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Alien species and the Water Framework Directive: Recommendations for assessing ecological status in fresh waters in Norway

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Abstract

1. Invasive alien species are recognized as a significant anthropogenic threat to freshwater ecosystems, because they may bring about the local extinction of native species and the collapse of habitat types of special conservation concern.
2. The Water Framework Directive (WFD) is an important legislative tool for the protection of water bodies in the European Union. It requires the assessment of the ecological status of water bodies and the enforcement of measures for water bodies that fail to achieve at least 'good' ecological status. However, the WFD does not explicitly mention alien species.
3. This article presents a three-tiered approach for the incorporation of data on alien species into WFD assessments of freshwater bodies in Norway. If relevant data on WFD parameters are available for the water body under consideration, its ecological status should be inferred from those data. Otherwise, ecological status should be assessed using evidence of the effects that the alien species have on biological quality elements in comparable water bodies. If neither of these options is feasible, the ecological status should be classified according to the ecological effect score of the alien species present, as obtained from the Generic Ecological Impact Assessment of Alien Species (GEIAA).
4. It is further recommended that a water body cannot be assigned 'high ecological status' if at least one alien species is present. If more than one alien species is present, the status is determined by the species with the highest impact.
5. Ecological, geographical, historical, and taxonomic delimitation criteria for this assessment method are presented, together with a list of the alien species that at present fulfil these delimitations in Norway.
6. The management implications of the recommendations are that more Norwegian freshwater bodies are likely to require measures, and that further data must be collected. Most of the recommendations are transferable to other countries, although they may require adjustment.

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KEYWORDS
dispersal, ecological impact, freshwater bodies, invasive alien species, lakes, rivers

1 | INTRODUCTION

Globally, the human introduction of alien species is regarded as one of the most important threats to naturally occurring biodiversity (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019). The huge potential of alien species to impair the ecological status of freshwater bodies has long been recognized (Arbačiauskas et al., 2008; MacNeil et al., 2010; Vandekerkhove, Cardoso & Boon, 2013; Gallardo et al., 2016; Magliozzi et al., 2020), and can be illustrated by three examples. Canadian waterweed (*Elodea canadensis*), which was introduced into Norway in 1925, has been unintentionally spread and is rapidly colonizing new water bodies, where it outcompetes native macrophytes (Mjelde et al., 2012), resulting in eutrophication and reductions in water quality (Sarvala, Helminen & Heikkilä, 2020). Canadian waterweed has become established in a Norwegian Ramsar site (Nordre Tyrifjord Wetlands System, Ramsar site no. 802) and is listed as a threat. Signal crayfish (*Pacifastacus leniusculus*) was first recorded in Norway in 2006 and has become established in several watercourses as a result of illegal translocation (Johnsen et al., 2021). It threatens the endangered native noble crayfish (*Astacus astacus*; Johnsen et al., 2019), primarily by infecting it with crayfish plague (*Aphanomyces astaci*; Vrålstad et al., 2011), but also through competition (Westman, Savolainen & Julkunen, 2002). Northern pike (*Esox lucius*) is a species native to parts of Norway but has been translocated by fishers to hundreds of new water bodies (Huitfeldt-Kaas, 1918; Hesthagen & Sandlund, 2016). In many cases it has led to the local extinction of native species, such as brown trout (*Salmo trutta*; Hesthagen et al., 2015).

Although the European Union (EU) (2014) regulation on the management of alien species does not apply to Norway, Norwegian authorities have passed corresponding regulations and have adopted a biodiversity action plan and targeted strategies that explicitly aim to reduce the introduction, spread, and impact of alien species (Miljøverndepartementet, 2007; Klima- og miljødepartementet, 2015a; Klima- og miljødepartementet, 2015b; Klima- og miljødepartementet et al., 2020). Norwegian freshwater ecosystems typically contain comparatively few species, and the Norwegian government has a special responsibility, therefore, to protect such naturally species-poor ecosystems. For instance, alpine 'naturally fishless lakes' are mentioned as a 'prioritized nature type' in the Norwegian biodiversity action plan (Klima- og miljødepartementet, 2015b), owing to their unique invertebrate biodiversity. These are threatened by the intentional or unintentional introductions of alien fish species.

The effective management and conservation of freshwater resources is a fundamental global challenge in the 21st century (Jury & Vaux, 2005). Since the year 2000, the Water Framework Directive (WFD) has been an important legislative instrument for the protection and sustainable use of water in the EU (Council of the European Communities, 2000). The aim of the WFD is the protection of inland surface waters (rivers and lakes), transitional waters, coastal waters, and groundwater. This includes the aims of preventing and reversing the deterioration of the ecological status of aquatic ecosystems, promoting sustainable water use, and reducing the pollution of surface water.

The WFD requires the ecological status for each water body to be assessed using a holistic approach that combines biological indicators and hydromorphological and physico-chemical parameters. Following standardized guidelines, ecological status is classified as 'high' (corresponding to reference conditions), 'good', 'moderate', 'poor', or 'bad'. The ecological status of a water body can only be classified as 'high' if none of the biological quality elements are more than slightly altered from their reference condition. The four biological quality elements for freshwater habitats are phytoplankton, macrophytes/phytobenthos, benthic invertebrate fauna, and fish fauna, which are assessed according to abundance, composition, diversity, and age structure (for fish only). In addition to the biological quality elements, hydromorphological, chemical, and physico-chemical variables are described as 'supporting' quality elements, measured to describe environmental conditions, where the values of each element should also lie within the values of the reference conditions to achieve high ecological status.

The ecological status of a water body, as described in the WFD, is not strictly equivalent to, but overlaps with, the nature conservation value of the water body. First, by defining ecological status in terms of departure from naturalness (i.e. with the reference state reflecting undisturbed conditions), the WFD identifies one key component of conservation value, although it does not address others, such as rarity or representativeness (Boon, 2012). Second, the objective for the WFD is to achieve at least good status for all EU water bodies, and to prevent the deterioration of water bodies, including those with high status. Each member state is required to produce river basin management plans and to monitor water bodies to ensure that their status is in line with the WFD objectives. For water bodies that do not meet the objectives, recovery plans or 'programmes of measures' need to be put in place. The original deadline to achieve these ambitious goals was first set for 2015. The deadline was later extended to 2021 and subsequently to 2027.

Although the WFD does not explicitly mention alien species, they are generally assumed to be covered by 'other significant anthropogenic impacts on the status of surface waters' (Council of the European Communities, 2000; IMPRESS, 2003; Shine et al., 2008; Filipe et al., 2019). In addition, biological quality elements can only attain high status when 'the taxonomic composition corresponds totally or nearly totally to undisturbed conditions' (Council of the

European Communities, 2000). By definition, alien species change the taxonomic composition of the water bodies that they colonize. The invasion of an alien species can also influence the biological quality elements directly, such as through competition or predation. Alien species can even affect hydromorphological, chemical, and physico-chemical characteristics, for instance by altering the structure of a lake shore or increasing the biogeochemical cycling of nutrients.

As the WFD does not mention alien species, how (and indeed whether) alien species are taken into account in assessments of ecological status vary widely among EU member states (Boon, Clarke & Copp, 2020). Aspects that differ include the definition of alien species, which species should be considered (all alien species or only those with a high impact), whether 'translocated' native species should be included, the use of historical criteria (i.e. whether alien species should be considered only when introduced after a certain year), and how information on alien species and their effects should be incorporated in WFD assessments (Boon, Clarke & Copp, 2020).

Norway, although not an EU member state, follows the WFD through the adoption of national regulations (Miljøverndepartementet, 2006). So far, Norway has no coherent guidelines on dealing with alien species in freshwater habitats. The overall objective of this article is to present recommendations on how the effect of alien species should be accounted for when classifying the ecological status of freshwater bodies in Norway. More specifically: (i) we provide unambiguous delimitations for the subset of alien species that should be considered in the context of WFD assessments; (ii) we present an updated list of the alien species fulfilling these delimitations in Norway; (iii) we develop a decision tree for incorporating the effect of alien species into assessments of the present ecological status of freshwater bodies; (iv) we give recommendations on how to evaluate the risk that alien species may cause the future degradation of water bodies; and (v) we address the question of whether and how to incorporate terrestrial alien species on river banks and lake shores into WFD assessments. These recommendations have previously been reported to the Norwegian Environment Agency (Sandvik et al., 2020c).

2 | MATERIALS AND METHODS

Following guidance from the International Union for Conservation of Nature (IUCN) (2000) and Norwegian practice, an alien species is defined here as 'a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans)', including 'any part, gametes or propagule of such species that might survive and subsequently reproduce' (Sandvik, Gederaas & Hilmo, 2017). All alien species known to be reproducing in the wild in Norway without external aid are recorded and their impact assessed by the Norwegian Biodiversity Information Centre (NBIC), according to the Generic Ecological Impact Assessment of Alien Species (GEIAA) protocol (Sandvik et al., 2019a). The current study used data from the inventory and impact assessments that were finalized in 2018. These data are available from an online database (Artsdatabanken, 2018) and through published articles on the inventory (Sandvik et al., 2019b), as well as from the impact assessments (Sandvik et al., 2020a; Sandvik et al., 2020b).

The present methodology used to evaluate how alien species affect the ecological status of freshwater bodies in Norway is described in two guidelines (Direktoratsgruppen, 2018a; Direktoratsgruppen, 2018b). The paragraphs mentioning alien species in these guidelines were identified and evaluated. The recommendations presented in this article are intended as improvements to these guidelines. Information collected about Norwegian water bodies under the WFD is available online (NVE & Miljødirektoratet, 2020).

In addition, a method is presented that can be used to evaluate the effects of introducing some selected alien fish species into lakes with allopatric brown trout (cf. Hesthagen et al., 2012; Hesthagen & Sandlund, 2013). The method is based on expert judgement, using available knowledge on the effects caused by alien species. Lakes were grouped into 11 types according to surface area and mean depth.

3 | CRITERIA FOR DETERMINING WHICH ALIEN SPECIES SHOULD BE CONSIDERED

As a prerequisite for a standardized assessment methodology, it is important that there is no ambiguity about the taxa to which it applies. Rather than specifying a list of alien species of WFD concern, we recommend a unified treatment for all alien species that fulfil certain testable delimitation criteria. The definition of alien species (see section 2) is so broad that it needs to be made operational by a set of criteria that define the ecological, geographical, historical, and taxonomic delimitations. If one of the criteria is not met, a taxon is either ignored or treated as if it were native, even though it may meet the definition of an 'alien species'.

3.1 | Ecological delimitation criteria

According to the WFD, in order to be considered an 'anthropogenic impact on the status of surface waters' an alien species has to meet at least one of the following two criteria: (i) the species belongs to one of the biological quality elements of the WFD; or (ii) the species affects at least one of the biological quality elements of the WFD and has a lasting association with specific water bodies.

The WFD specifies four biological quality elements for freshwater bodies (see section 1). In Norway, microcrustaceans (cladocerans and copepods) are included in the invertebrate quality element, owing to a long tradition of including microcrustaceans in national monitoring and quality assessment in Norway, and because macroinvertebrates have naturally very low densities and diversities in many Norwegian lakes.

Alien species that belong to a quality element are included by default as, for example, competition with native members of the same quality element may be expected. However, species not included in any quality element may also adversely affect native biota. For example, *Gyrodactylus salaris*, a monogenean flatworm, does not belong to any quality element, but is a fish parasite that has a major effect on its host species, the Atlantic salmon (*Salmo salar*). On the other hand, some species may have detrimental effects on native biota, while at the same time visiting specific water bodies for shorter time periods only. Examples of the latter case are alien species of waterfowl, such as the Canada goose (*Branta canadensis*). As irregular visitors, such species should not be included in assessments of ecological status.

3.2 | Geographical delimitation criteria

The definition by IUCN (2000) of an alien species does not specify any minimum distance by which a species has to be relocated anthropogenically in order to be regarded as alien. A rather obvious category of species encompasses those that have been introduced across national borders, which may be referred to as 'nationally alien species'. We recommend that species translocated within a country ('translocated native species' *sensu* Boon, Clarke & Copp, 2020), here referred to as 'regionally alien species', should be managed in the same way, given that they have been introduced anthropogenically to a water body outside their natural range and dispersal potential.

3.3 | Historical delimitation criteria

Several countries treat alien species as if they were native when the introduction happened before a specified year (Boon, Clarke & Copp, 2020): for example, the year 1900 in Estonia and Spain, the year 1800 in Sweden, or the year 1492, as a common demarcation between archaeophytes/archaeozoans and neophytes/neozoans (rounded up to the year 1500 in Belgium and Italy). Current practice in Norway is a historical delimitation of 'circa 1900' (Direktoratsgruppen, 2018a), whereas NBIC uses 1800 for its impact assessments (Sandvik et al., 2020a).

An anthropogenically introduced population remains alien (by definition), no matter when the introduction event took place. From an ecological perspective it is not possible to establish a year before which an introduction somehow has less effect. Any introduction (as well as any natural colonization by a new species) results in a new dynamic equilibrium among the members of the local ecological community that differs to some degree from the previous dynamic equilibrium. The passage of time does not normally affect the nature of this change. As it does not constitute a testable hypothesis, a historical delimitation is thus not a scientific statement but mere convention. However, there may be good pragmatic reasons for a historical delimitation. For instance, the certainty that an occurrence is the result of human introduction will decrease with the length of time elapsed since the (suspected) introduction event. In the absence of ecological criteria, no specific year is recommended; it should be emphasized that it is advantageous to use the same historical delimitations for WFD assessments as for impact assessments of alien species (which is the year 1800 in Norway).

3.4 | Taxonomic delimitation criteria

The assessment guidelines presented here are only meant to cover alien taxa that are classified as 'species'. This should not be taken to imply that human introduction or translocation of subspecific taxa (such as subspecies, varieties, forms, etc.) is free from ecological problems. On the contrary, it is well known, for example, that escaped farm salmon can have devastating effects on wild salmon populations (Bolstad et al., 2017; Glover et al., 2017). The exclusion of subspecific taxa only means that such problems are not addressed in this article.

4 | DELIMITATION RESULTS

4.1 | Nationally alien species

At present, 34 nationally alien species are known to occur in fresh waters in Norway and fulfil the delimitation criteria outlined earlier (Table 1). Approximately half of these species are currently listed as impacts in the WFD reporting system in Norway: all fishes (11 species), two plant species, two disease organisms, and one crustacean. An application of the criteria specified in section 3 thus implies that an additional 18 species should be included in the reporting system (those marked as NA in the 'Water body' column of Table 1). Several of these species have a rather restricted occurrence, e.g. 11 species with 10 or fewer occupancies (where an 'occupancy' is defined as a colonized 2 km $\times$ 2 km grid cell, i.e. the counting unit of the 'area of occupancy', or 'AOO', as defined by IUCN, 2022). In addition, for two species (the sweetgrass *Glyceria maxima* and the copepod *Moraria sphagnicola*), most or all known occurrences are in moist terrestrial habitats rather than in freshwater bodies (Table 1). So far, therefore, they do not affect the ecological status of any Norwegian water body, but may do so in future.

Five of the additional species are fish parasites (Table 1). Whereas *Anguillicoloides crassus* and the two species of *Pseudodactylogyrus* are parasites of the European eel (*Anguilla anguilla*), which is a native species, the two species of *Onchocleidus* have been reported only from pumpkinseed (*Lepomis gibbosus*), which is alien to Norway.

4.2 | Regionally alien species (translocated native species)

No full inventory of regionally alien species is available for Norway. The 10 species for which impacts have been assessed and/or

TABLE 1 Nationally alien freshwater species in Norway. The table is an exhaustive list of all nationally alien species known to occur in freshwater environments of Norway and to fulfil the delimitation criteria outlined in this article. The information provided includes: the year of the first record of reproducing individuals in Norway; the number of water bodies in Norway for which the species has been reported as an impact according to the WFD (species not included in the reporting system are indicated by 'NA'); the best available estimate of the total area of occupancy (AOO) in Norway; the ecological impact category (NK, no known impact; LO, low impact; PH, potentially high impact; HI, high impact; and SE, severe impact); and the scores for invasion potential and ecological effect (ranging from 1 to 4). Except for the number of water bodies (which was based on NVE & Miljødirektoratet, 2020), the information was obtained from the most recent ecological impact assessment of alien species in Norway (Artsdatabanken, 2018; Sandvik et al., 2020b)

Scientific name	Common name	Year establ.	Water bodies	AOO (km^2)	Ecol. impact	Inv. pot.	Ecol. effect
Actinopterygii							
Ameiurus nebulosus	Brown bullhead	1890	1	80	LO	2	1
Carassius auratus	Goldfish	1870	9	180	HI	4	2
Cyprinus carpio	Common carp	1840	27	400	HI	4	2
Gobio gobio	Gudgeon	1991	4	180	LO	2	1
Lepomis gibbosus	Pumpkinseed	2004	9	48	LO	2	1
Leucaspius delineatus	Sunbleak	1997	3	20	LO	2	1
Oncorhynchus gorbuscha	Pink salmon	1958	55	1,300	HI	4	2
Oncorhynchus mykiss	Rainbow trout	1910	23	1,900	HI	4	2
Salvelinus fontinalis	Brook trout	1883	49	3,200	LO	2	1
Salvelinus namaycush	Lake trout	1971	21	220	LO	3	2
Tinca tinca	Tench	1810	56	2,000	HI	3	3
Amphibia							
Pelophylax esculentus	Edible frog	2003	NA	32	SE	4	4
Crustacea							
Crangonyx pseudogracilis	–	2012	NA	8	LO	2	1
Daphnia ambigua	–	2004	NA	40	PH	1	4
Moraria sphagnicola[a]	–	2010	NA	400	LO	2	1
Pacifastacus leniusculus	Signal crayfish	2008	7	88	SE	4	4
Proasellus coxalis	–	2012	NA	144	NK	1	1
Magnoliophyta							
Elodea canadensis	Canadian waterweed	1925	72	2,400	SE	4	4
Elodea nuttallii	Western waterweed	2005	4	60	SE	3	4
Glyceria maxima[a]	Reed sweetgrass	1827	NA	2,500	HI	3	3
Stratiotes aloides	Water pineapple	1995	NA	16	PH	1	4
Marchantiophyta							
Ricciocarpos natans	–	1976	NA	144	PH	4	1
Mollusca							
Bithynia tentaculata	Mud bithynia	2002	NA	16	LO	2	1
Planorbarius corneus	Great ramshorn	1897	NA	56	LO	2	1
Planorbis carinatus	–	1900	NA	24	LO	2	1
Potamopyrgus antipodarum	NZ mud snail	1954	NA	3,800	SE	4	4
Viviparus viviparus	–	1853	NA	60	LO	2	1
Monogenea							
Gyrodactylus salaris	Salmon fluke	1975	99	250	SE	3	4
Onchocleidus dispar	–	2005	NA	8	LO	2	1
Onchocleidus sp.	–	2005	NA	8	LO	2	1
Pseudodactylogyrus anguillae	–	1996	NA	16	HI	3	3
Pseudodactylogyrus bini	–	1997	NA	8	HI	3	3
Nematoda							
Anguillicoloides crassus	–	2008	NA	1,600	SE	3	4

(Continues)

TABLE 1 (Continued)

Scientific name	Common name	Year establ.	Water bodies	AOO (km^2)	Ecol. impact	Inv. pot.	Ecol. effect
Oomycetes							
Aphanomyces astaci	Crayfish plague	1971	32	260	SE	4	4

[a]For two species, most or all records were from terrestrial habitats rather than freshwater bodies.

TABLE 2 Selected regionally alien freshwater species in Norway. This list of species is not exhaustive: it incorporates only the regionally alien species that have been impact assessed and/or that are currently included in the WFD reporting system of Norway

Scientific name	Common name	Water bodies	AOO (km^2)[a]	Ecol. impact[b]	Inv. pot.[c]	Ecol. effect[d]
Actinopterygii						
Carassius carassius	Crucian carp	NA	1,700	LO	2	2
Coregonus albula	Vendace	NA	220	LO	2	1
Esox lucius	Northern pike	178	1,500	SE	4	3
Phoxinus phoxinus	European minnow	1,295	5,700	SE	4	4
Rutilus rutilus	Roach	24	860	HI	3	3
Sander lucioperca	Zander	2	NA	NR	–	–
Scardinius erythrophthalmus	Rudd	73	680	SE	4	3
Crustacea						
Heterocope borealis	–	NA	240	LO	1	2
Mysis relicta	–	2	100	HI	2	3
Pallasiola quadrispinosa	–	NA	440	LO	2	1

[a]Best available estimate of the total area of occupancy in Norway.
[b]Ecological impact: LO, low; HI, high; SE, severe; NR, not risk assessed.
[c]Invasion potential.
[d]Ecological effect.

included in the national WFD reporting system are listed in Table 2. Four of these species have been assessed but are not included in WFD reporting, whereas the reverse is true of one species (Table 2). It is generally recognized that this list is not exhaustive; most likely, specimens from all 28 ray-finned fish species that are native to Norway have been introduced to new water bodies at some point in time (Hesthagen & Sandlund, 2016).

5 | GUIDELINES FOR ASSESSING ECOLOGICAL STATUS IN THE PRESENCE OF ALIEN SPECIES

The method recommended for assessing the current ecological status of freshwater bodies in the presence of alien species is based on a decision tree with three tiers (Figure 1; Table 3). The precision of the three procedures decreases from tier 1 (high precision), to tier 2 (intermediate precision), to tier 3 (low precision), owing to the increasing uncertainty as to whether the information used is representative of the water body assessed.

Irrespective of the procedure chosen, the following two auxiliary rules apply:

- The ecological status of a water body cannot be better than good if it contains at least one alien species fulfilling the delimitation criteria
- If more than one alien species occurs in the water body, the ecological status should be based on the alien species with the greatest effect

The following sections provide more detailed explanations of each procedure and rule.

5.1 | First tier: inferring ecological status from data on the specific water body

If surveillance data or other types of data on relevant biological quality elements are available for the specific water body under consideration, these data should be used. Even somewhat informal knowledge should be taken into account, provided it allows an assessment of the change in ecological status after the arrival of the alien species. The relevant criterion is whether the surveillance data or other available knowledge can be assumed to capture the relevant effects of the alien species on the water body in question. If this is the case, and if ecological status is assessed as good or worse, no additional reduction in the status is required.

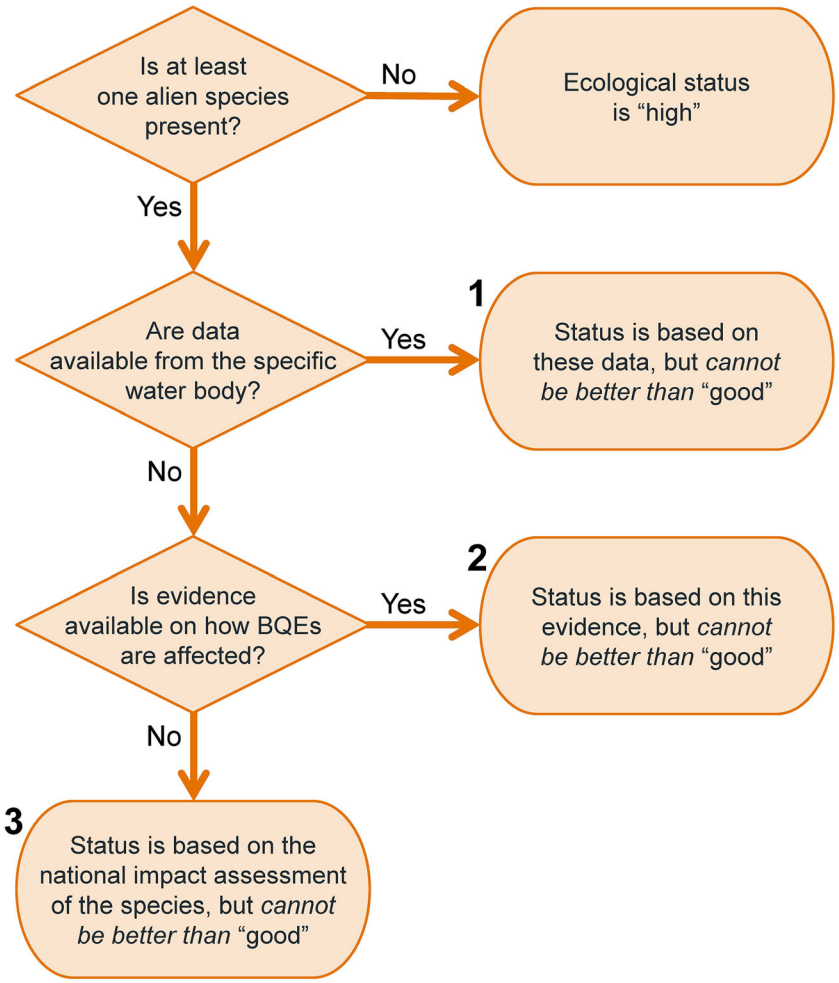

FIGURE 1 Flow chart describing the decision tree of the assessment method. The numbers 1–3 refer to the three alternative procedures (see Table 3). Note that the flow chart is only concerned with the pressure from 'alien species'; other pressures may indicate lower ecological status. BQE, biological quality element

TABLE 3 Characteristics and applicability of the three procedures suggested for assessing the effect of alien species on the ecological status of freshwater bodies in Norway. The choice of procedure is based on the flow chart in Figure 1. BQE, biological quality element; GEIAA, Generic Ecological Impact Assessment of Alien Species (Artsdatabanken, 2018; Sandvik et al., 2020b)

Procedure	Evidence on alien species required	Uncertainty	Currently applicable to BQE (parameter)	Data used
1	Effect on BQE in the specific water body	Low	Fish fauna (population decrease, community composition index), benthic invertebrates (noble crayfish)	Field data from the specific water body
2	Effect on BQE	Intermediate	Fish fauna (brown trout)	Status classifications such as Table 4
3	Presence only	High	All	GEIAA

Depending on the alien species and the nature of its effects, different quality elements and indices might be relevant. Some of the indices used to assess the status of the quality element 'fish fauna' in Norway can be assumed to be suitably sensitive to the presence of alien species (especially the attributes 'decrease in population size' and the 'Norwegian index of change in the composition of fish communities'; Direktoratsgruppen, 2018b). In addition, the auxiliary indicator 'presence of noble crayfish' is highly sensitive to alien species (Holdich et al., 2009). For the indices representing other quality elements, the sensitivity to alien species is largely low or unknown.

One way to make this procedure applicable to other biological quality elements is by developing novel indices that are specifically designed to capture changes brought about by alien species. An example of this approach is the 'biocontamination index' that has been developed for benthic macroinvertebrate communities (Arbačiauskas et al., 2008; Šidagytė, Višinskienė & Arbačiauskas, 2013), and assigns ecological status according to the relative abundance (percentage of

TABLE 4 Classification of the status of allopatric brown trout (*Salmo trutta*) populations after the human introduction of seven different regionally alien fish species, depending on the surface area and mean depth of the lake water body. Cells are left empty if they represent combinations of area and depth that do not occur in Norway. Based on Hesthagen et al. (2012) and Hesthagen & Sandlund (2013)

	Surface area (km^2)				
Mean depth (m)	**<0.1**	**0.1–0.5**	**>0.5–5**	**>5–50**	**>50**
	European minnow (*Phoxinus phoxinus*)				
<3	bad	bad	poor	–	–
3–15	poor	poor	moderate	moderate	–
>15	–	moderate	good	good	good
	Rudd (*Scardinius erythrophthalmus*) or roach (*Rutilus rutilus*)				
<3	bad	bad	poor	–	–
3–15	poor	poor	moderate	moderate	–
>15	–	moderate	moderate	good	good
	Northern pike (*Esox lucius*)				
<3	bad	bad	bad	–	–
3–15	bad	bad	poor	poor	–
>15	–	poor	poor	poor	poor
	European perch (*Perca fluviatilis*)				
<3	bad	bad	poor	–	–
3–15	bad	poor	poor	poor	–
>15	–	poor	poor	moderate	moderate
	Arctic charr (*Salvelinus alpinus*)				
<3	high	high	good	–	–
3–15	good	good	moderate	moderate	–
>15	–	moderate	moderate	moderate	moderate
	European whitefish (*Coregonus lavaretus*)				
<3	good	good	good	–	–
3–15	good	good	moderate	moderate	–
>15	–	moderate	moderate	moderate	moderate

specimens) and taxonomic richness (percentage of orders) of alien organisms.

5.2 | Second tier: inferring ecological status from evidence on relevant quality elements

The second procedure is to base ecological status on evidence of the effect that the alien species have on specific biological quality elements in comparable water bodies. At present, this procedure is only available for one WFD parameter in Norway – 'allopatric brown trout populations' – for which the effects of seven regionally alien fish species have been quantified (Table 4; Hesthagen et al., 2012; Hesthagen & Sandlund, 2013). As can be seen from Table 4, the effect on brown trout varies among different water body types, as defined by the depth and surface area of lakes. We recommend that analogous evidence for effects on other biological quality elements should be assembled. This can be achieved by evaluating the effect of different alien species on existing WFD indices, as has been done for brown trout. The effect of alien species may vary with the depth or surface area of lakes, as for brown trout (Table 4), or with other descriptors such as altitude or geology. This variation should be taken into account when assembling the available evidence. The second procedure has lower precision than the first because it is based on an extrapolation of evidence, from water bodies for which data are available to other water bodies of a similar type. Therefore, this procedure should only be used if no relevant data are available for the specific water body under consideration.

5.3 | Third tier: assigning ecological status based on knowledge of the alien species present

In Norway, the impact of alien species is regularly assessed and summarized in the Alien Species List (Artsdatabanken, 2018; Sandvik et al., 2020a). These impact assessments can be used to assign an ecological status even if the two above procedures are inapplicable.

The impact categories reported by the Alien Species List ('severe', 'high', etc.; Table 1) are a combined measure of the invasion potential of species and their ecological effect. Whereas invasion potential may be relevant for inferring the future spread of a species to hitherto unaffected water bodies, it is irrelevant for classifying the

ecological status of the water bodies affected. Therefore, the relevant variable for WFD assessments is not the overall impact category of the species under consideration, but the partial score for its ecological effect. These scores range from 1 (no known effect) to 4 (major effects). Tables 1 and 2 provide the impact categories and ecological effect scores for the species listed.

We recommend that a water body is:

- Classified as good when the alien species present has an effect score of 1 or 2
- Classified as moderate when the alien species present has an effect score of 3
- Classified as poor when the alien species present has an effect score of 4

The effect scores used in this third procedure are based on an overall (national) assessment of the alien species, which applies the same criteria to all terrestrial, freshwater, and marine species, irrespective of taxonomy. As such, these scores are not necessarily representative of any specific WFD quality element. For example, a lake water body with introduced European minnow (*Phoxinus phoxinus*) would be classified as poor according to this procedure, because the ecological effect score of this species is 4 (Table 2). As can be seen from Table 4, this would be a misclassification for several types of trout lakes; more specifically, it would overestimate the ecological status of shallow, very small lakes, and underestimate the ecological status of deep or large lakes. This illustrates why this third procedure should only be used if the two previous procedures are inapplicable, because those take the specific characteristics of the water body under consideration into account. Nevertheless, this third procedure is more reliable than the current practice in Norway, which is to reduce the status classification by one level if an alien species with high or severe impact is present. According to current practice, a water body with European minnow might be classified as good, which is clearly misleading for most water body types (Table 2).

5.4 | First auxiliary rule: presence of alien species rules out high ecological status

This auxiliary rule requires that in the presence of at least one alien species that meets the delimitation criteria described earlier the ecological status of a water body cannot be classified as high. The rule is to be applied irrespective of which of the three classification procedures is used. The rationale for this rule is that the WFD specifies that a water body cannot be classified as high unless 'The taxonomic composition and abundance correspond totally or nearly totally to the undisturbed conditions' (Council of the European Communities, 2000). Alien species change the taxonomic composition of a water body by their mere presence. Even if they have negligible effects otherwise, this means that their presence is incompatible with undisturbed conditions.

5.5 | Second auxiliary rule: the one-out, all-out principle

By demanding that 'the ecological status classification [...] shall be represented by the lower of the values for the [...] monitoring results for the relevant quality elements' (Council of the European Communities, 2000), the WFD enforces the so-called 'one-out, all-out principle'. Applying this principle to alien species means that if more than one alien species occurs in a water body, the ecological status should be based on the alien species with the greatest effect, rather than on an average of the individual effects. The rationale for applying the one-out, all-out principle in this case, even though different alien species may belong to the same biological quality element, is that evaluations of different alien species do not attempt to estimate a common underlying quantity, in which case averaging would be advisable. Different alien species exert different effects on the native biota, and these effects do not average out.

The one-out, all-out principle also applies when combining the effect of alien species with that of other pressures. Therefore, when the decision tree (Figure 1) indicates, for example, high status because of the absence of alien species, this does not preclude other pressures (such as eutrophication or acidification) from reducing the ecological status of the water body to good or worse.

5.6 | Assessing the risk of future deterioration

Even when a water body satisfies the relevant environmental objectives, it may be at risk of future deterioration. It is important that such risks are considered, assessed, and managed accordingly. In the case of alien species, the prevention of deterioration entails preventing future colonizations.

Direct (intentional or unintentional) introduction events of alien species are difficult to predict within reasonable levels of certainty. However, if sufficient data on historical introductions events are available, statistical models can be used to predict future introductions and to estimate the likelihood of their establishment (Strayer & Dudgeon, 2010; Leathwick et al., 2016; Perrin et al., 2021). These methods are better suited to predict the invasion risk for groups of water bodies, such as river basins or groups of fish, rather than individual water bodies or species. On the other hand, natural dispersal from colonized to uncolonized water bodies is well suited for water body-specific modelling (Perrin et al., 2020). Such models need to be based on: (i) occurrence data of relevant alien species in nearby water bodies; (ii) knowledge of the pathways, mechanisms, and speed of dispersal; and (iii) data on the connectivity between the colonized and the uncolonized water bodies.

It should be added that ecological status may deteriorate even in water bodies that are already colonized by an alien species. This may happen if climate change enables the alien species present to increase in density. As impact assessments according to GEIAA include the

likely ecological effects of species that may occur 50 years into the future, this potential is already taken into account by the third procedure (although with high uncertainty).

5.7 | Accounting for the effects of species alongside water bodies

Alien species in the riparian zones of rivers and the shore zones of lakes, of mainly terrestrial or semiaquatic vegetation, may have an impact on water bodies. For instance, giant hogweed (*Heracleum mantegazzianum*), Himalayan balsam (*Impatiens glandulifera*), Japanese knotweed (*Reynoutria japonica*), and rhododendron (*Rhododendron ponticum*) are treated in this way in Great Britain (UK Technical Advisory Group, 2013). No systematic survey of alien species alongside water bodies has taken place in Norway; however, we recommend that in certain circumstances such species should be included in the WFD classification system. If surveillance data or more informal knowledge about relevant biological quality elements are available for the specific water body, these data should be used. This is in accordance with the first tier of the decision tree for freshwater species (Figure 1). Potential examples include the eutrophication of small lakes caused by alien plant litter and the shading of water bodies by alien vegetation, which may in turn affect water temperature or the growth conditions for algae (Hladyz et al., 2011). However, such effects should only be considered when they differ from the effects that the displaced native vegetation would have had.

In contrast, the remaining tiers of the decision tree (Figure 1) should not be applied to alien species alongside water bodies. This follows from the ecological delimitation (section 3.1) and because species alongside water bodies are not part of any biological quality element according to the WFD. However, vegetation is an aspect of the 'structure and condition' of the riparian zones or lake shore zones, which means that it can affect the hydromorphological quality element 'morphological conditions'. Being a supporting quality element, hydromorphology can only be used to reduce the ecological status classification of a water body from high to good. For this to be the case, the effect of the alien species must clearly change the structure or condition of the riparian zones or lake shore zones from those of undisturbed conditions (Council of the European Communities, 2000). Examples include the potential of some alien riparian plants, such as Himalayan balsam and Japanese knotweed, to increase the erosion of river banks (Colleran, Lacy & Retamal, 2020; Greenwood, Gange & Kuhn, 2020).

As the WFD does not mention taxonomic composition and abundance as criteria of undisturbed hydromorphology, the mere presence of an alien species alongside a water body is not sufficient for downgrading its status from high to good, whereas a mass occurrence of the species may be. This contrasts with the first auxiliary rule for biological quality elements (see section 5.4.).

6 | DISCUSSION

Based on the WFD definition that a water body cannot have high ecological status unless the taxonomic composition of its quality elements 'corresponds totally or nearly totally to undisturbed conditions' (Council of the European Communities, 2000), we concur that the effects of alien species need to be taken into account when a water body is classified according to the WFD (IMPRESS, 2003; Shine et al., 2008; Vandekerkhove, Cardoso & Boon, 2013). However, there are no intercalibrated guidelines on how alien species should be accounted for in the WFD, so practices vary greatly among EU member states (Boon, Clarke & Copp, 2020). In Norway, WFD assessments have previously taken alien species into account (Direktoratsgruppen, 2018a), although only partially and in a somewhat incoherent manner. The recommendations developed here attempt to standardize the treatment of alien species within the context of the WFD.

6.1 | Guidelines for assessing ecological status in the presence of alien species

The flow chart presented in Figure 1 summarizes the approach proposed here, presenting three available procedures in order of priority. With decreasing priority, the data requirements decrease, whereas the uncertainty of the classifications derived from the procedures increases.

According to the first procedure, the ecological status of a given water body is directly inferred from surveillance or other data on relevant biological quality elements. Among the WFD indices available in Norway, this procedure is only possible at present for the quality element 'fish fauna' and the auxiliary indicator 'presence of noble crayfish'. Other indices do not seem to be sufficiently sensitive to alien species, although some studies have shown the Average Score Per Taxon (ASPT) index, based on benthic invertebrates, to be negatively correlated with the presence of alien species (MacNeil & Briffa, 2009; MacNeil et al., 2010; Harrower et al., 2021; but see Mathers et al., 2016). For benthic macroinvertebrate communities, the 'biocontamination index' may also be an alternative (Arbačiauskas et al., 2008; Šidagytė, Višinskienė & Arbačiauskas, 2013), although it has yet to be tested in Norway. If this first procedure is used, it is important that the ecological status is not modified in an additional step based on the presence of alien species, as this would constitute a double 'punishment' for one and the same effect. As the only exception from this rule, it is recommended that no water body with at least one alien species should be classified as having high ecological status.

The second procedure presupposes that the effect of alien species on a certain biological quality element or WFD parameter is known. In Norway, this procedure is currently available for one WFD parameter (brown trout; Table 4), representing the biological quality element 'fish fauna'. It is recommended that analogous evidence is collected for other biological quality elements and parameters.

The third procedure is to assign an ecological status according to the national impact assessment of the alien species present, irrespective of the typology of the water body and the biological quality elements present.

6.2 | Delimitation criteria

Clear delimitations are as important as a standardized assessment procedure. If there is no consistency about which taxa to include in an assessment, even a standardized procedure cannot ensure testable or repeatable results. The criteria outlined here allow an unambiguous ecological, geographical, historical, and taxonomic delimitation of WFD assessments of alien species.

According to the geographical delimitation criterion, we recommend that nationally and regionally alien species are treated in the same way. As far as regionally alien species are concerned, this represents a clear change from current practice in Norway. Previously, only selected regionally alien species have been considered (Table 2). This also means that impact assessments (and thus the third procedure) are not currently available for all regionally alien species; however, this does not imply that a species without an impact assessment does not pose any risk. It is recommended, therefore, that impact assessments are carried out on the remaining regionally alien species. This would also include, for example, brown trout, which has been introduced intentionally to a large number of lakes in Norway.

6.3 | Management implications for fresh waters in Norway and other countries

In many cases, the introduction of alien species causes irreversible adverse effects on freshwater ecosystems. This raises the concern that the approach presented here may conflict with the WFD aim of reaching at least good ecological status for all water bodies. For instance, Canadian waterweed is present in 38 Norwegian water bodies that are currently classified to have good or high status. If applying the third procedure, these would have to be classified as poor. Likewise, if the third procedure is used for regionally alien species, as we recommend, the same would happen to 1,003 water bodies with European minnows (approximately 4% of all recognized Norwegian water bodies). Although these are high numbers, we believe our recommendations are justified. First, if there is reason to believe that the third procedure gives misleading results, this means that there must be some evidence to apply the first procedure or that it is possible to collect the data needed. Second, although we propose that the presence of alien species is incompatible with high ecological status, it may be compatible with good status, viz. under the first or second tier and/or for alien species with low ecological impact. Third, the information conveyed by the fact that a water body has moderate or poorer status may be an important incentive and background knowledge for the development of plans to reduce further spread from the affected to hitherto unaffected water bodies. Finally, we believe that this problem ought not to be 'solved' by lowering the reference state. Good ecological status may indeed be unobtainable if the eradication of certain alien species is impossible or unrealistic. If this is the case, however, it might be better that this fact is made visible – also to decision makers – by the non-fulfilment of the WFD requirements, rather than concealing it. We are aware that this opinion may be difficult to reconcile with the situation in some EU countries, where the prevalence of alien species is higher than in Norway. This problem may be circumvented by introducing partial exceptions to the WFD goals, which could, for example, be considered analogous to the 'heavily modified water bodies' included in the WFD.

In principle, most of the recommendations in this article are transferable to other countries, although they require certain types of evidence to be available. For instance, the third procedure presupposes that the relevant alien species have been risk assessed. In Norway, this is the case for all nationally alien species known to reproduce in the wild (Artsdatabanken, 2018; Sandvik et al., 2020a). However, it is not necessarily a precondition that other countries should use the same impact assessment framework as in Norway (i.e. GEIAA; Sandvik et al., 2019a). For instance, countries using the Environmental Impact Classification for Alien Taxa (EICAT) protocol (Hawkins et al., 2015), may modify procedure 3 by classifying water bodies as 'poor' when the alien species present has been assessed to have 'massive' impact, as 'moderate' when the alien species has 'major' impact, and as 'good' otherwise. Other impact assessment schemes may be adjusted accordingly. We therefore hope that our recommendations can also inspire other countries to adopt or develop guidelines along these or similar lines.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest associated with this work.

DATA AVAILABILITY STATEMENT

All data used are available from open repositories.

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