Methods and set of criteria

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At present, there is no internationally accepted set of criteria for ecological impact assessments of alien species (see e.g. Verbrugge et al. 2010). The set of criteria used here has been developed specifically for this purpose (Sandvik et al. 2013, with some minor modifications). The development of the set of criteria aimed at *quantitative* and *generic* methods, and at risk categories that convey the *ecological impact* of a species in Norwegian nature (see Box 1).

The most important alteration compared to the set of criteria used in the previous Norwegian Black List 2007 (Gederaas et al. 2007), is that the new set of criteria is semi-quantitative. The set of criteria uses precisely defined threshold values, as also used in connection with Red Lists (IUCN 2001, Kålås et al. 2010). There are a number of advantages associated with quantitative as opposed to qualitative impact assessments. The most obvious is that the method reduces the subjectivity which is always a part of expert judgements. The result is therefore transparent, repeatable and testable. Decision-makers, interested parties or other experts can therefore easily verify the assessments that built the basis for the impact category of a given species. Quantitative assessments are also easily adjusted to newly acquired knowledge or potential corrections, as the end category is not based upon a subjective total assessment of the species, but upon independent criteria, which may be updated or corrected separately.

The main difference from other sets of criteria for impact assessment of alien species is that the Norwegian criteria are generic, i.e. they can be used for all groups of organisms (*taxa*). The impact categories are therefore comparable for fungi, insects, echinoderms etc.

The ecological impact of alien species in nature is proportional to the area that is colonised, to the density the species achieves within that area, and to the effect that an individual of the species has in Norwegian nature (Parker et al. 1999). As the exact area colonised is often unknown, especially when colonisation is not complete, area may be replaced with the species' invasion potential. Population density and per-capita effect can on the other hand be integrated into a measure of local ecological effect. The expected ecological *impact* can thus be defined as the product of *invasion potential* and ecological *effect* (see Box 22). As these two factors must be multiplied, and not added, if the ecological impact is to be quantified, a species will have a small impact whenever one of the factors are small, regardless as to how large the other factor is. For this reason, alien species' impact on Norwegian nature can best

Petasites hybridus
Photo: Åslaug Viken

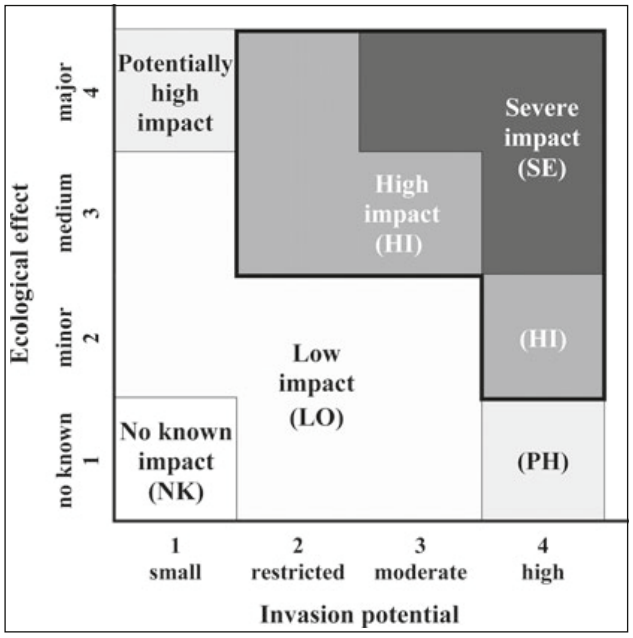

Figure 3. Impact categories for alien species are dependent upon their invasion potential and ecological effect. The system is based upon five impact categories (Table 1), dependent upon the interaction between invasion potential (Table 2) and ecological effect (Table 3). Species with a severe or high impact make up the Black List.

be portrayed as a two-dimensional figure, where impact is indicated by the species position along two axes – an invasion axis and an effect axis (Figure 3).

Classification of alien species into impact categories comprises nine criteria, of which three determine the species' invasion potential and six the ecological effect. Species are evaluated in relation to all criteria, and can on that basis be placed into four subcategories along each of the axes (Figure 3). A species' position along each axis is determined by those criteria which result in the highest subcategory. The species is then placed into one of the five following impact categories: *severe* (SE), *high* (HI), *potentially high* (PH), *low* (LO) or *no known* (NK) impact (Table 1; cf. Box 22). The following sections explain these criteria in more detail. The corresponding threshold values are shown in Tables 2 and 3.

Invasion axis

Alien species are classified along the invasion axis dependent upon whether they have a small, restricted, moderate or high invasion potential. Invasion processes can be split into two phases, which form the basis for one criterion each: establishment and expansion (Table

Box 22
Risk, impact and effect – an explanation of terminology used

A risk assessment does not only take into consideration the consequences of a future undesirable event, but also the probability of that event occurring. A risk might therefore be quite high, even though the probability for the event occurring is small, given that the consequences of such an event are great. Risk is therefore defined as the product of an event's consequences and probability. Events which are considered for alien species are their invasion of Norwegian nature (invasion axis in Figure 3 and subcategories in Table 2), their ecological effect (effect axis in Figure 3 and subcategories in table 3), and their impact on Norwegian nature (grey shaded areas in Figure 3 and final categories in Table 1). Both invasion potential, ecological effect and impact on Norwegian nature can all be understood as risks, i.e. they are separately determined by their respective consequences and probabilities. At the same time impact is defined as the product of invasion potential and ecological effect, something which can be expressed as:

$$\text{Impact} = \underbrace{\text{consequence of invasion} \cdot \text{probability of invasion}}_{\text{invasion potential (= risk of invasion)}} \cdot \underbrace{\text{consequence of effect} \cdot \text{probability of effect}}_{\text{(risk of) effect}}$$

$$= \underbrace{\text{consequence of invasion} \cdot \text{consequence of effect}}_{\text{consequence of impact}} \cdot \underbrace{\text{probability of invasion} \cdot \text{probability of effect}}_{\text{probability of impact}}$$

During the risk assessments of alien species, probability was taken into account by providing prediction or confidence intervals (see section on "Uncertainty"). Criterion documentation indicates the upper confidence limit, i.e. the greatest consequence resulting from invasion, effect or impact which might occur with reasonable probability.

Table 1. Impact categories for alien species. Assignment of species to these categories is according to Figure 3 and the criteria which are described in Tables 2 and 3 as well as in the main text. "Axis / axes" refer to the invasion and effect axes in Figure 3.

SE	Severe impact	Alien species with a severe impact are actually or potentially ecologically harmful species and have the potential to become established across large areas. These species are included in the Black List.
HI	High impact	Alien species with a high impact are characterized by a combination of a high subcategory along one axis and a intermediate category along the other. These have either restricted/ moderate ability to spread, but cause at least a medium ecological effect, or alternatively only a minor ecological effect but have a high invasion potential. These species are included in the Black List.
PH	Potentially high impact	Alien species with a potentially high impact have a maximum score along one axis, but a minimal score along the other. They have either high ecological effects combined with a low invasion potential, or a high invasion potential without any known ecological effect. These species are not included in the Black List.
LO	Low impact	Alien species with a low impact are not documented as having any substantial impact upon Norwegian nature. These species are not included on the Black List.
NK	No known impact	Alien species which achieve the lowest subcategory along both axes, have no known impact. These species are not included on the Black List.

Table 2. Subcategories, criteria and threshold values for classifying the invasion potential of alien species. Species are assessed according to all criteria (B_1 - B_3 are considered as one criterion), and the highest subcategory which satisfies at least one criterion, is chosen.

Criterion	A	B_1	B_2	B_3	C
Subcategory for invasion potential	Expected population lifetime[a]	Expansion velocity	Increase in area of occupancy	Increase in occurrences	Area of habitat type occupied
1: Small invasion potential	< min. (10 years, 5 generations)	< 0,3 km/year	≤ 0 % per year	≤ 0 % per decade	< 5 %
2: Restricted invasion potential	≥ min. (10 years, 5 generations)	≥ 0,3 km/year	> 0 % per year	> 0 % per decade	≥ 5 %
3: Moderate invasion potential	≥ min. (50 years, 10 generations) *AND* **B** ≥ **2**[b]	≥ 10 km/year *AND* **A** ≥ **2**[b]	> 1 % per year *AND* **A** ≥ **2**[b]	> 25 % per decade *AND* **A** ≥ **2**[b]	≥ 10 %
4: High invasion potential	≥ 1000 year *AND* **B** ≥ **3**[b]	≥ 30 km/year *AND* **A** ≥ **3**[b]	> 2 % per year *AND* **A** ≥ **3**[b]	> 50 % per decade *AND* **A** ≥ **3**[b]	≥ 20 %

Noter
a When the expected population lifetime is expressed in both years and generations, the one giving the shortest period is prevailing
b In order that categories A and B satisfy the two highest subcategories (3/4), the other criterion (B or A) must meet the conditions 2 or 3, respectively, for invasion potential. If these additional conditions are not met, the subcategory one step lower is chosen.

2). A third invasion criterion relates to the proportion of habitats that can be colonised.

A. *Expected population lifetime.* The greater the probability a species has for establishment, the higher it scores along the invasion axis. Establishment probability is here evaluated in terms of the species' expected population lifetime in Norway. Expected population lifetime is defined as the arithmetic mean time to extinction (see Sandvik et al. 2013). This method to specify establishment probability is closely related to extinction probability that is used in species Red Lists. Therefore, the A-criterion can be considered as a mirrored version of the E-criterion in Red Lists (IUCN 2001, Kålås et al. 2010): the greater the likelihood that an alien species has to become extinct in Norway (alternatively, the shorter the expected lifetime for the species in Norway), the less likely it will become established. The two measures can be readily converted into one another, e.g. expected lifetimes of 10, 50 and 1000 years (Table 2) imply extinction probabilities within 20 years of 86, 33 and 2 per cent, respectively. For species with short generation times these threshold values may be too high, and therefore the set of criteria operates with two alternative time scales – one indicated as years and the other as generations. Of these the shortest time interval shall be used (Table 2). There are different ways to estimate expected lifetime, and the set of criteria does not specify how this is accomplished in each individual case. One way is to use population viability analyses (Beissinger & McCullough 2002), which model a species' future population dynamics; another is numerical estimation (Sandvik 2011). The expected population lifetime of an alien species is affected by several factors, in particular population size and growth rate, but also by their variability (Lande et al. 2003). The population size of alien species is determined initially by the *propagule pressure,* i.e. the frequency of introductions and the number of individuals per introduction (Lockwood et al. 2005, Colautti et al. 2006, Blackburn et al. 2009). Growth rate is determined by the species' demographic

properties such as lifespan, age of maturity, fecundity etc. Variability is mainly due to demographic or environmental stochasticity (chance variation in mortality, fertility or sex ratio; cold winters, drought periods etc.). The advantage of using species' expected lifetime as a criterion is that it integrates several factors into one measure, and can therefore be used across a wide range of species with very different lifestyles and demography / life histories. Population lifetime – and consequently establishment probability – will be greater when the species has a large population, a high growth rate and/or a low demographic or environmental variance.

B. *Mean expansion rate.* – The greater a species' capability to spread, the higher its score will be along the invasion axis. Expansion is in this case defined as *any* form of movement or spread of the species, regardless as to which mechanisms, vectors or means of transport are involved. Expansion therefore includes not only "natural" spread via active movements or passive dispersal (e.g. with the aid of wind, water or animals), but also intentional or unintentional anthropological transport or separate introductions. Expansion capability may be specified in three different ways (Table 2), and it is sufficient that one of the three sub-criteria is assessed for a species:

B_1. *Expansion velocity.* – Expansion velocity is defined as the average speed of an actual or assumed invasion front, measured in kilometres per year from the first observation of the species or its reconstructed place of reintroduction and up to the invasion front. In accordance with the broad definition of expansion, expansion velocity is estimated on the basis of all observations of the species, even where these may be the result of separate introductions. This definition of expansion velocity might overestimate the species' "natural" dispersal rate, but provides an approximate description of the annual increase in the species' extent of occurrence (Sandvik & Sæther 2012).

B_2. *Increase in area of occupancy.* – Where expansion velocity is difficult to estimate, it can be replaced with a rough estimate of the increase in the species' area of occupancy. This increase is estimated as the annual growth rate of the area of occupancy (e.g. based upon a survival analysis; Skarpaas & Stabbetorp 2011, Skarpaas 2012).

B_3. *Increase in occurrences.* – Where there is too few data to estimate increase in area of occupancy, the increase in occurrences can be used instead. This is defined as the percentage change in total recorded occurrences per decade. Threshold levels differ from criterion B2, both because the period of time is longer and because the total number of occurrences is more variable.

C. *Area of habitat type occupied.* – This criterion measures the degree of colonisation of the various habitat types in which an alien species occurs. For each of the habitat types affected, it quantifies the percentage of the area of occupancy of the habitat type that will become colonised by the species in the course of 50 years. The criterion is used when this proportion exceeds a certain threshold for at least one habitat type (Table 2). The definition and boundaries of habitat types are in accordance with "Nature types in Norway" (Halvorsen et al. 2009. To be precise, major and basic types within the landscape element and ecological systems are assessed. In some cases a finer resolution can be used). It is expected that criterion C will seldom be a decisive criterion along the invasion axis, as criteria A and B will in most circumstances give a result long before criterion C. The criterion is included to take account of the fact that single, proportionately rare habitat types could become colonised (and affected) by an alien species which evades criteria A and B. This might for example be the case where an alien species is a specialist of a less common habitat type. Such a species might pose a threat towards that habitat type, even though the population lifetime and rate of spread are not known to be particularly high.

The placement of an alien species along the invasion axis is determined by the subcategory to which the species is assigned as the result of criteria A to C. The invasion potential is determined as a product – and not as the sum – of the establishment probability and the expansion rate. An alien species which is well established within a restricted area and which shows no sign of further spreading has low invasion potential. The same applies to alien species which experience numerous and regular introductions across the country, whilst the individual populations are not viable. Therefore, a species cannot achieve invasion categories 3 and 4 of criteria A and B unless the other criterion also exceeds a certain threshold. If this additional condition is not fulfilled, the subcategory which is one step lower is chosen (i.e. 2 instead of 3; 3 instead of 4). This takes into account that a species does not have a great invasion potential if it *only* has a high establishment probability or *only* has high expansion rate, whereas the other category is low. Criterion C does not interfere with A and B, as the intention is to take account of invasion of relatively rare habitat types, and its definition contains aspects of both establishment and expansion. A threat towards

Table 3. Subcategories, criteria and threshold values for classifying the ecological effect of alien species. Species are assessed according to all criteria, and the highest subcategory which satisfies at least one criterion, is chosen. (Bracketed information is not regarded as threshold value. The term "unlikely" thus leads to subcategory 1, whereas the next threshold value involves an effect leading directly to subcategory 3).

Criterion	D	E	F	G	H	I
	Documented or potential effect within 50 years* upon				Documented or potential transmission of	
	native species		habitat types			
Ecological effect subcategory	threatened/keystone	other	threatened/rare	other	genes	parasites or pathogens
1: No known effect	unlikely	little	unlikely	≥ 0 %	unlikely	unlikely
2: Minor effect	[unlikely]	weak	[unlikely]	≥ 5 %	[unlikely]	existing parasites to existing hosts such that prevalence increases
3: Medium effect	negligble	local displacement	> 0 %	≥ 10 %	to native species	existing parasites to novel hosts
4: Major effect	≥ weak	regional displacement	≥ 5 %	≥ 20 %	to threatened native species	existing parasites to novel threatened hosts OR of novel parasites

* or within five generations, if this is a longer time frame than 50 years (yet no more than 300 years).

rare habitat types alone can therefore give a result along the invasion axis, i.e. without "help" from the A- or B-criterion.

Effect axis

Alien species are classified along the effect axis depending upon whether they have no known effect, minor, medium or a major ecological effect in Norwegian nature. The more interactions an alien species has with a native species and the greater the change of state that the species causes to Norwegian habitat types, the higher its score along the effect axis (Table 3). The effects are considered over a 50-year perspective. This means that not only current effects are assessed, but also effects which, based upon documented knowledge on the alien species' biology, can be expected to occur within the next 50 years. For species with generation times of more than 10 years, a time horizon of 5 generations is used.

Interactions with native species include mainly competition with, predation upon and parasitism of wild native species, but can also include indirect effects (e.g. so-called apparent competition or trophic cascades; White et al. 2006). Only negative effects are taken into account; neutral and positive interactions (e.g. facilitation; Bruno et al. 2003) are not considered, as these do not pose any threat towards Norwegian nature. In principle, ecological effects can be quantified rather accurately (Laksa & Wootton 1998), e.g. by measuring the reduction in the growth rate of native species, carrying capacity, area occupied or extent of occurrence caused by an alien species. As such quantifications require extensive and time-consuming field studies (Doak et al. 2008, Novak & Wootton 2008), the set of criteria allows for a more subjective judgement of the effect upon native species. Effects upon native species are considered as unlikely if the species is not involved in negative interactions with native species; as negligible if the interactions with native species will not result in negative effects which are measureable at population level; and as weak if interactions reduce the growth rate or carrying capacity of native species, but without displacing species. Displacement is defined as a (potential) reduction of the area of occupancy or extent of occurrence of native species. Ecological interactions with native species are measured by two criteria:

D. *Effects on native threatened or keystone species.* – Any documented or likely negative ecological interaction with at least one native threatened species or native keystone species is automatically classified as at least a medium effect (i.e. subcategory 3). Threatened species here refers to vulnerable, endangered or critically endangered species according to the Norwegian Red List for Species 2010 (Kålås et al. 2010). Keystone species are species which, despite low amounts (measured in numbers or biomass), can have a great effect on the amount, distribution and diversity of other species.

E. *Effects on other native species.* – If none of the native species involved in interactions with the alien species is threatened or a keystone species, its effect is classified as weaker. To achieve a medium or major effect,

there must be documentation of, or likelihood for, displacement locally or regionally.

Alien species can also have negative effects at the landscape level, e.g. by altering vegetation stratification, overgrowing, and thinning of woodland or eutrophication of a waterbody. These effects can be measured in the habitat types affected as changes in condition along relevant ecoclines, i.e. as changes in the species composition or structure of a habitat (see "Nature types in Norway" for definition of habitat types, condition ecoclines and changes in condition; Halvorsen et al. 2009). A change in condition caused by an alien species is considered as *significant* if in the course of 50 years it amounts to at least one defined step along a condition ecocline. (In the case of changes in conditions that have already begun, changes need to be at least one step *more* than would have taken place without the presence of the alien species). The effect of an alien species is here quantified as the proportion of the habitat type's area of occupancy or extent of occurrence that is subjected to significant changes. Where several habitat types are affected by a species, the value for the habitat type with the greatest affected proportion of area is used.

F. *Effects on threatened or rare habitat types.* – Any significant change in conditions in at least one threatened or rare habitat type is automatically classified as having at least a medium effect (i.e. subcategory 3). By threatened habitat we mean vulnerable, endangered or critically endangered habitat types according to the Norwegian Red List for habitat types (Lindgaard & Henriksen 2011). By rare habitat types we mean habitat types that are near threatened due to few occurrences (i.e. on the basis of criteria 2 or 3 for red-listing of habitat types: Lindgaard & Henriksen 2011).

G. *Effects on other habitat types.* – If none of the habitat types that undergo state changes caused by alien species are threatened or rare, the effect is classified as weaker. Habitat types that are largely affected by human activities, such as constructed and artificial sites, are not considered.

The two remaining criteria deal with the transmission of genetic material or parasites.

H. *Transmission of genes (genetic introgression).* – If it is documented or likely that an alien species can transmit genes to native species (*introgression* e.g. by hybridising), it is automatically classified as having a medium effect (i.e. subcategory 3). If at least one of the native species affected is a threatened or keystone species, the effect is raised to "major".

I. Transmission of parasites or pathogens. – This criterion is used if it is documented or likely that an alien species can act as a vector for, i.e. transmit, parasites (including pathogens such as bacteria and viruses) to native species. If this transmission leads to an increased *prevalence* (occurrence) of existing parasites in a native species which already is a host for the same parasite, then the effect is classified as minor (i.e. subcategory 2). If the transmission affects a native species which was not previously a host for that parasite, then the alien vector is classified as having a medium effect (i.e. subcategory 3). The effect is upgraded to major (i.e. subcategory 4) under two conditions: If the alien species is a vector for a parasite not previously observed in Norway, or if at least one of the affected native species is a threatened or a keystone species.

The placement of an alien species along the effect axis is determined by the *highest* subcategory which the species obtains using criteria D to I. This is better than summing the various effects, which would underestimate the effect of a species that scores very high in one criterion, yet low in other criteria (Makowski & Mittinty 2010).

The effect axis is limited to identifying ecological effects. Anthropocentric effects of alien species, such as direct or indirect effects upon human health, economy or aesthetics, are deliberately excluded. This is because the aim of the set of criteria is a purely ecological impact assessment. Where knowledge on anthropocentric effects is available, this information is included in the species information, but is not used in the impact assessment itself.

Impact categories

The four subcategories along each axis provide the basis for 16 possible combinations of invasion potential and ecological effects (Figure 3). The position of a species in Figure 3 shows the risk to Norwegian nature posed by that species, and determines which of the five impact categories the species is placed in (Table 1). Species in the two highest impact categories (SE and HI) are included in the Black List.

Alien species with a potentially high impact (PH) have at present little influence on Norwegian nature, but are placed in their own impact category because their influence can increase, due to unforeseen changes. These changes might be evolutionary or ecological. Even though rapid evolutionary changes have been documented in several alien species (Cox 2004, Lavergne &

Molofsky 2007, Whitney & Gabler 2008), such changes cannot be predicted. The same applies to unexpected ecological interactions, especially indirect ones (White et al. 2006, Doak et al. 2008). The category PH (potentially high impact) is adopted to take into account and to highlight such unpredictability.

If the exact combination of subcategories is given, such information is added after the abbreviation: **HI:4,2** or **HI:2,3** show two high impact species, where the first one has a high invasion potential and minor effects, whereas the second has a restricted invasion potential and medium effects. This will be particularly relevant for species with potentially high impact, where **PH:1,4** and **PH:4,1** species will have different properties. Further, one can present the criterion which forms the basis for classification. For example, **HI:2(b1),4(egi)** indicates a species that has been classified as a high-impact species because it displaces native species, alters habitat types, transmits parasites and has a limited capability to spread; and similarly a species given as **H1:2(a),4(h)** falls under the same impact category due to hybridisation and the population's expected lifetime.

Documentation

A criterion has to be documented using published or available data in order to be considered as having been fulfilled. Quantitative assessments demand more thorough documentation than qualitative. Criteria documentation may consist of one specific, referenced number. It may on the other hand be a qualified estimate. Qualified estimates are not in contrast to a quantitative method, as long as they are documented and based upon numerical threshold values. Documentation may thus underpin that a value lies between two specified threshold levels, and does not necessarily have to present a single number.

For a number of species there will not be enough documentation on their invasion potential or ecological effects on Norwegian nature. This applies to 'door knockers', but also to many alien species which already occur in Norway, either because they are new, difficult to discoverer or merely poorly studied. If there is not enough good data available from Norway, then documentation should, in this order, be sought from:

- Data for the species in countries with ecoclimatic conditions comparable to those in Norway
- Data for the species in countries with ecoclimatic conditions different to those in Norway,
- Data from closely related species with comparable lifestyles and demography.

For most species, only part of the population, area of occupancy and extent of occurrence in Norway will be known. Therefore, to assign a level of uncertainty is an important part of the impact assessment. This level of uncertainty is the factor used for adjusting known occurrences in relation to supposed occurrences, or an estimate of how large a part of the Norwegian population where we do not know the occurrence. This is a percentage and is estimated by combining knowledge of a species' habitat requirements and known occurrences in Norway with knowledge of area of occupancy of relevant habitats. For small organisms with a discreet way of life, the level of uncertainty may be many times higher than the known part of the population. The degree of uncertainty may illustrate knowledge gaps about a species' occurrence in Norway.

Uncertainty

The classification system for alien species does not operate with a category for data deficiency (as in "DD" in the Red List). There are several reasons for this. First, uncertainty is not either/or, but rather a question of degree, and should therefore be included in the impact assessment, and not be separated from it as a category in its own right. There are several ways to take uncertainty into account. For numerical estimates (such that e.g. are required for criteria along the invasion axis) one can assign uncertainty as prediction intervals or as confidence intervals. If the lower and upper confidence limits lie within the same thresholds, then this subcategory is chosen. However, if the confidence intervals cover span over several subcategories, then the highest of these applies. (With an estimated rate of spread of 5 ± 4 km per year, the whole confidence interval lies within subcategory 2. If however the rate of spread is estimated to be 9 ± 2 km per year, the confidence interval includes subcategories 2 and 3, such that subcategory 3 is assigned; cf. Table 2.). This approach combines a precautionary principle with scientific requirements of testability and documentation.

Whenever it is not possible to calculate confidence intervals, the available knowledge can be used to give likely and documented extremes for this parameter. These are treated in the same way as confidence intervals.

Another reason to deviate from the Red List system's data deficient category is that lack of data has different

meanings for threatened than for invasive species. If one has little or no documented knowledge about a species, this is often due to its rareness. All else being equal, this makes it more likely that the species is threatened with extinction, but is also less likely that it is invasive. When documentation about invasion potential or ecological effect is lacking, a species will be classified as having "no known impact". This does not necessarily mean that a species will not have an effect on Norwegian nature, but merely that no knowledge is available that suggests this. Even though such an assessment may later be shown to have been erroneous and require a revision, it is merely likely that the species will present a high or severe impact, as in this case one would expect that there was documentation available from other countries.