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NINA Report

Panel-based Assessment of Ecosystem Condition (PAEC)

Technical protocol version 2

Jane Uhd Jepsen, Per Arneberg, Rolf Anker Ims, Anna Siwertsson og Nigel Gilles Yoccoz






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Norway, Ecosystem assessment, Ecosystem condition, Ecosystem state, System for Assessment of Ecological Condition

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Change log

The change log documents all changes made to the technical protocol (Definition of Terms and Chapters 1-9). since the first version. Changes made in abstracts and introduction are not tracked, as these are not part of the technical protocol.

Version	Date	Changes made	Reference
1	01.06.2019		Jepsen et al. 2019, Appendix 1 (in Norwegian)
2	15.12.2020	Protocol translated to English. Added table with definitions of terms (**Table 1**). Added guidelines for how to handle lack of consensus (p. 12). Added new chapter on definition of reference condition (Chapter 2). Evidence (EP) categories increased from 4 to 5 categories (**Figure 7.2**). Added instructions of how changes between repeated assessments should be visualized and discussed (**Tables 7.1**, **7.2, Figures 7.3.2, 7.3.3**, Appendix 3). Added standardized colour codes for use in figures and tables (Appendix 4). Added new appendix with R code and example data for producing assessment figures (Appendix 5).	This report

Abstract

Jepsen, J.U., Arneberg, P., Ims, R.A., Siwertsson, A., Yoccoz, N.G. 2020. Panel-based Assessment of Ecosystem Condition (PAEC) – Technical protocol version 2. NINA Report 1890. Norwegian Institute for Nature Research.

Panel-based Assessment of Ecosystem Condition (PAEC) is a new structured protocol for assessing the condition of an ecosystem relative to a given reference condition. This report describes in detail how each step of the assessment should be performed. The assessment is done by a panel of scientists with openings for stakeholder involvement. As a basis for the assessment, a set of ecosystem characteristics are defined, that together capture key aspects of structure and processes in the system and covering both biotic and abiotic parts of the ecosystem. The protocol consists of four phases: scoping, analysis, assessment and reporting & peer review. First, the *scoping phase* identifies a set of indicators used to assess the condition of each of the ecosystem characteristics. The second step is the formulation of formalized expectations (termed phenomena) describing expected directional changes in each of the indicators away from the reference condition as a result of relevant drivers in the system. Phenomena are thus the equivalent of a scientific hypothesis formulated prior to a scientific study. The validity of each phenomenon is assessed, reflecting how well we understand the links between drivers and indicator, how well the indicator reflects the condition of the ecological characteristics and the wider ecological significance of the phenomenon. Data sources are identified and data coverage in time and space are described for each indicator. The *analysis phase* consists of statistical analyses of the underlying data to permit an evaluation of the level of evidence for each phenomenon. In the *assessment phase*, the condition of each ecosystem characteristic is evaluated by taking into account phenomenon validity, evidence and data coverage across all phenomena within the characteristic. Based on this, an overall assessment for the ecosystem as a whole is done. The final step is an independent *peer review* of the assessment report with the aim of continuous improvements of the evidence base for phenomena and other elements of the assessment.

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Sammendrag

Jepsen, J.U., Arneberg, P., Ims, R.A., Siwertsson, A., Yoccoz, N.G. 2020. Panel-based Assessment of Ecosystem Condition (PAEC) – Technical protocol version 2. NINA Rapport 1890. Norsk institutt for naturforskning.

Panelbasert vurdering av økologisk tilstand, også betegnet Fagpanelmetoden (engelsk: Panel-based Assessment of Ecosystem Condition (PAEC)) er en ny strukturert protokoll for å vurdere tilstanden i et økosystem sammenlignet med en gitt referansetilstand. Denne rapporten beskriver i detalj hvordan hvert steg i vurderingen skal gjøres. Vurderingen gjøres av et forskerpanel med mulighet for involvering av interessenter. Som et utgangspunkt for vurderingen blir det definert et sett av økosystemegenskaper som til sammen dekker de viktigste strukturene og prosessene i systemet og som omfatter både biotiske og abiotiske deler av økosystemet. Protokollen er bygget opp rundt fire faser: En innledende kartleggingsfase ('Scoping'), en analysedel, en vurderingsdel, samt rapportering og ekstern fagfellevurdering av prosessen. I *kartleggingsfasen* blir det først identifisert et sett av indikatorer som skal brukes til å vurdere tilstand for hver av økosystemegenskapene. Det neste steget er å formulere formaliserte forventninger (kalt *fenomener*) som beskriver forventede retningsbestemte endringer i hver av indikatorene bort fra referansetilstanden som et resultat av relevante påvirkningsfaktorer i systemet. Fenomener tilsvarer altså vitenskapelige hypoteser som blir formulert før et vitenskapelig studium. Gyldigheten til hvert fenomen blir vurdert. Dette skal reflektere hvor godt vi forstår sammenhengen mellom indikator og påvirkningsfaktorer, hvor godt indikatoren gjenspeiler tilstanden til økosystemegenskapen den tilhører, samt den økologiske betydningen til fenomenet. Datakilder identifiseres og datadekning i tid og rom beskrives for hver indikator. I *analysefasen* blir det gjort statistiske analyser av dataene for å vurdere evidensen for at de ulike fenomenene har inntruffet. I *vurderingsfasen* blir tilstanden for hver økosystemegenskap vurdert på tvers av fenomenene innen egenskapen på bakgrunn av gyldighet, evidens og datadekning for hvert fenomen. Basert på dette gjøres det en samlet vurdering av tilstand for økosystemet som helhet. Det siste steget er en uavhengig fagfellevurdering av tilstandsrapporten, hvor målet er å bedre kunnskapsgrunnlaget for fenomenene og andre elementer av vurderingen.

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Contents

Foreword

Since 2016, the Norwegian Environment Agency has been leading the process of developing a new system for integrated assessments of ecosystem condition of Norwegian terrestrial and marine ecosystems. The system is termed ***System for Assessment of Ecological Condition*** (in Norwegian: *System for vurdering av økologisk tilstand*, previously *Fagsystem for fastsetting av god økologisk tilstand*), and the framework for the system was established by a national expert council, and outlined in a comprehensive report (Nybø & Evju 2017).

Since then, three working groups (one marine and two terrestrial) have been charged with developing and testing specific methods for integrated ecosystem-based assessments building on the premises outlined in the report from the expert council. The Panel-based Assessment of Ecosystem Condition (PAEC), which is the topic of this report, has been developed jointly by the marine, and one of the terrestrial working groups. According to PAEC, ecosystem level assessments are done by a broad scientific panel following a structured protocol. In 2019, the 1st version of the PAEC protocol was tested for two data rich Arctic ecosystems; the Arctic part of the Barents Sea, and Arctic tundra (in high arctic Svalbard and low arctic Northern Norway) and used to produce preliminary assessments of the condition of these ecosystems (Jepsen et al. 2019). In this report, we publish the PAEC protocol v2, which, in addition to being translated to English, also incorporates improvements and additions highlighted during the tests made in both ecosystems. In late 2020 and 2021, the PAEC protocol v2 will be used to develop full scale ‘operational’ assessments for both the Arctic part of the Barents Sea and for Arctic tundra. In addition, further tests of the protocol are planned in 2021 targeting other, and in part less data rich, Norwegian ecosystems.

We thank the Norwegian Environment Agency for support, and the participants in the 2019 test panels for the Arctic part of the Barents Sea and for Arctic tundra for constructive feedback on the protocol. Research Director Cathrine Henaug (NINA), and Senior Scientist Jarle W. Bjerke (NINA) both made valuable contributions in the quality control of this report.

Introduction to PAEC

The backdrop for developing PAEC (Panel-based Ecosystem Assessment of Ecosystem Condition) is an increasing demand for integrated assessments of the condition of entire ecosystem units under intensified anthropogenic pressures. PAEC is inspired by approaches used in several national and international organs, including IPBES, IPCC and EFESE (l'Évaluation française des écosystèmes et des services écosystémiques). These organs share the common notion, that the condition or state of complex systems (climate systems, ecosystems), and the level of evidence for change in the state of such systems as a cause of anthropogenic and natural drivers, are assessed by broad scientific panels following stringent and structured protocols.

PAEC is a structured protocol for a panel-based assessment of the condition of an ecosystem relative to a specific reference condition. It has been a goal that PAEC should provide a framework for making reproducible qualitative assessments based on solid quantitative analyses of the underlying data.

A PAEC assessment is made in a hierarchical manner and consists of four phases summarized in Figure 1; *Scoping*, *Analysis*, *Assessment* and *Reporting & Peer review*. Key to the *Scoping Phase*, is the formulation of specific formalized expectations (termed *Phenomena*) describing expected directional changes in a given indicator as a result of relevant drivers in the system. Phenomena are thus the equivalent of a scientific hypothesis formulated prior to a scientific study. The Scoping phase may include a plenary session involving all members of the scientific panel to ensure a coherent understanding of the phenomena and their scientific evidence base.

The *Analysis Phase* consists of a state-of-the-art statistical analysis of the underlying data to permit an assessment of the level of evidence for each phenomenon. The *Assessment Phase*, consists of a plenary session where the assessment panel scrutinizes and assesses the knowledge base underlying the assessment, assesses the condition of each of a set of *ecosystem characteristics* covering both structural and functional components (both biotic and abiotic) of the ecosystem, and finally assesses the condition of the ecosystem as a whole. An independent *Peer review* of the final assessment report with the aim of continuous improvements is a fundamental step in PAEC.

An assessment according to PAEC is primarily a scientific exercise, and the scientific assessment panel should consist of a group of scientists with in-depth knowledge of the focal ecosystem characteristics, as well as relevant quantitative methodology (study design and statistical modelling). However, PAEC is also envisioned to be a tool for adaptive management of ecosystems, or specific ecosystem components. Thus, the protocol allows for the integration of a stakeholder group (consisting for instance of representatives for management agencies responsible for the particular ecosystem) into the assessment process (Figure 1). This is non-mandatory, but may serve to broaden PAEC from a purely scientific assessment, to an operational tool for developing adaptive management strategies and the implementation and assessments of specific management actions. Depending on the type of process the protocol is used in, the level of stakeholder involvement in the assessment phase may vary.

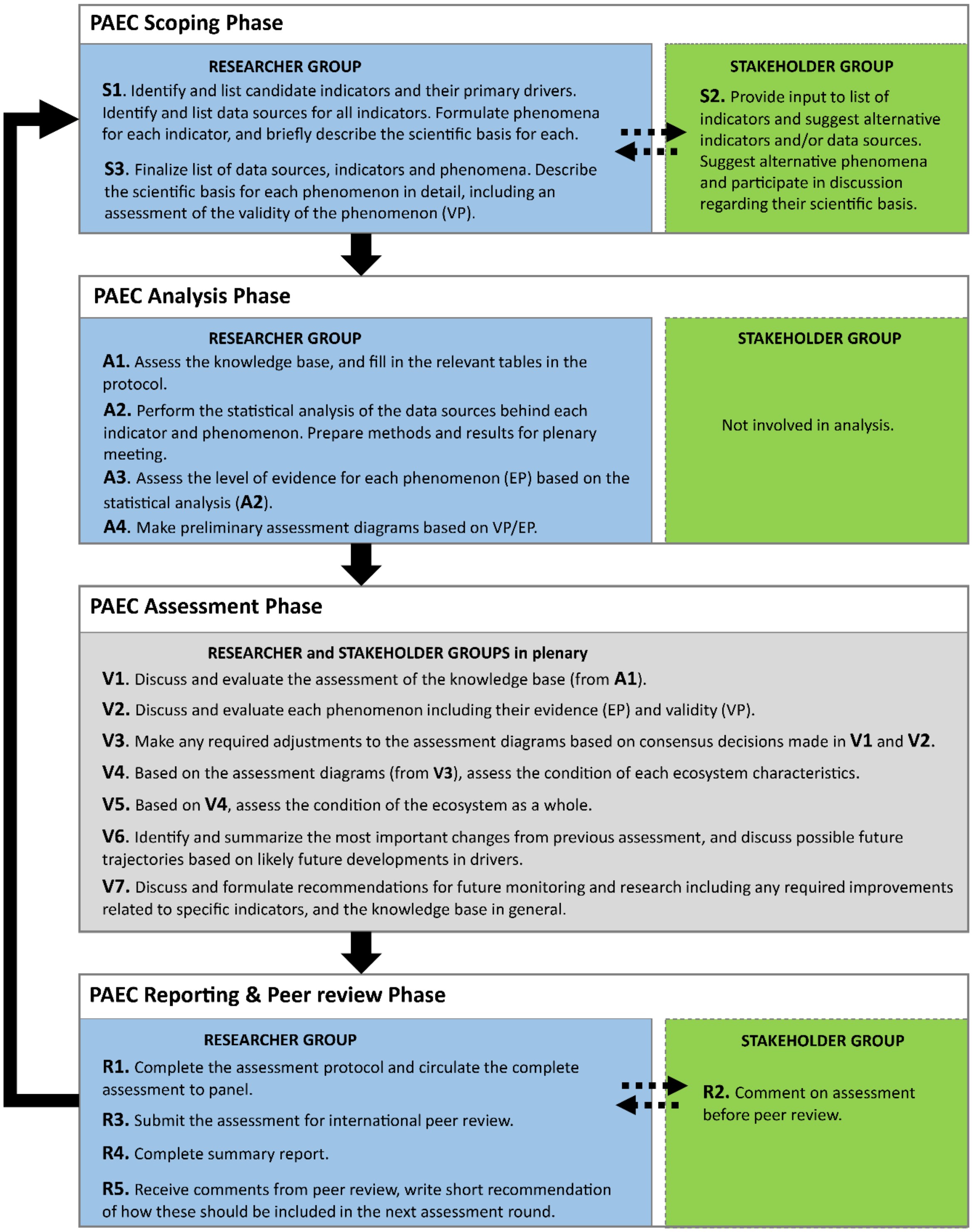


Figure 1. *Summary of the four phases of ecosystem condition assessment according to PAEC, and the main tasks involved in each phase. PAEC allows non-mandatory involvement of a stakeholder group in the assessment panel in addition to the scientific panel. In such cases, the stakeholder group provides input during the Scoping Phase (task S2), participates in the plenary assessment meeting (tasks V1-V7) and provides comments on the assessment report prior to peer review. Without stakeholder involvement, tasks S2 and R2 are excluded from the assessment process.*

Definition of Terms

Table 1. *Definition of key terms used in the System for Assessment of Ecological Condition in general, and in PAEC specifically.*

Term	Definition
Ecosystem characteristics	Characteristics of an ecosystem underlying how abiotic factors, ecosystem structure and functions interact. In the current assessment framework, seven characteristics are considered; primary productivity, biomass distribution among trophic levels, diversity of functional groups, functionally important species and biophysical structures, landscape ecological patterns, biological diversity, and abiotic factors.
State variable	Ecosystem feature describing an ecosystem characteristic. A state variable measures directly the functions and processes of its corresponding ecosystem characteristic(s). State variables can be used to build models for estimating causal relations between ecosystem characteristics and external drivers and to make quantitative predictions across space and time. One state variable can be associated with several ecosystem characteristics.
Ecosystem condition	Describes the current state of the ecosystem across all ecosystem characteristics by summarizing the state variables, often in terms of their dynamical regime. We consider here the term ecosystem condition synonymous with ‘ecosystem state’. State is often used in the context of alternative states, when the ecosystem can shift between regimes that persist at a particular spatial extent and temporal scale, but state changes may also be gradual.
Reference condition	Describes the state of the ecosystem at a pre-defined time period (e.g., “a climatic reference period”), or according to specific criteria such as the absence of local and global human influences (“a pristine state”), or the maintenance of important functional or structural components (e.g., population cycles, “a functional ecosystem”). Such reference condition is characterized by the range of variation and covariation among state variables due to ecosystem dynamics over a period that is long enough to get statistically reliable estimates, but with persistent (stable) environmental conditions.
Indicator	A preferably simple and easily interpreted surrogate for a state variable or a driver/pressure (the “canary in the mine”). Because indicators are required to have many properties (e.g. sensitive to changes, applicable over a large area, valid over a wide range of stress, cost-effective), a set of complementary indicators is often required. In this document the term *indicator* denote all metrics that are used to describe the focal ecosystem characteristics. Accordingly, it is important to note that indicators may range from *state variables* that directly denotes ecological functions and structures to *surrogate indices* that have more or less validated indirect relations to such functions and structures.
Ecosystem significance	A change in an indicator and its associated ecosystem characteristics is of ecosystem significance when the deviation from the reference condition implies ecologically large changes in the ecosystem characteristic the indicator is associated with or other ecosystem characteristics and generally in ecosystem condition. This is not related to statistical significance.
Phenomenon	A phenomenon is an expected directional change in an indicator which is of ecosystem significance and which can be attributed to one or more relevant drivers. Phenomena are thus the equivalent of scientific hypotheses formulated prior to a scientific study.
Quantitative phenomenon	A phenomenon is quantitative if one can identify and estimate a threshold value for the change in the indicator which, if exceeded, results in a change away from the reference condition which is of ecosystem significance.
Qualitative phenomenon	A phenomenon is qualitative when one cannot identify and estimate such a threshold value, but rather focuses on the type and direction of changes away from the reference condition linked to drivers that can lead to changes of ecosystem significance.
Validity of Phenomenon (VP)	Validity of a phenomenon addresses the links between drivers and ecosystem significance by assessing 1) how well we understand the mechanisms

	by which drivers affect an indicator, and 2) how well we understand how the change in an indicator leads to changes that are of ecosystem significance.
Evidence for Phenomenon (EP)	Assessment of the quality of empirical evidence for 1) that expected change in an indicator has occurred (incl. statistical significance) and 2) that the change is of ecosystem significance. The assessment hence considers both the relationship between state variables and indicators, and between indicators and ecosystem condition. The assessment relies upon the consistency in observed changes (over space and time), and the uncertainty of the estimated changes. In particular, a distinction is made between the absence of evidence for a phenomenon due to large uncertainties, and evidence that no change of ecosystem significance has occurred.
Design-based sampling and estimation	Given that one can define a target population with a list of units, design-based sampling uses either probability sampling where the probability that each unit is sampled is known a priori (e.g. stratified sampling with more variable strata being sampled more intensively) or some form of systematic sampling (e.g. grid). In the former case, one can use the design to estimate parameters of interest (e.g. averages) with known uncertainty without relying on statistical models.
Model-based sampling and estimation	Model based sampling aims at maximizing the accuracy of estimates of relationships between predictors (e.g. drivers) and responses (e.g. ecosystem state variables). Designs combine precision of estimates by having large contrasts in predictor values and accuracy of the functional response by allowing for non-linear responses and sampling intermediate values of predictors. Model based estimation used the model to extrapolate to non-sampled units and is sensitive to the model used and robustness needs to be evaluated.

Guide to handling lack of consensus in PAEC

The scientific panel should strive to achieve a common understanding and consensus in the assessments. However, in case the panel fails to achieve this, at a level where the disagreement has implications for the overall assessment of the condition of the ecosystem and its characteristics, the topic of disagreement and the alternative score, wording or choice of category, should be indicated in a footnote at the relevant place in the assessment text. The name of the panel member(s) who declare(s) reservations against a particular score, wording or choice of category should be indicated to ensure transparency. A member of the scientific panel cannot block the progress of the assessment, but may choose to stand aside, if unable to accept the decision made by the panel. In such event, this should be indicated in the list of panel members given in Chapter 1. In any case of disagreement, the leader of the scientific panel has the final authority to decide the score, wording or choice of category used in the final assessment.

1 Composition of the scientific panel

Chapter 1 of the assessment report must contain a complete list of all participants in the assessment panel, as well as their respective roles and expertise (**Table 1.1**). This includes participants in the scientific panel, authors of the final assessment report, people who have acted as experts on one or more ecosystem characteristics (and their indicators and associated phenomena), and people who have acted as internal reviewers by reading and commenting on drafts of the assessment report. If the scientific panel has been composed of both scientific members and stakeholders, these roles must be defined as well. Details can be provided in text if needed.

The scientific members of the panel should be scientists that together possess the following competence:

- Knowledge of the focal ecosystem with a sufficient depth and breadth to formulate and validate phenomena at all relevant levels for the assessment (indicators, ecosystem characteristics, and overall ecosystem condition). This means that the panel should encompass expertise about the properties of the individual indicators (including their data and knowledge base), the indicators' role/contributions to the ecosystem characteristics and experience with ecosystem-level synthesis, modelling or condition assessments.
- Expertise on quantitative methodology (in particular study design and statistical modelling) in order to make: i) inferences about evidence for changes in indicators and some (primarily low-dimensional) ecosystem characteristics, and ii) whenever appropriate/possible make model-based inferences about causal driver – indicator response relations that may underlie observed condition changes.

Table 1.1. *Example of composition of the assessment panel with definitions of roles.*

Name, institution, email	Role and expertise	Expert on single indicators
NN1	Panel leader, food web ecology	indicator X
NN2	Panel member, herbivores, statistical modelling	indicator Y, indicator Z
NN3	Panel member, climatology	-
NN4	Expert and data contributor, carnivores	indicator Z
NN5	Panel member, stakeholder	-
NN6	Internal reviewer of assessment report	-
etc	etc	

2 Definition of the reference condition

Chapter 2 must contain a clear description of the chosen reference condition (see **Table 1** Definitions of Terms), with reference to relevant scientific literature. PAEC is not limited to a particular reference condition, but the expectations of what constitutes a deviation from the reference condition will depend on whether the chosen reference condition is for instance a particular point in time, a 'pristine ecosystem' state, a 'functionally intact ecosystem', etc. The definition of the reference condition should be clear on whether the reference condition is valued (e.g. "good", "pristine" etc) or pragmatic (e.g. a particular year or time period chosen for reasons such as data availability).

3 Ecosystem delineation and data sources

Chapter 3 must contain a description of i) which ecosystem has been assessed, ii) whether and how the ecosystem has been divided into subsystems/ecosystem types, iii) how the ecosystem has been delineated geographically (including a map if possible; **Figure 3.1**). It should further describe any general choices made regarding which data sources to include or exclude. The latter is particularly relevant for choice of remote sensing data sources as well as design-based sampling (i.e., defining the target population), but can also have bearings for meteorological and ecological data. Finally, the chapter must include a complete overview (**Table 3.1**) of all individual data sets used in the assessment of ecosystem condition including simplified metadata stating, as a minimum, data availability (incl. unique identifier if possible), ownership, content and temporal coverage.

[Figure 3.1 in here]

Figure 3.1. *Map figure(s) showing the geographical delineation of the ecosystem. If the geographical delineation is made based on dated data sources (for instance classifications of remote sensing data) the map should be dated to indicate this.*

Table 3.1. *Description of data sources.*

Data set name	Data set ID	Data set DOI/URL	Owner institution	Storage	Content and methods	Temporal coverage
Data set x…n	A running ID number to link data set to indicators (**Table 4.1**)	DOI/URL for open access data, else NA	The institution that owns the data	For data without DOI/URL, include a description of where the data are stored/can be obtained	Short description of the content of the data, key sampling methods incl. references to studies using the data	Start-end date of the data series

4 Estimation of indicators

Chapter 4 must describe how indicators are estimated based on the data sources listed in Chapter 3. The general analytical framework used can be described in detail in text, but specific details should be given for each indicator in a table (**Table 4.1**), listing the indicator name, the individual ID for each data set contributing to the indicator, and methods used for estimating the indicator, including how uncertainties are estimated. Chapter 4 should also contain plots of indicator values with estimated uncertainties. The figures can be placed in Appendix 1 if too extensive to fit in the main text. For indicators based on multiple data sets (for instance several species or regions), each underlying dataset should be plotted in addition to the derived indicator values. These plots will be an important basis for the assessment of the condition of the ecosystem.

Table 4.1. *Methods for estimating indicators.*

Indicator	Dataset ID	Methods
Indicator 1…n	The dataset IDs of the relevant datasets from **Table 3.1**	A brief description of how indicator values are estimated from the underlying data.

5 Assessment of deviations from the reference condition

Chapter 5 must describe how the assessment of deviations from the reference condition is made for each indicator. In PAEC, the formulation of one or more *phenomena* associated with each indicator is a fundamental step in the assessment.

A phenomenon is *a directional change in the indicator which is of ecosystem significance and which can be attributed to one or more relevant drivers* (See **Table 1** Definitions of Terms).

A phenomenon is thus a formalised description of how each indicator can be expected to change as a result of relevant drivers in the system, and the equivalent of a scientific hypothesis formulated prior to a scientific study. In assessments of ecosystem condition the focus will most often be on changes in ecosystem condition as a consequence of anthropogenic drivers. In such cases *relevant drivers* will hence be limited to anthropogenic drivers, including climate change. The term *ecosystem significance* refers to changes which adversely influence either the ecosystem characteristic the indicator is associated with, or other characteristics of the ecosystem (see Definition of Terms and Chapter 6).

A phenomenon can be formulated either *quantitively* or *qualitatively*. A *quantitative phenomenon* requires that an absolute threshold value for the indicator can be estimated, which, if exceeded, is expected to result in adverse changes of ecosystem significance. The assessment of whether or not a quantitative phenomenon has occurred hence consists of estimating whether the value of the indicator is above or below the threshold value. This should take into account the uncertainties in both the estimated indicator values and in the threshold. A *qualitative phenomenon*, on the other hand, makes no use of absolute threshold values. Instead a qualitative phenomenon expresses the type and direction of change, given relevant drivers, which is expected to lead to adverse changes of ecosystem significance. The assessment of whether or not a qualitative phenomenon has occurred, hence involves an estimation of the magnitude and rate of change away from the reference condition, including uncertainties, and an evaluation of the extent to which observed changes are of ecosystem significance.

Chapter 5 should contain two parts: i) a summary table (**Table 5.1**) where all phenomena for all indicators are listed, and ii) a text (section 5.1) describing the scientific evidence base for each phenomenon. The summary table should indicate the overall approach used when determining whether or not (or the extent to which) each phenomenon has occurred. As a minimum one or more of the three predefined approaches (see **Table 5.1**, last column) should be listed, but additional details on the approach can be given as needed either in Table 5.1 or under Supplementary methods in Appendix 1.

Table 5.1. *A list of all phenomena including overall approach used to determine the extent to which each phenomenon has occurred.*

Indicator	Phenomenon name [ID]	Approaches used to determine the extent to which the phenomenon has occurred
Indicator name	Short name for phenomenon [phenomenon ID]	(1) For quantitative phenomena: The values of the indicator relative to an estimated quantitative threshold value (2) For qualitative phenomena: The value of the indicator relative to variation estimated from the indicator time series or other qualitative or quantitative information about a reference state (3) For all phenomena: Observed and expected effects of changes in the indicator on other components of the ecosystem (i.e. ecosystem significance)

5.1 Scientific evidence base for the phenomena

This section must contain a textual description of the scientific evidence base of the phenomenon formulated for each indicator. It should contain one short section for each indicator. The scientific evidence base must be supported by references to the scientific literature and addresses the following:

- A description of each phenomenon under the reference condition. This is trivial if the chosen reference condition corresponds to a baseline year e.g. “year 2000”, but non-trivial if the reference condition corresponds to for instance a “pristine ecosystem” or a “functionally intact ecosystem”.
- A description of the most important biotic or abiotic drivers of change in the indicator.
- A rating of the current understanding of the link between drivers and changes in the indicator as either certain or less certain. This rating also includes how well the indicator is known to capture the expected state change. This is needed to assess the validity of the phenomenon (VP) in Chapter 7.2.
- A description of why the occurrence of the phenomenon constitutes a development away from the reference condition which is of ecosystem significance. This is a vital point. For quantitative phenomena, with an estimated threshold value, it must be described why exceedance of the threshold value constitutes a change of ecosystem significance. For qualitative phenomena it must be described when a change can be considered being of ecosystem significance.
- A rating of the current understanding of the role of the indicator in the ecosystem, and hence our understanding of the importance of changes in the indicator, as good or less good. This is needed to assess the validity of the phenomenon (VP) in Chapter 7.2.
- If possible, give examples of changes which would be of ecosystem significance. This is particularly relevant for qualitative phenomena.

6 Ecosystem characteristics

In PAEC, an ecosystem is described using a set of ecosystem characteristics (see **Table 1** Definition of Terms), and the indicators are selected to represent a particular ecosystem characteristic. Chapter 6 must describe the role that each indicator has for the ecosystem characteristic to which they are associated, and hence the role that each indicator should play in the assessment of the condition of the ecosystem characteristic as a whole. Closely related indicators associated with the same ecosystem characteristic can be described together. The description can be made in a table format (**Table 6.1**).

Table 6.1. *Description of the indicators per ecosystem characteristic.*

Ecosystem characteristic	Indicator(s)	The role of the indicator in the assessment of the ecosystem characteristic
Name of ecosystem characteristic	Name(s) of indicators(s)	Short textual description of the role of the indicators(s) in the assessment of the ecosystem characteristic

7 Assessments

Chapter 7 must contain the actual assessment. The assessment consists of three parts. First, an assessment of the knowledge base from the level of individual data sets to the level of ecosystem characteristics (Chapter 7.1). Second, an assessment of each phenomenon with respect to their validity and the amount of evidence for their occurrence (Chapter 7.2). Third, based on the former two, an assessment of the condition of each ecosystem characteristic and of the ecosystem as a whole relative to the chosen reference condition (Chapter 7.3).

7.1 Assessment of the knowledge base

The assessment of the knowledge base should include the following aspects:

- The spatial representativity (*SR*) of *each data set* relative to the target ecosystem (Chapter 3) as determined by the sampling design employed (design-based, model-based, no design, see Definitions of Terms). A design-based sampling is evaluated based on 3 criteria: 1) whether or not the entire population has the possibility of being included in the sampling (*SRd1*), 2) whether or not sampling is based on randomization (*SRd2*), and 3) whether or not there is a known probability of including each sampling unit (*SRd3*). A model-based sampling (*SRm*) is evaluated based on just one criterium; whether or not sampling is based on a model that is relevant for the indicator or phenomenon in question.
- The temporal representativity (*TR*) of *each data set* relative to any temporally defined reference condition. A temporally defined reference condition includes both explicit definitions (e.g. the reference condition equals the condition of the ecosystem at a particular point in time), and implicit definitions (e.g. the reference condition equals the condition of the ecosystem under, for instance, a preindustrial climate). Temporal representativity is evaluated based on two criteria: 1) with respect to years (*TRyr*; e.g. the length of the time series relative to relevant dynamics and any temporally defined reference conditions), and 2) with respect to seasonality (*TRse*; whether or not relevant seasonality is taken into account in the sampling or not).
- The data coverage (*DC*) for each indicator, derived directly from *SR* and *TR* of its data sets.
- The indicator coverage (*IC*) for each ecosystem characteristic.

Each aspect should be scored according to predefined categories (**Figure 7.1**) and presented in a table (**Table 7.1**). The table should be colour-coded (see Appendix 4 for colour codes) to present a relatively quick overview of stronger and weaker sectors in the knowledge base. Commonly, the same data set might be used for calculating several indicators. In such cases, it should also appear several times in the table. The decisions made by the scientific panel regarding the quality of the knowledge base (e.g. why a certain category was chosen), should be supported by a foot note inserted in each cell of the table and placed in Appendix 2.

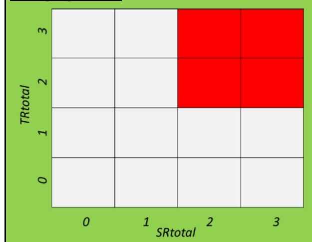
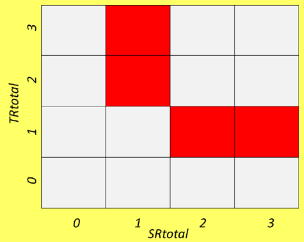
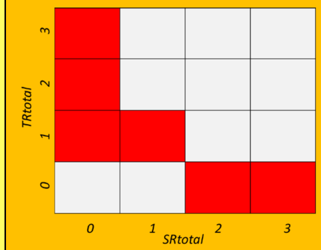
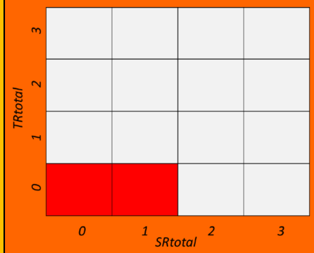
<table>
<tr><th></th><th></th><th colspan="4">Categories</th></tr>
<tr><td rowspan="5">Spatial Representativity (SR)</td><td>SRd1</td><td colspan="2"><u>Fulfilled</u>: Design-based sampling where the entire sampling population has a possibility of being included</td><td colspan="2"><u>Not fulfilled</u>: Design-based sampling where only a SUBSET of the sampling population has a possibility of being included</td></tr>
<tr><td>SRd2</td><td colspan="2"><u>Fulfilled</u>: Design-based sampling based on randomization</td><td colspan="2"><u>Not fulfilled</u>: Design-based sampling NOT based on randomization</td></tr>
<tr><td>SRd3</td><td colspan="2"><u>Fulfilled</u>: Design-based sampling, with known probability of including each sampling unit</td><td colspan="2"><u>Not fulfilled:</u> Design-based sampling, with UNKNOWN probability of including each sampling unit</td></tr>
<tr><td>SRm</td><td colspan="2"><u>Fulfilled</u>: Model-based sampling based on a model that is relevant for the indicator and the phenomenon in question</td><td colspan="2"><u>Not fulfilled</u>: Model-based sampling based on a model that is NOT relevant for the indicator and the phenomenon in question</td></tr>
<tr><td>SRtotal</td><td><u>Category 3</u>: SRm fulfilled with an adequate sample size OR SRd1-SRd3 all fulfilled</td><td><u>Category 2</u>: SRm fulfilled with a limited sample size OR two of SRd1-SRd3 fulfilled</td><td><u>Category 1</u>: SRm not fulfilled, one of SRd1-SRd3 fulfilled</td><td><u>Category 0</u>: SRm not fulfilled, none of SRd1-SRd3 fulfilled</td></tr>
<tr><td rowspan="3">Temporal Representativity (TR)</td><td>TRyr</td><td><u>Adequate:</u> A long time series relative to relevant dynamics. In case of a temporally defined reference condition, time series is partly or fully overlapping with the reference period</td><td colspan="2"><u>Partially adequate:</u> A long time series relative to relevant dynamics. In case of a temporally defined reference condition, time series are NOT overlapping with the reference period</td><td><u>Inadequate:</u> A short time series relative to relevant dynamics</td></tr>
<tr><td>TRse</td><td colspan="2"><u>Adequate</u>: Seasonal variability is relevant and taken into account in the sampling OR seasonal variability is not relevant</td><td colspan="2"><u>Inadequate</u>: Seasonal variability is relevant, but not, or to a very limited degree taken into account in the sampling</td></tr>
<tr><td>TRtotal</td><td><u>Category 3:</u> Both TRyr and TRse are Adequate</td><td><u>Category 2</u>: TRyr Adequate and TRse Inadequate OR TRyr Partially adequate and TRse Adequate</td><td><u>Category 1</u>: TRyr Inadequate and TRse Adequate OR TRyr Partially adequate and TRse Inadequate</td><td><u>Category 0</u>: Both TRyr and TRse Inadequate</td></tr>
<tr><td>Data coverage</td><td>DC</td><td><u>Very good:</u>
</td><td><u>Good:</u>
</td><td><u>Intermediate:</u>
</td><td><u>Poor:</u>
</td></tr>
<tr><td>Indicator coverage</td><td>IC</td><td><u>Adequate:</u> The set of indicators represent the major aspects of the ecosystem characteristic with no obvious shortcomings</td><td colspan="2"><u>Partially adequate:</u> The set of indicators has certain shortcomings which might limit our ability to assess the condition of the ecosystem characteristic</td><td><u>Inadequate:</u> The set of indicators has severe shortcomings which will definitely limit our ability to assess the condition of the ecosystem characteristic</td></tr>
</table>

Figure 7.1. *The criteria and colour coding used in the assessment of the knowledge base (**Table 7.1**). See also Appendix 4 for a full list of colour codes used in tables and figures.*

Table 7.1. *Assessment of the knowledge base. For definitions of categories and criteria, see* ***Figure 7.1.*** *In the case of repeated assessments, any changes in assessment categories for data coverage (DC) and Indicator coverage (IC) are indicated a number in brackets following the name. The number should give the change in number of categories. For instance, if data coverage (DC) for the indicator "Plant biomass" has changed from 'Intermediate' in the previous assessment to 'Good' in the current assessment, the change is one step in a positive direction and therefore indicated by Plant biomass (+1)'. Changes in a negative direction, e.g. towards lower data coverage or lower indicator coverage, are less likely, but are indicated by a negative number (for instance '(-1)'), while no change in category in indicated by '(0)'.*

DATA									INDICATOR	ECOSYSTEM CHARACTERISTIC
Data set ID	**Spatial representativity (SR)**					**Temporal representativity (TR)**			**Data coverage**	**Indicator coverage**
	SRd1	**SRd2**	**SRd3**	**SRm**	**SRtotal**	**TRyr**	**TRse**	**TRtotal**	**DC**	**IC**
From **Table 3.1**	[1]	[2]	[3]						Name of indicator	Name of ecosystem characteristic

[1] Foot note 1
[2] Foot note 2
[3] Etc.

7.2 Assessment of the phenomena

The assessment of the phenomena must consist of an assessment of the validity of each phenomenon (VP), and an assessment of the level of evidence that a given phenomenon has occurred (EP). VP and EP are scored according to predefined categories (**Figure 7.2**) and presented in a table (**Table 7.2**). In the table, the columns for VP and EP are colour-coded to present a relatively quick overview of phenomena of higher and lower validity, and the level of evidence for their occurrence.

VP depends partly on how certain we are of the link between relevant drivers and changes in the indicator (indicated as either <u>certain</u> or <u>less certain</u> in Chapter 5.1), and partly on the level of understanding of the role of the indicator in the ecosystem (indicated as either <u>good</u> or <u>less good</u> in Chapter 5.1). A phenomenon of high validity is hence one for which we are both certain that changes are caused by relevant drivers and have a good understanding of how these changes are likely to affect other parts of the ecosystem. That Chapter 5.1 presents a thorough and sound description of the scientific basis for the phenomena is hence a prerequisite for an assessment of the validity of these phenomena.

EP depends both on the level of evidence that the expected changes in the indicator have actually occurred, and on the expected (or observed) ecosystem significance of the observed changes. The level of evidence for change may be *regional* (e.g. evidence from all available geographical regions within the target ecosystem are in agreement), or *local* (the level of evidence differ between geographical regions within the target ecosystem). This can be expressed by scoring EP to different categories for different regions. A phenomenon with high level of evidence is hence one for which we see large or accelerating changes in the indicator values (qualitative phenomena) or a certain exceedance of the estimated threshold values (quantitative phenomena), and where the magnitude/extent of these changes are expected to be of ecosystem significance. The plots of the indicators and accompanying statistical analyses (Chapter 4, Appendix 1), form the basis for assessing the level of evidence that changes have occurred. This assessment must take into account uncertainties both in time series (for qualitative and quantitative phenomena), and in any absolute thresholds estimated for quantitative phenomena. In the assessment of whether observed changes can be expected to be of greater or lesser ecosystem significance, knowledge of the ecosystem in question, general knowledge of ecosystem ecology as well as observed changes in other parts of the ecosystem must be taken into account by the scientific panel.

The assessment of phenomena may in some cases be supported by formal statistical modelling of causal driver-response relations. This can be done when phenomena can be represented by state variable(s) that directly represents the ecological processes of concern and adequate data on driver variables are available. Causal modelling may be particularity useful in case of indicators or ecosystem characteristics that are subjected to multiple drivers, or where driver-response relations are complex (non-linear or interactive) or indirect (e.g. due to trophic cascades). Such modelling exercises should be done prior to the panel meeting so their results can be presented to the panel and thereby become a part of the assessment.

Where there is absence of evidence for change, the scientific panel must distinguish between cases where the underlying data are of sufficient quality and coverage to permit a conclusion that *no change has occurred* (EP=None), from cases where the underlying data *does not permit a conclusion of whether changes have occurred* (EP=Insufficient) due to low data quality, short time series etc.

<table>
<tr><th>Evidence for Phenomenon (EP)</th><th>Validity of Phenomenon (VP)</th></tr>
<tr><td>High: High level of evidence that the expected changes in the indicator have occurred. High (expected or observed) ecosystem significance of observed changes.</td><td>High: A CERTAIN link to relevant drivers, and a GOOD understanding of the role of the indicator in the ecosystem.</td></tr>
<tr><td>Intermediate: High level of evidence that the expected changes in the indicator have occurred. Limited (expected or observed) ecosystem significance of observed changes.</td><td rowspan="2">Intermediate: A LESS CERTAIN link to relevant drivers, and a GOOD understanding of the role of the indicator in the ecosystem OR A CERTAIN link to relevant drivers, and a LESS GOOD understanding of the role of the indicator in the ecosystem.</td></tr>
<tr><td>Low: Low level of evidence that the expected changes in the indicator have occurred. Low or no (expected or observed) ecosystem significance of observed changes.</td></tr>
<tr><td>None: No evidence that the expected changes in the indicator have occurred (sufficient data)</td><td rowspan="2">Low: A LESS CERTAIN link to relevant drivers, and a LESS GOOD understanding of the role of the indicator in the ecosystem.</td></tr>
<tr><td>Insufficient: No evidence that the expected changes in the indicator have occurred (insufficient data)</td></tr>
</table>

Figure 7.2. *The criteria and colour coding used in the assessment of the phenomena (**Table** 7.2). See also Appendix 4 for a full list of colour codes used in tables and figures.*

Table 7.2. *Assessment of the phenomena: For definitions and criteria, see **Figure 7.2**. In case of repeated assessments, the VP/EP cells are colour-coded according to the current assessment category, but any changes from the previous assessment should be indicated by text. For example, if VP was assessed to be 'Intermediate' in a 2020 assessment, but 'High' in the 2025 assessment, the cell would be green (for category 'High') and the text would be 'High (2020: Intermediate)'.*

Ecosystem characteristic	Phenomenon	Indicator	Validity of Phenomenon (VP)	Evidence for Phenomenon (EP)	Comments to EP
Name of ecosystem characteristic	Phenomenon name [ID] from Table 5.1	Name of Indicator	Colour-coded cells with VP category (Figure 7.2)	Colour-coded cells with EP category (Figure 7.2)	(*)

(*) EP should be substantiated by a written comment in particular in non-trivial cases, and cases where different values of EP have been assigned to different regions due to conflicting evidence for change. If substantial comments are needed, they can be placed in a separate section in the main text or Appendix 1.

7.3 Assessment of ecosystem condition

The assessment of ecosystem condition consists of the following sections: An assessment of each ecosystem characteristics based on all associated phenomena (Chapter 7.3.1), an assessment of the ecosystem as a whole (Chapter 7.3.2), a discussion of likely future trajectories in the condition of the ecosystem (Chapter 7.3.3), and recommendations for further monitoring and research in order to improve future assessments of the condition of the ecosystem.

7.3.1 Assessment of the condition of individual ecosystem characteristics

The basis for the assessment of the condition of individual ecosystem characteristics is a diagram (illustrated in Figure 7.3.1) in which each phenomenon associated with the characteristic is plotted using a circular symbol based on its evidence (EP, x-axis) and validity (VP, y-axis). If an assessment has been done previously, changes from the previous assessment should be indicated by arrows. Depending on the distribution of all the phenomena in the diagram, the ecosystem characteristic is scored to one of three categories: *no deviations from the reference condition*, *limited deviations from the reference condition*, or *substantial deviations from the reference condition*. In cases of local evidence (e.g. multiple EP values assigned to a given phenomenon due to conflicting evidence for change), this is indicated by splitting the circular symbol accordingly and placing it in each of the relevant EP categories. The data coverage for each indicator (DC in **Table 7.1**) is also taken into account in the assessment and is indicated by the size of the symbols. This permits the scientific panel to place somewhat higher emphasis on the phenomena with better data coverage if this is judged relevant. Phenomena that are scored as "insufficient" evidence for phenomena (EP), should not be taken into account in the assessment, but are included in the diagram to highlight phenomena for which data coverage and/or quality should be improved for future assessments. In addition to scoring the condition of the ecosystem characteristic to a category, the scientific panel must provide a short textual assessment of the condition of the ecosystem characteristics, which substantiate the choice of category. This is particularly important in cases where the phenomena are spread across several or all categories. In such cases the scientific panel must provide a description of why certain phenomena have been given higher emphasis than others in the choice of category. The general guidelines for the assignment to categories are as follows:

No deviation from the reference condition:
<u>Ecosystem characteristics assigned to this category show no or very limited deviations from the reference condition.</u> Most or all of the phenomena should be in the green cells in **Figure 7.3.1.** If any phenomena are located in the orange or red cells, the choice of category *No deviations from the reference condition* should be justified in the textual assessment. *No deviation* should be the conclusion when there is no evidence for the occurrence of most phenomena (EP=None). It is also the conclusion if there is low evidence for the occurrence of some phenomena, given that these phenomena are of low validity, since the implications of such changes are highly uncertain, both due to uncertain links to the relevant drivers and a poor understanding of the role of the indicator in the ecosystem.

Limited deviation from the reference condition:
<u>Ecosystem characteristics assigned to this category show limited deviations from the reference condition.</u> Most or all of the phenomena should be in the orange cells in **Figure 7.3.1.** If any phenomena are located in the green or red cells, the choice of category *Limited deviation from the reference condition* should be justified in the textual assessment. *Limited deviation* should be the conclusion when there is low evidence for the occurrence of most phenomena (EP=Low). It is also the conclusion if there is intermediate evidence for the occurrence of some phenomena, given that these phenomena are not of high validity. Even a high level of evidence for changes, can result in a conclusion of *Limited deviation*, but only if there are uncertain links to relevant drivers and a poor understanding of the role of the indicator in the ecosystem (i.e. a phenomenon of low validity).

Substantial deviation from the reference condition:
Ecosystem characteristics assigned to this category show substantial deviations from the reference condition. Most or all of the phenomena should be in the red cells in **Figure 7.3.1.** If any phenomena are located in the green or orange cells, the choice of category *Substantial deviation from the reference condition* should be justified in the textual assessment. Substantial deviation should be the conclusion if there is intermediate-high evidence for the occurrence of most phenomena, and that these phenomena are of intermediate-high validity. Substantial deviation from the reference condition for a given ecosystem characteristic, hence means that we observe changes in indicators which are expected to be of ecosystem significance, and that we have a relatively good understanding both of the link to relevant drivers and the role of the indicator in the ecosystem.

If an assessment has been done previously, change from the previous assessment to the current one should be evaluated. For each ecosystem characteristics, it should first be described whether the assessment category has changed. If it has, it should be described how the different parameters have contributed to this change, i.e. the influence of any changes in indicator coverage for the ecosystem characteristics, data coverage for the indicators and validity (VP) and evidence (EP) for each phenomenon. If there is no change in assessment category, important changes in assessment parameters should be summarized.

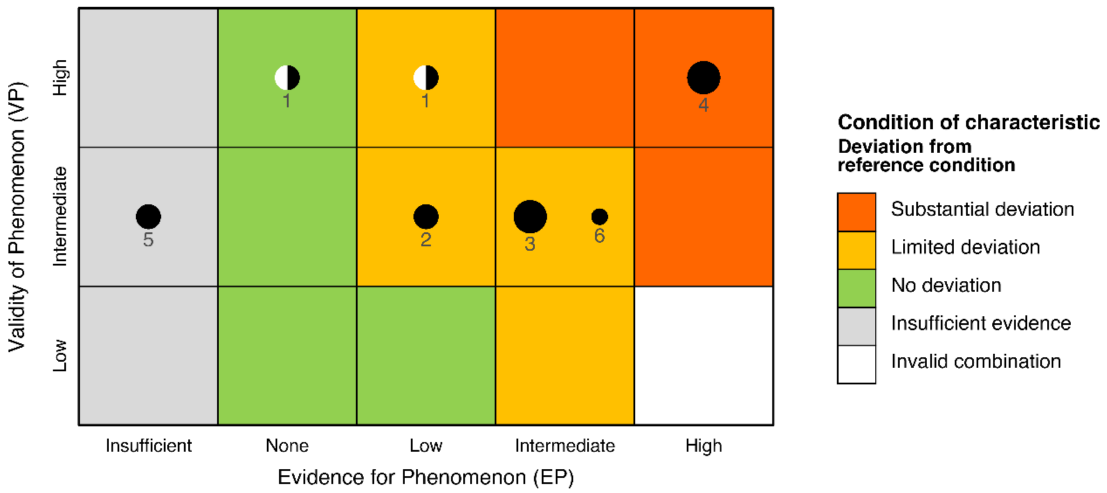


Figure 7.3.1. *An illustration of how the level of deviation from the reference condition is assessed for a single ecosystem characteristic based on the validity of (VP) and the evidence for (EP) its associated phenomena. The deviation from the reference condition is increasing with increasing evidence for change and increasing validity of the phenomena, e.g. along the diagonal from lower left to the upper right corner. Each circle represents a phenomenon with ID and the size of the circle indicating the data coverage (DC: larger symbols=better coverage). Phenomenon 1 has conflicting evidence for change (e.g. EP=None in one region, and EP=Low in another) and is hence shown by a split symbol. Phenomena which are scored as EP=Insufficient, should not be taken into account in the assessment, but are plotted to highlight phenomena for which data coverage and/or quality should be improved for future assessments. Note also that the lower right square, shown in white, is an invalid combination of VP and EP. The use of the category EP=High implies a good understanding of the implications of change in a given indicator for ecosystem condition. This is not compliant with the category VP=Low which implies a poor understanding of the role of the indicator in the ecosystem.*

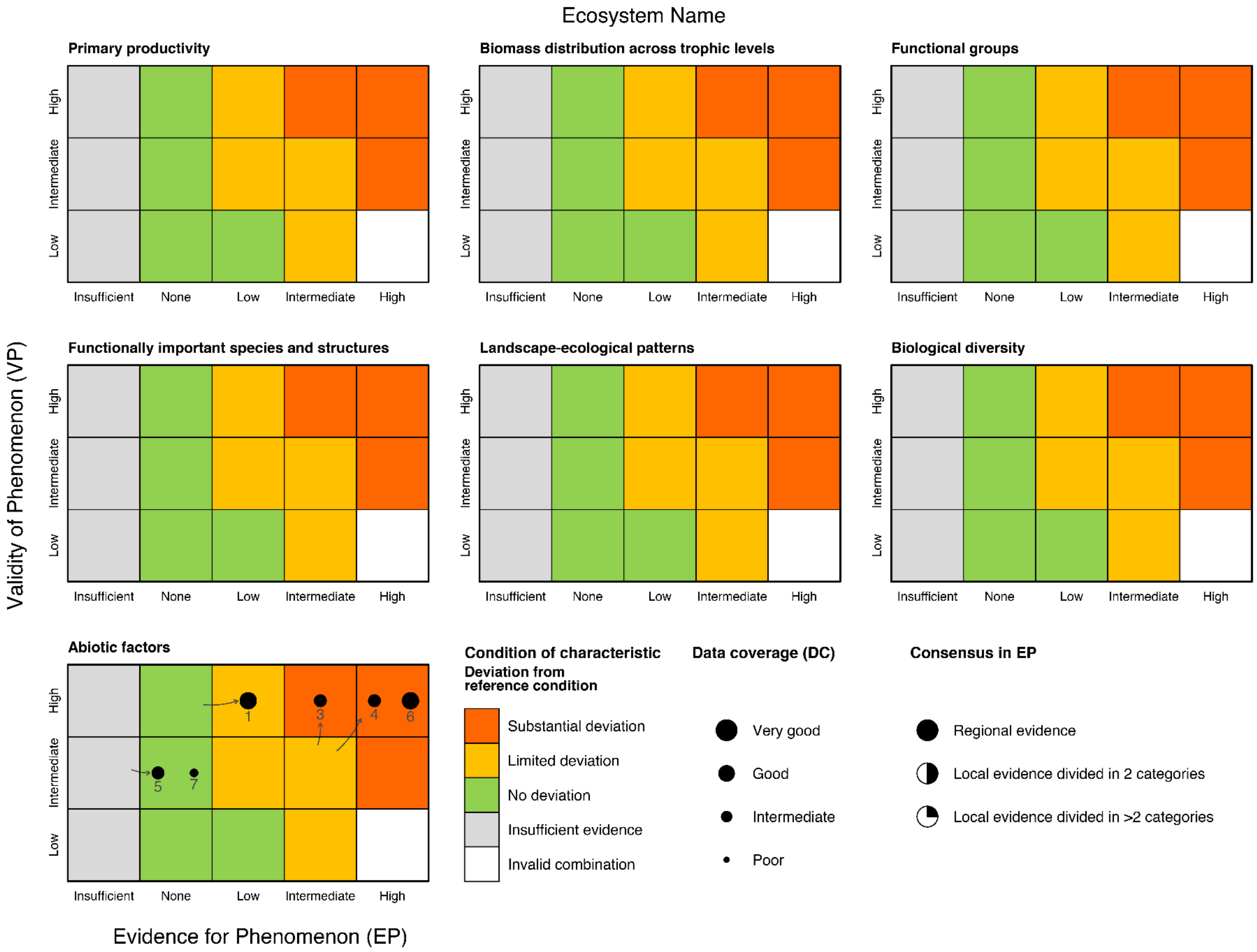

Ecosystem Name
Primary productivity
Biomass distribution across trophic levels
Functional groups
Functionally important species and structures
Landscape-ecological patterns
Biological diversity
Abiotic factors
High
Intermediate
Low
Insufficient
None
Low
Intermediate
High
Validity of Phenomenon (VP)
Evidence for Phenomenon (EP)
1
3
4
6
5
7
Condition of characteristic
Deviation from reference condition
Substantial deviation
Limited deviation
No deviation
Insufficient evidence
Invalid combination
Data coverage (DC)
Very good
Good
Intermediate
Poor
Consensus in EP
Regional evidence
Local evidence divided in 2 categories
Local evidence divided in >2 categories

Figure 7.3.2. *A joint graphical overview of how all phenomena for all ecosystem characteristics should be presented as an aid to the scientific panel for the textual assessment of each ecosystem characteristics as well as the assessment of the ecosystem as a whole. Each circle represents a phenomenon with ID and the size of the circle indicating the data coverage (DC: larger symbols=better coverage). Phenomena which are scored as EP=Insufficient, should not be taken into account in the assessment, but should be plotted to highlight phenomena for which data coverage and/or quality need to be improved for future assessments. Phenomena with conflicting evidence for change (for instance in different regions or data sources) can be given multiple values for EP and indicated by split symbols (local versus regional consensus in evidence). In case of repeated assessments, it is recommended to show any changes from the previous assessment by an arrow indicating the direction of change. For example, as shown for the ecosystem characteristic* Abiotic factors*, phenomenon 1 was assessed as EP=None in the previous assessment, but as EP=Low in the subsequent assessment. The layout of the figure can be adapted as relevant, for instance to include more than the seven ecosystem characteristics, used in the development of PAEC. See Appendix 5 for the R code and example data for producing this figure in R.*

7.3.2 Assessment of ecosystem condition

The assessment of ecosystem condition is closely based on the assessment of the condition of each ecosystem characteristic. It is a textual assessment which must contain the following:

- A short ingress which highlights the conclusion reached by the scientific panel regarding the condition of the ecosystem, beginning with a statement such as “Based on this assessment, the scientific panel concludes that….”.
- A section on the current state of knowledge of the reference condition. What is the base line of the assessment and how specific can we be when describing (or quantifying) this base line? This is particularly important if the reference condition is valued (e.g. “a pristine ecosystem”), or if it refers to a distant point in time (e.g. “preindustrial”).
- What are the main drivers of change in ecosystem condition in the system?
- How have these drivers changed over time?
- Which changes are observed in the ecosystem as a result of changes in the relevant drivers, and what is the level of evidence for observed changes?
- What are the primary gaps in data coverage and indicator coverage and what are the implications of these for the assessment?
- A graphical summary of the assessment for use in communication of the results (**Figure 7.3.3**).

If an assessment has been done previously, change in conclusions about the condition of the ecosystem from the previous assessment to the current one should be described. If the category of the overall conclusion has changed, it should be described how the assessments for the individual ecosystem characteristics have contributed to this. If the conclusion has not changed, a summary should still be given on important changes in assessments for the different ecosystem characteristics.

Ecosystem characteristic	Deviation from reference condition			Indicator coverage		
	No	Limited	Substantial	Inadequate	Partially adequate	Adequate
Primary productivity			●			●
Biomass distribution among trophic levels						
Diversity of functional groups		●→	→		●→	→
Functionally important species and biophysical structures						
Landscape ecological patterns						
Biological diversity						
Abiotic factors						

Figure 7.3.3. *The assessment of the condition of each ecosystem characteristic is summarized in a colour-coded table. The first time the ecosystem is assessed, the chosen category can be indicated by a single symbol/dot (see example for ecosystem characteristic* Primary productivity*).*

In the case of repeated assessments, any changes in assessment categories are indicated by an arrow showing the direction of change from the previous to the current assessment (see example for ecosystem characteristic Functional groups*). This table can be collated over multiple ecosystems, to provide a quick overview of the relative assessment of ecosystem characteristics. It is recommended to include evaluation of the indicator coverage in the same table to highlight assessments made on weaker or stronger grounds. See Appendix 4 for a full list of colour codes used in tables and figures.*

7.3.3 Future trajectories for ecosystem condition

This is a limited discussion of how the ecosystem is likely to change in the near future, given the observed changes in drivers and indicators. It should be substantiated by references to the scientific literature, and might take the following aspects as a point of departure:

- What is the likely future development in the main drivers, and what are the likely implications of this development for the ecosystem condition. This can be done for drivers which have a certain amount of predictability in their near-future trajectories, such as climate, land-use change, ocean acidification, nitrogen deposition, urban development etc.

- What is the potential for developing and using more complex statistical models of indicator dynamics as a function of drivers to develop near term forecasts[4] of likely future changes in the state of central indicators.

- What is known about latent effects in the ecosystem, meaning delayed responses in indicators or ecosystem condition which might occur in the future as a consequence of past changes in the drivers[5].

7.3.4 Recommendations for monitoring and research

The assessment is concluded by recommendations for further monitoring and research in order to strengthen the basis for future assessments of the ecosystem. It should address the following, as relevant:

- The primary data needs, including needs for inclusions of new prioritized indicators.

- Highlight key data sources used in the assessment which have uncertain or lack of funding in order to secure these in the future.

- Needs for research and development in order to strengthen the knowledge base of future assessments, including priorities. It is particularly important to address how the understanding of the effects of drivers on the indicators can be improved in order to increase the validity of phenomena and hence the degree of confidence in the assessments.

[4] *Sensu* Dietze et al. 2018, see also White et al. 2018 and Henden et al. 2020.
[5] Dullinger et al. 2012, Essl et al. 2015

8 Appendices

8.1 Appendix 1 Supplementary information on indicators

Appendix 1 should contain one to a few pages per indicator, and include the following sections where relevant:

Supplementary metadata
This section should contain supplementary metadata for the data set(s) underlying the indicator.

Supplementary methods
This section should contain supplementary methods for estimating indicator values and any threshold values used to assess quantitative phenomena, including their uncertainties.

Plots of indicator values
This section should contain plots of indicators (time series plots with trend analysis, or tables as relevant). The plots are central in the assessment of evidence for change. Additional information about the interpretation of the plots can be inserted here.

Background data and supplementary analysis
This section should contain plots of any additional background data used to calculate indicators, and supplementary statistical analysis of driver-response relationships for indicators showing large changes.

Recommendations for further development of the indicator
This section should contain specific recommendations regarding further development of the indicator or associated phenomena before the next assessment.

8.2 Appendix 2 Foot notes to Table 7.1

This appendix should contain footnotes documenting the assessment of the knowledge base made in **Table 7.1** often be too extensive to be placed at the bottom of the page.

8.3 Appendix 3 Previous assessment diagrams

In case of repeated assessments, the diagrams (Figure 7.3.2) from the previous assessment should be included here as documentation for the panel´s summary of the main changes between the previous and the current assessment.

8.4 Appendix 4 Colour codes for tables and figures

To ensure comparability between assessments made at different times and for different ecosystems, the following standardized use of colour codes in tables and figures is recommended.

	RGB: 217:217:217 HEX: #d9d9d9	RGB: 146:208:80 HEX: #92d050	RGB: 255:255:102 HEX: #ffff66	RGB: 255:192:0 HEX: #ffc000	RGB: 255:102:0 HEX: #ff6600
Validity of Phenomenon (VP)		High		Intermediate	Low
Evidence for Phenomenon (EP)	Insufficient	None	Low	Intermediate	High
Data coverage (DC)		Very good	Good	Intermediate	Poor
Indicator coverage (IC)		Adequate		Partially adequate	Inadequate
Condition of ecosystem attribute		No deviations from reference condition		Limited deviations from reference condition	Substantial deviations from reference condition

8.5 Appendix 5 R code for producing Figure 7.3.2

8.5.1 Example data

The R code below illustrates how the assessment figure (Figure 7.3.2) can be produced using data from either a single assessment, or from two repeated assessments of the ecosystem. It requires as input a data file with the following mandatory columns:

Characteristic: *Character*. The names of the ecosystem characteristics used in the assessment. In the example below seven ecosystem characteristics are used: *Abiotic factors*, *Primary productivity*, *Biomass distribution across trophic levels*, *Functional groups*, *Functionally important species and structures*, *Landscape-ecological patterns*, *Biological diversity.*
Year: *Integer*. The year of the assessment(s).
Ind: *Character*. Name of the indicator.
Phe: *Character*. Name of the phenomenon.
ID_Phe: *Character*. ID of the phenomenon. Can be consecutive numbers (eg. 1, 2, ..) or combination of letters and numbers (eg. P1, P2, ..).
DC: *Integer*. Data coverage. Scored to 1: poor, 2: good, 3: intermediate, 4: very good.
VP: *Integer*. Validity of Phenomenon: scored to 1: low, 2: intermediate, 3: high.
EP: *Integer*. Evidence for Phenomenon: scored to 0: insufficient, 1: none, 2: low, 3: intermediate, 4: high.
C: *Integer*. Consensus in EP. Scored to 1: regional evidence (i.e. consensus), 2: local evidence over 2 categories of EP, 3: local evidence over 3 or more EP categories. For phenomena where consensus is not = 1; the phenomenon will have several rows, one for each different value of EP.

Table 8.5. *Template showing the required structure of the input data file. Example data for six indicators, each with one associated phenomenon, are added for the ecosystem characteristic Abiotic factors for two repeated assessment years.*

Characteristic	Year	Ind	Phe	ID_Phe	DC	VP	EP	C
Abiotic factors	2000	Ind1	Phe1	1	3	3	1	1
Abiotic factors	2000	Ind2	Phe2	2	3	2	2	1
Abiotic factors	2000	Ind3	Phe3	3	3	2	3	1
Abiotic factors	2000	Ind4	Phe4	4	3	2	3	1
Abiotic factors	2000	Ind5	Phe5	5	2	2	0	1
Abiotic factors	2000	Ind6	Phe6	6	4	3	4	1
Primary productivity	2000	NA	NA	NA	NA	NA	NA	NA
Biomass distribution across trophic levels	2000	NA	NA	NA	NA	NA	NA	NA
Functional groups	2000	NA	NA	NA	NA	NA	NA	NA
Functionally important species and structures	2000	NA	NA	NA	NA	NA	NA	NA
Landscape-ecological patterns	2000	NA	NA	NA	NA	NA	NA	NA
Biological diversity	2000	NA	NA	NA	NA	NA	NA	NA
Abiotic factors	2020	Ind1	Phe1	1	4	3	2	1
Abiotic factors	2020	Ind2	Phe2	3	3	3	3	1
Abiotic factors	2020	Ind3	Phe3	4	3	3	4	1
Abiotic factors	2020	Ind4	Phe4	5	3	2	1	1
Abiotic factors	2020	Ind5	Phe5	6	4	3	4	1
Abiotic factors	2020	Ind6	Phe6	7	2	2	1	1
Primary productivity	2020	NA	NA	NA	NA	NA	NA	NA
Biomass distribution across trophic levels	2020	NA	NA	NA	NA	NA	NA	NA
Functional groups	2020	NA	NA	NA	NA	NA	NA	NA

Characteristic	Year	Ind	Phe	ID_Phe	DC	VP	EP	C
Functionally important species and structures	2020	NA	NA	NA	NA	NA	NA	NA
Functionally important species and structures	2020	NA	NA	NA	NA	NA	NA	NA
Functionally important species and structures	2020	NA	NA	NA	NA	NA	NA	NA
Landscape-ecological patterns	2020	NA	NA	NA	NA	NA	NA	NA
Biological diversity	2020	NA	NA	NA	NA	NA	NA	NA

8.5.2 R code

The following code first reads in a file with the assessment data formatted exactly as **Table 8.5**, then preprocess the data, produce legends, and finally plots the assessment diagram shown in **Figure 7.3.2**. If the assessment data contains results from two assessments (indicated by the column 'Year'), the position of the phenomena in the 2nd assessment year are plotted as circular symbols, and any changes in their position from the 1st to the 2nd assessment indicated by an arrow.

```
# ******* 1. LIBRARIES *********
rm(list = ls())

library(ggplot2)
library(scatterpie)
library(ggforce)
library(gridExtra)
library(grid)
library(ggnewscale)
library(flextable) #for smooth output of tables to word
library(officer) #for smooth output of tables to word

#*********END 1 ****************

# ******** 2. READ IN EXAMPLE DATA ********

eco <-  read.delim("Assessment_Data.txt", header=T, sep="\t", colClasses = c("character"
, "integer", rep("character", 3), rep("integer", 4)))
# Print example data file
ft<-flextable(eco)
ft<-set_table_properties(ft, width = .8, layout = "autofit")
ft<-width(ft, j=1,width = 1)
ft<-fontsize(ft, i = NULL, j = NULL, size = 9, part = "all")
ft

#********** END 2  ************************

# ********* 3. PRE_PROCESS DATA ***************

# Insert column with part of circle to be filled, and "complimentary" part
eco$part <- ifelse(eco$C==1, 100, ifelse(eco$C==2, 50, 25))
eco$partc<-100-eco$part
# Add a "group" variable, representing each scatterpie symbol
eco$group<-as.factor(seq.int(from = 1, along.with = eco$Phe))

# Different point sizes for each value of "Data coverage"
eco$pointsize <- ifelse(eco$DC==1, 0.03, ifelse(eco$DC==2, 0.06,
                 ifelse(eco$DC==3, 0.09, 0.12)))
# Add columns with all Data coverage and pointsize values for use in legend
eco$legend <- rep(1:4, len=length(eco$DC))
eco$legend.ptsize <- rep(c(0.03, 0.06, 0.09, 0.12), len=length(eco$DC))
```

```
# Vector of all characteristic, and split characteristics into separate data frames
Characteristic <- unique(eco$Characteristic)
ecos <- split(eco, eco$Characteristic)

# Adjust coordinates (EP and VP) to avoid overplotting
dst<-.25
for (i in 1:7) {
  avals <- unique(ecos[[i]]$EP)
  bvals <- unique(ecos[[i]]$VP)
  ecos[[i]]$ep_mod<-ecos[[i]]$EP
  ecos[[i]]$vp_mod<-ecos[[i]]$VP
  if (length(unique(ecos[[i]]$Year)) > 1) {
    ecos[[i]][ecos[[i]]$Year == min(ecos[[i]]$Year), "ep_mod"] <- NA
    ecos[[i]][ecos[[i]]$Year == min(ecos[[i]]$Year), "vp_mod"] <- NA
  }
  keeprows <- (!duplicated(ecos[[i]][,c("Year", "ID_Phe", "EP", "VP")]))
  ecos[[i]][!keeprows, "ep_mod"] <- NA
  ecos[[i]][!keeprows, "vp_mod"] <- NA
  for (k1 in seq_along(avals)) {
    for (k2 in seq_along(bvals)) {
      subk <- (ecos[[i]]$ep_mod==avals[k1] & ecos[[i]]$vp_mod==bvals[k2])
      subk <- replace(subk, is.na(subk), FALSE)
      if (sum(subk, na.rm=T)>1) {
        subdf <- ecos[[i]][subk,]
        angsk <- seq(0,2*pi,length.out=nrow(subdf)+1)
        ak <- subdf$EP+cos(angsk[-1])*dst
        bk <- subdf$VP+sin(angsk[-1])*dst
        ecos[[i]][subk,c("ep_mod","vp_mod")] <- cbind(ak,bk)
      }
    }
  }
  duprow <- duplicated(ecos[[i]][,c("Year", "ID_Phe", "EP", "VP")], fromLast = TRUE)
  ecos[[i]][!keeprows, "ep_mod"] <- ecos[[i]][duprow, "ep_mod"]
  ecos[[i]][!keeprows, "vp_mod"] <- ecos[[i]][duprow, "vp_mod"]
}

#********** END 3 ********************

#******* 4. LEGENDS ********************

# Colour categories legend
colorlegend_plot <- ggplot() +
  geom_rect(aes(xmin=c(1), xmax=c(1.4), ymin=c(0.75), ymax=c(1.15)), fill = "#FFFFFF", co
lor = "black") +
  geom_rect(aes(xmin=c(1), xmax=c(1.4), ymin=c(1.15), ymax=c(1.55)), fill = "#d9d9d9", co
lor = "black") +
  geom_rect(aes(xmin=c(1), xmax=c(1.4), ymin=c(1.55), ymax=c(1.95)), fill = "#92d050", co
lor = "black") +
  geom_rect(aes(xmin=c(1), xmax=c(1.4), ymin=c(1.95), ymax=c(2.35)), fill = "#ffc000", co
lor = "black") +
  geom_rect(aes(xmin=c(1), xmax=c(1.4), ymin=c(2.35), ymax=c(2.75)), fill = "#ff6600", co
lor = "black") +
  coord_fixed(xlim=c(0.9, 2.9), ylim=c(0.5, 3.5), clip = "off") +
  theme_bw() +
  annotate("text", x=c(1.5, 1.5, 1.5, 1.5, 1.5), y=c(0.95, 1.35, 1.75, 2.15, 2.55), label
=c("Invalid combination", "Insufficient evidence", "No deviation", "Limited deviation", "
Substantial deviation"), hjust=0, size=5) +
  annotate("text", x=1, y=3.4, label="Condition of characteristic", hjust=0, size=5.2, fo
ntface="bold") +
  geom_text(aes(x=1, y=3.1, label="Deviation from \nreference condition", lineheight = 0
.8), hjust=0, size=4.8, fontface="bold") +
  theme(panel.border = element_blank(),
        panel.grid.major = element_blank(),
```

```
        panel.grid.minor = element_blank(),
        axis.text.x=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank(),
        axis.ticks.x=element_blank(),
        axis.title.x=element_blank(),
        axis.title.y=element_blank())


# Data Coverage Legend
x_circle = rep(1, 4)
y_circle = c(1, 1.5, 2, 2.5)

dc_plot <- ggplot() +
  geom_circle(aes(x0=x_circle, y0=y_circle, r=unique(eco$legend.ptsize)), fill="black") +

  coord_fixed(xlim=c(0.5, 2), ylim=c(0.5, 3.5), clip = "off") +
  theme_bw() +
  annotate("text", x=c(1.3, 1.3, 1.3, 1.3), y=c(1, 1.5, 2, 2.5), label=c("Poor", "Interme
diate", "Good", "Very good"), hjust=0, size=5) +
  annotate("text", x=0.6, y=3.4, label="Data coverage (DC)", hjust=0, size=5.2, fontface=
"bold") +
  theme(panel.border = element_blank(),
        panel.grid.major = element_blank(),
        panel.grid.minor = element_blank(),
        axis.text.x=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank(),
        axis.ticks.x=element_blank(),
        axis.title.x=element_blank(),
        axis.title.y=element_blank())

# Consensus legend
cons <- data.frame(part = c(100, 50, 25),
                   partc = c(0, 50, 75),
                   x_circle = c(1, 1, 1),
                   y_circle = c(2.5, 2, 1.5))

consensus_plot <- ggplot() +
  geom_scatterpie(data=cons, aes(x = x_circle, y = y_circle, r=0.12),
                  cols = c("part", "partc")) +
  scale_fill_manual(values = c("part" = "black", "partc" = "white")) +
  coord_fixed(xlim=c(0.5, 4.5), ylim=c(0.5, 3.5), clip = "off") +
  theme_bw() +
  annotate("text", x=c(1.3, 1.3, 1.3), y=c(1.5, 2, 2.5), label=c("Local evidence divided
in >2 categories", "Local evidence divided in 2 categories", "Regional evidence"), hjust=
0, size=5) +
  annotate("text", x=0.8, y=3.4, label="Consensus in EP", hjust=0, size=5.2, fontface="bo
ld") +
  theme(panel.border = element_blank(),
        panel.grid.major = element_blank(),
        panel.grid.minor = element_blank(),
        axis.text.x=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank(),
        axis.ticks.x=element_blank(),
        axis.title.x=element_blank(),
        legend.position = "none",
        axis.title.y=element_blank())

# ******** END 4 ***************************

#********** 5. FUNCTIONS **************
```

```
# Function calculating arrow coordinates
arrow.function <- function(data, add_dist = 0.02) {
  arrowcoord_row <- c()
  arrowcoord_row <- data.frame(matrix(NA, ncol = 5, nrow = 1))
  colnames(arrowcoord_row) <- c("ID_Phe", "ep_start", "ep_end", "vp_start", "vp_end")
  x1 <- data$EP[data$Year == min(data$Year)]
  y1 <- data$VP[data$Year == min(data$Year)]
  x2 <- data$ep_mod[data$Year == max(data$Year)]
  y2 <- data$vp_mod[data$Year == max(data$Year)]
  # calculate sides of triangle btw center of points
  a <- abs(y1-y2)    # side parallel to y-axis
  b <- abs(x1-x2)    # side parallel to x-axis
  h <- sqrt(a^2+b^2) # distance btw points, hypotenuse
  # adding extra distance if arrow crosses label
  if (((y1-y2) < 0) & ((x1-x2)/(y1-y2) >= -1.2 & (x1-x2)/(y1-y2) <= 1.2)) {
    add_dist_label_end <- 0.13 # adjust value if necessary
  } else {
    add_dist_label_end <- 0
  }
  # distance from center of symbol or square to arrow
  d1 <- 0.36 + add_dist
  d2 <- data$pointsize[data$Year == max(data$Year)] + add_dist + add_dist_label_end
  # new coordinates based on conservation of proportions
  # a) distance from center of symbol
  # starting point: A1/a = B1/b = d1/h
  A1 <- (d1 * a) / h # y-axis, vp
  B1 <- (d1 * b) / h # x-axis, ep
  # ending point: A2/a = B2/b = d2/h
  A2 <- (d2 * a) / h # y-axis, vp
  B2 <- (d2 * b) / h # x-axis, ep
  # b) direction depend on relative position of start and end
  # arrow EP coordinates
  if (x1 < x2) {
    ep_start <- x1 + B1
    ep_end <- x2 - B2
  } else {
    if (x1 > x2) {
      ep_start <- x1 - B1
      ep_end <- x2 + B2
    } else {
      ep_start <- x1
      ep_end <- x2
    }
  }
  # arrow VP coordinates
  if (y1 < y2) {
    vp_start <- y1 + A1
    vp_end <- y2 - A2
  } else {
    if (y1 > y2) {
      vp_start <- y1 - A1
      vp_end <- y2 + A2
    } else {
      vp_start <- y1
      vp_end <- y2
    }
  }
  # add random number for horisontal and vertical arrows
  if (ep_start == ep_end) {
    ep_start <- ep_start + runif(1,-0.06, 0.06)
  }
  if (vp_start == vp_end) {
    vp_start <- vp_start + runif(1,-0.06, 0.06)
```

```
  }
  arrowcoord_row[1,1] <- data$ID_Phe[1]
  arrowcoord_row[1,2] <- ep_start
  arrowcoord_row[1,3] <- ep_end
  arrowcoord_row[1,4] <- vp_start
  arrowcoord_row[1,5] <- vp_end
  return(arrowcoord_row)
}

# ******** END 5 ******************

#********** 6. DATA FRAME WITH ARROW COORDINATES *************

add_dist <- 0.02 # set default distance btw symbol and arrow start/end

arrowframe <- c()
arrowframe <- data.frame(Characteristic = character(0), ID_Phe = character(0), ep_start =
 numeric(0), ep_end = numeric(0), vp_start = numeric(0), vp_end = numeric(0))

for (j in 1:7) {
  arrowcoord_v3 <-
    data.frame(Characteristic = character(0), ID_Phe = character(0), ep_start = numeric(0
),
      ep_end = numeric(0), vp_start = numeric(0), vp_end = numeric(0))
  if (!all(is.na(ecos[[j]]$EP))) {
    # allow plotting when some characteristics have no phenomena
    arrowcoord_v2 <- data.frame(ID_Phe = character(0), ep_start = numeric(0),
        ep_end = numeric(0), vp_start = numeric(0), vp_end = numeric(0))
    pids <- sort(unique(na.omit(ecos[[j]]$ID_Phe)))
    for (i in 1:length(unique(na.omit(ecos[[j]]$ID_Phe)))) {
      pid <- ecos[[j]][ecos[[j]]$ID_Phe %in% pids[i], ]
      if (length(unique(pid$Year)) > 1) {
        if (nrow(pid) == 2 && !((pid$EP[pid$Year == min(pid$Year)] == pid$EP[pid$Year ==
max(pid$Year)]) && (pid$VP[pid$Year == min(pid$Year)] == pid$VP[pid$Year == max(pid$Year)
]))) {
          arrowcoord_reg <- arrow.function(data = pid, add_dist = add_dist)
          arrowcoord_v2 <- rbind(arrowcoord_v2, arrowcoord_reg)
        } else {
          if (nrow(pid) > 2) {
            first <- pid[pid$Year == min(pid$Year),]
            last <- pid[pid$Year == max(pid$Year),]
             if (nrow(first) == 1) {
              first <- first[rep(row.names(first), nrow(last)),]
            } else {
              if (nrow(last) == 1) {
                last <- first[rep(row.names(last), nrow(first)),]
              } else {
                nkeep <- min(nrow(first), nrow(last))
                first <- first[1:nkeep,]
                last <- last[1:nkeep,]
              }
            }
            for (m in 1:max(c(nrow(first), nrow(last)))) {
              first_data <- first[m,]
              last_data <- last[m,]
              first_last <- rbind(first_data, last_data)
              if (!((first_last$EP[first_last$Year == min(first_last$Year)] == first_last
$EP[first_last$Year == max(first_last$Year)]) && (first_last$VP[first_last$Year == min(fi
rst_last$Year)] == first_last$VP[first_last$Year == max(first_last$Year)]))) {
                arrowcoord_loc <- arrow.function(data = first_last, add_dist = add_dist)
                arrowcoord_v2 <- rbind(arrowcoord_v2, arrowcoord_loc)
              } else {
                arrowcoord_samesq <- data.frame(ID_Phe = pid$ID_Phe[1], ep_start = NA,
```

```
            ep_end = NA, vp_start = NA, vp_end = NA)
                arrowcoord_v2 <- rbind(arrowcoord_v2, arrowcoord_samesq)
              }
            }
          } else {
            arrowcoord_samesq <- data.frame(ID_Phe = pid$ID_Phe[1], ep_start = NA,
            ep_end = NA, vp_start = NA, vp_end = NA)
            arrowcoord_v2 <- rbind(arrowcoord_v2, arrowcoord_samesq)
          }
        }
      } else {
        arrowcoord_oneyear <- data.frame(ID_Phe = pid$ID_Phe[1], ep_start = NA,
            ep_end = NA, vp_start = NA, vp_end = NA)
        arrowcoord_v2 <- rbind(arrowcoord_v2, arrowcoord_oneyear)
      }
      arrowcoord_v3 <- cbind(Characteristic = (rep(ecos[[j]]$Characteristic[1], nrow(arro
wcoord_v2))), arrowcoord_v2)
    }
  } else {
    arrowcoord_v3 <- data.frame(Characteristic = ecos[[j]]$Characteristic[1], ID_Phe = NA
, ep_start = NA, ep_end = NA, vp_start = NA, vp_end = NA)
  }
  arrowframe <- rbind(arrowframe, arrowcoord_v3)
  arrowframe$ep_start <- as.numeric(arrowframe$ep_start)
  arrowframe$ep_end <- as.numeric(arrowframe$ep_end)
  arrowframe$vp_start <- as.numeric(arrowframe$vp_start)
  arrowframe$vp_end <- as.numeric(arrowframe$vp_end)
}
# split into separate dataframes for each characteristic
arrowcoords <- split(arrowframe, arrowframe$Characteristic)

#********** END 6 ****************************

#************ 7. ASSESSMENT DIAGRAM   ***********
plot_list = list()

for (j in 1:7) {
  p <-  ggplot(data = ecos[[j]]) +
    # color background in figure
    geom_rect(aes(xmin=c(3.5), xmax=c(4.5), ymin=c(2.5), ymax=c(3.5)), fill = "#ff6600")
+
    geom_rect(aes(xmin=c(2.5), xmax=c(3.5), ymin=c(2.5), ymax=c(3.5)), fill = "#ff6600")
+
    geom_rect(aes(xmin=c(3.5), xmax=c(4.5), ymin=c(1.5), ymax=c(2.5)), fill = "#ff6600")
+
    geom_rect(aes(xmin=c(0.5), xmax=c(1.5), ymin=c(0.5), ymax=c(1.5)), fill = "#92d050")
+
    geom_rect(aes(xmin=c(1.5), xmax=c(2.5), ymin=c(0.5), ymax=c(1.5)), fill = "#92d050")
+
    geom_rect(aes(xmin=c(0.5), xmax=c(1.5), ymin=c(1.5), ymax=c(2.5)), fill = "#92d050")
+
    geom_rect(aes(xmin=c(0.5), xmax=c(1.5), ymin=c(2.5), ymax=c(3.5)), fill = "#92d050")
+
    geom_rect(aes(xmin=c(2.5), xmax=c(3.5), ymin=c(0.5), ymax=c(1.5)), fill = "#ffc000")
+
    geom_rect(aes(xmin=c(3.5), xmax=c(4.5), ymin=c(0.5), ymax=c(1.5)), fill = "#ffffff")
+
    geom_rect(aes(xmin=c(1.5), xmax=c(2.5), ymin=c(1.5), ymax=c(2.5)), fill = "#ffc000")
+
    geom_rect(aes(xmin=c(2.5), xmax=c(3.5), ymin=c(1.5), ymax=c(2.5)), fill = "#ffc000")
+
    geom_rect(aes(xmin=c(1.5), xmax=c(2.5), ymin=c(2.5), ymax=c(3.5)), fill = "#ffc000")
+
    geom_rect(aes(xmin=c(-0.5), xmax=c(0.5), ymin=c(0.5), ymax=c(1.5)), fill = "#d9d9d9")
```

```
 +
    geom_rect(aes(xmin=c(-0.5), xmax=c(0.5), ymin=c(1.5), ymax=c(2.5)), fill = "#d9d9d9")
 +
    geom_rect(aes(xmin=c(-0.5), xmax=c(0.5), ymin=c(2.5), ymax=c(3.5)), fill = "#d9d9d9")
 +
    # data most recent assessment year
    geom_scatterpie(data = subset(ecos[[j]], Year == max(Year)), aes(x = ep_mod, y = vp_m
od, group = group, r= pointsize), cols = c("part", "partc"), colour = NA) +
    scale_fill_manual(values = c("part" = "black", "partc" = "white")) +
    # labels of phenomenon IDs for recent assessment
    geom_text(data = subset(ecos[[j]], Year == max(Year)), aes(label = ID_Phe, x = ep_mod
, y = vp_mod - pointsize-0.02), size = 3, hjust=0.5, vjust=1, color="grey30")  +
    # arrows between same phenomenon in recent and previous assessment years
    geom_curve(data = arrowcoords[[j]], aes(x=ep_start, y=vp_start, xend=ep_end, yend=vp_
end), color = "grey30", arrow=arrow(length = unit(0.15, "cm"), type = "open"), angle = 90
, ncp = 10, curvature = 0.1) +
    # square grid lines
    geom_hline(yintercept = 1.5, size = 0.5) +
    geom_hline(yintercept = 2.5, size = 0.5) +
    geom_vline(xintercept = 0.5, size = 0.5) +
    geom_vline(xintercept = 1.5, size = 0.5) +
    geom_vline(xintercept = 2.5, size = 0.5) +
    geom_vline(xintercept = 3.5, size = 0.5) +
    # axes labels and titles
    scale_x_continuous(expand = c(0, 0), breaks = c(0, 1, 2, 3, 4), labels = c("Insuffici
ent", "None", "Low", "Intermediate", "High"), name = "Phenomenon Evidence (EP)") +
    scale_y_continuous(expand = c(0, 0), breaks = c(1, 2, 3), labels = c("Low", "Intermed
iate", "High"), name = "Phenomenon Validity (VP)", position = "left") +
    labs(subtitle = paste(unique(ecos[[j]]$Characteristic))) +
    # format diagram
    theme_linedraw(base_size = 18) +
    theme(panel.grid = element_blank(),
          legend.position="none",
          axis.ticks = element_blank(),
          axis.text.y = element_text(angle=90, vjust=0, hjust=0.5, size=12,
                                     margin=margin(l=10, r=5)),
          axis.title.y = element_blank(),
          axis.title.x = element_blank(),
          axis.text.x = element_text(margin=margin(b=5, t=5), size=12),
          plot.title = element_blank(),
          plot.subtitle = element_text(hjust = 0, size=14, face="bold")) +
    coord_fixed(xlim=c(-0.5, 4.5), ylim=c(0.5, 3.5), clip = "off")

  plot_list[[j]] = p
}

# save plot (Fig 7.3.2), add the name of your Ecosystem
png("Assessment_diagram.png", width=10000, height=7500, res=600, type = "cairo")
eco_list <- list(plot_list[[7]], plot_list[[3]], plot_list[[4]], plot_list[[5]], plot_lis
t[[6]], plot_list[[2]], plot_list[[1]], colorlegend_plot, dc_plot, consensus_plot)
grid.arrange(grobs = eco_list,  top=textGrob("Ecosystem name", gp=gpar(fontsize=20)), lef
t=textGrob("Validity of Phenomenon (VP)", gp=gpar(fontsize=20), rot=90),
  bottom=textGrob("Evidence for Phenomenon (EP)", x = 0.07, hjust = 0, gp=gpar(fontsize=2
0)),
  widths = c(2, 1, 1, 2),
  layout_matrix = rbind(c(1, 2, 2, 3),
                        c(4, 5, 5, 6),
                        c(7, 8, 9, 10)))

dev.off()

#******* END 7 ****************
```

9 References

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