FRESHWATER BIODIVERSITY

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ABSTRACT: This chapter describes the state, trends and potential drivers of fish and macro-invertebrate biodiversity in New Zealand fresh waters, but does not discuss the other components of freshwater biodiversity, namely the micro fauna, plants, fungi and microbial life. Trends reveal that New Zealand's fresh waters are under increasing pressure through agricultural intensification, urbanisation, invasion of exotic species, and climate change. The evaluation shows that the response from resource managers has been insufficient to limit the many impacts and has lagged behind the degradation and declines. The future for freshwater biodiversity looks bleak as agricultural intensification and urban spread expand while at the same time environmental regulation is reduced.

Key words: agricultural intensification, freshwater biodiversity, freshwater fish, freshwater invertebrates.

NEW ZEALAND'S FRESHWATER FISH

The freshwater fish fauna

At present, 50 genetically distinct, extant fish species are recognised in freshwaters in New Zealand with another three or four species yet to be formally named (Allibone et al. 2010) (Table 1). However, the actual species number is hard to define because eight are classified as 'freshwater indeterminate': they are essentially marine species but move far into fresh waters for long periods. Only one native fish, the endemic grayling (*Prototroctes oxyrhynchus*), is known to have become extinct since the first human settlement of New Zealand c. 700 years ago, although many other species have become locally extinct over much of their pre-European range. New Zealand's freshwater fish fauna is unique, with 92% of the named species found nowhere else in the world. The fauna comprises nine families: Geotriidae, Anguillidae, Retropinnidae, Prototroctidae, Galaxiidae, Cheimarrhichthyidae, Eleotridae, Mugilidae, and Pleuronectidae. Galaxiidae make up more than half the species. In addition to these native fish species, a further 21 exotic species have been introduced to New Zealand (Table 2).

The total number of described native species has increased in the last few decades because new species have been discovered and new genetic techniques have allowed some morphologically cryptic species to be discriminated (Waters and Wallis 2000; Wallis et al. 2009). Nevertheless, the number of freshwater fish species in New Zealand is low compared with other regions globally (Leveque et al. 2008); for example, it is much lower than the number of species found in a single South American river, although higher than the total fauna of the United Kingdom.

Diadromy

One feature of the New Zealand freshwater fish fauna is the large proportion of diadromous species: namely, fish that undertake two migratory movements between the ocean and fresh water in their life cycles. Diadromous fish employ three very distinctly different strategies: anadromy, catadromy, and amphidromy (Table 3). Anadromous fish spend their adult life in the sea, move to fresh water to breed, then die; catadromy is essentially the opposite, with fish spending most of their adult life in fresh water before a final migration to the ocean to breed and die; and amphidromy is an intermediate strategy in which adults live in fresh water, usually breed yearly, and the juveniles spend time in the ocean before returning to fresh water (McDowall 1988). A few decades ago diadromy was thought to be obligatory in most diadromous species, but we now know that in some species diadromy seems to be facultative, as not all individuals migrate. In the currently recognised extant taxa, diadromy is thought to be obligatory in 13 species and facultative in 6, and at least one diadromous species is present in each of the nine families in the New Zealand fauna (Ling 2010). Seven diadromous species include landlocked populations, usually, but not always, are formed when a lake outlet is blocked (Closs et al. 2003).

Implications of diadromy for biodiversity

Diadromous individuals belong to national populations with large overlapping ranges covering most of New Zealand or wider; some are found on offshore islands or even further in Australia and South America (e.g. lamprey and inanga). In contrast, non-diadromous species have much more restricted ranges, especially in the south-eastern South Island where they are thought to have evolved as a result of glacial or geomorphological vicariance during the Pleistocene (Wallis et al. 2009). Most of these species are small-bodied galaxiids that are now restricted to small tributary streams where they can find refuge from downstream predatory exotic salmonids (McIntosh 2000; McDowall 2003, 2006). However, the non-diadromous species of bullies (Eleotridae) have broader ranges: the upland bully is found over most of the South Island as well as the lower half of the North Island, and the Crans bully is found over most of the North Island but not the South Island. One exception is the non-diadromous Tarndale Bully found in a very restricted area of a few tarns in the northern South Island

New Zealand's native fish are not only unique taxonomically (92% endemic), but are also unusual in that they are mostly small, benthic, riverine, largely nocturnal, diadromous, and cryptic (McDowall 1990). Most are found almost exclusively in riverine habitats, with the few exceptions being species found in both rivers and lakes. These exceptions are the two eel species, common bully, koura, two inanga species, and giant kōkopu; none dwell exclusively in lakes. Most New Zealand fish species are benthic (resting on the bottom) rather than pelagic (mostly swimming in the water column). Even more unusually, some species spend a large proportion of time within the substrate, living below the stream bed in the spaces between rocks and boulders (McEwan and Joy 2011, in press).

International trends in freshwater fish biodiversity

Freshwater fish are declining throughout the world (Dudgeon et al. 2006). In the early 1990s more than 20% of the world's 10 000 recorded freshwater fish species had become extinct, threatened, or endangered (Moyle and Leidy 1992). By 2009 the IUCN Red List of Threatened Animals listed 37% of freshwater

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TABLE 1 Native freshwater fishes in New Zealand, including migratory status and threat classification. Cat = catadromy; Amp = amphidromy (Allibone et al. 2010; McDowall 2010).

Family	Formal name	Common name	Threat classification (2010)	Endemic/ Indigenous	Diadromous	Landlocked populations	Usual habitat
Anguillidae	*Anguilla australis schmidtii*	Shortfin eel	Not threatened	Indigenous	Cat	Never	Stream/ wetland
	Anguilla dieffenbachii	Longfin eel	Declining	Endemic	Cat	Never	Stream/lake
	Anguilla reinhardtii	Australian longfin eel	Coloniser	Indigenous	Cat	Never	Stream
Eleotridae	*Gobiomorphus alpinus*	Tarndale bully	Naturally Uncommon	Endemic	No	N/A	Lake
	Gobiomorphus basalis	Crans bully	Not threatened	Endemic	No	N/A	Stream
	Gobiomorphus breviceps	Upland bully	Not threatened	Endemic	No	N/A	Stream
	Gobiomorphus cotidianus	Common bully	Not threatened	Endemic	Amp	Often	Stream/lake
	Gobiomorphus gobioides	Giant bully	Not threatened	Endemic	Amp	Never	Stream
	Gobiomorphus hubbsi	Bluegill bully	Declining	Endemic	Amp	Never	Stream
	Gobiomorphus huttoni	Redfin bully	Declining	Endemic	Amp	Never	Stream
Galaxiidae	*Galaxias* aff. *paucispondylus* “Manuherikia”	Alpine galaxias (Manuherikia)	Nationally Endangered	Endemic	No	Never	Stream
	Galaxias aff. *paucispondylus* “Southland”	Alpine galaxias (Southland)	Not threatened	Endemic	No	Never	Stream
	Galaxias “Northern sp.”	Possible new non-diadromous galaxias	Naturally Uncommon	Endemic	No	Never	Stream
	Galaxias “Southern sp.”	Possible new non-diadromous galaxias	Not threatened	Endemic	No	Never	Stream
	Galaxias “Teviot”	Possible new non-diadromous galaxias	Nationally critical	Endemic	No	Never	Stream
	Galaxias aff. cobitinis “Waitaki”	Waitaki Lowland longjaw galaxias	Nationally critical	Endemic	No	Never	Stream
	Galaxias aff. *gollumoides*”Nevis”	Smeagol galaxias	Nationally vulnerable	Endemic	No	Never	Stream
	Galaxias aff. *prognathus* (Waitaki)	Upland longjaw galaxias (Waitaki)	Nationally vulnerable	Endemic	No	Never	Stream
	Galaxias anomalus	Roundhead galaxias	Nationally vulnerable	Endemic	No	N/A	Stream
	Galaxias argenteus	Giant kokopu	Declining	Endemic	Amp	Occasional	Stream/lake
	Galaxias brevipinnis	Koaro	Declining	Indigenous	Amp	Often	Stream/lake
	Galaxias cobitinis	Kakanui Lowland longjaw galaxias	Nationally critical	Endemic	No	N/A	Stream
	Galaxias depressiceps	Taieri Flathead galaxias	Not threatened	Endemic	No	N/A	Stream
	Galaxias divergens	Dwarf galaxias	Declining	Endemic	No	N/A	Stream
	Galaxias eldoni	Eldon’s galaxias	Nationally vulnerable	Endemic	No	N/A	Stream
	Galaxias fasciatus	Banded kokopu	Not threatened	Endemic	Amp	Occasional	Stream/lake
	Galaxias gollumoides	Gollum galaxias	Declining	Endemic	No	N/A	Stream
	Galaxias gracilis	Dwarf inanga	Naturally uncommon	Endemic	No	N/A	Lake
	Galaxias macronasus	Bignose galaxias	Nationally vulnerable	Endemic	No	N/A	Stream
	Galaxias maculatus	Inanga	Declining	Indigenous	Cat	Rarely	Stream/lake
	Galaxias paucispondylus	Alpine galaxias (Canterbury)	Not threatened	Endemic	No	N/A	Stream
	Galaxias postvectis	Shortjaw kokopu	Declining	Endemic	No	Occasional	Stream

	Galaxias prognathus	Upland longjaw galaxias (Canterbury)	Nationally vulnerable	Endemic	No	N/A	Stream
	Galaxias pullus	Dusky galaxias	Nationally endangered	Endemic	No	N/A	Stream
	Galaxias sp.	Dune lakes galaxias	Naturally uncommon	Endemic	No	N/A	Lake
	Galaxias sp. D./Clutha flat-head	Clutha flat-head galaxias	Nationally vulnerable	Endemic	No	N/A	Stream
	Galaxias vulgaris	Canterbury galaxias	Not threatened	Endemic	No	N/A	Stream
Geotriidae	*Geotria australis*	Lamprey	Declining	Indigenous	Yes	Never	Stream
Neochanna	*Neochanna apoda*	Brown mudfish	Declining	Endemic	No	N/A	Wetland
	Neochanna burrowsius	Canterbury mudfish	Nationally endangered	Endemic	No	N/A	Wetland
	Neochanna diversus	Black mudfish	Relictual	Endemic	No	N/A	Wetland
	Neochanna heleios	Northland mudfish	Nationally vulnerable	Endemic	No	N/A	Wetland
	Neochanna rekohua	Chatham Island mudfish	Naturally uncommon	Endemic	No	N/A	Lake
Pinguipedidae	*Cheimarrichthys fosteri*	Torrentfish	Declining	Endemic	Yes	Never	Stream
Pleuronectidae	*Rhombosolea retiaria*	Black flounder	Not threatened	Endemic	Yes	Never	Estuaries and lowland lakes
Retropinidae	*Prototroctes oxyrhynchus*	Grayling	Extinct	Indigenous	Yes	Never	Stream
	Retropinna retropinna	Common smelt	Not threatened	Endemic	Yes	Often	Stream/lake
	Stokellia anisodon	Stokells smelt	Naturally uncommon	Endemic	Yes	Never	Stream
Mugilidae	*Aldrichetta forsteri*	Yelloweyed mullet	Not threatened	Indigenous	No	N/A	Lowland streams
	Mugil cephalus	Grey mullet	Not threatened	Indigenous	No	N/A	Lowland streams
Tripterygiidae	*Grahamina nigripenne*	Estuarine triplefin	Not threatened	Endemic	No	N/A	Estuaries
Gobiidae	*Gobiopterus semivestitus*	Glass goby	Coloniser	Indigenous	No	N/A	Lowland streams
Microdesmidae	*Parioglossus marginalis*	Goby	Coloniser	Indigenous	No	N/A	Lowland streams

TABLE 2 Exotic fish species established in New Zealand

Common name	**Formal name**
Atlantic salmon	*Salmo salar*
Bridled goby	*Arenigobius bifrenatus*
Brook char	*Salvelinus fontinalus*
Brown trout	*Salmo trutta*
Catfish	*Ameiurus nebulosus*
Caudo	*Phallocerus caudimaculatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Gambusia	*Gambusia affinis*
Goldfish	*Carassius auratus*
Guppy	*Poecilia reticulata*
Grass carp	*Ctenophoryngodon idella*
Koi carp	*Cyprinus carpio*
Lake char/mackinaw	*Salvelinus namaycush*
Orfe	*Leuciscus idus*
Perch	*Perca fluviatilis*
Rainbow trout	*Oncorhynchus mykiss*
Rudd	*Scardinius erythrophthalmus*
Sailfin molly	*Poecilia latipinna*
Sockeye salmon	*Oncorhynchus nerka*
Swordtail	*Xiphophorus helleri*
Tench	*Tinca tinca*

fish species as extinct or threatened. While alarming, these figures undoubtedly underestimate the true extent of decline because available data on freshwater biodiversity are meagre, and when biodiversity is declining the data inevitably lag behind actual range restrictions and extinctions. Furthermore, extinction debt causes an additional lag. Extinction debt describes the situation where species, particularly the long-lived ones, survive initial environmental impacts but lack of recruitment means extinction of remaining populations is inevitable (Jackson and Sax 2010).

Even disregarding the likely underestimation of declines, where national data are available the trend is ominous. In South Africa, 63% of freshwater fish were listed as threatened or endangered; in Europe, 42%; in Iran, 22% (Moyle and Leidy 1992). In the United States, 37% of freshwater fish species are threatened or have become extinct (Master et al. 1998) and 3.7% of freshwater

TABLE 3 Freshwater fish species, their migratory strategy and prevalence in the New Zealand Freshwater Fish Database (flowing waters), and Mann–Kendall trend test score. Species not found in all time classes and thus not included in temporal analyses have no Mann–Kendall statistic (bold denotes introduced species; + denotes facultative migratory status).

Common name	Scientific name	Migratory strategy	Prevalence (%)	Mann–Kendall score	Adjusted *P*-value
Lamprey	*Geotria australis*	Anadromous	1.73	−54	0.00
Black flounder	*Rhombosolea retiaria*	Amphidromous	0.83	−54	0.00
Torrentfish	*Cheimarrichthys fosteri*	Amphidromous	6.68	−50	0.00
Brown trout	*Salmo trutta*	Anadromous+	21.99	−48	0.00
Common bully	*Gobiomorphus cotidianus*	Amphidromous+	15.71	−48	0.00
Bluegill bully	*Gobiomorphus hubbsi*	Amphidromous	3.18	−48	0.00
Koaro	*Galaxias brevipinnis*	Amphidromous+	8.06	−45	0.03
Common smelt	*Retropinna retropinna*	Anadromous+	3.87	−42	0.03
Longfin eel	*Anguilla dieffenbachii*	Catadromous	35.92	−39	0.05
Yelloweye mullet	*Aldrichetta forsteri*	Marine	0.85	−35	0.10
Giant kokopu	*Galaxias argenteus*	Amphidromous+	3.16	−32	0.13
Redfin bully	*Gobiomorphus huttoni*	Amphidromous	13.16	−30	0.16
Shortfin eel	*Anguilla australis*	Catadromous	18.02	−25	0.21
Catfish	*Ameiurus nebulosus*	Non-migratory	0.75	−25	0.21
Rainbow trout	*Oncorhynchus mykiss*	Anadromous+	5.95	−20	0.34
Dwarf galaxias	*Galaxias cobitinis*	Non-migratory	1.77	−20	0.34
Shortjaw kokopu	*Galaxias postvectis*	Amphidromous+	2.14	−17	0.43
Canterbury galaxias	*Galaxias vulgaris*	Non-migratory	2.17	−12	0.62
Giant bully	*Gobiomorphus gobioides*	Amphidromous	1.57	−3	0.94
Goldfish	*Carassius auratus*	Non-migratory	2.1	−2	0.95
Inanga	*Galaxias maculatus*	Catadromous+	10.88	4	0.92
Perch	*Perca fluviatilis*	Non-migratory	1.29	8	0.76
Upland bully	*Gobiomorphus breviceps*	Non-migratory	10.91	10	0.69
Banded kokopu	*Galaxias fasciatus*	Amphidromous+	11.58	26	0.23
Alpine galaxias	*Galaxias paucispondylus*	Non-migratory	1.53	26	0.23
Gambusia	*Gambusia affinis*	Non-migratory	2.64	33	0.12
Crans bully	*Gobiomorphus basalis*	Non-migratory	3.89	-	-
Rudd	*Scardinius erythrophthalmus*	Non-migratory	0.86	-	-
Flathead galaxias	*Galaxias divergens*	Non-migratory	0.74	-	-
Gollum galaxias	*Galaxias gollumoides*	Non-migratory	0.60	-	-
Koi carp	*Cyprinus carpio*	Non-migratory	0.45	-	-
Tench	*Tinca tinca*	Non-migratory	0.38	-	-
Upland longjaw galaxias	*Galaxias prognathus*	Non-migratory	0.34	-	-
Grey mullet	*Mugil cephalus*	Marine	0.24	-	-
Grass carp	*Ctenopharyngodon idella*	Non-migratory	0.19	-	-
Australian longfin eel	*Anguilla reinhardtii*	Catadromous	0.07	-	-
Tarndale bully	*Gobiomorphus alpinus*	Non-migratory	0.02	-	-
Lowland longjaw galaxias	*Galaxias depressiceps*	Non-migratory	0.01	-	-

species are projected to become extinct in North America each decade. Sadly, this rate of decline is nearly five times higher than that of terrestrial animals (Ricciardi and Rasmussen 1999).

New Zealand trends in freshwater fish biodiversity

New Zealand's record of threatened species is one of the world's worst: 68% of all native fish species are listed as threatened. Nationally, fish abundance and diversity have been declining for at least the last century but this has accelerated over the last 40 years (Figure 1). While only one species, the grayling (see above), has become extinct, the range and abundance of most species has declined. This can be seen from the increase in the number of species listed as threatened over the last 20 years, with the proviso that the criteria for threat rankings change over time and data for the listings inevitably lag behind actual declines. In 1992 the New Zealand Department of Conservation (DOC) recorded 10 species as threatened; by 2002 that number had risen to 16 species (4 were classified as acutely threatened,

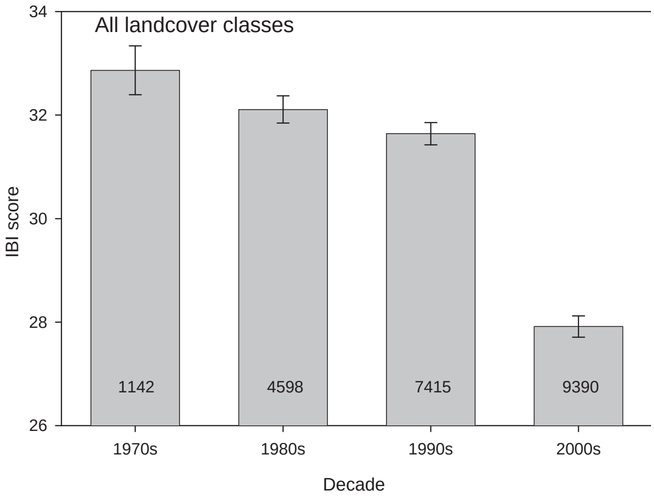

FIGURE 1 Average decadal IBI (Index of Biotic Integrity; Joy and Death 2004) score for all sites (number of sites inside bars, whiskers = standard error). The higher the score, the healthier the ecosystem.

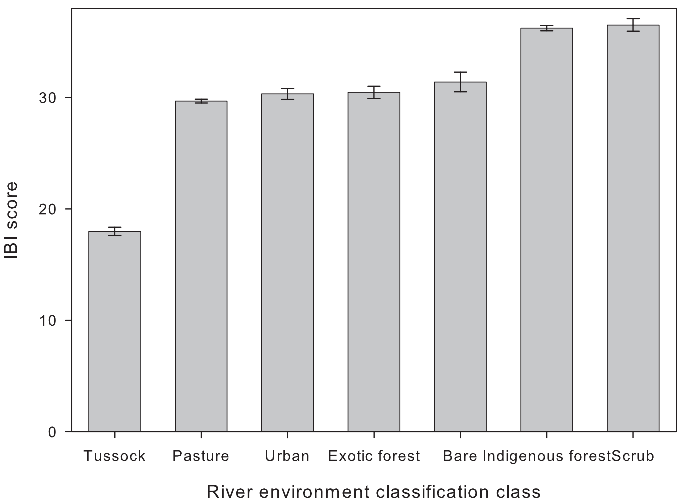

FIGURE 2 Average IBI (Index of Biotic Integrity; Joy and Death 2004) score for all sites grouped by River Environment Classification (REC) land-cover class (ANOVA F7, 22538 = 247; P < 0.0001) (whiskers = standard error).

12 as chronically threatened, 4 as at risk, and 5 as data deficient) (Hitchmough 2002). Three years later, in 2005, 24 species were listed as threatened (6 were listed as acutely threatened, 14 as chronically threatened, 4 as at risk, and 5 as data deficient) (Hitchmough et al. 2007). In 2007 a new threat classification scheme was established (Townsend et al. 2008) using a reduced set of categories but retaining the key threat descriptors from previous classifications. Under this new system 68% of all extant native taxa and 76% of all non-diadromous taxa are considered threatened or at risk (1 species is listed as extinct, 1 as nationally critical, 2 as nationally endangered, 3 as nationally vulnerable, 1 as in serious decline and 13 as in gradual decline, 2 as sparse, 4 as range restricted, and 3 as data deficient) (Allibone et al. 2010).

To assess and visualise trends in the status of New Zealand freshwater fish species over the last 40 years, we analysed fish distribution data from the New Zealand Freshwater Fish Database (NZFFDB). This database is maintained by New Zealand's National Institute of Water and Atmospheric Research (NIWA) (McDowall and Richardson 1983; McDowall 1991); it contains more than 30 000 records of fish distribution, beginning in 1901, and is continuously updated. We analysed more than 22 000 records of presence and absence of 38 species found in flowing waters for the period January 1970 to December 2009. Individual species trends were analysed by comparing the proportions of sites containing each species over time. To compare changes in fish communities rather than just individual species we used an index of biotic integrity (IBI) adapted for New Zealand (Joy and Death 2004). The IBI is a robust and internationally used measure of the state of freshwater fish assemblages; it is used to assess the health of freshwater ecosystems, with high IBI values indicating healthier systems than those with low IBI values. The IBI has been applied to a large database of freshwater fish distribution, collected throughout New Zealand over the last 40 years, to summarise temporal and land-use trends in freshwater health for the Ministry for the Environment (Joy 2009).

TABLE 4. Results of regression analyses for all sites and land cover classes using IBI scores for years and decades. Trend is significant if P-value is less than 0.05 (ns = not significant)

REC land-use class	Direction of change	Number of sites	All years		Decades	
			F-value	*P-value*	*F-value*	*P-value*
All sites	Negative	22545	191.2	0.0001	223.7	0.0001
Pasture	Negative	9931	92.0	0.0001	118.4	0.0001
Tussock	Negative	2805	21.1	0.0001	38.83	0.0001
Indigenous	Positive	5529	41.5	0.0001	24.7	0.0001
Urban	Negative	1157	29.6	0.0001	19.9	0.001
Scrub	Negative/ns	1193	3.9	0.047	1.21	0.27
Exotic	ns	1318	2.4	0.13	0.09	0.77

Freshwater fish biodiversity land-cover relationships

The IBI revealed clear relationships between fish assemblages in catchments under different land-cover or land-use types (Figure 2). The average fish IBI score was significantly higher for the least-modified indigenous forest and scrub sites than for the other land-cover classes, and the score for tussock was significantly lower than for all other land-cover classes. Pasture sites had the next lowest scores but did not differ significantly from urban, exotic and non-vegetated (bare land) sites.

Freshwater fish community trends

Trend analysis of the IBI scores clearly shows the decline in fish communities at all sites over the last four decades (Table 4). To assess which of the land-cover classes contributed to this decline the different classes were analysed separately. IBI scores for indigenous forest sites increased significantly for both years and decades, but decreased significantly in pasture sites. Sites covered in scrub did not change over decades but declined between years. IBI scores in urban sites declined over the four

TABLE 5 Freshwater invertebrates recognised with a conservation threat status by the Department of Conservation in 2001 (McGuinness, 2001), 2005 (C McGuinness, pers. comm.) and current review (N Grainger, pers. comm.)

2001								
	Nationally critical	Sparse	Range restricted	Data deficient	Total			
Mollusca			14	4	18			
Polychaeta		1	1		2			
Nematoda				1	1			
Ephemeroptera			3	6	9			
Trichoptera	4	2	19	10	35			
Notostraca		1			1			
Amphipoda		1			1			
Isopoda		1	1		2			
	4	6	38	21	69			
2005								
	Nationally endangered	Nationally critical	Nationally vulnerable	Gradual decline	Sparse	Range restricted	Data deficient	Total
Platyhelminthes					2			2
Mollusca		1		1		59	3	64
Polychaeta					1	1		2
Nematoda							1	1
Ephemeroptera					1	4	4	9
Plecoptera						1		1
Coleoptera		2						2
Diptera						1	1	2
Trichoptera	2	8	1		3	18	9	41
Notostraca					1			1
Amphipoda					1			1
Isopoda					1	1	8	10
Decapoda				2	1			3
	2	11	1	3	11	85	26	139
2010								
	Nationally endangered	Nationally critical	Nationally vulnerable	Declining	Naturally uncommon	Data deficient	Total	
Platyhelminthes			1	1			2	
Mollusca	1	14	1	2	25	23	66	
Polychaeta					1	1	2	
Ephemeroptera		1	1		3	31	36	
Plecoptera		21			10	15	46	
Zygoptera (Damselfly)		1					1	
Anisoptera (Dragonfly)					1		1	
Coleoptera	1	2			3		6	
Diptera		1			2		3	
Trichoptera	4	14	15		37	22	92	
Notostraca					1		1	
Conchostraca		1					1	
Cladocera				1			1	
Amphipoda		2			10	10	22	
Isopoda		1			3	7	11	
Decapoda				2	1	1	4	
	6	58	18	6	97	110	295	

decades. The exotic forest sites dipped in the 1990s but there was no significant linear trend for both years and decades, whereas scores for tussock sites declined for both years and decades.

Freshwater fish species trends

Twenty-six fish species had sufficient data over the four decades to be analysed for trends in the proportion of sites they occupied. Twenty (77%) had negative coefficients, meaning the number of sites at which they were found had decreased (Table 3). After correcting for false discovery (FDR) (Benjamini and Hochberg 1995), nine (35%) of the 26 species had significant trends and all were declines. Of the nine, eight were native, six endemic, and one non-native (brown trout). All nine are migratory: five are amphidromous (black flounder, torrentfish, common bully, bluegill bully, and koaro), two are anadromous (brown trout and common smelt), and one is catadromous (longfin eel). Trends for each species were also measured in the two major land-cover classes; namely, native vegetation (indigenous forest and scrub) and pasture. Coefficients for the trend tests were plotted for these two land-use types to show trends for individual species with land use (Figure 3). The plot of Mann–Kendall proportional site occupancy scores reveals that most species are declining in pasture and native forest.

This decline of freshwater biodiversity in New Zealand echoes global declines in biodiversity. This is not surprising given the drivers of decline in New Zealand and their impacts on freshwater biodiversity are similar to those occurring globally. These pressures include eutrophication, habitat loss and population isolation caused by the damming of rivers, habitat destruction, species invasion, overharvesting, and climate change (Allan and Flecker 1995). While this list of pressures is not comprehensive, it does include the major impacts; however, ascertaining how they interact, particularly the question of whether they are additive or multiplicative, is difficult (Ormerod et al. 2010).

Furthermore, impacts are often not direct. Thus, when nutrients in rivers increase, fish at first are not affected directly (although at high levels these nutrients may be toxic), but algal growth can lead to extreme fluctuations in oxygen availability. For example, oxygen saturation varies hugely in the Manawatu River below an intensively farmed catchment with an urban wastewater discharge. At this point in the river (Hopelands Road) oxygen saturation levels in summer vary from less than 40% in the early morning to more than 140% in the late afternoon of the same day (Clapcott and Young 2009). These extremes (both low and high) are potentially lethal, or at least harmful, for fish, but because guidelines and measurements are based on sampling that fails to record much of this variation, the detrimental consequences are generally not apparent to resource managers.

Freshwater fish biodiversity threats

In New Zealand the health of freshwater ecosystems has declined substantially in recent years, with almost all water quality parameters measured via the national water quality monitoring network declining significantly over the last two decades (NIWA 2010). A study of more than 300 lowland waterways showed that 80% of the sites in pasture catchments exceeded guideline levels for phosphorus and nitrogen (Larned et al. 2004), and 44% of monitored lakes in New Zealand are now classed as polluted with excess nutrients and sediment (Verburg et al. 2010).

The relationship between land cover – a surrogate for land use – and fish communities reveals the likely causes of the declines (see Table 4). In general, deterioration in the health of fresh waters is related to agricultural impacts: excess sediment, phosphorus and nitrogen, as well as faecal pathogens (NIWA 2010). The major driver of this deterioration is the expansion and intensification of agriculture, particularly dairy farming (Wright 2007). The decline in fish biodiversity is also related to the loss of habitat, a result of barriers to migration such as hydroelectric dams and weirs and the draining of more than 90% of wetlands, mainly for agriculture (Joy 2012).

One of the dominant natural patterns of the distribution of diadromous species within New Zealand is the way species richness and abundance are greatest near the coast in unimpacted waterways but decrease inland (Joy et al. 2000; Joy and Death 2001). This arises from the movement of diadromous species between these two biomes, and has major implications for fish distribution and biodiversity. Although freshwater health progressively deteriorates downstream, so the lower reaches are generally more degraded, this is where biodiversity potential is highest; conversely, the healthiest waterways lie in the upper reaches of rivers where diversity is naturally lowest. Because diadromous fish comprise a large part of freshwater fish biodiversity, changes in land use, chemical barriers, or physical barriers like dams will affect these fish in particular, and therefore the patterns of diversity and abundance. In the geological past, having part of the population out at sea at any one time was a good bet-hedging

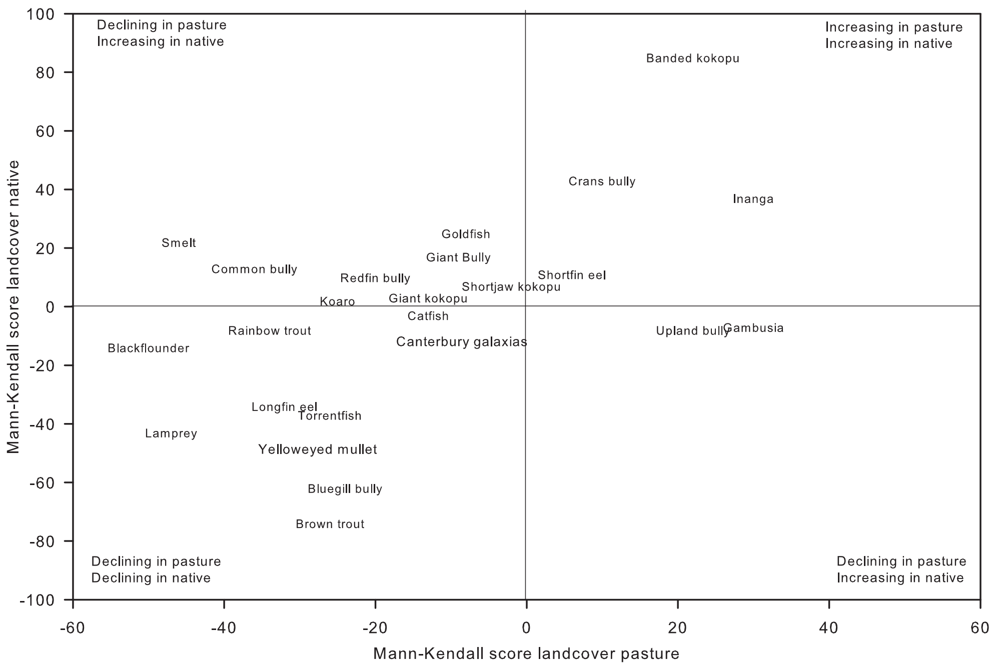

FIGURE 3 Mann–Kendall trend test scores for trends in proportional site occupancy over the years 1970–2010. Scores for sites in pastoral catchments plotted against scores for sites in native forest (Indigenous forest and Scrub REC classes) catchments.

strategy, but recent changes wrought on rivers in New Zealand mean this may no longer be true.

Another major impact is accelerated sediment deposition caused by forest clearance and poor management of hill country land. Suspended sediment receives most attention but a major and probably more important issue for native fish is deposited sediment. Most New Zealand fish species are benthic and some spend a considerable proportion of their time in the substrate below the stream bed (McEwan and Joy 2011, in press); this makes them susceptible to sediment build-up because deposited sediment fills the interstitial spaces in which they live, severely reducing the amount of available habitat. Many New Zealand streams are affected by deposition of fine sediment, reducing the number of individuals that can occupy any reach of a waterway.

None of the threatened native fish species are legally protected; indeed, five are harvested commercially and recreationally. The Freshwater Fisheries Act 1983 formally protects the extinct grayling (last seen in the 1930s) and some introduced fish, mainly trout and salmon, but native fish are only protected if they are not used for 'human consumption or scientific purposes' – which means no protection. Thus, four of the five species that make up the whitebait catch (juveniles of the migratory galaxiids; a popular recreational and commercial seasonal harvest in New Zealand) are listed as threatened.

Other impacts on freshwater fish biodiversity include competition from and predation by exotic fish. The New Zealand freshwater fish fauna evolved without large pelagic species like salmonids, and this has potentially increased the likelihood of negative interactions with these introduced species (McDowall 2006). On the other hand, the economic and sport values of trout mean that without them fresh waters would potentially have less protection and be in a worse state (Joy and Atkinson 2012).

The future for freshwater fish biodiversity

The conflicting needs of agricultural intensification, biodiversity conservation, sport fisheries management, and urban spread have created many pressures on water resources. These show no sign of abating – in fact, all are increasing. Despite the many measured impacts on fresh water from intensification of farming, the government is backing a movement for further intensification, mainly of dairy farming, through irrigation in drier areas. Consequently, impacts on freshwater biodiversity will accelerate. Irrigation has already increased; for example, from 1999 to 2006 water allocation grew by 50%, mostly for irrigation, and this is likely to increase substantially. In short, the combination of climate change, agricultural intensification, and further urban spread has very serious consequences for native fish diversity in New Zealand (Ling 2010).

NEW ZEALAND'S FRESHWATER INVERTEBRATE FAUNA

Invertebrates occupy a pivotal role in food webs in running water, by linking fish and periphyton as food and consumers respectively. Consequently, they perform an important ecosystem service in rivers and streams by processing organic matter and regulating the flow of energy. As flying adults, invertebrates also form an important dietary component for many terrestrial food webs, e.g. birds, spiders, and bats (O'Donnell 2004; Polis et al. 2004; Burdon and Harding 2008). Some also provide food for humans (e.g. koura (crayfish) and kākahi (mussel)).

Invertebrates have also become particularly important in the bioassessment of fresh waters in New Zealand through the use of indices such as the Macroinvertebrate Community Index (MCI) (Boothroyd and Stark 2000) and reference condition modelling (Joy and Death 2003). The taxonomy of many of the groups, particularly the insects, has been well researched since the 1800s (see references in Winterbourn 2000b, 2004), but studies focused on conservation of aquatic invertebrates have been much less common (Collier 1993; Collier et al. 2000). On the other hand, New Zealand's stream invertebrate biodiversity has been the subject of numerous excellent publications, prompted largely by the scientific interest of this biodiversity and its role in water body management (e.g. chapters in Collier and Winterbourn 2000; Winterbourn 2004; Winterbourn et al. 2006; Chapman et al. 2011). This section only briefly reiterates the main points about the general characteristics of the invertebrate fauna, and instead focuses primarily on the environmental drivers of biodiversity and how this diversity is faring in the anthropocene.

What is unique about New Zealand's freshwater invertebrate species?

The New Zealand invertebrate fauna is characterised by a high degree of endemicity at species and genus levels, and by a relatively low number of introduced species (Boothroyd 2000; Winterbourn 2004). Many Northern Hemisphere families are absent and some are only represented by a single species. In general, New Zealand stream insects differ from those in northern climes in having flexible, poorly synchronised life-histories and extended periods of flight and egg-hatching (Scarsbrook 2000). Furthermore, many are generalist feeders; in particular, the guild of specialised leaf-shredding species is meagre compared to similar Northern Hemisphere streams (Winterbourn 2000a). These characteristics reflect New Zealand's climate and topography, with high rainfall and short, steep streams resulting in frequent floods that regularly remove invertebrates and their food (Winterbourn 1997). Although the total invertebrate diversity of New Zealand is lower than that of continental regions, the diversity of individual New Zealand streams is similar to that in North America, Europe, and Asia, but lower than that in South America, Australia and Africa (Thompson and Townsend 2000).

International trends in freshwater invertebrate biodiversity

As outlined for fish, threats to aquatic invertebrates globally appear to be significantly greater than those for their terrestrial counterparts (Dudgeon et al. 2006; Dudgeon 2010; Strayer and Dudgeon 2010; Vorosmarty et al. 2010). In more developed regions of North America and Europe it is not unusual to find more than a third of freshwater species extinct or imperilled, and globally perhaps 10 000 to 20 000 species are now extinct (Strayer and Dudgeon 2010). Furthermore, the decline in more sedentary invertebrate groups may be as much as twice that for freshwater fish, birds, and mammals (Strayer and Dudgeon 2010). Conservation of freshwater invertebrates also suffers more than that of their larger aquatic vertebrate counterparts from a lack of information and taxonomic resolution (Strayer 2006), with many assessments of invertebrate conservation status being based on only one or two groups, e.g. Odonata or Decapoda. Global threats have apparently not been assessed for any freshwater invertebrate group.

This rate of decline is so dramatic and well advanced that action is urgent. Accordingly, Strayer and Dudgeon (2010) recently appealed to freshwater ecologists to focus more on species conservation in their studies of riverine communities and to coordinate better with research in conservation biology. They also argued that the literature on freshwater conservation is sparse, out of proportion to the number of species in peril, and underrepresented in textbooks on conservation biology. However, these shortcomings may in part be a result of aquatic biologists focusing their research and activity more strongly on habitat restoration and preservation than on conservation of individual species (e.g. Lake et al. 2007; Bunn et al. 2010; Bernhardt and Palmer 2011). In Europe a consortium of scientists is currently compiling available information on the global freshwater fauna under a European Union funded project BioFresh (http://www.freshwaterbiodiversity.eu/).

Conservation status of New Zealand freshwater invertebrates

In contrast to freshwater fish, for which there is a national database, there is no consistently used national repository of information on aquatic invertebrates, particularly those of conservation interest. Regional councils, NIWA, and universities have databases of information on lake and/or riverine freshwater invertebrates, collected mainly for environmental assessment, but these collections often focus on calculating biological indices like the MCI, and lack the degree of taxonomic resolution (even if it were possible with the juvenile life stages usually collected) necessary to identify invertebrates of conservation concern. Furthermore, although DOC is currently re-evaluating the threat status of freshwater invertebrates (R. Miller pers. comm.), there is no widely available repository of the current status information except for Trichoptera (caddisflies), for which a national database is accessible through the internet (http://nzcaddis.massey.ac.nz/). New Zealand is a signatory to the 1992 and 2012 Conventions on Biological Diversity and has had a biodiversity strategy in place since 2000. Nevertheless, the invertebrate freshwater fauna of New Zealand seems largely ignored from a conservation perspective.

Trends in New Zealand freshwater invertebrate biodiversity

As highlighted above, knowledge of New Zealand's freshwater invertebrate biodiversity is patchy, often anecdotal, and difficult to find. Consequently, it is difficult to know how that biodiversity is faring in the anthropocene. While New Zealand's extensive monitoring network for assessing water quality in rivers does include sampling of invertebrate communities, the taxonomic resolution is not adequate for identifying taxa of conservation interest (Scarsbrook et al. 2000; Scarsbrook 2002; Larned et al. 2004). Thus, applications for resource consents require environmental effects to be assessed, but even when these assessments specifically consider freshwater invertebrate biodiversity, they are based on collections of larvae and are therefore unlikely to allow taxa of conservation concern to be identified. For example, the application process for a proposed hydroelectric development in the South Island included extensive in-stream sampling that revealed no taxa of conservation interest, but two trapping events of adult aquatic invertebrates yielded a handful of taxa new to science, and thus clearly of conservation interest.

Although there is a dearth of specific information on the biodiversity trends of New Zealand's aquatic invertebrates, considerable circumstantial evidence suggests biodiversity is not faring well. As noted earlier, many New Zealand fish taxa are declining, and because both fish and invertebrates live in the same habitats, the invertebrates are likely to be negatively affected by many of the same drivers of decline. Many rare and range-restricted invertebrates live in highly specialised habitats including seeps, springs and braided rivers, all of which are increasingly threatened by agricultural intensification (Scarsbrook et al. 2005; Collier and Smith 2006; Gray et al. 2006; Barquin and Scarsbrook 2008). Diversity in small first to second-order streams is often high, both locally and regionally, and again these habitats are being degraded by human activity (Clarke et al. 2008, 2010; Finn et al. 2011).

Changes in the conservation status of New Zealand freshwater invertebrates reinforce these apparent trends; thus, the number of taxa that might be considered at risk to some degree has increased from 69 in 2002, to 139 in 2005, to 295 in 2010 (Table 1). Although some of this rise reflects increasing knowledge of taxonomy and distribution, the number of nationally critical taxa has increased from 4 in 2002, to 11 in 2005, to 58 in 2010. Even within this assessment there are some clear gaps, with the crayfish *Paranephrops* listed, but its commensal flatworm, the platyhelminth *Temnocephala novaezealandiae*, not listed. Finally, given the gaps in taxonomic knowledge of many of the lesser known groups, the backlog (with many taxonomists) of currently undescribed species, and the lack of sampling of many rarer habitats, information is likely to be lacking for many taxa; indeed, new genera and species with limited distributions are still regularly collected (e.g. *Aupouriella*, a Northland mayfly; Winterbourn 2009). All these indicators suggest New Zealand's invertebrate fauna is faring no better than the international fauna or New Zealand's freshwater fish, and the apparent dearth of focused monitoring of rare or endangered invertebrates bodes ill for the future of our smaller aquatic taxa.

Drivers of freshwater invertebrate declines

Clearly, the multiple stressors on water bodies throughout New Zealand, which may be linked with the decline in fish diversity discussed above, potentially contribute to declines in diversity of the invertebrate fauna. For invertebrates, these stressors include water abstraction for industrial, domestic and agricultural needs (Poff et al. 2003; Arthington et al. 2006; Dewson et al. 2007; Poff and Zimmerman 2010); changes in flow regime (Poff et al. 1997, 2007); invasive species (Olden et al. 2010); channelisation, sedimentation, and eutrophication (Carpenter et al. 1998; Allan 2004; Clapcott et al. 2012); changes in riparian vegetation; and changing climate (Palmer et al. 2008; Strayer and Dudgeon 2010).

One of the most pervasive stresses for New Zealand stream ecosystems is agricultural intensification (Quinn 2000). Several studies found greater freshwater invertebrate diversity in forested land than in agricultural land (Quinn and Hickey 1990; Harding and Winterbourn 1995; Death and Collier 2010). In contrast, three separate studies found similar richness in forested and non-forested streams (Townsend et al. 1997; Quinn et al. 1997; Scarsbrook and Halliday 1999). When Death (2002) and Death and Zimmermann (2005) examined the effect of canopy removal on periphyton biomass, a major invertebrate food source, they found periphyton biomass increased, resulting in increased diversity. However, the agricultural sites differed from the forest sites only by the absence of forest canopy whereas agricultural streams in other studies will in addition be affected by a range of anthropogenic disturbances arising from changes in land use. Although the effects of agriculture on diversity in streams may depend on the exact nature of intensification, the change in land use from native forest clearly affects the taxonomic composition of those communities: they switch from a fauna dominated by Ephemeroptera, Plecoptera and Trichoptera to one dominated by Mollusca, Chironomidae and Oligochaeta (Harding and Winterbourn 1995; Quinn 2000). However, because all these taxa are represented more or less equally in our threatened species lists, it remains unclear how this massive change in land use may have affected the national diversity of our aquatic invertebrates.

Linking freshwater invertebrate species loss to ecosystem services and functioning

As noted earlier, stream invertebrates play a pivotal role in the food web of rivers and streams. The role of biodiversity in ecosystem function has been a major theme of research in ecology (e.g. Kinzig et al. 2001; Loreau et al. 2002; Srivastava and Vellend 2005; Cardinale et al. 2012), and the role of aquatic invertebrate diversity in the functioning of Northern Hemisphere stream ecosystems has been thoroughly investigated (e.g. Jonsson et al. 2001, 2002; Gessner and Chauvet 2002). However, in New Zealand the role of biodiversity in the functioning of running-water ecosystems has had little attention, although the role of ecosystem function for assessing ecological health has been studied extensively (e.g. Young et al. 2004, 2008; Death et al. 2009; Young and Collier 2009; Clapcott et al. 2010). Given the likely impacts of ecosystem stress on biodiversity and the link between environmental impairment and ecosystem function, invertebrate diversity is almost certainly linked directly to the proper functioning of New Zealand's river ecosystems, as it is in the Northern Hemisphere. In particular, the link between diversity and leaf decomposition (one of a number of potential ecosystem functions) has been a traditional focus of ecosystem health assessment, and this link has also been the focus of research on relationships between Northern Hemisphere stream biodiversity and ecosystem function. Unfortunately, the lack of obligate shredders in New Zealand streams may have discouraged freshwater ecologists in New Zealand from examining this link. Many other ecosystem functions are also directly affected by in-stream biodiversity, and these include many that can be considered human ecosystem services, such as nutrient cycling (Cardinale et al. 2002; Cardinale 2011). Yet again, there is clearly a large gap in New Zealand research on the linkage between biodiversity, ecosystem function and environmental stress.

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