Odonatologica 39(2): 133-140 *June 1, 2010*

ADULT ODONATA COMMUNITY IN DINAGAT ISLAND, THE PHILIPPINES: IMPACT OF CHROMIUM ORE MINING ON DENSITY AND SPECIES COMPOSITION

R.J.T. VILLANUEVA
D3C Gahol Apartment, Lopez Jaena St., PH-8000 Davao, Philippines
rjtvillanueva@gmail.com

Received December 4, 2009 / Revised and Accepted December 14, 2009

Mining modifies the surrounding environment and causes habitat deterioration along river systems receiving mine tailings. Here it is assessed whether chromium ore mining affects the odon. abundance and diversity. Line transect surveys were conducted during 4 months at the Henry river (along a pristine section and a previously mined section), and at the Lecing river, which is currently receiving tailings from chromium ore mines. The density of adult odon. was 10 times higher in the pristine than in the mined river. Species richness was reduced in both the currently and in the previously mined sections (5 spp.) as compared to that of the pristine river (12 spp.), showing a detrimental effect of chromium mining on dragonfly diversity and abundance.

INTRODUCTION

Freshwater is currently the fastest dwindling resource for humans as a consequence of domestic, agricultural and industrial consumption, and lack of maintenance leading to its depletion and contamination (DUDGEON, 1992; TWUMASI & MEREM, 2007; FAIRLESS, 2008). Additionally, freshwater represents less than 1% of the global surface water and is thus an important resource of limited availability. The United Nations General Assembly recognized this issue and declared the years 2005-2015 the International Decade for Action ‘Water for Life’.

Freshwater systems host an extremely rich vertebrate and invertebrate biodiversity, and in some areas high level of endemism is noted where some species are confined to a single river system (PONDER, 1997; DUDGEON et al., 2006; BALIAN et al., 2008). However, inadequate biological information and lack of prioritization by policy makers hamper protection and conservation efforts related to freshwater ecosystems worldwide (ABELL, 2002; DUDGEON et al., 2006; TWUMASI & MEREM, 2007).

Mining is a recognized contributor to water pollution leading to biodiversity decline in river systems (PUSCH & HOFFMANN, 2000; TARRAS-WAHLBERG et al., 2001). The main consequence of mining is the discharge of unused material into freshwater systems; these so-called tailings vary depending on the mineral extracted, but act as chemical or physical pollutants and eventually alter freshwater ecology (PUSCH & HOFFMANN, 2000; TARRAS-WAHLBERG et al., 2001). While the chemical and physical consequences of mining are well documented, there is limited information on how biological communities are affected by mining (WOOD & ARMITAGE, 1997; WANTZEN, 2006).

Mining for minerals has become a fast growing industry in many tropical countries, including the Philippines. On Dinagat Island, nickel and chromium ore are the most sought-after minerals currently being extracted at industrial scales. The most commonly used method for removing chromium ore in Dinagat Island is a modification of strip mining by allowing water to erode the soil to remove silt and clay, leaving the heavy sandy ore behind. This leads to high level of sediment load in rivers with ongoing mining activity upstream. Though various media reports on mercury contamination, fish kills and mine/tailing accidents, no published paper is available concerning biodiversity impact in the Philippine settings.

Sediment load and water turbidity have been shown to affect aquatic organisms (WOOD & ARMITAGE, 1997; WANTZEN, 2006), thus there is a clear potential for mine tailings to affect biological communities, including Odonata, in waterways receiving mine tailings.

Odonata belong to a group of insects where adult and larvae live in two habitat types; terrestrial and aquatic (CORBET, 1999; KALKMAN et al., 2008). This life cycle renders the group vulnerable to changes affecting either its terrestrial or aquatic habitat (REMSBURG & TURNER, 2008). Due to sensitivity to habitat alteration, dragonflies are used as biological indicator in grazing effect, forest and in landscape structure, and habitat integrity studies (BUTLER & DEMAYNADIER, 2008; CLARK & SAMWAYS, 1996; FOOTE & HORNUNG, 2005; JONSEN & TAYLOR, 2000; OSBORN, 2005; RITH-NAJARIAN,1998). The conspicuous nature of some species makes them easy to spot even for non--odonatologist. This conspicuousness, close association with freshwater and their sensitivity to habitat alteration make them a useful tool for ecologist working on ecological assessments of freshwater habitats.

Presently no published account on Odonata in chromium ore mining areas is available. Here, the adults are used as an indicator of water quality in rivers exposed to varying levels of chromium mining activity on Dinagat Island by assessing the composition and density of their assemblage in a river system.

For a general review of the Dinagat Island odonate fauna, see VILLANUEVA (2009).

METHODS

The study was conducted on Dinagat Island, the Philippines. This is the third largest island in the Mindanao biogeographic subregion, situated NE of Mindanao. The island has a unique faunal and floral composition, with a high level of endemism (HEANEY et al., 1982; ROSS & LAZELL, 1991; HÄMÄLÄINEN & MÜLLER, 1997).

Besides having very rich biological resources, the island also has abundant mineral deposits that are currently being utilized by various mining firms. The major minerals extracted are nickel and chromium ore, using tunnel and strip mining methods.

The Odonata were studied at three sites in the north-central part of the island. The climate at the study sites is seasonal, with a dry season (April-October) and a rainy season (November-March) periods. The study area comprises two small rivers (the Lecing and the Henry) that are about 3 km apart and are separated by a gently sloping hill.

These two rivers were chosen for their similar ecological characteristics, but different level of mining activity. They fluctuate from 3-6 m in width, and have slow to moderate flow depending on the season. During the study period the rivers were 3-4 m wide with a depth ranging from 10 to 200 cm at various points. The surrounding areas are mostly forested, except for some open portions of about 100-200 m^2 due to cutting for firewood and logging activity.

The Lecing (10°17'33" N / 125°34'58" E; alt. 34 m a.s.l.) is currently being mined for chromium ore. Mining is daily and more intense during the wet season when there is an abundant supply of water. Mining sites are located in the forest approximately 100 m away from the river. The heavy ore is collected in artificial canals up to 3 m deep and 1-2 m wide, and sediment-laden water from those canals is flushed out into the river system. The mine tailings from over a hundred canals drain into the river, resulting in a high content of sediments in the water. The turbidity is very high, and in slow-moving sectors the sediment content is so high that water consistency is highly viscous. The study site was surrounded by 15 draining canals with several dozen more canals upstream from the study site (hereafter referred to as site 1, mining).

The Henry (10°15'53" N / 125°34'45" E; alt. 60 m a.s.l.), is located along the northern border of the Paragua Forest Reserve, a newly established protected area in the municipality of Libjo. The reserve used to be a mining concession that was relinquished two years prior to the present study. The Henry river running West to East, was dissected by the "largest highway" on Dinagat Island (same with the Lecing river) and divided into two sections, one with pristine (least altered of the three sites) waterway upstream of the road (site 2 started 50 m West from roadside and going further West, control), and one with previous chrome ore mining history downstream of the road (site 3 started 50 m East from roadside and going further East, recovering). Site 2 is over 100 m from the nearest transects.

At site 2, the water was clear with a sandy substrate and occasional gravel interspersed with rocks and boulders. Site 3, which had been exposed to mine tailings until two years prior to the present study, also had clear water, but the bottom substrate was covered by fine muddy sediments, especially in deeper parts of the river.

FIELD SAMPLING. – A total of 15 random 50 m-transect lines were established, with a total transect length of 750 m along 3 km of the Lecing river (site 1, mined). At site 2, I also established 15 transect lines with a total length of 750 m along a 3 km section of the river. At site 3, only 9 transect lines were set up with a total length of 450 m along a 1 km section of the river, since a large creek converge with the river beyond the last transect line. Transect length was set to 50 m in order to obtain at least one record, based on trial transect walk conducted prior the actual survey.

Transect surveys were conducted monthly: 5 at sites 1 and 2, and 3 at site 3, between May and August 2008. Each site was sampled on randomly selected days except for August 21, 2008 when all sites were sampled on the same day. These months were selected due to fair weather conditions during this period and relatively stable water current. I sampled the three sites between 09:00 h to 15:00 h on sunny days with very little cloud coverage. Transect surveys were conducted only when the river was exposed to sunlight.

Sampling was carried out along random transect lines parallel to the river (OPPEL, 2006a) with transects 5-30 m apart. I moved upstream or downstream in a straight line from a fixed point maintaining a speed of 3 m per minute. I followed the distance sampling protocol (BUCKLAND et al., 1993), surveyed both sides of the transect line and recorded each individual on the spot where I first noticed it. I then captured Corduliidae individuals with a hand-held net to identify the species and returned to the exact spot where I left and continued the transect walk. All other species were identified to species level without capture, save for *Neurothemis*, the females of which are difficult to identify at a distance.

The distance of each encountered individual from the transect line was recorded in four categories: 0.5 (0-1 m), 1.5 (1-2 m), 2.5 (2-3 m) and 3.5 (3-4 m). The species noted more than 4 m away from the transect line, were not included.

ANALYSIS. – The density and encounter rate were estimated using the program Distance v. 5.0 (THOMAS et al., 2006). Sample size was insufficient to estimate density parameters for each species separately, therefore all species were pooled in order to estimate overall density (OPPEL, 2006a).

RESULTS

In all, 17 species were recorded (Tab. I): 5 for sites 1 and 3, and 13 for site 2. The odonate assemblage at site 1 was composed entirely of oriental Anisoptera; sites 2 and 3 were inhabited predominantly by endemic Zygoptera. The most common species encountered were *Agrionoptera insignis* (Ramb.) at site 1, *Rhinocypha turconii* Sel. at site 2, and *R. colorata* (Hag.) at site 3. *Orthetrum s. sabina* (Dru.)

Table I

List of species recorded as adults during summer 2008 in the Lecing (site 1, mined) and the Henry rivers (sites 2 and 3, pristine and previously mined, respectively), Dinagat Island, the Philippines

Species	Site 1	Site 2	Site 3
Agrionoptera insignis (Rambur)	X		
Amphicnemis cantuga (Needham & Gyger)		X	
Coeliccia dinocerus Laidlaw		X	
Cyrano angustior Hämälainen		X	
Diplacodes trivialis (Rambur)	X		
Euphaea amphicyana Ris		X	
Heteronaias heterodoxa (Selys)		X	
Idionyx philippa Ris		X	
Neurothemis r. ramburii (Brauer)	X		
Orthetrum pruinosum clelia (Selys)	X		
Orthetrum sabina sabina (Drury)	X	X	X
Prodasineura integra (Selys)		X	X
Pseudagrion pilidorsum (Brauer)		X	
Rhinocypha colorata Hagen		X	X
Rhinocypha turconii Selys		X	X
Risiocnemis praeusta Hämälainen		X	
Vestalis melania Selys		X	X

Table II
Estimates (± standard error) of adult Odonata density, encounter rate, and effective strip width (ESW) using distance sampling at three sites with different mining intensity on Dinagat Island, the Philippines, in summer 2008

Site	Encounter rate [individual./km]	ESW [m]	Density [individual/hectares]
Site 1 (mined)	40	1.98 ± 0.48	101 ± 36
Site 2 (pristine)	280	1.93 ± 0.98	725 ± 69
Site 3 (previously mined)	100	3.23 ± 0.61	161 ± 40

was the only species recorded in all three study sites, but it was encountered more frequently in the Lecing (site 1) than in the Henry (sites 2 and 3) river.

Estimated odonate density (Tab. II) in the pristine site was approximately seven times higher than in the site polluted by mine tailings. The area that had experienced previous mining activity had an estimated density 1.6 times as high as the presently worked mine site, but less than a quarter of the pristine site.

DISCUSSION

The results of this study suggest that mine tailings have a detrimental effect on Odonata communities in rivers. The estimated Odonata density was about seven times higher in a pristine river. Cessation of mining did not result in a quick recovery of the community, and it remained at the site with previous mining history was depauperate both in species richness and in density compared to a pristine site in the same river after two years.

In general, pristine forest has higher species richness and diversity, and also has different species composition (OPPEL, 2006b). In the Philippines, a large majority of Odonata are forest specialists dependent on forested habitats. The Platystictidae, Platycnemididae and *Amphicnemis* (Coenagrionidae) comprise the bulk of forest species. The inconspicuous and rheophilous nature of many members of this group usually results in lower encounter especially in river areas. In this study, some members of the group were occasionally encountered in the pristine site, but not in the presently or previously mined sites.

The Calopterygidae and Chlorocyphidae prefer open spaces in forested waterways, and their metallic reflections are highly visible, consequently they represent the most recorded group. They were recorded mainly in the pristine and some also in the previously mined site. No species was noted though in the presently mined site. Among the *Rhinocypha* (Chlorocyphidae) species encountered, *R. colorata* dominated in the previously mined site, suggesting fast recovery of this species compared to its congener *R. turconii*. The available data are too limited to assess rates of Odonata recovery in mining areas (D'AMICO et al., 2004) especially chromium ore mine, but it seems that *R. colorata* is more tolerant to silty sediments than *R. turconii*, thus facilitating faster recolonization. These data suggest that both *Rhinocypha* species could be used as indicator species for the assessment of habitat quality in forested small rivers.

Land use influences stream biological diversity (ALLAN, 2004; SUBRAMANIAN et al., 2005), and DUDGEON (1999) emphasized that it is difficult to assess changes resulting from human activity due to natural variability in tropical Asia. The sites chosen for the present study have similar human disturbance levels, and differ only in the intensity of mining. The closeness of the study sites and similarity of habitat most likely eliminate natural variability as explanatory factor for differences in Odonata assemblages among sites. Though traffic pollution from the road may confound the results for the previously mined river at site 3, it is considered negligible since less than one motor bike passes every hour, and only one or two cars per day. It is therefore assumed that Odonata density and species composition are affected primarily by mining activity.

The majority of Philippine Odonata are forest specialists especially the endemic species that are confined to very restricted ranges. However, forest specialists were not encountered at site 1, despite the presence of similar forest characteristics at the other sites. The absence of forest specialists in forested river with mine tailings suggests that forest species are highly sensitive to water quality where the most notable difference exists. Although the water is presumably free of chemical pollutants, the physical pollution by high sediment load in the water possibly is not favourable for larval growth, consequently affecting adult density and composition. This is in agreement with a similar study that showed that erosion or siltation affected aquatic species (WANTZEN, 2006). Further study is suggested to validate this finding in other regions with chromium ore mining sites.

The odonate community at the site that had previously experienced mining activity was depauperate similar to site 1, despite clear flowing water and forest cover. The presence of only five species, including the generalist *Orthetrum s. sabina,* and low species density nearly two years after mining showed the slow recovery of forest species. The pristine and the formerly mined sites were located in the same river, and the nearest transects were separated by only 100 m. This distance should facilitate rapid recolonization of the formerly mined site from the pristine area by active dispersing of adults and downstream drift of larvae. However, despite this recolonization potential, only few species became established within two years, indicating that habitat quality at this site does not permit the continued existence of many species. While more research is required to understand what factors limit recolonization by Odonata, the habitat degradation demonstrates the negative effect of chromium ore mining on aquatic invertebrate diversity.

The odonate larvae are vulnerable to high sediment load in the water and the adverse effects of chromium ore mining on the adult odonate assemblage are here demonstrated, but further research is required to examine the mechanism by which odonata larvae are affected by sediment loads in tropical streams.

In conclusion, this study clearly shows the negative effect of chromium ore mining on adult Odonata density and composition, and I recommend careful consideration of these impacts before approving future mining operations.

ACKNOWLEDGEMENTS

I am indebted to my field assistant Mr HILARIO CAHILUG, and I am deeply thankful to Dr M. HÄMÄLÄINEN for commenting on the earlier manuscript draft, Dr S. OPPEL for the manuscript review and relevant literature, and to Dr T. BROOKS for helping with some additional publications.

REFERENCES

ABELL, R., 2002. Conservation biology for the biodiversity crisis: a freshwater follow-up. *Conserv. Biol.* 16: 1435-1437.

ALLAN, J.D., 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annu. Rev. Ecol. Evol. Syst.* 35: 257-284.

BALIAN, E.V., H. SEGERS, C. LEVEQUE & K. MARTENS, 2008. The freshwater animal diversity assessment: an overview of the results. *Hydrobiologia* 595: 627-637.

BUCKLAND, S.T., D.R., ANDERSON, K.P., BURNHAM, J.L. LAAKE, 1993. *Distance sampling: estimating abundance of biological populations.* Chapman & Hall, London.

BUTLER, R.G., P.G. DEMAYNADIER, 2008. The significance of littoral and shoreline habitat integrity to the conservation of lacustrine damselflies (Odonata). *J. Insect Conserv.* 12: 23-36.

CLARK, T.E. & M.J. SAMWAYS, 1996. Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park, South Africa. *J. appl. Ecol.* 33: 1001-1012.

CORBET, P.S., 1999. *Dragonflies: behaviour and ecology of Odonata.* Harley Books, Colchester.

D'AMICO, F., S. DARBLADE, S. AVIGNON, S. BLANC-MANEL & S.J. ORMEROD, 1992. Odonates as indicators of shallow lake restoration by liming: comparing adult and larval responses. *Restor. Ecol.* 12(3): 439-446.

DUDGEON, D., 1992. Endangered ecosystems: a review of the conservation status of tropical Asian rivers. *Hydrobiologia* 248: 167-191.

DUDGEON, D., 1999. *Tropical Asian streams: zoobenthos, ecology and conservation.* Hongkong Univ. Press, Hongkong.

DUDGEON, D., A.H. ARTHINGTON, M.O. GESSNER, Z. KAWABATA, D.J. KNOWLER, C. LÉVÊQUE, R.J. NAIMAN, A. PRIEUR-RICHARD, D. SOTO, M.L.J. STIASSNY & C.A. SULLIVAN, 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol. Rev.* 81: 63-182.

FAIRLESS, D., 2008. Muddy waters. *Nature, Lond.* 452: 278-281.

FOOTE, A.L. & C.L.R. HORNUNG, 2005. Odonates as biological indicators of grazing effects on Canadian prairie wetlands. *Ecol. Ent.* 30: 273-283.

HÄMÄLÄINEN, M. & R.A. MÜLLER, 1997. Synopsis of the Philippine Odonata, with lists of species recorded from forty islands. *Odonatologica.* 26: 249-315.

HEANEY, L.R. & D.S. RABOR, 1982. Mammals of Dinagat and Siargao Islands, Philippines. *Occ. Pap. Mus. Zool. Univ. Michigan.* 699: 1-30.

JONSEN, I.D. & P.D. TAYLOR, 2000. Fine-scale movement behaviors of calopterygid damselflies are influenced by landscape structure: an experimental manipulation. *Oikos.* 88: 553-562.

KALKMAN, V.J., V. CLAUSNITZER, K.D.B. DIJKSTRA, A.G. ORR, D.R. PAULSON & J.

VAN TOL, 2008. Global diversity of dragonflies (Odonata) in freshwater. *Hydrobiologia* 595: 351-363.
OPPEL, S., 2006a. Using distance sampling to quantify Odonata density in tropical rainforests. *Int. J. Odonatol.* 9: 81-88.
OPPEL, S., 2006b. Comparison of two Odonata communities from a natural and a modified rainforest in Papua New Guinea. *Int. J. Odonatol.* 9: 89-102.
OSBORN, R., 2005. Odonata as indicators of habitat quality at lakes in Louisiana, United States. *Odonatologica* 34: 259-270.
PONDER, W.F., 1997. Conservation status, threats and habitat requirements of Australian terrestrial and freshwater mollusca. *Mem. Mus. Victoria.* 56: 421-430.
PUSCH, M. & A. HOFFMANN, 2000. Conservation concept for a river ecosystem (River Spree, Germany) impacted by flow abstraction in a large post-mining area. *Landsc. urban Plann.* 51: 165-176.
REMSBURG, A.J. & M.G. TURNER, 2008. Aquatic and terrestrial drivers of dragonfly (Odonata) assemblages within and among north-temperate lakes. *Jl N Am. benthol. Soc.* 28(1): 44-56. doi: 10.1899/08-004.1
RITH-NAJARIAN, J.C., 1998. The influence of forest vegetation variables on the distribution and diversity of dragonflies in a northern Minnesota forest landscape: a preliminary study (Anisoptera). *Odonatologica* 27: 335-351.
ROSS, C.A. & J. LAZELL, 1991. Amphibians and reptiles of Dinagat and Siargao islands, Philippines. *Philipp. J. Sci.* 119: 257-286.
SUBRAMANIAN, K.A., K.G. SIVARAMAKRISHNAN & M. GADGIL, 2005. Impact of riparian land use on stream insects of Kudremukh National Park, Karnataka state, India. *J. Insect Sci.* 5: 1-10.
TARRAS-WAHLBERG, N.H., A. FLACHIER, S.N. LANE & O. SANGFORSA, 2001. Environmental impacts and metal exposure of aquatic ecosystems in rivers contaminated by small scale gold mining: the Puyango River basin, southern Ecuador. *Sci. total Envir.* 278: 239-261.
THOMAS, L., J.L., LAAKE, S. STRINDBERG, F.F.C. MARQUEZ, S.T. BUCKLAND, D.L. BORCHERS, D.R. ANDERSON, K.P. BURNHAM, S.L. HEDLEY, J.H. POLLARD, J.R.B. BISHOP & T.A. MARQUES, 2006. *Distance 5.0. Release "2"1.* Research Unit for Wildlife Population Assessment, Univ. St Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/
TWUMASI, Y.A. & E.C. MEREM, 2007. Using remote sensing and GIS in the analysis of ecosystem decline along the river Niger basin: the case of Mali and Niger. *Int. J. envir. Res. public Health* 4: 173-184.
VILLANUEVA, R.J.T., 2009. Odonata of Dinagat Island, The Philippines: updated species list and notes on conservation of species and habitats. *Notul. odonatol.* 7(3): 27-35.
WANTZEN, K.M., 2006. Physical pollution: effects of gully erosion on benthic invertebrates in a tropical clear-water stream. *Aquat. Conserv.: Marine Freshw. Ecosyst.* 16: 733-749.
WOOD, J. & P. ARMITAGE, 1997. Biological effects of fine sediment in the lotic environment. *Envir. Mngmt* 21: 203-217.