve taxonomic differentiation This required the development and validation of identification models (likely machine learning based). These could be validated using more specific local radars (e.g. birdscan, robin radar). Generate user-friendly software
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): The data format for polar volume data is reasonably well defined within the meteorological community (https://www.eumetnet.eu/wp-content/uploads/2021/07/ODIM_H5_v2.4.pdf) allowing for interoperability of data between countries and radars (most radars are very comparable within country as they are run by the same meteorological office). More countries are sharing polar volume data and this will increase with the high value data directive. However data are increasingly filtered for meteorological applications, removing a large part of the biological signal. In some cases this can be resolved by obtaining data at the source meteorological offices so unfiltered data can be accessed. The data format for vertical profile data (of biological signals) is also reasonably well defined (https://github.com/adokter/vol2bird/wiki/ODIM-bird-profile-format-specification). It is the format used/generated by the software packages vol2bird and bioRad. In addition to hdf5 files, the data can now also be expressed in a more convenient tabular format (https://aloftdata.eu/vpts-csv/).			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): Ideally, an open centralized repository for unfiltered polar volume data that can be used for meteorological and biological application (Shamoun-Baranes et al. 2022). This requires large storage (TB of data per year), processing infrastructure, long term investments and close collaboration between the meteorological and biodiversity research community. This is especially urgent for countries that do not store unfiltered data after a			

period of time (e.g. Denmark, Germany) and are thus lost for biological applications. Other countries (e.g. Netherlands) provide open access to unfiltered data. So in the midterm, a country by country approach is likely needed while meteorological offices update the data they are sharing. In addition to storage of the source data, pipelines (e.g. the one maintained by BALTRAD and INBO) need to be maintained to process the data to biological data products (e.g. vertical profile data and higher resolution products) that can feed into EBVs.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- OPERA - Operational Programme for the Exchange of weather Radar Information in Europe. https://www.eumetnet.eu/activities/observations-programme/current-activities/opera/
- ENRAM - European Network for the Radar surveillance of Animal Movement. https://www.enram.eu
- GloBAM - Monitoring, understanding and forecasting global biomass flows of aerial migrants. https://globam.science
- Aloftdata - Bird movement data from European weather radars. https://aloftdata.eu (website that centralises open data efforts by the European radar aeroecology community)
- Dokter, A. M., P. Desmet, J. H. Spaaks, S. van Hoey, L. Veen, L. Verlinden, C. Nilsson, G. Haase, H. Leijnse, A. Farnsworth, W. Bouten and J. Shamoun-Baranes (2019). "bioRad: biological analysis and visualization of weather radar data." Ecography, 42(5): 852-860. https://doi.org/10.1111/ecog.04028
- Nussbaumer, R., Benoit, L., Mariethoz, G., Liechti, F., Bauer, S., & Schmid, B. (2019). A geostatistical approach to estimate high resolution nocturnal bird migration densities from a weather radar network. Remote Sensing, 11(19), 2233. https://doi.org/10.3390/rs11192233
- Shamoun-Baranes J, Bauer S, Chapman JW, Desmet P, Dokter AM, Farnsworth A, van Gasteren H, Haest B, Koistinen J, Kranstauber B, Liechti L, Mason THE, Nilsson C, Nussbaumer R, Schmid B, Weisshaupt N, Leijnse H (2022) Meteorological Data Policies Needed to Support Biodiversity Monitoring with Weather Radar. Bulletin of the American Meteorological Society 103(4): E1234-E1242. https://doi.org/10.1175/BAMS-D-21-0196.1

Functional composition of soil biota			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Land Use/Cover Area Frame Statistical Survey (LUCAS):** **-** over ~20000 soil sampling points across all EU member states revisited every 3 years (starting in 2009) - currently, a small fraction (885 plots) of samples are deployed to address the taxonomic composition of living components of topsoil, including Bacteria and Archaea (16S rDNA), Fungi (ITS), Eukaryotes (18S rDNA), Microfauna (nematodes), Mesofauna (arthropods), Macrofauna (earthworms), Metagenomics with DNA metabarcoding; started in 2018 across all EU-MS, sampled every 3 years - organic content (microbial carbon and general organic carbon combined) could potentially be used; started in 2009	**Sounding Soil: Soil monitoring via acoustics** - Ecoacoustic data recorded from soils can be used as a proxy of macro- and mesofauna diversity. -the method has great potential to obtain high-resolution temporal data on specific soil organisms. **AI tools to characterise the composition of soil invertebrate communities preserved in fluid:** - based on macro photography and deep-learning-based computer vision workflow to count, sort and identify individuals from soil community samples. - this method can advance the way soil meso and macrofauna communities are sampled and characterised. https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.14001	**Increase and standardise temporal resolution:** The sampling frequency could be increased (e.g. do it every year for a period of time, or do it several times in one year) to capture rapid changes in soil communities' composition or account for the seasonality of some organisms that may be underestimated in current surveys. **Standardizing the temporal sampling scheme** to mitigate phenological shifts' influence on sampling outcomes. Currently, it seems that sampling within season is done randomly, probably due to shortage of manpower. **Increase the number of samples subjected to biodiversity assessment**, reaching at least an order of magnitude increase.

	- minimum sampling unit likely adequate for 1 x 1 km spatial resolution **<u>National initiatives</u>** **DSQN: Dutch Soil Quality Network** - Random stratified grid design across ~ 300 locations comprising stringent combinations of land use and soil type. Represents ~75% surface area of the Netherlands. - Categories comprise conventional farms, organic farms (dairy or arable), nature, parks - All locations sampled in a six-year cycle. - The measurements are combined in the Biological Indicator of Soil Quality (BISQ), comprising average values for biomass, abundances and taxonomic diversity of various soil-dwelling organisms (including Nematodes, Protists, Fungi, Bacteria, Collembola, Earthworms, Enchytraeids, Acari). **ORCHAMP Observatoire spatio-temporel de la biodiversité et du fonctionnement des socio-écosystèmes de montagne:**		**Increase taxonomic coverage:** The LUCAS initiative uses eDNA metabarcoding to sample soil organisms and is thus biased towards microbes or micro and mesofauna but can be less effective for macrofauna sampling. Having a full picture of the functional composition of soil biota may need to combine this data with other initiatives, such as Eudaphobase, that better represent macrofauna. Adding a macrofauna sampling to the LUCAS survey could be an option in the future. We could learn from the initiative SilBON food webs, which aims at complementing a sampling based on molecular data (SoilBON), through a standardized protocol for fauna sampling, to better represent soil fauna and better link with ecosystem functioning (https://soilbonfoodweb.org/) **Design new systematic monitoring approaches:** Molecular methods (e.g. metabarcoding) used in current initiatives have the advantage to sample a wide range of taxa, but do not allow to have estimates of

	- A multi-disciplinary observatory bringing together a range of academic partners from different disciplines and local players in France (2016-ongoing) - taxonomic composition of living components of topsoil, including Bacteria (16S rDNA), Fungi (ITS), Eukaryotes (18S rDNA), Microfauna (nematodes), Mesofauna (arthropods), Macrofauna (earthworms), Metagenomics with DNA metabarcoding; started in 2016 across different sites (>24) in the French Alps and Pyrenees. - Selected elevational gradients are sampled every year - Raw data is produced and stored at the Laboratoire d'Ecologie Alpine, in Grenoble France **LTSER: long-term socio-ecological research site Matschertal_Val Mazia, Italy:** - sampling of soil macrofauna in the site of Val Mazia, Italy. - No information on the regularity of sampling or on the data available		abundance of the different organisms, taxa, functional groups. Complementary approaches to estimate the abundance of some organisms, e.g., fungi and bacteria biomass (see future challenges in the EBV of microbial biomass), fauna biomass (as they do in SoilBON food web), soil ecoacoustics could be implemented in the monitoring campaigns.

Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Land Use/Cover Area frame statistical Survey (LUCAS):** - standardized sampling procedure & central laboratory - sequencing performed once and raw sequences are then provided to the users. - Database creation on European Soil Data Center (ESDAC) available and downloadable after registration. https://esdac.jrc.ec.europa.eu/projects/lucas - Previous processing is done independently by the user and no specific protocol is defined. **EUdaphobase** (https://www.eudaphobase.eu/edaphobase/): - non-commercial data infrastructure developed by the Senckenberg Museum of Natural History Görlitz in Germany. - combines data from heterogeneous sources on soil animals, their distribution and habitat parameters of their sites of occurrence and makes these data available to the public (open access). - currently includes data on Nematoda, Collembola, Oribatida,	**Standardization & harmonization:** Automatized soil food web reconstruction (https://www.biorxiv.org/content/10.1101/2023.02.03.526812v1.abstract and https://doi.org/10.1111/brv.12832) **Integration:** - ebioatlas: platform to integrate eDNA data at global scale. - Global Fungi database(https://globalfungi.com/) : Integration of fungal sequencing data from various geographical regions, ecosystems and habitats. **Automated data streams:** Soil acoustics can be continuously recorded.	Way of data aggregation: - **Improve integration of data from various sampling methods and sources:** the challenge remains in how to combine different types of data, eg.g molecular data (LUCAS) and occurrences (GBIF, EUDAPHOBASE) as they don't have the same sampling points (not the same community), and samplings are not carried out in the same periods or years nor with the same frequency. Protocols & Metadata forms: - **Improve soil organisms genetic reference databases: t**he effectiveness of molecular data for sampling diversity depends on the completeness of the reference databases. The work of taxonomists that identify, sequence and publish those sequences in public databases is thus still necessary. This is especially important for soil organisms, that are still largely unknown. Automated data streams: - Fully automated data flows for the bioinformatic processing of

	Gamasina, Chilopoda, Diplopoda, Isopoda, Enchytraeidae, and Lumbricidae. **Databases containing functional information for soil organisms:** - The Biological and Ecological Traits of Soil Invertebrates database (BETSI, https://portail.betsi.cnrs.fr/) is a European database dedicated specifically to soil organisms' traits. - FungalTraits (https://doi.org/10.1007/s13225-020-00466-2) -FAPOTRAX for Bacteria. - Nemaplex, NINJA, for nematodes.		data after sequencing for initiatives using molecular data such as LUCAS. **- Improving the definition of the EBV/ standardizing how we measure it:** 'the functional composition of soil biota' can be interpreted in different ways. For example, it can cover multiple or single soil taxa (e.g. Fungi). It can refer to the functional diversity by using functional traits, or it can refer to the diversity of trophic groups present in the community. This can create problems in the long term monitoring of the EBV or in integrating different studies that use different measures or interpretations of the same EBV. Moreover, defining the functional composition of soil biota presents an additional challenge, as it requires functional annotation of highly diverse taxa, but functional classification or definitions can be heterogeneous and without consensus across different soil taxa (Hedde et al. 2022).
Modelling	**Types of models:**		Types of models & Predictors:

Types of models Predictors Estimation & uncertainty Software	- Machine learning models (RF, XGBoost) for current and future prediction of the diversity of different soil functional groups retrieved from LUCAS topsoil biodiversity survey (2018). Diversity map of each functional group and of the whole functional diversity would be created at the European scale. -CLIMIFUN: The project CLIMIFUN aimed at identifying the factors that control soil microbial diversity and multiple functions linked to plant production and nutrient cycling under a changing environment. - Generalized dissimilarity models, biodiversity samples (species diversity per area) and combined with EO spatial covariates, predicted compositional dissimilarity (beta diversity), gdm R package - SDMs for different species of soil fauna using GBIF data, and stacked SDMs to assess diversity of a specific taxa (e.g. earthworms, Zeiss *et al under review*) **Predictors**	SoilTemp Project - soil temperature and moisture for the globe, but much well covered in Europe. Relevant data to modeling soil biota as several of the environmental covariates currently used are measured at a relevant scale for microorganisms and other dwelling soil organisms.	- **Improving the coupling of the predictors and the EBV measured:** Standardized paired sampling of species information and environmental covariates, as much of the EO covariates available for use are not always appropriate to capture the response of dwelling soil organisms (https://onlinelibrary.wiley.com/doi/10.1111/ecog.03947) - **Improving the estimation of soil parameters for future scenarios:** Some of the main soil predictors of functional diversity are available at the European scale for the present. Yet, if we want to make predictions for future scenarios of functional diversity we would first need to model these predictors (e.g., soil organic matter, pH, nitrogen, etc) based on future climatic scenarios to then use them as predictors for microbial biomass. Implementing hierarchical modeling would help to do both at the same time (e.g. neuronal network SEM).

	Common predictors include land use and land cover, climatic variables (e.g., from CHELSA or local climatic models), topographic variables, soil physical-chemical variables (LUCAS), soil threats (e.g. erosion, compaction, from LUCAS). Most of the predictors useful for modelling this EBV are available in the European Soil Data Center (ESDAC).		
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability): All data acquired should follow FAIR (findability, accessibility, interoperability, and reusability) data principles, except in case of sensitive species.			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): https://esdac.jrc.ec.europa.eu/projects/lucas			
Others: SOILGUARD: Soilmentor **; https://www.soundingsoil.ch/en/** https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0263618)			

Vertical structure of terrestrial vegetation			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Global Ecosystem Dynamics Investigation (GEDI)** High-resolution laser ranging of Earth's forests and topography from the International Space Station (ISS) Global tree height dataset openly available **SAR survey from Sentinel-1** **eLTER Europe:** 500 sites all over Europe, https://elter-ri.eu/ **National initiatives** **Belgium** Lidar data (available for 2012-2013 and 2021-2022 for Wallonia) analysed by Lifewatch-Belgium (Belgium only) through structural indices within ecotopes. (JR) Measurement network 'local status of habitats' (Flanders) LiDAR flight data 2013-2015 available for Flanders	**Oblique imaging** (drones) **LiDAR sensors under drones** **Tandem-L**: Interferometric Radar Mission: is a proposal for an innovative radar satellite mission consist of two identical L-band radar satellites used to investigate dynamic processes in the biosphere, cryosphere, geosphere and hydrosphere. **GLOBE Observer**: Citizen science app () for validation of Lidar data from ICESat-2, GEDI, G-LiHT missions on tree height	

	Denmark Country-wide ALS Denmark 2006/2007, 2014/2015, 2018-2022 extract information which is also measured by the national vegetation monitoring program (NOVANA) The Danish EU Habitats Directive Annex I monitoring program collects field information on some vegetation structural parameters. These can be made available for many thousand plots in DK. Processing country-wide ALS datasets with OPALS (developed by TU-Wien) for Denmark (https://doi.org/10.5194/essd-14-823-2022) **AHN - The Netherlands** Country-wide ALS flights covering the Netherlands provided by AHN and the data products generated from AHN **Spain** Spanish PNOA Regular Lidar flights over all Spain with derived digital terrain models and digital surface models used to get		

	canopy height and biomass together the Spanish Forest Inventory		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**ICP Forests** Vegetation on 723 Lev. II plots (every 5 years) http://icp-forests.net/page/level-ii **3DFORECOTECH** Cost Action focused on gathering EU-wide 3D forest scan data and fuse/merge with RS information https://3dforecotech.eu	**Modern Approaches to Monitoring of Biodiversity (MAMBO)**: EU Horizon project: Point cloud data collection in selected EU study sites for the EU Horizon MAMBO project - intended for use for habitat condition metrics, including vegetation vertical structures. **Laserfarm:** High-throughput workflow to generate country-wide ecosystem structure data products from airborne LiDAR **Photogrammetric point clouds**: Direct processing of 3D point clouds **CEOS Task Force ecosystem extent** - will look at vegetation structure as one of the EBVs to the Data Cube (contact S. Luque, Gary Geller co-coordinators of the Task)	Using differently measured ALS datasets to extract ecosystem structure-related information- how to do it robustly? (issues: https://doi.org/10.1016/j.ecolind.2021.107752) A standardized way of classifying ALS datasets (lot of errors in initial classifications across countries and time steps) (https://doi.org/10.1016/j.softx.2020.100626) Infrastructure gathering and preprocessing point cloud data with standardised metadata and access Standardised metadata The provenance of data processing workflow.: - Information about how the ALS data was acquired (when, which flight parameters - Information for radiometric calibration of ALS data

Modelling Types of models Predictors Estimation & uncertainty Software	Predictors : Canopy opening, canopy height, distribution of leaves, rugosity of soil, reflection of trees (relative cover of trunks)SAR-Tomography Softwares: JULIA / R (treeTop package, FORTLS package) 3D Forests / Computree / SimpleForest / Metashape / Reality capture / LASTool / FUSION Type of models: Canopy elevation model (CEM) / Digital elevation model (DEM) Types of models: Disappearance of tree crowns based on LiDAR/aerial/satellite combination (yearly): project 'Kruinafname' (Flanders) "**Laserchicken**" software, which provides a easy tool to generate different LiDAR metrics representing ecosystem height, ecosystem cover, and ecosystem structural complexity. (https://doi.org/10.1016/j.softx.2020.100626)	**Modern Approaches to Monitoring of Biodiversity (MAMBO)**: EU Horizon project: Point cloud data collection in selected EU study sites for the EU Horizon MAMBO project - intended for use for habitat condition metrics including vegetation vertical structures. EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data (habitat and species). JULIA: LazIO, PointCloudRasterizers Packages	Algorithms, notably deep learning based that works directly on point cloud data and on point cloud data combined with e.g. fine resolution drone or orthophoto data and produces measures like grazing intensity, herb vegetation height, herb/shrub encroachment and many others A list of important features/metrics quantifying vegetation structure.

	LidR - R package (https://doi.org/10.1016/j.rse.2020.112061) OPALS - processing and handling ALS datasets (https://doi.org/10.1016/j.compenvurbsys.2013.11.002)		
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):			

Ecosystem distribution of terrestrial EUNIS habitats			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Habitats directive reporting** Nearly all EU countries carry out some kind of habitat mapping in the context of reporting under the EU Hab. Dir (Art 17) - need to explore how these data can be used (focus is on Annex I of HD). For an example see Lüttgert et al. (2022). **Satellite signal and products** **Thematic data of Copernicus services** (European-wide but not complete: riparian area, Natura 2000 areas, coastal areas) + Corine Land cover **Ground truth data** **LUCAS (ESTAT):** The Land Use/Cover Area Frame Survey (LUCAS) is a harmonised *in situ* land cover and land use data collection exercise that extends over the whole of the EU's territory. 76 subclasses for land cover, not to the level of EUNIS.	**EEA (and ESA**) have financed studies on how to combine satellite and field survey data; lessons learned from these are to be released in the coming months. An early conclusion: one-third of habitats can be mapped well with satellite data, one-third more or less, and one-third not really at all. Key constraint is suitable & well-matching field survey data. **Habitat and Biotope** mapping shapefiles exist and increasingly become open access but require huge effort for locating and harmonisation, but they might serve as valuable ground truth data **In-situ data** **EVA's ReSurveyEurope** assessment initiative will promote	Improve spatial and taxonomic coverage of ReSurveyEurope Improve temporal resolution of EVA (important to calibrate change detection models) Improve taxonomy distribution of all EUNIS habitat types according to area-based sampling of EVA. Improve geospatial accuracy of EVA, or at least add uncertainty measure (this is important, especially when mapping on 10m resolution) Establish a network of EUNIS classes training areas, standardise data collection and metadata. Leverage publicly funded national and regional work to integrate it into a European platform for these training areas.

	About 6-year revisit, more than 1,000,000 points in total. **EMBAL**: European Monitoring of Biodiversity in Agricultural Landscapes. Collects information on the state of biodiversity in agricultural landscapes in EU Member States. It builds on the LUCAS methodology, so does not follow EUNIS levels. Currently in first rollout across the EU with field data collected for ~3000 sites in 2022 and 2023 (in preparation). **National initiatives** **Lifewatch-Belgium** Integration of land cover data at 10 m resolution by Lifewatch-Belgium (done for Europe in 2018) **Cartography of habitats in Catalonia**: - EUNIS habitats of Catalonia at a 1:25.000 scale (polygons and points). Minimum area of polygons, 15000 m2. - EUNIS habitats of protected areas at a 1:10000 scale (polygons and points). Minimum area of polygons, 2000 m2. - Land use changes monitoring by remote sensing.	the generation of time series data from EVA sampling plots **National initiatives** **New habitat mapping program Germany** - (coordination BfN) about to start within the next few years. In-situ habitat mapping on stratified randomly distributed sampling plots of 1 km². (See Stenzel et al. 2021). **Catalonia Habitat mapping** at different scales (1:10.000 and 1:50.000) in Catalonia is being updated regularly (data source: orthophoto images interpretation and field validation). This is now the basis of a new tool that consists in comparing satellite images (by remote sensing) to get land cover changes and EUNIS habitat shifts.	Establish a network of EUNIS classes training areas, possibility of using citizen science to help generate/maintain these training areas. To have very high resolution (e.g. 1m) satellite images for the whole of EU, once every 3 to 6 years, in order to improve habitat mapping with existing or to be developed models and to identify vegetation composition would be an aspect to be achieved for a better assessment of habitats of Community interest on the basis of Article 17 of the Habitats Directive (every 6 years). Integration of hyper-spectral signals to distinguish more habitat habitats. Generate a model for assessing changes in training areas for maintenance and updating. Temporal LIDAR data-series across entire European continent (one of the important drivers to distinguish vegetation height - can be linked to EBV vertical structure of terrestrial vegetation)

	National Inventories of Landscapes in Sweden **(NILS**) collects and analyzes data on Sweden's underrepresented natural habitats. - This adaptable and cost-effective program combines remote sensing and field inventories. - It enables long-term monitoring and data collection for tracking landscape and biodiversity changes.		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**In situ data** European Vegetation Archive (EVA) Data repository of vegetation-plot observations from 99 national and supranational vegetation plots databases from 53 countries - integration of national and supranational vegetation plots databases - Data not fully open; three data availability regimes assigned by data custodian	Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species. To be tested in 4 field sites (Bulgaria, Romania, Spain and Ukraine) **Lifewatch-ERIC**: efforts to include multisource data (remote sensing + vector maps + point inventories) available at European level into a harmonized database (Ecopatches)	Repeated habitat mapping data which are available for many parts of Europe, need standardization with respect to habitat type definition, characteristics monitored (e.g. species lists etc.) and data storage formats (GIS shape files, database system etc.). For an example, see Lüttgert et al. (2022). Establish protocols for the generation of EUNIS class training areas based on monitoring work on habitats of Community interest and natural sites in EU countries. Open access to EVA data. For an example of open access resurvey

			data in Germany see Jandt et al. (2022) Fully automate data flow from the field to the database Establish a flow to automate the distribution of these data in a network of training areas.
Modelling Types of models Predictors Estimation & uncertainty Software	**TurboVeg.** - data uploaded using TurboVeg3. TurboVeg software platform uses metadata standards for harmonization	**EUROPABON Habitat demonstrations**. Automated machine learning workflow with Convolutional Neural Network & CatBoost classification for Annex-1 or EUNIS (up to L3). Tested over several regions (NL, Austria, Spain, Germany), scalable to run at European scale. **EUNIS habitat using EVA:** Modeling of EUNIS habitat distributions using machine-learning and Maxent presence-background model. Provides spatially-explicit predictions **Triplet loss function** (Tile2Vec, Jean et al. 2019) for Habitat change detection. **TERRA 3 project,** a regional project (NW Spain-Galicia).	Making model code publicly available Spectro-phenological mapping by remote sensing could help to monitor EUNIS conservation status and changes.

		Habitat Classification model (RF-training areas-set of rules) to map EUNIS and Annex I habitats. Used and tested in different sites. It is being integrated in **Nature-FIRST** project as a tool to manage protected areas (species, habitats and HWC).	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):
Copernicus Data Access Ecosystem platform (CDAE): Sentinel time-series and scalable cloud computing

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Schaminée J.H.J., et al. (2014) Vegetation analysis and distribution maps for EUNIS habitats. Report EEA/NSV/14/006. EEA, Copenhagen. URL.
- Schaminée J.H.J., et al. (2016 a) Review of grassland habitats and development of distribution maps of heathland, scrub and tundra habitats of EUNIS habitats classification. Report EEA/NSV/15/005. European Environment Agency, Copenhagen. URL.
- Schaminée J.H.J, et al. (2016 b) Development of distribution maps of grassland habitats of EUNIS habitat classification. Report EEA/NSV/16/005. EEA, Copenhagen. URL
- Nature-FIRST project: Forensic Intelligence and Remote Sensing Technologies for nature conservation. CORDIS URL.
- TERRA 3 project. Civil UAVs Initiative. (*Boris Hinojo. 3edata ingeniería ambiental*).
- FP7 SPACE project MS.MONINA (Multi-scale Service for Moni-toring Natura 2000 Habitats of European Community Interest). Grant agreement No. 263479
- Strasser, T., Lang, S., 2015. Object-based class modelling for multi-scale riparian forest habitat mapping. International Journal of Applied Earth Observation and Geoinformation 37, 29-37.
- Catalan Habitats Mapping: https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/sistemes_dinformacio/habitats/ http://www.ub.edu/geoveg/en/semhaveg.php

- Jandt, U., Bruelheide, H., Berg, C., Bernhardt-Römermann, M., Blüml, V., Bode, F., Dengler, J., Diekmann, M., Dierschke, H., Doerfler, I., Döring, U., Dullinger, S., Härdtle, W., Haider, S., Heinken, T., Horchler, P., Jansen, F., Kudernatsch, T., Kuhn, G., Lindner, M., Matesanz, S., Metze, K., Meyer, S., Müller, F., Müller, N., Naaf, T., Peppler-Lisbach, C., Poschlod, P., Roscher, C., Rosenthal, G., Rumpf, S.B., Schmidt, W., Schrautzer, J., Schwabe, A., Schwartze, P., Sperle, T., Stanik, N., Stroh, H.-G., Storm, C., Voigt, W., von Heßberg, A., von Oheimb, G., Wagner, E.-R., Wegener, U., Wesche, K., Wittig, B., Wulf, M., 2022. ReSurveyGermany: Vegetation-plot time-series over the past hundred years in Germany. Scientific Data 9, 631. https://doi.org/10.1038/s41597-022-01688-6
- Lüttgert, L., Heisterkamp, S., Jansen, F., Klenke, R., Kreft, K.-A., Seidler, G., Bruelheide, H., 2022. Repeated habitat mapping data reveal gains and losses of plant species. Ecosphere 13, e4244. https://doi.org/10.1002/ecs2.4244
- Stenzel, S., Benzler, A., Hünig, C., Neukirchen, M., Züghart, W., 2021. Gefäßpflanzen im bundesweiten Naturschutz-Monitoring. Natur und Landschaft 96, 434–443. https://doi.org/10.17433/9.2021.50153943.434-443

Connectivity of terrestrial ecosystem habitat types			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building			Ensure long-term population monitoring by telemetry data, combined with non-invasive genetic samples to analyse functional connectivity.
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Movebank**: a platform to manage, share, analyse and archive animal tracking		
Modelling Types of models Predictors Estimation & uncertainty Software	**Grassland connectivity model, Latvia** - Countrywide data sources were employed to model the connectivity of grassland habitats in Latvia. - Grasslands identified during the Nature Census project (2017-	**Lifewatch data for Belgium** Structural connectivity indices South of Europe (to be extended to all Europe soon) : distance to roads, distance to settlements, distance to forest patch, proportion of 10 land cover types within 250, 500 and 1000 m buffers in Belgium / same for	High-quality information of environmental variables

	2021) were used as habitat patches. - The cost landscape map was developed using various databases including the Rural Support Service GIS, the State Forest Service, the Latvian Geospatial Agency, and the Institute of Environmental Solution's Sentinel 2 satellite imagery. - Graphab 2.6.4 software was used in the process. - Various functional connectivity indices were calculated for Latvian grasslands, including betweenness centrality index and interaction flux index, among others (15 in total). **Binary model** (connected/not connected) or probabilistic models (based on graphs) **Patch connectivity indicators**, comparison of path importance; Conefor Sensinode; Circuit-based methods **Research paper** English index of habitat connectivity (from landcover): Mancini et al (2022)	Europe but with 500 m and 1 km buffers. These indices proportions are based on 10 m raster map. The indices are integrated into the Lifewatch ecopatches together with other variables. EU Horizon project Nature-FIRST: Semantic Technologies and Knowledge graph creation for integrating and harmonising data for the monitoring of habitats and species.	

Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

It can be used standalone or within the https://jeodpp.jrc.ec.europa.eu/bdap (also open to be used for external people with ECAS account)

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/
- Fedorca, A., Russo, IR.M., Ionescu, O. et al. Inferring fine-scale spatial structure of the brown bear (Ursus arctos) population in the Carpathians prior to infrastructure development. Sci Rep 9, 9494 (2019). https://doi.org/10.1038/s41598-019-45999-y
- Saura, S. & J. Torné. 2009. Conefor Sensinode 2.2: a software package for quantifying the importance of habitat patches for landscape connectivity. Environmental Modelling & Software 24: 135-139.
- Préau C, Tournebize J, Lenormand M, Alleaume S, Gouy Boussada V & **Luque S** (2022) Habitat connectivity in agricultural landscapes improving multi-functionality of constructed wetlands as nature-based solutions. *Ecological Engineering* 182, 106725. [arXiv][pdf] https://doi.org/10.1016/j.ecoleng.2022.106725

  Préau C, Dubos N, Lenormand M, Denelle P, Le Louarn M, Alleaume S & **Luque S** (2022) Dispersal-based species pools as sources of connectivity area mismatches. *Landscape Ecology* 37, 729-743. [arXiv][pdf][code] https://doi.org/10.1007/s10980-021-01371-y(0
- (more references in the link above)GuidosToolbox reference paper:
  Vogt P. and Riitters K. (2017). GuidosToolbox: universal digital image object analysis. European Journal of Remote Sensing, 50, 1, pp. 352-361, doi: 10.1080/22797254.2017.1330650
- GuidosToolbox Workbench reference paper:
  Vogt P. et al. (2022). GuidosToolbox Workbench: spatial analysis of raster maps for ecological applications, Ecography, Volume 2022, Issue 3, doi: 10.1111/ecog.05864
- Mancini F, Hodgson JA, Isaac NJB. Co-designing an Indicator of Habitat Connectivity for England. Front Ecol Evol. 2022;0:654. doi:10.3389/FEVO.2022.892987
- Kays, R., Davidson, S. C., Berger, M., Bohrer, G., Fiedler, W., Flack, A., ... & Wikelski, M. (2022). The Movebank system for studying global animal movement and demography. Methods in Ecology and Evolution, 13(2), 419-431.

Terrestrial primary productivity			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Satellite signal and products** **USGS-NASA MODIS GPP/NPP Project (MOD17):** MOD17A3HGF Version 6.1 product provides information about annual Gross and Net Primary Production (GPP and NPP) at 500 m pixel resolution. GPP and NPP is derived from the sum of all 8-day GPP Net Photosynthesis (PSN) products (MOD17A2H) from the given year. The PSN value is the difference of the GPP and the Maintenance Respiration (MR). **Copernicus Land Monitoring Service (CLMS) - Dry Matter Productivity** Overall growth rate or dry biomass increase of the vegetation. Global product 300m **Integrated Carbon Observation System**, ICOS, European-wide greenhouse gas research infrastructure. ICOS produces	**FP7 ImagineS project** (http://fp7-imagines.eu/) support the provision of a ground dataset for the validation of Copernicus Global Land products	Increase temporal data coverage for remote sensing. Increase spatial scales for satellite products Needs comprehensive and consistence approaches and initiative to calibrate the algorithm, especially in tropical areas. This is essential in remote sensing products related to primary productivity

	standardised data on greenhouse gas concentrations in the atmosphere, as well as on carbon fluxes between the atmosphere, the earth and oceans **Ground truth data** **Copernicus Land Monitoring Service Ground-Based Observations for Validation (GBOV) of Copernicus Global Land Products** The GBOV service provides multiple years of high quality in-situ measurements to validate 7 core land products (Top-of-canopy reflectances, Surface albedo, fAPAR, LAI, fCover, Land Surface Temperature and Soil Moisture) **eLTER** Pan-European, in-situ research infrastructure provides researchers with access to over >500 sites		

Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**European Fluxes Database Cluster**: Carbon flux data estimated through the eddy covariance method. Level 4 data includes GPP estimations (not available or updated for all the sites).		Networks and facilities for integrating expertise between active and passive sensors products
Modelling Types of models Predictors Estimation & uncertainty Software	**ONEFlux processing pipeline** as implemented in Fluxnet2015 Spatio-Temporal Upscaling of Flux Tower Gross Primary Productivity Measurements [1]: Empirical approach to upscale in-situ GPP estimations. **FLUXCOM:** upscaling of FLUXNET sites based on ML **USGS-NASA MODIS GPP/NPP Project (MOD17):** Empirical light use efficiency model	**iLand** iLand is a model of forest landscape dynamics, simulating individual tree competition, growth, mortality, and regeneration. It addresses interactions between climate (change), disturbance regimes, vegetation dynamics, and forest management. **LANDIS-II** The LANDIS-II forest landscape model simulates forests (both trees and shrubs) at decadal to	Trajectory of ecosystem dynamics under Global Change drivers Integration of mechanistic models Harmonization between the algorithm and models to evaluate EBVs from same tools but with different sources (e.g. satellite products between the space agencies and different satellites within the same programmes)

	VITO Terra-P model (based on fAPAR) Research paper GPP workflows - the workflow integrates Sentinel-2 data and in situ measurements for GPP estimation STEMMUS-SCOPE: combining process based and machine learning modelling	multi-century time scales and spatial scales spanning hundreds to millions of hectares. The model simulates change as a function of growth and succession and, optionally, as they are influenced by range of disturbances (e.g., fire, wind, insects), forest management, land use change. BIOME-BGCMUSO Biome-BGCMuSo is a biogeochemical model that simulates the storage and flux of water, carbon, and nitrogen between the ecosystem and the atmosphere, and within the components of the terrestrial ecosystem. SVIT is an algorithm for monitoring primary productivity vegetation indices trends through remote sensing analysis. We published the initial release of the algorithm, but the aim is to increase its potentiality [3].	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): Optimization of data processing and storage. Also, create data lighter in terms of size.			

Access to the European Fluxes Database Cluster through API or webservices.

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- [1] Spinosa, A.; Fuentes-Monjaraz, M.A.; El Serafy, G. Assessing the Use of Sentinel-2 Data for Spatio-Temporal Upscaling of Flux Tower Gross Primary Productivity Measurements. *Remote Sens.* **2023**, *15*, 562. https://doi.org/10.3390/rs15030562
- [2] European Fluxes Database Cluster. (n.d.). Retrieved February 22, 2023, from http://www.europe-fluxdata.eu/home
- [3] Baldo, M., Buldrini, F., Chiarucci, A., Rocchini, D., Zannini, P., Ayushi and K., Ayyappan, N., (2023). Remote sensing analysis on primary productivity and forest cover dynamics: a Western Ghats India case study. Ecological Informatics, 73, 101922 https://doi.org/10.1016/j.ecoinf.2022.101922.
- **Luque, S**; Pettorelli, N; Vihervaara, P; Wegmann, M. 2018. **Improving biodiversity monitoring using satellite remote sensing to provide solutions towards the 2020 conservation targets**; *MEE* 9(8):1784-1786 **DOI:** 10.1111/2041-210X.13057
- [5] Nestola, E.; Sánchez-Zapero, J.; Latorre, C.; Mazzenga, F.; Matteucci, G.; Calfapietra, C.; Camacho, F. Validation of PROBA-V GEOV1 and MODIS C5 & C6 fAPAR Products in a Deciduous Beech Forest Site in Italy. *Remote Sens.* **2017**, *9*, 126. https://doi.org/10.3390/rs9020126

Fire disturbance per habitat type			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**<u>Satellite signal and products</u>** **EFFIS - European Forest Fire Information System - Copernicus.** Rapid Damage Assessment (RDA) module includes products specific to Europe. - The Burned Areas updates are provided daily, with the burn area derived from MODIS Sentinel-2, with a minimum detection capability of 30 hectares. -Active fire data is derived from the VIIRS - Statistics of the burnt area categorised by land cover type are derived from the CORINE Land Cover database. **Copernicus Sentinel-3 NRT Fire Radiative Power - EUMETSAT** Global product Quantifies the radiative power of any hotspot present on land and ocean that radiates a heating signal within a pixel size of 1 km2		Improve spatial resolution to 10 x 10 m

	National initiatives: **Wildfire monitoring (Israel):** Long-term monitoring of wildfire occurrences throughout Israel. Biennial report for decision-makers - Using historical and current satellite remote sensing - Historical data collection from 1984 and ongoing		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**European Forest Fire Information System (EFFIS)** Interactive current situation viewer updated 6 times daily for burnt area and active fires Current Statistics Portal and a Wildfire Risk Viewer Data flows fully automated for website portals Data stored and managed in central repository EFFIS data and related Copernicus products fully accessible and freely downloadable JRC's European Fire Database: updated regularly every year		Standardise long-term reporting methodology.
Modelling	**European Forest Fire Information System (EFFIS)**	**Nature-FIRST** EU Horizon project: Develop predictive,	Develop product for EUNIS habitats affected by fires

Types of models Predictors Estimation & uncertainty Software	Models for active fires differences in temperature between neighbouring land covers, but currently not linked to EUNIS habitats	proactive and preventative capabilities for nature conservation stakeholders based on Digital Twins	Improve uncertainty around fire hotspots.
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): • European Forest Fire Information System (EFFIS) Data portal: Current situation viewer and Current Statistics Portal • Google Earth Engine could be a good platform to collect and share existing script/tools/models for fire disturbance and automatic burned area detection. • A share data pool where people could add in-situ data as training data for machine learning algorithms.			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):			

Ecosystem disturbance as measured by HANPP			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**EUROSTAT** EU Harvest statistics per NUTS regions	**Remote sensing data** Fine-resolution monitoring with remote sensing can detect forest harvest and harvest in agriculture. However, this approach has not been integrated into HANPP estimates as far as I am aware.	Improve spatial resolution to 10 x 10m
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams		**Global Forest Watch**: near real-time information about where and how forests are changing worldwide.	Calibration sites across Europe for estimated HANPP Data transparency (and traceability)
Modelling Types of models Predictors Estimation & uncertainty Software	**Research paper** HANPP for Europe has been modelled by Karl Heinz Erb and colleagues at the Institute for Social Ecology, Vienna. Based on remote sensing of land cover, combined with information on	**GEE implementation of metabolic energy** (e.g. Sierra Nevada Spain Carlos Passera). **Software iLand** (BITE (biotic agents), ABE (management) iLand modules)	Mechanistic models Trajectory stability of EBV under Global Change drivers

	national statistics on forestry, agriculture and other aspects. Predictors (Ecosystem Structures,Picea abies, management, wind, drought, bark beetle)	**Nature-FIRST** EU Horizon project: Develop predictive, proactive and preventative capabilities for nature conservation stakeholders based on Digital Twins	
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):			
References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project): • Haberl, H., Erb, K.-H., & Krausmann, F. (2014). Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries. *Annual Review of Environment and Resources*, *39*(1), 363–391. doi: 10.1146/annurev-environ-121912-094620 • Global Forest Watct • Nature-FIRST project: Forensic Intelligence and Remote Sensing Technologies for nature conservation. CORDIS URL.			

Terrestrial ecosystem phenology			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**Satellite signal and products** **Copernicus Land Monitoring Service (CLMS) -Vegetation Phenology and Productivity Parameters** European high-resolution product produced from Sentinel-2 dataset, 13 phenology and productivity parameters, 2 seasons/year, 10 m resolution **USGS-NASA MODIS phenology product MCD12Q2** Global land surface phenology metrics at yearly intervals at 500 m resolution **Ground truth data** **European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL):** EMBAL is a robust monitoring tool to collect information on the state of	**Ground truth data** **Phenocams** Digital cameras use to monitor ecological phenomena. They capture periodic images to provide detailed, high-resolution data on ecosystem changes over time, particularly phenological shifts. They are employed in various projects, e.g. Aarhus University Mambo project	Improve higher spatial resolution (e.g. PlanetLabs) to produce EBV at a sub 10 x 10mresoultion to monitor urban trees. Deployment of in-field cameras at scale with standardised protocols for deployment of cameras and image annotation Check if EMBAL survey protocol is already supporting EBV workflow needs and/or could be adapted/improved. Enhance temporal coverage to increase the precision of phenophase dates by integrating Earth Observation datasets.

	biodiversity in agricultural landscapes in EU Member States. Currently implemented in the first EU-rollout for 2022/2023 by DG Env. Data are derived by field surveys in optimal survey periods. **National initiatives** **EnMAP** The Environmental Mapping and Analysis Program (EnMAP) is a German hyperspectral satellite mission that monitors and characterizes Earth's environment on a global scale.		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**Copernicus Land Monitoring Service (CLMS)** Products match perfectly with EBV metrics Free, openly accessible data Raw metadata with code is shared Use their own catalogue to store and manage products		Merging existing EO databases Standardize methods (sensors, pre-processing, post-processing) Define key variables (e.g. LAI), particularly from RS (indices) and harmonize phenopase classes
Modelling	**TIMESAT** software used to generate land surface phenology	**Nature-FIRST** EU Horizon project: Develop predictive,	Uncertainty and reliability estimate for phenology maps

Types of models Predictors Estimation & uncertainty Software	products. Documents explaining algorithm, calibration and validation of the models shared **Phenofit R package** An R package for extracting vegetation phenology from time series remote sensing - Adopted 'TIMESAT' and 'phenopix'. - Whittaker-based snow elimination. - 7 curve fitting methods and 4 phenology extraction methods. - Parameter boundaries set for ecology. - Used 'optimx' for optimisation **PROSAIL** Estimation of vegetation biophysical properties (LAI, leaf pigment content, LMA, equivalent water thickness) from remote sensing optical images (multi & hyperspectral) based on physical model inversion	proactive and preventative capabilities for nature conservation stakeholders based on Digital Twins	Completing EU-wide harmonized access to recent digital aerial orthophotos (e.g. via EEA CORDA) to support field survey based projects like EMBAL.
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			
IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services): - Very high computational needs for very large data amount of satellite based time series data. Apply the big-data paradigm shift moving the algorithm to the data, use of Copernicus cloud infrastructure			

-WEkEO is the EU Copernicus DIAS reference service for environmental data, virtual processing environments and skilled user support. A platform for all audiences

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Francesco Chianucci, Sofia Bajocco, Carlotta Ferrara, Continuous observations of forest canopy structure using low-cost digital camera traps, Agricultural and Forest Meteorology, Volume 307, 2021, 108516, ISSN 0168-1923, https://doi.org/10.1016/j.agrformet.2021.108516.
- Feng Tian, Zhanzhang Cai, Hongxiao Jin, Koen Hufkens, Helfried Scheifinger, Torbern Tagesson, Bruno Smets, Roel Van Hoolst, Kasper Bonte, Eva Ivits, Xiaoye Tong, Jonas Ardö, Lars Eklundh, 2021: Calibrating vegetation phenology from Sentinel-2 using eddy covariance, PhenoCam, and PEP725 networks across Europe. Remote Sensing of Environment, Volume 260, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2021.112456.

Standing and lying deadwood			
Workflow components			
	Current initiatives	**Emerging tools and projects**	**Future needs**
Data collection and sampling Data collection method Sampling design (EU-wide monitoring) Type of raw data Novel monitoring methods Capacity building	**European initiative** Forest: deadwood — European Environment Agency **National and subnational initiatives** National forest inventories - Slovenia - national forest inventory, several ongoing projects (LIFE SySTEMiC, …) - Germany - National Forest Inventory Germany - Monitoring of forest habitats of the Habitats Directive Germany - several regular inventories in national parks and other types of protected area (partly done in some biosphere reserves) - Finland National Forest Inventory - Flanders (Belgium): line intersects sampling for lying deadwood, standing deadwood, standing deadwood in concentric circle with radius depending on diameter of the tree.	Cost Action Bottoms-Up Gathering knowledge of European multi-taxonomic forest biodiversity through the collaboration of research groups that collect data locally. Deadwood spatial distribution, type and decay.	Include the monitoring of microhabitats Robust and consistent field data calibration.

	https://www.natuurenbos.be/sites/default/files/inserted-files/handleiding_bosinventarisatie_3.pdf NGO - Ancient Tree Inventory - Woodland Trust		
Data integration Standardisation & harmonisation Pre-processing Protocols & metadata Way of data aggregation Integration nodes (national or EU) Automated data streams	**International initiative** **IPC Forests**: The Level I monitoring is based on 5624 observation plots (as at 2021) on a systematic transnational grid of 16 x 16 km throughout Europe and beyond to gain insight into the geographic and temporal variations in forest condition.	Cost Action Bottoms-Up Gathering knowledge of European multi-taxonomic forest biodiversity through the collaboration of research groups that collect data locally. Deadwood spatial distribution, type and decay.	Standardization of definition/characterisation of deadwood across EU MS
Modelling Types of models Predictors Estimation & uncertainty Software	**Research project** Sofware: SORTIE-ND **Research project** Sofware: ForClim ForClim is a climate-sensitive forest gap model developed to simulate forest stand dynamics over a wide range of environmental conditions (Bugmann 1996). The model is being tested in the Eastern Italian	**iLand** iLand is a model of forest landscape dynamics, simulating individual tree competition, growth, mortality, and regeneration. It addresses interactions between climate (change), disturbance regimes, vegetation dynamics, and forest management. **LANDIS-II**	Integration of mechanistic models: Improvement of decay rates and deadwood dynamics in forest models Deep learning CNNs to identify dead trees in forests Consistent set of indicators (i.e., linker functions) of biodiversity provision that can be obtained

	Alps and its outputs can be linked to with indicators to assess biodiversity provision (Mina et al 2017). Predictors (Saproxilic species, Fungis, AGB-BGB, Forest Structures)	The LANDIS-II forest landscape model simulates forests (both trees and shrubs) at decadal to multi-century time scales and spatial scales spanning hundreds to millions of hectares. The model simulates change as a function of growth and succession and, optionally, as they are influenced by range of disturbances (e.g., fire, wind, insects), forest management, land use change. **BIOME-BGCMUSO** Biome-BGCMuSo is a biogeochemical model that simulates the storage and flux of water, carbon, and nitrogen between the ecosystem and the atmosphere, and within the components of the terrestrial ecosystem. **Forrescalc R package** Draft R package to aggregate raw dendrometric data collected with Fieldmap https://github.com/inbo/forrescalc Modeling of Dead Wood Potential Based on Tree Stand Data: https://doi.org/10.3390/f11090913	from the outputs of different models Improve accessibility to real orthophotos in Flanders (with no relief displacement)
Interoperability aspects (e.g. access to and sharing of primary data, metadata standards, open access licenses, APIs, machine readability):			

IT infrastructure needs (e.g. data portals, use of European Research Infrastructures, data storage, central repositories, scalable computing, cloud services):

References and sources (e.g. name and institution of expert who provided information for this template, literature, online sources, web pages of EU project):

- Bugmann, H.K.M. (1996) A simplified forest model to study species composition along climate gradients. *Ecology*, 77, 2055– 2074.
- Sirén, A, C. Sutherland, A.Karmalkar, M. J. Duveneck, & T. L. Morelli. Forecasting species distributions: Correlation does not equal causation. 2022. Diversity and Distributions.
- Tonini, F., C. Jones, B.R. Miranda, R.C. Cobb, B.R. Sturtevant, and R.K. Meentemeyer. 2018. Modeling epidemiological disturbances in LANDIS-II. Ecography 41: 1-7.
- Hilpold A., Anderle M., Guariento E., Marsoner T., Mina M., Paniccia C., Plunger J., Rigo F., Rüdisser J., Scotti A., Seeber J., Steinwandter M., Stifter S., Strobl J., Suarez-Muñoz M., Vanek M., Bottarin R., Tappeiner U., Handbook – Biodiversity Monitoring South Tyrol, Bozen/Bolzano, Italy: Eurac Research, 2023, https://doi.org/10.57749/2qm9-fq40
- Hidy, D., Barcza, Z., Marjanovic, H., Ostrogovic Sever, M. Z., Dobor, L., Gelybó, G., Fodor, N., Pintér, K., Churkina, G., Running, S., Thornton, P., Bellocchi, G., Haszpra, L., Horváth, F., Suyker, A., and Nagy, Z., 2016. Terrestrial ecosystem process model Biome-BGCMuSo v4.0: summary of improvements and new modeling possibilities. Geosci. Model Dev., 9, 4405-4437. doi:10.5194/gmd-9-4405-2016
- Mina, M., Bugmann, H., Cordonnier, T., Irauschek, F., Klopcic, M., Pardos, M., & Cailleret, M. (2017). Future ecosystem services from European mountain forests under climate change. *Journal of Applied Ecology*, 54, 389– 401.
- Russell, M. B., Fraver, S., Aakala, T., Gove, J. H., Woodall, C. W., D'Amato, A. W., & Ducey, M. J. (2015). Quantifying carbon stores and decomposition in dead wood: A review. Forest Ecology and Management, 350, 107-128.
- Venier, L. A., Hébert, C., De Grandpré, L., Arsenault, A., Walton, R., & Morris, D. M. (2015). Modelling deadwood supply for biodiversity conservation: Considerations, challenges and recommendations. The Forestry Chronicle, 91(4), 407-416.
- Sabina Burrascano, Giovanni Trentanovi, Yoan Paillet, Jacob Heilmann-Clausen, Paolo Giordani, Simonetta Bagella, Andrés Bravo-Oviedo, Thomas Campagnaro, Alessandro Campanaro, Francesco Chianucci, Pallieter De Smedt, Itziar García-Mijangos, Dinka Matošević, Tommaso Sitzia, Réka Aszalós, Gediminas Brazaitis, Andrea Cutini, Ettore D'Andrea, Inken Doerfler, Jeňýk Hofmeister, Jan Hošek, Philippe Janssen, Sebastian Kepfer Rojas, Nathalie Korboulewsky, Daniel Kozák, Thibault Lachat, Asko Lõhmus, Rosana Lopez, Anders Mårell, Radim Matula, Martin Mikoláš, Silvana Munzi, Björn Nordén, Meelis Pärtel, Johannes Penner, Kadri Runnel, Peter Schall, Miroslav Svoboda, Flóra Tinya, Mariana Ujházyová, Kris Vandekerkhove, Kris Verheyen, Fotios Xystrakis, Péter Ódor, 2021 Handbook of field sampling for multi-taxon biodiversity studies in European forests, Ecological Indicators 132, 108266, https://doi.org/10.1016/j.ecolind.2021.108266