Grading Coal Mine Wastewater impacts to Aquatic Ecosystems, measured through a new Macroinvertebrate Diagnostic Biotic Index.

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Abstract

Macroinvertebrate biotic indexes are well-developed robust methods to rapidly assess anthropogenic impacts on aquatic ecosystems, used since the early 1980's (Washington 1984 and Chessman 2003). The SIGNAL method (Stream Invertebrate Grade Number Average Level) is one method employed to assess the level and degree of impacts from anthropogenic influences in South Eastern Australia (Chessman 2003). This study investigates the impacts from coal mining wastewaters, which often consist of high concentrations of heavy metals and modified ionic composition. 12886 individual macroinvertebrates, the majority of which were identified to the family level (55 families) from eight waterways were used to derive a Coal Mine Impact Grade (CMIG) biotic index. Results comparing CMIG to SIGNAL show the potential of using the specific grading system as a robust, low impact and rapid method for the assessment of coal mine wastewater impacts to aquatic ecosystems. Coal mine wastewater discharges are regulated by the New South Wales Environmental Protection Authority to ensure the protection of the receiving waterway's aquatic ecosystem. However, the regulation and subsequent 'protection', performed through water quality and chemical concentrations, does not effectively assess the aquatic ecosystem. Although the proposed grades are preliminary, they would help provide a more effective monitoring system than end of pipe pollutant concentration limits alone.

Keywords

SIGNAL, biological monitoring, biotic index, aquatic macroinvertebrates, water quality, coal mine impact biotic index

Introduction

Macroinvertebrate biotic indices are a well-developed and rapid method to assess anthropogenic impacts on aquatic ecosystems and have been used since the early 1980's (Washington 1984 and Chessman 2003). The Average Score Per Taxon (ASPT) version of the Biological Monitoring Working Party (BMWP) system is used within Great Britain (Hawkes 1997). The SIGNAL method (Stream Invertebrate Grade Number Average Level) is one method employed to assess the level and degree of impacts from anthropogenic influences in South Eastern Australia and is derived from the afore mentioned methods (Chessman 2003). The SIGNAL method developed in 1995 by Chessman (1995) uses family level sensitivity grades for individual taxa ranging from "sensitive taxa" graded as 10 to "tolerant taxa" graded as 1 with many taxa in between varying due to their sensitivity to anthropogenic stressors. The SIGNAL method has evolved over the years and has become a reliable and robust method for the rapid assessment of macroinvertebrate communities impacted by urban development, industrial activities, agricultural impacts and stormwater runoff. The SIGNAL method is currently used as part of multi-layer waterway management practices which include the Victorian Index of Stream Condition (Ladson et al 1999). It was incorporated into the Victorian State Environment Protection Policy proposed by the Victorian Environmental Protection Authority (Anon 2001a). Nationally the SIGNAL method has been incorporated into the Australian River Assessment System (AUSRIVAS) and is a part of Australia's National River Health Program (NRHP) (Davies 2000).

Since its inception in 1995 the SIGNAL method has been modified to ensure the greatest integrity of its assessment outcomes. For instance, it was found by Chessman and McEvoy (1998) that different anthropogenic stressors such as sewage and metal contamination showed differing sensitivities for the same taxa. This later publication divided the anthropogenic stressors into three different categories (Dam, Sewage and Metal) impacts. It was concluded that the derived SIGNAL indices performed to varying degrees. For instance, the SIGNAL-DAM method showed less reliability than the SIGNAL-METAL and SIGNAL-SEWAGE indices in that order (Chessman 1998). This current study proposes a new index that reflects the tolerance of freshwater invertebrate families to coal mining wastewaters which are often contaminated with high concentrations of heavy metals, changes in pH and modified ionic composition. 12886 individual macroinvertebrates, the majority of which were identified to the family level (55 families) across eight different waterways have been used here to derive a preliminary Coal Mine Impact Grade (CMIG) biotic index. The proposed CMIG biotic index has been derived on presence and absence abundance data. In conjunction with Chessman (1995) and Chessman and McEvoy's (1998) SIGNAL index as a surrogate index to test the rigor of the Coal Mine Impact Grades (CMIG) derived here.

Methods

The Coal Mine Impact Grades (CMIG) derived in this study have been developed from presence and absence data collected at eight waterways within the greater Sydney Basin. All of the eight waterways are or have been subject to licensed and regulated coal mine wastewater discharges resulting in differing ecological impacts measured through water column (Belmer et al 2014, Wright et al 2015, Wright et al 2018 and Belmer et al 2019), river sediment (Belmer et al 2019), aquatic macroinvertebrates (Belmer et al 2014, Wright et al 2017, Wright et al 2018, Belmer et al 2019) and riparian vegetation (Belmer et al 2018). A total of 12866 individual macroinvertebrates from 55 families were collected from a single upstream and a single downstream sample location at the eight waterways (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research). Ten replicated quantitative macroinvertebrate samples were collected at five of the waterways and 5 identically sampled replicates at each remaining waterways upstream and downstream sample locations. From the entire 12886 macroinvertebrates collected 7531 (as these were identified to family level) were used from 51 families to derive Coal Mine Impact Grade (CMIG) of which 3038 were collected upstream of the coal mine wastewater inflows and 4494 downstream.

Initially data was analysed for presence and absence of family level taxa between the upstream and downstream samples. Differences were calculated based on how many sample locations (upstream and downstream) recorded each family level taxa. This difference in presence and absence calculation was performed for 45 family level taxa from the original 51 (A "low abundance" cut-off of <10 taxa from all replicates was decided). These initial grades gave some indication of the degree of spacing between each individual taxa's initial Coal Mine Impact Grade (CMIG) and with some adjustment a range of grades between 1 and 10 were derived and as per Chessman (1995) the grade of 10 was given to the most sensitive taxa and 1 to the most tolerant taxa.

Results and Discussions

These individual taxa Coal Mine Impact sensitivity grades (Table 1) were then calculated using the SIGNAL method of using family level taxonomic richness to derive a site specific CMIG score. I.e each individual taxa's CMIG grade was summed, the sum of individual taxa CMIG grades was then divided by the number of family taxa at that specific site resulting in the CMIG site specific score. The individual taxa Coal Mine Impact Grade (CMIG) was assessed alongside the individual taxa SIGNAL grade and the Chessman and McEvoy (1998) individual taxa SIGNAL-METAL grades to assess the overall integrity of the newly derived individual taxa Coal Mine Impact Grades (CMIG) and subsequent scoring system (Table 1).

Table 1. Coal Mine Impact Grade (CMIG) (Belmer and Wright), SIGNAL-METAL (Chessman and McEvoy 1998) and SIGNAL (Chessman 1995) grades comparison derived from (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

TAXA/SIGNAL grades	Coal Mine Impact Grade (CMIG)	SIGNAL-METAL	SIGNAL 95
Atriplectididae	5	n/a	8
Baetidae	4	7	5
Caenidae	3	7	4
Calamoceratidae	10	8	7
Calocidae	7	n/a	9
Coloburiscidae	10	10	8
Conoesucidae	10	8	6
Eustheniidae	10	n/a	10
Glossomatidae	10	8	9
Gripopterygidae	8	8	8
Hydrobiosidae	6	6	8
Hydropsychidae	3	10	7
Hydroptilidae	2	6	7
Leptoceridea	5	7	8
Leptophlebiidae	8	8	8
Limnephilidae	8	n/a	8
Notonemouridae	3	1	6
Philopotamidae	4	10	6
Philorheithridae	7	n/a	8
Athericidae	3	n/a	8
Aeshnidae	5	3	4
Bithyniidae	3	n/a	3
Chironomidae	1	6	3
Coenagrionidae	4	3	2
Corbiculidae	4	n/a	4
Corixidae	3	4	2
Corydalidae	4	4	1
Culicidae	4	3	1
Curculionidae	3	n/a	2
Diphlebiidae	5	n/a	6
Dixidae	3	n/a	7
Dolichopodidae	1	n/a	3
Dugesiidae	3	3	2
Dytiscidae	5	4	2
Empididae	1	n/a	5
Gomphidae	3	5	5
Gyrinidae	3	4	4
Haliplidae	3	n/a	2
Hydraenidae	5	7	3
Libellulidae	3	1	4
Lymnaeidae	3	7	1
Notonectidae	3	6	1
Physidae	1	5	1
Planorbidae	4	6	2
Psephenidae	4	8	6
Sciomyzidae	3	n/a	2
Scirtidae	8	8	3
Simuliidae	1	5	10
Sphaeriidae	1	n/a	5
Stratiomydae	1	n/a	2
Tipulidae	1	n/a	3

After deriving each individual family level taxa grade with the use of family richness data from each site a Coal Mine Impact Grade (CMIG) was calculated and compared to mean SIGNAL Grade Scores (Chessman 1995) to assess how each calculation fits within a similar grading system. Results from the above presence/absence calculations show strong relationships between upstream (non-impact) and downstream (impact) samples. By comparing SIGNAL grades and CMIG grades (table 3) a similar pattern of impact was observed, though it should be noted that SIGNAL grades are somewhat more conservative and returned a greater SIGNAL grade in comparison to CMIG grade. Along with the CMIG score a colour definition of the grading system has been obtained from the Chessman (1995) SIGNAL system (table 2).

Table 2. Coal Mine Impact Grade (CMIG) score definitions and original SIGNAL score definitions (Chessman et al 1995).

CMIG		SIGNAL (Chessman 1995)	
Healthy	>5.5	Healthy	>6
Minimal Impact	4.5-5.5	Healthy to Minimal Impact	5-6
Mild Impact	4-4.5	Mild Impact	4-5
Moderate Impact	3.5-4	Moderate Impact	3-4
Severe Impact	<3.5	Severe Impact	<3

Table 3. Comparison of mean SIGNAL (Chessman 1995) and Coal Mine Impact Grade (CMIG) mean scores. (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

Waterway name/Mean derived SIGNAL vs CMIG scores	Mean SIGNAL score (Chessman 1995)	Mean Coal Mine Impact Grade (CMIG) score	Measured Impact (SIGNAL 95)	Measured Impact (CMIG)
Wollangambe River upstream	6.84	6.05	Wollangambe	Wollangambe
Wollangambe River downstream	4.53	3.38	Mild	Severe
Wingecarribee River upstream	5.06	4.64	Wingecarribe e	Wingecarribe e
Wingecarribee River downstream	4.69	3.25	Mild	Severe
Bargo River upstream	6.21	6.07	Bargo	Bargo
Bargo River downstream	6.00	5.20	None	Minimal
Dalpura Creek upstream	5.78	4.65	Dalpura	Dalpura
Dalpura Creek downstream	5.10	3.78	None	Moderate
Georges River upstream	4.55	4.14	Georges	Georges
Georges River downstream	4.42	3.92	None	Moderate
Sawyers Swamp upstream	5.05	4.58	Sawyers	Sawyers
Sawyers Swamp downstream	3.89	2.56	Moderate	Severe
Springvale Creek upstream	5.38	5.08	Springvale	Springvale
Springvale Creek downstream	3.79	2.79	Moderate	Severe
Sawyers Swamp upstream	5.05	4.58	Kangaroo	Kangaroo
Kangaroo Creek downstream	4.50	3.00	Mild	Severe

Comparison between SIGNAL (Chessman 1995) and CMIG derived scores (Table 2 and 3) shows a clear depiction of each coal mines wastewater impact on their receiving waterways. Mean SIGNAL scores for five of the mines show that the wastewaters are impacting the macroinvertebrate community but are perhaps underrepresenting the level of impact, especially for the remaining three mines waterways (Bargo River, Dalpura Creek and the Georges River) which show no impact to the macroinvertebrate community (table 3). This is most likely due to the SIGNAL method being specifically derived to assess the impact of sewage and urban pollution impacts (Chessman 1995). In comparison, CMIG is depicting differing degrees of impact to the receiving waterways macroinvertebrate community for all eight mine discharges (Table 2). By using the same family level taxa method employed by Chessman (1995) along with the derived (CMIG) grades for individual taxa, plot graphs depicting each coal mines impact to their respective receiving waterway are offered below (Figures 1, 2, 3, 4, 5 and 6).

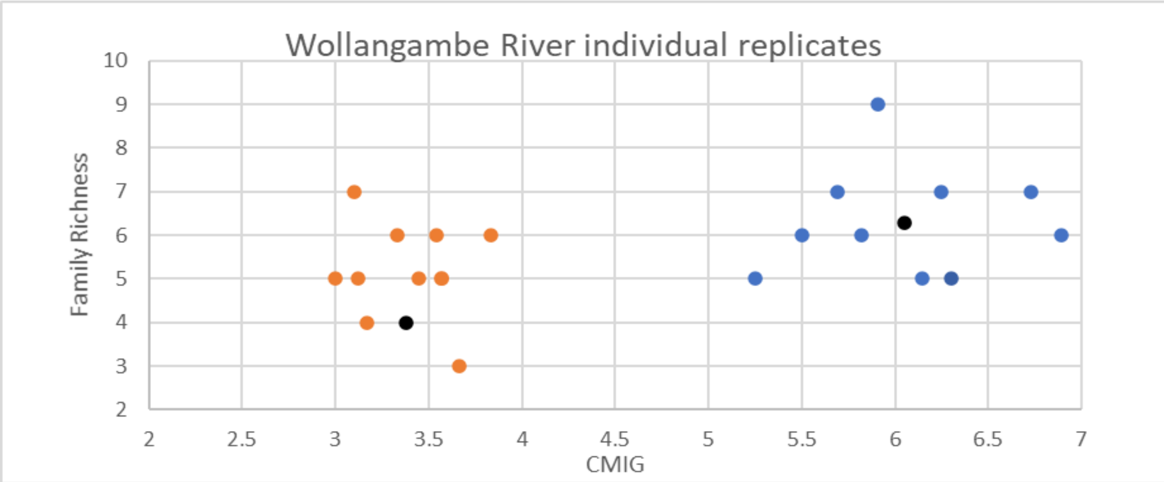

Figure 1. Wollangambe River (Clarence Colliery) CMIG Family Richness plot graph. Orange is downstream of the mine wastewater inflow and blue is upstream. Black is the mean CMIG score for downstream (centre left) and upstream (centre right) (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

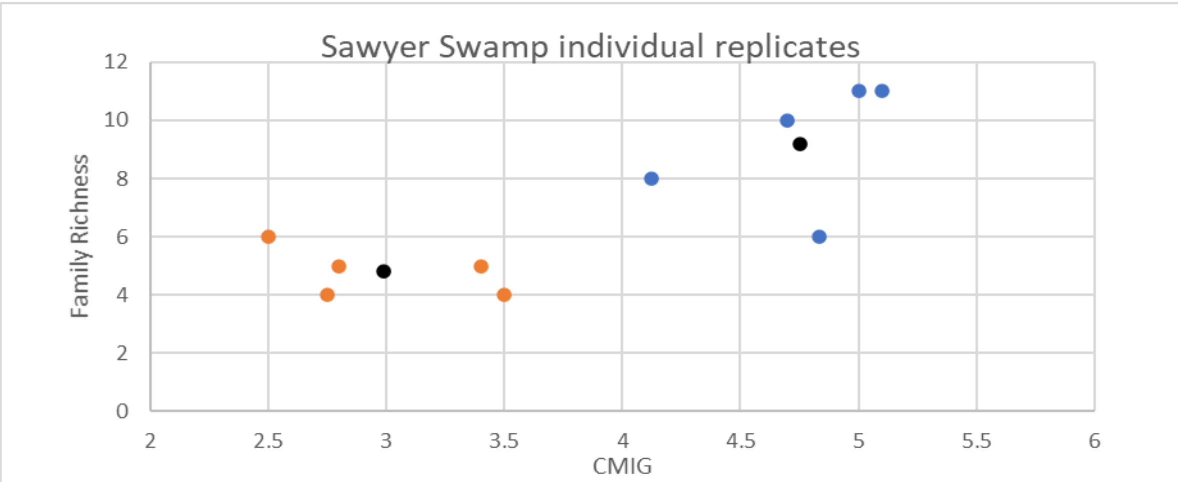

Figure 2. Sawyer Swamp (Angus Place and Springvale Collieries and coal ash dam) CMIG Family Richness plot graph. Orange is downstream of the mine wastewater inflow and blue is upstream. Black is the mean CMIG score for downstream (centre left) and upstream (centre right). (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

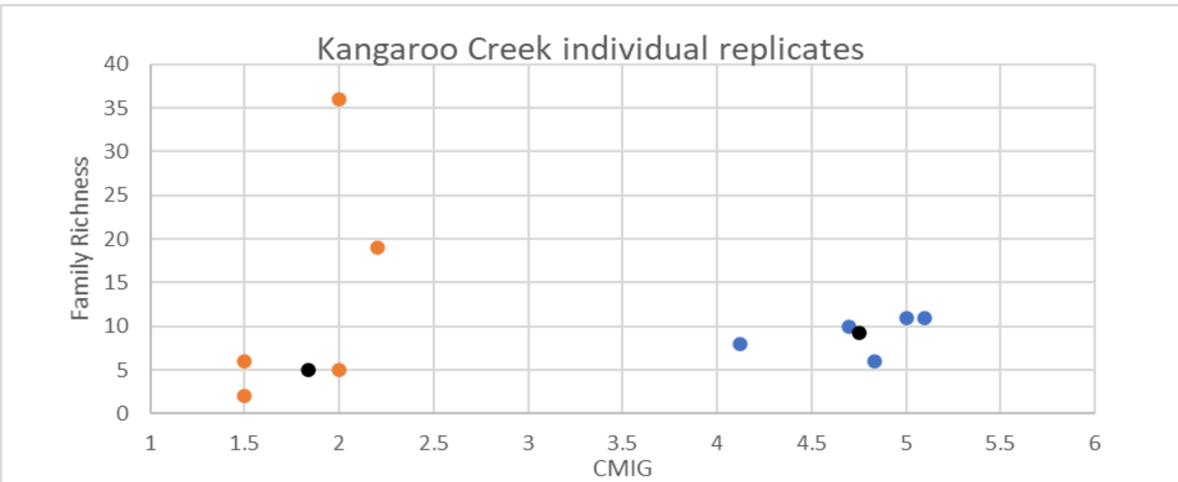

Figure 3. Kangaroo Creek (Angus Place Colliery) CMIG Family Richness plot graph. Orange is downstream of the mine wastewater inflow and blue is upstream. Black is the mean CMIG score for downstream (centre left) and upstream (centre right). (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

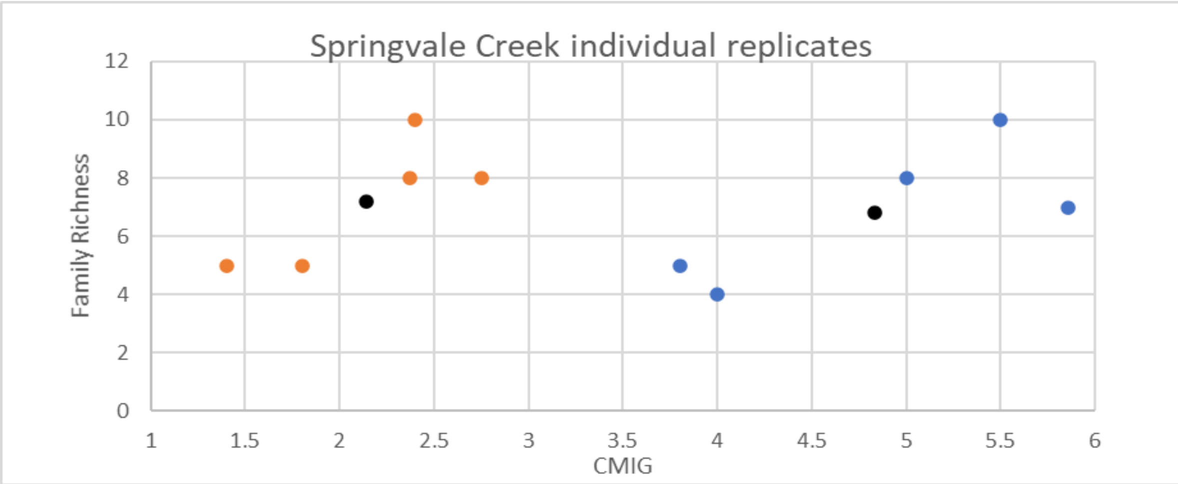

Figure 4. Springvale Creek (Springvale Colliery) CMIG Family Richness plot graph. Orange is downstream of the mine wastewater inflow and blue is upstream. Black is the mean CMIG score for downstream (centre left) and upstream (centre right). (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

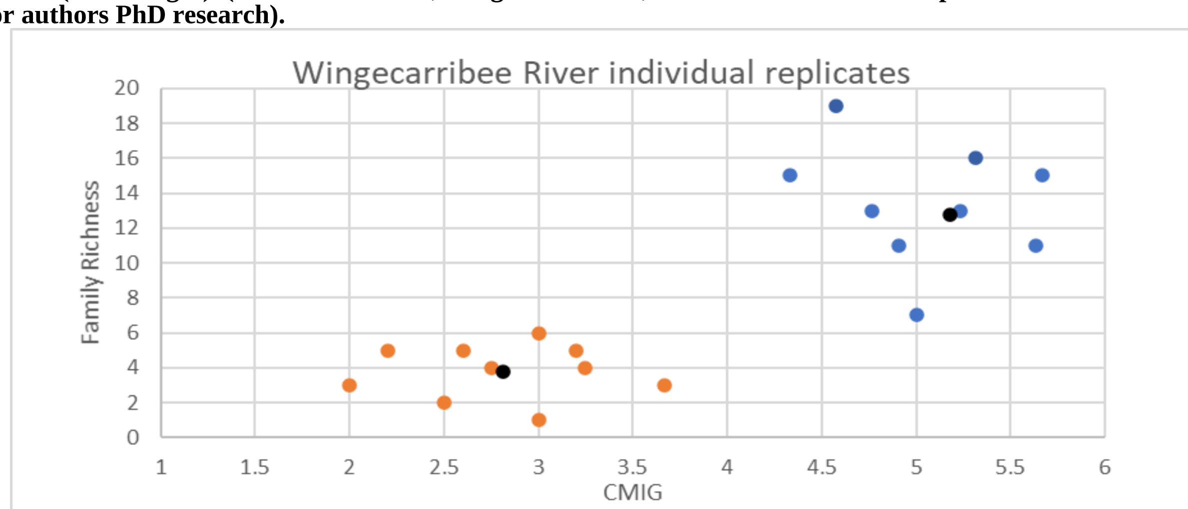

Figure 5. Wingecarribee River (Berrima (Medway) Colliery) CMIG Family Richness plot graph. Orange is downstream of the mine wastewater inflow and blue is upstream. Black is the mean CMIG score for downstream (centre left) and upstream (centre right). (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

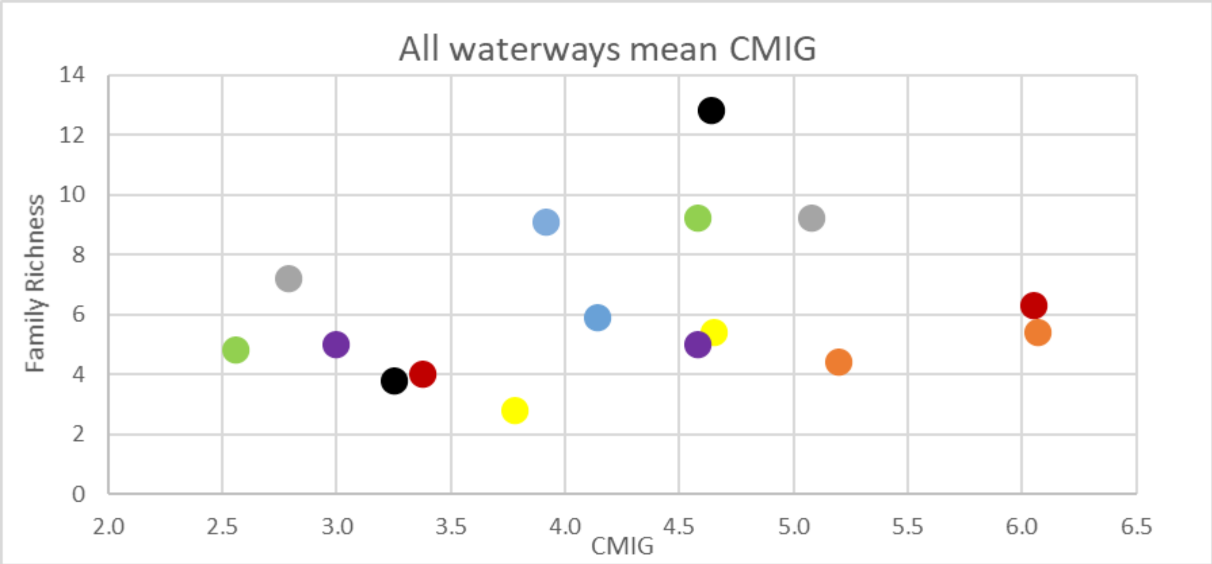

Figure 6. All Waterways and Collieries mean upstream and downstream CMIG Family Richness plot graph. Each respective waterways upstream CMIG grade is positioned to the right of the unit 4.0 on the x axis and its paired downstream CMIG grade is positioned to the left of the 4.0 unit on the x axis. Red is the Wollangambe River (Clarence Colliery), Orange is Bargo River (Tahmoor Colliery), Grey is Springvale Creek (Springvale Colliery), Black is the Wingecarribee River (Berrima (Medway) Colliery), Green is Sawyers Swamp (Springvale and Angus Place Colliery), Yellow is Dalpura Creek (Canyon Colliery), Purple is Kangaroo Creek (Angus Place Colliery) and Blue is the Georges River (West Cliff Colliery). (Belmer et al 2014, Wright et al 2017, Belmer et al 2019 and unpublished data from the senior authors PhD research).

Conclusions

Results of the CMIG/SIGNAL grade comparison, CMIG calculated mean scores and the CMIG/Family Richness plot graphs show the great potential of using the grading system as a robust and rapid method for the assessment of coal mine wastewater impacts to the receiving waterways aquatic ecosystem. Coal mine wastewater impacts to receiving waterways are regulated by the New South Wales Environmental Protection Authority to ensure the protection of the receiving waterway's aquatic ecosystem. However, the current regulation and subsequent 'protection', performed through water quality and chemical concentrations, never actually assess the aquatic ecosystem. It should be noted that the grades derived here may only suit Sydney Basin coal mining impacts and in fact perhaps only those which mine ore from identical and or similar coal seam measures. This is a preliminary grading system and further research is needed to extend the geographical range of the grades and add to the overall robustness of the data set. Though these grades are only preliminary, they are the only grades which in fact assess the impact of coal mine wastewater discharges to a receiving waterway's aquatic ecosystem and would provide a much better monitoring system than generalised water column pollutant concentration limits alone. These preliminary grades offer a new approach to assess the ecological impact of coal mine wastes to streams and rivers and could be used for multiple purposes. This could include improved environmental regulation beyond the current focus on 'end of pipe' pollutant concentrations along with the assessment of post mining impacts.

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