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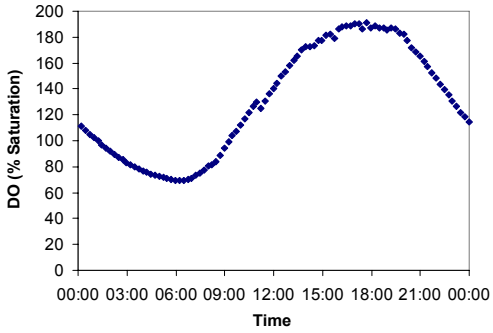
Ecosystem metabolism in the Manawatu River

The concentrations of dissolved oxygen (DO) in the water are a critical component affecting the life supporting capacity of a river system. Ecosystem metabolism – the combination of algal productivity or photosynthesis (GPP) and ecosystem respiration (ER) – is a measure of the main factors controlling dissolved oxygen dynamics in rivers, and indicates how much organic carbon is produced and consumed in river systems. Recent research has shown that ecosystem metabolism is a useful indicator of river ecosystem health and complements traditional monitoring tools such as water quality analysis, periphyton assessments, and invertebrate community composition. Ecosystem metabolism is influenced by a wide variety of factors such as nutrient inputs, organic waste discharges, shading, river flow and water temperature.

Ecosystem metabolism can be measured by monitoring the daily changes in oxygen concentration at a site. Dissolved oxygen concentrations rise during the daytime when sunlight facilitates photosynthesis, and then decline during the night when only respiration is occurring. The size of the daily fluctuations depends on the amount of photosynthesis and respiration occurring within the river and also the movement of oxygen through the river surface.



Sites with high rates of GPP are likely to experience algal and cyanobacterial blooms that can degrade aesthetic and recreational values, and have potential health implications for humans and animals. High algal densities associated with high rates of GPP can also cause large pH fluctuations, smother habitat for invertebrates, cause taste and odour problems for water supplies, and cause problems with low DO (such as fish kills) when the periphyton mats mature and decompose. The highest rates of production will occur in situations where there is plenty of light and nutrients available to support plant growth.

Sites with high rates of ER are normally characterised by large inputs of organic matter from point source discharges of sewage/waste water, or large diffuse inputs from sources such as deciduous trees. High biomasses of algae and other aquatic plants are also often associated with high rates of ecosystem respiration. Sites with high rates of ER will be prone to low minimum dissolved oxygen concentrations and have the potential to kill fish and other aquatic life.

As part of a study on the ecosystem integrity of New Zealand's large rivers, ecosystem metabolism was measured at 16 sites throughout the country. The results showed that rates of GPP and ER in the lower Manawatu River at Opiki were among the highest ever reported internationally and well above the thresholds considered to represent the transition from satisfactory to poor ecosystem health -- GPP values above 7 gO_2/m^2/day and ER values above 10 gO_2/m^2/day are considered to indicate poor ecosystem health.

On November 26th 2009, the Dominion Post ran a front page story focusing on the health of the Manawatu River and included a headline pronouncing the river as the 'worst in the west'. Measurements of GPP (and ER) from the lower Manawatu are higher than has been seen in any other sites around the world where this measurement has been conducted (Table 1 – below). However, only a tiny fraction of the world's rivers have been tested using this approach and it is likely that other rivers would have higher measurements if they were tested. Our research DOES NOT indicate that the Manawatu River is the worst in the western world. Nevertheless, our results do indicate that the Manawatu River is very unhealthy. Other indicators of river health such as nutrient concentrations, water clarity, faecal bacteria, and stream invertebrates also indicate the poor status of the Manawatu River (http://www.mfe.govt.nz/environmental-reporting/freshwater/river/league-table/river-water-quality-league-tables.html).

Recognition of the poor health of some of New Zealand's waterways is the first step in trying to rehabilitate them. Improvements to waste discharges, nutrient budgeting, fencing stock out of waterways, and better management of the banks of rivers and streams is vital before water quality will improve. At a regional level, focused plans with clear guidelines and standards are required. Collaborative efforts involving the full range of stakeholders involved with water management is the best way forward.

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Table 1 Ecosystem metabolism data from a variety of sites around the world. The data have been sorted from highest to lowest based on measures of GPP. The data are distributed among the following areas – New Zealand 293 measurements, USA 115, Canada 5, EU 81, Switzerland 2, Brazil 6, Puerto Rico 27, Australia 20, Japan 23.

Site	GPP ($gO_2/m^2/day$)	ER ($gO_2/m^2/day$)	Country	Data source
Manawatu @ Opiki	107.1	65.2	NZ	Collier et al 2009
Demnitzer Mill Brook DS	59.0	52.0	EU	Gucker et al 2006
Erpe DS	47.0	59.0	EU	Gucker et al 2006
Vermilion21	44.2	18.9	US	Wiley et al 1990
Shinmei	43.9	65.8	Japan	Iwata et al 2007
Irongate	36.0	55.8	NZ	Young et al 2006
Vermilion13	35.8	24.9	US	Wiley et al 1990
Erpe US	32.0	32.0	EU	Gucker et al 2006
WaitoaW	29.2	21.2	NZ	Wilcock et al 1998
Awaroa	24.4	13.8	NZ	Wilcock et al 1998
Raupare	23.3	33.3	NZ	Young et al 2006
Topehaehae2	21.8	20.2	NZ	Wilcock et al 1998
Nishi	21.0	32.3	Japan	Iwata et al 2007
Motupipi	20.5	34.2	NZ	Young 2006b
Thur	20.2	14.6	EU	Uehlinger 2000
Oreti trib	20.2	37.1	NZ	Clapcott et al 2010
Takisawa	19.1	36.7	Japan	Iwata et al 2007
Kurosawa	19.0	23.8	Japan	Iwata et al 2007
Mangaotama	18.9	37.5	NZ	Wilcock et al 1998
Waitoa1	18.2	25.4	NZ	Wilcock et al 1998
Demnitzer Mill Brook US	18.0	24.0	EU	Gucker et al 2006
Heathcote Curtletts	17.4	32.7	NZ	Clapcott et al 2010
Makarewa Lora	17.1	19.4	NZ	Clapcott et al 2010
Vermilion57	17.0	18.5	US	Wiley et al 1990
Otouto	17.0	37.7	Japan	Iwata et al 2007
Mokoreta	16.0	31.5	NZ	Clapcott et al 2010
Vermilion53	15.9	14.1	US	Wiley et al 1990
Vermilion96	15.5	15.4	US	Wiley et al 1990
Topehaehae1	15.3	30.6	NZ	Wilcock et al 1998
SCAZ	15.0	8.3	US	Mulholland et al 2001
Vermilion24	14.6	41.6	US	Wiley et al 1990
Kamata2	14.5	19.3	Japan	Iwata et al 2007
Higasihanawa	14.4	24.6	Japan	Iwata et al 2007
Winton Lady	14.3	24.2	NZ	Clapcott et al 2010
Tussock	14.0	26.7	NZ	Clapcott et al 2010
Otapiri	14.0	13.7	NZ	Clapcott et al 2010
SCAZ	13.8	9.6	US	Webster & Meyer 1997
Motupipi @ Reilly's	13.8	22.7	NZ	Young 2006b
Vermilion50	13.4	21.8	US	Wiley et al 1990
Ani	13.0	29.2	Japan	Iwata et al 2007
Taieri14	12.7	4.0	NZ	Young & Huryn 1996

Thur	12.6	10.3	EU	Uehlinger 2000
Muhlibach	12.5	8.9	EU	Kaenel et al 2000
Vermilion18	11.4	11.5	US	Wiley et al 1990
Mangaoronga	11.3	12.4	NZ	Wilcock et al 1998
Ohinemuri Karangahape	11.2	37.4	NZ	Clapcott et al 2010
Waihekau	11.1	24.3	NZ	Wilcock et al 1998
Te Rahu canal	11.0	19.9	NZ	Clapcott et al 2010
Vermilion11	11.0	24.1	US	Wiley et al 1990
MES1	11.0	17.2	EU	Izagirre et al 2008
Waikato 12	10.9	10.4	NZ	Clapcott & Young 2009
Shinmei2	10.7	17.2	Japan	Iwata et al 2007
Waitoa2	10.7	6.0	NZ	Wilcock et al 1998
Vermilion84	10.7	13.5	US	Wiley et al 1990
Byodo	10.6	19.4	Japan	Iwata et al 2007
Yoko	10.5	23.0	Japan	Iwata et al 2007
Piako1	10.5	10.6	NZ	Wilcock et al 1998
Vermilion19	10.2	9.7	US	Wiley et al 1990
Sanno	9.7	16.9	Japan	Iwata et al 2007
Ivel	9.6	8.5	EU	Edwards & Owens 1962
Taieri1	9.6	3.9	NZ	Young & Huryn 1996
Glenmaru	9.6	13.8	NZ	Clapcott et al 2010
Kaniwhaniwha	9.5	2.8	NZ	Wilcock et al 1998
Vermilion33	9.4	17.0	US	Wiley et al 1990
Waikato A	9.3	20.6	NZ	Clapcott & Young 2009
Porangahau river @ Kates quarry	9.2	12.3	NZ	Young et al 2006
Shimoda	9.2	16.6	Japan	Iwata et al 2007
Whangapouri @ Paerata	9.2	17.4	NZ	Young 2006
Taieri5	8.9	7.9	NZ	Young & Huryn 1996
Omo1	8.8	20.3	Japan	Iwata et al 2007
Waikato 17	8.7	15.7	NZ	Clapcott & Young 2009
Vermilion12	8.6	8.5	US	Wiley et al 1990
Aguera5	8.6	13.5	EU	Elosegui & Pozo 1998
Vermilion55	8.5	18.8	US	Wiley et al 1990
MacunP3	8.5	9.9	Switzerland	Logue et al 2004
Taieri8	8.5	7.0	NZ	Young & Huryn 1996
Blue	8.3	10.5	US	Duffer & Dorris 1966
Cam R	8.1	19.4	NZ	Clapcott et al 2010
Taieri10	8.0	1.8	NZ	Young & Huryn 1996
Necker	8.0	7.0	EU	Naegeli & Uehlinger1997
Oreti	8.0	10.3	NZ	Collier et al 2009
Taieri1	8.0	4.7	NZ	Young & Huryn 1996
Hirusawa	7.9	13.7	Japan	Iwata et al 2007
Waikato 4	7.8	5.4	NZ	Clapcott & Young 2009
Aguera7	7.8	3.1	EU	Elosegui & Pozo 1998
KCAU	7.7	9.2	Australia	Webster & Meyer 1997
Oli3	7.7	21.7	EU	Izagirre et al 2008
Taieri8	7.6	6.1	NZ	Young & Huryn 1996
Necker	7.5	6.9	EU	Naegeli & Uehlinger1997

Mohikinui	7.4	22.6	NZ	Collier et al 2009
Taieri4	7.4	8.3	NZ	Young & Huryn 1996
Ai	7.4	7.4	Japan	Iwata et al 2007
Necker	7.1	6.5	EU	Naegeli & Uehlinger1997
Spol	7.1	5.2	EU	Uehlinger et al 2003
Makarewa	7.1	6.4	NZ	Young 1998
Waikato 16	7.1	9.8	NZ	Clapcott & Young 2009
Taieri13	7.0	3.3	NZ	Young & Huryn 1996
Wangapeka u/s Dart	7.0	11.3	NZ	Young & Collier 09
Vermilion98	7.0	10.7	US	Wiley et al 1990
Ohinemuri	6.9	8.1	NZ	Wilcock et al 1998
Motueka @ Woodstock	6.9	4.9	NZ	Young & Collier 09
Waikato 1a	6.8	2.8	NZ	Clapcott & Young 2009
Taieri5	6.8	5.7	NZ	Young & Huryn 1996
Taieri13	6.8	6.7	NZ	Young & Huryn 1996
Piako2	6.8	12.9	NZ	Wilcock et al 1998
Nagare	6.6	11.9	Japan	Iwata et al 2007
EU1	6.6	12.5	EU	Izagirre et al 2008
Aguera5	6.5	3.5	EU	Elosegui & Pozo 1998
Waikato B2	6.5	4.4	NZ	Clapcott & Young 2009
Hakataramea	6.5	10.8	NZ	Young 1998
Styx North	6.5	15.2	NZ	Clapcott et al 2010
Vermilion15	6.4	11.5	US	Wiley et al 1990
PO3	6.4	42.6	EU	Izagirre et al 2008
Taieri3	6.4	12.5	NZ	Young & Huryn 1996
Mauku at Ake Ake	6.3	24.0	NZ	Young 2006
EU3	6.3	13.5	EU	Izagirre et al 2008
Necker	6.3	6.1	EU	Naegeli & Uehlinger1997
Taieri5	6.3	8.2	NZ	Young & Huryn 1996
Oli4	6.2	15.2	EU	Izagirre et al 2008
Mokoreta	6.2	8.4	NZ	Young 1998
Vermilion54	6.2	10.6	US	Wiley et al 1990
Taieri1	6.1	3.4	NZ	Young & Huryn 1996
Aguera7	6.1	2.0	EU	Elosegui & Pozo 1998
Thur	6.1	8.8	EU	Uehlinger 2006
Aguera7	6.0	5.3	EU	Elosegui & Pozo 1998
Necker	5.9	5.6	EU	Naegeli & Uehlinger1997
Mataura	5.9	11.7	NZ	Collier et al 2009
Motueka @ Hinetai	5.9	9.1	NZ	Young & Collier 09
Matahuru	5.8	4.6	NZ	Wilcock et al 1998
Styx Radcliffe	5.8	21.5	NZ	Clapcott et al 2010
Glatt	5.8	8.2	EU	Uehlinger 1993
Motueka @ Woodmans Bend	5.8	4.0	NZ	Young & Collier 09
Waikato B3	5.8	9.5	NZ	Clapcott & Young 2009
Vermilion95	5.7	13.8	US	Wiley et al 1990
Avon Wood	5.7	12.9	NZ	Clapcott et al 2010
Waikato 2	5.6	12.7	NZ	Clapcott & Young 2009
Omo2	5.6	12.9	Japan	Iwata et al 2007

Taieri8	5.6	4.2	NZ	Young & Huryn 1996
Vermilion89	5.5	14.5	US	Wiley et al 1990
Caddon Burn	5.5	8.2	NZ	Clapcott et al 2010
Taieri3	5.4	7.5	NZ	Young & Huryn 1996
Waikato 1	5.4	4.7	NZ	Clapcott & Young 2009
Fuji	5.4	12.3	Japan	Iwata et al 2007
3O'Clock	5.4	5.2	NZ	Young & Huryn 1999
Taieri12	5.3	2.9	NZ	Young & Huryn 1996
Karamea	5.3	3.9	NZ	Collier et al 2009
Thur	5.2	7.0	EU	Uehlinger 2000
Taieri3	5.2	6.6	NZ	Young & Huryn 1996
Taieri7	5.2	9.8	NZ	Young & Huryn 1996
Vermilion49	5.1	6.2	US	Wiley et al 1990
Mulholland 2005_1	5.1	3.8	US	Mulholland et al 2006
Taieri3	5.1	5.9	NZ	Young & Huryn 1996
Kaniwhaniwha	5.1	11.0	NZ	Wilcock et al 1998
Waikato 3	5.1	3.9	NZ	Clapcott & Young 2009
Punui 11	5.0	7.4	NZ	Clapcott & Young 2009
Taieri1	4.9	2.3	NZ	Young & Huryn 1996
Hirusawa2	4.9	14.5	Japan	Iwata et al 2007
Taieri14	4.9	5.7	NZ	Young & Huryn 1996
Taieri3	4.9	6.2	NZ	Young & Huryn 1996
Taieri8	4.8	3.8	NZ	Young & Huryn 1996
Wangapeka @ Walters	4.8	4.8	NZ	Young & Collier 09
MontesinaJ	4.7	3.7	EU	Molla et al 1996
Mulholland 2005_1	4.7	4.7	US	Mulholland et al 2006
Raritan	4.7	4.5	US	Flemer 1970
Hatter	4.7	2.4	Australia	Oliver & Merrick 2006
Taieri8	4.7	3.9	NZ	Young & Huryn 1996
Taieri1	4.7	1.9	NZ	Young & Huryn 1996
Waikato ds	4.6	6.4	NZ	Collier et al 2009
Powell @ Reilly's	4.6	6.9	NZ	Young 2006b
Oli2	4.6	6.3	EU	Izagirre et al 2008
Mangaokewa Site 5	4.5	10.3	NZ	Young & Collier 09
MacunMG	4.5	5.4	Switzerland	Logue et al 2004
Taieri5	4.5	4.7	NZ	Young & Huryn 1996
Tarawera	4.5	26.0	NZ	Clapcott et al 2010
Kaputone	4.5	24.6	NZ	Clapcott et al 2010
Whakapipi	4.5	13.5	NZ	Wilcock et al 1998
Taieri1	4.4	1.8	NZ	Young & Huryn 1996
FRMA	4.4	9.1	US	Webster & Meyer 1997
Taieri4	4.4	4.9	NZ	Young & Huryn 1996
MES2	4.4	36.9	EU	Izagirre et al 2008
EU2	4.4	12.5	EU	Izagirre et al 2008
Bott2006_2	4.3	8.3	US	Bott et al 2006
3O'Clock	4.3	2.4	NZ	Young & Huryn 1999
Taieri10	4.3	1.3	NZ	Young & Huryn 1996
Vermilion99	4.3	8.3	US	Wiley et al 1990
Taieri1	4.2	1.5	NZ	Young & Huryn 1996

Taieri1	4.2	3.5	NZ	Young & Huryn 1996
Taieri2	4.2	0.7	NZ	Young & Huryn 1996
Bott2006_3	4.2	8.2	US	Bott et al 2006
Waikato 6	4.2	3.5	NZ	Clapcott & Young 2009
Taieri5	4.1	4.1	NZ	Young & Huryn 1996
MES3	4.1	15.1	EU	Izagirre et al 2008
MES5	4.1	16.8	EU	Izagirre et al 2008
PO2	4.1	15.4	EU	Izagirre et al 2008
Necker	4.1	5.2	EU	Naegeli & Uehlinger1997
Hedgehope	4.0	10.6	NZ	Clapcott et al 2010
Maraekakaho	4.0	3.2	NZ	Young et al 2006
Taieri3	3.9	5.0	NZ	Young & Huryn 1996
Mangaokewa Site 4	3.9	16.5	NZ	Young & Collier 09
Oli1	3.9	9.2	EU	Izagirre et al 2008
Thur	3.9	4.1	EU	Uehlinger 2006
Ohinemuri Waikino	3.9	5.9	NZ	Clapcott et al 2010
3O'Clock	3.9	1.9	NZ	Young & Huryn 1999
WCPA	3.9	3.2	US	Webster & Meyer 1997
Tongariro 5	3.9	12.6	NZ	Clapcott & Young 2009
Lower Mataura	3.8	8.4	NZ	Young 1998
Taieri12	3.8	1.6	NZ	Young & Huryn 1996
Gryde	3.8		EU	Kelly et al 1983
Big Gully	3.8	8.9	NZ	Young & Collier 09
Taieri7	3.7	8.9	NZ	Young & Huryn 1996
ORGA	3.7	21.3	US	Webster & Meyer 1997
Taieri3	3.7	4.1	NZ	Young & Huryn 1996
Taieri5	3.6	4.6	NZ	Young & Huryn 1996
Mokau 13	3.6	3.4	NZ	Clapcott & Young 2009
Bott2006_6	3.6	3.9	US	Bott et al 2006
Avon Gloucester	3.5	4.1	NZ	Clapcott et al 2010
Catlins	3.5	3.2	NZ	Clapcott et al 2010
Taieri11	3.5	2.0	NZ	Young & Huryn 1996
PO4	3.5	8.8	EU	Izagirre et al 2008
Otutaikino	3.4	9.5	NZ	Clapcott et al 2010
MontesinaM	3.4	3.0	EU	Molla et al 1996
Necker	3.4	4.9	EU	Naegeli & Uehlinger1997
Waikuku	3.3	17.0	NZ	Clapcott et al 2010
Oli5	3.3	17.1	EU	Izagirre et al 2008
Taieri5	3.3	4.4	NZ	Young & Huryn 1996
Bott2006_1	3.3	5.4	US	Bott et al 2006
Taieri8	3.2	2.6	NZ	Young & Huryn 1996
Taieri5	3.2	3.1	NZ	Young & Huryn 1996
Taieri5	3.2	6.3	NZ	Young & Huryn 1996
Haast	3.2	6.6	NZ	Young 1998
Paritu	3.2	4.8	NZ	Young et al 2006
H&T2	3.1	8.4	US	Hall & Tank 2003
Taieri7	3.1	5.6	NZ	Young & Huryn 1996
MES4	3.1	10.6	EU	Izagirre et al 2008
Barmah	3.1	3.5	Australia	Oliver & Merrick 2006

Taieri3	3.1	4.3	NZ	Young & Huryn 1996
Waikato B1	3.1	5.1	NZ	Clapcott & Young 2009
Taieri5	3.1	2.5	NZ	Young & Huryn 1996
Mokoreta trib	3.0	3.6	NZ	Clapcott et al 2010
Taieri10	3.0	1.4	NZ	Young & Huryn 1996
Demnitzer Mill Brook US	3.0	28.0	EU	Gucker et al 2006
Demnitzer Mill Brook DS	3.0	38.0	EU	Gucker et al 2006
Aguera5	3.0	2.2	EU	Elosegui & Pozo 1998
Kamata1	3.0	9.8	Japan	Iwata et al 2007
MES6	3.0	6.8	EU	Izagirre et al 2008
Blue	3.0	6.6	US	Duffer & Dorris 1966
Waikato us	3.0	3.6	NZ	Collier et al 2009
Taieri13	3.0	3.2	NZ	Young & Huryn 1996
McTam4	3.0	3.2	US	McTammany et al 2003
Waitoki	3.0	7.1	NZ	Clapcott et al 2010
Vermilion34	2.9	12.7	US	Wiley et al 1990
Taieri14	2.9	2.5	NZ	Young 1998
Waikato 5	2.8	3.7	NZ	Clapcott & Young 2009
PO1	2.8	9.8	EU	Izagirre et al 2008
Selwyn trib	2.8	7.2	NZ	Clapcott et al 2010
Waitoa 10	2.8	5.1	NZ	Clapcott & Young 2009
Upper Mataura	2.8	4.9	NZ	Young 1998
South Bk	2.7	8.9	NZ	Clapcott et al 2010
Taieri3	2.7	2.8	NZ	Young & Huryn 1996
Ortiz-Zayas2	2.7	3.0	Puerto Rico	Ortiz-Zayas et al 2005
MES7	2.7	6.6	EU	Izagirre et al 2008
Necker	2.7	4.7	EU	Naegeli & Uehlinger1997
Quinneys	2.7	5.5	NZ	Young & Collier 09
Waiwera	2.7	6.4	NZ	Clapcott et al 2010
Makarewa Scott	2.6	2.8	NZ	Clapcott et al 2010
Cam trib	2.6	11.8	NZ	Clapcott et al 2010
Taieri1	2.6	2.1	NZ	Young & Huryn 1996
Opouriki	2.6	14.4	NZ	Clapcott et al 2010
Bott2006_5	2.6	8.1	US	Bott et al 2006
Thur	2.6	3.4	EU	Uehlinger 2000
Taieri1	2.5	1.1	NZ	Young & Huryn 1996
Burma Rd	2.5	3.4	NZ	Clapcott et al 2010
Taieri11	2.5	1.8	NZ	Young & Huryn 1996
Arawata	2.5	8.4	NZ	Young 1998
Taieri7	2.4	7.7	NZ	Young & Huryn 1996
MOQB	2.4	1.5	Canada	Webster & Meyer 1997
Taieri1	2.4	0.9	NZ	Young & Huryn 1996
Tuapo	2.4	13.8	NZ	Clapcott et al 2010
Harts	2.4	10.9	NZ	Clapcott et al 2010
Maclennan	2.4	2.3	NZ	Young 1998
Meyer4	2.4	2.8	US	Meyer et al 2005
Taieri3	2.3	6.4	NZ	Young & Huryn 1996
Ararimu @ Old North Road	2.3	11.1	NZ	Young 2006

Mahurangi @ College	2.3	2.8	NZ	Young 2006
Mangaone	2.3	23.1	NZ	Wilcock et al 1998
Rainy	2.3	6.5	NZ	Young & Collier 09
Taieri3	2.3	4.7	NZ	Young & Huryn 1996
Louisa	2.3	7.8	NZ	Young et al 2006
Taieri3	2.2	5.6	NZ	Young & Huryn 1996
Winton Benmore	2.2	13.0	NZ	Clapcott et al 2010
Ortiz-Zayas2	2.2	6.5	Puerto Rico	Ortiz-Zayas et al 2005
Nigori	2.2	24.1	Japan	Iwata et al 2007
Lee	2.2	1.9	NZ	Young & Huryn 1999
Owaka	2.2	2.5	NZ	Clapcott et al 2010
Wairarapa Ilam	2.2	3.6	NZ	Clapcott et al 2010
Big	2.1	2.2	NZ	Young & Huryn 1999
Taieri1	2.1	1.3	NZ	Young & Huryn 1996
Taieri4	2.1	2.6	NZ	Young & Huryn 1996
Ortiz-Zayas2	2.1	4.0	Puerto Rico	Ortiz-Zayas et al 2005
Albury	2.1	2.5	Australia	Oliver & Merrick 2006
Big	2.1	3.8	NZ	Young & Huryn 1999
Taharua River @ Wairogo (nearest to SH5)	2.1	14.7	NZ	Young et al 2006
Mangaone	2.1	2.8	NZ	Clapcott et al 2010
Birdlings Bk	2.1	9.8	NZ	Clapcott et al 2010
Taieri1	2.0	0.7	NZ	Young & Huryn 1996
Bott2006_4	2.0	4.1	US	Bott et al 2006
McTam3	2.0	2.8	US	McTammany et al 2003
Ortiz-Zayas2	2.0	6.0	Puerto Rico	Ortiz-Zayas et al 2005
Erpe US	2.0	11.0	EU	Gucker et al 2006
Erpe US	2.0	24.0	EU	Gucker et al 2006
Mulholland 2005_1	2.0	2.2	US	Mulholland et al 2006
Ohourere	2.0	16.0	NZ	Clapcott et al 2010
Taieri5	2.0	1.8	NZ	Young & Huryn 1996
Back	2.0	2.5	NZ	Clapcott et al 2010
Pomahaka	2.0	2.3	NZ	Young 1998
DarlingtonPoint	2.0	2.2	Australia	Vink et al 2005
MTQB	1.9	1.9	Canada	Webster & Meyer 1997
H&T1	1.9	6.5	US	Hall & Tank 2003
Taieri2	1.9	2.0	NZ	Young & Huryn 1996
Ohinemuri Golden	1.9	3.5	NZ	Clapcott et al 2010
MCOR	1.9	11.4	US	Mulholland et al 2001
Ortiz-Zayas1	1.9	7.5	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas2	1.9	5.0	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas2	1.9	1.0	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas2	1.9	3.0	Puerto Rico	Ortiz-Zayas et al 2005
Mangaokewa Site 2	1.9	7.2	NZ	Young & Collier 09
La Trobe4	1.9	3.8	Australia	Chessman 1985
Kaihuka	1.9	2.3	NZ	Clapcott et al 2010
Taieri2	1.9	1.5	NZ	Young & Huryn 1996
Maraetotara	1.8	12.2	NZ	Clapcott et al 2010

Taieri5	1.8	5.0	NZ	Young & Huryn 1996
Meyer6	1.8	8.3	US	Meyer et al 2005
KCKS	1.8	2.5	US	Mulholland et al 2001
Ortiz-Zayas2	1.8	0.9	Puerto Rico	Ortiz-Zayas et al 2005
Necker	1.8	4.6	EU	Naegeli & Uehlinger1997
Makarewa Taylors	1.8	2.3	NZ	Clapcott et al 2010
Taieri2	1.8	4.2	NZ	Young & Huryn 1996
Lill Burn	1.7	4.7	NZ	Clapcott et al 2010
Waikopikopiko	1.7	3.7	NZ	Clapcott et al 2010
Galina	1.7	14.7	US	Fellows et al 2001
Taieri2	1.7	0.9	NZ	Young & Huryn 1996
Narrandera	1.7	1.8	Australia	Vink et al 2005
KPKA	1.6	1.0	US	Webster & Meyer 1997
H&T3	1.6	8.8	US	Hall & Tank 2003
MontesinaM	1.6	1.9	EU	Molla et al 1996
Oreti	1.6	3.6	NZ	Young 1998
Taieri3	1.6	4.2	NZ	Young & Huryn 1996
WaikatoA B2	1.6	13.9	NZ	Clapcott & Young 2009
Mangaokewa Site 3	1.6	11.9	NZ	Young & Collier 09
Hi	1.6	11.8	Japan	Iwata et al 2007
Pyrenee	1.6	8.0	EU	Capblancq & Lavandier 1975
Raritan	1.6	9.8	US	Flemer 1970
Kaukapakapa @ Taylors	1.6	2.1	NZ	Young 2006
Taieri5	1.6	2.1	NZ	Young & Huryn 1996
RIU	1.5	2.2	EU	Von Schiller et al 2008
Ortiz-Zayas1	1.5	4.0	Puerto Rico	Ortiz-Zayas et al 2005
Rolling	1.5	2.7	NZ	Young & Collier 09
Styx Husseys	1.5	17.4	NZ	Clapcott et al 2010
Sutton	1.5	4.0	NZ	Young & Huryn 1999
Boggy Ck	1.5	1.7	NZ	Clapcott et al 2010
Tairua	1.5	5.0	NZ	Clapcott et al 2010
Vermilion59	1.5	23.3	US	Wiley et al 1990
Taieri9	1.4	1.0	NZ	Young & Huryn 1996
Dudley	1.4	19.6	NZ	Clapcott et al 2010
Walker Br	1.4	3.5	US	Roberts 2007
Ortiz-Zayas2	1.4	5.0	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas2	1.4	4.5	Puerto Rico	Ortiz-Zayas et al 2005
Mangaokewa Site 1	1.4	7.3	NZ	Young & Collier 09
WaikatoA	1.4	3.7	NZ	Clapcott & Young 2009
Powder	1.4	4.5	NZ	Young & Huryn 1999
WBTN	1.4	11.7	US	Webster & Meyer 1997
WaikatoB	1.4	12.0	NZ	Clapcott & Young 2009
Walker Br	1.3	4.5	US	Roberts 2007
Lee	1.3	1.5	NZ	Young & Huryn 1999
Taieri5	1.3	1.3	NZ	Young & Huryn 1996
WBTN	1.3	5.5	US	Mulholland et al 2001
Ortiz-Zayas1	1.3	3.5	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas2	1.3	7.5	Puerto Rico	Ortiz-Zayas et al 2005
Piakonui	1.2	2.5	NZ	Wilcock et al 1998

Ashley trib	1.2	13.0	NZ	Clapcott et al 2010
Motu	1.2	4.3	NZ	Collier et al 2009
Heathcote Rose	1.2	4.1	NZ	Clapcott et al 2010
Catlins	1.2	1.5	NZ	Young 1998
MRQB	1.2	1.1	Canada	Webster & Meyer 1997
Ortiz-Zayas1	1.2	1.5	Puerto Rico	Ortiz-Zayas et al 2005
McTammany2007_3	1.2	7.2	US	McTammany et al 2007
3O'Clock	1.2	1.1	NZ	Young & Huryn 1999
Meyer1	1.2	5.2	US	Meyer et al 2005
RES	1.2	2.4	EU	Von Schiller et al 2008
Lee	1.2	1.4	NZ	Young & Huryn 1999
KGKA	1.2	1.1	US	Webster & Meyer 1997
Waione	1.2	31.7	NZ	Clapcott et al 2010
Waipa 15	1.2	1.3	NZ	Clapcott & Young 2009
McTam2	1.2	2.8	US	McTammany et al 2003
Avon trib	1.1	9.0	NZ	Clapcott et al 2010
Bott2006_7	1.1	6.1	US	Bott et al 2006
Big	1.1	1.2	NZ	Young & Huryn 1999
Styx trib	1.1	6.2	NZ	Clapcott et al 2010
Ortiz-Zayas1	1.1	10.0	Puerto Rico	Ortiz-Zayas et al 2005
MROR	1.1	0.9	US	Webster & Meyer 1997
H&T8	1.1	13.3	US	Hall & Tank 2003
Rangitikei	1.1	29.0	NZ	Collier et al 2009
Ohinemuri Waihi	1.0	0.7	NZ	Clapcott et al 2010
H&T7	1.0	2.0	US	Hall & Tank 2003
McTam1	1.0	3.8	US	McTammany et al 2003
LCOR	1.0	0.9	US	Webster & Meyer 1997
Taieri3	1.0	9.4	NZ	Young & Huryn 1996
Taieri7	1.0	2.9	NZ	Young & Huryn 1996
Taieri9	1.0	0.9	NZ	Young & Huryn 1996
Taieri1	1.0	0.3	NZ	Young & Huryn 1996
Taieri7	1.0	3.3	NZ	Young & Huryn 1996
Taieri1	1.0	0.1	NZ	Young & Huryn 1996
Ortiz-Zayas1	1.0	4.2	Puerto Rico	Ortiz-Zayas et al 2005
North Brook	1.0	17.6	NZ	Clapcott et al 2010
Taieri8	1.0	4.3	NZ	Young & Huryn 1996
Wairapukao	1.0	3.9	NZ	Clapcott et al 2010
Sutton	1.0	4.8	NZ	Young & Huryn 1999
WaggaWagga	0.9	1.3	Australia	Vink et al 2005
ECMI	0.9	6.6	US	Mulholland et al 2001
Ortiz-Zayas1	0.9	2.6	Puerto Rico	Ortiz-Zayas et al 2005
Mulholland 2005_2	0.9	6.0	US	Mulholland et al 2006
Meyer5	0.9	1.3	US	Meyer et al 2005
Sutton	0.9	7.4	NZ	Young & Huryn 1999
Taieri11	0.9	0.9	NZ	Young & Huryn 1996
Toenepi	0.9	2.3	NZ	Wilcock et al 1998
Bott2006_9	0.9	2.6	US	Bott et al 2006
Komata	0.9	7.1	NZ	Clapcott et al 2010
FUI	0.9	0.7	EU	Von Schiller et al 2008

Brazil4	0.8	3.2	Brazil	Gucker et al 2008
Brazil6	0.8	2.2	Brazil	Gucker et al 2008
Taieri11	0.8	0.9	NZ	Young & Huryn 1996
Meyer3	0.8	8.7	US	Meyer et al 2005
Taieri8	0.8	4.3	NZ	Young & Huryn 1996
Fuirosos	0.8	4.6	EU	Acuna et al. 2004
Tahakopa	0.7	1.2	NZ	Clapcott et al 2010
La Trobe5	0.7	2.8	Australia	Chessman 1985
Pourokino Pourokino	0.7	2.5	NZ	Clapcott et al 2010
Taieri11	0.7	1.1	NZ	Young & Huryn 1996
Taieri5	0.7	8.6	NZ	Young & Huryn 1996
Ortiz-Zayas1	0.7	7.0	Puerto Rico	Ortiz-Zayas et al 2005
Spol	0.7	0.9	EU	Uehlinger et al 2003
Taieri11	0.7	0.8	NZ	Young & Huryn 1996
Pourokino Ermadale	0.7	1.1	NZ	Clapcott et al 2010
Mangakara	0.7	6.7	NZ	Clapcott et al 2010
McTammany2007_4	0.7	4.3	US	McTammany et al 2007
Waimeamea	0.6	3.6	NZ	Clapcott et al 2010
H&T6	0.6	4.1	US	Hall & Tank 2003
Calaveras	0.6	2.3	US	Fellows et al 2001
La Trobe2	0.6	4.6	Australia	Chessman 1985
Taieri7	0.6	8.7	NZ	Young & Huryn 1996
Taieri3	0.6	1.2	NZ	Young & Huryn 1996
Big	0.6	2.1	NZ	Young & Huryn 1999
GUA	0.6	1.2	EU	Von Schiller et al 2008
Taieri10	0.6	5.5	NZ	Young & Huryn 1996
Taieri8	0.6	3.5	NZ	Young & Huryn 1996
MCOR	0.6	0.7	US	Webster & Meyer 1997
Camp	0.6	15.3	NZ	Clapcott et al 2010
W3OR	0.6	4.9	US	Webster & Meyer 1997
W4OR	0.6	4.9	US	Webster & Meyer 1997
McConnell Creek	0.5	2.6	NZ	Young 2006b
Chloris	0.5	2.9	NZ	Clapcott et al 2010
Waipa 14	0.5	11.4	NZ	Clapcott & Young 2009
Taieri13	0.5	0.9	NZ	Young & Huryn 1996
Wharekawa	0.5	5.0	NZ	Clapcott et al 2010
COLn	0.5	2.3	EU	Von Schiller et al 2008
Mulholland 2005_2	0.5	5.2	US	Mulholland et al 2006
Calaveras	0.5	2.9	US	Fellows et al 2001
Taieri7	0.5	4.8	NZ	Young & Huryn 1996
Powder	0.5	7.9	NZ	Young & Huryn 1999
Creightons3	0.5	3.7	Australia	Atkinson et al 2008
Wairarapa Glandovey	0.5	3.6	NZ	Clapcott et al 2010
COLs	0.5	1.0	EU	Von Schiller et al 2008
AGMI	0.5	1.2	US	Webster & Meyer 1997
Ham	0.5	6.3	NZ	Clapcott et al 2010
Waimairi	0.5	5.1	NZ	Clapcott et al 2010
MontesinaJ	0.5	0.8	EU	Molla et al 1996
Meyer2	0.4	7.6	US	Meyer et al 2005

Karaponga	0.4	2.6	NZ	Clapcott et al 2010
BCQB	0.4	0.7	Canada	Webster & Meyer 1997
Creightons7	0.4	3.0	Australia	Atkinson et al 2008
WaikatoB3	0.4	1.0	NZ	Clapcott & Young 2009
Ohineangaanga	0.4	8.5	NZ	Clapcott et al 2010
CSNC	0.4	5.0	US	Webster & Meyer 1997
GCNM	0.4	6.8	US	Mulholland et al 2001
Ortiz-Zayas1	0.4	5.0	Puerto Rico	Ortiz-Zayas et al 2005
Brazil2	0.4	4.3	Brazil	Gucker et al 2008
Houser6	0.4	3.3	US	Houser et al 2005
Bott2006_8	0.4	2.3	US	Bott et al 2006
Taieri9	0.4	0.3	NZ	Young & Huryn 1996
Creightons6	0.4	0.8	Australia	Atkinson et al 2008
H&T9	0.4	5.8	US	Hall & Tank 2003
Houser4	0.4	3.5	US	Houser et al 2005
Powell @ Glenview	0.4	4.8	NZ	Young 2006b
Taieri5	0.3	0.7	NZ	Young & Huryn 1996
Lee	0.3	3.2	NZ	Young & Huryn 1999
H&T11	0.3	1.9	US	Hall & Tank 2003
Ortiz-Zayas3	0.3	3.5	Puerto Rico	Ortiz-Zayas et al 2005
Brazil3	0.3	6.2	Brazil	Gucker et al 2008
Taieri2	0.3	0.8	NZ	Young & Huryn 1996
Duckaday	0.3	7.4	NZ	Clapcott et al 2010
DCOR	0.3	0.6	US	Webster & Meyer 1997
FCQB	0.3	1.0	Canada	Webster & Meyer 1997
Powder	0.3	5.3	NZ	Young & Huryn 1999
Houser2	0.3	4.2	US	Houser et al 2005
McTammany2007_2	0.3	4.0	US	McTammany et al 2007
MON	0.3	1.3	EU	Von Schiller et al 2008
H&T4	0.2	1.0	US	Hall & Tank 2003
Powder	0.2	3.8	NZ	Young & Huryn 1999
Bott2006_10	0.2	1.4	US	Bott et al 2006
La Trobe3	0.2	4.1	Australia	Chessman 1985
Ruruanga	0.2	8.6	NZ	Clapcott et al 2010
BBNH	0.2	6.5	US	Mulholland et al 2001
Ortiz-Zayas3	0.2	1.5	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas3	0.2	1.0	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas3	0.2	3.0	Puerto Rico	Ortiz-Zayas et al 2005
Houser9	0.2	2.2	US	Houser et al 2005
Mulholland 2005_1	0.2	1.9	US	Mulholland et al 2006
McTammany2007_6	0.2	6.5	US	McTammany et al 2007
Brazil5	0.2	5.6	Brazil	Gucker et al 2008
Galina	0.2	6.7	US	Fellows et al 2001
Waikamihi	0.2	7.3	NZ	Clapcott et al 2010
Houser1	0.2	5.8	US	Houser et al 2005
Houser3	0.2	4.1	US	Houser et al 2005
Gundagai	0.2	0.8	Australia	Vink et al 2005
Styx Gardiners	0.2	30.5	NZ	Clapcott et al 2010
H&T10	0.2	6.1	US	Hall & Tank 2003

Aguera7	0.2	2.1	EU	Elosegui & Pozo 1998
Creightons5	0.2	0.9	Australia	Atkinson et al 2008
Houser5	0.2	1.8	US	Houser et al 2005
McTammany2007_5	0.2	6.6	US	McTammany et al 2007
La Trobe1	0.2	3.0	Australia	Chessman 1985
RIE	0.2	0.3	EU	Von Schiller et al 2008
Creightons1	0.2	1.0	Australia	Atkinson et al 2008
Mimiha	0.1	0.8	NZ	Clapcott et al 2010
Puamane	0.1	8.6	NZ	Clapcott et al 2010
H&T5	0.1	1.6	US	Hall & Tank 2003
Houser8	0.1	2.5	US	Houser et al 2005
Freshwater	0.1	6.1	NZ	Young 1998
Aguera5	0.1	2.4	EU	Elosegui & Pozo 1998
Waiari	0.1	5.2	NZ	Clapcott et al 2010
Waiwakareto	0.1	9.9	NZ	Clapcott et al 2010
AGP	0.1	0.3	EU	Von Schiller et al 2008
Ortiz-Zayas3	0.1	5.0	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas3	0.1	2.8	Puerto Rico	Ortiz-Zayas et al 2005
Ortiz-Zayas3	0.1	0.1	Puerto Rico	Ortiz-Zayas et al 2005
Erpe US	0.1	6.0	EU	Gucker et al 2006
Mulholland 2005_2	0.1	3.9	US	Mulholland et al 2006
McTammany2007_1	0.1	7.0	US	McTammany et al 2007
Granity	0.1	0.3	NZ	Young & Collier 09
CEL	0.1	2.0	EU	Von Schiller et al 2008
Brazil1	0.1	8.0	Brazil	Gucker et al 2008
Omaru	0.1	1.1	NZ	Clapcott et al 2010
Pikowai	0.1	8.0	NZ	Clapcott et al 2010
Creightons4	0.1	1.0	Australia	Atkinson et al 2008
Muletal1	0.1	7.8	US	Mulholland et al 2001
Vermilion29	0.1	34.0	US	Wiley et al 1990
Vermilion30	0.1	13.0	US	Wiley et al 1990
Erpe US	0.1	6.0	EU	Gucker et al 2006
Demnitzer Mill Brook DS	0.1	7.0	EU	Gucker et al 2006
Erpe DS	0.1	18.0	EU	Gucker et al 2006
Houser7	0.1	1.6	US	Houser et al 2005
Thur	0.1	0.8	EU	Uehlinger 2000
Thur	0.1	2.4	EU	Uehlinger 2000
FR	0.1	1.0	EU	Von Schiller et al 2008
HWNC	0.0	1.6	US	Webster & Meyer 1997
SBNC	0.0	1.6	US	Webster & Meyer 1997
BBNH	0.0	0.8	US	Webster & Meyer 1997
CAS	0.0	0.4	EU	Von Schiller et al 2008
BBVA	0.0	18.3	US	Webster & Meyer 1997
MB	0.0	0.4	EU	Von Schiller et al 2008
Sutton	0.0	2.2	NZ	Young & Huryn 1999
Creightons2	0.0	0.7	Australia	Atkinson et al 2008

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