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Working paper on functional relationships between ecosystem characteristics and services in support of condition assessments

Bálint Czúcz, Martin Götzl, Elisabeth Schwaiger,
Bernhard Schwarzl and Gabriele Sonderegger

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Authors' affiliation:

Bálint Czúcz**,** Muséum national d'Histoire naturelle (FR)
Martin Götzl, Umweltbundesamt (AT)
Elisabeth Schwaiger, Umweltbundesamt (AT)
Bernhard Schwarzl, Umweltbundesamt (AT)
Gabriele Sonderegger, Umweltbundesamt (AT)

EEA project manager:

Markus Erhard, European Environment Agency (DK)

ETC/BD production support:

Muriel Vincent, Muséum national d'Histoire naturelle (FR)

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European Topic Centre on Biological Diversity
c/o Muséum national d'Histoire naturelle
57 rue Cuvier
75231 Paris cedex, France
Phone: + 33 1 40 79 38 70
E-mail: etc.biodiversity@mnhn.fr
Website: http://bd.eionet.europa.eu/

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1 Introduction

Assessments of ecosystems and their services (ES) are a relatively new and intensively expanding field connecting policy and science. The EU *MAES assessment framework* (Maes et al., 2013, 2014), and the underlying *cascade model* (Potschin & Haines-Young, 2011) provides a logical and operative structure for such assessments. A key element of the MAES framework is the concept of *ecosystem condition*, which can establish the “missing link” between the various ecosystem types and the services enjoyed by humans. Nevertheless, both the concept of ecosystem condition and its potential indicators are still under discussion and development. This report aims to contribute to these discussions by synthesizing scientific information in a highly structured way.

A careful examination of the MAES, SEEA-EEA, and OpenNESS definitions (ETC/BD, 2017) suggests the following operative definition for:

> ***ecosystem condition***: “the overall quality of an ecosystem unit, in terms of its main characteristics underpinning its capacity to generate ecosystem services”.

There are a few closely related concepts that also deserve some attention. ***Ecosystem capacity*** is “the ability of a given ecosystem unit to generate a specific ecosystem service in a sustainable way” (SEEA-EEA 2012), thus, in an operative sense, the main distinction between condition and capacity is that condition is always general, whereas capacity is always service-specific. There is a third, closely related definition from SEEA-EEA, ***ecosystem characteristic***, defined in the following way: “Key attributes of an ecosystem unit describing its components, structure, processes, and functionality, frequently closely related to biodiversity. The term “characteristics” is intended to be able to encompass all of the various perspectives taken to describe an ecosystem” (ETC/BD, 2017).

These operative definitions are fully compatible with the targets of the Biodiversity Strategy, as well as EU-level and international initiatives of ecosystem accounting. The problem is there are a huge number of biotic and abiotic ecosystem characteristics, many of which could be qualified as ecosystem condition indicators in an assessment context. On the other hand many characteristics are correlated (redundant), many are impractical (e.g. too expensive to measure, no data flows), and the overall number of ecosystem condition indicators should be limited for further practical reasons (e.g. monitoring/assessment costs, dilution of useful information). The selection of the appropriate ecosystem characteristics as condition indicators for inclusion into a condition assessment is a key element in the success of the MAES process.

There are many recommendations available on how to select appropriate indicators for a specific assessment (e.g. Niemeijer & de Groot, 2008, Müller & Burkhard, 2012). Most of these criteria are also valid for ecosystem condition indicators, which should accordingly be:

- *relevant* (really influence the supply of several services, as prescribed by the definition),
- *reliable* (they should really capture what they intend to measure), and
- *available* (they should rely on already existing and readily available data as much as possible);

and the whole set of variables/maps should be:

- *parsimonious* (no redundancy between variables/maps, each map should convey new information).

In order to operationalize the selection of indicators a further distinction can be made between a more conceptual level, ***condition aspects*** which are ecosystem characteristics defined in a general sense (without specific measurement instructions, units or scale -- e.g. “species diversity” or “vascular plant diversity”), and their practical implementations, ***condition indicators*** (with well-defined measurement instructions, units and scale, e.g. “the Shannon diversity of vascular plant species sampled using this or that protocol”, see also Czúcz & Arany, 2016). The reason for this is that some of the criteria need to be handled on a conceptual level (relevance, parsimony), while others can be more adequately addressed at the level of practical details (availability, reliability, parsimony). Thus in order to be able to observe all criteria, condition has to be addressed both at the conceptual (condition aspects) and the practical (condition indicators) level. This distinction between condition aspects and their indicators is very much in line with the long-standing and universally accepted distinction between ES types, and ES indicators.

The definitions and the criteria described above suggest the following “step-by-step” protocol for operationalizing the concept of ecosystem condition:

(1) identify which ecosystem characteristics are most relevant for the delivery of services in the case of different ecosystems;

(2) prepare an inventory of the datasets readily available for developing condition indicators;

(3) and link the two sets by constructing reliable indicators based on accessible data.

The focus of the work under ETC BD 1.7.5.A III/vii described in this report is the point (1) shown above: to give a systematic overview of the ecosystem characteristics (i.e. potential ‘condition aspects’) most relevant for the delivery of services -- based on published studies. Luckily, there is a massive body of scientific literature that had addressed exactly this kind of question with respect to various ES during the previous decades. And even more luckily, there are a few recent comprehensive systematic review studies that have already expended serious efforts in synthesizing what can be learned from these studies. This report relies on one of these systematic review studies, performed by the EU FP7 project OpenNESS, that has set out very similar goals and objectives.

2 The OpenNESS database

The systematic review performed under OpenNESS Task 3.1 involved 13 ES (Table 2.1). For each of these services 60 scientific papers had been selected, following a standardized search protocol based on customized keywords (Harrison et al. 2014, Pérez-Soba et al, 2015). Wherever possible the selection has been built upon the papers reviewed in a previous similar systematic review exercise (the BESAFE review and the underlying database, Harrison et al. 2014), which was significantly extended both in terms of new services, new papers (to the existing ES), and also with new review questions (to the existing ES and papers). Each ES was assigned to an OpenNESS partner institution (preferably to the same institution that coordinated the review for that service during the BESAFE project, and preferably to the same person). The whole review process was performed in a standardized way, supported by detailed guidelines and a dedicated data collection tool. Altogether 780 scientific papers have been reviewed by 16 individuals, and the resulting database was checked for consistency.

The final database is organized in 44 linked SQL tables (MS Access), out of which five tables (Review, ConditionValue, ProviderValue, TraitValue, FactorValue) are of particular interest for this work (Pérez-Soba et al., 2015). *Traits* (biotic ecosystem or landscape characteristics), *factors* (abiotic characteristics), *providers* (a rough classification of organizational levels essentially responsible for the production of the ES following the ESP concept of Kremen, 2005 and Luck et al., 2009) and *ecosystem types* (following the MAES classification) are assigned to papers, and each paper can have multiple of them. Traits and factors, moreover, are characterized by their “direction” in the database, signalling if an increase in the trait value would mean an increase or a decrease in the studied ES. Possible values for the direction are: *positive*, *negative*, *both* (positive & negative), and *unclear*. The relevant tables of the OpenNESS database are described more in detail in Appendix 1.

The OpenNESS database documents repeating patterns in the relationships between *ecosystem characteristics* and *ecosystem services*. Accordingly, in the case of each major MAES ecosystem type, this database can serve as a basis for identifying those characteristics which meet the abovementioned definition of *ecosystem condition* the most (i.e. which exert the "most influence" on the "highest number" of ES). However, the OpenNESS database has also a few considerable shortcomings from this perspective, namely:

- Most of the ES studies in the OpenNESS database were performed outside Europe (43%-82% depending on the ES), and the applicability of non-European papers in an European context is doubtful (different ecosystem types, socio-economic context, etc.);

- The selection of papers can be seen as representative for the services but not for the ecosystem types. Marine ecosystem types are particularly badly represented in the papers reviewed;

- The dataset does not link the attributes (traits, factors) to the ecosystem types. This can be a problem if a paper documents a service that is provided by multiple ecosystem types, but the trait mentioned is valid/relevant/influential only for one of them;

- Similarly if there are multiple ESPs for a service, and the paper identifies different traits for each of them, then it is not obvious which ESP is characterized by which trait;

- The 2D / two-way classification system used to describe the characteristics (ESPs x Traits) is overly complex (too many categories, relatively redundant and ambiguous (difficult to interpret), and many of the categories don't really make sense in a MAES context (e.g. population-level life history traits, or the presence of a few specific tiny species, which can be seen as thematically inappropriate *"micro-characteristics"* for national and continent-level mapping and assessment studies);

- The review was of uneven quality, for some ES there was a high number of problematic and/or poorly documented records.

The first analysis of the OpenNESS systematic review database published by Smith et al. (2017) also had to face several of the issues mentioned here. Ultimately the ESP concept (inherited from the RUBICODE and the BESAFE projects) was not found to be helpful at all in summarising the relationships, and the list of traits was also found to be too detailed. Eventually Smith et al. implemented a much simpler five-scale classification of "natural capital attributes" which is essentially a simplification of the traits (biotic attributes) and factors (abiotic attributes) classifications (see Appendix 1 for the details of this classification).

This analysis aims for an intermediate level of detail in classifying ecosystem characteristics between the overly simplistic five class system of Smith et al. (2017), and the overwhelming complexity of the original OpenNESS data tables. To this end the OpenNESS database was taken as a starting point, trying to implement a new classification for ecosystem (=site & landscape) characteristics that is (1) compatible with the simple classes from Smith et al. (2017), (2) detailed enough to identify attributes potentially useful as ecosystem condition indicators, (3) but as clear, well-defined and simple as possible so that it could be used in policy discussions. To prioritize the records according to their relevance for the EU MAES work, two types of papers were dropped entirely from the transcription process (Table 2.1):

- non-European papers: in line with the spatial focus of the EU MAES assessment European studies (including global and entirely modelling studies relevant for European landscapes) were prioritized;

- non-priority ES: two provisioning ES (12: Potable water /quantity/, and 13: Food production /cultivated crops/) were given lower priorities. These ES depend much more on the human economic activities (extraction efforts, human inputs) than the characteristics the biotic characteristics of the ecosystems. These two ES are also relatively well captured by existing economic accounts, and there is thus less need for them being represented in the MAES assessment products (which can be seen as a "natural" extension of the traditional economic accounting). Furthermore potable water is also highly abiotic, originating from and governed by the abiotic processes and components of the environmental system, and is thus less in the focus of MAES.

Table 2.1: the list of ES and the distribution of papers studied in the OpenNESS database and in this work

ES id		**ES name (OpenNESS)**	**CICES 5.1[a]**	**reviewer (OpenNESS)**	**tr[b]**	**d1[c]**	**d2[d]**	**r1[e]**	**r2[f]**
01	**timber**	Timber production	1152p	INBO	BS	39	9	10	2
02	**fish**	Freshwater fishing	1161 (3112p)	MTA OK	BS/ BC	40	10	10	0
04	**pollin**	Pollination	2221	JRC / ALTERRA	MG	30	5	10	15
05	**pest**	Pest regulation	2231	UOXF	MG	25	7	10	18
06	**carbon**	Atmospheric regulation (carbon sequestration)	2261p	UOXF	ES	43	6	10	1
07	**erosion**	Mass flow regulation (erosion protection)	2211	IRSTEA / UOXF	ES	33	4	10	15
08	**flood**	Water flow regulation (flood protection)	2213	UOXF	GS	27	13	10	10
09	**w.qual**	Water quality regulation	211x 225x	UNOTT	MG	49		10	1
10	*recreat[g]*	*Recreation (species-based)*	*3111p 3112p*	*JRC*	*(GS)*	*36*	*24*	0[g]	
11	**aesth**	Aesthetic landscapes	3124	INBO	GS	26	10	10	14
12	*water[h]*	*Potable water (quantity)*	*4211-2, 4221-2*	*SYKE*	--		*60*	0[h]	
13	*crop[h]*	*Food production (cultivated crops)*	*111x (113x)*	*ALTERRA / UOXF*	--		*60*	0[h]	
14	**a.qual**	Air quality regulation	2262p	NINA	ES	33	14	10	12

a: CICES v5.1 codes (p: partially; codes assigned by BC based on http://cices.eu)
b: tr: transcriber (the person who did the 'transcription': BC: Bálint Czúcz, BS: Bernhard Schwarzl, ES: Elisabeth Schwaiger, GS: Gabriele Sonderegger, MG: Martin Götzl)
c: d1: number of non-European papers dropped before the transcription work
d: d2: number of papers dropped because of other problems (scope issues, quality of review, outdatedness, etc.) before/during the transcription work
e: r1: number of papers transcribed and used in this work
f: r2: number of remaining papers in the OpenNESS database still available for the continuation of this work
g: ES 10 (species-based recreation) was dropped due to a conceptual overlap with ES11 (aesthetic landscapes) and a high number of problematic reviews
h: ES 12 (potable water) and 13 (cultivated food crops) were dropped due to conceptual considerations (ES 12 is an abiotic service, and ES 13 is provided through economic activities in highly anthropogenic managed systems)

3 Data analysis

3.1 New reporting categories and automatic recoding

As discussed above, the OpenNESS database describes the condition-service relationships in several tables (see also Appendix 1). These tables encompass many topics beyond the focus of this study, so first all relevant information needed to be extracted and restructured in a useful way with condition-service relationships in the rows (=records/objects), and multiple "variables" (=fields) describing the relationships, as well as the literature source documenting them in the columns. In other words, each row/line (=record) of the new table represents a single trait (or factor) with influence on a specific service as documented by a scientific paper. A single paper can thus occur in multiple rows of the new table if it documents the influence of several ecosystem characteristics on the studied ES. The MAES ecosystem types in which the relationship was documented, the ES influenced by the trait, and the direction of the influence (positive, negative or ambiguous) are among the most important variables (=fields) of the new table (Table 3.1).

In order to be able to customize the results for the purposes of the EU MAES condition assessment, two simple reporting categories were created: *attribute type* (AT) and *object type* (OT) based on the *traits*/*factors*, and the *provider* (ESPs) documented in the OpenNESS database (Table 3.2). Beyond the need for simplification, the most important motivation for this reclassification was the fact, that the biotic attributes mentioned under "trait" were not necessarily the attributes of the ESP ("provider"), but many times attributes of a broader or more specific entity (the whole landscape, or a specific functional group). In many cases the underlying real *object* (the one which is characterised by the *attribute* in question) can be automatically deduced from the ESP ("provider") and the attribute / trait studied. The OT and AT combinations used are listed and explained in Table 3.2.

The new database was created from the records of the *TraitValue* and *FactorValue* tables of the OpenNESS database. The OT, AT and the DIR fields of the new table (see Table 3.1) were prefilled based on the trait and factor class-associations given in the "OpenNESS link" column of Table 3.2. The ecosystem type columns (E01-E12) were prefilled based on the types associated to the paper in the *ConditionValue* table, and the ESid of the service studied was also recorded. There were several trait (6, 7, 8, 9, 22, 24, 28) and factor (1, 2, 3, 4, 5, 11, 12) classes that resolved to attributes out of the focus of this work, either because they were considered too detailed for a MAES-style assessment (like life history traits of populations of a certain species), or because they were considered to have a trivial impact on ES uninteresting in a MAES context (like climate or slope). Such records were marked in this step, and were dropped later in the manual transcription phase of the work. This way the scope was limited to those "macro-attributes" that can be used in mapping studies: i.e. those that might be covered by global observatories today or in the foreseeable future (relatively easily observable characteristics of major species groups, sites & landscapes). There were also several trait classes (4, 14, 15, 30) that could not be resolved unambiguously to any OT:AT combination. For these records OT and AT fields were left blank. Such records were resolved to a specific OT:AT combination during the transcription, or also dropped, if this was not possible. On the other hand, a new attribute type, 'management intensity' (mi) was also included in the list of selectable categories, which could only be assigned manually in the transcription phase. This new characteristic type related to human use and disturbance regimes can potentially help to identify options to integrate pressures among the condition dimensions in a logical and coherent way, which is an important challenge ahead of MAES assessments.

Table 3.1: The main columns (fields) of the new database

Column	Description	Transcriber instructions
Ecosystem / landscape type columns	12 binary columns, specifying for which MAES ecosystem types the relationship described in the record is valid / documented	prefilled, can be revised
Object type (OT)	a binary typology of the “objects” (site or landscape) which are characterized by the “attributes” studied	prefilled, can be revised
Attribute type (AT)	a broad typology of characteristics (attributes) of the objects – characteristics which eventually influence (or just are correlated with) the services in the relationships documented	prefilled, can be revised
Object / attribute specification (OAS)	a concise formal refinement of OT and AT categories (the identity of the objects and/or the type of metric used to describe the attribute)	blank, should be filled
Directionality of the relationship (DIR)	the direction of the attribute -- ES relationship	prefilled, can be revised
Ecosystem service (ESid)	the ecosystem service (ES) being influenced (for which the paper has been selected)	prefilled, should not be changed
Transcriber	the name (monogram) of the transcriber who verified and filled in the record	blank, should be filled
New comments	any new comments wherever reasonable (why a record has been dropped, why some data fields been changed, any peculiarities, etc). In particular, in the case of dropped records the reason for dropping should be mentioned	blank, should be filled for dropped records, optional otherwise
Reference	Full reference of the paper	prefilled, just for information
Hyperlink	a doi-based clickable link to the published article	prefilled, just for information
Original reviewer	the name of the OpenNESS reviewer(s) [+ his/her institution]	prefilled, just for information
Tcomment	the trait ID and comment associated with each “trait” recorded in the openness DB (different content for each record)	prefilled, just for information
Pcomment	the ESP (=ecosystem service provider) and comment associated with the studied ESP in the paper (one for each reviewed paper)	prefilled, just for information
Ecomment	the ecosystem IDs and comments associated with each ecosystem recorded in the openness DB (there can be multiple ecosystems listed per paper, which are concatenated to a single cell -- the same content per paper)	prefilled, just for information
Rcomment	a top-level comment given by the openness reviewer to the entire paper (the same content per paper)	prefilled, just for information
Icomment	indicators comment: for each paper several indicators can be mentioned, all of which might come with a unit and/or threshold and a comment. (The different indicators are concatenated to a single cell -- the same content per paper)	prefilled, just for information
Lcomment	the scale and location of the study underlying the paper, as documented by the OpenNESS reviewer (the same content per paper)	prefilled, just for information

Table 3.2: The object types (OT) and attribute types (AT) used in this work, the corresponding OpenNESS categories, and the type of additional information (specifications) extracted during the transcription process

OT	AT	Description	OpenNESS link*	object specification	attribute specification
T	**ab**	Presence/ abundance of a specific (functional) group	2, 11; C	group	(metric)
T	**bi**	Total biomass of (a compartment of) the site/habitat	20, 21, 23, 27; A	compartment	(metric)
T	**di**	Diversity of a specific (functional) group	3, 12, 13; D	group	(metric)
T	**ft**	Any “structural” attribute (measurable trait) of a specific (functional) group	5; C	group	metric
T	**mi**	Management / land-use intensity of the site/habitat	**	(compartment)	metric
T	**pp**	Primary productivity of the site/habitat	19, A	(compartment)	(metric)
T	**so**	Soil type and/or soil fertility of the site/habitat	*6, 7, 10*; E		metric
T	**st**	Structure of the site/habitat (spatial arrangement of subtypes /major elements/ compartments within the site/habitat)	18; B, D ***	(compartment)	metric
T	**ta**	(Successional) age of the stand/site/habitat	25, 26; A	(compartment)	(metric)
T	**wa**	Water availability or quality at/for the site/habitat	*8, 9*; E	(compartment)	metric
L	**ab**	Presence / abundance of a specific ecosystem (sub)type in the landscape (mosaic of multiple habitats/ecosystem types)	17; B	(subtype)	(metric)
L	**di**	Landscape diversity, typically in terms of the number (or other diversity metric) of ecosystem/habitat types constituting the landscape	29; D		metric
L	**pr**	Coexistence (co-presence / co-abundance) of two different ecosystem (sub)types in a close proximity (is needed in order for the service to happen)	17; B	ecosystem, (subtype)	(metric)
L	**st**	Landscape structure, typically in terms of the spatial configuration (shape, size, etc.) of the distinct ecosystem/habitat patches constituting the landscape	18; B, D ***	(ecosystem)	metric

** Lookup link to the categories used in the OpenNESS database and Smith et al (2017): trait classes (numbers in normal typeface), factor classes (numbers in italics), and the simplified classes of Smith et al. (letters).*
*** the AT class “management intensity” (mi) was only introduced during the transcription, there is no ESP:trait combination in the OpenNESS database which would have been resolved automatically to this AT.*
**** the initial class for trait 18 (Community/habitat structure) depends on the ESP: L if ESP is 6 (=Two or more communities or habitats); and T otherwise*

3.2 Manual transcription of records

The creation of the new table was followed by a manual one-by-one “transcription” of the records of the selected papers, which consisted of a human review of the automatic class assignments, and the specification of the object and attribute details as indicated in Table 3.2. The transcription was performed by five transcribers from MNHN and UBA (see Table 2.1) in the new table structure (described in Table 3.1) using google spreadsheets. The most important resources for the transcription process were the textual comment fields in the OpenNESS database. The analysis of these comments could both help to verify the validity of the prefilled cell values, and to specify the *objects* and *attributes* in the OAS field. OAS specification was first implemented in a free text cell using a simple semi-structured notation scheme. With the help of the OAS field instead of highly general statements (like “*the abundance of some habitat type is the most crucial landscape factor*”) it also became possible to name the ecosystem/habitat the abundance of which was crucial. Similarly, based on OAS the relevant structure metric could also be determined, instead of just simply knowing that landscape structure was relevant. This type of added detail can highly increase the MAES relevance of the results.

During the verification of the records particular emphasis was laid on the ecosystem types for which the studied relationship was documented to be valid. These fields were considered to describe the “statistical population” (kind of sites or landscapes) for which the documented relationship is claimed to be valid by the papers reviewed. For site-level characteristics (OT=T) the MAES ecosystem types mentioned in the OpenNESS database were in most cases just appropriate. However, in the case of landscape-level characteristics (OT=L) some additional work needed to be done. For example, most of the records, that documented that the abundance of a specific habitat type (e.g. forests) is important in a landscape, just mentioned “forest” as the only relevant ecosystem type, which has little practical information (the abundance of forest in a forest). To overcome this kind of interpretational difficulty, OT=L records focussed at “landscape types” defined as landscapes (co-)dominated by specific MAES ecosystem types. This way the same (MAES) ecosystem typology could be used for both T and L records, but with a different meaning. The starting point for determining the relevant “landscape types” for the L records was the textual comment fields of the OpenNESS database. If there was no clue there for the “statistical population” considered by the study, then either the original pdf was consulted, or an estimation was made based on the knowledge of the transcribers on typical European landscapes at the location of the study. These ‘guesses’ were made as conservative as possible, and such cells were marked with a special code, allowing for later debugging or update.

The transcription, furthermore, created an opportunity to correct for some typical mistakes in the dataset. For example, all documented “relationships” should document a relationship between an ecosystem (condition) descriptor and an ecosystem service descriptor, both of which are generally quantified with some metrics in the reviewed papers. In the openness review the *ESP* and *trait* tables were designed to contain information of the ecosystem side of the relationship, and the *indicators* table was originally designed to contain information on the service descriptors. However, it sometimes happened that ecosystem service (ES) indicators / metrics were added to the *traits* table (and even more frequently ecosystem descriptors were added to the *indicators* table, which is of no interest now…). This mistake was corrected during the transcription process by dropping the erroneous records. The transcribers were requested to drop entire records if one of the following conditions are met:

- Records that contain “**micro-attributes**” (too detailed for a MAES-style assessment), like life history traits of populations of a certain species;

- Records that contain entirely **abiotic attributes** that are close to trivial (like the influences of climate or slope);

- Records that refer to **ES indicators** erroneously as ecosystem attributes (see above). This can be sometimes misleading at first sight, as e.g. timber production (as ES) might be described with indicators of (harvestable) biomass – but as biomass is an ES indicator in this case it should not be recorded in the new database, even if there are ways to record (aspects of) biomass in the table (as an ecosystem attribute which it truly is in many cases);

- “**Duplicated**” records that eventually resolve to “the same line”, i.e. the same combination of OT, AT and OAS for the same paper. For pairs of records that mentioned the absence/presence (ap) and the abundance (ab) of the same functional group or ecosystem type the record mentioning ‘ap’ was considered to be duplicated;

- **Unclear/ambiguous/contradictory** records (in some interesting cases, however, such records were also resolved with the help of the original papers);

- **Negative/nonsignificant** results (if it is stated clearly in the comments that the relationship documented in the record has in fact been tested by the paper, but found not to be convincingly supported by the data).

3.3 Summary statistics

Based on these new reporting categories several "aggregated statistics" were calculated, which describe the importance of the different attribute types in the generation of the different ES. During the transcription process transcribers continuously aimed at using a simple and harmonized language for filling the OAS field. This language was further unified after the end of the work, leading to the classes of "ecosystem and landscape characteristics" presented in Table 4.2 and 4.3.

After the construction of these "final" characteristics classes the following summary statistics were calculated for each class:

- TT: overall *total influence*: the number of all relationships documented (for all ES, in all ecosystem types);

- NN: overall *net influence*: the number of positive relationships minus the number of negative relationships found (for all ES, in all ecosystem types);

- Relevant ES: a list of the ES influenced by the characteristic (in any ecosystem type) sorted in an order of decreasing relevance (the ES most influenced by the service are named first);

- Relevant ET (ecosystem types): a list of the ecosystem types in which the characteristic exerts a documented influence (on any ES) sorted in an order of decreasing relevance (the ES most influenced by the service are named first).

4 Results

Due to the relatively low number of useful papers in the OpenNESS database only 10 papers from each of the 10 selected ecosystem services could eventually be re-analysed in this study (Table 2.1). This made up altogether 100 papers with 295 condition-service relationships, out of which 224 are positive, 45 are negative and 26 are of ambiguous direction (Table 4.1). The different ecosystem types are not equally well represented in the database: the "most studied" ecosystem type is croplands, whereas there are very few studies for marine ecosystems, partly due to the choice of ES to include in the OpenNESS review.

Table 4.1: Number of documented *condition-service* relationships in the OpenNESS database grouped with respect to the direction categories

			Direction (DIR)			
			positive	**negative**	**both & unclear**	**any (total)**
per ecosystem type						
	01	Urban (urban)	20	8	7	35
	02	Cropland (crop)	83	20	5	108
	03	Grassland (grass)	67	11	3	81
	04	Woodland and forest (forest)	64	23	4	91
	05	Heathland and shrub (heath)	27	6	4	37
	06	Sparsely vegetated land (SVL)	11	5	2	18
	07	Wetlands (wet)	22	1	3	26
	08	Rivers and lakes (water)	34	2	4	40
	09	Marine inlets and transitional waters (trans)	8	0	0	8
	10	Coastal (coast)	2	0	0	2
	11	Shelf	0	0	0	0
	12	Open ocean	0	0	0	0
per ES type						
	01	Timber production (timber)	13	5	2	20
	02	Freshwater fishing (fish)	22	2	4	28
	04	Pollination (pollin)	25	4	2	31
	05	Pest regulation (pest)	27	3	2	32
	06	Atmospheric regulation (carbon)	35	4	2	41
	07	Mass flow regulation (erosion)	19	11	2	32
	08	Water flow regulation (flood)	17	5	1	23
	09	Water quality regulation (w.qual)	35	1	2	38
	11	Aesthetic landscapes (aesth)	22	6	2	30
	14	Air quality regulation (a.qual)	9	4	7	20

Table 4.2: List of site-level ecosystem characteristics with a documented influence on ecosystem services -- TT: total influence (number of papers which document an effect of the characteristics on any of the studied ES in any ecosystem type); NN: net influence (the number of papers documenting a positive ES effect minus the number of papers with a negative effect)

Characteristics type	TT	NN	Relevant ET (ecosystem types)	Relevant ES
Biodiversity (in general) [T di]	**34**	**26**	forest, grass, crop, urban, water, wet, heath, SVL	timber, pollin, carbon, aesth, fish, w.quality, pest, erosion, a.quality
trees	**12**	**8**	forest, urban	timber, carbon, a.quality
diversity of plants	**9**	**8**	grass, crop, forest, heath, SVL, wet, water	pollin, carbon, erosion, pest, w.quality, aesth
pollinators	**4**	**3**	crop, grass, forest, heath	pollin
fishes	**2**	**1**	water	fish
Occurrence / abundance of a specific species (functional) group [T ab]	**17**	**14**	crop, water, grass, forest, heath, trans, SVL, wet, coast	fish, pest, carbon, timber, pollin, w.quality, erosion
parasitoids	**3**	**3**	crop	pest
predators	**3**	**3**	crop	pest
macrophytes	**2**	**2**	wet, water, trans	w.quality
pollinators	**2**	**2**	crop, grass	pollin
shrubs	**2**	**2**	grass, heath, crop, forest, SVL	carbon, erosion
Functional traits of a major species group [T ft]	**8**	**2**	urban, grass, forest, crop, SVL, water	a.quality, carbon, fish, erosion, w.quality
traits of trees	**5**	**-1**	urban, forest, crop, SVL	a.quality, carbon, erosion
traits of herbs/grasses	**2**	**2**	grass	carbon, w.quality
traits of trees [mature body size]	**2**	**0**	urban, crop, SVL	erosion, a.quality
traits of trees [leaf size]	**2**	**-2**	urban, forest	a.quality
Age of site / community [T ta]	**11**	**9**	forest, heath, crop, grass, urban	carbon, erosion, timber, flood, aesth
since abandonment	**4**	**4**	heath, crop, grass, forest	erosion, carbon
since fire	**3**	**3**	forest, crop, grass, heath	carbon, erosion
since cutting	**2**	**2**	forest	carbon, flood
Primary productivity [T pp]	**3**	**3**	water, grass	fish, carbon
Biomass at the site [T bi]	**30**	**20**	forest, urban, grass, heath, wet, SVL, crop, water	a.quality, carbon, flood, erosion, w.quality, fish, aesth
belowground biomass	**9**	**9**	grass, forest, crop, heath, SVL	carbon, erosion, flood, w.quality
ground layer	**6**	**3**	grass, forest, crop, heath, SVL, wet	erosion, w.quality, carbon, flood
litter	**4**	**1**	grass, forest, heath, wet	w.quality, carbon, flood
tree layer	**4**	**2**	urban, forest	a.quality
total [cover]	**3**	**3**	grass, forest, heath, SVL	flood
total [height]	**3**	**2**	wet, heath	flood, w.quality
total [LAI]	**3**	**0**	urban, forest	a.quality
Management / disturbance intensity [T mi]	**24**	**-13**	forest, crop, grass, heath, urban, SVL, water, wet	aesth, erosion, flood, timber, pollin, pest, fish, carbon, w.quality
bare soil frequency	**4**	**-4**	crop, grass, forest, heath, urban, SVL	erosion, pest
clearcutting	**4**	**-2**	forest	timber, flood, aesth
tillage intensity	**2**	**-2**	crop	pest, erosion
fire frequency	**2**	**-2**	forest, crop, grass, heath, SVL	flood
grazing intensity	**2**	**1**	grass	pollin, carbon
Site structure [T st]	**6**		urban, forest, wet, water	timber, fish, flood, w.quality, aesth, a.quality
Soil characteristics [T so]	**4**		crop, forest, grass, heath, SVL	carbon, erosion, w.quality
Water availability / quality [T wa]	**8**	**5**	water, wet, urban, heath, trans	fish, w.quality, carbon

Tables 4.2 and 4.3 show the abovementioned summary statistics for each of the characteristics found in the papers transcribed. These tables can provide valuable insight for the MAES condition assessment showing which types of ecosystem and landscape characteristics can be important to be considered as condition aspects, and which are probably not worth investigation in specific contexts.

Table 4.3: List of landscape characteristics with a documented influence on ecosystem services -- TT: total influence (number of papers which document an effect of the characteristics on any of the studied ES); NN: net influence (the number of papers documenting a positive ES effect minus the number of papers with a negative effect)

Characteristics type	TT	NN	Relevant ET (ecosystem types)	Relevant ES
The extent (abundance) of the target ET (or a specific subtype) [L ab]	**40**	**32**	crop, grass, wet, forest, heath, water, urban, trans	pest, w.quality, flood, erosion, pollin, aesth, fish, carbon, a.quality
any seminatural feature (hedgerows, treerows, roadsaides, oldfields)	**13**	**10**	crop, grass, urban	pest, pollin, aesth, w.quality
washland (regularly flooded land)	**4**	**4**	crop, grass, wet, forest, heath	flood, fish
fallows	**3**	**1**	crop	pest, pollin
hedgerows	**2**	**2**	crop, grass, urban	aesth
roadsides	**2**	**2**	crop	pest, w.quality
treerow	**2**	**2**	crop, grass	w.quality, aesth
The co-existence / proximity of the target ET and an other ET [L pr]	**20**	**18**	crop, water, urban, grass, forest, SVL	pollin, pest, flood, w.quality, fish, aesth
Landscape diversity [L di]	**10**	**9**	crop, grass, forest, heath, SVL, urban, wet, water	pest, aesth, fish, pollin, erosion
Landscape structure [L st]	**1**		water	fish

At the local (site / ecosystem) level (Table 4.2) the most relevant ecosystem characteristics are the biodiversity and the biomass of the site, both of which affects a wide (but different) range of ES. Biodiversity can be characterised by the diversity of many species (functional) groups, including the dominant plant species of the various ecosystem types (trees, shrubs), or the functional groups actually performing the particular ESs (predators, parasitoids). However, as the diversity of the different species groups is often correlated, many of these biodiversity proxies can be useful as general ecosystem condition indicators. As for biomass, any readily available metrics of aboveground biomass seem to be good candidates for site level condition indicators for many ecosystem types. Furthermore, the age of the site (time since last management intervention (harvest, abandonment), or since last major disturbance event (fire)) seem also to be important condition aspects for some ecosystem types. The intensity of human management (e.g. tillage, grazing/mowing) can also be an important condition aspect in the context of several ecosystem types, connecting the concept of condition to the slightly related concept of pressures. Any management activity that creates temporary or permanent bare soil patches in an ecosystem type (e.g. intensive forest management creating dirt roads) opens it up for erosion or the advent of invasives, thus the frequency of bare soil due to management seems to be a relevant condition aspect for a broad range of ecosystem types. The quality (and quantity) of the available water also seems to be a relevant criterion for ES provision in wet ecosystem types.

The most important ‘universal’ landscape characteristics applicable to a broad range of ecosystem types is the abundance of small seminatural features in the landscape, particularly in production landscapes (croplands, intensive grasslands, Table 4.3). Such features (hedgerows, trees, roadsides, oldfields) are typically subgrid elements in broad-scale ecosystem maps, and are thus considered to be parts of the dominant ecosystem types of the landscape (cropland, urban, etc.). However, thanks to the availability of high resolutions remote sensing imagery, automated detection of such features is possible, and there are already even European level datasets/maps available (García-Feced et al., 2015). Similarly, there are several useful landscape indicators that can be calculated from broad-scale ecosystem maps using simple landscape metrics (the local diversity of ecosystem types, the abundance of a specific ecosystem type in a moving window, or the proximity of several ecosystem types. Temporarily flooded wetlands (washlands, i.e. floodplains with free floodwater access) also seem to be a relevant factor for some ES, thus the landscape-level abundance of washlands can also be an interesting condition aspect for the EU MAES assessment.

5 Status of the work and next steps

In this work 100 papers from the OpenNESS systematic review database were re-analysed. In the case of multiple ES the capacities of this review database have been exhausted in terms of relevant European papers. To continue this work, new papers will have to be identified and reviewed. Thus ETC/BD work in 2018 will progress at two main types of activities:

- the ETC/BD ‘functional relationships’ systematic review database will be extended with the inclusion of new papers; and

- thematic summaries will be created in the form of “fact sheets” covering specific ecosystem types and ecosystem service types.

The production of fact sheets will start in early 2018 based on the results from 2017 from the OpenNESS review presented here, in order to maximize policy relevance for the EU MAES assessment process. The fact sheets will then be updated as the database will get extended with the newly reviewed papers. Finally, as a detailed documentation of all of this work a scientific manuscript will also be prepared.

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Annex 1: Ecosystem characteristics in the OpenNESS systematic review database

The OpenNESS systematic review database is organized in 44 linked SQL tables (Pérez-Soba et al., 2015), out of which the following ones were of particular interest for this work:

- *Review*: the key table of the database, containing all metadata of the reviewed papers and the ES studied in the paper (for which the paper was selected);

- *ConditionValue*: the ecosystem types that the study was performed in are reported in this table according to the MAES typology. A single paper can be linked to multiple *ecosystem types*. This database table was also intended to capture information about the condition (=conservation status according to simplified English Nature SSSI reporting categories) of these ecosystem whenever this was mentioned in the papers. But as this information was missing from the vast majority (90 %) of the papers surveyed, it was not included it in this study;

- *ProviderValue*: the ‘entities’ (ecosystem service *provider*s, ESP sensu Kremen, 2005 and Luck et al., 2009) that are essentially responsible for the production of the ES in question. ESPs were classified according to their ecological organizational levels into the following classes (“broad ecosystem service provider classes”):

    - *Single specific species population* (A group of organisms, all of the same species, which occupies a particular area (geographic population), is genetically distinct (genetic population) or fluctuates synchronously (demographic population));
    - *Two or more specific species populations*;
    - *Single functional group* (A collection of organisms with similar functional trait attributes in the study area, i.e. a feature of an organism, which has demonstrable links to the organism’s function. Sometimes referred to as a guild, especially when referring to animals);
    - *Two or more functional groups*;
    - *Entire community or habitat* (An association of interacting populations, usually defined by the nature of their interactions or by the place in which they live);
    - *Two or more communities or habitats*;
    - *Dominant community* (defined either qualitatively or quantitatively based on the article).

- *TraitValue*: the biotic attributes (*traits*) of the ESPs that affect the delivery of the ES studied. These were classified into 30 categories:

    - 1. Presence of a specific species type (with the name of the species in a free text box);
    - 2. Species abundance (number of individuals of a species expressed per unit area or volume of space. Synonymous with species population density);
    - 3. Species richness (number of different species represented in a set or collection of individuals);
    - 4. Species population diversity (the number, size, density, distribution and genetic variability of populations of a given species);
    - 5. Species size/weight (includes body size or weight, diameter at breast height - DBH - for trees, species/vegetation/tree height, basal area defined as the cross section area of the stem or stems of a plant or of all plants in a stand, generally expressed as square units (per unit area));
    - 6. Population growth rate (change in the number of individuals of a species in a population over time);
    - 7. Mortality rate (number of deaths of individuals per unit time);
    - 8. Natality rate (number of new individuals produced per unit time);
    - 9. Life span/longevity (duration of existence of an individual/expected average life span);
    - 10. Presence of a specific functional group (with the name of the functional group(s) in a free text box);

- 11. Abundance of a specific functional group;
- 12. Functional richness (the number of functional groups or trait attributes in the community);
- 13. Functional diversity (range, actual values and relative abundance of functional trait attributes in a given community);
- 14. Flower-visiting behavioural traits (pollination) (with a free text box specifying the behavioural type/preference/strategy);
- 15. Predator behavioural traits (biocontrol) (with a free text box specifying the behavioural type/preference/strategy to be entered);
- 16. Presence of a specific community/habitat type (with the name of habitat(s) or ecosystem(s) in a freetext box);
- 17. Community/habitat area (includes width or diameter, i.e. for buffer zones);
- 18. Community/habitat structure (in terms of complexity - amount of structure or variation attributable to absolute abundance of individual structural component - and heterogeneity - kinds of structure or variation attributable to the relative abundance of different structural components);
- 19. Primary productivity (rate at which plants and other photosynthetic organisms produce organic compounds in an ecosystem);
- 20. Aboveground biomass (the total mass of aboveground living matter within a given area);
- 21. Belowground biomass (the total mass of belowground living matter within a given area);
- 22. Sapwood amount (include allocation of carbon to sapwood and sapwood area);
- 23. Stem density (measured as the number of stems/specified area);
- 24. Wood density (measured as the weight of a given volume of wood that has been air-dried);
- 25. Successional stage (changes in the number of individuals of each species of a community and by establishment of new species populations that may gradually replace the original inhabitants; categorised into early and late stages);
- 26. Community/habitat/stand age (includes young and old-growth forests, even and uneven-aged forests, or can specify the age);
- 27. Litter/crop residue quality (quality of plant litter with respect to decomposition often defined by the C:N ratio, but ratios of C, N, lignin and polyphenols are other chemical properties and particle size and surface area to mass characteristics are physical properties);
- 28. Leaf N content;
- 29. Landscape diversity (diversity of landscapes and landscape features);
- 30. Other (any attribute or trait not in this list, described in a free text box).

- *FactorValue*: abiotic environmental characteristics of the ecosystems (or ESPs) that also affect the delivery of the ES studied. The intention was to record only cases when abiotic factors influence the ability of an ecosystem to deliver a service. (E.g. it is obvious that heavy rainfall influences flooding, but this relationship is not related to the functioning of ecosystems at all. Such direct and/or trivial relationships are excluded.) Abiotic *factors* were selected from the following list:

    - 1. Temperature,
    - 2. Precipitation,
    - 3. Evaporation,
    - 4. Wind,
    - 5. Snow,
    - 6. Soil,
    - 7. Geology,
    - 8. Water availability,
    - 9. Water quality,
    - 10. Nutrient availability,
    - 11. Slope (angle, aspect),
    - 12. Other.

In the first analysis of the OpenNESS systematic review database Smith et al. (2017) implemented a simpler five-scale classification of “natural capital attributes” which is essentially a simplification of the traits (biotic attributes) and factors (abiotic attributes) classifications:

A. *Amount of vegetation*: a group of biotic attributes related to the physical amount of vegetation within an ecosystem. Traits such as community/habitat type and area, structure, stand age, successional stage, stem density and above- and below-ground biomass resolve here. (traits: 16, 17, 19, 20, 21, 23, 24, 25, 26, 27);

B. *Provision of supporting habitat*: the existence of suitable habitats to support specific species (e.g. natural or semi-natural habitats surrounding crops to support pollinators and predators; and suitable aquatic habitats with the right ecological, hydrological and climatic conditions to support fish through all stages of their life cycle). The presence/abundance of specific community types, as well as their area and structure resolve here. (traits: 16, 17, 18);

C. *Presence of a particular species, functional group or trait*: Specific functional groups are cited as being important for some services: these include groups of pollinators and pest predators such as bees and wasps, as well as several functional groups of plants (such as large-leaved vs small-leaved trees or deep vs shallow-rooted shrubs). (traits: 1, 2, 5, 10, 11, 14, 15, 22, 24, 28);

D. *Biological and physical diversity* involves biological diversity (also reflected in the attributes of species and functional richness), functional diversity and (for food crops) intra-species population diversity. Physical diversity is reflected in the attributes of landscape diversity and, to a large extent, community or habitat structure (e.g. a forest with a range of vegetation heights and root depths) and structural diversity / complexity. (traits: 3, 4, 12, 13, 18, 29);

E. *Abiotic factors* interact with the biotic attributes in complex and context-dependent ways, with much variation between services. (all the factors);

PD. *Population dynamics* attributes (mortality, natality, growth rate and life span) interact with all these groups. This group of attributes was therefore not analysed by Smith et al. (2017). (traits: 6, 7, 8, 9). (The PD class was then considered to be a “micro-characteristic” out of the scope of the paper, and thus was completely left out of the analysis and discussion.).