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Impact of mine tailings on the species diversity of Odonata fauna in Surigao Del Sur, Philippines

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Abstract

Odonata is very sensitive to changes in habitat, making it a reliable bio-indicator of environmental health. This study was conducted to assess the impact of mine tailings on the species diversity of Odonata in Surigao del Sur, Philippines. Eight sampling sites were surveyed comprising four sites with mine tailings and four sites without mine tailings. Opportunistic sampling using sweep nets was conducted on August 24-27, 2013 and October 26-29, 2013. Eighteen species were documented belonging to sixteen genera and six families. Over-all endemism was low at 22%. Seven species were recorded under sub-order Zygoptera, and eleven under sub-order Anisoptera. Species diversity and evenness were significantly different between areas with mine tailings and those without. Sites without mine tailings had higher abundance, species richness, and endemism than sites with mine tailings. Results indicate that mine tailings adversely affect species diversity of Odonata.

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Introduction

The order Odonata comprises two sub-orders: the damselflies (Zygoptera) and the dragonflies (Anisoptera) which are among the dominant groups of aquatic and terrestrial insects (Prasad *et al.,* 2013). Odonata is a flagship group, and an important component of aquatic ecosystems (Balzan, 2012).There are about 5,680 species of Odonata that are known, 2,739 belonging to the suborder Zygoptera (19 families) and 2,941 to the suborder Anisoptera (12 families) (Kalkman *et al.,* 2008). The order is found in all continents except Antarctica (Nelson *et al.,* 2011) and inhabits both aquatic and terrestrial environments, reflecting environmental variation at different scale (Balzan, 2012). The life cycle is closely linked to water bodies as it prefers both lentic and lotic waters (Prasad *et al.,* 2013). Adults lay eggs in specific aquatic habitats and larvae which emerge from the eggs are predatory feeding on diverse aquatic organisms like small crustaceans (Andrew *et al.,* 2008).

Odonata is specific to habitat structure and is very sensitive to changes in landscape (Andrew *et al.,* 2008) making it suitable for evaluating environmental changes both in long term (biogeography and climatology) and in short term (biology conservation, water pollution, structural alteration of running and standing waters) (Kalkman *et al.,* 2010). The association of Odonata with its habitat, including its functional importance within ecosystems, and its association with other species and resources, makes surveys of Odonata communities an important tool for characterizing and assessing the land-water interface through its function as indicator of ecosystem quality (Balzan, 2012).

Philippines, a tropical country which is composed of more than 7,100 islands has a high number of endemic odonata species (Kalkman et *al.,* 2008) but is among the top priority hotspots for global conservation (Lin and Yen, 2011) due to continuing loss of forest and other habitat destruction (Hamalainen, 2004) and degradation which is the main threat to threatened and non- threatened species, and is affecting dragonfly species (Riservato *et al.,* 2009). Such habitat destruction can be attributed to logging, both legal and illegal mining and energy projects, and use conversion and slash-and-burn farming (Oliva, 2007).

Mining of minerals which often creates imbalances, adversely affects the environment and its key environmental impacts are on wildlife and fishery habitats, the water balance, local climates & the pattern of rainfall, sedimentation, the depletion of forests and the disruption of the ecology (Mehta, 2002). Particles of toxic metals blown or leached from tailings by rainfall can contaminate surface water and groundwater (Miller, 2002). It modifies the surrounding environment and causes habitat deterioration along river systems receiving mine tailings which affects the Odonata abundance and diversity (Villanueva 2009a).

A survey conducted by Quisil *et al.* (2013) in San Agustin, Surigao del Sur found 34 species of adult Odonata. However, no assessment was done in the neighboring areas, Barobo and Lianga, Surigao del Sur where ongoing small-scale mining particularly in Tambis, Barobo, Surigao del Sur is rampant. There appears to be a need to survey the area using Odonata as bio-indicator. Surigao del Sur is geologically prospective and a highly promising area for metallic and non-metallic deposits and the two of the best source of minerals in the province are coming from the municipalities of Bayabas and Carrascal, Surigao del Sur (Surigaodelsur.gov, 2012).

In this study, the impact of mining on the species diversity of Odonata in Surigao del Sur was assessed by comparing the species richness, species diversity, and endemism of Odonata in sampling sites with mine tailings and those without.

Materials and methods

Study Area

Eight sites (Fig. 1) comprising four sites with small-scale mine tailings in Barobo, Surigao del Sur, two sites without mine tailings also in Barobo, Surigao del Sur and two sites without tailings in Lianga, Surigao del Sur were established as sampling sites. Barobo, Surigao del Sur was chosen as the area of the study due to abundance of streams and presence of small-scale mining. It is considered as having the most number of small-scale mining activities in the province of Surigao del Sur. No mining activities, however, occur in Lianga, Surigao del Sur but this area was chosen to serve as point of comparison.

Fig. 1. Map of the Philippines showing the location of the eight sampling sites in Lianga and Barobo Surigao del Sur (Googlemaps.com, 2014).

Site 1, Javier River is a site with tailings located at Barangay Javier, Barobo, Surigao del Sur (8' 29.114" N 126' 4.990" E) and has a flat slope with highly elevated land on its sides. It has very disturbed vegetation. Carabao grasses (*Paspalum conjugatum*) are dominant and coconut trees (*Cocos nucifera*) can be seen near households, which are about 5 meters away from the river. Pigs (*Sus domesticus*) and carabaos (*Bubalus bubalis*) were observed wallowing in the river. Falcata (*Acacia falcata*) and banana (*Musa* sp.) were abundant. Trash and plastics were seen. The water pH was 7.9 and relative humidity was recorded to be 79%.

Site 2, Dinuyan River is a site with tailings located at Sitio Ebo, Barangay Tambis, Barobo, Surigao del Sur (8'32.234" N 126'2.738" E). It has flat slope and disturbed vegetation. The site is an open field, with vast array of grasses and gust of wind blowing from different directions. Soil type is muddy with some protruding rocks. Households are about 30 m away from river. The river has a dirt road across it. The water pH was 7.31 and relative humidity of 78.5%.

Site 3, Bananghilig River is a site with tailings located at Barangay Bananghilig, Tambis, Barobo, Surigao del Sur (8'32.562' N 126'2.458 E). It has a flat slope with disturbed vegetation type. A forested mountain is on its side. Banana (*Musa* sp.) and coconut (*Cocos nucifera*) were abundant on residential areas on the sides of the river. Rocks are prevalent, with mud seeping through it. Two roads are built across it, one is a dirt road for heavy machineries, and the other one is a bridge for lighter ones. The water is very turbid, but people created a way to have clearer water for washing laundry. The water pH is 7.92, with a salinity level of 2%. The relative humidity of the area was 72%.

Site 4, Anoling River is a site with tailings located at Sitio Agutay, Barangay Tambis, Barobo, Surigao del Sur (8'32.207" N 126'2.237" E). It has flat slope with very disturbed vegetation. Small scale mining activities were observed. Pigs were present. Large stones protrude from the water, with mud seeping within. Opposite sides of the river showed opposite features, one has the anthropogenic disturbance all over it, while the other showed a slightly disturbed abundant forest. Logs were seen on some areas. A leaf eater was spotted. Coconuts, falcata, pandan, and bamboo were abundant. Water pH was 7.62 with salinity of 1%. The relative humidity of the area was 66%.

Site 5, Javier Stream is a site without tailings located at Barangay Javier, Barobo, Surigao del Sur (8'29.068" N 126'4.985" E). It has a flat slope with a disturbed vegetation type. Coconut (*Cocos nucifera*), bamboo, "gabi" (*Colocasia esculenta*), carabao grass (*Paspalum conjugatum*), and water hyacinth were prevalent in the site. Residential houses can be seen 10 m away from the site. Small stones were common. Water pH was 6.82 and relative humidity was 61%.

Site 6, Upper Binuoyan River is a site without tailings located at Barangay Guinhalinan, Barobo, Surigao del Sur (8'27.805" N 126'4.113" E). It has a flat slope with disturbed vegetation type. "Gabi" (*Colocasia esculenta*), falcata (*Acacia falcata)*, timber, and some logs were present. Leaf litter was prevalent everywhere. A bridge overlaps the stream, with signs of anthropogenic disturbance. The water pH was 7.48 and the site had a relative humidity of 79%.

Site 7, Bao-bao River is a site without tailings located at Barangay Diatagon, Lianga, Surigao del Sur (8°40'22"N 126°8'18"E). It has a mountainous slope. Large trees like narra were dominant. Water flows on large boulders. Leaf litter was observed everywhere. Fishes were also observed. The water pH was 7.25 and relative humidity was 64%.

Site 8, Manyayay Stream is a site without tailings located at Barangay Manyayay, Lianga, Surigao del Sur (8˚63361'N 126˚09472'E). It has a flat slope. Various trees were observed which provide about 70% canopy. Banana (*Musa* sp.), gabi

(*Colocasia esculenta*), and ferns (*Asplenium platyneuron*) were dominant. Leaf litter was observed on the sides of the stream. The pH of water was 7.04 and relative humidity was 71%.

Collection, Processing of Samples, and Analysis of Data

Opportunistic sampling was employed in the survey using sweep net with a long-handled net of at least 18" diameter. The sample was placed with its wings folded back in a triangular envelope then placed in an air-tight container. Pictures were taken to further study the samples revealing its details in color, structure or behavior that were missed in the wild and that help contribute to the identification (Klym and Quinn, 2003). Samples were submerged in acetone in a tightly closed plastic container for 12 hours for damselflies, and 24 hours for dragonflies (Mapi-ot *et al.,* 2013). Samples were stored in new envelopes and kept in a sturdy plastic container without packing them tightly (Quisil *et al.,* 2013). Naphthalene balls were added to the container to prevent entry of other insects that can damage the preserved samples (Cayasan *et al.,* 2013). The plastic containers containing the specimens were then placed in a cool and dry place.

The samples collected were transported to Mindanao State University- Iligan Institute of Technology, Iligan City. Identification was done with the help of the third author. Biodiversity indices (species richness, species diversity, relative abundance, and evenness) were computed. Kruskal-wallis test was performed. It is a non-parametric method for testing whether samples originate from the same distribution. It is used for comparing more than two samples that are independent, or not related (Spurrier, 2003). Comparisons of species richness, abundance, endemism, species diversity and evenness were made across sites and between sites with and without mine tailings.

Results and discussion

Eighteen species belonging to six families were identified of which seven species were under sub-order Zygoptera, and 11 species were under sub-order Anisoptera (Table 1). This result is relatively high compared to the odonata fauna in Similipal (Sethy and Siddiqi, 2007) and relatively low compared to the odonata fauna in Misamis Occidental (Mapi-ot *et al.,* 2013) and Zamboanga del Sur (Cayasan *et al.,* 2013). Sites without mine tailings showed higher species richness than sites with mine tailings. The result agrees with the findings of Villanueva (2009a) that about 10 times higher diversity of adult odonata are in the pristine than in the mined river.

Table 1. Species Richness and Relative Abundance of Odonata in Lianga and Barobo, Surigao del Sur, Philippines.

SPECIES	AREAS WITH MINE TAILINGS				AREAS WITHOUT MINE TAILINGS				Total
	1 Javier River	2 Dinuyan River	3 Bananghilig River	4 Anoling River	5 Javier Stream	6 Upper Binuoyan	7 Bao-bao River	8 Manyayay Stream	
SUB-ORDER ZYGOPTERA									
CALOPTERYGIDAE									
Vestalis melania Selys, 1873*	-	-	-	-	-	4(8.16)	3(7.32)	9(16.67)	17
CHLOROCYPHIDAE									
Rhinocypha colorata (Hagen in Selys, 1869)*	1(4.76)	-	4(19.05)	2(5.71)	14(29.79)	15(30.61)	5(12.2)	9(16.67)	50
COENAGRIONIDAE									
Agriocnemis sp.	-	-	-	3(8.57)	-	-	4(9.76)	6(11.11)	13
Ischnura ramburii (Selys, 1850)	2(9.52)	-	-	-	3(6.38)	-	-	6(11.11)	11
Pseudagrion microcephalum (Rambur, 1842)	-	-	-	-	-	-	7(17.07)	5(9.26)	12
Pseudagrion pilidorsum pilidorsum (Brauer,1868)	-	-	-	12(34.29)	8(17.02)	3(6.12)	4(9.76)	-	27

SPECIES	AREAS WITH MINE TAILINGS				AREAS WITHOUT MINE TAILINGS				Total
	1 Javier River	**2 Dinuyan River**	**3 Bananghilig River**	**4 Anoling River**	**5 Javier Stream**	**6 Upper Binuoyan**	**7 Bao-bao River**	**8 Manyayay Stream**	
PROTONEURIDAE									
Prodasineura integra (Selys, 1882) *	-	-	-	-	7(14.89)	8(16.33)	-	3(5.56)	18
SUB-ORDER ANISOPTERA									
GOMPHIDAE									
Heliogomphus bakeri Laidlaw, 1925*	-	-	-	-	2(4.26)	4(8.16)	-	1(1.85)	7
LIBELLULIDAE									
Agrionoptera insignis (Rambur, 1842)	-	-	-	-	-	-	1(2.44)	5(9.26)	6
Diplacodes trivialis (Rambur, 1842)	-	-	2(9.52)	-	-	-	-	-	2
Neurothemis terminata Ris, 1911	5(23.81)	4(13.33)	5(23.81)	4(11.43)	2(4.26)	11(22.45)	4(9.76)	7(12.96)	42
Orthetrum sabina sabina (Drury, 1770)	10(47.02)	13(43.33)	9(42.86)	8(22.86)	5(10.64)	2(4.08)	-	-	47
Orthetrum testaceum (Burmeister, 1839)	-	-	-	4(11.43)	-	-	-	-	4
Pantala flavescens (Fabricius, 1798)	-	-	-	-	4(8.51)	-	10(24.39)	3(5.56)	17
Potamarcha congener (Rambur, 1842)	-	-	-	2(5.71)	-	-	-	-	2
Raphismia bispina (Hagen, 1867)	-	13(43.33)	1(4.76)	-	2(4.26)	2(4.08)	-	-	18
Tholymis tillarga (Fabricius,1798)	3(14.29)	-	-	-	-	-	-	-	3
Trithemis festiva (Rambur, 1842)	-	-	-	-	-	-	3(7.32)	-	
Total Number of Individuals	21	30	21	35	47	49	41	54	289
Species Richness	5	3	5	7	9	8	9	10	18
Number of Endemic Species	1[5.55]	0	1[5.55]	1[5.55]	3[16.67]	4[22.22]	2[11.11]	4[22.22]	4

*Philippine Endemic, () Relative Abundance, [] Endemicity

More endemic species (22.22% endemism) were found in sites without tailings, while sites with tailings only have 5.55% endemism. Quisil *et al.,* (2013) also recorded low endemism (47%) in San Agustin, Surigao del Sur due to the unsustainable and rapid agricultural expansion that was observed as the main threat to the habitats of Odonata. Cayasan *et al.,* (2013) also found low endemism of odonata in disturbed habitat and characterized predominantly by Oriental species. Low endemism of odonata is attributed to anthropogenic disturbances (Aspacio *et al.,* 2013). This indicates that the low endemism of odonata species in the sampling sites could be due to the slow detrimental effects of human activities, especially mining.

Stream (Site 8) had the highest number of species (10) which coincides to the fact that this is one of the sites without mine tailings and which concurs with the observation of Cayasan *et al.,* (2013) that undisturbed streams could hold high species of odonata. *Rhinocypha colorata,* an endemic species, was the most abundant (50), and found in seven out of the eight sampling sites indicating that this species can adapt to sites with mine tailings. This damselfly species was also recorded as the most abundant in Misamis Occidental which can adapt and tolerate disturbed habitats (Mapi-ot *et al.,* 2013). This finding coincides with the observation of Villanueva *et al.,* (2012) that this species can be found even in areas with significant human activity and can tolerate streams that have agricultural and domestic runoffs. Abundance, of *R. colorata* however, was much lower in sites with tailings. The three other endemic species, *Vestalis melania*, *Prodasineura integra*, and *Heliogomphus bakeri* were absent in sites with mine tailings. These endemic species appear to be indicators of the disturbance due to mine tailings.

Fig. 2 shows that plots and sites with similar Odonata fauna are found together in the Cartesian plane whereas those with dissimilar community assemblages are plotted far from each other. The results showed that sites without mine tailings (Site 5-Javier Stream, Site 6-Upper Binuoyan River, Site 7-Bao-bao River, and Site 8-Manyayay Stream) are plotted closer in the diagram which means that these sites have similar species assemblages. Sites with mine tailings are also plotted closer in the diagram. The results suggest that sites affected by mining have a characteristic community structure distinct from those without mine tailings. This result might also mean that mining really affects community structures of Odonata in an area. Most of the Odonata associated with sites affected by mining are dragonflies or Anisopterans, predominantly by widespread and oriental species while sites that are free from mine tailings are host to damselflies or Zygopterans. Dragonflies are more robust (Mitra, 2006) while damselflies are smaller and more slender (Klym and Quinn, 2003). This means that those Oriental dragonflies species can tolerate disturbance, thus surviving even the harshest environment while damselfies, however, have lower tolerance being small and fragile. Aspacio *et al.,* (2013) and Cayasan *et al.,* (2013) found that widespread and oriental Odonata species can tolerate habitat disturbance and are able to survive in human settlements and are therefore indicators of degraded environments.

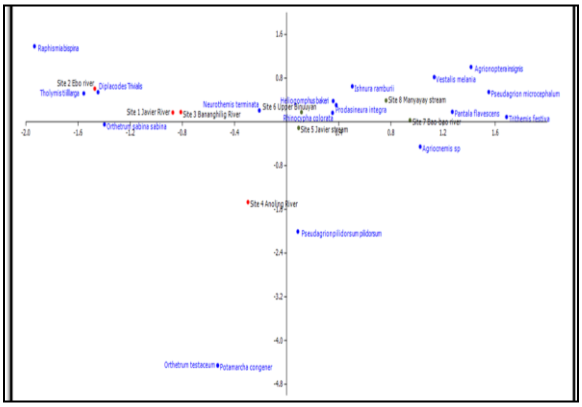

Fig. 2. Scatter Plot of the Species Distribution per Site.

Sites without mine tailings are greatly concentrated with all of the recorded endemic species which indicate a good habitat. Forested creeks, streams, and semi-pristine sites are expected to hold much of the endemic species (Jomoc *et. al.,* 2013). These endemic species need to be protected before they become endangered. When species becomes endangered, it is an indicator that the health of these vital ecosystems is beginning to unravel. It is estimated that losing one plant species can trigger the loss of up to 30 other insects, plants and higher animal species (Kurpis, 2002).

Fig. 3 shows that Family Libellulidae had the most species (10), and abundance (144 individuals), and the only family that is represented in every site which concurs with the statement of Kalkman *et al.,* (2008) that Family Libellulidae is the largest family of Anisoptera. Libellulidae was also found to be the most abundant family in Misamis Occidental, Philippines (Mapi-ot *et al.,* 2013), in Cagayan De Oro and Bukidnon, Philippines (Jomoc *et al.,* 2013) and in Eastern Ghat, India (Das *et al.,* 2012). Three families (Calopterygidae, Protoneuridae, and Gomphidae) were represented by only one species each and were found only in sites without tailings.

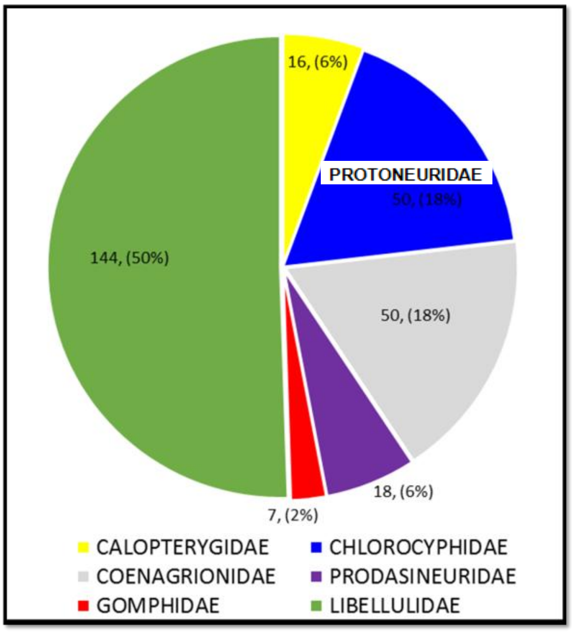

Fig. 3. Species Distribution According To Family.

Fig. 4 shows that four species (22.22%) are endemic species found in sites without mine tailings. Malawani *et al.,* (2014) found high percent of endemism (50%) in Lanao del Sur which indicates more Odonata species could be recorded through exploring undisturbed sites. Undisturbed sites mainly host endemic species (Jumawan *et al.,* 2012). Present results indicate that endemic species of Odonata prefer forested and undisturbed areas. *Rhinocypha colorata*, an endemic species, was most abundant (50) and mostly found in sites without mine tailings. *R. colorata* prefers open flowing waterways where it perches on exposed twigs adjacent to the water and can tolerate moderate habitat disturbance (Villanueva *et al.,* 2012). *Orthetrum sabina sabina* was the second most abundant species (47), which is mostly found in sites with mine tailings. *Orthetrum s. sabina* is a very widespread species that is well adapted to various kinds of habitats in fresh and brackish waters, including disturbed ones (Mitra, 2013). This species was also recorded in disturbed areas of Lanao del Sur (Malawani *et al.,* 2014), Misamis Occidental (Mapi-ot *et al.,* 2013) and in the mining sites of Isabela and Aurora Provinces, and Polillo Island, Philippines (Villanueva *et al.,* 2012). *Neurothemis terminata*, a non-endemic species had higher abundance in sites without tailings. It is widespread and often common species which can occur in man-made habitats and mostly found in lakes and marshes (Kalkman, 2009)

Seven species were confined only in sites without mine tailings, three of which are the endemic species, *Vestalis melania*, *Prodasineura integra*, and *Heliogomphus bakeri*. The three species are of conservation concern because they are not widespread and may be confined to only one or two protected areas (Wildlife Conservation Society, 2014). Among the seven species are: *Pseudagrion microcephalum* which prefers freshwater, *Agrionoptera insignis* which is present in swampy lowland forest, and *Pantala flavescens*, and *Trithemis festiva* which breed in streams and rivers. These species could be good bio-indicators of ecosystem health. Good bio-indicators are species that effectively indicate the condition of the environment (Holt and Miller, 2011) through changes in their morphology, physiology, or behavior (Gerhardt, 2002).

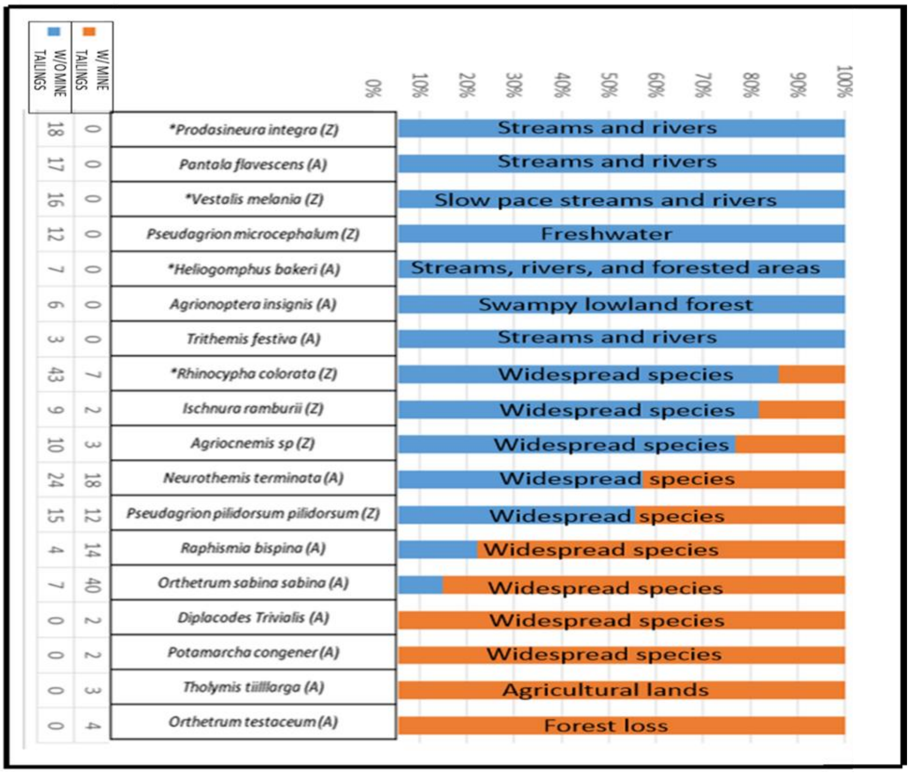

Fig. 4. Distribution and Abundance of Odonata in Sites With And Without Mine Tailings.

Seven species were recorded to thrive both in sites with and without mine tailings namely: *Rhinocypha colorata, Ischnura ramburii, Agriocnemis* sp., *Neurothemis terminata*, *Pseudagrion pilidorsum pilidorsum*, *Raphismia bispina,* and *Orthetrum sabina sabina*. These are widespread species which are not reliable bio-indicators as they can tolerate disturbed sites and still thrive on healthy environment.

The last four species recorded were only found on sites with mine tailings. Two of which are widespread species namely, *Diplacodes trivialis* and *Tholymis tillarga*. Their presence does not greatly signify anything to this study, unlike the other two species namely, *Orthetrum testaceum* and *Potamarcha congener*, which are reportedly good indicators, of disturbed environment. *O. testaceum* thrives on forest loss while *P. congener* thrives on agricultural lands (Mitra, 2010).

Table 2 shows that sites with tailings have lower species diversity compared to sites without tailings. Species richness of odonata in currently and previously mined area is less compared to pristine sites (Villanueva, 2009a). Site 8 had the highest species diversity (H'=2.19), and site 2 had the lowest species diversity (H'=0.99). Site 8 showed the most diverse species composition meaning that this habitat is preferred by different species, while site 2 showed the least species diversity, due to environmental destruction and human disturbances. The diversity of Odonata is high in forested streams and rivers than in impounded wetlands, such as ponds, lakes, and reservoirs (Andrew *et al.,* 2008).

Table 2. Species Diversity and Evenness Of Odonata In Lianga and Barobo, Surigao Del Sur.

	SITE	SPECIES DIVERSITY (H)	EVENNESS (E)
WITH MINE TAILINGS	Site 1. Javier River	1.341895213	0.440757209
	Site 2. Dinuyan River	0.993402024	0.292074206
	Site 3. Bananghilig River	1.389585173	0.456421393
	Site 4. Anoling River	1. 737828273	0.488792727
WITHOUT MINE TAILINGS	Site 5. Javier Stream	1.972471156	0.512310529
	Site 6. Upper Binuoyan Stream	1.834842465	0.471461251
	Site 7. Bao-bao River	2.056947247	0.553899914
	Site 8. Manyayay Stream	2.186047381	0.548021089

Distribution was more or less even in sites 5, 7, and 8. A distinct uneven distribution was observed in site 2 due to the dominance of *Orthetrum s. sabina* and *R. bispina.*

The result of the Kruskal–Wallis test (Table 3) indicates that mine tailings drastically affect the number and species of Odonata present in an area. The result showed significant difference in the species diversity and evenness between sites with and without mine tailings. The average species diversity was lower in sites with mine tailings (H'=1.3657) compared to sites without mine tailings (H'=2.0126). On the other hand, the average evenness value for sites with mine tailings is significantly lower at 0.41951 compared to the sites without mine tailings (0.52142).

Evenness when value is closer to zero means a species dominates the area in number. And if evenness will value close to one, it means the abundance of the compared species are of the same counts (Gross and Harrell, 2000).

Table 3. Kruskal-Wallis between Species on Sites With And Without Mine Tailings In Surigao Del Sur.

TEST	KRUSKAL-WALLIS TEST		INTERPRETATION
	H(chi²)	P (same)	
Species Diversity	5.333	0.02092	Significant difference between sample
Evenness	4.083	0.04331	Significant difference between sample

Conclusion

Barobo, Surigao del Sur and its neighboring municipality Lianga, Surigao del Sur, are species-poor (18 species) with a very low endemism of 22.22%. Sites without mine tailings have higher species richness, endemism, abundance, species diversity, and have more or less even distribution compared to sites with mine tailings. Seven species, of which three are endemic, were found only in sites without mine tailings. Four widespread species appear to be indicators of disturbed habitats and they were found only in sites with mine tailings.

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