Received: 30 May 2023 | Revised: 11 August 2023 | Accepted: 12 August 2023

DOI: 10.1002/aqc.4014

RESEARCH ARTICLE

WILEY

Extinction risks and threats facing the freshwater fishes of Britain

Andy D. Nunn[1] | Rachel F. Ainsworth[1] | Silas Walton[2] | Colin W. Bean[3] | Tristan W. Hatton-Ellis[4] | Andy Brown[5] | Rob Evans[6] | Allison Atterborne[7] | Dave Ottewell[8] | Richard A.A. Noble[1]

[1]Hull International Fisheries Institute, School of Natural Sciences, University of Hull, Hull, UK

[2]Natural England, Penrith, UK

[3]NatureScot, Clydebank, UK

[4]Natural Resources Wales, Llandarcy, UK

[5]Natural England, Peterborough, UK

[6]Natural Resources Wales, Cardiff, UK

[7]Natural England, Worthing, UK

[8]Natural England, Worcester, UK

Correspondence
Andy D. Nunn, Hull International Fisheries Institute, School of Natural Sciences, University of Hull, Hull, HU6 7RX, UK.
Email: a.d.nunn@hull.ac.uk

Funding information
The study was funded by Natural England.

Abstract

1. Extinctions occur naturally in all environments, but rates have accelerated rapidly during the Anthropocene, especially in fresh water. Despite supporting many fish species of conservation importance, there has never been a formal assessment of their extinction risks in Britain, which has impeded their inclusion in relevant legislation and policy. This study therefore used the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species™ Categories and Criteria to conduct the first systematic assessment of the extinction risks and threats facing the native freshwater and diadromous fishes of Britain. In addition, national assessments were produced for England, Scotland and Wales, reflecting the level at which environmental policy decisions are taken in Britain.
2. Seven species were categorized as being threatened with extinction at the regional level, with European eel *Anguilla anguilla* and allis shad *Alosa alosa* classified as Critically Endangered, Atlantic salmon *Salmo salar*, vendace *Coregonus albula* and European whitefish *Coregonus lavaretus* classified as Endangered, and Arctic charr *Salvelinus alpinus* and twaite shad *Alosa fallax* classified as Vulnerable. In addition, burbot *Lota lota* was classified as Regionally Extinct, ferox trout *Salmo ferox* was categorized as Data Deficient, and 25 species were categorized as Least Concern. European sturgeon *Acipenser sturio* and houting *Coregonus oxyrinchus*, although probably native, qualified as only vagrants in fresh water, so were categorized as Not Applicable.
3. The assessments provide objective baselines against which future changes can be determined, and a key evidence base to support policy and management decisions for the conservation of freshwater and diadromous fish species and their habitats in Britain. It is recommended that the assessments are repeated every 10 years, which would enable changes in conservation status, the effectiveness of policies and where targeted interventions may be required to be examined using the Red List Index.

KEYWORDS

conservation, Critically Endangered, Data Deficient, Endangered, IUCN Red List, Least Concern, Red List Index, Regionally Extinct, threatened, Vulnerable

1 | INTRODUCTION

Extinctions occur naturally in all environments, but rates have accelerated rapidly during the Anthropocene. This has particularly affected freshwater environments, which are suffering steeper declines in biological diversity than most marine and terrestrial ecosystems (Reid et al., 2019; Tickner et al., 2020). For example, it was estimated that the World Wide Fund (WWF) for Nature Living Planet Index for populations of freshwater species declined by 83% between 1970 and 2012, compared with 38 and 36%, respectively, in terrestrial and marine environments (WWF, 2022). Indeed, fresh water is considered the most threatened environment on Earth, with a third of species currently at risk of extinction (WWF, 2021).

Freshwater fishes account for more than 25% of vertebrate species globally (Carrizo, Smith & Darwall, 2013), but a significant proportion have declined in abundance or range in recent decades and at least 81 have been declared extinct, including 16 since 2020 (IUCN, 2023a). The most common threats to freshwater fishes are habitat loss, degradation (including pollution and water abstraction) and fragmentation (including loss of river connectivity), overexploitation, invasive species and climate change (Arthington et al., 2016; Miranda et al., 2022). A reduction in water quality, for example, has been implicated in the extinctions of at least eight species of European freshwater fish, and many sturgeon and paddlefish species worldwide are severely threatened by overexploitation (Freyhof & Brooks, 2011). There are particular concerns over possible synergistic effects of multiple threats occurring simultaneously, such as species invasions facilitated by habitat degradation and climate change, which could exacerbate existing issues (Jacoby et al., 2015).

The International Union for the Conservation of Nature Red List of Threatened Species™ (IUCN Red List) Categories and Criteria (IUCN, 2012, 2022) have been widely used to assess global, regional and national extinction risks, including for fish (Freyhof & Brooks, 2011; Dulvy et al., 2014; Chakona et al., 2022). Despite supporting many fish species of conservation importance, there has never been a systematic assessment of their extinction risks in Britain, which has impeded their inclusion in relevant legislation and policy, priority species lists, protected site selection guidance and general assessments of wildlife trends. This study therefore used the IUCN Red List Categories and Criteria to conduct the first formal assessment of the extinction risks and threats facing the native freshwater and diadromous fishes of Britain. The extinction risks, threats, overall qualification against the Red List Criteria and confidence in the assessments are discussed, and recommendations to address important knowledge gaps and mitigate key threats are provided.

2 | METHODS

2.1 | Geographical and taxonomic scope

The IUCN Red List Categories and Criteria were developed for assessing global extinction risks, but guidelines for their application at regional and national levels were subsequently produced (IUCN, 2012). The geographical area covered by this study was Britain (i.e. England, Scotland and Wales), including offshore islands, but excluding the Channel Islands and Isle of Man (dependencies of the British Crown, but not under the jurisdiction of the British Government). The primary focus was at regional level (Britain), but assessments were also conducted at national/country level (England, Scotland and Wales), reflecting the level at which environmental policy decisions are taken in Britain.

All primary and secondary freshwater fish species native to Britain were considered for assessment. Species were classified as native or non-native according to Maitland (2004), with 42 considered for assessment; note that the status of crucian carp *Carassius carassius* (L.) has recently been changed to 'non-native' on the evidence of a genetics study (Jeffries et al., 2017) that suggests it was introduced (Dodd et al., 2019). Non-native species were Not Evaluated (IUCN, 2012, 2022). European sturgeon *Acipenser sturio* L. and houting *Coregonus oxyrinchus* (L.), although probably native, were treated as vagrants in fresh water, so were categorized as Not Applicable (*sensu stricto* IUCN, 2012). Similarly, amphidromous species, which migrate between marine and freshwater environments only for non-reproductive purposes, were not assessed.

Many postglacial water bodies support fish that exhibit a high degree of infraspecific structuring, which can result in taxonomic uncertainties (Skúlason et al., 2019). Kottelat & Freyhof (2007), for example, proposed that the European whitefish *Coregonus lavaretus* (L.) in England, Scotland and Wales are endemic to those countries and should revert to their former scientific names of *Coregonus stigmaticus* Regan, *Coregonus clupeoides* Lacépède and *C. pennantii* Valenciennes, respectively. However, subsequent phenotypic (Etheridge et al., 2012) and genetic studies (Crotti et al., 2021) argued that they are all most appropriately classified as *C. lavaretus*, and that approach was followed in this study. Similarly, Kottelat & Freyhof (2007) referred to vendace in Britain as the endemic *Coregonus vandesius* Richardson, but subsequent British studies (Winfield, Fletcher & James, 2017; Lyle et al., 2019) found no robust evidence to suggest deviation from *Coregonus albula* (L.). The situation with Arctic charr is particularly complex as global assessments have been conducted on 10 alleged endemic species in Britain, whereas *Salvelinus alpinus* (L.) is reported as being absent (Kottelat & Freyhof, 2007). However, subsequent studies on Arctic charr in

Britain (Winfield et al., 2010; Maitland & Adams, 2018) have treated all taxa as *S. alpinus*, and that was the approach in this study. The taxonomy of ferox trout *Salmo ferox* L. is uncertain, but given that genetic analyses suggest it is an ancient ancestral form of brown trout *Salmo trutta* L., it was assessed as a distinct taxonomic entity (Ferguson & Prodöhl, 2022). Finally, a revision of the *Cottus* genus (Freyhof, Kottelat & Nolte, 2005) concluded that the species in Britain is chabot fluviatile *Cottus perifretum* Freyhof, Kottelat & Nolte (hereafter bullhead), rather than the European bullhead *Cottus gobio* L., but this did not affect the assessments in this study as only one *Cottus* species is believed to be present in Britain (Freyhof, Kottelat & Nolte, 2005; McLeish et al., 2020).

2.2 | Extinction risks and threats

Assessments of the extinction risk and threats facing each species were conducted according to the Guidelines for Application of IUCN Red List Criteria at Regional and National Levels (IUCN, 2012). The process uses combinations of parameters describing taxon abundance and geographical range to assess extinction risk against five criteria (A–E). For regional assessments, taxa are assigned to one of nine categories, namely Extinct (EX), Extinct in the Wild (EW), Regionally Extinct (RE), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC) or Data Deficient (DD). Together, CR, EN and VU are referred to as the threatened categories. Threatened taxa are assigned an alphanumeric code (e.g. CR B1ab(iii)+2ab(iii); C2a(ii)) that describes their extinction risk and the criteria and conditions upon which the assessment was based (IUCN, 2012, 2022). In this example, the taxon was assessed as Critically Endangered (CR) owing to its restricted geographical range (B1, B2), small number of locations (B1a, B2a), a continuing decline in the area, extent and/or quality of habitat (B1b(iii), B2b(iii)), small population size (C), a continuing decline in population size (C2), and the high percentage of mature individuals in one subpopulation (C2a (ii)) (see IUCN, 2012, 2022 for further details).

It is important to note, to avoid possible misinterpretations of the results, that the IUCN Red List Criteria include terms with definitions that differ from those used in general ecology or fisheries science. In addition, some of the parameters must be calculated using specific, standardized methods, to enable comparisons across taxa, space and time. The terms and parameters of most relevance to this study include 'population size', 'subpopulation', 'generation', 'extent of occurrence' (EOO), 'area of occupancy' (AOO), 'continuing decline', 'number of locations' and 'rescue effect' (see IUCN, 2022).

Reductions in population size were determined using the Criterion A population reduction calculator (IUCN, 2023b). As prescribed for fresh waters, the native range (i.e. excluding catchments into which species have been translocated) of each fish species (Maitland, 2004; Dodd et al., 2019) was mapped using HydroBASINS (Level 5) (IUCN, 2021) and EOO was determined using the calculator in the IUCN ArcGIS toolkit (version 10.8), while AOO was calculated by superimposing a 2 × 2 km grid on species occurrence point data (IUCN, 2021). Information sources included national fish monitoring datasets for England (Environment Agency), Scotland (Scottish Environment Protection Agency) and Wales (Natural Resources Wales), targeted surveys for designated species, peer-reviewed publications, grey literature and personal communications; full details are available in Appendix S1.

The assessments were reviewed in a global context, to determine whether species could be 'rescued' by the immigration of individuals from elsewhere and, therefore, whether categorizations of extinction risk needed to be 'downlisted' (IUCN, 2012). Meta-analyses were then conducted to examine: (i) the numbers of species categorized as threatened vs. not threatened; (ii) the proportions of species for which it was possible to use each of the five assessment criteria (A–E); and (iii) the types and prevalence of threats identified as being of greatest concern to threatened species. The present status of freshwater and diadromous fishes (all species combined) in Britain, England, Scotland and Wales was assessed using the IUCN Red List Index. The index is based upon the proportions of species in each IUCN Red List Category (EX, CR, EN, VU, NT and LC), and ranges from 0 (all species Extinct) to 1 (all species Least Concern) (Bubb et al., 2009). Although intended to determine changes in extinction risk over time, it was considered useful to calculate the current values as a reference point for future assessments.

3 | RESULTS

The first systematic assessment of the extinction risks and threats facing the native freshwater and diadromous fishes of Britain classified one species as Regionally Extinct, two as Critically Endangered, three as Endangered, two as Vulnerable, 25 as Least Concern and one as Data Deficient (Table 1). Thus, seven species were categorized as being threatened with extinction, and the current IUCN Red List Index values for Britain, England, Scotland and Wales, respectively, were 0.87, 0.84, 0.81 and 0.81. Where relevant, differences in the regional and national assessments are described below.

3.1 | Regionally Extinct

Historically, burbot *Lota lota* (L.) were relatively widespread in eastern England, especially in the catchments of the Humber, Wash and Norfolk Broads (Worthington et al., 2011). Abundances started declining in the early 1900s, however, and the species was rare by the 1960s, with the last confirmed record dating from 1969 (Worthington et al., 2010). Despite extensive fishing and environmental DNA (eDNA) surveys within the species' former range, there have been no further records and the burbot is now widely considered to be extirpated in Britain. The exact causes of this loss are unknown, but pollution and habitat degradation are the pressures most likely to be responsible (Worthington et al., 2010). Burbot was therefore classified as Regionally Extinct in Britain, given that there is no

TABLE 1 Extinction risks facing the native freshwater and diadromous fishes of Britain, England, Scotland and Wales, compared with the European and global IUCN Red List of Threatened Species™ assessments.

Family		Red List classification					
Species	Vernacular name	Britain	England	Scotland	Wales	Europe	Global
Acipenseridae							
Acipenser sturio	European sturgeon	NA	NA	NA	NA	CR	CR
Anguillidae							
Anguilla anguilla	European eel	CR	CR	CR	CR	CR	CR
Balitoridae							
Barbatula barbatula	Stone loach	LC	LC	LC	LC	LC	LC
Clupeidae							
Alosa alosa	Allis shad	CR	CR	NA	CR	LC	LC
Alosa fallax	Twaite shad	VU	EN	NA	VU	LC	LC
Cobitidae							
Cobitis taenia	Spined loach	LC	LC	NA	NA	LC	LC
Coregonidae							
Coregonus albula	Vendace*	EN	CR	EN	NA	EN	EN
Coregonus lavaretus	European whitefish*	EN	CR	EN	CR	EN/VU/CR	EN/VU/CR
Coregonus oxyrinchus	Houting	NA	NA	NA	NA	EX	EX
Cottidae							
Cottus perifretum	Bullhead	LC	LC	NE	LC	LC	LC
Cyprinidae							
Abramis brama	Common bream	LC	LC	NE	NE	LC	LC
Alburnus alburnus	Bleak	LC	LC	NE	NE	LC	LC
Barbus barbus	Barbel	LC	LC	NE	NE	LC	LC
Blicca bjoerkna	Silver bream	LC	LC	NE	NE	LC	LC
Gobio gobio	Gudgeon	LC	LC	NE	NE	LC	LC
Leuciscus leuciscus	Common dace	LC	LC	NE	LC	LC	LC
Phoxinus phoxinus	Eurasian minnow	LC	LC	LC	LC	LC	LC
Rutilus rutilus	Roach	LC	LC	LC	LC	LC	LC
Scardinius erythrophthalmus	Rudd	LC	LC	NE	LC	LC	LC
Squalius cephalus	Chub	LC	LC	NE	NE	LC	LC
Tinca tinca	Tench	LC	LC	NE	NE	LC	LC
Esocidae							
Esox lucius	Northern pike	LC	LC	LC	LC	LC	LC
Gadidae							
Lota lota	Burbot	RE	RE	NA	NA	LC	LC
Gasterosteidae							
Gasterosteus aculeatus	Three-spined stickleback	LC	LC	LC	LC	LC	LC
Pungitius pungitius	Ten-spined stickleback	LC	LC	LC	LC	LC	LC
Osmeridae							
Osmerus eperlanus	European smelt	LC	LC	NT	NT	LC	LC
Percidae							
Gymnocephalus cernuus	Ruffe	LC	LC	NE	NE	LC	LC
Perca fluviatilis	European perch	LC	LC	LC	LC	LC	LC

(Continues)

TABLE 1 (Continued)

Family *Species*	Vernacular name	Red List classification Britain	England	Scotland	Wales	Europe	Global
Petromyzontidae							
Lampetra fluviatilis	River lamprey	LC	LC	LC	LC	LC	LC
Lampetra planeri	Brook lamprey	LC	LC	LC	LC	LC	LC
Petromyzon marinus	Sea lamprey	LC	LC	LC	LC	LC	LC
Salmonidae							
Salmo ferox	Ferox trout	DD	DD	DD	DD	DD	DD
Salmo salar	Atlantic salmon	EN	EN	EN	EN	NE	LC
Salmo trutta	Brown trout	LC	LC	LC	LC	LC	LC
Salvelinus alpinus	Arctic charr*	VU	EN	VU	EN	LC	LC
Thymallidae							
Thymallus thymallus	Grayling	LC	LC	NE	LC	LC	LC

Abbreviations: CR, Critically Endangered; DD, Data Deficient; EN, Endangered; EX, Extinct; LC, Least Concern; NA, Not Applicable; NE, Not Evaluated; NT, Near Threatened; RE, Regionally Extinct; VU, Vulnerable.
*Note taxonomic differences between the regional/national and European/global assessments (see Section 2.1 for details).

reasonable doubt that the last individual potentially capable of reproduction in the region has died (IUCN, 2012, 2022).

3.2 | Critically Endangered

The global abundance of European eel *Anguilla anguilla* (L.) has declined markedly over the last four decades, probably owing to a combination of habitat loss and fragmentation (including barriers to migration), climate-mediated shifts in oceanic conditions, and increases in impingement/entrainment, exploitation and disease mortality (Jacoby et al., 2015). As the species exists as a panmictic population, the global decline (International Council for the Exploration of the Sea (ICES) recruitment index −98.6% in the North Sea series; ICES, 2022) is reflected in Britain (Aprahamian & Walker, 2008). Despite recent increases in glass (juvenile) eel recruitment and potentially silver (adult) eel escapement (ICES, 2022), the long generation time and panmictic population mean that European eel was classified, following the global assessment, as Critically Endangered in Britain (CR A2bd+4bd) because of its population size reduction (≥80% in three generations) (Tables 1 and 2). There is no possibility of a rescue effect as species classified as Critically Endangered at global level cannot rescue regional populations in the event of their extinction (IUCN, 2012).

Although recorded from a large number of rivers, the British population of allis shad *Alosa alosa* (L.) is substantially lower than it was historically, which has been attributed to the impacts of migration barriers and reductions in water quality (Aprahamian, Lester & Aprahamian, 1998). The species spawned historically in the River Severn (as far upstream as Welshpool) and possibly elsewhere (Aprahamian, Lester & Aprahamian, 1998), but the River Tamar is currently the only confirmed location (Hillman, 2020). Even there, numbers have been falling, with very few immigrating adults in 2012 and 2013 and a complete absence of spawning fish in 2015 (R. Hillman, pers. comm.). All mature individuals occur in one subpopulation, and gravel extraction from the single spawning site (Hillman, 2020) could plausibly eliminate or severely reduce the population within a single generation. Allis shad was therefore classified as Critically Endangered in Britain and England (CR B1ab(iii) +2ab(iii); C2a(ii)) as a result of its restricted geographical range (EOO < 100 km^2, AOO < 10 km^2, one location, continuing decline in the area, extent and/or quality of habitat) and small population size (<250 mature individuals, continuing decline in population size, 90–100% of mature individuals in one subpopulation; Tables 1 and 2; Figures 1 and 2). It is considered unlikely that sufficient individuals would immigrate from outside of the region to rescue the British population in the event of its extinction, given that allis shad are not known to have colonized other British rivers via individuals straying from the Tamar. It is possible that allis shad spawn in Wales, although numbers are likely to be extremely small and hybridization with (the considerably more abundant) twaite shad *Alosa fallax* (Lacépède) (Antognazza et al., 2022) may mean that it is functionally extinct. Nevertheless, doubt remains and exhaustive surveys have not been conducted, so the species was classified as Critically Endangered (CR C2a(i)) rather than Critically Endangered (Possibly Extinct). There are no spawning records for allis shad in Scotland, so the species qualifies as only a vagrant in fresh waters there and was categorized as Not Applicable.

3.3 | Endangered

Atlantic salmon *Salmo salar* L. are widespread in the rivers of Britain, particularly in Scotland, Wales and northern/south-west England, and the EOO and AOO far exceed the thresholds to qualify potentially as threatened under criterion B. However, the species is threatened by

TABLE 2 Core metrics for the native freshwater and diadromous fishes threatened with extinction in Britain.

Family *Species*	Vernacular name	Red List code	Population size	Generation time (years)	Percentage decline	EOO (km^2)	AOO (km^2)	Continuing decline	No. of locations**
Anguillidae									
Anguilla anguilla	European eel	CR A2bd+4bd	>10,000	13	>80	508,831	34,432	Yes	n/a
Clupeidae									
Alosa alosa	Allis shad	CR B1ab(iii)+2ab(iii); C2a(ii)	<250	6	?	8	8	Yes	1
Alosa fallax	Twaite shad	VU A2b; B1ab(v)	>10,000	6	41	8,350	656	Yes	4
Coregonidae									
Coregonus albula	Vendace*	EN B1ab(iii)+2ab(iii)	?	4	?	2,253	68	Yes	1
Coregonus lavaretus	European whitefish*	EN B2ab(iii)	>10,000	5	?	26,734	320	Yes	1
Salmonidae									
Salmo salar	Atlantic salmon	EN A4b	>10,000	5	63	425,691	18,068	Yes	n/a
Salvelinus alpinus	Arctic charr*	VU A2b	>10,000	5	44	157,281	3260	Yes	n/a

Abbreviations: AOO, area of occupancy; EOO, extent of occurrence; n/a, not applicable (not threatened under criteria B or D); ?, insufficient data.

*Note taxonomic differences between the regional/national and European/global assessments (see Section 2.1 for details).

**Number of locations is determined in relation to the threat identified as most important in terms of extinction risk, and does not necessarily equal the number of subpopulations (IUCN, 2012; see Section 3 for details).

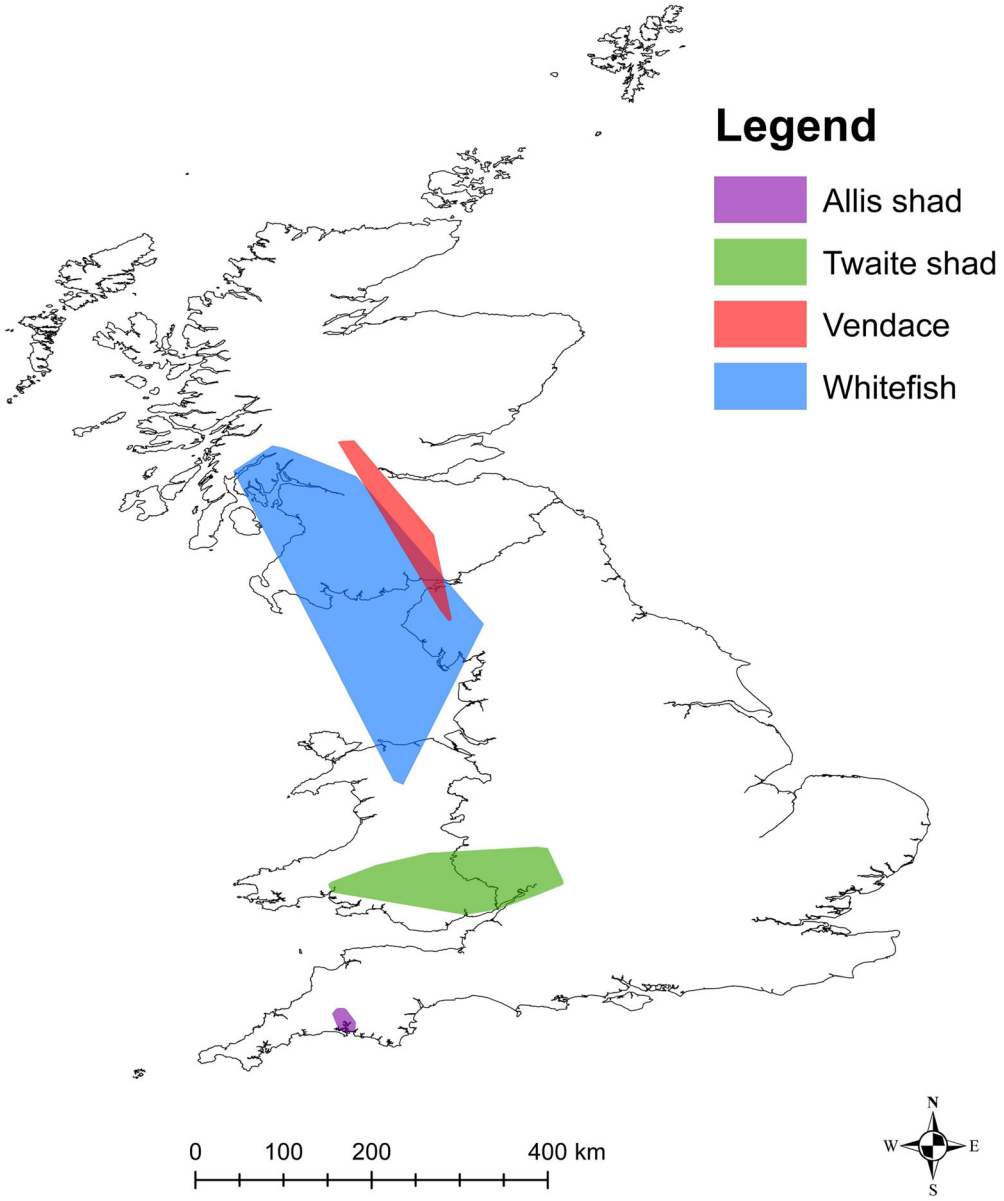

FIGURE 1 Extent of occurrence (EOO) for the four native freshwater or diadromous fish species that are threatened with extinction in Britain owing to their restricted geographical range.

poor marine survival, climate change, habitat loss, degradation and fragmentation, predation and overexploitation (Dadswell et al., 2022), and has suffered substantial declines in abundance in the last century, and particularly since 2010. The population size is estimated to far exceed the thresholds to qualify potentially as threatened under criteria C and D (10,000 and 1,000 individuals, respectively), but the three-generation percentage change, based on the rate of change in annual ICES pre-fishery abundance estimates for England, Scotland and Wales (ICES, 2021), was −63%. Atlantic salmon was therefore classified as Endangered in Britain (EN A4b) as a result of its continuing population size reduction (≥50% in three generations) (Tables 1 and 2). Although the species is anadromous and straying does occur, it is unlikely that sufficient individuals would immigrate from outside of the region to rescue the British population in the event of its extinction given that the species is also declining in neighbouring regions (IUCN, 2012).

Vendace is the rarest freshwater fish in Britain, and only two native populations remain, in Derwent Water and Bassenthwaite Lake in the English Lake District (Winfield et al., 2012). Two additional populations in Scotland were extirpated in the 1910s (Castle Loch) and 1970s (Mill Loch) owing to eutrophication and the introduction of non-native fish species (Winfield et al., 2012). Attempts have been made to establish refuge populations at one site in England (Sprinkling Tarn) and five in Scotland (Doune North Pond, Loch Earn, Loch Skeen/Skene, Loch Valley and Daer Reservoir) (Lyle et al., 2019). The Doune North Pond attempt failed and there is not yet any evidence of self-sustaining populations in Sprinkling Tarn or Loch Valley (B. Hänfling, pers. comm.; Lyle et al., 2019). In contrast, the species has established in Loch Earn, Loch Skeen and Daer Reservoir (Lyle et al., 2019), so these 'benign introductions' were included in the assessments (IUCN, 2012, 2022). Although the population size is unknown, the geographical range is small and climate change has

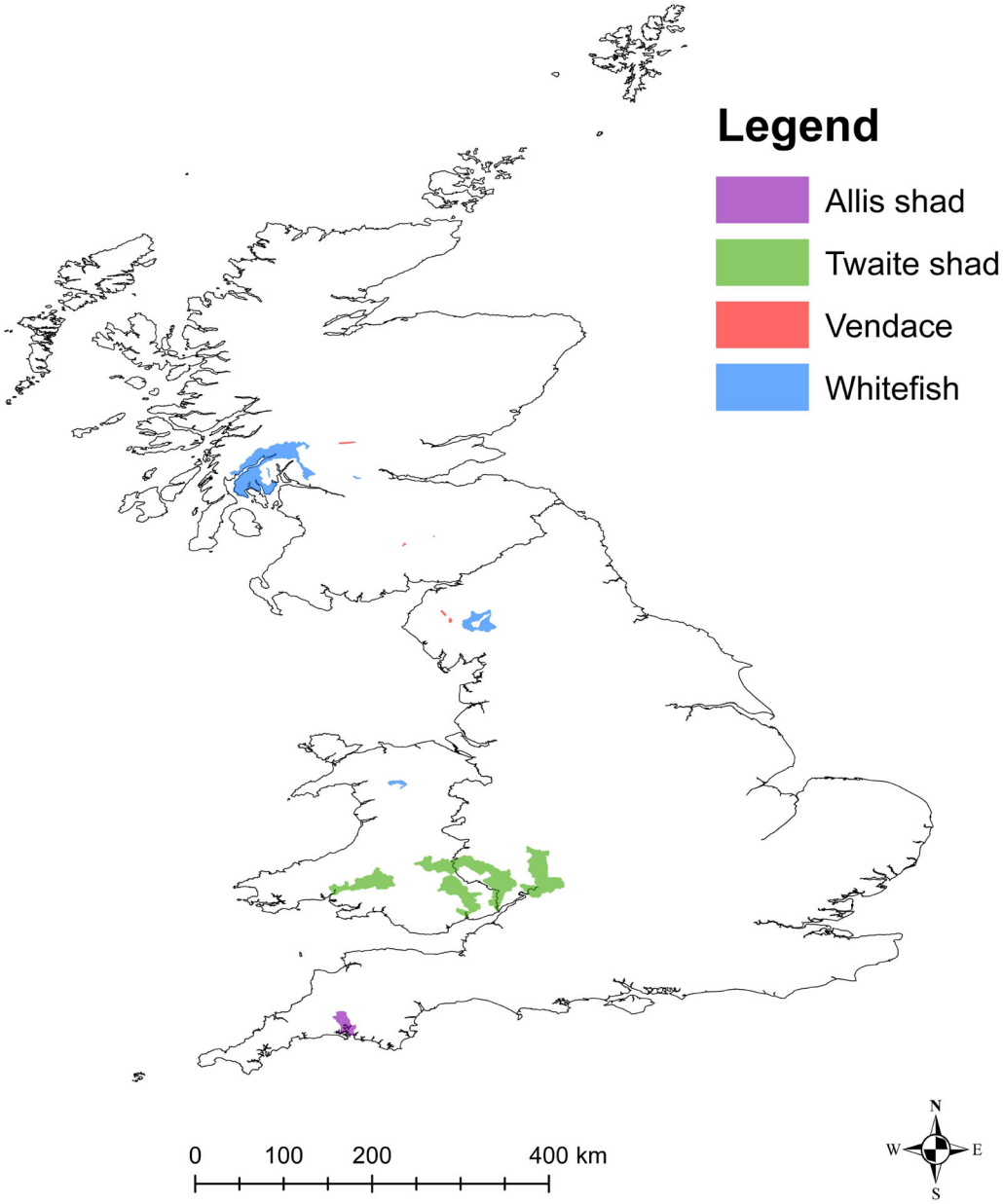

FIGURE 2 Area of occupancy (AOO) for the four native freshwater or diadromous fish species that are threatened with extinction in Britain owing to their restricted geographical range.

been identified as the main threat (Elliott & Bell, 2011) and is likely to affect all subpopulations simultaneously (i.e. 'number of locations' = 1). Vendace was therefore classified as Endangered in Britain and Scotland (EN B1ab(iii)+2ab(iii)) owing to its restricted geographical range (EOO < 5,000 km^2, AOO < 500 km^2, ≤5 locations, continuing decline in the area, extent and/or quality of habitat), and as Critically Endangered in England (CR B1ab(iii)) because of its smaller range (Tables 1 and 2; Figures 1 and 2). There is no possibility of a rescue effect in the event of the British population's extinction. The species is not native to Wales and there have been no benign introductions (Not Applicable).

European whitefish is native to four sites in England (Ullswater, Haweswater, Brotherswater and Red Tarn), two in Scotland (Loch Lomond and Loch Eck) and one in Wales (Llyn Tegid) (Winfield et al., 2013). There are also nine confirmed benign introductions (Blea Water and Small Water in England; Loch Sloy, Carron Valley Reservoir, Lochan Shira, Loch Tarsan, Loch Glashan and Allt na Lairige in Scotland; Llyn Arenig Fawr in Wales) (Winfield et al., 2013; Lyle, Stephen & Adams, 2017). The population size is unknown, but the geographical range is small and climate change has been identified as the main threat and is likely to affect most subpopulations simultaneously (Winfield et al., 2013). European whitefish was therefore classified as Endangered in Britain (EN B2ab(iii)) and Scotland (EN B1ab(iii)+2ab(iii)) owing to its restricted geographical range (EOO < 5,000 km^2, AOO in Scotland <500 km^2, ≤5 locations, continuing decline in the area, extent and/or quality of habitat), and as

Critically Endangered in England and Wales (CR B1ab(iii)) as a result of its smaller range (Tables 1 and 2; Figures 1 and 2). There is no possibility of a rescue effect in the event of the British population's extinction.

3.4 | Vulnerable

Arctic charr is a circumpolar species that in Britain is confined to high-altitude or deep lakes and reservoirs. There are at least 197 confirmed populations (Maitland & Adams, 2018), largely in Scotland but including some of high national conservation value in England (eight populations) and Wales (three extant natural populations and seven benign introductions). Given the species' temperature requirements and the location of Britain at the southern extremity of its global range, climate change is considered the main threat and is likely to affect most subpopulations simultaneously (Winfield et al., 2010). The population size is estimated to exceed the threshold to qualify potentially as threatened under criterion C (10,000 individuals), but the three-generation percentage change, based on catch-per-unit-effort (Coniston Water, Windermere) and hydroacoustic (Ennerdale Water, Llyn Padarn, Llyn Cwellyn, lochs Doon, Eck, Insh and Girlsta) data, was −44%. Although few of the datasets extend beyond 2016 and some of the populations in England and Wales are supplemented by stocking, the declines observed were considered to be representative and continuing. Arctic charr was therefore classified as Vulnerable in Britain and Scotland (VU A2b) owing to its population size reduction (≥30% in three generations), and as Endangered in England (EN A2b, B2ab(iii,v)) and Wales (EN B2ab(iii,v)) owing to its population size reduction (in England; ≥50% in three generations) and restricted geographical range (AOO < 500 km^2, ≤5 locations, continuing decline in the area, extent and/or quality of habitat and number of mature individuals) (Tables 1 and 2). Although anadromous Arctic charr occur elsewhere, those in Britain inhabit isolated lakes and reservoirs, and it is considered unlikely that sufficient individuals would immigrate from outside of the region to rescue the population in the event of its extinction.

The British population of twaite shad is substantially lower than it was historically, which has generally been attributed to the impacts of migration barriers and pollution (Aprahamian, Lester & Aprahamian, 1998). The species is currently known to spawn only in the catchments of the rivers Severn, Wye, Usk and Tywi, although smaller satellite and/or remnant populations may occur elsewhere (Aprahamian, Lester & Aprahamian, 1998). In England, twaite shad spawn in the Severn downstream of Worcester, the Teme (a tributary of the Severn) downstream of Powick, and the whole of the English section of Wye upstream of Monmouth. In Wales, the species spawns in the Wye downstream of Newbridge-on-Wye, the Irfon (a tributary of the Wye) near Builth Wells, the Usk downstream of Crickhowell, and the Tywi downstream of Llwynjack. Spawning run estimates are available for the Severn Estuary, but not the River Tywi. However, given that three of the four British rivers that support twaite shad discharge into the Severn Estuary, it was considered appropriate to use this as an 'index site' to assess potential changes in population size at regional level. Spawning run estimates exceeded 10,000 individuals for every year between 1979 and 2020, but the three-generation percentage change was −41% and the geographical range is small. Migration barriers and poor water quality were identified as the main threats (Aprahamian, Lester & Aprahamian, 1998), so each river (Severn, Wye, Usk and Tywi) was considered to be a separate location in the assessment. Twaite shad was therefore classified as Vulnerable in Britain (VU A2b; B1ab(v)) and Wales (VU A2b; B1ab(v) +2ab(v)) owing to its population size reduction (≥30% in three generations) and restricted geographical range (EOO < 20,000 km^2, AOO in Wales <2,000 km^2, ≤10 locations, continuing decline in the number of mature individuals), and as Endangered in England (EN B1ab(v)) because of its smaller geographical range (Tables 1 and 2; Figures 1 and 2). It is considered unlikely that sufficient individuals would immigrate from outside of the region to rescue the British population in the event of its extinction, given that genetics and telemetry studies suggest that straying rates are low (Jolly et al., 2012; Davies et al., 2020). Twaite shad possibly spawn in the estuary (beyond the scope of this assessment) of the River Cree (Maitland & Lyle, 2005), but there are no records from Scottish fresh waters, so the species qualifies as only a vagrant there and was categorized as Not Applicable.

3.5 | Least Concern

All members of the Balitoridae, Cobitidae, Cottidae, Cyprinidae, Esocidae, Gasterosteidae, Osmeridae, Percidae, Petromyzontidae and Thymallidae were classified as Least Concern at regional level as their population sizes and geographical ranges exceeded the thresholds (<10,000 mature individuals, EOO < 20,000 km^2, AOO < 2,000 km^2) to qualify potentially as threatened (Table 1). In addition, brown trout was classified as Least Concern, despite a 39% reduction in angling catches of the anadromous form (sea trout) over three generations, as the population size of the more abundant freshwater form is considered to be stable. All but one of these species were also classified as Least Concern, Not Applicable (absent or a vagrant) or Not Evaluated (non-native) at national level. However, European smelt *Osmerus eperlanus* (L.) was classified as Near Threatened in Scotland and Wales owing to its restricted geographical range and small number of locations, and because future surveys may reveal declines in the area, extent and/or quality of habitat and/or the number of mature individuals.

3.6 | Data Deficient

Ferox trout was classified as Data Deficient as it was not possible to estimate population size or geographical range, in the context of the thresholds to qualify potentially as threatened, with sufficient precision, i.e. the data were so uncertain that both Critically Endangered and Least Concern were plausible categories. Although

ferox trout may have been recorded from more than 200 sites (Ferguson & Prodöhl, 2022), only 25 are considered to be 'confirmed' (Adams, 2016), population studies have been conducted only in lochs Awe and Rannoch (Thorne, MacDonald & Thorley, 2016), and whether those in Loch Rannoch are sufficiently distinct from sympatric brown trout to be considered a separate species is uncertain (Thorne, MacDonald & Thorley, 2016). The geographical range calculated using only the 25 confirmed populations is <2,000 km^2 (the AOO threshold to qualify potentially as threatened under criterion B), but far exceeds 2,000 km^2 if based upon the ~200 possible populations. There is virtually no information on population sizes, but applying the mean annual estimate for Loch Awe of 197 adults (A. Kettle-White, pers. comm.) equates to a population size of between 4,925 (197 × 25 confirmed populations) and 39,400 (197 × 200 possible populations) for Britain, i.e. spanning the threshold of <10,000 to qualify potentially as threatened under criterion C.

3.7 | Overall qualification against the Red List Criteria

There was considerable variation in the use of the five criteria in the assessments. For example, 28, 32, 31 and 33 species were assessed under criteria A, B, C and D, respectively, whereas none were assessed under criterion E (as no suitable data or life history models were available) (Table 3). Four, four, one and three species qualified as threatened under criteria A, B, C and D, respectively, of which four, four, one and zero were ultimately classified under those criteria (Table 3). Overall, 28, three, one, zero and one species were assessed against four, three, two, one and no criteria, respectively. Five of the threatened species (Arctic charr, Atlantic salmon, European eel, European whitefish and vendace) were classified under one criterion, with two (allis shad and twaite shad) classified under two. The majority of the species for which there were insufficient data to be assessed under criteria A (allis shad, European smelt, European whitefish, ferox trout and vendace), B (ferox trout) or C (ferox trout and vendace) are listed in national conservation legislation, and three were categorized as threatened under other criteria.

4 | DISCUSSION

4.1 | Extinction risks and threats

This study represents the first formal IUCN Red List assessment of the extinction risks and threats facing the native freshwater and diadromous fishes of Britain. The proportion of species that are threatened with extinction (21%) is less than in similarly data-rich taxa, such as mammals (26%), amphibians (29%), reptiles (33%), butterflies (41%) and birds (46%), but substantially greater than in more than 30 other groups for which assessments have been conducted in Britain (Mathews & Harrower, 2020; Foster et al., 2021; Stanbury et al., 2021; Fox et al., 2022). For most species, the results reflect the global assessments conducted in the 1990s and 2000s, with the majority categorized as Least Concern (IUCN, 2023a). The exceptions, however, include some of the species that are listed in national conservation legislation in Britain.

Allis shad was classified as Least Concern at global level (IUCN, 2023a). This contrasts markedly with the situation in Britain, where there is just a single known spawning site, the population size is small and the species was classified as Critically Endangered. Twaite shad was also classified as Least Concern at global level (IUCN, 2023a), but is restricted to only four rivers in Britain, the population size is declining and it was classified as Vulnerable. Gravel extraction from the spawning site was identified as the most significant threat to allis shad in Britain (Hillman, 2020). It is essential in the short term, therefore, that the site is fully protected, both by prohibiting gravel extraction and ensuring that habitat quality and quantity are maintained at sufficient levels. Migration barriers and poor water quality were identified as the main threats to twaite shad (Aprahamian, Lester & Aprahamian, 1998). It is anticipated that the recent construction of fish passes at weirs in the River Severn will allow an expansion of the spawning distribution of twaite shad in the catchment, and potentially the recolonization of allis shad, but the efficiency of the passes is not yet known and migration barriers remain an issue in the Usk catchment. Spawning aggregations in discrete localities are extremely susceptible to habitat degradation and environmental perturbations, so passage improvements would also benefit allis shad in the Tamar. Indeed, there are plans for a multispecies fish pass at Gunnislake Weir, immediately upstream of the spawning site,

TABLE 3 Qualification against criteria A–E in the regional IUCN Red List of Threatened Species™ assessments for the native freshwater and diadromous fishes of Britain.

	Criteria				
	A	B	C	D	E
No. (%) species assessed*	28 (85%)	32 (97%)	31 (94%)	33 (100%)	0 (0%)
No. (%) species qualified as threatened	4 (14%)	4 (13%)	1 (3%)	3 (9%)	n/a
No. (%) species classified as threatened**	4 (14%)	4 (13%)	1 (3%)	0 (0%)	n/a

Abbreviation: n/a, not applicable.

*Excluding burbot (Regionally Extinct).

**The species that qualified as threatened under a criterion D (allis shad, vendace, European whitefish) were ultimately classified at a higher risk of extinction under criteria B and C.

to improve access to underexploited areas (R. Hillman, pers. comm.). Water quality is generally better than when the populations started to decline, but a pollution event during the spawning period could have significant implications, especially for allis shad.

Atlantic salmon was last classified as Least Concern at global level (IUCN, 2023a), but the British population size is declining and the species was classified as Endangered. It should be noted, however, that the last global assessment was in 1996, since when many stocks have declined and the species is likely to be re-categorized globally as threatened. Poor marine survival, climate change (e.g. increases in water temperatures), habitat loss, degradation and fragmentation, predation and overexploitation are the main threats to Atlantic salmon throughout its range, with the latter recently identified as probably the most serious issue (Dadswell et al., 2022). Despite international conservation and management efforts, the species has continued to experience widespread declines in abundance and only limited and localized recoveries, a situation that is complicated by variations in life history strategy (one- vs. multi-sea-winter fish) and genetically distinct stocks and stock components within many rivers (Garcia de Leaniz et al., 2007).

For Arctic charr, given that 10 'species' endemic to Britain have been individually assessed (IUCN, 2023a), direct comparisons of the global and regional assessments are impossible. Seven of the 10 'species' received the same classification as the single species in this study (Vulnerable), but the assessments were based upon a restricted geographical range or a very small or restricted population, rather than a declining population size. A direct comparison is possible for Wales as the sites in the two assessments were the same, with the species classified as Vulnerable at global level (IUCN, 2023a), but Endangered at a national level. That the range and number of locations are similar in the two assessments suggests that there has been a decline in the area, extent and/or quality of habitat and/or the number of mature individuals since the global assessment was conducted. Indeed, there has been an estimated 44% reduction in the British population size in the last three generations and, given that climate change is considered the main threat and will probably affect most subpopulations simultaneously (Winfield et al., 2010), it is likely that this has been reflected in Wales.

European eel has been classified as Critically Endangered at both global (IUCN, 2023a) and regional levels on the basis of its declining population trend. Although a panmictic population, the ICES recruitment index suggests that the stocks in the North Sea area have declined more than elsewhere (98.6% vs. 94.0% lower than the 1960–1979 reference levels) (IUCN, 2022). The most recent long-term analysis for Britain indicated that recruitment of glass eels to the western coast was approximately 30% of the pre-1980 level (Aprahamian & Walker, 2008). Recruitment has increased in recent years, but it is unknown whether it will continue and there may be a considerable time lag before a corresponding increase in the number of silver eels is observed (ICES, 2022). Habitat loss and fragmentation, climate-mediated shifts in oceanic conditions and increases in impingement/entrainment, exploitation and disease mortality have been identified as the most significant threats to European eel (Jacoby et al., 2015). Inland threats can potentially be managed and, indeed, there is optimism that the situation is improving following the development of national management plans (Jacoby et al., 2015), but there is still considerable work required to mitigate the impacts of migration barriers (Drouineau et al., 2018).

Vendace was classified at global level (as *C. vandesius*) as Endangered (IUCN, 2023a). The alphanumeric code (EN B1ab(iii)+2ab (iii)) implies that there was a continuing decline in the area, extent and/or quality of habitat at the time of the assessment, but the details are unclear; the only threats listed are invasive species (ruffe *Gymnocephalus cernuus* (L.); 'low impact') and pollution (habitat quality; 'past impact, unlikely to return', i.e. not continuing). Nonetheless, vendace was also classified as Endangered in this study and under the same sub-criteria and conditions, but with a projected continuing decline in the area of habitat. Specifically, Elliott & Bell (2011) calculated that: (i) climate change will cause a mean increase of >2°C in water temperature and a 10% reduction in dissolved oxygen in Bassenthwaite Lake; and (ii) habitat volume will decline greatly, with all of the 20 years simulated having periods of zero habitat volume for >7 consecutive days, suggesting that the long-term viability of the lake as a habitat for vendace is extremely low. Given the close proximity of Bassenthwaite Lake to the other subpopulations, it is likely that all will be affected by climate change simultaneously.

For European whitefish, although the taxonomy has been shown to be incorrect (Etheridge et al., 2012; Crotti et al., 2021), it is necessary to compare the national assessments for England, Scotland and Wales, respectively, with the global assessments for *C. stigmaticus*, *C. clupeoides* and *C. pennantii* to evaluate whether there have been any changes in extinction risk. For England, the species was classified as Endangered at global level but Critically Endangered at national level, and for Scotland it was Vulnerable and Endangered, respectively (IUCN, 2023a). The main reason for the differences between the global and national assessments is that climate change, specifically increases in water temperature and reductions in dissolved oxygen concentrations, is now considered the main threat and is likely to affect all subpopulations simultaneously (Winfield et al., 2013). For Wales, the global and national assessments both classified the species as Critically Endangered (IUCN, 2023a).

There are concerns that some of the vendace and European whitefish benign introductions might not persist as the sites are suboptimal. For example, some of the sites are supply reservoirs and exposed to substantial fluctuations in water levels, which has the potential to expose spawning habitats at critical times of the year. However, the suitability of at least some of the sites was assessed using the IUCN guidelines for conservation translocations (Adams et al., 2014), and monitoring indicates that populations have established and, hence, that conditions are currently adequate (Lyle, Stephen & Adams, 2017; Lyle et al., 2019). Furthermore, the native populations of European whitefish in Haweswater and Llyn Tegid are also exposed to considerable fluctuations in water level caused by abstraction. It is a requirement that even benign introductions that have previously been, but are not currently, successful are included in Red List assessments (IUCN 2012, 2022). Nonetheless, if benign introductions were excluded, vendace would be classified as Critically

Endangered in Britain and Regionally Extinct in Scotland, demonstrating the conservation importance of the translocated populations. In contrast, the assessments for European whitefish would be unchanged, reflecting the relatively small contribution of the benign introductions to the estimates of EOO and AOO.

The IUCN Red List process assesses extinction risk, and a categorization of Least Concern does not necessarily imply that there is no concern. Indeed, a number of protected species, including river lamprey *Lampetra fluviatilis* (L.), sea lamprey *Petromyzon marinus* L. and European smelt, were classified as Least Concern. There is no doubt, however, that all three species are considerably less abundant than they were historically (Maitland & Lyle, 1996; Maitland et al., 2015), but the reductions have been insufficient, in the context of the threshold used in the Red List Criteria (≥30% in 10 years/three generations), for the species to qualify as threatened. For European smelt, although the reductions in range and population size are believed to have occurred mainly in the early 1900s and, owing to improvements in habitat quality and reductions in exploitation, appear to have reversed, both are still substantially lower than they were historically (Maitland & Lyle, 1996; Colclough & Coates, 2013). Similarly, although water quality has generally improved in recent decades, river lamprey and sea lamprey are still widely affected by migration barriers (Nunn et al., 2008, 2017; Davies et al., 2021; Jubb et al., 2023) and concerns over other impacts (e.g. habitat degradation) remain (Maitland et al., 2015).

Brook lamprey *Lampetra planeri* (Bloch), bullhead and spined loach *Cobitis taenia* (L.) are also listed in national conservation legislation in Britain, but were classified as Least Concern. However, these species are under-recorded by standard fish surveys (Cowx et al., 2009), and the accuracy and precision of some of the parameters used in the assessments could undoubtedly be improved. Targeted surveys (Nunn et al., 2008, 2014; JNCC, 2015) at 'index sites' would help to better quantify regional population sizes and changes on appropriate time scales. Unfortunately, practicable monitoring programmes could be resource intensive, difficult to implement and, given the lack of evidence of a serious risk of extinction of these species, may not be justified; it should be recognized, however, that a low extinction risk at regional or national level does not necessarily imply that these species are meeting conservation targets (JNCC, 2015) in designated sites (e.g. Special Areas of Conservation and Sites of Special Scientific Interest). There are also concerns over perceived declines in some barbel *Barbus barbus* (L.) and grayling *Thymallus thymallus* (L.) populations (Antognazza et al., 2016; Marsh et al., 2021), despite being classified as Least Concern at regional level, and in the abundance of sea trout. If assessed as a separate taxonomic entity, rather than the anadromous form of brown trout, sea trout would have been classified as Vulnerable (VU A2b).

4.2 | Overall qualification against the Red List Criteria and confidence in the assessments

It is comparatively rare for freshwater fish to be assessed under criterion A (population size reduction), as estimates of reductions in population size and generation length are required and, often, routine monitoring data are not fit-for-purpose. In this study, however, 85% of species were assessed under criterion A, of which 14% were classified as threatened under this criterion. Notwithstanding, it should be noted that there were data suitable for the Criterion A population reduction calculator in only 12% of cases, but there was no evidence of reductions sufficient to qualify as threatened (≥30% in 10 years/three generations) for the other species.

For European eel and Atlantic salmon, estimates of reductions in population size were possible as a result of long-term monitoring of commercial and recreational fisheries at a regional level, and that the trends have also occurred in neighbouring regions provides high confidence in the assessments. Conversely, it was fortuitous that a long-term series of bycatch data from the Severn Estuary salmon fishery enabled population size reduction to be estimated for twaite shad. Nonetheless, given that three of the four British rivers that support twaite shad discharge into the Severn Estuary, confidence in the assessment is high. Similarly, long-term datasets were available for 11 Arctic charr 'index sites' across the species' geographical range in Britain, of which 10 have suffered significant declines in abundance, providing high confidence in the assessment; it should be noted, however, that these datasets ended in the late 2010s, so it is not possible to ascertain whether the situation has changed since then.

There is a severe lack of fish monitoring in Britain's still waters. Inevitably, this made calculating population sizes for lacustrine species, such as tench *Tinca tinca* (L.) and rudd *Scardinius erythrophthalmus* (L.), problematic, but it was also an issue for species that inhabit both lentic and lotic habitats on a regular basis, such as roach *Rutilus rutilus* (L.) and European perch *Perca fluviatilis* L. However, although the possibility of undetected population declines cannot be excluded, it was clear in the majority of cases that the population sizes far exceeded the thresholds to qualify potentially as threatened. The main exceptions were the species threatened with extinction. For example, in spite of annual monitoring of England's two vendace populations for many years, it was not possible to calculate trends in population size at regional level because although there was an estimate for England in 2017, no equivalent was available for prior to 2017 or for Scotland. Similarly, it was not possible to determine whether there had been a reduction in population size of sufficient magnitude for European whitefish to qualify as threatened.

The population sizes of some native species, especially salmonids and cyprinids, are artificially enhanced by stocking (i.e. releasing captive-reared fish into watercourses where populations of the species already exist). This is potentially important because such species are unlikely to qualify as threatened under criteria B, C or D as their geographical ranges and population sizes are too large, leaving criterion A as the only possible route. However, although it is possible for intensive stocking to obscure local reductions in abundance (as intended), it is unlikely to increase population size significantly at regional level as, for the majority of species in Britain, the prevalence and relative numbers of fish released (i.e. compared with the numbers of wild fish) are low. A possible exception is barbel, as there is genetic evidence that some native populations in small rivers mainly comprise

stocked fish (Antognazza et al., 2016), but regular natural recruitment in larger watercourses probably contributes more to the overall population size. Similarly, although stocking may have masked declines in the abundance of wild Arctic charr in Ennerdale Water and Llyn Padarn, it is unlikely to have had a major effect at regional level (>160 confirmed populations).

Although not considered the most important threats with respect to extinction risk, the potential impacts of stocking, translocating and introducing fish are manifold (Gozlan et al., 2010; Skeate et al., 2022). Indeed, some populations of the priority conservation species in Britain, particularly vendace and European whitefish, are threatened by translocated species (Winfield et al., 2012, 2013), and the adverse impacts of stocking on Atlantic salmon are well documented (McGinnity et al., 2003). Conversely, translocation has been used as a tool in the conservation of Arctic charr, vendace and European whitefish in Britain (McCarthy, 2007; Adams et al., 2014), and stocking has been used in an attempt to increase the recruitment of European eel (Aprahamian & Walker, 2008).

Geographical range (criterion B) is the parameter most frequently used to assess the extinction risk of freshwater fish (Freyhof & Brooks, 2011). Indeed, all but one species was assessed under criterion B in this study; the exception was ferox trout, for which there was insufficient information even to ascertain whether the range was larger or smaller than the thresholds to qualify potentially as threatened (EOO < 20,000 km^2, AOO < 2,000 km^2). In contrast, the British distributions of the majority of the species listed in national conservation legislation are well documented. For example, the specific sites occupied by vendace and European whitefish, and the usual upstream limits of allis shad and twaite shad, are known, making it possible to calculate ranges with both accuracy and precision. The ranges are less precisely known for European eel, Atlantic salmon and Arctic charr, but it is clear that they far exceed the thresholds to qualify potentially as threatened. For most species, ranges have been extended by translocations, but the native distributions of many are relatively well documented (Maitland, 2004; Dodd et al., 2019). The main sources of potential uncertainty are therefore in determining the number of 'locations' and whether there is a continuing decline in habitat area (allis shad, European whitefish, vendace) and the number of mature individuals (twaite shad). In these cases, however, the main threats are well known and confidence in the assessments is high.

Confidence in the assessments under criterion C (small population size and decline) was relatively low, as the threshold to qualify potentially as threatened (<10,000 mature individuals) was definitely (based upon known abundances in monitored water bodies) exceeded in only 24% of cases (eight species), but probably (based upon known abundances in monitored water bodies extrapolated across the full geographical range) also in a further 61% of cases (20 species). Notwithstanding, in the case where the population size was definitely <10,000 (allis shad), confidence in the assessment was high. In contrast, all species were assessed under criterion D (very small or restricted population) as it was possible to determine whether the population size was smaller (allis shad) or greater (all other species) than the threshold to qualify potentially as threatened (<1,000 mature individuals). Thus, confidence in the assessments based upon criterion D is high. It has seldom been possible to assess taxa under criterion E (quantitative analysis, e.g. population viability analysis) as the requisite data are invariably lacking. The majority (85%) of species were assessed against four criteria, but five were assessed against three or fewer. This is potentially important as using too few criteria could reduce the accuracy of the overall classifications.

4.3 | Conclusions, implications for conservation and recommendations

Seven of the native freshwater and diadromous fishes of Britain were categorized as being threatened with extinction at regional level, with European eel and allis shad classified as Critically Endangered, Atlantic salmon, vendace and European whitefish classified as Endangered, and Arctic charr and twaite shad classified as Vulnerable. In addition, burbot was classified as Regionally Extinct, ferox trout was categorized as Data Deficient, and 25 species were categorized as Least Concern. The data requirements under the five Red List Criteria highlighted some important knowledge and information gaps, and priorities for mitigation:

- For European eel, the priorities are to update the catch-per-unit-effort data for British elver and silver eel fisheries, as the most recent long-term analysis is now 15 years old (longer than one generation), and mitigate the impacts of migration barriers.
- For allis shad, the priorities are to obtain estimates of the spawning run in the River Tamar over three generations, so that the species can be assessed under criterion A, and fully protect the only known spawning site. Further information is also required on the status of the species in Wales.
- For Atlantic salmon, the priorities are to continue the long-term monitoring programme and enhance international efforts to address overexploitation at sea.
- For Arctic charr, vendace and European whitefish, the priorities are to monitor appropriate 'index sites', to enable the health of each population to be assessed and trends in population size to be estimated, and ensure that water quality is maintained at a sufficient level to minimize the impacts of climate change. Given that many water bodies in Scotland with the potential to support Arctic charr have never been surveyed, it is also desirable to improve knowledge of the species' distribution, in addition to re-evaluating the status of populations not monitored in the last decade.
- For twaite shad, the priorities are to continue monitoring the Severn Estuary spawning run and mitigate the impacts of migration barriers.
- For ferox trout, the priorities are to address the severe knowledge gaps regarding taxonomic status and geographical range, and monitor appropriate 'index sites' to enable trends in population size to be estimated.

- For European smelt, the priorities are to address knowledge gaps regarding its range and status in Scotland and Wales, where new data may reveal declines in habitat availability and/or population size and could result in the species being categorized as threatened.
- European sturgeon qualified as only a vagrant in fresh water, so was categorized as Not Applicable. There is some evidence, however, that British coastal waters may be important juvenile and/or adult foraging areas (S. Colclough, pers. comm.). It is recommended, therefore, that this species, and Atlantic sturgeon *Acipenser oxyrinchus* Mitchill, is re-evaluated if spawning in Britain is confirmed.
- There is a general lack of information suitable for calculating trends in population sizes. This is important because the majority of British freshwater and diadromous fishes are widespread and abundant, leaving population size reductions as the only possibility for being categorized as threatened, but the lack of data potentially prevented some from qualifying. It is recommended, therefore, that a set of regularly monitored sites is used to estimate trends in population sizes. For protected species, designated sites (Special Areas of Conservation and Sites of Special Scientific Interest) should be monitored according to national protocols (e.g. JNCC, 2015), as the data could be employed both in IUCN Red List and EC Habitats Directive (92/43/EEC) assessments. Although the reporting frequency under the EC Habitats Directive (6 years) is longer than the life span of some species, making it difficult to detect the early signs of possible catastrophes, it is sufficient for calculating trends in population size (over three generations) for IUCN Red List assessments.

Effective conservation of threatened species requires objective assessments of the status of their populations, but this can be hampered by suboptimal sampling programmes and natural variations in population dynamics (Nunn et al., 2014). Assessments must therefore be of sufficient frequency and rigour to be able to detect changes in status over time and evaluate the impacts of management interventions and conservation measures (Cowx et al., 2009; Radinger et al., 2019). The strategies and methods used to monitor freshwater fishes are changing. Technological advances in the use of eDNA, for example, have made considerable increases in surveillance effort, both spatially and temporally, possible at relatively low cost, and it is already an efficient tool for confirming the continued presence, and potentially absence, of species of interest (Hänfling et al., 2016). It is important to note, however, that eDNA and other remote (non-capture) methods cannot provide all of the information often required for monitoring purposes, such as absolute abundance, population structure, recruitment success and body length growth rates. It is likely, therefore, that a combination of traditional (capture) and more contemporary (non-capture) methods will be required in many situations (Hering et al., 2018).

The assessments in this study provide objective baselines against which future changes can be determined, and a key evidence base to support policy and management decisions for the conservation of freshwater and diadromous fish species and their habitats in Britain. It is critical, however, that the results are interpreted correctly (with reference to the Red List Categories and Criteria guidelines; IUCN, 2012, 2022) and not used as an indicator of the general ecological health of Britain's fresh waters. For example, a categorization of Least Concern (lowest extinct risk) is not equivalent to achieving Favourable Conservation Status under the EC Habitats Directive or Good Ecological Status under the EC Water Framework Directive (2000/60/EC). Instead, IUCN Red List results should complement multivariate assessments of ecological status, such as those under the auspices of the EC Water Framework Directive. The rationale is that species categorized at regional or national level as Least Concern in terms of extinction risk could simultaneously fail conservation or ecological targets at site level. It is recommended that the assessments conducted in this study are repeated every 10 years, which would enable changes in conservation status, the effectiveness of policies and where targeted interventions may be required to be examined using the IUCN Red List Index (Bubb et al., 2009; Rondinini et al., 2014).

AUTHOR CONTRIBUTIONS

Andy D. Nunn: Data curation; formal analysis; funding acquisition; investigation; validation; visualization; writing—original draft; writing—review and editing. **Rachel F. Ainsworth**: Data curation; formal analysis; investigation; validation; visualization; writing—original draft. **Silas Walton**: Conceptualization, project administration. **Colin W. Bean**: Writing—review and editing. **Tristan W. Hatton-Ellis**: Writing—review and editing. **Andy Brown**: Project administration; writing—review and editing. **Rob Evans**: Writing—review and editing. **Allison Atterborne**: Writing—review and editing. **Dave Ottewell**: Writing—review and editing. **Richard A. A. Noble**: Data curation; formal analysis; funding acquisition; investigation; project administration; validation; visualization; writing—original draft.

ACKNOWLEDGMENTS

ADN, RFA and RAAN thank and acknowledge all who contributed advice, information and data to the assessments, including Colin Adams, Miran Aprahamian, Tea Basic, Rob Britton, Barry Byatt, Pete Clabburn, Richard Cove, Charles Crundwell, William Darwall, Sean Dugan, Jonathan Gillson, Matt Gollock, Nora Hansen, Rob Hillman, Alan Kettle-White, Iain Malcolm, Graeme McKee, Lesley Morrell, Catherine Sayer, the Scottish Fisheries Coordination Centre and constituent members, Brian Shields, Aya Thorne, Angus Tree, Alan Walker and Ian Winfield. Many thanks also to Kathy Hughes and Angela Arthington for reviewing the manuscript. The study was funded by Natural England.

CONFLICT OF INTEREST STATEMENT

The authors have no competing interests to declare.

DATA AVAILABILITY STATEMENT

The dataset is freely available at DOI: 10.5281/zenodo.7940246.

ORCID

Andy D. Nunn https://orcid.org/0000-0001-8370-1221
Colin W. Bean https://orcid.org/0000-0003-3502-0995
Richard A.A. Noble https://orcid.org/0000-0002-6275-9253

REFERENCES

Adams, C.E. (2016). *Assessing the conservation value of Arctic charr, ancestral brown trout populations and fishless lochs in Scotland. Scottish Natural Heritage Commissioned Report No. 412 (ROAME No. R07AC616)*. Glasgow: Scottish Natural Heritage.

Adams, C.E., Lyle, A.A., Dodd, J.A., Bean, C.W., Winfield, I.J., Gowans, A.R. et al. (2014). Translocation as a conservation tool: case studies from rare freshwater fishes in Scotland. *Glasgow Naturalist*, 26(1), 7–24.

Antognazza, C.M., Andreou, D., Zaccara, S. & Britton, J.R. (2016). Loss of genetic integrity and biological invasions result from stocking and introductions of *Barbus barbus*: insights from rivers in England. *Ecology and Evolution*, 6(5), 1280–1292. https://doi.org/10.1002/ece3.1906

Antognazza, C.M., Sabatino, S.J., Britton, J.R., Hillman, R.J., Aprahamian, M., Hardouin, E. et al. (2022). Hybridization and genetic population structure of *Alosa* population in the United Kingdom. *Journal of Fish Biology*, 101(2), 408–413. https://doi.org/10.1111/jfb.14917

Aprahamian, M. & Walker, A. (2008). Status of eel fisheries, stocks and their management in England and Wales. *Knowledge and Management of Aquatic Ecosystems*, (390-391), 07. https://doi.org/10.1051/kmae/2009007

Aprahamian, M.W., Lester, S.M. & Aprahamian, C.D. (1998). *Shad conservation in England and Wales. R&D Technical Report W110*. Bristol: Environment Agency.

Arthington, A.H., Dulvy, N.K., Gladstone, W. & Winfield, I.J. (2016). Fish conservation in freshwater and marine realms: status, threats and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 26(5), 838–857. https://doi.org/10.1002/aqc.2712

Bubb, P.J., Butchart, S.H.M., Collen, B., Dublin, H., Kapos, V., Pollock, C. et al. (2009). *IUCN Red List Index: Guidance for national and regional use*. Gland: IUCN.

Carrizo, S.F., Smith, K.G. & Darwall, W.R.T. (2013). Progress towards a global assessment of the status of freshwater fishes (Pisces) for the IUCN Red List: application to conservation programmes in zoos and aquariums. *International Zoo Yearbook*, 47(1), 46–64. https://doi.org/10.1111/izy.12019

Chakona, A., Jordaan, M.S., Raimondo, D.C., Bills, R.I., Skelton, P.H. & van der Colff, D. (2022). Diversity, distribution and extinction risk of native freshwater fishes in South Africa. *Journal of Fish Biology*, 100(4), 1044–1061. https://doi.org/10.1111/jfb.15011

Colclough, S. & Coates, S. (2013). *A review of the status of smelt* Osmerus eperlanus *(L.) in England and Wales*. York: Environment Agency.

Cowx, I.G., Harvey, J.P., Noble, R.A.A. & Nunn, A.D. (2009). Establishing survey and monitoring protocols for the assessment of conservation status of fish populations in river Special Areas of Conservation in the UK. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 19(1), 96–103. https://doi.org/10.1002/aqc.968

Crotti, M., Bean, C.W., Gowans, A.R.D., Winfield, I.J., Butowska, M., Wanzenböck, J. et al. (2021). Complex and divergent histories gave rise to genome-wide divergence patterns amongst European whitefish (*Coregonus lavaretus*). *Journal of Evolutionary Biology*, 34(12), 1954–1969. https://doi.org/10.1111/jeb.13948

Dadswell, M., Spares, A., Reader, J., McLean, M., McDermott, T., Samways, K. et al. (2022). The decline and impending collapse of the Atlantic salmon (*Salmo salar*) population in the North Atlantic Ocean: a review of possible causes. *Reviews in Fisheries Science and Aquaculture*, 30(2), 215–258. https://doi.org/10.1080/23308249.2021.1937044

Davies, P., Britton, J.R., Nunn, A.D., Dodd, J.R., Bainger, C., Velterop, R. et al. (2021). Cumulative impacts of habitat fragmentation and the environmental factors affecting upstream migration in the threatened sea lamprey, *Petromyzon marinus*. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 31(9), 2560–2574. https://doi.org/10.1002/aqc.3625

Davies, P., Britton, J.R., Nunn, A.D., Dodd, J.R., Crundwell, C., Velterop, R. et al. (2020). Novel insights into the marine phase and river fidelity of anadromous twaite shad *Alosa fallax* in the UK and Ireland. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 30(7), 1291–1298. https://doi.org/10.1002/aqc.3343

Dodd, J.A., Vilizzi, L., Bean, C.W., Davison, P.I. & Copp, G.H. (2019). At what spatial scale should risk screenings of translocated freshwater fishes be undertaken—River basin district or climo-geographic designation? *Biological Conservation*, 230, 122–130. https://doi.org/10.1016/j.biocon.2018.12.002

Drouineau, H., Durif, C., Castonguay, M., Mateo, M., Rochard, E., Verreault, G. et al. (2018). Freshwater eels: a symbol of the effects of global change. *Fish and Fisheries*, 19(5), 903–930. https://doi.org/10.1111/faf.12300

Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., Kyne, P.M., Harrison, L.R. et al. (2014). Extinction risk and conservation of the world's sharks and rays. *eLife*, 3, e00590. https://doi.org/10.7554/eLife.00590

Elliott, J.A. & Bell, V.A. (2011). Predicting the potential long-term influence of climate change on vendace (*Coregonus albula*) habitat in Bassenthwaite Lake, UK. *Freshwater Biology*, 56(2), 395–405. https://doi.org/10.1111/j.1365-2427.2010.02506.x

Etheridge, E.C., Adams, C.E., Bean, C.W., Durie, N.C., Gowans, A.R.D., Harrod, C. et al. (2012). Are phenotypic traits useful for differentiating among *a priori Coregonus* taxa? *Journal of Fish Biology*, 80(2), 387–407. https://doi.org/10.1111/j.1095-8649.2011.03189.x

Ferguson, A. & Prodöhl, P.A. (2022). Identifying and conserving sympatric diversity in trout of the genus *Salmo*, with particular reference to Lough Melvin, Ireland. *Ecology of Freshwater Fish*, 31(2), 177–207. https://doi.org/10.1111/eff.12651

Foster, J., Driver, D., Ward, R. & Wilkinson, J. (2021). *IUCN Red List assessment of amphibians and reptiles at Great Britain and country scale*. Peterborough: Natural England.

Fox, R., Dennis, E.B., Brown, A.F. & Curson, J. (2022). A revised Red List of British butterflies. *Insect Conservation and Diversity*, 15(5), 485–495. https://doi.org/10.1111/icad.12582

Freyhof, J. & Brooks, E. (2011). *European Red List of freshwater fishes*. Luxembourg: European Commission.

Freyhof, J., Kottelat, M. & Nolte, A. (2005). Taxonomic diversity of European *Cottus* with description of eight new species (Teleostei: Cottidae). *Ichthyological Exploration of Freshwaters*, 16(2), 107–172.

Garcia de Leaniz, C., Fleming, I.A., Einum, S., Verspoor, E., Jordan, W.C., Consuegra, S. et al. (2007). A critical review of adaptive genetic variation in Atlantic salmon: implications for conservation. *Biological Reviews*, 82(2), 173–211. https://doi.org/10.1111/j.1469-185X.2006.00004.x

Gozlan, R.E., Britton, J.R., Cowx, I. & Copp, G.H. (2010). Current knowledge on non-native freshwater fish introductions. *Journal of Fish Biology*, 76(4), 751–786. https://doi.org/10.1111/j.1095-8649.2010.02566.x

Hänfling, B., Lawson Handley, L., Read, D.S., Hahn, C., Li, J., Nichols, P. et al. (2016). Environmental DNA metabarcoding of lake fish communities reflects long-term data from established survey methods. *Molecular Ecology*, 25(13), 3101–3119. https://doi.org/10.1111/mec.13660

Hering, D., Borja, A., Jones, J.I., Pont, D., Boets, P., Bouchez, A. et al. (2018). Implementation options for DNA-based identification into ecological status assessment under the European Water Framework Directive. *Water Research*, 138, 192–205. https://doi.org/10.1016/j.watres.2018.03.003

Hillman, R. (2020). *Habitat mapping and monitoring of allis shad (Alosa alosa) on the River Tamar. Research Report 1947*. Peterborough: Natural England.

ICES (International Council for Exploration of the Seas). (2021). Working group on North Atlantic salmon. ICES Scientific Reports, 3, 29. https://doi.org/10.17895/ices.pub.7923

ICES (International Council for Exploration of the Seas). (2022). European eel (*Anguilla anguilla*) throughout its natural range. Report of the ICES Advisory Committee. ICES Advice 2022, ele.2737.nea. https://doi.org/10.17895/ices.advice.19772374

IUCN (International Union for the Conservation of Nature). (2012). *Guidelines for application of IUCN Red List criteria at regional and national levels. Version 4.0*. Gland: IUCN.

IUCN (International Union for the Conservation of Nature). (2021). *Mapping standards and data quality for the IUCN Red List spatial data. Version 1.19*. Gland: IUCN.

IUCN (International Union for the Conservation of Nature). (2022). *Guidelines for using the IUCN Red List categories and criteria. Version 15*. Gland: IUCN.

IUCN (International Union for the Conservation of Nature). (2023a). *The IUCN Red List of Threatened Species. Version 2022–2*. Available at: https://www.iucnredlist.org [Accessed 19th February 2023].

IUCN (International Union for the Conservation of Nature). (2023b). *Criterion A tool: Population reduction calculator*. Available at: https://www.iucnredlist.org/resources/criterion-a [Accessed 19th February 2023].

Jacoby, D.M., Casselman, J.M., Crook, V., DeLucia, M.B., Ahn, H., Kaifu, K. et al. (2015). Synergistic patterns of threat and the challenges facing global anguillid eel conservation. *Global Ecology and Conservation*, 4, 321–333. https://doi.org/10.1016/j.gecco.2015.07.009

Jeffries, D.L., Copp, G.H., Lawson-Handley, L.J., Sayer, C.D. & Hänfling, B. (2017). Genetic evidence challenges the native status of a threatened freshwater fish (*Carassius carassius*) in England. *Ecology and Evolution*, 7(9), 2871–2882. https://doi.org/10.1002/ece3.2831

JNCC (Joint Nature Conservation Committee). (2015). *Common standards monitoring guidance for freshwater fauna*. Peterborough: JNCC.

Jolly, M.T., Aprahamian, M.W., Hawkins, S.J., Henderson, P.A., Hillman, R., O'Maoiléidigh, N. et al. (2012). Population genetic structure of protected allis shad (*Alosa alosa*) and twaite shad (*Alosa fallax*). *Marine Biology*, 159(3), 675–687. https://doi.org/10.1007/s00227-011-1845-x

Jubb, W.M., Noble, R.A.A., Dodd, J.R., Nunn, A.D., Lothian, A.J., Albright, A.J. et al. (2023). Understanding the impact of barriers to onward migration; a novel approach using translocated fish. *Journal of Environmental Management*, 335, 117488. https://doi.org/10.1016/j.jenvman.2023.117488

Kottelat, M. & Freyhof, J. (2007). *Handbook of European freshwater fishes*. Berlin: Kottelat, Cornol & Freyhof.

Lyle, A.A., Bean, C.W., Honkanen, H.M., Koene, J.P. & Adams, C.E. (2019). The establishment of Scotland's rarest freshwater fish, the vendace (*Coregonus albula*), in conservation refuge sites. *Glasgow Naturalist*, 27(1), 27–31. https://doi.org/10.37208/tgn27104

Lyle, A.A., Stephen, A. & Adams, C.E. (2017). Establishment of conservation refuge populations for Scotland's rare freshwater fish, the powan *Coregonus lavaretus*. *Glasgow Naturalist*, 26(3), 3–9.

Maitland, P. (2004). *Keys to the freshwater fish of Great Britain and Ireland with notes on their distribution and ecology. Scientific Publication No. 62*. Ambleside: Freshwater Biological Association.

Maitland, P.S. & Adams, C.E. (2018). *Arctic charr in the lochs of Scotland: An assessment of distribution and status*. Peterborough: Fast-Print Publishing.

Maitland, P.S. & Lyle, A.A. (1996). The smelt in Scotland. *Freshwater Forum*, 6, 57–68.

Maitland, P.S. & Lyle, A.A. (2005). Ecology of allis shad *Alosa alosa* and twaite shad *Alosa fallax* in the Solway Firth, Scotland. *Hydrobiologia*, 534(1–3), 205–221. https://doi.org/10.1007/s10750-004-1571-1

Maitland, P.S., Renaud, C.B., Quintella, B.R., Close, D.A. & Docker, M.F. (2015). Conservation of native lampreys. In: Docker, M.F. (Ed.) *Lampreys: Biology, conservation and control*, Vol. 1. Dordrecht: Springer, pp. 375–428. https://doi.org/10.1007/978-94-017-9306-3_8

Marsh, J.E., Cove, R.J., Britton, J.R., Wellard, R.G., House, A. & Gregory, S.D. (2021). Medium-term environmental changes influence age-specific survival estimates in a salmonid population. *Freshwater Biology*, 66(8), 1530–1545. https://doi.org/10.1111/fwb.13736

Mathews, F. & Harrower, C. (2020). *IUCN-compliant Red List for Britain's terrestrial mammals*. Peterborough: Natural England.

McCarthy, I.D. (2007). The welsh torgoch (*Salvelinus alpinus*): a short review of its distribution and ecology. *Ecology of Freshwater Fish*, 16(1), 34–40. https://doi.org/10.1111/j.1600-0633.2006.00166.x

McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N.Ó., Baker, N. et al. (2003). Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London B*, 270(1532), 2443–2450. https://doi.org/10.1098/rspb.2003.2520

McLeish, J., Briers, R.A., Dodd, J.A. & Rueckert, S. (2020). First genetic evidence that invasive bullhead (*Cottus* L. 1758) in Scotland is of English origin and the difficulty of resolving the European *Cottus* species taxonomy. *Journal of Fish Biology*, 96(3), 617–630. https://doi.org/10.1111/jfb.14247

Miranda, R., Miqueleiz, I., Darwall, W., Sayer, C., Dulvy, N.K., Carpenter, K.E. et al. (2022). Monitoring extinction risk and threats of the world's fishes based on the sampled Red List Index. *Reviews in Fish Biology and Fisheries*, 32(3), 675–991. https://doi.org/10.1007/s11160-022-09710-1

Nunn, A.D., Harvey, J.P., Noble, R.A.A. & Cowx, I.G. (2008). Condition assessment of lamprey populations in the Yorkshire Ouse catchment, north-east England, and the potential influence of physical migration barriers. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 18(2), 175–189. https://doi.org/10.1002/aqc.863

Nunn, A.D., Taylor, R.J., Cowx, I.G., Noble, R.A.A., Bolland, J.D. & Harvey, J.P. (2017). Demography of sea lamprey (*Petromyzon marinus*) ammocoete populations in relation to potential spawning-migration obstructions. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 27(4), 764–772. https://doi.org/10.1002/aqc.2748

Nunn, A.D., Tewson, L.H., Bolland, J.D., Harvey, J.P. & Cowx, I.G. (2014). Temporal and spatial variations in the abundance and population structure of the spined loach (*Cobitis taenia*), a scarce fish species: implications for condition assessment and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 24(6), 818–830. https://doi.org/10.1002/aqc.2451

Radinger, J., Britton, J.R., Carlson, S.M., Magurran, A.E., Alcaraz-Hernández, J.D., Almodóvar, A. et al. (2019). Effective monitoring of freshwater fish. *Fish and Fisheries*, 20(4), 729–747. https://doi.org/10.1111/faf.12373

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T. et al. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, 94(3), 849–873. https://doi.org/10.1111/brv.12480

Rondinini, C., Di Marco, M., Visconti, P., Butchart, S.H.M. & Boitanti, L. (2014). Update or outdate: long-term viability of the IUCN Red List. *Conservation Letters*, 7(2), 126–130. https://doi.org/10.1111/conl.12040

Skeate, E.R., Perrow, M.R., Tomlinson, M.L., Madgwick, G., Harwood, A.J., Ottewell, D. et al. (2022). Fish stocking for recreational angling is culpable for the poor condition of many English lakes designated for conservation purposes. *Inland Waters*, 12(1), 19–32. https://doi.org/10.1080/20442041.2020.1867467

Skúlason, S., Parsons, K., Svanbäck, R., Räsänen, K., Ferguson, M., Adams, C. et al. (2019). A way forward with eco-evo-devo: an extended theory of resource polymorphism with postglacial fishes as

model systems. *Biological Reviews*, 94(5), 1786–1808. https://doi.org/10.1111/brv.12534

Stanbury, A., Eaton, M., Aebischer, N., Balmer, D., Brown, A., Douse, A. et al. (2021). The status of our bird populations: the fifth birds of conservation concern in the United Kingdom, Channel Islands and Isle of Man and second IUCN Red List assessment of extinction risk for Great Britain. *British Birds*, 114, 723–747.

Thorne, A., MacDonald, A.I. & Thorley, J.L. (2016). The abundance of large, piscivorous ferox trout (*Salmo trutta*) in Loch Rannoch, Scotland. *PeerJ*, 4, e2646. https://doi.org/10.7717/peerj.2646

Tickner, D., Opperman, J.J., Abell, R., Acreman, M., Arthington, A.H., Bunn, S.E. et al. (2020). Bending the curve of global freshwater biodiversity loss: an emergency recovery plan. *Bioscience*, 70(4), 330–342. https://doi.org/10.1093/biosci/biaa002

Winfield, I.J., Adams, C.E., Bean, C.W., Durie, N.C., Fletcher, J.M., Gowans, A.R. et al. (2012). Conservation of the vendace (*Coregonus albula*), the UK's rarest freshwater fish. *Advances in Limnology*, 63, 547–559. https://doi.org/10.1127/advlim/63/2012/547

Winfield, I.J., Bean, C.W., Gorst, J., Gowans, A.R., Robinson, M. & Thomas, R. (2013). Assessment and conservation of whitefish (*Coregonus lavaretus*) in the UK. *Advances in Limnology*, 64, 305–321. https://doi.org/10.1127/1612-166X/2013/0064-0023

Winfield, I.J., Fletcher, J.M. & James, J.B. (2017). The 'reappearance' of vendace (*Coregonus albula*) in the face of multiple stressors in Bassenthwaite Lake, UK. *Fundamental and Applied Limnology*, 189(3), 227–233. https://doi.org/10.1127/fal/2016/0799

Winfield, I.J., Hateley, J., Fletcher, J.M., James, J.B., Bean, C.W. & Clabburn, P. (2010). Population trends of Arctic charr (*Salvelinus alpinus*) in the UK: assessing the evidence for a widespread decline in response to climate change. *Hydrobiologia*, 650(1), 55–65. https://doi.org/10.1007/s10750-009-0078-1

Worthington, T., Kemp, P., Osborne, P.E., Howes, C. & Easton, K. (2010). Former distribution and decline of the burbot (*Lota lota*) in the UK. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 20(4), 371–377. https://doi.org/10.1002/aqc.1113

Worthington, T., Kemp, P.S., Osborne, P.E., Howes, C. & Easton, K. (2011). A review of the historical distribution and status of the burbot (*Lota lota*) in English rivers. *Journal of Applied Ichthyology*, 27(Supplement 1), 1–8. https://doi.org/10.1111/j.1439-0426.2011.01836.x

WWF (World Wide Fund for Nature). (2021). *The world's forgotten fishes*. Gland: WWF.

WWF (World Wide Fund for Nature). (2022). *Living planet report 2022: Building a nature positive society*. Gland: WWF.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Nunn, A.D., Ainsworth, R.F., Walton, S., Bean, C.W., Hatton-Ellis, T.W., Brown, A. et al. (2023). Extinction risks and threats facing the freshwater fishes of Britain. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 33(12), 1460–1476. https://doi.org/10.1002/aqc.4014