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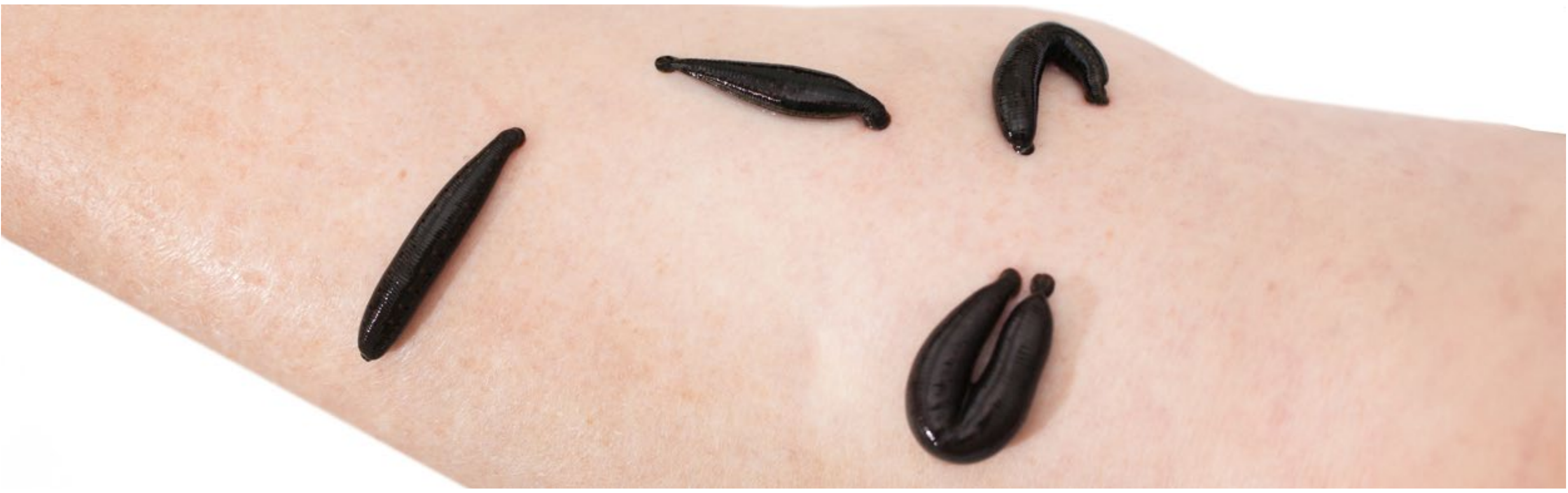

Assessment of risks posed by import of live medicinal leeches to biodiversity in Norway

Lawrence R. Kirkendall, Kyrre Kausrud, Martin Malmstrøm, Paul Berg, Anders Bryn, Kjetil Hindar, Johanna Järnegren, Anders Nielsen, Erlend B. Nilsen, Brett Sandercock, Eva B. Thorstad and Gaute Velle

Scientific Opinion of the Panel Biodiversity of the Norwegian Scientific Committee for Food and Environment

Abstract: VKM has assessed the risks to Norwegian biodiversity posed by the import of two species of medical leeches (Hirudo medicinalis, H. verbana). Hirudo medicinalis occurs naturally in Norway, but H. verbana does not. VKM has reviewed the taxonomy, ecology and uses of medical leeches generally, while focusing on these two species. The assessment includes the potential mechanisms that would have negative consequences for biodiversity should these freshwater leeches be introduced: predation on native invertebrates and vertebrates, parasitism of aquatic vertebrates, intraspecific and interspecific hybridisation, and introducing or spreading diseases. The general conclusion is that import of these two species poses little risk to Norwegian biodiversity. Mitigating measures are also discussed: importing from reputable dealers and destroying used or unwanted leeches responsibly.

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Norwegian Scientific Committee for Food and Environment (VKM)
Postboks 222 Skøyen
0213 Oslo
Norway

Phone: +47 21 62 28 00
Email: vkm@vkm.no

vkm.no

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Assessment of risks posed by imports of live medicinal leeches to biodiversity in Norway

Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion. The project group consisted of two VKM members and one VKM staff. Two referees commented on and reviewed the draft opinion. The Committee, by the Panel on Biodiversity, assessed, and approved the final opinion.

Authors of the opinion

The authors have contributed to the opinion in a way that fulfils the authorship principles of VKM (VKM, 2019). The principles reflect the collaborative nature of the work, and the authors have contributed as members of the project group and/or the VKM Panel on Biodiversity.

Members of the project group

Lawrence Kirkendall – Member of the Panel on Biodiversity in VKM and chair of the project group. Affiliations: 1) VKM; 2) University of Bergen (UiB)

Kyrre Kausrud – Member of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Norwegian Veterinary Institute (NVI)

Martin Malmstrøm – Project leader, VKM staff. Affiliation: VKM.

Members of the Panel on Biodiversity

Paul Ragnar Berg – Member of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Norwegian Institute for Water Research (NIVA)

Anders Bryn – Member of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Natural History Museum, University of Oslo; 3) Norwegian Institute of Bioeconomy Research (NIBIO)

Kjetil Hindar – Member of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Norwegian Institute for Nature Research (NINA)

Johanna Järnegren – Member of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Norwegian Institute for Nature Research (NINA)

Anders Nielsen – Vice chair of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Norwegian Institute of Bioeconomy Research (NIBIO)

Erlend B. Nilsen – Member of the Panel on Biodiversity in VKM and chair of the project group. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), 3) Nord University

Brett K. Sandercock – Member of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Norwegian Institute for Nature Research (NINA)

Eva Thorstad - Member of the Panel on Biodiversity in VKM. Affiliations: 1) VKM; 2) Norwegian Institute for Nature Research (NINA)

Gaute Velle – Chair of the Panel on Biodiversity in VKM. Affiliation: 1) VKM; 2) NORCE Norwegian Research Centre; 3) University of Bergen (UiB).

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VKM would like to thank the referees Eivind Oug (Norwegian Institute for Water Research, Norway) and Serge Utevsky (V. N. Karazin Kharkiv National University, Ukraine) for their valuable comments through critical review of the draft opinion. VKM emphasises that the referees are not responsible for the content of the final opinion. In accordance with VKM's routines for approval of a risk assessment (VKM, 2018), VKM received their comments before evaluation and approval by VKM Panel Biodiversity, and before the opinion was finalised for publication. Project leader Daniel Flø (VKM secretariat) is acknowledged for contributing help on GBIF data and illustration.

Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

Table of Contents

Summary

The Norwegian Environment Agency has asked VKM to evaluate the risks to biodiversity associated with the import of two species of leeches to Norway, *Hirudo medicinalis* and *H. verbana* (so-called medicinal leeches). In addition, they ask that the project group suggest mitigating measures that could reduce any potential risks, should import of the two species be granted.

Background

Bloodsucking leeches have been employed by humans for millennia. The two species *Hirudo medicinalis* and *H. verbana* have dominated the trade in medicinal leeches in Europe. Overcollection combined with loss or degradation of freshwater habitats led to a precipitous decline in European populations by the 1800s and led to a corresponding increase in imports from Turkey, North Africa, Russia and the Middle East. By the turn of the 19th century, the demand for live leeches in Europe had tapered off as contemporary medicine developed, only to have a small resurgence over the last decades as live leeches became recognized as useful for a variety of medical and cosmetic procedures, and to be the source of bioactive molecules of interest to medical researchers. As traditional medicine in Asia also uses a variety of leech products, there is a robust global market for live leeches and leech derivatives that is being met mostly by leech aquaculture, where the live leech trade seems dominated by *H. verbana*. There is increasing interest in commercializing production and sale of three similar leech species, *H. orientalis* from Central Asia, *H. sulukii* from a small region in Turkey, and *H. troctina* from North Africa.

Hirudo medicinalis has been used medicinally in Norway since at least the Middle Ages when they were used by barber-surgeons for bloodletting. Leeches have been dispensed by apothecaries up until the end of the 1950s. Phylogeographic studies have treated the species as native to southern Norway and the Norwegian Biodiversity Information Centre has numerous records of *H. medicinalis,* with recent records primarily from the eastern coast of southern Norway. The Norwegian Red List for Species categorizes *H. medicinalis* as being of Least Concern in Norway. *Hirudo verbana* naturally occurs in southern Europe and has not been observed in Scandinavia so far (see map in Figure 2).

Methods for the risk assessment

VKM established a small working group with expertise in invertebrates and risk assessment. Our group combed the scientific literature and relevant websites for information on the taxonomy, natural history, ecology, and medical uses of medicinal leeches broadly and *H. medicinalis* and *H. verbana* specifically. The project group contacted major leech providers in Europe and North America to learn more about leech production and sale. Using the EICAT (Environmental Impact Classification for Alien Taxa) system developed by the IUCN, The project group identified those mechanisms (“hazards”) through which these two species could affect native biodiversity in Norway should imported specimens become established in Norwegian nature, and characterized the risk related to each of these hazards. The project group then conducted a semi-quantitative risk assessment for the species according to four categories: Low, Medium, Possibly high, and High risk.

Hazards: how likely, how impactful, and overall risks

In our report, VKM regard *H. medicinalis* as a native species, since it is so treated by *Hirudo* experts and is widespread in Norway. The project group regards *H. verbana* as non-native to Norway.

The potential hazards from the EICAT system that could be associated with introducing one or both species include predation and parasitism, competition, disease transmission, and hybridization. In considering hazards, we also discuss the possible consequences of climate change, which could favour the establishment and spread of the southernly *H. verbana* should the species spread or be introduced to Norway, as increasing average annual temperatures already are higher than in recorded history of leech use in Europe.

- For *H. medicinalis,* VKM concludes that intraspecific ***hybridization*** would have minimal impact, with medium confidence. We assess that it would be moderately likely to occur with low confidence. We assess the overall risk, to be low, with medium confidence. For *H. verbana,* we assess that the interspecific hybridization would have minor impact and is unlikely to occur with medium confidence. We assess the overall risk to be low with medium confidence.

- VKM concludes that, for hazards associated with ***predation, parasitism and competition***, the magnitude of impact of *H. medicinalis* being released in Norway would be minimal, with medium confidence, while the impact of *H. verbana* would be minor with medium confidence. For *H. medicinalis*, the likelihoods of the assessed hazards are all very unlikely. These are all assessed with medium confidence. For *H. verbana*, VKM finds that it is very unlikely, with medium confidence, that any of the hazard will come into effect. Overall, the risk posed by predation, parasitism and competition was assessed to be low for both species.

- VKM concludes that, for ***disease transmission,*** the magnitude of impact of *H. medicinalis* or *H. verbana* being released in Norway would be minor, with low confidence, its likelihood very unlikely with moderate confidence, and hence the overall risk we assess as being low with moderate confidence.

Risk-reducing measures

The standard procedure for importing, holding and disposal of live leeches is to treat them as hazardous waste or biological waste and destroy them after they are used in medical procedures. As long as the safety guidelines for HAZMAT protocols are followed by hospitals and cosmetic clinics in Norway, there should be little, or no risk of medicinal leeches be introduced into Norwegian nature from imports. Any remaining risks are associated with private buyers importing leeches for use by alternative therapy actors or as aquarium animals. An important measure would be to inform private importers that it is illegal, according to the Regulation relating to alien organisms §10, to release these organisms into natural habitats in Norway.

Uncertainties and data gaps

Despite their long associations with human use, there are considerable lack of knowledge about the ecology and natural history of the two species of medicinal leeches. Knowledge gaps result in uncertainty regarding the potential for survival and establishment of introduced leeches, particularly of *H. verbana* in warmer Norwegian climates.

There are also uncertainty surrounding proper identification of species of leeches. Traditionally, there are many cases of leeches being sold as *H. medicinalis* that are actually other species of leeches. A main uncertainty regarding the importation of medical leeches, presumed to be *H. verbana* or *H. medicinalis*, is the potential risk of receiving a different species with different biological characteristics.

Conclusions

VKM concludes that the overall risk to biodiversity in Norway from importing live *H. medicinalis* and *H. verbana* is low.

Key words: VKM, risk assessment, Norwegian Scientific Committee for Food and Environment, Norwegian Environment Agency

Sammendrag på norsk

Miljødirektoratet har bedt VKM om å vurdere risikoen for biologisk mangfold knyttet til import av to arter av igler til Norge, *Hirudo medicinalis* og *H. verbana* (såkalte blodigler, medisinske igler, eller legeigler). I tillegg ber de om at VKM foreslår risikoreduserende tiltak som kan redusere mulig risiko dersom import av de to artene innvilges.

Bakgrunn

Blodsugende igler har vært brukt av mennesker i årtusener. De to artene *Hirudo medicinalis* og *H. verbana* har dominert handelen med blodigler i Europa. Overinnsamling kombinert med tap eller forringelse av ferskvannshabitater og endringer i husdyrhold førte til en kraftig nedgang i europeiske bestander på 1800-tallet og førte til en tilsvarende økning i import fra Tyrkia, Nord-Afrika, Russland og Midtøsten. Ved begynnelsen av 1800-tallet hadde etterspørselen etter levende igler i Europa avtatt etter hvert som moderne medisin utviklet seg; den har fått en liten gjenoppblomstring de siste tiårene hvor levende blodigler har blitt tatt i bruk internasjonalt i en rekke medisinske og kosmetiske prosedyrer og som kilde til lovende bioaktive molekyler for medisinsk forskning. Ettersom tradisjonell medisin i Asia også bruker en rekke igleprodukter, er det et stort globalt marked for levende igler og iglederivater som for det meste møtes av igle-akvakultur, hvor den europeiske handelen med levende igler nå domineres av *H. verbana*. Det er økende interesse for kommersialisering av produksjon og salg av tre beslektede arter tradisjonelle blodigler; *H. orientalis* fra Sentral-Asia, *H. sulukii* fra en liten region i Tyrkia *og H. troctina* fra Nord-Afrika.

Hirudo medicinalis har vært brukt medisinsk i Norge i det minste siden middelalderen da de ble brukt til årelating, og har blitt solgt av apotekere frem til slutten av 1950-tallet. Fylogeografiske studier har behandlet arten som hjemmehørende i Sør-Norge og Artsdatabanken har en rekke registreringer av *H. medicinalis*, med nyere registreringer primært fra østkysten av Sør-Norge. Norsk rødliste for arter kategoriserer *H. medicinalis* som Livskraftig. *Hirudo verbana* forekommer naturlig i Sør-Europa og er så langt ikke observert i Skandinavia (se kart i figur 2).

Metoder for risikovurderingen

VKM etablerte en liten arbeidsgruppe med ekspertise på virvelløse dyr og risikovurdering. Gruppen gjennomgikk den vitenskapelige litteraturen og relevante nettsteder for informasjon om taksonomi, naturhistorie, økologi og medisinsk bruk av medisinske igler generelt og *H. medicinalis* og *H. verbana* spesifikt. Prosjektgruppen kontaktet store igleleverandører i Europa og Nord-Amerika for å lære mer om igleproduksjon og salg. Ved å bruke EICAT-systemet (Environmental Impact Classification for Alien Taxa) utviklet av IUCN, identifiserte prosjektgruppen de mekanismene («hazards») som disse to artene kan påvirke biologisk mangfold i Norge gjennom, dersom importerte igler skulle etablere seg i norsk natur, og karakteriserte risikoen knyttet til hver av disse farene. Prosjektgruppen gjennomførte deretter en semikvantitativ risikovurdering for arten etter fire kategorier: Lav, Middels, Mulig høy og Høy risiko.

Risikofaktorer: hvor sannsynlige, hvor virkningsfulle og overordnet risiko

I rapporten anser VKM at *H. medicinalis* er en hjemmehørende art, siden den er slik behandlet av *Hirudo*-eksperter og den er utbredt i Norge. Prosjektgruppen anser at *H. verbana* ikke er hjemmehørende i Norge.

I henhold til EICAT-systemet inkluderer de potensielle farene som kan være assosiert med å introdusere en eller begge arter predasjon og parasittisme, konkurranse, sykdomsoverføring og hybridisering. I vurderingen av farer diskuterer vi også mulige konsekvenser av klimaendringer, som kan favorisere etablering og spredning *av H. verbana* dersom arten skulle spre seg eller bli introdusert til Norge i en varmere fremtid.

- For *H. medicinalis* konkluderer VKM med at intraspesifikk **hybridisering** vil ha minimal innvirkning, med middels sikkerhet. Vi vurderer at det vil være moderat sannsynlig for at hybridisering skjer, med lav sikkerhet. Vi vurderer den samlede risikoen til å være lav, med middels sikkerhet. For *H. verbana* vurderer vi at den interspesifikke hybridiseringen vil ha liten innvirkning og det er usannsynlig at den vil skje. Sikkerheten vurderes som middels. Vi vurderer den samlede risikoen til å være lav, med middels sikkerhet.
- VKM konkluderer med at for farer forbundet med **predasjon**, **parasittisme** og **konkurranse** vil omfanget av virkningen av *H. medicinalis* som slippes ut i Norge være minimal, med middels sikkerhet, mens virkningen av *H. verbana* vil være liten, med middels sikkerhet. For *H. medicinalis* er sannsynlighetene for de vurderte farene svært usannsynlige. Disse er alle vurdert med middels sikkerhet. For *H. verbana* finner VKM at det er svært usannsynlig, med middels sikkerhet, at noen av farene trer i kraft. Samlet sett ble risikoen ved predasjon, parasittisme og konkurranse vurdert til å være lav for begge arter.
- VKM konkluderer med at for **sykdomsoverføring** vil omfanget av virkningen av at *H. medicinalis* eller *H. verbana* slippes ut i Norge være liten, med lav sikkerhet, sannsynligheten svært usannsynlig med moderat sikkerhet, og dermed den totale risikoen vi vurderer som å være lav, med moderat sikkerhet.

Risikoreduserende tiltak

Standardprosedyren for import, oppbevaring og avhending av levende igler er å behandle dem som farlig avfall og destruere dem etter at de er brukt i medisinske prosedyrer. Så lenge sikkerhetsretningslinjene for HAZMAT-protokoller eller protokoller for biologisk avfall følges av sykehus og kosmetiske klinikker i Norge, bør det være liten eller ingen risiko for at medisinske igler blir introdusert i norsk natur fra import. Eventuell gjenværende risiko er forbundet med private kjøpere som importerer igler for bruk av alternative terapiaktører eller som akvariedyr. Et viktig tiltak vil være å gjøre private importører oppmerksomme på at det er ulovlig i henhold til forskrift om fremmede organismer §10 å sette disse organismene ut i naturlige habitater i Norge.

Usikkerheter og kunnskapshull

Lite er kjent om naturhistorien til de to artene av medisinske igler. Kunnskapshull gir usikkerhet om potensialet for overlevelse og etablering av introduserte igler, spesielt av *H. verbana* i fremtidige varmere norsk klima.

Det er også usikkerhet rundt riktig identifikasjon av arter av igler. Historisk sett har det vært mange tilfeller av igler som selges som *H. medicinalis* som faktisk var andre arter av medisinske igler. En usikkerhet knyttet til import av medisinske igler, antatt å være *H. verbana* eller *H. medicinalis,* er den potensielle risikoen for å motta en annen art med potensielt forskjellige biologiske egenskaper.

Konklusjoner

VKM konkluderer med at den samlede risikoen for biologisk mangfold i Norge ved import av levende *H. medicinalis og H. verbana* er lav.

Background as provided by the Norwegian Environment Agency

The Norwegian Environment Agency has received applications for the import of *H. verbana* for cosmetic and hobby use. In addition, applications are received by the CITES Management Authority for the import of *H. medicinalis* for medicinal use.

When assessing the applications, particular emphasis must be placed on whether the organism applied for may entail a risk of adverse consequences for biological diversity. Permission cannot be granted if there is reason to assume that the importation will entail significant adverse consequences for biological diversity, cf. regulation on alien organisms §§ 6 and 10.

The aim of this risk assessment is to determine whether the species can be included in Annex 2 to the regulation on alien organisms.

Terms of reference as provided by the Norwegian Environment Agency

The Norwegian Environment Agency commissions VKM to:

1. Carry out a risk assessment related to the import of the leeches *H. verbana* and *H. medicinalis* against negative effects on biological diversity in Norway.

2. Propose possible measures that can reduce the risk to Norwegian natural diversity, if the species are imported.

1 Introduction and background on medical leeches

1.1 Historical uses of medicinal leeches

"Medical leeches" (or 'medicinal leeches; *blodigler, blodigler*) is the commonly used term for a small number of species of hermaphroditic blood-feeding aquatic worms (Annelida) with suckers at both ends of their bodies. Medical leeches can be defined narrowly to include those species used alive for medical purposes: in reconstructive surgery, microsurgery and cosmetic surgery. The term is sometimes used more broadly to also include species used dried and powdered as medicine as well as species from which medically useful chemical compounds are extracted and sold. Even more broadly, the term can also encompass species that have been subject to medicinally relevant research.

Live leeches have been employed by humans for millennia (Elliott & Kutschera, 2011), principally for bloodletting ("phlebotomy", based on the Greek for vein, *phlebos*) as chemicals in their saliva prevent blood from clotting. The first written mention of the practice of using live leeches for bloodletting ("leeching" or "phlebotomy", based on the Greek for vein, *phlebos*) seems to be that found in a medical poem by Nicander of Colophon (185–135 BC), a Greek poet and physician, but leeches can be seen in pharaoic wall paintings that are over 3000 years old (Whitaker et al., 2004). Leeching has been so intertwined with medical practice that the English word "leech" is derived from the Old English "læce", a word that meant physician (Mory et al., 2000, Gayek, 2020).

Using leeches for medicinal purposes has been widely practiced in Eurasia and goes back several thousands of years (Whitaker et al., 2004; Tan, 2008; Elliott & Kutschera, 2011; Alharbi, 2015; Lemke & Vilcinskas, 2020; Alaama et al., 2024). The widespread but dangerously incorrect belief that "leeching" blood (the most common form of bloodletting) could cure nearly every ailment (Munshi et al., 2008) led to the near-extinction of the medical leech, *Hirudo medicinalis* Linnaeus, 1758*,* in Europe by the mid-1800s due to over-collecting combined with loss of freshwater ecosystems favourable for leeches (Elliott & Kutschera, 2011; Kutschera & Elliott, 2014; Saglam et al., 2016). Kutschera & Elliott (2014) invoke the use of troughs instead of ponds for watering cattle and horses as a further factor contributing to declining populations of medical leeches. The decimation of native populations in Europe, in turn, led to an increase in the use of leeches imported from Turkey, North Africa, the Middle East, and Russia: *H. medicinalis*, *H. verbana* Carena 1820, *H. troctina* Johnson, 1816, or *H. orientalis* Utevsky & Trontelj, 2005 (Kasparek et al. 2000; Hechtel & Sawyer, 2002; Elliott & Kutschera, 2011; Godekmerdan et al., 2011). The commercial interest in *Hirudo* species resulted in first *H. medicinalis* and later *H. verbana* being added to CITES Appendix II —the only parasitic species in this Appendix.

Overcollection is similarly considered an important factor in the decline of east Asian leech populations of the most used species *H. nipponia.* Leeches have been used medicinally in China for over two millennia, in both traditional and contemporary medical practice, where extracts from freeze-dried leeches are currently prescribed for treating arthritis, stroke, and several other conditions (Wang et al. 2022).

1.2 Current uses

Both live leeches and extracts of specific biochemicals from leeches are used in modern medicine. Reliance on *H. medicinalis* (and relatives) for bloodletting using live leeches was replaced by evidence-based medical procedures in the early 20th century. However, a growing demand by the pharmaceutical industry for extracts of leeches for preparation of medicines (e.g. Lemke & Vilcinskas, 2020; Alaama et al., 2024) has again increased pressure on *H. medicinalis* populations and led to a proliferation of leech farms, mainly for producing *H. verbana* (Petrauskiené et al., 2011; Trontelj & Utevsky, 2012; Saglam et al., 2016).

In 2004, The United States Federal Drug Administration (FDA) approved the use of *H. medicinalis* and *H. verbana* in plastic surgery as "medical devices" but with the proviso that they must be imported from approved suppliers in Europe (Hackenberger & Janis, 2019; McClure et al., 2021). There has been renewed interest over the past half century in using live leeches (now called hirudotherapy), especially to help restore blood circulation and hinder blood clotting after plastic or restorative surgery. Leeches are now used in conjunction with re-attachment of severed body parts such as nose tips, fingertips, or ears (Kraemer et al., 1988; Weinfield et al., 2000; Whitaker et al., 2004a, 2011, 2012; Sig et al., 2017; Facchin et al., 2018; Hackenberger & Janis 2019). Additional applications include (among others) use after breast surgery (Rajaram et al., 2024); use after urological and other forms of microsurgery (Whitaker et al., 2011; Battin et al., 2023); to treat abscesses and glaucoma (Singh, 2010); for controlling migraine headaches (Khan et al., 2019); and for uses in dermatology and cosmetology (Zabkowska et al., 2022) (for further human uses, see Lemke & Vilcinskas, 2020 and Alaama et al., 2024). Potential drawbacks from use of medical leeches include an increased risk of secondary bacterial infections (Schnabl et al., 2010, Verriere et al., 2016). Live leeches are also now used in veterinary surgery (Sobczak & Kantyka, 2014; Kermanian et al., 2022). Extracts from leeches (such as those sold in gels or creams) can be used to keep blood from coagulating, have anti-inflammatory properties, and can relieve pain (Sig et al., 2017; Lukas et al., 2019; Alaama et al., 2024). There are also a rising number of traditional or alternative practices, often dubbed holistic, that use leeches outside of the official knowledge-based medical system and under varying degrees of oversight (Lemke et al., 2020).

An advantage to using live leeches is that, unlike drugs with the same effects, leeches have no serious side effects beyond a manageable risk of infection. The utility of leeches in keeping blood flowing has naturally led to considerable research into exactly how they achieve this, with the goal being to develop equivalent treatments not requiring live individuals. Consequently, anticoagulants isolated from leeches are now being studied for their wide range of medicinal applications (Salzet, 2001; Phillips & Siddal, 2009; Kvist et al., 2013, 2020; Müller et al., 2016, 2022; Iwama et al., 2019; Lukas et al., 2019; Lemke & Vilcinskas, 2020; Tong et al., 2022; Alaama et al., 2024).

Leech anticoagulents are ancestral, meaning that they arose before bloodfeeding evolved and that even some non-bloodfeeding taxa produce them (Iwama et al., 2022). Thus, the predatory species *Whitmania pigra* is raised in large-scale aquaculture where juvenile leeches are fed purpose-bred invertebrates like juvenile snails (Xiong et al. 2023). These are not used live; rather, dried extracts of *Whitmania* leeches are taken orally in traditional Chinese medicine for "disorders of blood stasis" (Müller et al., 2022). Similarly, Asian buffalo leeches (*Hirundinaria*, *Poeciobdella*) are often used in the form of dried powders distributed orally in the treatment against thrombosis and related conditions (Liu et al. 2023). Essentially, several species of buffalo leeches are used similarly to the European medicinal leeches. They produce many of the same compounds as *Hirudo* leeches and have a similar feeding behaviour even though they are adapted to feed on larger mammals.

In Norway, *H. medicinalis* leeches were used in the same ways as they were used in other parts of Europe. In the Middle Ages, bloodletting was the prerogative of so-called barber-surgeons (Elliott & Kutschera, 2011). As the institution of apothecaries evolved, they because the local suppliers of leeches, and Norwegian apothecaries carried leaches up through the 1950s (Jonsson & Jonsson, 2012).

Currently, the Oslo University Hospital (*Rikshospitalet*) uses leeches in replantation surgery (the reattachment of severed body parts) when there are problems with restoring blood circulation (Bergsagel, 2020). The hospital's handbook for nurses includes a section on the maintenance, application, and disposal of live leeches (https://sykepleien.no/2020/02/sykepleiernes-blodigler-redder-pasydde-fingre-og-taer?auHash=M4TUEMt4FwVBi_0446GtCfp8BUx7zr_J6uhOGqKFOAk). We are unaware of leech use by other hospitals or clinics in Norway.

1.3 Taxonomy and distributions

1.3.1 Taxonomy

Leeches (subclass Hirudinea) are one of the major lineages of segmented worms in Phylum Annelida with 900+ species described worldwide (Magalhães et al., 2021). The three groups of leeches that have received the greatest use within traditional and modern medicine belong to three major families—Hirudinidae (66 spp.), Macrobdellidae (16 spp.), and Praobdellidae (24 spp.). They are found in freshwater habitats around the world (de Carle 2022 following Sket & Trontelj, 2008 and Phillips, 2011). Most of the species that have been used for medicinal bloodletting purposes belong to the genus *Hirudo*, but species from other genera have therapeutic or pharmaceutic importance in modern and traditional or alternative medicine and therefore are collected in nature or are raised in aquaculture (Lukas et al., 2019; Wang et al., 2022).

Hirudo (Hirudinidae) are the leeches best known for medical use in Europe. The taxonomy of the genus has been the subject of much study in recent decades. Despite the advent of molecular methods, some systematic relationships remain unresolved. In addition to seven known species of *Hirudo*, it is likely that a formal re-definition of the genus will also include the jawless, non-bloodfeeding genus *Whitmania* (Phillips & Siddal, 2009; Ye et al., 2015; de Carle, 2022) (Figure 1). The formally unpublished results in the de Carle (2022) thesis support an earlier finding that the genus *Hirudo* is probably paraphyletic unless *Whitmania* (grey in the figure) is included (Phillips & Siddal, 2009; Ye et al., 2015). Other than the recently described *H. sulukii* Saglam, Saunders, Lang and Shain, 2016, these species seem to have been extensively used for various medical practices, at times interchangeably.

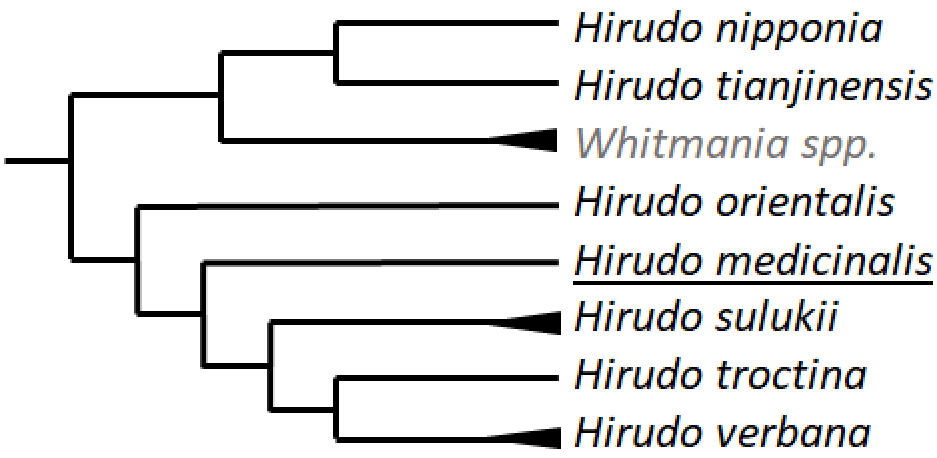

Figure 1 An updated taxonomy of *Hirudo*, simplified from de Carle (2022), with *H. tianjinensis* added according to Wang et al. (2022). Collapsed branches are shown with triangles, and the type species is underlined.

The genus *Hirudo* was defined by Linnaeus for the commercial species *Hirudo medicinalis* Linnaeus, 1758. His description of the new species was presumably based on leeches available in the local apothecary, and the taxonomy of leeches was based almost entirely on external morphology throughout most of the 18th and 19th centuries (Hechtel & Sawyer, 2002). However, Moquin-Tandon (1846) concluded that the numerous named colour varieties in use at that time all belonged to *H. medicinalis,* with the single exception of the North African species *H. troctina* Johnson, 1816 (Hechtel & Sawyer 2002).

Hirudo medicinalis and *H. troctina* were thus the only accepted *Hirudo* species until the late 20th century. *Hirudo verbana* was also described quite early but was subsequently considered a subspecies of *H. medicinalis* (Moquin-Tandon, 1846) until it was recognized as an independent species by Nesemann and Neuberts (1999). The conclusion that *H. verbana* is a valid species is supported by data from morphological, biochemical, karyological, ecological, and life history studies, as well as from molecular taxonomy (Trontelj & Utevsky, 2005, 2012; Kutschera, 2012; Phillips & Siddall, 2009; Utevsky et al., 2009; Petrauskiené et al., 2011; Kutschera & Elliott, 2014; Saglam et al., 2016; Wang et al., 2022).

Hirudo verbana was long confused with *H. medicinalis,* because they are both European species with similar morphology and natural history. Mistakes in identification have frequently been made in published studies and by companies selling leeches, despite that distinctive features separating *H. medicinalis* and *H. verbana* are “obvious” and have been repeatedly described in the literature (see Kutschera & Elliott, 2014 and the references they cite). The two species are clearly distinguishable by DNA-based methods, which in turn have clarified how to identify adults or larvae based on morphological characters such as the repeating segmental patterns of dark spots, lines or blotches (Kutschera & Elliott, 2014: Figure 1). *Hirudo medicinalis* and *H. verbana* do not successfully hybridize in aquaculture (Kustchera 2004a, 2012).

Hirudo orientalis, too, was long confused with *H. medicinalis*, and has seen extensive medical use. It was first recognized as a separate, more southerly species by Utevsky and Trontelj (2005). The "Turkish medicinal leech", *H. sulukii* (Saglam et al. 2016) has added another species that could become a candidate for the medical application markets, as it seems well suited for aquaculture (Ceylan et al., 2021). In the future, this species is likely to be used in parallel and possibly interchangeably with the other medical leeches.

Further east, several species of native *Hirudo* leeches have been used medically for millennia in China. Medicinal leeches there belong to the species *H. nipponia* Whitman, 1886 and the newly described *H. tianjinensis* Liu, 2022 (Wang et al., 2022). *Hirudo nipponia* and *H. tianjinensis* are often used together with other leeches like *Whitmania* spp. (see below) in traditional Chinese pharmacies (see Tong et al. 2022, Müller et al. 2022), but they are ecologically more similar to the western *Hirudo* species. They are used as live leeches in more similar fashions for bloodletting and thrombosis prevention. As the species are closely related, morphologically similar, and commonly referred to as "medicinal leeches" in everyday speech, it seems likely that these taxa are part of the medicinal leech trade. Trade in leeches from Asia is likely to increase given that *H. nipponia* is currently bred in large quantities for sale.

As mentioned above, the genus *Hirudo* was found by de Carle (2022) to be paraphyletic unless the predatory *Whitmania* species are included, unless they are excluded together with current *Hirudo* species *nipponia* and *tianjinensis* (see also Tong et al. 2022). Certain *Whitmania* species, such as *W. pigra* Whitman, 1844, and *W. laevis* Baird, 1869 are commonly employed as medical leeches in Asia, with *W. pigra* being the most commonly available leech in the Chinese commercial leech market (Dong et al., 2016). Being jawless, *Whitmania* species are easy to distinguish from *Hirudo* species upon closer examination. As predators, *Whitmania pigra* and the other *Whitmania* species are ecologically different from the rest of the *Hirudinidae.* However, due to their bioactive compounds and ready availability, they are frequently used in medical practice and research (Tong et al. 2022, Müller et al. 2022); they are used so extensively in traditional Chinese medicine that they are often referred to as "medical leeches" in everyday speech. In the common "Shuizhi" medicine, *Whitmania* species are used together with a mix of *Hirudo* species such as *H. medicinalis* or *H. nipponia* (Dong et al. 2016). Large quantities of *W. pigra* are bred and traded, and several other *Whitmania* species are also traded for use in medicine or medicinal research, but not as live individuals.

The family *Macrobdellidae,* also known as the "New World medical leeches", includes five species in the genus *Macrobdella.* Two species of North American *Macrobdella* have similar bloodfeeding habits to those of *Hirudo* and are known to attack humans, *M. decora* (Say, 1824) and *M. sestertia* Whitman, 1886. Though at least *M. decora* has been used medicinally siince the 1800s, *Macrobdella* species have not been widely exploited for medicinal use because of weaker anticoagulant properties (Phillips & Siddall, 2005; Poly, 2018 McClure et al., 2021). *Macrobdella decora* is the most well-known and well-studied North American medical leech, native to Canada and the northern United States. However, considering the poorly resolved taxonomy and the 2019 discovery of *M. mimicus* Phillips, Salas-Montiel, Kvist, and Oceguera-Figueroa, 2019, hailed as a new medical leech (Phillips et al., 2019), it is likely that these different species have been used interchangeably throughout most of American medical history, in a manner very similar to *Hirudo medicinalis*.

Leeches in the genus *Hirudinaria* are sometimes called “Asian medicinal leeches”, but this genus and the closely related genus *Poeciobdella* are also called “Asian buffalo leeches” or sometimes “Asian cattle leeches”. These leeches tend to be large in body size, feed on mammals and are used both pharmaceutically and externally in both traditional and contemporary medicine much like the European medicinal leeches (Phillips, 2012; Jiranuntskul et al., 2022; Marchiori et al., 2024). Five currently recognized species include *H. javanica* (Walberg, 1855); *H. bpling* Phillips, 2012; *H. thailandica* Jeratthitkul & Panha, 2020); *H.manilensis* Lesson, 1842; and *H. granulosa* (Savigny, 1822). The genus is little studied and cryptic diversity is likely high, and indeed *H. manilensis* often assumed to be a species complex (Tan, 2008; Lukas et al., 2019; Jiranuntskul et al., 2022). They are often over-harvested but are also raised in aquaculture commercially for medical use in traditional medicine and for modern research and practice (Liu et al., 2016; Guan et al., 2019; Liu et al., 2023).

Table 1: Summary list of leech groups mentioned above that may be involved in import of medicinal leeches directly, or through misidentification through neglect or misapprehension. **Distribution key:** N/S/E/W=cardinal direction C=central (as in CAs); Eu=Europe, Af=Africa, As=Asia, Am=Americas, Glo=Global.

Family	Genus	Species	Distribution
Hirudinidae	*Hirudo*	*medicinalis*	Eu
Hirudinidae	*Hirudo*	*verbana*	SEu/CAs
Hirudinidae	*Hirudo*	*orientalis*	CAs/EAs
Hirudinidae	*Hirudo*	*troctina*	SEu
Hirudinidae	*Hirudo*	*sulukii*	SEu/NAf/WAs
Hirudinidae	*Hirudo*	*nipponia*	EAs
Hirudinidae	*Hirudo*	*tianjinensis*	EAs
Hirudinidae	*Whitmania*	*spp.*	EAs
Hirudinidae	*Hirudinaria*	*spp.*	EAs/SAs
Hirudinidae	*Poeciobdella*	*spp.*	EAs/Sas
Macrobdellidae	*Macrobdella*	*spp.*	NAm/SAm

In addition to the genera and species given in Table 1, the families *Praobdellidae* and *Glossiphoniidae* are occasionally referred to as medical leeches (Phillips et al. 2010, de Carle 2022) but they are not used in live leech therapy, being used only in medical research where they are unlikely to be released. These two families have a markedly different morphology from Hirudinidae—the former differing in jaw morphology, the latter in having a proboscis rather than a jaw—and species in Praobdellidae or Glossiphoniidae are thus unlikely to be confused with any *Hirudo* species. They are therefore of tangential relevance to this assessment. Further information about these groups is found in Appendix I.

1.3.2 *Distributions of H. medicinalis, H. verbana, and close relatives, and potential for hybridization*

The primary medical leech used currently in Europe is *H. verbana*, specimens of which are purchased in large numbers from leech farms (see section 3.1). *Hirudo medicinalis* is no longer widely available but may be in use as well. Three other species are or probably will in the future be available for purchase and can be used in medical applications: *H. troctina, H. orientalis*, and *H. sulukii*. Records from GBIF are plotted in Figure 2. As this is a map of Europe, the ranges of several species are not completely shown in the figure. As detailed below, *H. troctina* ranges from Spain to northwestern Africa, *H. verbana* further east than shown, and *H. orientalis* does not occur in Europe.

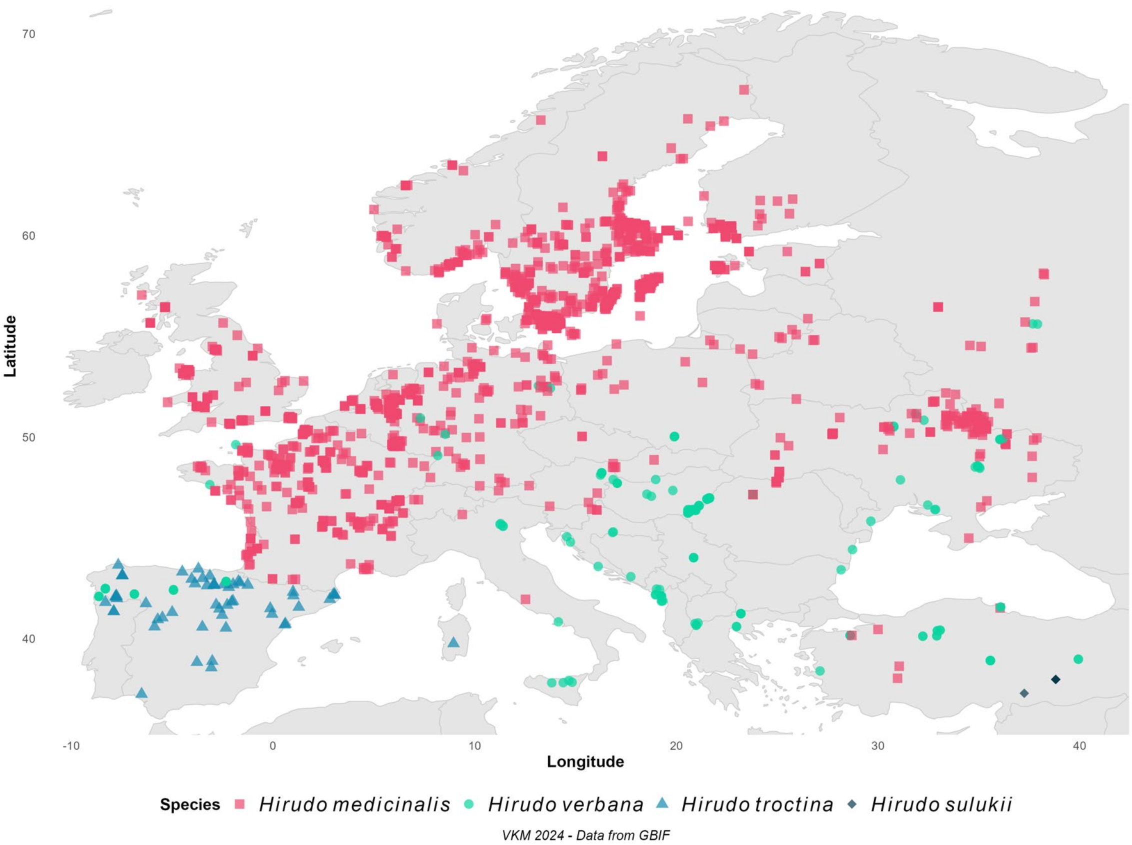

Figure 2 Observations from GBIF of the European Hirudo species. Ref: GBIF.org (15 August 2024) GBIF Occurrence Download (https://doi.org/10.15468/dl.32zmv2). The range of *H. verbana* extends much further east than is shown on the map, where it overlaps with *H. orientalis* (see text). The GBIF records for *H. medicinalis* that are from southern Ukraine and from Italy are well outside the range of that species, and presumably represent errors in identification or local introductions (Utevsky et al., 2010 and pers. comm., Sept. 2024).

Earlier discussions described the range of ***H. medicinalis*** as being from western and southern Europe to the Ural mountains (e.g. Kasparek et al., 2000; Hechtel & Sawyer, 2002; Utevsky et al., 2010). Saglam et al. (2016) characterised the current range of *H. medicinalis* as being in deciduous forests stretching from Britain and southern Norway to at least the southern Urals and east to the Altai Mountains (Mongolia).

Utevsky et al. (2010), Kutschera & Elliott (2014: Fig. 8) and Saglam et al. (2016: Fig. 9) present the range of ***H. verbana*** as extending from central and southern Europe to Central Asia. *Hirudo verbana* overlaps with *H. medicinalis* in central Europe and with *H. orientalis* in the easternmost part of its range.

Hirudo orientalis is found across more mountainous areas including Transcaucasia (South Caucasus), Iran, and Central Asia (Utevsky et al., 2010; Darabi-Darestani et al., 2019), while ***H. troctina*** is found in Spain and northwestern Africa. In addition, native *Hirudo* leeches in Turkey were thought to be *H. verbana* until the discovery and description of ***H. sulukii*** (Saglam et al. 2016), a species thus far only known from a small region of southeastern Turkey (Saglam et al., 2016; Saglam, 2019).

Hirudo medicinalis, H. verbana, and *H. orientalis*, can be forced to **hybridize** in the laboratory (Patrauskiené et al., 2009; Utevsky et al., 2009 and references therein). However, there are no observations of hybrids or reports of natural hybridization in the literature, despite wide areas where species' ranges overlap (Kutschera, 2004a, Utevsky et al, 1998, 2008). Further, Kutschera (2004a) remarks that in freshwater aquaria, where *H. medicinalis* and *H. verbana* had been kept together for several generations, no hybrids had ever been observed. Patrauskiené et al. (2009) found that in the laboratory, all three species were able to mate and produce hybrid offspring. However, fewer viable offspring were produced from interspecific crosses compared with intraspecific crosses. Decreased fecundity among hybrids indicates a degree of reproductive isolation, as well as a detrimental effect of hybridization.

1.3.2.1 Presence of medical leeches in Norway

The only medicinal species (Table 1) known to occur in Norway in the wild is *H. medicinalis* (Økland & Økland, 2008). It is unclear whether *H. medicinalis* populations in Norway represent the edge of a native species' range or are the result of anthropogenic spread (Jonsson & Jonsson, 2012). It was common practice in Europe for medical leeches to be returned to nature (dumped into ditches or ponds) after being used for bloodletting (Elliott & Kutschera, 2011). *H. medicinalis* occurs in nutrient-rich coastal freshwater habitats from Møre to the Oslo fjord according to Jonsson & Jonsson (2012), but there are now records of the species from Trøndelag and from as far north as 65.7 N (Figure 2). That Norwegian records in The Norwegian Biodiversity Information Centre are scattered but widespread suggests viable populations, particularly along the eastern coast of southern Norway, with observations being as recent as 2023. Since many localities with leeches are known and there is no indication that *H. medicinalis* populations are diminishing, the species was categorized as being of Least Concern (LC) - "*Livskraftig*" in the 2021 edition of the Norwegian Red List of Species (https://artsdatabanken.no/lister/rodlisteforarter/2021/16709).

There are no Norwegian records of *H. verbana*. This species has a more southernly distribution than *H. medicinalis* (Kutschera & Elliott, 2016; Saglam et al., 2016, see also Utevsky et al. 2010 and figure 2), suggesting that it cannot currently establish viable populations in ponds or lakes in Norway. However, *H. verbana* is not easily distinguished from *H. medicinalis* by non-experts and recent introductions of medicinal leeches into Norwegian nature could potentially have been *H. verbana* (see section 1.3.2).

1.3.3 Problems with identification

Non-experts often cannot identify *Hirudo* species based on external appearance. Additionally, the general similarity in their medical use makes it unreliable to determine to what extent medical practitioners are or have been using *H. medicinalis* despite this often being claimed or assumed. Based on molecular data, Siddal et al., (2007) demonstrated that it was *H. verbana,* not *H. medicinalis* as previously thought, being sold by commercial facilities for medicinal use and biological research. Subsequently, Trontelj & Utevsky (2012) found that most of the commercial and aquaculture medical leeches that they sequenced were *H. verbana.* Elliott and Kutschera (2011) and Kutschera and Elliott (2014) provide multiple instances of scientific publications (as well as of marketing) that confused *H. medicinalis* with *H. verbana* or other morphologically similar leech species including species as unrelated (and as dissimilar) as *Hirundinaria mallinensis* and a species of *Malagabdella.*

Morphological characters can be used to identify the western Palaearctic leeches *H. medicinalis, H. verbana, H. troctina, H. sulukii,* and *H. orientalis* (Siddall et al., 2007; Kutschera, 2012; Kutschera & Elliott, 2014; Saglam et al., 2016; Arias et al., 2021; Farzali & Saglam, 2022). The pattern of external pigmentation is the easiest to use and arguably the best character for distinguishing these species, as is clearly detailed in Saglam et al. (2016), but a variety of external and internal characters (especially those associated with reproduction) also differ among species (Saglam et al., 2016; Wang et al, 2022). But because these species of *Hirudo* leeches are closely related and morphologically similar and are used in the same medical procedures, all are referred to as “medicinal leeches” in both scientific publications and everyday speech. All these species are, or could become, involved in trade of medicinal leeches.

The Asian buffalo leeches (*Hirudinaria* spp., *Poeciobdella* spp.) have a long and continuous history of medical use in traditional Asian medicine. They are often used in the form of dried powders distributed orally, as live bloodletters, and as sources of other products derived from leeches. They are used in modern medical research in treatment against thrombosis and related conditions (Liu et al. 2023). Essentially, several species of buffalo leeches are used similarly to the European medicinal leeches. They produce many of the same compounds as *Hirudo* leeches and have a similar feeding behaviour even though they are adapted to feed on larger mammals. They are often over-harvested but are also raised in aquaculture commercially for medical use in traditional medicine and for modern research and practice (Liu et al., 2016; Guan et al., 2019; Liu et al., 2023).

1.4 Biological and ecological traits of medicinal leeches

Most published research on H. medicinalis and closely related species has focused on medical applications, whether through the use of live leeches or, increasingly, the medical use of specific compounds extracted from leeches. There are relatively few papers on the ecology of leeches published after the clarification of the taxonomic status of H. medicinalis and the species previously subsumed in that taxon. Previous European research into the biology and ecology of “*H. medicinalis*” almost certainly included H. verbana, but could even have included *H. sulukii*, *H. orientalis* or *H. troctina*.

Elements of the basic ecology of *H. medicinalis* and *H. verbana* can be found in Elliott & Tullett (1986), Merila & Sterner (2002), Elliott & Kutschera (2011), Petrauskienė et al. (2011), and especially in Kutschera & Elliott (2014).

1.4.1 *Life cycle and ecology*

1.4.1.1 Diversity and adaptability

With more than 700 described species, leeches are morphologically, physiologically, and behaviourally diverse, and occur in terrestrial, freshwater, estuarine, and marine ecosystems. The habitats include several extreme environments with regards to temperature, moisture, lack of salinity, pressure, light, and pollution. In some cases, leech species in extreme environments have specialized morphological, physiological, or behavioural adaptations, but such unique adaptations are not apparent in all species, and leech phylogeny suggests that there have been independent successful invasions of environments with extreme conditions (Phillips et al. 2020). Transcriptome studies of related taxa of leeches have showed great variations in gene expression of olfactory transduction pathways (Liu et al. 2018) and hinted that adaptability through environmentally regulated expression pathways may allow adaptation to new environments with little need for local selection.

Leeches have a wide range of life history strategies. Even diet is not a discrete character in Hirudinea: for example, several species commonly assumed to be obligate blood-feeders exploit other food sources. In addition to blood-feeding, some species additionally resort to predation (Sawyer, 1986; Verberk et al., 2008; Petrauskiené et al., 2011, Shikov, 2011; Phillips et al., 2020; Lynggaard et al., 2021). Some suck fluids from invertebrates, such as crabs or octopuses, while others have close associations with invertebrate taxa or engage in predation, swallowing amphibian eggs and aquatic invertebrates. Blood-feeding as ectoparasites is exhibited by only around one-half of the known species while the other half are predators of different invertebrates. A few species are endoparasites that can become established in the nasal or digestive orifices of birds or mammals (Phillips et al. 2020). Blood-feeding leeches have salivary secretions that increase the permeability of the skin, histamine-like secretions that dilate blood vessels, secretions that inhibit the inflammatory response, and anticoagulants (Phillips et al. 2020). Leeches attached to a host feed until they are completely engorged and then detach to slowly digest the bloodmeal over a period of several months. Leeches in the wild may persist for months between meals but may also feed far more frequently when given the opportunity (Davies & McLoughlin, 1996 Elliott and Kutschera 2011; Marden et al., 2016).

1.4.1.2 Life cycle

In general, blood-feeding leeches have three life stages: egg, juvenile and adult. Most take 1–2 years to maturation and can live for 18–27 years in a suitable environment, surviving for up to a year after their last bloodmeal. Leeches are hermaphrodites, and may in some cases self-fertilize, but mostly use another individual to reproduce. After copulation, a specialized organ secretes several cocoons, each containing about fifteen eggs, which are deposited in damp soil, attached to a surface, plant, or even future host, depending on leech species. For the first few days after hatching, juveniles feed on protein within the cocoon. After emergence from the cocoon, juveniles often feed on amphibian body fluids because amphibian skin is easily penetrable by the jaws of juvenile leeches (Boctor 2022). Early field experiments suggest that within suitable habitats, food (prey) limitation was a major factor for diversity and abundance for related leech species (Martin et al. 1994, Young & Splelling 1989).

The youngest juveniles cannot penetrate the skin of mammals and hence feed on frog or toad tadpoles and salamander larvae. Adults, too, feed on amphibians (primarily frogs and toads) though these are a suboptimal host. Though *H. medicinalis* and *H. verbana* mainly feed on the blood of large mammals (cattle, horses, sheep, deer, humans), they will also suck the blood of fish, waterfowl, and amphibians (Elliott & Tullett, 1986; Merila & Sterner, 2002; Elliott & Kutschera, 2011; Petrauskiené et al., 2011; Kutschera & Elliott 2014).

1.4.1.3 Habitat, dispersal and genetic structure

Most blood-sucking leeches inhabit nutrient-rich (eutrophic) ponds and streams with a mud bottom, well developed shoreline vegetation (such as reeds), and high summer temperatures. Laboratory data and field observations suggest that optimal temperatures for growth and reproduction lie between 22° and 28° C (reviewed in Kutschera & Elliott, 2014). Though not an optimal temperature, laboratory *H. medicinalis* populations can survive and effectively reproduce at 20° C (see their Table 2). Notably, Elliott & Tullett (1986) found that *H. medicinalis* in the wild was unable to reproduce in many water bodies due to low water temperatures: the threshold for activity was 5–9° C, and only about 10 % of juveniles can swim well enough to find hosts below 12° C. Other species have wider or different tolerances (see below). See Utevsky et al. (2010) for maps over the European *Hirudo* species distributions in relation to landscape and climate.

As leeches are hermaphroditic and most may be able to self-fertilize in the absence of mates, one would expect that modes of reproduction are likely to be reflected in their dispersal biology. *Hirudo* species and leeches with similar life histories disperse readily among water bodies primarily by attaching to vertebrates that move widely in the landscape facilitated by their ability to survive for long periods out of water (Utevsky, 2010; Trontelj & Utevsky, 2012). The European medicinal leeches can be dispersed over long distances by amphibious and mammalian hosts, such as horses, cattle, sheep, and deer. The cocoons can be spread by large waterfowl, as demonstrated for some species of freshwater leeches (Davies et al., 1982), and waterfowl are among the vertebrate hosts recorded for *H. medicinalis* and *H. verbana* (Kutschera & Elliott, 2014). Trontelj and Utevsky (2012) compared the genetic structure of *H. verbana*, *H. medicinalis* and *H. orientalis* and found that populations from across their ranges in Europe, Asia Minor, the Caucasus, and Central Asia showed surprisingly little genetic differentiation despite vast ranges. The only clear genetic structure was observed in *H. verbana,* which was subdivided into an Eastern (southern Ukraine, North Caucasus, Turkey and Uzbekistan) and Western phylogroup (Balkans and Italy). The two phylogroups did not overlap, suggesting postglacial colonization from separate refugia or survival during glacial times in separate regions. As with *H. orientalis*, long-range dispersal after the Pleistocene glaciations is assumed to have occurred via vertebrate hosts (Darabi-Darestani et al., 2018). *Hirudo verbana* and *H. medicinalis* have experienced recent rapid population growth and range expansion while isolation by distance has shaped the genetics of *H. orientalis* (Saglam et al. 2016).The habitat of the latter species is patchy and scattered among inhospitable arid and alpine areas of Central Asia and Transcaucasia.

The potential role of the spread of medicinal leeches through human activities is unclear. In modern hospital settings, leeches are destroyed after usage (Kutschera & Elliott, 2014) rather than being released to the wild as was earlier practiced. Despite extensive earlier international trade in medicinal leeches, analyses of geographic patterns of genetic variants (phylogeography) do not show clear signs of widespread establishment of imported leeches, such as eastern *H. verbana* imported into western *H. verbana* populations, and there is some evidence that medicinal leeches bred for several generations in aquaculture may not survive in natural conditions (Trontelj & Utevsky, 2012). Trontelj and Utevsky (2012) found leeches supplied by commercial facilities to belong to the Eastern phylogroup of *H. verbana,* from leading areas of leech export in Turkey and the Krasnodar Territory in Russia.

1.4.1.4 The great decline

The demand for medicinal leeches in Europe and Asia has long been greater than the supply. From historical sources, we know that leech therapy had been in use since pre-Roman times in Europe, and demand had been increasing whenever rising human population sizes periodically adopted medical leech practices. However, since medieval times, other socioeconomic processes had also been driving the wild supply down. Not all causative factors for the decline are known, but likely include land clearance, drainage of ponds and wetlands, decreasing wildlife populations, and an increasing proportion of livestock being watered from wells and troughs rather than natural water sources. Thus, by the early 1800s, the medicinal leeches were practically extinct in many countries, including Ireland, England, Wales, and the Netherlands and wild leech harvesting went from being a lucrative source of income for rural communities to offering low return. Demand for leeches drove a burgeoning international trade with imports from places such as Russia, Hungary, and the Ottoman Empire, where France alone in the early 1800s imported between 15 and 57 million leaches per year (Sawyer, 1981; Elliott & Kutschera, 2011). Import from Russia in the 1800s stressed leech populations there to the extent that collecting seasons were instituted (Wells & Coombs, 1987). A gap between supply and demand gave rise to increasingly large-scale attempts at raising leeches in aquaculture, built on treatises and increasingly accurate natural histories.

With the rise of industrialization, mechanization of the agricultural sector and the modern era the wild medicinal leech populations seem to have dwindled further as the twin processes of habitat destruction and decreasing host access accelerated and were probably exacerbated by pollution, pesticide use, and reduced populations of amphibians, as well as diseases. While the wild East Asian *Hirudo* species may have been suffering less due to the extensive wet rice agriculture providing habitat, but the other causative factors were present. For instance, the medicinal market for the East Asian *Hirudo* is larger and more focused on dried leech products rather than live ones, and there are ongoing attempts to control leech populations in fields where people work (Saglam 2018; Liu et al., 2016).

It seems likely that there are direct climate effects on leech population dynamics, little is known about this beyond that periodic drying of wetlands likely has a detrimental effect (Saglam, 2018). However, the alarming decline in insect biomass (over 74 % reduction even in protected areas of Central Europe over the last three decades) was recently found to be largely attributed to changes in climatic patterns (Müller et al. 2024). Such large-scale fluctuations in ecologically crucial groups are bound to have ecologically cascading effects, including impacts on leeches that feed on invertebrates for at least part of their life cycle.

Kubová & Schenkova (2014) studied 16 free-living aquatic leech species in the Czech Republic, including *H. medicinalis.* Only one population of the critically endangered *H. medicinalis* was found, and they were unable to assess even general ecological requirements. They comment that *H. medicinalis* populations in the Czech Republic have never recovered from extensive draining of ponds. While amphibians are important prey for medical leeches (Merila & Sterner, 2002), restricted access to mammals and forcing adult leeches to rely on the less nutritious amphibian blood would strongly impact their growth rate and fecundity, even in the presence of abundant amphibians (Davies & McLoughlin, 1996). Still, amphibians are critical for the early life stages. Kutschera and Elliott (2014) suggest that the loss of natural freshwater ecosystems, with flat, warm banks, and amphibians (frogs, newts and toads) as preferred host organisms, to be largely responsible for the decline of *H. medicinalis* in Northern Europe (see also Saglam, 2018).

1.4.1.5 Ecological differences

Beyond the generalized descriptions above, some relevant aspects about the biology of specific groups relative to *H. medicinalis* are described in the following.

Hirudo verbana Petrauskiené et al. (2011) found that *H. medicinalis* had one-third the fecundity of *H. verbana*, but that hatchlings were nearly 50 % heavier (that is, fewer but larger offspring). *Hirudo verbana* had lower survival of hatchlings but a higher growth rate. The differences in reproductive traits led the authors to conclude that *H. medicinalis* is “*K*-selected”, i.e., reproduces more slowly, producing fewer offspring and occurs in more stable and predictable habitats than *H. verbana*. *Hirudo verbana* is an “*r*-strategist” that reproduces quickly, produces a large number of offspring and inhabits unstable environments, such as temporary ponds in steppe landscapes.

Hirudo orientalis is associated with more mountainous regions than *H. medicinalis* and seems to have intermediate fecundity between *H. medicinalis* and *H. verbana* (Petruskiené et al. 2009).

Hirudo troctina is a Mediterranean, Iberian, and North African species that seem to thrive in more arid landscapes. However, little is known about the ecology of *H. troctina*. It was used intensively and interchangeably in leech treatment because it was mistaken for *H. medicinalis* in the 19th century (Trontelj and Utevsky 2012, Marrone et al. 2024).

Hirudo sulukii (Saglam et al. 2016) reaches adult size faster than *H. medicinalis*, can reproduce in colder conditions, and displays high reproductive performance, thus making it a strong candidate for leech aquaculture (Ceylan et al. 2021). This combination of traits adapted to mountaineous and colder habitats suggests that *H. suluki* could be a potentially invasive species in Norway if imported and introduced in nature, as it may have a large niche overlap and be competitive with *H. medicinalis* in its already sparse habitat.

Hirudo nipponia is an East Asian leech endemic to Japan, Korea, China, Taiwan, and eastern Russia, with a similar range of hosts compared to its European counterparts, consisting of many amphibians, reptiles, and mammals, including humans. The species is traditionally found in rice paddies, irrigation and drainage ditches, open sewers, and ponds. However, *H. nipponia* has seen a similar reduction in abundance to the European *Hirudo* species, possibly due to the use of pesticides and fertilizers. Also, widespread infections with *Klebsiella,* a gram-negative bacterium, have been implicated as part of the decline (Yibin et al., 2021).

Hirudo tianjinensis. This newly described species has an overlapping distribution with *H. nipponia* near its name city of Tianjin. Little is known about ecological preferences, except that *H. tianjinensis* has been observed to feed on *H. nipponia* when they co-occur in aquaculture but not vice versa (Wang et al. 2022).

Whitmania. The *Whitmania* species of *Hirudinidae* are ecologically different from the *Hirudo* genera in that they are not blood-feeders but rather are free-living predators that take bites out of their prey. Though not used for live leech treatments, they are still often referred to as medical leeches, especially *W. pigra.* The latter species is often called "Asian medicinal leech" in everyday speech because it is the most readily available from the Chinese traditional medicine markets as a dried powder where it is highly valued for its purported effects against poor blood circulation (Kui et al., 2024). *Whitmania pigra* has a secondary role as pest control as it feeds on snails and other crop pests.*Whitmania pigra* is thus widely distributed in southeast Asia and reared in large quantities for pest control as well as for the medicinal markets.

***Macrobdella*.** Despite being in another family, the ecology of the "North American medicinal leeches" seems to be similar to the European *H. verbana* with even the simplified gut microbiota being remarkably similar (McClure et al. 2021).

Hirudinaria, Poeciobdella. Little ecological information is available for the Asian buffalo leeches (*Hirudinaria and Poeciobdella*). In general, they tend to be large-bodied and more specialized towards larger mammals than their European *Hirudo* counterparts (Jiranuntskul et al. 2022). Their life histories seem to be relatively similar.

Other Norwegian leeches. *Acanthobdella peledina*, *Piscicola geometra* and *Cystobranchus mammilatus* are external parasites of freshwater or brackish fish, and not further discussed here. The horse leech *Haemopis sanguisuga (hesteigle)*, and dog leech *Erpobdella testacea* (hundeigle) and its close relative *Erpobdella octoculata* are predators that mostly feed on freshwater invertebrates; despite their common names, they are not ectoparasites that feed on blood from mammals. *Erpobdella testacea* is common in Norway, while *Erpobdella octoculata* has an uncertain occurrence status in Norway. *Erpobdella octoculata* is common elsewhere in Europe where it occurs in lakes, ponds, and even faster moving streams with rocky bottoms. It can also tolerate acidic and more polluted waters in Poland (Koperski 2005, 2006). *Haemopis sanguisuga* is sometimes mistaken for *H. medicinalis* or, in southern Europe or Africa, mistaken for *Limnatis nilotica* but unlike the latter *H. sanguisuga* does not enter the nasal cavity of livestock. Instead, it feeds on insect larvae, fish eggs and fry, tadpoles, worms, other leeches and gastropods, sucking its prey or swallowing them whole. It may occasionally emerge from the water to hunt earthworms (Shikov 2011). The nine species of *Glossiphoniid* leeches found in Norway have a variety of life histories but tend to parasitize amphibians or be predators on other invertebrates in freshwater.

1.5 Other relevant assessments

1.5.1 CITES

Hirudo medicinalis was considered endangered in 1987 by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (se Kasparek et al. 2000). Both *H. medicinalis* and *H. verbana* are now listed in Appendix 2 of CITES II which regulates the trade of listed species. Consequently, international import and export of these two leech species require proper certification. Challenges with species identification makes it difficult to ensure sustainable use of leeches of conservation concern. Notably, DNA sequencing of farmed medical leeches in Azerbaijan that were being exported as "*H. medicinalis"* in CITES reports were all *H. orientalis* (Farzali & Saglam 2022). In addition, there is an ongoing illegal transatlantic trade of wild-caught leeches contrary to CITES protocols (Williams et al. 2020).

1.5.2 The Norwegian Biodiversity Information Centre and the Red List

Since many localities with leeches are known and there is no indication that *H. medicinalis* populations are diminishing, the species is categorized as being of Least Concern (LC) ("*Livskraftig"*) in the 2021 edition of the Norwegian Red List (https://artsdatabanken.no/lister/rodlisteforarter/2021/16709).

The Norwegian glossiphoniid leeches are all classified as least concern or data deficient: *Alboglossiphonia heteroclita (LC), Glossiphonia paludosa (DD), Glossiphonia verrucata (LC), Glossiphonia complanata (LC), Glossiphonia concolor (DD), Helobdella stagnalis (LC), Hemiclepsis marginata (LC), Theromyzon maculosum (LC),* and *Theromyzon tessulatum (LC).*

The non-medical, freshwater leeches may have some prey overlap with juvenile medicinal leeches, *Haemopis sanguisuga*, *Erpobdella testacea and Erpobdella octoculata,* are all of Least Concern (LC). *Haemopis sanguisuga* may also be a predator on medicinal leeches (S. Utevsky 2024, pers. comm.).

The leech fauna of Norway likely includes more thanmarine species that are ectoparasites of fish (Karlsbakk 2005), but these taxa were not evaluated in this report as they were deemed irrelevant for interaction with the freshwater medicinal leeches.

In terms of potential host in Norway, the project group find that native amphibians are the most relevant species to assess the impact on. All Norwegian amphibian species, and their Red List status is listed in Table 2.

Table 2: The amphibian species, which as a group seem most likely to be impacted through predation, parasitism or disease, are categorized as follows in 2021:

Scientific name	**English name**	**Norwegian name**	**Status**
Bufo bufo	Common toad	Nordpadde	LC
Lissotriton vulgaris	Smooth newt	Småsalamander	LC
Pelophylax lessonae	Pool frog	Damfrosk	**CR**
Rana arvalis	Moor frog	Spissnutefrosk	**VU**
Rana temporaria	Common frog	Buttsnutefrosk	LC
Triturus cristatus	Northern crested newt	Storsalamander	**NT**

2 Methodology and data

2.1 Risk assessment methodology

For the questions outlined in the ToR, hazards were identified and assessed separately. VKM assessed each potential hazard, as a mechanism through which impact occurs, in four standardized steps: hazard identification, hazard characterization, likelihood, and risk characterization, as described below.

2.1.1 Description of possible mechanisms for impact

Each potential hazard is associated with a mechanism through which it has an effect on the physical environment or biological resources. VKM uses the EICAT classification system (IUCN, 2020) to first identify what mechanisms are relevant for each of the assessed species (Table 3).

Table 3. Mechanisms through which a non-native taxon can have negative impacts on native biodiversity (IUCN, 2020).

#	Impact mechanism	Description
1	Competition	The alien taxon competes with native taxa for resources (e.g., food, water, space), leading to deleterious impact on native taxa
2	Predation	The alien taxon depredates the native taxa, leading to deleterious impact on native taxa
3	Hybridization	The alien taxon hybridizes with native taxa, leading to deleterious impact on native taxa
4	Transmission of disease	The alien taxon transmits diseases to native taxa, leading to deleterious impact on native taxa
5	Parasitism	The alien taxon parasitizes native taxa, leading to deleterious impact on native taxa
6	Poisoning/toxicity	The alien taxon is toxic, or allergenic by ingestion, inhalation, or contact, or allelopathic to plants, leading to deleterious impact on native taxa
7	Bio-fouling or other direct physical disturbance	The accumulation of individuals of the alien taxon on the surface of a native taxon (i.e., biofouling), or other direct physical disturbances not involved in a trophic interaction (e.g., trampling, rubbing, etc.) leads to deleterious impact on native taxa.
8	Grazing/herbivory/browsing	Grazing, herbivory or browsing by the alien taxon leads to deleterious impact on native taxa
9	Chemical impact on ecosystem	The alien taxon causes changes to the chemical characteristics of the native environment (e.g., pH; nutrient and/or water cycling), leading to deleterious impact on native taxa
10	Physical impact on ecosystem	The alien taxon causes changes to the physical characteristics of the native environment (e.g., disturbance or light regimes), leading to deleterious impact on native taxa
11	Structural impact on ecosystem	The alien taxon causes changes to the habitat structure (e.g., changes in architecture or complexity), leading to deleterious impact on native taxa
12	Indirect impact through interactions with other species	The alien taxon interacts with other native or alien taxa (e.g., through any mechanism, including pollination, seed dispersal, apparent competition, mesopredator release), facilitating indirect deleterious impact on native taxa

2.1.2 Description of hazard identification

In the hazard identification section, we describe each specific hazard, including the mechanism it has effect through, and why this hazard is considered in the current assessment. Examples include predation on-, or competition with native species or spread of disease-causing organism. The known effects of the hazard are presented and referenced examples of the known impacts from other countries are included where information was available.

2.1.3 Description of hazard characterization

In the hazard characterization section, the specific potential effects of the hazard in question are described under current Norwegian conditions. Examples include identifying which native species the focal species could compete with or prey on. The potential magnitude of the specific hazard is then characterized from "Minimal" to "Massive" (Table 4).

Table 4. Rating of the potential magnitude of impact on biodiversity in Norway

Rating	Impact descriptors
Minimal	Impact on biodiversity is limited to occasional deaths of individuals. No expected effects on the local-, regional-, or national population size.
Minor	Impact on biodiversity includes limited reductions in local abundance of one or a few species and these effects are temporary and spatially limited. No expected effects on the regional-, or national population size.
Moderate	Impact on biodiversity can result in moderately reduced abundance of one or more species, with potential implications on population viability on a regional level.
Major	Impact on biodiversity may cause severe reductions in the abundance of one or more species, including potential extinction of local or regional populations. Consequences may also affect ecosystem functions and services. The consequences are likely reversible should the assessed species be eradicated.
Massive	Impact on biodiversity may cause detrimental reductions in the abundance of more than one species, including extinction of local populations and potentially threaten the survival of the national population. Consequences are likely to affect ecosystem functions and services and are likely irreversible.

2.1.4 Description of likelihood

In the likelihood section we assess how likely it is that the characterized hazard occurs. Likelihood intervals range from "Very unlikely" to "Very likely", as described in Table 5. In most cases unless otherwise stated explicitly, the likelihood is based on subjective assessments or expert judgement, rather than frequency-based likelihood or specific modelling that estimates the likelihood.

Table 5. Rating of the likelihood of the specific impacts in the assessment.

Rating	Likelihood descriptors
Very unlikely	Negative consequences would be expected to occur with a likelihood of 0-5%
Unlikely	Negative consequences would be expected to occur with a likelihood of 5-10%
Moderately likely	Negative consequences would be expected to occur with a likelihood of 10-50%
Likely	Negative consequences would be expected to occur with a likelihood of 50-75%
Very likely	Negative consequences would be expected to occur with a likelihood of 75-100%

2.1.5 Description of risk characterization

In the risk characterization section, the risk to biodiversity in Norway, posed by the specific hazard, is characterized as either "Low", "Medium", "Possibly high" or "High". The characterization is based on the combination of the magnitude of potential impact of that hazard (given that it becomes realized) and the overall likelihood of this occurring (Figure 3)**.**

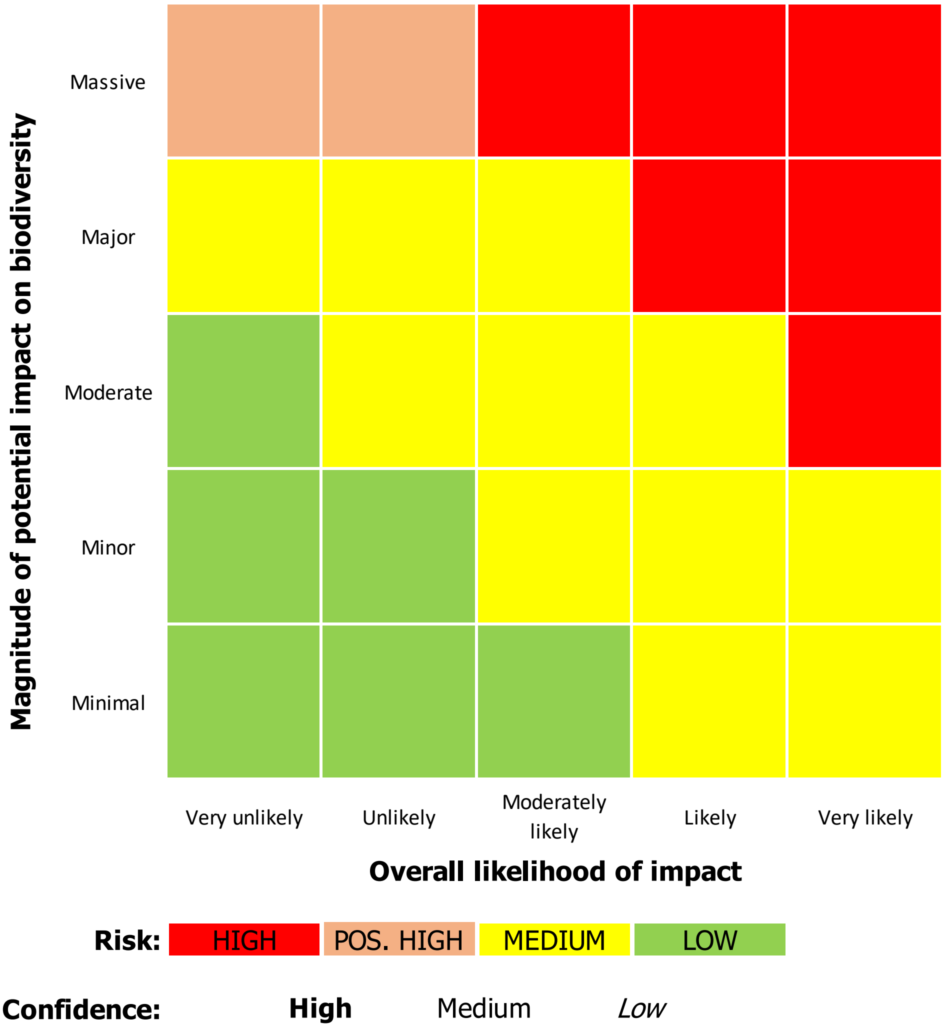

Figure 3: The risk-matrix used to graphically illustrate the assessed risks and the confidence of these assessments.

2.1.6 Description of confidence assessments

For each assessment of potential impact (hazard characterization) and likelihood, and eventually the risk, VKM describes the level of confidence with which these assessments are made. Confidence is based on both the level of information available on that subject, the relevance of that information, and to what degree expert judgement is used (Table 6).

Table 6. Qualitative scale used for describing the level of confidence in a risk assessment.

Rating	Confidence descriptors
Low	There is limited information on the specific subject from comparable environmental settings. Subjective expert judgements may be introduced without supporting evidence. Little peer reviewed literature is available and there are limited empirical and quantitative data to support the assessment.
Medium	Relevant information on the specific subject is available, but only limited information from comparable environmental settings. Some subjective expert judgements are introduced. Both grey literature and peer reviewed literature are used and there are some empirical and quantitative data to support the assessment.
High	There is extensive information on the specific subject, also from comparable environmental settings. Little or no subjective expert judgements is introduced. Primarily peer reviewed literature is used and there are empirical and quantitative data to support the assessment.

2.2 Data and information gathering

2.2.1 Literature search and selection

As a starting point for identifying relevant literature, we searched for publications that was linked to the highly relevant article by Utevsky et al (2010): "Distribution and status of medicinal leeches (genus *Hirudo*) in the Western Palaearctic: anthropogenic, ecological, or historical effects?" in Connected Papers, receiving the following graph:

https://www.connectedpapers.com/main/4d389925bb9196fa3f37ec4b3a37dc6cca2fb866/graph?utm_source=share_popup&utm_medium=copy_link&utm_campaign=share_graph

Both older and more recent relevant articles were identified through exploring the graph and the literature cited within these.

Additionally, as information on medicinal leeches was spread across older literature, interspersed in medically focused literature, additional literature was identified by searching for specific topics on use, taxonomy and ecology of the relevant species, and then finding connected articles as the topic became clear.

2.2.2 Information from leech suppliers

Information on the production and sale of *H. medicinalis* and *H. verbana* was difficult to find. Using results from a Google search for "medicinal leeches for sale", we sent queries to companies in Europe and North America that offer medicinal leeches for sale. We asked how they acquire medicinal leeches (farmed or collected from nature), which species they sell, if the species for sale have been sequenced to confirm identity, and if their leeches are screened for human pathogens.

3 General assessments

3.1 What do we know about commercially available leech species?

We queried eight commercial leech suppliers that advertise on internet and received five replies. The information we received is summarized in Table 7, from companies based in Europe and North America. The live leeches that are supplied in large quantities for medical purposes are usually *H. verbana*. Biopharm Leeches (U. K.) is an old leech farm (established in 1812) and claims to supply "the majority of leeches used in modern medicine worldwide", while Leeches Europe (Austria) claims to have supplied over 5,000 clients and shipped leeches to 198 countiries: both companies produce only *H. verbana.*

Two minor suppliers, Hirudo horti and Leeches U.S.A., claim to supply *H. medicinalis*. However, in 2012, Professor Ulrich Kutschera examined commercially produced leeches that were marketed as *H. medicinalis* and sold by Leeches U.S.A. Ltd to researchers at University of California (Berkeley). The medicinal leeches were not actually *H. medicinalis*: all were unequivocally confirmed to be *H. verbana* (Kutschera & Elliott, 2014.

It is likely that there are leech suppliers that we have not found, and apparently there are at least a few that supply large quantities of *H. orientalis* (Farzani & Saglam, 2022). In addition, many more species of broad sense "medical leeches" are bred and kept in research laboratories around the world (see 1.3.1)

Websites generally claim that leeches are produced under sterile conditions and quarantined for several months before shipping. Buyers are sent the necessary CITES and government health certificates. How some minor suppliers have arrived at the taxonomic identification of their leeches is unclear.

Table 7. Responses to questions to specified suppliers about the sourcing of marketed *Hirudo* medicinal leeches. "Which species" describes the species that the supplier sell", "DNA" describes whether species identification is (or was originally) verified by DNA sequencing, "How acquired" describes the origin of the leaches that are sold "Screened" describes whether the specimens are screened for human pathogens. We did not receive a reply from Hirudo horti or Leeches USA. Information from these companies was taken directly from their website.

Supplier	Which species / DNA	How acquired	Screened
Biopharm Leeches UK Ltd, UK	*H. verbana* DNA: previously.	"produced in our facility"	Website: "Our leeches are maintained in as sterile and pure environment as is possible" E-mail: "They are produced as a medical device under the FDA, our registration number is - K 13 29 58 / D 21 40 64"
Buy Leech, Turkey	*H. verbana* DNA: no, use morphology	Cultivated and wild-caught	"We have never encountered with any complaints … and we keep them in quarantine for 3-6 months to prevent any possible cause. … Leeches are examined by government veterinary and health certificates are being issued upon departure." (From website) "Buy Leech exports leeches to all around the world

			with globally acknowledged CITES and health certificates….[We] deliver unfed and sterilized leeches…””
EURO-BION Leech farm, Poland	H. verbana DNA: unknown	Website: bred in lab, fed artificial blood	Website: Use of artificial blood, plus quarantine
Hirudo horti, Lithuania	Unclear DNA: unknown	Website: company breeds H. medicinalis, H. verbana	Website: “Our Company sells only medical leeches quarantined for at least 5 months.”
ILFARM (new company 2022), Italy	*H. verbana* DNA: yes	Purchased now, will be breeding in future	(Some at least)
Leeches Europa, Austria	*H. verbana* DNA: yes	Cultivated	“certified with Health certificate and CITES”
Leeches U.S.A. Ltd, USA	*H. medicinalis* DNA: unknown	Website: no information	Website: no information
North America BioPharma, USA	*H. verbana* DNA: no	Buy from Turkey, want to breed	“Laboratory grade,... come with a health certificate from the [Turkish] government”

There are also Asian suppliers of *Hirudo* species, some of which are being sold via Alibaba. We have not researched these further.

3.2 Assessment of potential problems related to importing leeches

Unless otherwise stated, the following assessments apply to both *H. medicinalis* and *H. verbana.*

According to the ToR, VKM is asked to evaluate the risks to Norwegian biodiversity following import of *H. verbana* and *H. medicinalis* to Norway and suggest how the risks might be mitigated. The project group therefore assesses risks connected to these two processes:

1) Direct risks associated with different types of legal import of *H. verbana* and *H. medicinalis* to Norway, focusing on the effects of imported animals or their genes, offspring or associated microfauna escaping into the Norwegian environment. We do not assess general risks associated with the medical procedures for which the leeches are imported.

2) As pointed out in section 1.3.3 there is longstanding and ongoing confusion and some subterfuge surrounding trade with medicinal leeches, where most individuals sold as *H. medicinalis* have been shown to be *H. verbana* or other species. There is ongoing illegal trade, and the potential for hobbyist, practitioners of alternative medicine and even professional medical institutions suffering a minor lapse of diligence to suffer from miscommunications or less than honest dealers and end up getting “medicinal leeches” from very different species than the two mentioned in the ToR. Therefore, in the interest of a realistic approach to the risks involved, we also briefly address hazards associated with other species that could be introduced as a consequence of trade with *H. medicinalis* and *H. verbana*.

Also, although not specifically requested in the ToR, we briefly address whether trade itself is likely to have a detrimental impact on protected species globally or in their country of origin. We included this as both the species in question, and several of the other mentioned species, are CITES regulated.

3.2.1 Potential mechanisms of impact

For (1) and (2) we categorize mechanisms for hazards associated with introduced species according to the EICAT system (see table 3 in 2.1.1). For the sake of readability, we have grouped in three overarching themes: (**i**) Direct trophic interactions, such as predation, parasitism, and herbivory (Impact mechanisms 2, 5 or 8), where the introduced species directly feeds on or otherwise impacts native species; (**ii**) Indirect interactions including disease transmission and competition (Impact mechanisms 1, 4 or 12), where the effect of the introduced species is mediated through a third party; or (**iii**) Habitat effects where the introduced species influences the ability of a native species to thrive in its current habitat by changing the habitat physically through fouling, toxicity or restructuring, or through changing the native species' ability to thrive in its environment through hybridization (Impact mechanisms 3, 6, 7, 9, 10 or 11).

3.2.2 Direct trophic interactions

3.2.2.1 Leeches as parasites or predators (EICAT mechanisms 2, 5)

When feeding on body fluids of their prey, leeches become predators on the smallest prey (eggs, small amphibian larvae) but are parasites of larger animals.

A heavy parasite burden may cause anemia in smaller mammals, and, where prevalent, leeches may significantly affect the health and productivity of livestock (Seyoum et al., 2023). In humans, parasitism seems unlikely to be a significant issue in Norway

Many leeches have amphibians as a critical food resource as juveniles. As adults, amphibians are an important but not optimal food source (Elliott & Kutschera, 2011). Thus, leeches may have particularly strong population effects on amphibians. Merilä and Sterner (2002) review a considerable set of observations demonstrating direct impacts of leeches, with reports of common toads being unable to remove leeches, climbing out from their pond with large numbers of leeches remaining attached until the toads are literally sucked dry of blood. Sahlin (1930) noted that while early breeding common and moor frogs in a southern Swedish locality were heavily attacked by leeches, later spawning edible frogs escaped leech attacks even though leeches were seen swimming among spawning edible frogs. He suggested this was because leeches had already satiated with the blood of common and moor frogs by the time edible frogs spawned. Such interactions seem likely to have indirect effects regarding selection and phenology in amphibian populations in leech-rich areas. Sahlin and several later authors also note that despite the decline of the European (including Norwegian) medicinal leeches, parasitism on amphibians might have increased in the remaining leech populations as the reduced availability of mammalian blood to leeches (see 1.1.1.4) may have caused leeches to switch to feed mainly on amphibians, as also indicated by serological field studies (Elliott and Kutschera 2011). As an example, Stead and Pope (2010) propose that a proliferation of freshwater leeches may be a major cause of a precipitous population decline of Cascades Frogs (*Rana cascadae*) in the Lassen region of California.

The populations of Norwegian frogs and salamanders are currently under pressure from habitat destruction, climate change, pollution and, possibly, disease (see VKM report by Nielsen et al. 2019). It seems unlikely that any imported leeches would be released and spread on a scale where it would threaten amphibian species of least concern. However, the three red-listed species, including pool frog *Pelophylax lessonae* ("damfrosk" Critically Threatened), moor frog *Rana arvalis* ("spissnutefrosk", Vulnerable), and northern crested newt *Triturus cristatus* ("storsalamander", Near Threatened) all have restricted distributions or small populations that might be vulnerable to an influx of leeches. Similarly, several invertebrates with freshwater life stages and restricted distributions might be vulnerable to increased predation. However, it should be noted that the red-listed amphibians and invertebrates are already exposed to the dynamics not only of the endemic *H. medicinalis* but also the common and more predatory leeches *Haemopis sanguisuga* and *Erpobdella testacea.* An impact of imported leeches would only be apparent if they were released somewhere these native predatory leeches are absent, or if they become established in addition to native species and increase the net predation by leeches. The latter is not impossible as the niche overlap of the adult stages would be limited with most of the medicinal leeches in Table 1, except for the *Whitmania* species.

3.2.3 Indirect interactions

3.2.3.1 Leeches as vectors of disease (mechanism 4)

Leeches as a group are potentially significant vectors of disease in some animal populations, particularly amphibians where the amphibian leech (*Placobdella picta*) seems to play a role in *Ichthyophonus* sp. transmission in North American amphibians, possibly interacting with human-driven eutrophication (Raffel et al., 2006). Some glossiphoniid leeches are known to transmit protozoan parasites, and potentially fungal pathogens, and at least three species of parasites and pathogens have been introduced to widespread habitats outside their native ranges (Slesak 2015, Nehili et al. 1994).

Few human diseases are commonly associated with leeches or have been shown to have leeches as a main vector. However, many bacteria persist in significant numbers for at least 6 months in the guts of experimentally infected leeches, and some protozoan parasites such as *Toxoplasma gondii, Trypanosoma brucei and Plasmodium berghei* seem capable of reproducing inside the leech gut. Direct transmission may be limited by penetration of such pathogens into the leech salivary glands, but direct transmission may be possible when attached leeches are squeezed or exposed to salt (a common method to release leeches) while they are attached to a host. Leeches may thus be a partially neglected vector of some human pathogens (Nehili et al. 1994, Slesak et al. 2015). One of the relatively few recent studies examine infections potentially vectored by leeches found that *H. nipponia* may be a significant vector of *Klebsiella pneumoniae* infections in areas where the leech is common (Yibin et al. 2021). Studies on risks associated with leeches used in post-surgical treatments (Hackenberger and Janis 2019, Whitaker et al. 2012) have found an infection rate of about 14% in patients receiving leech therapy. The authors of these studies point out that leeches rely on a symbiotic relationship with *Aeromonas* species bacteria such as *A. hydrophila* and *A. veronii* within their digestive tract that can be injected via saliva or regurgitation at therapeutic bite sites. As a result, up to 79% of patients receiving leech therapy are also started on antibiotic prophylaxis.

Furthermore, Hackenberger and Janis (2019) found that *Aeromonas* species account for 88% of leech therapy-associated infections, but state that recent reports of several other pathogens, including *Serratia marcescens, Vibrio fluvialis*, various viruses, and emerging multidrug-resistant organisms (see also Marden et al. 2016), have increased risk estimates of leech therapy. von Rheinbaben et al. (2014) suggested that leeches fed on vertebrate blood may be considered virologically safe for medical use six months after last feeding.

The vector potential of leeches may depend on factors, such as environmental temperature, host availability, and meal frequency. The risk of leeches being vectors for human and animal infections in Norway as climate change progresses is not readily quantifiable. If alternative practitioners subscribe to the traditional method of catching wild leeches and then using them within a short time frame, and/or releasing leeches back into the environment after they have taken a blood meal from a human (or animal), it would add to the risk of disease transmission both for zoonoses and reverse zoonoses.

3.2.3.2 Introduced leeches as competitors to native leeches (mechanism 1)

However, as most freshwater leeches have amphibians as an important host group, it is conceivable that a new leech species establishing in the Norwegian fauna could be a competitor for *H. medicinalis* or even the non-sanguinivorous native species. Increased competition could be a potential hazard if the alien species *H. sulukii* becomes established as it is more fecund than *H. medicinalis* and is adapted to colder habitats. Likewise, *H. verbana*, that seems adapted to warmer waters, could be a competitor in case of a future warmer climate.

3.2.3.3 Interactions with climate change

Ongoing climate change is likely to change the relative competitive strengths between species. The invasive *Helobdella europaea* has spread with hobbyist trade in Europe but it is unclear whether import for medical or alternative/holistic practices has played a role in the spread or whether it has been imported along with *H. verbana* or other species relevant to this report.

The more warm-adapted *H. verbana* seems likely to gain in relative competitive strength at higher latitudes, and with more variable climates the same might be true for the continental *H. orientalis* and *H. sulukii,* but too little is known about the exact climatic niches of these species and the future conditions in Norway to be sure. Whether climate change or other environmental change also affect the odds of Asian *Hirudo* species, or even the *Macrobdella* or *Hirudinaridae* species, establishing in Norway in the event of introduction is unknown.

In a warmer climate, the lack of genetic structure in European populations of *H. medicinalis*, suggests that introducing genes from more southernly populations is unlikely to affect the overall population performance. With ongoing climate change, it seems even less likely that introducing southernly genes would harm the northern populations.

3.2.3.4 Hybridization (EICAT mechanism 3)

Hybridization between *H. verbana* and *H. medicinalis* has sometimes (but not always) been observed in the laboratory (see section 1.3.2), but it does not seem to occur under natural conditions where the species overlap. While hybridization might occur in cases where, for instance ,*H. medicinalis* are locally vastly outnumbered by *H. verbana*, this seems unlikely to happen unless large amounts of imported leeches are dumped locally. Any hybrids formed are unlikely to become established or spread as they seem to be less fecund than either parental species (Patrauskiené et al. 2009).

3.2.4 *Habitat effects*

A Polish study found that median values of leech diversity were significantly higher at sites with moderate than with low or high environmental quality. This suggests low and doubtful usefulness of leech diversity as an element tfor biological assessment of lowland watercourses (Koperski 2017). However, blood-feeding leeches may be useful indicators and sources of biodiversity data through blood meal analyses (Drinkwater et al. 2019). An imported leech species seems unlikely to have major physical, chemical or structural effects on the habitat under current conditions.

3.3 Assessment of the magnitude of import of live leeches

3.3.1 *For medical use*

As described in chapter 1.3, "medical leeches" refers to a variety of taxa of leeches in three major families (Table 1). Leeches can be used by placing live specimens on patients or by employing a product derived from leeches. This report is only concerned with import of live leeches.

Regarding the use of the two species of *Hirudo* covered by the ToR, little information is available about current use in Norway.

As medical use depends on having access to medical-quality leeched (raised in a clean environment) and these are hard to come by in Norway, the current use in medical practices probably doesn't reflect the potential use if import is mandated. However, as standard procedures involve humane destruction of leeches after use our main concern regarding biodiversity impacts from import would be with hobbyists/alternative practitioners.

3.3.2 *For hobbyists and alternative practitioners*

Private keeping of leeches as a hobby is considered a specialized niche within aquarium keeping. In contrast to fishkeeping aquarists, leech-keeping is thought to only be practiced by very few people in Norway (Svein Fosså[1], personal communication, Aug. 2024). The traditional application of live leeches is currently not practiced to the extent that we could find a practitioner offering the therapy. (Such practitioners do exist in neighboring Denmark: Iglebehandling i kombination med akupunktur - Klinik Gahlenbeck (klinik-gahlenbeck.com)).

The use of live leeches in alternative medicinal practices is not part of the Norwegian health care system and occupies a grey zone between regulated medical practices and private hobby use. No alternative or holistic hirudotherapists currently practicing in Norway were found

[1] Chairman of the Board and Secretary General, The Norwegian Pet Trade Association

through a web search in August 2024, so such use is likely to result in a very small import market unless alternative therapy trends shift.

It is difficult to estimate total potential future use of leeches in Norway. The project group thus assumes that the import of live leeches to Norway for medicinal or alternative medicine use including research will be limited (up to 10 imports per year with up to 100 adult leeches in each import).

3.4 Assessment of import of live leeches resulting in establishment of the specified species

Leeches used as live organisms for medical or cosmetic are procedurally destroyed after use in standard operating procedures. Thus, as long as existing procedures are followed by all importers, they do not represent a potential source of new introductions to Norway. Should import of *H. verbana and H. medicinalis* result in imported individuals entering suitable habitats in Norway, the only relevant pathway would be intentional or unintentional release from hobbyists/ alternative practitioners. As discussed in the previous subchapter, the magnitude of potential hobbyist (presumably mostly alternative practitioners) keepers of leeches in Norway is believed to be limited. Also, as release of all organisms that are not of native origin (and belong to the same population as are present where the organisms are to be released), is illegal without a specific approval, according to the Regulation relating to alien organisms (§10)[2]. Therefore, VKM assesses that the likelihood of leeches being released by non-medical practitioners into suitable habitat is assessed as unlikely.

3.5 Assessment of live leeches as vectors of pathogens and parasites that could establish in Norway

As described in subchapter 1.4, the two species covered by the ToR, *H. verbana* and *H. medicinalis*, have a limited host range with regards to vectors of pathogenic organisms. The bacterium *Klebsiella pneumoniae* can be found in *H. nipponia* (Yibin et al., 2021), and likely also present in *H. verbana* and *H. medicinalis*. However, *K. pneumoniae* is already present in Norway, and does thus not represent a novel threat to biodiversity in Norway.

If holistically oriented therapists or similar unregulated medicinal users keep imported live leeches in natural ponds and release used leeches back into the environment, releases may potentially result in zoonosis or reverse zoonosis. However, this risk is independent of whether the leeches in question are imported or were collected from local populations and thus isn't further discussed here.

Because of the low number of annual imports of live leeches to hobbyists and alternative practitioners who do not just destroy live leeches after use but may intentionally or unintentionally release them, the annual number of released secondary species seems likely to be low. Thus, establishment of purchased leeches is considered only moderately likely in a ten-year persective.

[2] https://www.regjeringen.no/en/dokumenter/forskrift-om-fremmede-organismer/id2479700/

4 Risk assessments

4.1 *Hirudo medicinalis*

As described in chapters 2.1 and 4, there could be hazards associated with the trade of the native species *H. medicinalis* should it be released into habitats from which it is currently absent, thereby affecting local biodiversity, or into habitats with conspecifics, where it can change the native gene pool.

4.1.1 Hazard identification

Based on the possible hazards described in section 2.1.1 (Table 3) and further in 3.2.1, VKM has identified the following hazards in relation to import of *H. medicinalis*:

a. **Hybridization (EICAT category #3).** This hazard, in terms of intraspecific hybridization, is possible (see section 1.3.2) if imported *H. medicinalis* leeches were to be released into habitats occupied with conspecifics, potentially reducing local adaptation and hence a decline in local population sizes (Allendorf et al., 2001).

b. **Competition, predation, and parasitism (EICAT mechanisms #1, 2 and 5).** The release of imported *H. medicinalis* into a habitat that is not currently occupied by this species, or in such a large number that they would become dominant, could alter the population dynamics of other leech species. Amphibian populations, if present, may be affected through increased predation or parasitism by leeches. Species of leech with a phenology to which native amphibians are not adapted could have serious consequences for already vulnerable amphibian populations, especially when the seasonal dynamics are perturbed by climate change.

c. **Transmission of disease (EICAT mechanism #4).** Some animal diseases (especially those affecting amphibians such as the protozoan parasites *Ichthyophonus* sp.*,* see Raffel et al. 2006) that are mostly associated with non-native leeches, but could in principle be transmitted by native leeches if the disease was imported and leech density high, can in theory be accompanying the imported leeched and consequently spread to habitats in Norway if released.

4.1.2 Hazard characterization

In Norway, VKM find that the identified hazards could have the following potentially negative effects:

a. **Hybridization.** Imported leeches are likely to originate from central Europe and show limited genetic variation. Mixing of these imported genotypes with native leeches could possibly lead to loss of genetic local adaptations. However, the native leeches already have a shallow genetic structure, shaped by millennia of use and trade. Furthermore, imported leeches are likely being better suited to increasingly warmer climates, which we must expect to experience in Norway during the coming decades. VKM therefore assess that the potential impact of hybridization would be **Minimal.** This is assessed with **Medium confidence**.

b. **Competition, predation, and parasitism.** The presence of leeches in increased numbers can clearly have a dramatic impact on local biodiversity of invertebrates and amphibians. However, the native species *Haemopis sanguisuga*, *Erpobdella octoculata* and *Erpobdella testacea* are specialized predators on amphibians and invertebrates and seem to be competitively superior to the blood-sucking leeches in the absence of sufficient mammal hosts. Thus, except for unlikely cases where a high rate of release into the local environment is sustained from, say, aquaculture, or bad luck sees the repeated release into a refuge for a red-listed species of amphibian, release of imported *H. medicinalis* seems to be of **Minimal impact** with **Medium confidence**.

c. **Transmission of disease**. We have not found any data suggesting that these leeches would potentially transmit novel diseases to leeches in Norway. Therefore, the primary concern would be transmission of diseases to the red-listed amphibians with a conservation status; Pool frog, Moor frog and the Northern crested Newt (Table 2). The potential impact is assessed as **Minor** with **Low confidence**.

4.1.3 Likelihood

In terms of how likely it would be that the identified hazards (4.1.1) would result in the characterized effects (4.1.2), VKM assesses as follows:

a. **Hybridization.** As popularity of traditional and alternative medicine and seemingly hobby use, is increasing, intraspecific hybridization (introgressive hybridization) following deliberate or accidental release of *H. medicinalis* is assessed as **Moderately likely** to occur at least once before 2050. As the popularity of alternative medicinal practices are extremely hard to predict, the **confidence** for this likelihood estimate is **Low**.

b. **Competition predation, and parasitism.** *H. medicinalis* is already present in Norway and limited by habitat and host availability. In the absence of plentiful mammalian hosts, it is a weaker competitor in most environments dominated by the amphibian/arthropod specialist leeches. Import of this species to Norway is therefore assessed as **Very unlikely (Medium confidence)** to increase population densities of the species to a degree that it will have negative effects through competition, predation or parasitism.

c. **Transmission of disease**. Few zoonotic or animal diseases are associated with leeches, and the only widely successful invasive leech species is *Helobdella europeae*, a species associated with aquarium hobbyists. However, as the number of leeches assessed to be imported each year is less than 100, and escape or intentional release is very unlikely, the likelihood of non-native species establishing to vector a new disease or transmit a disease to native leech species through regulated medicinal or hobbyist trade seems **Very unlikely** with **Medium confidence.** The most likely case would be amphibian diseases.

4.1.4 Risk characterization

a. **Hybridization**, in terms of potential negative impact through genetic changes following influx of novel genotypes, is characterized as posing a **Low** risk. This is assessed with **Low confidence** due to lack of data.

b. **Competition, predation, and parasitism** are both assessed as having a potential Minimal impact and moderate likelihood. The risks associated with these hazards are therefore characterized as **Low**, with **Medium confidence**.

c. **Transmission of disease** is assessed to have a potentially Minor impact on biodiversity in Norway of threatened or near threatened amphibian species. Also, as this is assessed to be Very unlikely to occur, the overall risk is **Low**, with **Medium confidence**.

4.2 *Hirudo verbana*

As described in chapters 2.1 there might be hazards associated with the trade of the non-native *H. verbana* or if it is released to habitats from which it is currently absent, thereby affecting native leech species or other local biodiversity, or for it to be mistaken for other medicinal leeches with greater impact. Nearly all medicinal leeches sold by major distributors in Europe and North America are now *H. verbana* (Table 7), so future imports of *H. verbana* should be expected to be much greater than imports of *H. medicinalis*.

4.2.1 Hazard Identification

Based on the possible hazards described in section 2.1.1 (Table 3) and further in 3.2.1, VKM has identified the following three hazards in relation to import of *H. verbana*:

a. **Hybridization (EICAT mechanism #3)**. *Hirudo verbana* is not native to Norway and currently not observed in Norway. Import for hobby- and medicinal use could introduce the species and allow it to spread and in theory hybridize with native *H. medicinalis* (see section 1.3.2).

b. **Competition, predation, and parasitism (EICAT mechanisms #1, 2 and 5)**. *Hirudo verbana,* if established in Norway, could impact *H. medicinalis* and other leeches, as well as local biodiversity of amphibians and invertebrates.

c. **Transmission of disease (EICAT mechanism #4).** As stated in section 4.1.1-c, some diseases could in theory be transmitted to species in Norway if *H. verbana* is released.

4.2.2 Hazard characterization

a. **Hybridization.** *Hirudo verbana* has been sold under the name of *H. medicinalis* and has provided the bulk of the sale of "medicinal leeches" in Europe for decades. According to our survey of online European (including Turkey) and North American suppliers, nearly all medical leeches in aquaculture are at present *H. verbana*. If introduced to Norwegian ponds or streams, the nonnative leech could compete or hybridize with *H. medicinalis*. However, hybrid fecundity is lower and the two species already have a considerable contact zone where *H. verbana* is the more southernly and continental species. No natural hybridization of these two species has been detected in the field or in recent DNA-based studies. Ongoing climate change could change this, but in such an event the apparent dispersal ability of the leeches suggests that *H. verbana* would outcompete less well adapted *H. medicinalis* and take over its ecosystem role without trade having an impact. The impact is thus assessed as **Minor** with **Medium confidence**.

b. **Competition, preadation, and parasitism**. *Hirudo verbana* has a similar niche in the ecosystem as *H. medicinalis* and may affect the abundance of vulnerable amphibians and invertebrates. Lack of suitable wetlands and mammal hosts are limiting factors to the abundance and distribution of *H. medicinalis*. If *H. verbana* were to be released in addition to (or instead of) *H. medicinalis,* the impact on the ecosystem from these two species would not change but *H. verbana* might outcompete *H. medicinalis* in case of a warmer climate. The impact is thus assessed as **Minor** with **Medium confidence**.

c. **Transmission of disease**. We have not found any data suggesting that these leeches would potentially transmit novel diseases to leeches in Norway. Therefore, the primary concern would be transmission of diseases to the red-listed amphibians with a conservation status; Pool frog, Moor frog and the Northern crested Newt (Table 2). The potential impact is assessed, as for *H. medicinalis*, as **Minor** with **Low confidence**.

4.2.3 Likelihood

a. **Hybridization.** Limited trade seems unlikely to have a meaningful impact on hybridization beyond what is happening due to ongoing ecological changes like climate change shifting the contact zone between the native *H. medicinalis* and *H. verbana.* **Unlikely** with **Medium confidence**.

b. **Competition, preadation, and parasitism**. The presence of *H. medicinalis* and the non-medicinal predatory species already specializing in feeding on amphibians and invertebrates suggests that local biodiversity already is long adapted to the presence of leeches. Considering the large niche overlap between *H. verbana* and the native leeches (*H. medicinalis*) it seems **Very unlikely** (with **Medium confidence**) that accidental establishment of *H. verbana* will add to the total parasitism/predation pressure experienced by leeches by other groups.

c. **Transmission of disease**. As for H. medicinalis (see section 4.1.3-c), we find that, as the number of leeches assessed to be imported each year is less than 100, and escape or intentional release is unlikely, the likelihood of non-native species establishing to vector a new disease or transmit a disease to native leech species through regulated medicinal or hobbyist trade seems **Very unlikely** with **Medium confidence.** The most likely case would be amphibian diseases.

4.2.4 Risk characterization

a. **Hybridization** is assessed to have a minor impact and is unlikely to occur. The associated risk is therefore **Low.** This is assessed with **Medium confidence.**

b. The environmental effects of **competition, predation or parasitism** would be Minor in Norway, This is Very unlikely to occur. The associated risk is therefore **Low.** This is assessed with **Medium confidence.**

c. **Transmission of disease.** is assessed to have a potentially Minor impact on biodiversity in Norway of threatened or near threatened amphibian species. Also, as this is assessed to be Very unlikely to occur, the overall risk is **Low**, with **Medium confidence**.

5 Risk-reducing measures

There is relatively little risk to Norwegian biodiversity from importing either H. medicinalis or H. verbana to Norway. However, it is important that importers be aware of the importance of properly disposing of leeches after they have been used and that imported leeches should never be released into nature. Hospitals and clinics using live leaches kill and dispose of them as hazardous waste or biological waste (as instructed in the nurses' handbook from the Oslo university hospital). Other users importing live leeches must also be required to destroy leeches that have been used or are no longer wanted.

It is important that hobbyists and alternative medicine practitioners are informed of the fact that releasing imported leeches into the wild is illegal, and why.

Another important risk-reducing measure is to ensure that importers purchase leeches from dependable sources. This would be companies that breed leeches themselves under proper hygienic conditions and quarantine them for several months before shipping them, and that can assure importers of the identity of the species being sold. It is important that imported leeches originate from leech farms (leeches produced in aquaculture) and not collected from the wild

As there are many leeches that are sold as "Medicinal" or "Medical" leeches, perhaps the most important mitigating measure is to ensure that the imported species have been correctly identified.

Should an unwanted species of medicinal leech become established in Norway, local eradication may be possible as spread seems slow. We have not found any literature in which eradication of such species has been proposed or attempted, so cannot suggest concrete mitigation measures.

6 Uncertainties

Despite millennia of use and two centuries of scientific attention, some aspects of the lives of leeches remain unclear. As several research groups have remarked in their publications, there has been surprisingly little basic research on the life histories of *H. medicinalis* and *H. verbana*.

The distributions of *H. medicinalis* and *H. verbana* only partly overlap, but we do not fully understand how their environmental requirements differ. It is difficult to know which species was the subject of early research or being used medicinally prior to the taxonomic studies with advances in molecular tools that started in the 1980s. We do not know how average seasonal temperatures (winter, summer) and periods with extreme cold or extreme warmth affect survival and reproduction of the leeches. Consequently, it is difficult to predict how climate change in Norway might affect the suitability of freshwater ecosystems in the southernmost part of the country for *H. verbana*.

With respect to the potential for introduction, we can only make an educated guess as to the potential demand for medicinal leeches by hospitals, clinics, alternative medicine practitioners, and hobbyists.

Our risk analysis focuses on *H. medicinalis* and *H. verbana.* Traditionally, there has been a risk of misidentification of the species. As pointed out earlier, there are several leech species referred to as "medicinal leeches" other than *H. medicinalis* and *H. verbana*. Some of these can easily be confused with the two target species and imported in their place, either by being sold under a false name (as has happened for *H. verbana* and other *Hirudo* species being sold under the name *H. medicinalis*) or being sold under the assumption that a medicinal leech is a medicinal leech. The *Hirudinaridae* (Asian buffalo medicinal leeches), *Macrobdellidae* (New World medicinal leeches) and other *Hirudinidae* (other *Hirudo* species, or*Whitmania* due to its dominance in the Chinese market) are the species most likely to be imported mistakenly. Importantly, it is possible to select leech suppliers in Europe that breed populations and that have already verified the species of the leeches that they sell (Table 7).

7 Conclusions - with answers to the ToR

7.1 ToR 1: Assessment of the risks associated with import of *H. verbana* or *H. medicinalis*

Despite considerable data gaps, we conclude that the overall risk from importing *H. medicinalis* and *H. verbana* to Norway is **Low**. No moderate or large impact on biodiversity is likely to occur under any plausible import scenario. The individual risks are summarized in Figures 4 and 5. Should impacts be suspected later on, effective mitigation strategies seem to be available (see 7.2).

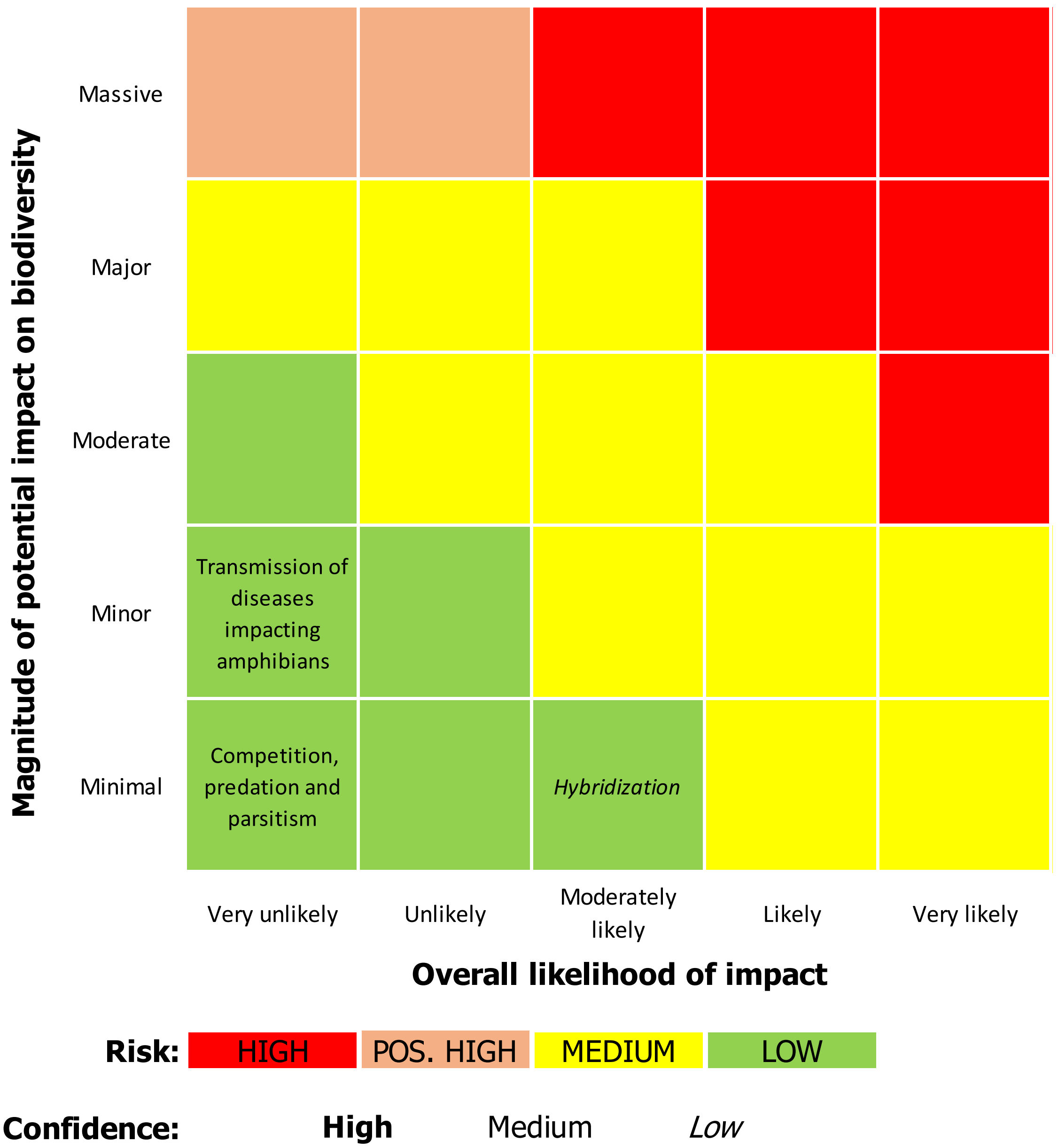

Figure 4: Summarized risks associated with Import of *Hirudo medicinalis* to Norway.

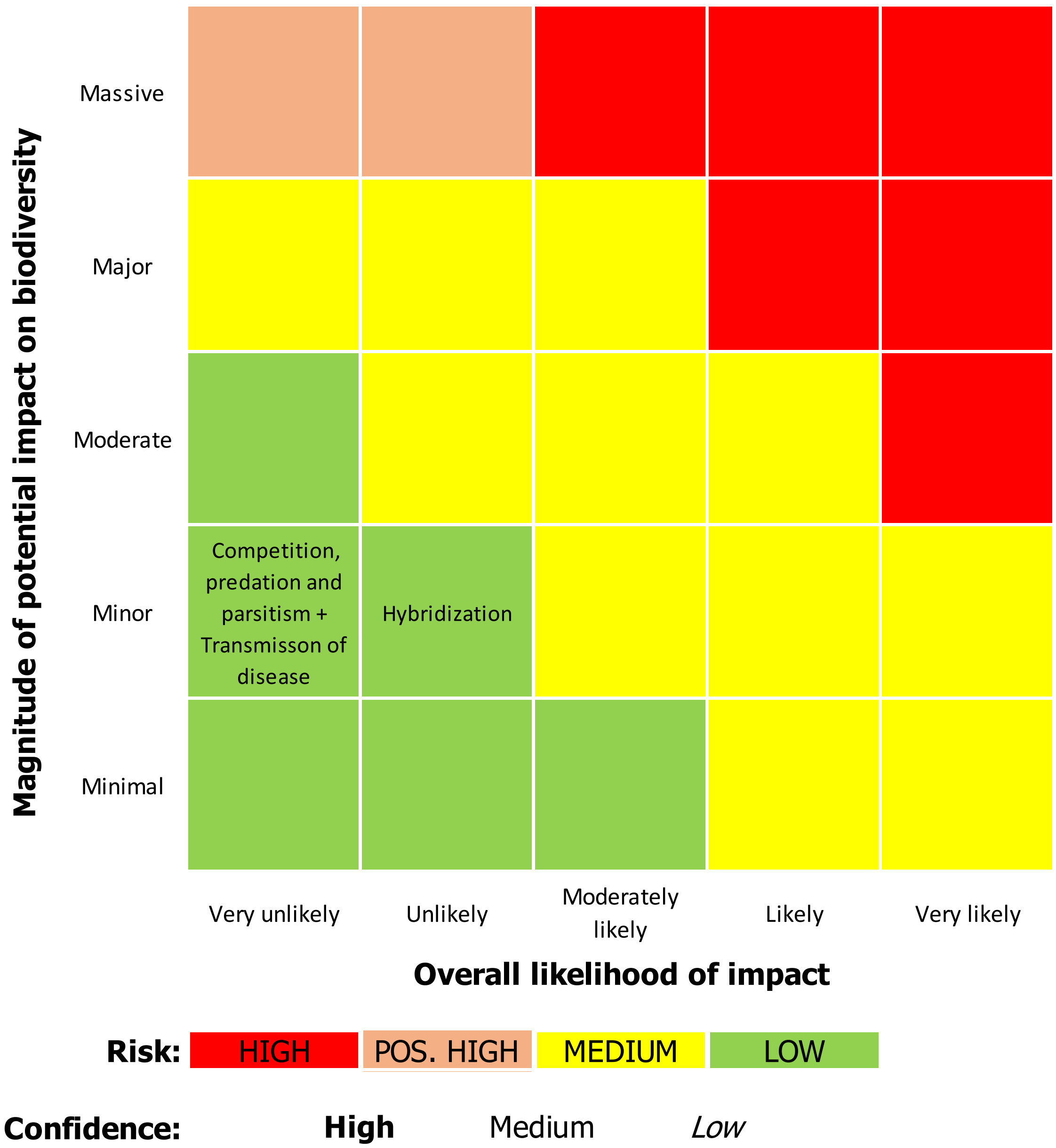

Figure 5: Summarized risks associated with import of *Hirudo verbana* to Norway.

However, the conclusions of low risks are conditional on the magnitude of import being low, and while some error is expected, importers must confirm that the species they import live is one of the two in question, and do not release any leeches into the wild. This is paramount near populations of threatened amphibians.

Note that likelihood and impact assessments in this report addresses impacts directly associated with import, and not any future large-scale commercial aquaculture. Commercial production of leeches in Norway would presumably require a separate assessment that considers the scales and practices employed.

7.2 ToR 2: Potential risk-reducing measures

The most impactful risk-reducing measures would be:

1) to ensure that all institutions, businesses or persons importing medical leeches purchase them from reputable dealers in order to ensure proper hygiene and correct taxonomy and that the leeches were not collected in the wild

2) that all parties importing leeches are required to kill and dispose of leeches properly, and not release live individuals into nature.

8 Data gaps

The basic ecology for leeches is surprisingly poorly known. Knowledge gaps include their modes and speed of dispersal in the landscape and impacts on amphibians and invertebrates. The impact of climate change on interactions between species in the Norwegian ecosystems is also hard to predict. The impact from climate change will likely vastly overshadow any effects of import, also when it comes to the biodiversity and ecosystem services associated with leeches and their prey.

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Appendix I

***Praobdellidae* .** The *Praobdellidae* are treated as a group of medicinally relevant leeches by de Carle (2022) and Phillips (2011). They are highly diversified and found in distributed in tropical regions of Africa, Asia and Central and South America (Schenkova et al. 2021). They are mostly used in modern research, being investigated for their anticoagulant repertoires. Like the *Whitmania* leeches they enter medicine as sources of pharmacological substances including novel anticoagulants (Iwama et al. 2019). However, this family almost exclusively live as internal parasites on the mucous membranes of mammals and sometimes invertebrates. They have a reduced number of teeth and a large posterior sucker and are not used for live hirudotherapy like a classical medical leech (Schenkova et al. 2021, Iwama et al. 2019), but like the *Whitmania* leeches as sources of pharmacological substances including novel anticoagulants (Iwama et al. 2019). The family currently contains the genera *Dinobdella, Limnatis, Limnodbella, Myxobdella, Pintobdella and Tyrannobdella* (Phillips et al. 2010, de Carle 2022). While the most casual inspection of morphology clearly differentiates the *Praobdellidae* from the *Hirudo* species, layman usage of the term may cause some confusion or carelessness in some less stringent user groups just wanting medicinal leeches.

***Glossiphoniidae* g. sp.** Where most leeches abandon their egg cocoons the glossiphoniid leeches have the most developed parental care among the known annelids, where the eggs are carried in a ventral “nest” or even a specially produced a membranous bag to hold the eggs until hatching, whereupon the young attach to the parent’s belly and are then transported to their first meal (Starzecka et al., 2020). The *Glossiphoniidae* tend to parasitize amphibians or be predators on other invertebrates but have a variety of life histories. The family *Glossiphoniidae* (flat leeches) are freshwater leeches with a proboscis, generally flattened body and a poorly defined anterior sucker. Most feed on prey body fluids of aquatic invertebrates and some opportunistically feed from humans. They are of considerable medical interest, but their taxonomy at the species level remains remarkably unresolved. Given that they do suck circulatory fluids and occasionally human blood, there is a slight possibility for confusion with medical leeches by the general public, though almost certainly not by researchers or informed hobbyists.

There is considerable interest in the symbiotic bacteria that at least some of the leech family *Glossiphoniidae* house in specialized organs called bacteriomes, and in anticoagulants originally isolated from glossiphoniid leeches including *Haementeria officinalis* and the Amazon giant leech *H. ghilianii*. The glossiphoniid genus *Helobdella* has been of particular medical interest as it has been used as a model system for phenomena ranging from including stem cell lineage fate and evolution, to neurogenesis, photoreception and the evolution of segmentation. The family is globally distributed from the tropics to the arctic in the Americas and Eurasia, and includes a considerable high-latitude diversity (Bolotov et al. 2022), and demonstrate the ability of leeches to spread with the help of humans. *Helobdella europaea* Kuschnera is, despite the name, indigenous to South America, where its natural range is still unknown, and is now known to be invasive in Europe, California, Hawai’i, Taiwan, northern Africa, Fuiji, New Zealand and Australia (Rashni et al., 2023), probably introduced through import via freshwater aquarium hobbyists; in Europe, it competes with the native *H. stagnalis* (Kutschera, 2004b; Pfeiffer et al., 2004; Morhun et al., 2021). *Helobdella europaea* was first detected in Germany, and later over southern and central Europe where it may be competing with *Helobdella stagnalis* (which is endemic to Norway as a species of Least Concern according to the Red List 2021–see below). Thus, while it has not been observed in Scandinavia, further climate change might allow it to establish if imported through trade with leeches (or amphibians) (Perera et al. 2019).