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Special Issue: Advances in the study of the management of biological invasions in inland waters and the legacy of Gordon Howard Copp (1956−2023)
Guest editors: Lorenzo Vilizzi and Calum MacNeil

Editorial

Special issue: Advances in the study of the management of biological invasions in inland waters and the legacy of Gordon Howard Copp (1956–2023)

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Co-Editors' Note: This paper was contributed as part of the Special Issue "Advances in the study of the management of biological invasions in inland waters and the legacy of Gordon Howard Copp (1956–2023)". This collaborative effort has attracted some of the most prominent invasion biologists who have contributed a diverse collection of high-profile papers addressing current knowledge gaps, research advances, and future opportunities in the management of biological invasions.

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Abstract

This special issue of *Management of Biological Invasions* is dedicated to the late Professor Gordon H. Copp, a pioneer in invasion biology and recipient of the prestigious Doctor of Science title for his exceptional scientific contributions. Over his career, Gordon met the "gold standard" of scientific excellence through his peer-reviewed publications, successful research funding, international collaborations, and leadership roles. In the early 2000s, Gordon shifted his main focus from fish conservation biology to invasion biology, where he significantly advanced the field, particularly in non-native species risk analysis. Alongside his career-long collaborator Lorenzo Vilizzi, he developed decision support tools for risk identification, including the Freshwater Fish Invasiveness Screening Kit and "ISK" siblings, and its successor, the Aquatic Species Invasiveness Screening Kit (AS-ISK), which has been used globally to assess the risk of non-native aquatic organisms. Gordon's work laid the foundation for the European Non-native Species in Aquaculture Risk Analysis Scheme, influencing policies and practices worldwide. This special issue features contributions from some of Gordon's closest collaborators and mentees, who explore a wide range of topics in invasion biology. Highlights include updated methodologies for risk screening with the AS-ISK, case studies from diverse geographic regions, and discussions on the socio-economic impacts of invasive species. This special issue also introduces a new screening toolkit, which addresses gaps in current tools for risk identification. Collectively, these studies honour Gordon's legacy by continuing to advance understanding and management of biological invasions, ensuring his influence endures for future generations of scientists. We hope this special issue serves as a valuable reference for researchers and practitioners in the field and that Gordon would have appreciated the quality and scope of the contributions as a testament to his lasting impact.

Key words: invasion biology, risk analysis tools, non-native species, risk screening, conservation biology

Introduction

Shortly before his passing, Professor Gordon H. Copp was honoured with the prestigious title of Doctor of Science in recognition of his exceptional scientific contributions. Gordon's standing and excellence in his field have

been the result of meeting the rigorous standards in four key areas of scientific activity, globally recognized as the "gold standard": peer-reviewed publications, success in research and development funding, an international profile, and appointments to academic and research leadership roles. Since the early 2000s, Gordon's main research focus shifted from fish conservation biology and early ontogeny to the emerging field of invasion biology, with particular emphasis on non-native species policy and the development of risk analysis tools. His pioneering work has significantly influenced global research in this scientific discipline, creating a lasting legacy for current and future scientists. Gordon's seminal contributions have opened several important avenues in invasion biology, including the development and application of decision support tools for non-native species risk analysis, the management and control of invasive species to conserve native biota, and the communication of biological invasion risks to decision-makers and the public.

This special issue of *Management of Biological Invasions* features research papers from distinguished researchers worldwide in the field of invasion biology. In tribute to Gordon, this issue includes contributions from some of his closest collaborators and mentees over the past two decades: David Almeida, Phil I Davison, Jennifer A Dodd, Allan S Gilles Jr., Jeffrey E Hill, Shan Li, Roberto Mendoza, Marina Piria, Predrag Simonović, Elena Tricarico, Hugo Verreycken, Lorenzo Vilizzi, Hui Wei, and Grzegorz Zięba.

Gordon's achievements in invasion biology

Since joining the Centre for Environment, Fisheries and Aquaculture Science in Lowestoft (UK) in the early 2000s, Gordon's research and development activities focused primarily on non-native freshwater fishes, with two objectives: (i) develop risk analysis schemes and (ii) complete field and laboratory studies to inform the risk analysis process.

Risk analysis schemes

Gordon's influence on non-native species risk analysis is global. The risk analysis process for non-native species consists of:

- Risk Identification (also known as Risk Screening) of potential invasive species.
- Risk Assessment of species deemed to pose a higher risk of invasion.
- Risk Management and Communication to implement non-native species policy objectives.

Distinguishing these three separate and sequential components of the risk analysis process is crucial (Copp et al. 2005a, b, 2016a) and is an aspect far too often ignored (Hill et al. 2020).

For risk identification, Gordon took an academic idea—the use of a questionnaire to predict the invasiveness of non-native aquatic species

across taxa and regions—and, alongside his career-long collaborator Lorenzo Vilizzi, developed a series of practical and effective decision support tools. The first of these tools was the Freshwater Fish Invasiveness Screening Kit (FISK: Copp et al. 2005a, b). This was followed by five "sister" taxon-specific toolkits for screening other groups of aquatic organisms: the Amphibian Invasiveness Screening Kit (AmphISK), the Freshwater Invertebrate Invasiveness Screening Kit (FI-ISK), the Marine Fish Invasiveness Screening Kit (MFISK), the Marine Invertebrate Invasiveness Screening Kit (MI-ISK), plus a Spanish language version of the FISK (S-FISK) (Copp 2013). The FISK was later improved in its second version (v2) to account for a wider variety of environments, including subtropical and tropical climates (Lawson et al. 2013). These first-generation, taxon-specific toolkits were eventually replaced by the taxon-generic, multilingual Aquatic Species Invasiveness Screening Kit (AS-ISK: Copp et al. 2016b, 2021). This second-generation toolkit is designed for screening all aquatic organisms (animals and plants, freshwater, brackish, and marine) under current and future climate conditions. It has been implemented across all six inhabited continents in approximately 100 published applications to date. Protocols and guidelines for the correct usage of these toolkits, with a special emphasis on the second-generation ones, have been made available to the scientific community with the key contribution of Gordon (Vilizzi et al 2022a, b). Unsurprisingly, Gordon was involved in a large number of screening studies for aquatic organisms using both the first- and second-generation screening toolkits.

The very first trial of screenings with the FISK for nine species of freshwater fishes in the UK (Copp et al. 2005b) was followed by the toolkit's first calibration for non-native freshwater fishes in England and Wales (Copp et al. 2009) and by the first calibration of the FI-ISK for freshwater invertebrates in Italy (Tricarico et al. 2010). Following release of the FISK v2 with its first application to Peninsular Florida (Lawson et al. 2013), Gordon was involved in several screening applications using this toolkit. These included studies in: the Iberian Peninsula (Almeida et al. 2013), Southern Finland (Puntila et al. 2013), the Balkans (Simonović et al. 2013), the Murray-Darling Basin in Australia (Vilizzi and Copp 2013), Anatolia and Thrace in Türkiye (Tarkan et al. 2014), Peninsular Florida (Lawson et al. 2015), Lake Balaton (Ferincz et al. 2016), Greece (Perdikaris et al. 2016), Croatia and Slovenia (Piria et al. 2016), and the River Neretva catchment in Bosnia-Herzegovina and Croatia (Glamuzina et al. 2017). Additionally, Gordon contributed to a meta-analytical review study of applications of the FISK (Vilizzi et al. 2019).

Following release of the AS-ISK (Copp et al. 2016b), Gordon was involved in screening applications with this toolkit for a diverse range of aquatic organisms in various regions including: the River Neretva Catchment of Bosnia-Herzegovina and Croatia (Glamuzina et al. 2017), the River Yarlung Zangbo on the Tibetan Plateau of China (Li et al. 2017), Anatolia

and Thrace in Türkiye (Tarkan et al. 2017), 12 River Basin Districts across Great Britain (Dodd et al. 2019), the Arabian Gulf and Sea of Oman (Clarke et al. 2020), the River Ob Basin in Russia (Interesova et al. 2020), the Mediterranean Sea (Killi et al. 2020), Türkiye (Tarkan et al. 2020), South Korea (Uyan et al. 2020), Poland (Zięba et al. 2020), North and South Italy (Haubrock et al. 2021), Anzali Wetland in Iran (Moghaddas et al. 2021), Viet Nam (Ruykys et al. 2021), the Eastern Mediterranean (Tarkan et al. 2021), the Southern Caribbean (Tidbury et al. 2021), China and Thailand (Wei et al. 2021), the North Sea (Dodd et al. 2022), Lake Taal in the Philippines (Gilles et al. 2023), the Northen Gulf of Mexico (O'Shaughnessy et al. 2023), and Great Britain [Pearson et al. 2025]. Additionally, Gordon contributed to a global application of the AS-ISK (Vilizzi et al. 2021).

For risk assessment, Gordon was involved in the development of the European Non-native Species in Aquaculture Risk Analysis Scheme (ENSARS: Copp et al. 2016a, b), which was created to support the implementation of the 2007 EU aliens in aquaculture Regulation. The ENSARS is modular in structure, featuring a pre-screening module originally constructed using existing risk screening toolkits, such as the FISK and its related tools mentioned above. Since these taxon-specific screening tools could not be used with all non-native species, the automated workbook architecture of FISK v2 and the questions from the taxon-generic protocol of the ENSARS pre-screening module were used to create the AS-ISK, which replaced the original ENSARS pre-screening module. The ENSARS is increasingly being used, with applications in Türkiye (Tarkan et al. 2020), where it is currently being considered for wider use. The ENSARS has been translated into simplified Chinese and applied by two early-career scientists in China mentored by Gordon to assess largemouth bass [*Micropterus nigricans* (Lacepède, 1802)], reflecting increased interest in the potential impacts of aquaculture on native species and ecosystems (Li et al. 2025).

Additional work by Gordon related to risk analysis schemes involved the analysis of vectors and pathways of introduction (Copp et al. 2005d, 2006a, b, 2007b, 2010a, b, 2017b; Copp and Wade 2006; Chan et al. 2019). Stakeholder involvement was also a key aspect in the implementation of risk analysis schemes, both in the UK (Britton et al. 2011a, b) and within the European context (Boon et al. 2020).

Risk analysis process

For any risk assessment to be "fit for purpose", it requires an evidence base from which to formulate responses to assessment questions and to rank assessor confidence in their responses. The evidence base for many non-native species is usually deficient, particularly regarding their impacts on native species and ecosystems. To address this, Gordon pursued various case studies to inform risk screenings and full assessments of freshwater

fishes. These case studies encompassed all four main risk assessment components: introduction, establishment, dispersal, and impact (Copp et al. 2005a; Mumford et al. 2010).

The introduction risks of non-native fishes were investigated by Gordon using existing literature and databases as well as new data from field-based studies (Copp et al. 2005c, d, 2006a, b, 2007a, b; Gozlan et al. 2010; Tarkan et al. 2012a; Tidbury et al. 2016). Establishment risks represent a key factor in assessing the likelihood of being (or becoming) invasive. The main traits being:

- Plasticity of growth and life-history traits (Copp et al. 2007c; Kováč et al. 2009; Tarkan et al. 2010; Gruľa et al. 2012; Vilizzi and Copp 2017; Wei et al. 2017, 2022).
- Plasticity of body morphology (Záhorská et al. 2009; Novomeská et al. 2013).
- Phylogenetics (Jeffries et al. 2016, 2017) and phylogeography (Yavno et al. 2020).
- Adaptation to local conditions for spawning (Skóra et al. 2023) and the potential impact of future changes in climate conditions on fishes (Britton et al. 2010) and the diseases they host (Guilder et al. 2022).

Once introduced and established, the risks of subsequent natural and human-assisted dispersal, including via navigation canals (Panov et al. 2009, 2010), water transfers (Copp and Wade 2006), and fish-consignment transport (Copp et al. 2010a, b, 2017b; Zięba et al. 2010), will influence the potential magnitude of impacts.

To address the scarcity of evidence with which to assess the risks of impacts, initial investigations by Gordon focused on non-native fish interactions with native species, examining both predatory (diet) and microhabitat use (Klaar et al. 2004; Beyer et al. 2007; Copp et al. 2008; Godard et al. 2013) social (Beyer et al. 2010) and competitive interactions (Stakėnas et al. 2013; Almeida et al. 2014), and the potential for biological resistance from native species (Beyer et al. 2006; Miranda et al. 2008; Balestrieri et al. 2013). Gordon was also involved in empirical studies to identify potential impacts (Copp et al. 2010c, 2017b; Tarkan et al. 2012b; Vilizzi et al. 2012, 2015), as well as experimental studies (Copp et al. 2017a; Bašić et al. 2018), ensuring that experimental and empirical evidence accurately depict reality. The ideal approach involved both laboratory and field confirmation. A case in point is a series of investigations to determine whether the introduced racer goby [*Neogobius gymnotrachelus* (Kessler, 1857)] is outcompeting the native, protected European bullhead (*Cottus gobio* Linnaeus, 1758). Laboratory experiments demonstrated the invader's ability to outcompete the native fish for preferred habitat (Kakareko et al. 2013) and in foraging for prey (Grabowska et al. 2016). However, *in situ* field observations revealed no evidence of the two species interacting in open waters (Kakareko et al. 2016).

Contributions to the Special Issue

As a prelude to this Special Issue, we offer a novel perspective on terminology for non-native species invasiveness, which is additionally provided in 28 non-English languages for wider usage and adoption worldwide (Vilizzi et al. 2025b). We then update and align the questionnaires of the three "sibling" state-of-the-art decision support tools for risk screening currently used worldwide (the AS-ISK; the Terrestrial Animal Species Invasiveness Screening Kit: TAS-ISK; and the Terrestrial Plant Species Invasiveness Screening Kit: TPS-ISK), stemming from Gordon's pioneering work in the early 2000s (Vilizzi et al. 2025a). We review the applications of the AS-ISK in the USA as an indicator of the extent of usage and adoption of this electronic toolkit in one of the world's leading economies (Hill et al. 2025). We then evaluate with the AS-ISK the risk of invasiveness of: (i) the non-native freshwater fishes currently present in the Philippines – a mega-biodiversity country whose native aquatic biota are on the brink of collapse from human-induced impacts including climate change (Gilles et al. 2025); (ii) the shimofuri goby (*Tridentiger bifasciatus* Steindachner, 1881) in Great Britain following the species' first reports in Europe (Pearson et al. 2025); (iii) six non-native lineages of brown trout in the Western Balkans with emphasis on fishery sustainability (Simonović et al. 2025); and (iv) the non-native freshwater fishes of England and Wales, 15 years since their first evaluation with the AS-ISK predecessor, the FISK (Yoğurtçuoğlu et al. 2025). We further employ the AS-ISK both jointly with two other risk screening toolkits in an integrated evaluation of the invasiveness risk posed by non-native crayfish in Lake Maggiore (Northwest Italy) (Boggero et al. 2025) and as part of the pre-screening module of the ENSARS for a full risk assessment of the widely farmed *Micropterus nigricans* in China (Li et al. 2025). Similarly, we use the TAS-ISK for evaluating the invasion risk of non-native insects to agricultural lands in Croatia – a terrestrial application of the ISK toolkits representing the "exception that proves the rule" for the papers contributed to this Special Issue (Pajač Živković et al. 2025). We then introduce a new toolkit, the Non-Indigenous Species Screening Tool (NISST), whose structure addresses some gaps in the currently available decision support tools for risk screening by featuring a more comprehensive socio-economic impact module and the explicit incorporation of uncertainty (Wilcox et al. 2025). We expand this collection of papers with a review of the status, pathways, mechanisms, and management of introduced freshwater fish for aquaculture in China with the aim to inform strategies for sustainable development (Wei et al. 2025) and with an evaluation of raw water transfer schemes in England and Wales that addresses the potential implications for management and surveillance programmes and discusses options for improved information access and stakeholder collaboration (Waine et al. 2025). We conclude this Special Issue with

three additional papers dealing with: (i) restoration strategies for Atlantic salmon *Salmo salar* in a highly regulated watershed accounting for related risks of "hitch-hiking" by invasive species (Velle et al. 2025); (ii) a comprehensive investigation of the functional and ecological traits and invasion history attributes that best correlate with the progressive success of non-native species along their invasion pathway in European rivers (Marcolin 2025); and (iii) an integrated management approach for the control of invasive populations of the red swamp crayfish [*Procambarus clarkii* (Girard, 1852)](Morbidelli et al. 2025).

We anticipate that this Special Issue will serve as a valuable reference for future studies in the field of invasion biology. We also trust that Gordon would appreciate these efforts to continue his legacy and hope that, as an "external" referee, he would approve of the quality of the contributions presented here. As Gordon once subtly expressed, being aware of the limitations imposed by the constraints of mortal existence: "Everything will be fine".

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