Extinction risks and threats facing the freshwater fishes of Britain

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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. Additionally, 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 categorised as being threatened with extinction at 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 categorised as Data Deficient, and 25 species were categorised as Least Concern. European sturgeon *Acipenser sturio* and houting *Coregonus oxyrinchus*, although probably native, qualified as only "vagrants" in fresh water, so were categorised 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 world-wide 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 employed to assess global, regional and national extinction risks, including for fish (e.g. 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 categorised 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 post-glacial waterbodies 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 be reverted to their former scientific names of *C. stigmaticus* Regan, *C. clupeoides* Lacépède and *C. pennantii* Valenciennes, respectively. However, subsequent phenotypic (e.g. Etheridge et al., 2012) and genetics studies (e.g. 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 (e.g. 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 ten 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 (e.g. 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 *C. perifretum* Freyhof, Kottelat & Nolte (hereafter bullhead), rather than the European bullhead *C. 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 employs 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 (see IUCN, 2012, 2022). In this example, the taxon was assessed as Critically Endangered (CR) due 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 sub-population [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, standardised methods, to enable comparisons across taxa, space and time. The terms and parameters of most relevance to this study include "population size", "sub-population", "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 the Supporting Information.

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 categorisations of extinction risk needed to be "downlisted" (see IUCN, 2012). Meta-analyses were then conducted to examine: (1) the numbers of species categorised as threatened vs. not threatened; (2) the proportions of species for which it was possible to use each of the five assessment criteria (A–E); and (3) the types and prevalence of threats identified as being of greatest concern to threatened species. Finally, the current 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, 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 categorised 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 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 due 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). Given that 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) due to 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 sub-population, 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)] due to 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 sub-population) (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 colonised 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 hybridisation with (the considerably more abundant) twaite shad *Alosa fallax* (Lacépède) (Antognazza et al., 2022) may mean 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 categorised 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 potentially qualify as threatened under criterion B. However, the species is threatened by 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 potentially qualify as threatened under criteria C and D (10,000 and 1000 individuals, respectively), but the three generation percentage change, based on the rate of change in annual ICES pre-fishery abundance (PFA) estimates for England, Scotland and Wales (ICES, 2021), was –63%. Atlantic salmon was therefore classified as Endangered in Britain (EN A4b) due to 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) due 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). By 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). Whilst the population size is unknown, the geographical range is small and climate change has been identified as the main threat (Elliott & Bell, 2011) and is likely to affect all sub-populations simultaneously (i.e. "number of locations" = 1). Vendace was therefore classified as Endangered in Britain and Scotland [EN B1ab(iii)+2ab(iii)] due to its restricted geographical range (EOO <5000 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)] due to 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, Red Tarn), two in Scotland (Loch Lomond, 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 sub-populations simultaneously (Winfield et al., 2013). European whitefish was therefore classified as Endangered in Britain [EN B2ab(iii)] and Scotland [EN B1ab(iii)+2ab(iii)] due to its restricted geographical range (EOO <5000 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)] due to 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 sub-populations simultaneously (Winfield et al., 2010). The population size is estimated to exceed the threshold to potentially qualify as threatened under criterion C (10,000 individuals), but the three generation percentage change, based on catch-per-unit-effort (CPUE) (Coniston, Windermere) and hydroacoustic (Ennerdale, Llyn Padarn, Cwellyn, Doon, Eck, Insh, 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) due 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)] due 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)] due to its population size reduction (≥30% in three generations) and restricted geographical range (EOO <20,000 km^2, AOO in Wales <2000 km^2, ≤10 locations, continuing decline in the number of mature individuals), and as Endangered in England [EN B1ab(v)] due to 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 categorised 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 <2000 km^2) to potentially qualify 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, or 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 due to its restricted geographical range, 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 potentially qualify 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 <2000 km^2 (the AOO threshold to potentially qualify as threatened under criterion B), but far exceeds 2000 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 4925 (197 × 25 confirmed populations) and 39,400 (197 × 200 possible populations) for Britain, i.e. spanning the threshold of <10,000 to potentially qualify 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, vendace) were classified under one criterion, with two (allis shad, 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, vendace), B (ferox trout) or C (ferox trout, vendace) are listed in national conservation legislation, and three were categorised 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 thirty 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 categorised 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 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 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 recolonisation 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 multi-species fish pass at Gunnislake Weir, immediately upstream of the spawning site, to improve access to under-exploited 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-categorised 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 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 localised 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 ten ‘species’ endemic to Britain have been individually assessed (IUCN, 2023a), direct comparisons of the global and regional assessments are impossible. Seven of the ten ‘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 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 sub-populations 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) (ICES, 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: (1) climate change will cause a mean increase of >2 °C in water temperature and a 10% reduction in dissolved oxygen in Bassenthwaite Lake; and (2) 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 sub-populations, 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 sub-populations 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 sub-optimal. 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 due to 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. By 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 categorisation 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, due 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 impacted by migration barriers (Nunn et al., 2008, 2017; Davies et al., 2021; Jubb et al., 2023) and concerns over other issues (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 (e.g. 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 recognised, however, that a low extinction risk at regional or national level does not necessarily imply that these species are meeting conservation targets (see JNCC, 2015) in designated sites [e.g. Special Areas of Conservation (SACs), Sites of Special Scientific Interest (SSSIs)]. 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 due to 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 ten 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 potentially qualify 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 significantly increase population size at regional level as, for the majority of species in Britain, the prevalence and relative numbers of fish released (i.e. compared to the numbers of wild fish) are low. A possible exception is barbel, as there is genetic evidence that some native populations in small rivers are comprised mainly of stocked fish (Antognazza et al., 2016), but regular natural recruitment in larger watercourses likely 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 negative 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).

Geographic 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 potentially qualify as threatened (EOO <20,000 km^2, AOO <2000 km^2). By 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 potentially qualify 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 potentially qualify as threatened (<10,000 mature individuals) was definitely (based upon known abundances in monitored waterbodies) exceeded in only 24% of cases (eight species), but probably (based upon known abundances in monitored waterbodies 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. By 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 potentially qualify as threatened (<1000 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 categorised 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 categorised as Data Deficient, and 25 species were categorised 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 CPUE 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 minimise the impacts of climate change. Given that many waterbodies 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 categorised as threatened.
- European sturgeon qualified as only a "vagrant" in fresh water, so was categorised 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 categorised 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 (SACs and SSSIs) 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 sub-optimal 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 employed 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 categorisation of Least Concern (lowest extinct risk) is not equivalent to achieving Favourable Conservation Status (FCS) under the EC Habitats Directive or Good Ecological Status (GES) 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 categorised 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).

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ADN: data curation, formal analysis, funding acquisition, investigation, validation, visualization, writing – original draft. RFA: data curation, formal analysis, investigation, validation, visualization, writing – original draft. SW: conceptualisation, project administration. CWB: writing – review & editing. TWH-E: writing – review & editing. AB: project administration, writing – review & editing. RE: writing – review & editing. AA: writing – review & editing. DO: writing – review & editing. RAAN: data curation, formal analysis, funding acquisition, investigation, project administration, validation, visualization, writing – original draft.

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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
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

EX = Extinct, RE = Regionally Extinct, CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient, NA = Not Applicable, NE = Not Evaluated

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

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)	% 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	8350	656	Yes	4
Coregonidae									
Coregonus albula	Vendace*	EN B1ab(iii)+2ab(iii)	?	4	?	2253	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

*Note taxonomic differences between the regional and 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 sub-populations (IUCN, 2012; see Section 3 for details)

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

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

*Excluding burbot (Regionally Extinct)

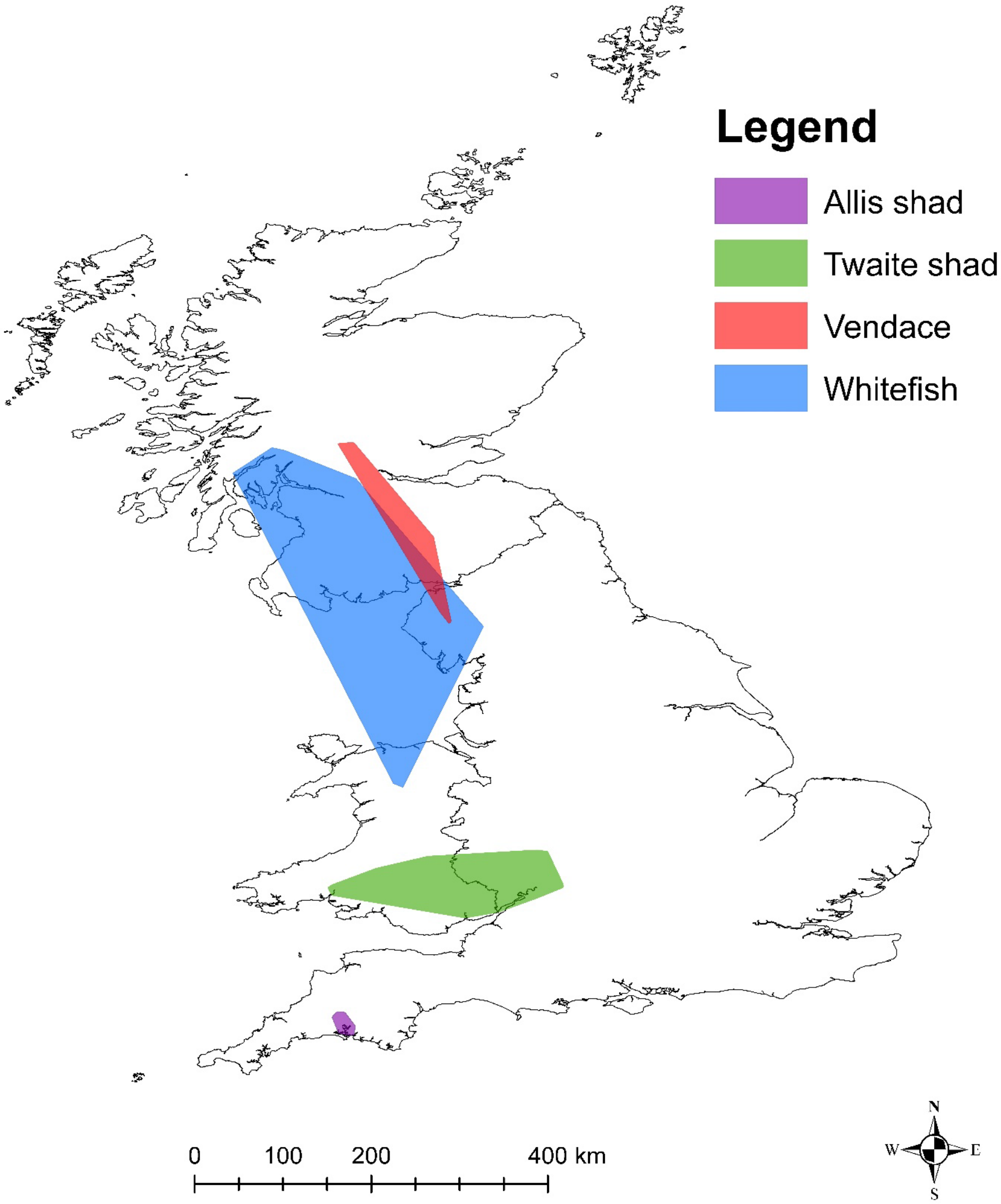
**The species that qualified as threatened under a criterion D (allis shad, vendace, European whitefish) were ultimately classified at a higher risk of extinction under criteria B and C

n/a not applicable

Figure captions

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

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


Legend
Allis shad
Twaite shad
Vendace
Whitefish
0
100
200
400 km
N
W
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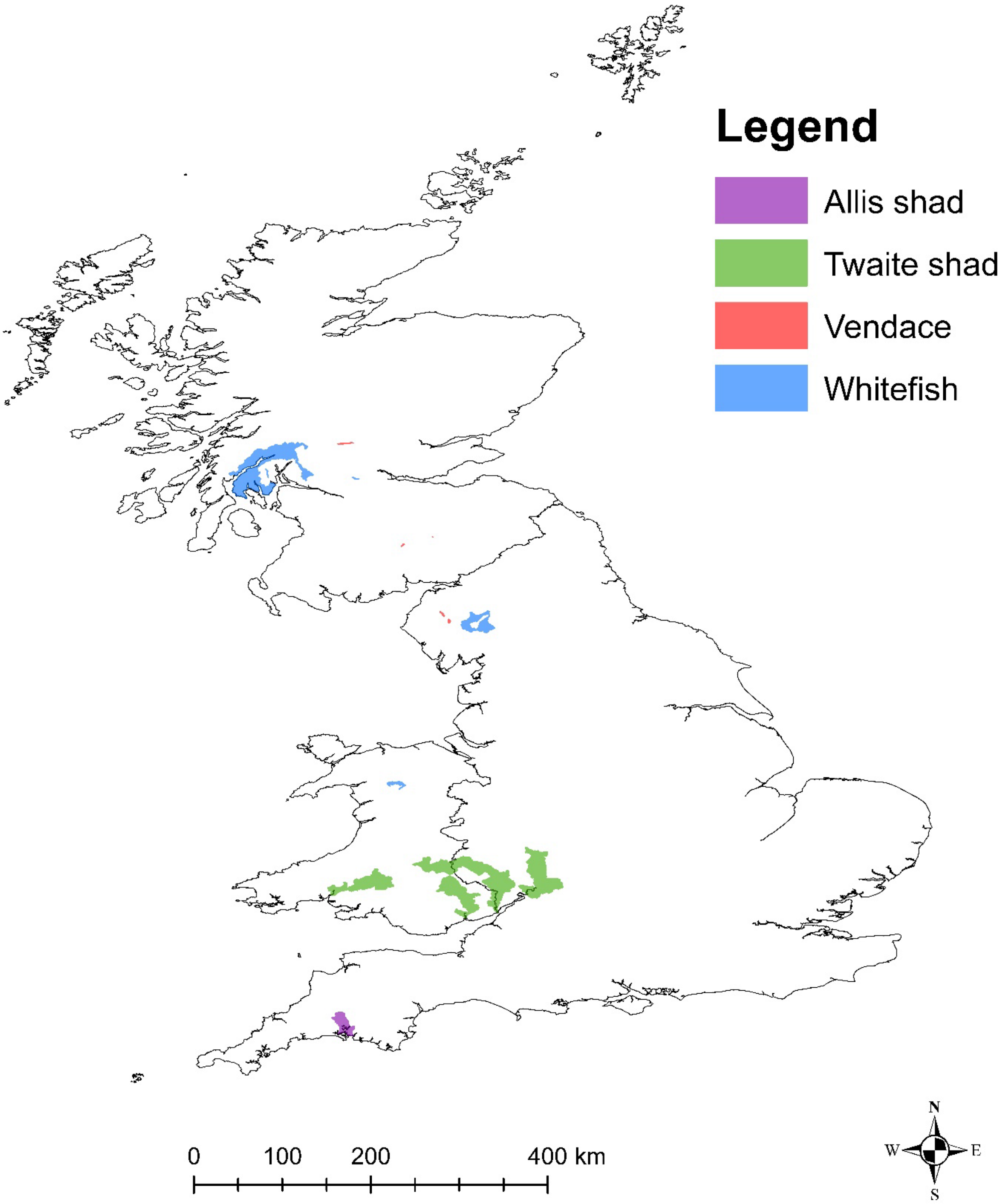
S


Legend
Allis shad
Twaite shad
Vendace
Whitefish
0
100
200
400 km
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E
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