Viewpoint

# "The absence of normal''; is it time for a Biocontamination Index for freshwater fauna in Aotearoa-New Zealand?

Calum MacNeil

*The Cawthron Institute, 98 Halifax Street East, Nelson 7010, Private Bag 2, Nelson 7042 New Zealand*

*Corresponding author: Calum MacNeil (calum.macneil@cawthron.org.nz)*

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## Abstract

Aotearoa-New Zealand was uninhabited by humans until c.1280 AD and almost 90% of its freshwater fish species are found nowhere else on earth. Now is the ideal time for the European derived biocontamination index to be adopted for freshwater fauna in Aotearoa-New Zealand. The index was developed nearly two decades ago for freshwater macroinvertebrates has been successfully used in several studies throughout Europe and in the British Isles. There is no index like this, which accounts for both the relative abundance and species number of non-natives, currently being applied to Aotearoa-New Zealand's freshwater systems, either for macroinvertebrates or fish. This is despite the presence of many introduced fish such as trout and catfish, which are known to impact on native species, many of which are rare, culturally "treasured" and under the threat of extinction. In addition, the very recent detection (May 2023) of the Gold/Asian clam, *Corbicula fluminea*, which is an "ecosystem engineer" that could arguably have the greatest ecological impact of any freshwater animal invader so far, makes the need for such an index even more compelling. Simple examples of publicly available fish species datasets are used to show how the biocontamination index could easily be applied with minimal extra effort to Aotearoa-New Zealand's systems and be used as an additional fisheries management tool. While some non-native fish are valued, some are designated pests and, in both cases, the biocontamination index could aid a variety of different management strategies. It is also suggested how the index could be employed, in respect of the surveillance and suppression strategy currently being adopted by the government in response to the recent Gold / Asian clam invasion.

**Key words:** *Corbicula fluminea*, fisheries management, Gold/Asian clam, introduced fish, non-native fish

## Introduction

Soldiers in the British Army, when on patrol in a hostile environment, are advised to be constantly aware of the "absence of normal" and the "presence of the abnormal" (Centre for Army Leadership 2020). This means being aware of things that should be there, suddenly not being there and, often simultaneously, the abrupt appearance of things that shouldn't be there, suddenly being there. This is sage advice for soldiers expecting an enemy attack on a battlefield. It is also a useful mindset for the ecologist attempting to detect changes in resident communities due to the presence of non-native species (NNS).

## The Biocontamination Index for freshwater macroinvertebrates – what it is and why it was needed

To gauge the extent to which the "normal" has been replaced by the "abnormal" in freshwater ecosystems, a biocontamination index was proposed nearly two decades ago to take account of NNS in Europe (Arbačiauskas et al. 2008). This index was designed for macroinvertebrate assemblages and can be derived from taxa presence and abundance data, often already collected by regulatory authorities, for ecosystem health and biological water quality assessment (Arbačiauskas et al. 2008, 2011; MacNeil et al. 2010). Acknowledging that NNS can affect the composition and functioning of assemblages, the index combines two metrics, an "abundance contamination index – ACI" (the numerical relative abundance of non-native individuals within an assemblage) and a "richness contamination index – RCI" (the proportion/ratio of non-native taxa within an assemblage). Combining these two metrics provides a simple (easy to understand), practical (easy to generate) but also integrated assessment of biocontamination. The "site-specific" biocontamination index (SBCI) value of a river or lake site is thus derived from the two metrics, using a simple matrix scoring system, ranging from 0 (no contamination – no NNS) to 4 (severe contamination – more than 50% of all individuals being NNS or more than 50% of all species being NNS, or both) (see Arbačiauskas et al. 2008 for details). The original SBCI was designed for benthic macroinvertebrates and the RCI component was tested at three different taxonomic levels, these being species, family and order (Arbačiauskas et al. 2008). Because results were similar, the order level was recommended for macroinvertebrates, for reasons of simplicity and practicality, as taxonomic resolution to species and sometimes family level can be difficult and some species in government monitoring programmes are identified at the higher taxon level. However, the species level is practical and appropriate for freshwater fish, if such an index were to be applied to fish assemblages.

Routine adoption of such a biocontamination index alongside current approaches to ecological status assessment is still not happening in many countries and yet this would seem an eminently wise move, in an era of increasing freshwater invasions and climate change (Hubbard et al. 2023). Many commonly used macroinvertebrate metrics in Europe, the U.K., North America and Australasia concerned with assessment of ecosystem health or biological water quality (i.e. the Biological monitoring working party (BMWP) score, Lotic-invertebrate Index for Flow Evaluation (LIFE), Macroinvertebrate Community Index (MCI) and Ephemeroptera Plecoptera Trichoptera (EPT) among others), still either ignore or underplay the influence of NNS on assemblage structure and function. For instance, many metrics do not even distinguish between natives and NNS from the same families in their scoring systems (MacNeil et al. 2013; Mathers et al. 2015). This is despite numerous studies showing that NNS can be more tolerant, or in some cases more sensitive, of organic pollution and other stressors than natives, can be more predatory and competitive than natives, can have different functional feeding modes than natives and so alter ecosystem energy processing and some are even "ecosystem engineers", radically altering invaded environments (Dick and Platvoet 2000; MacNeil et al. 2010, 2011; Emery-Butcher et al. 2020). All of these issues can significantly reduce the performance and reliability of many metrics to reflect changing environmental conditions (Arbačiauskas et al. 2008; MacNeil et al. 2010; Mathers et al. 2015).

## Fish Indices of Biological Integrity and the problem of non-native species

For freshwater fish metrics, the disruptive presence of NNS can present similar problems to their performance in providing reliable ecological status assessment, but again such metrics either ignore or underestimate the impacts of non-native fish (Jarvie and Jackson 2023). For instance, the first fish Index of Biotic Integrity (IBI) was developed by Karr (1981) to assess the overall "ecological condition" of North American assemblages and uses multiple metrics related to native species richness and composition, including the trophic and functional organisation of native assemblages. Although different versions of the IBI have now been adapted worldwide, the emphasis in all of them tends to remain firmly focussed on the "native". Unfortunately this means when establishing reference conditions, many fish IBIs either disregard or do not fully consider NNS as a potentially significant pressure driving loss of ecological integrity (Ruaro et al. 2018, 2021). For example, a version of the IBI was adapted to Aotearoa-New Zealand to account for the low diversity of the country's freshwater fish and the high proportion of migratory species (Joy and Death 2004). This Aotearoa-New Zealand IBI has twelve metrics, six of which are fish community composition metrics and of these, five are native focused and only one concerns NNS. This latter metric also only addresses the relative number of species in the assemblage which are NNS and thus takes no account of the relative abundance of non-native individuals in a sample. This is a serious omission, as numerical relative abundance is a crucial component for assessing the potential influence of NNS, as many NNS can rapidly overwhelm resident assemblages in terms of numbers (Arbačiauskas et al. 2008, 2011; MacNeil et al. 2010).

## Aotearoa-New Zealand – a troubled history of non-native species where a biocontamination index would be useful for future management

Aotearoa-New Zealand is unique in it contains the last of the Earth's major landmasses to remain uninhabited by humans (until c.1280 AD) but like many other small island nations, it has had a troubled history of ecological impacts from NNS (Champion 2018; King 2019). For instance, despite almost 90% of its freshwater fish species being found nowhere else on earth, over 75% are now at risk or under the threat of being at risk, of extinction (StatsNZ 2023). Many non-native fish were introduced deliberately as gamefish and for aquaculture and have been present for a long time, such as the brown trout *Salmo trutta*, introduced by British Victorian acclimatization societies in 1867 and the brown bullhead catfish *Ameiurus nebulosus* introduced from North America in 1878 (Grey 1926; Barnes and Hicks 2003; McDowall 1990). In contrast, some freshwater NNS have only just arrived and probably by accident, such as the macroinvertebrate *Corbicula fluminea*, the Gold/Asian clam, first detected in May 2023 (Ministry for Primary Industries (MPI) 2023). Both for new and established NNS, fish and macroinvertebrates, the biocontamination index could prove a useful addition to freshwater NNS management in countries such as Aotearoa-New Zealand.

It has been argued from a fish management perspective, that some NNS such as brown trout, are now so pervasive in Aotearoa-New Zealand, it is realistically impossible to remove or eradicate them on a large scale (Chadderton 2003). Therefore, a site-specific, “case by case”, pragmatic approach, has been advocated by some fisheries ecologists for NNS management (Chadderton 2003; Jellyman et al. 2018). This would mean protecting rare native fish from ongoing invasions of NNS in certain areas, such as NNS-free headwaters, while managing certain NNS as valuable “gamefish” in other areas (Chadderton 2003). Many studies have indicated that increased competition and predation from NNS such as brown trout and catfish has contributed to the decline of native species, many of which such as galaxiid fish and kōura (the crayfish, *Paranephrops planifrons*) are taonga or “treasured” by indigenous Māori (McDowall 1990; McIntosh et al. 2010; Jellyman et al. 2018; Dedual 2019; NIWA 2020). While catfish are designated “pests” in five Aotearoa-New Zealand regions and their catching, release and propagation is banned (NIWA 2020), trout management is a far more nuanced and controversial issue, crossing over boundaries of economics, legislation, conservation, colonialism and cultural identity (Chadderton 2003; Jellyman et al. 2018; Tadaki et al. 2022). For instance, regardless of its impact on native species, the brown trout is often used and indeed referred to as an “honorary native” in the fish IBI, because its presence can be indicative of good water quality (Joy and Death 2004). Views on its “management” depend on whether this NNS is in a particular location or another, the native species already present in the area, and whether stakeholders and Māori in that specific area, view trout as part of the “natural” healthy “riverscape” or an “alien invader” needing to be eradicated (Chadderton 2003; Dean 2003; Jellyman et al. 2018). A pragmatic approach to NNS fisheries management, could mean eradicating NNS in areas where only a few isolated populations and small numbers of NNS individuals exist or where protection of valued native species requires it, while accepting NNS in areas where they are already common and abundant, and natives are absent.

I would argue a biocontamination index would be an extremely useful tool, whatever NNS fish management strategy is ever adopted in Aotearoa-New Zealand. It could easily be used alongside more established metrics dealing with ecosystem health to provide a more comprehensive overview of the fish assemblages which generated such metrics, in terms of relative "nativeness" or "non-nativeness". To illustrate this, I will apply the biocontamination index to two example datasets. One is for a river system, where only a single NNS, the brown trout, is recorded in resident fish assemblages. The other is for a river where many NNS, including pests such as catfish, are present. Using the example of the Gold/Asian clam, I will also consider how the index could be profitably employed in managing and monitoring very recent and future invasions of macroinvertebrate NNS.

*Applying the biocontamination index to fish assemblage datasets – two worked examples*

The Riwaka (also called Riuwaka) River is a small South Island river system, where fish species abundance data are available via a publicly accessible national database (New Zealand Freshwater Fish Database https://nzffdms.niwa.co.nz/ accessed December 2023). Allowing for obvious caveats about operator error, sampling method, seasonality and "catchability" associated with such a database, where data has been lodged by local government and consultants, the site-specific fish species abundance and richness data for this river are readily available. This does provide a very basic starting point to further investigate "biocontamination" by the only NNS recorded in this system, the brown trout. Figure 1 shows the (a) relative NNS abundance, (b) relative NNS richness and (c) calculated biocontamination level, for 16 sites from 2010 to 2021. Site-specific ACI values ranged from 0.12 to 1.0, with 19% of sites in the 0.11–0.20 band, 56% in the 0.21–0.50 band and 25% in the < 0.50 band (Arbačiauskas et al. 2008). Site-specific RCI values ranged from 0.17 to 1.0, with 19% of sites in the 0.11–0.20 band, 75% in the 0.21–0.50 band and only 6% in the < 0.50 band. The site specific biocontamination level ranged from moderate to severe (Figure 1c), with the high biocontamination levels being influenced to varying degrees by the ACI and RCI (Arbačiauskas et al. 2008). For instance, of four severely biocontaminated sites (Figure 1c), trout numerically dominate the assemblage, comprising between 65% and 100% of all fish sampled, so in this case the ACI is largely driving the highest biocontamination levels (Figure 1a). Although one site contained only trout and no native species, being the single NNS recorded in the remaining fifteen sites, trout seldom dominated the species richness (Figure 1b). This is despite the overall number of freshwater fish species in Aotearoa-New Zealand tending to be low compared to Europe and North America (McDowall 1990; Champion 2018). This example shows the combination of a site-specific biocontamination level derived from these two metrics and the absolute

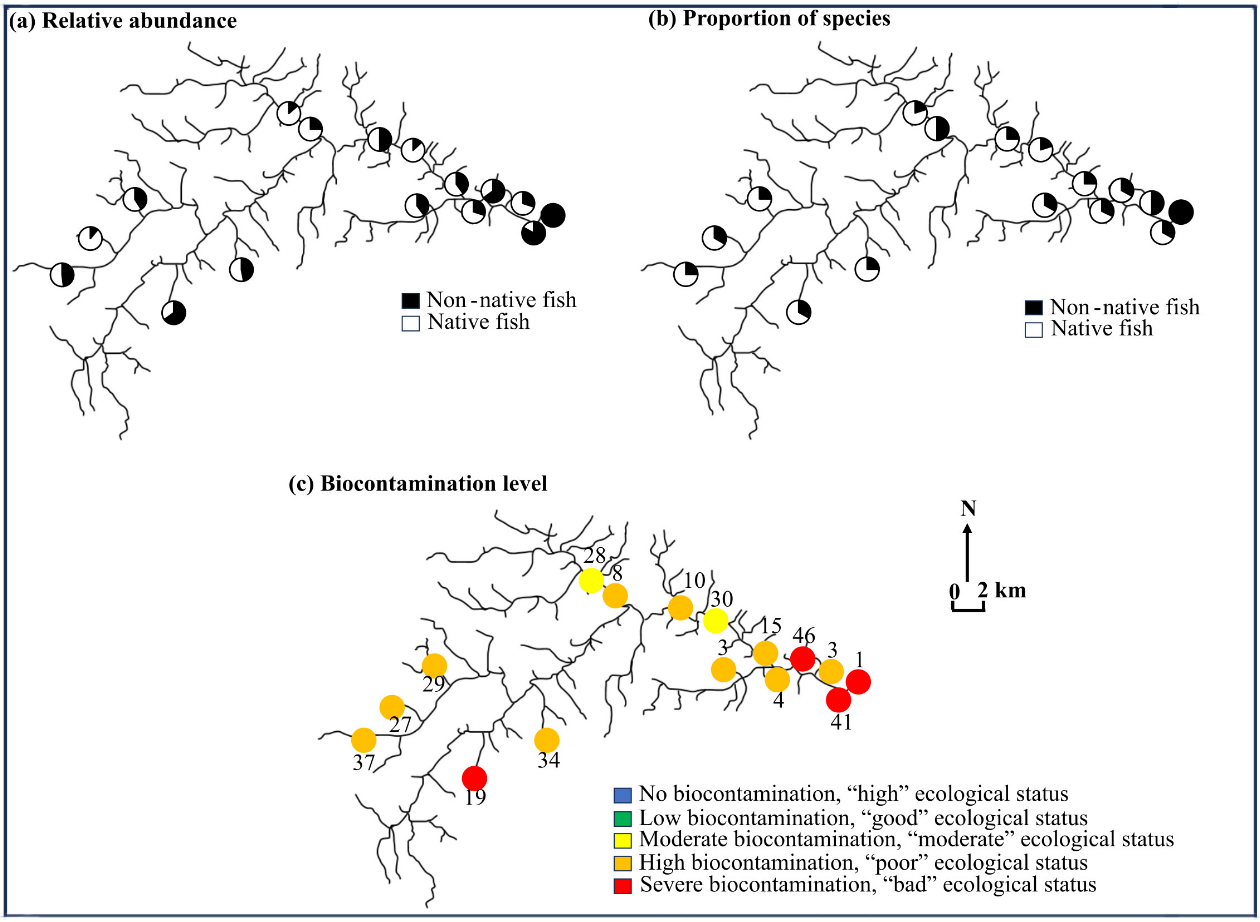


**Figure 1.** The (a) relative abundance of non-native fish (brown trout as an example), (b) proportion of NNS (brown trout being only the NNS present) and (c) site specific biocontamination level for fish sampled sites in the Riwaka (Riuwaka) River. Numbers in (c) indicate total numbers of all fish recovered by sampling and recorded on the New Zealand freshwater fish database, maintained by NIWA (https://nzffdms.niwa.co.nz/).

total numbers of fish recovered from each site (Figure 1c), could provide a useful pathway to manage NNS such as trout within invaded systems. For instance, tributaries with multiple sites with severe or high "trout" contamination but very few fish (ie. Figure 1c shows such biocontamination levels generated from sites with fewer than ten fish), might lend itself to a concerted effort at NNS eradication. In contrast, other tributaries or streams with multiple sites showing moderate or high contamination and dozens of non-native fish, could lend itself to a different management strategy.

A more extreme example of fish assemblage biocontamination can be found in the Lower Waikato River in the North Island, where historic fish density data is available for a week-long electrofishing survey conducted by university researchers in 2005 (Hicks et al. 2005). This recovered nearly three thousand (2915) fish from twenty-seven sites and included thirteen species, seven of which were NNS, including brown bullhead catfish, rudd (*Scardinius erythropthalmus*), koi carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) (Hicks et al. 2005). The Waikato is a highly invaded system and therefore it is unsurprising that only a few sites (11%) had no biocontamination and the vast majority (78%) exhibited high or severe

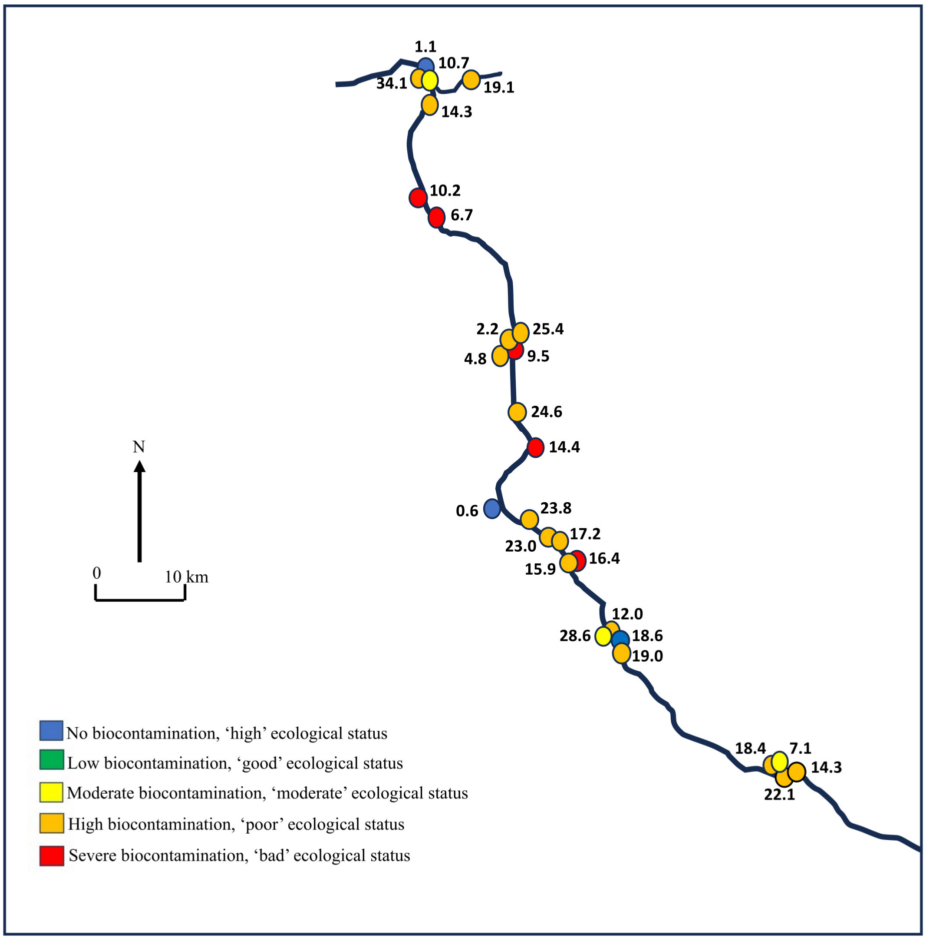


**Figure 2.** Biocontamination levels extrapolated from an electrofishing survey of the lower Waikato River and its tributaries between 8 and 15 February 2005, conducted by Hicks et al. 2005. A total of 2,915 fish were recovered, comprising six native and seven non-native fish species (see Hicks et al. 2005 for details). Numbers represent density of fish per site (number per 100 $m^{-2}$).

biocontamination (Figure 2). However, even here, some of the most severely biocontaminated sites also had the lowest fish densities recorded, with three severely biocontaminated sites with densities of 10.2 fish per 100 $m^{-2}$ or less (Figure 2). With such information, NNS eradication at such sites could at least be considered if ever warranted by stakeholders and Māori.

The Riwaka and Lower Waikato are just two examples of "biocontaminated" rivers and I have purposely taken a highly simplified approach to assessing the prevalence of NNS in sites which are undoubtedly interconnected and in the case of the Riwaka, have datasets spanning different seasons, years and operators. Nevertheless, both datasets were readily available to me or anybody else with internet access and allowed the generation of an additional metric for these rivers in a relatively short space of time. Both examples indicate that an assessment of biocontamination at minimal extra effort, than that already expended by government agencies and researchers, could yield an additional fish management tool worth pursuing, not just accounting for NNS presence but also potential influence. This could easily work alongside established metrics such as the fish IBI to provide an even more comprehensive assessment of the pressures on native fish assemblages. A combination of biocontamination level and absolute number of fish recovered, provides a useful starting point when considering a case-by-case management approach to NNS. Fortunately recent Aotearoa-New Zealand freshwater legislation (the National Policy Statement on Freshwater Management, NPSFM) now requires councils to sample fish abundance to calculate fish IBI scores (https://environment.govt.nz/acts-and-regulations/freshwater-implementation-guidance/nof/values-and-attributes/fish-index-of-biotic-integrity/), so this should facilitate a management approach using numerical abundance and the biocontamination index going forward.

*How the biocontamination index could be applied to Aotearoa-New Zealand's most recent freshwater non-native species*

Unlike many non-native fish, the Asian/Gold clam's impacts on the ecology of Aotearoa-New Zealand remain extremely geographically restricted and except for a single river, so far unrealised. However, it does appear to be thriving at its initial detection sites in the North Island's Waikato River, with an initial population boom well underway (Martin 2023) and it is now poised to invade the country's largest lake, Lake Taupo (Rotorua Daily Post 2024). The documented impacts of this "ecosystem-engineer" globally (radically changing water clarity, trophic interactions, phytoplankton and macroinvertebrate communities), its wide physiological tolerances, high reproductive potential and the apparently vacant niche ready to be exploited (Sousa et al. 2009; MPI 2023), all indicate it could have the greatest ecological impact of any freshwater animal invader in Aotearoa-New Zealand so far. Many freshwaters in Europe and North America are now already grossly biocontaminated with macroinvertebrate NNS and as such, application of the biocontamination index merely confirms this (Arbačiauskas et al. 2008; Cuk et al. 2019). Aotearoa-New Zealand has a distinct advantage over Central Europe, North America and many other regions of the world, in that its riverine macroinvertebrate assemblages are, thus far, relatively lightly impacted by the presence of NNS (Champion 2018; MPI 2023). Therefore, with Aotearoa-New Zealand's biosecurity awareness already high and before any significant influx of other potentially high impact freshwater NNS, now would be an ideal time to establish a baseline biocontamination assessment of the country's freshwater macroinvertebrate assemblages. This would allow ecologists to become familiar with the use and generation of the index alongside routine biological monitoring metrics already used by government and councils, to assess ecosystem health. For instance, the MCI is a core metric for general ecosystem health monitoring in Aotearoa-New Zealand and relies on macroinvertebrate species data, which immediately lends itself to generation of biocontamination estimates. Simultaneous collection of both MCI and biocontamination index values could then become part of a national surveillance strategy or "early warning" system for NNS detection. It is acknowledged that the biocontamination index and its associated five levels of biocontamination, ranging from none to severe, was originally constructed to be tailored to corresponding water quality classes of the European Water Framework Directive (Arbačiauskas et al. 2008). However, it has already been shown that the metrics of biocontamination can be readily modified and adapted to fit other regions (Šidagytė et al. 2013), so a similar process of adaptation to Aotearoa-New Zealand's unique freshwater systems should not be an obstacle, if this proves necessary. Taking the example of the clam, the government's technical advisory group (TAG) concluded that eradication from the Waikato catchment would be extremely unlikely, but a strategy of containment and suppression could be pursued, keeping long term eradication as a future option if possible (MPI 2023). Use of a biocontamination index would aid this strategy by allowing tracking of biocontamination levels in any of the clam's new incursions and selecting where a suppression strategy might be most effectively applied (i.e. mechanical removal, placement of impermeable benthic barriers and targeted chemical application – see Aldridge et al. 2015). "Forcing" ecologists to regularly use such an index alongside established macroinvertebrate metrics and to actively scan a sample for NNS, may also increase the probability of NNS detection, as may have been the case with non-native amphipods in the U.K. (MacNeil et al. 2010).

## Conclusions

NNS are already part of Aotearoa-New Zealand's freshwater landscape and more will be coming. Regularly applying the biocontamination index from now on, alongside routine ecosystem health metrics, means it can act as a surveillance tool to track further spread of NNS already present and establish a baseline of current "contamination levels" in rivers and lakes, before more NNS inevitably arrive. It will also aid fisheries ecologists, stakeholders and Māori attempting to manage non-native fish presence in Aotearoa-New Zealand's freshwater future. The biocontamination index is an example of a simple but effective tool for detecting and quantifying the 'absence of normal' and the "presence of the abnormal" but it really needs to be used.

## Authors' contribution

CM was entirely responsible for concept, writing, data analysis and interpretation.

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