

Research Article

Application of ECO-RIPRAP riverbank protection model to improve bank stability and to support biotic community in Surabaya River

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Abstract: Ecohydraulic river bank protection design was developed as ECO-RIPRAP model and has been applied along 100 meter length to restore accelerated erosion sites in Surabaya River at Wringinanom and Klubuk. The model combined re-profiled and re-vegetated bank with rock toe reinforcement and addition of log groynes at 10 meter length interval. Various native plant species were planted on bank slopes, including water plants *Ipomoea aquatica* and *Pistia stratiotes*, grasses and shrubs *Ipomoea carnea*, *Pluchea indica*, *Saccharum spontaneum*, *Arundo donax*, and native tree species *Ficus glomerata*, *Bambusa arundinacea*, *Dendrocalamus asper*, *Bambusa vulgaris*, *Ficus benjamina*, *Dillenia indica*, *Psidium guajava*, *Arthocarpus camansi*, *Arthocarpus elasticus*, *Hibiscus mutabilis*, *Nauclea sp.*, *Inocarpus edulis*, and *Syzygium polyanthum*. The river bank morphology after ECO-RIPRAP application showed alteration from erosion to sedimentation due to rock toe enforcement, log groynes protection, and increase of plant cover on littoral banks that decreased near bank velocity. The macro-invertebrate community shown increase of taxa richness, EPT richness, %EPT and %Atyidae, but decrease of %Chironomidae at restored sites. The fish community shown increase of taxa richness, increase of abundance by 54.2%, increase of *Pangasius micronemus* abundance by 25.6%, and increase of *Hemibragus nemurus* abundance by 6.3 % at restored reach. Rare fish species thrive back at restored area, namely *Oxyeleotris marmorata*, *Mastacembelus unicolor* and *Hampala macrolepidota*.

Keywords: macroinvertebrates, native fish, river bank protection, riparian habitat restoration

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Introduction

River and its riparian is a type of inland water ecosystem that is being threatened by massive exploitation and increase of human encroachment, that impacted on natural habitat degradation (Welcomme, 1985; Tocker et al., 2012). Surabaya River Fish Sanctuary is a river conservation area that was launched by Governor of East Java Province in 2013. Riverbank erosion occurs in some segments that impacted on water quality deterioration and littoral habitat degradation that threatens fish population in Surabaya River.

Cemented bank revetment is usually applied along eroded bank to improve bank stability, the river is channelized and straightened with uniform channel dimension, that reduce habitat diversity in river channel and adjacent riparian area.

Bank protection measures in current hydraulic approach aims to increase effectiveness of water flow and sediment flow by construction of massive cemented wall that highly impermeable and high cost. It tends to disregard ecological impacts on lost of connection between river channel and its riparian land that leads to riparian habitat degradation and biodiversity

extinction. Riparian land use conversion, bank erosion, channel modification and deterioration of water quality lead to degradation of natural habitat for river's organisms. Natural habitat needs to be protected through improving river and riparian management in integrated and effective way (Stromberg *et al.* 2004).

The Government Regulation No. 38/2011 stated that healthy river is reflected by thriving of various native flora and fauna. Government Regulation No. 26/2008 on National Spatial Planning Article 52 asserts riverbank or floodplain area as national conservation areas that are managed by regional government authority. Government has mandate to prevent river degradation occurs continuously in certain river segments and to restore degraded river back to healthy natural condition, through physical engineering and vegetation engineering.

Ecohydraulics is rapidly developed as sub discipline of river science with direct applications in water management and ecological restoration of degraded landscapes in river basin. Ecohydraulics connects ecological functions and hydrodynamic patterns at each spatio-temporal scale (Maddock *et al.*, 2013). The terms 'ecohydraulics' and 'ecohydrology' imply research at interface between hydrological and ecological (biological) science, that are underlined as a cross-disciplinary research approach that represent a holistic and interdisciplinary, rather than multidisciplinary science.

Ecohydraulic design has been tested in different applications and found to provide multi-benefit as alternatives design for channel reconfiguration, gravel injection, floodplain and side channel inundation, increasing habitat complexity, and spawning habitat rehabilitation (Pasternack and Brown, 2011). The riverbank erosion in Fish Sanctuary Area requires ecohydraulic approach to improve bank stability against fluvial erosion, as well as maintaining littoral habitat quality. Ecohydraulic bank protection design was developed as ECO-RIPRAP model to improve bank stability in Surabaya River Fishery Sanctuary Area. ECO-RIPRAP model combined reprofiled and revegetated bank with rock toe reinforcement, and addition of log groynes (Brisbane City Council, 2000; McCullah and Gray, 2005).

This research aimed to evaluate effects of ECO-RIPRAP model application to improve bank stability and assess the impacts of ECO-RIPRAP bank protection model on bank morphology, littoral macroinvertebrate and fish community in Surabaya River Fishery Sanctuary Area.

Materials and Methods

The research was carried out at lower Brantas Watershed in Surabaya River segment where maximum current velocity was 1 ms^{-1} , maximum water level increase was 2.5 meter, and maximum bank height is 3 meter. The research sites was grouped into 4 categories, namely Reference Site (Perning); Unrestored (Sumberame, Penambangan, Lebaniwaras); Pre-Restored (Wringinanom and Klubuk); and Post-Restored (Wringinanom and Klubuk). The sampling locations, sampling time and codes are shown in Table 1 and the map of study area is shown in Figure 1, while the design of ECO-RIPRAP bank protection model is shown in Figure 2. The boat survey along 7 km of Surabaya River Fishery Sanctuary Area was carried out during low flow in July 2014 to identify bank erosion sites. The ECO-RIPRAP bank protection model was constructed on September to November 2014 along 100 meter length of eroded bank sites at Wringinanom and Klubuk.

The ECO-RIPRAP model combined re-profiled and re-vegetated bank with rock toe reinforcement and addition of log groynes at 10 meter interval. Various native plants were planted to establish multi-strata littoral vegetation structure on bank slopes, including water plants *Ipomoea aquatica* and *Pistia stratiotes*, grasses and shrubs *Ipomoea carnea*, *Pluchea indica*, *Saccharum spontaneum*, *Arundo donax*, and native tree species, such as *Ficus glomerata*, *Bambusa arundinacea*, *Dendrocalamus asper*, *Bambusa vulgaris*, *Ficus benjamina*, *Dillenia indica*, *Psidium guajava*, *Arthocarpus camansi*, *Arthocarpus elasticus*, *Hibiscus mutabilis*, *Nauclea sp.*, *Inocarpus edulis*, and *Syzygium polyanthum*. The field sampling was conducted in dry season and rainy season during 2014 to 2016. The hydraulic variables measured were bank slope, % plant cover, river width, depth, near bank velocity and water quality parameters. The secondary data of monthly average river discharge and water level was collected from Perum Jasa Tirta I Malang. Field survey was done to get description on bank morphology profile at eroding sites using two measurement stakes or stadia rods installed in front of bank profile. The distance of measurement stake to banks edge was measured every 20 cm height from bank base up to the bank top (Lawler, 1993). The macro invertebrate samples were collected using 500 μm mesh size D-net, sampling and live sorting procedures followed Rini (2014). The macro invertebrate metrics used were taxa richness, Shannon diversity index, Margalef richness index, %EPT, %Chironomids and %Atyidae.

Table 1. Sampling group and locations, sampling time and sampling codes

Group	Location	Sampling Time	Code	Group	Location	Sampling Time	Code
Reference	Perning 1	2015	A-Ref1	PreRestored	Wringinanom 1	2014	A-Res1a
	Perning 2		A-Ref2		Wringinanom 2		A-Res1b
	Perning 3		A-Ref3		Wringinanom 3		A-Res1c
	Perning 1	2016	B-Ref1		Wringinanom upstream	B-Res1x	
	Perning 2		B-Ref2		Wringinanom Downstream	B-Res1y	
	Perning 3		B-Ref3		Klubuk 1	A-Res2a	
Unrestored	Sumberame 1	2014	A-Unres1a	PostRestored	Klubuk 2	2015	A-Res2b
	Sumberame 2		A-Unres1b		Klubuk 3		A-Res2c
	Penambangan 1		A-Unres2a		Klubuk Hulu		B-Res2x
	Penambangan 2	A-Unres2b	Wringinanom 1		2015	B-Res1a	
	Penambangan 3	A-Unres2c	Wringinanom 2		B-Res1b		
	Penambangan 1	2016	B-Unres2a		Wringinanom 3	B-Res1c	
	Penambangan 2		B-Unres2b		Wringinanom 1	2016	B-Res1d
	Penambangan 3		B-Unres2c		Wringinanom 2	B-Res1e	
	Lebaniwaras 1	2015	A-Unres3a		Wringinanom 3	B-Res1f	
	Lebaniwaras 2		A-Unres3b		Klubuk 1	2016	B-Res2a
Lebaniwaras 3	A-Unres3c		Klubuk 2	B-Res2b			



Figure 1. Map of study area with Reference Site (Perning), Unrestored Sites (Sumberame, Penambangan, and Lebianiwaras), Restored Sites (Wringinanom and Klubuk)

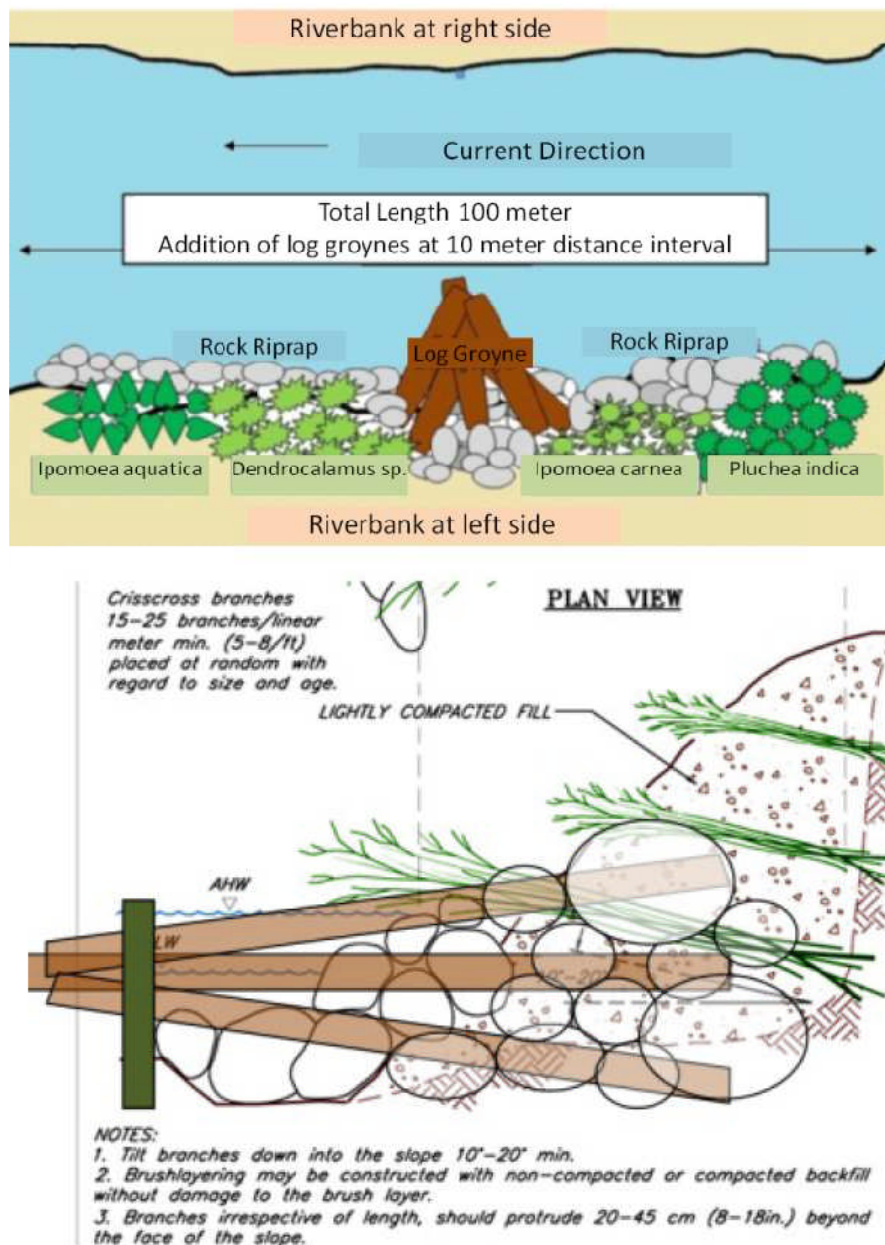


Figure 2. The design of ECO-RIPRAP bank protection model

Fish samples were collected to get data of total fish abundance and species composition by spreading fish nets 40 times in each station that were done by local river fishermen (Arisandi, 2012). Mann Whitney Pairwise Test was carried out to compare difference among locations, while Kendall's Tau correlation coefficient was used to analyze correlation among parameters. Multivariate statistical analysis *Principle Component Analysis* (PCA) was run to identify principal components in each location group with specific habitat condition and impacts on macro-

invertebrate community. Statistical analysis was done using software Paleontological Statistic PAST version 3.12 (Hammer, 2016).

Results and Discussion

Bank morphology at restored sites

The riverbank area in Surabaya River Fishery Sanctuary Area from Mlirip Mojokerto to Legundi Gresik were mostly used for agriculture, but in some parts it has been converted into permanent houses, shops, small factories and

impermeable roads. Some native riparian vegetation species can be seen on the banks, such as variety of bamboo and grasses, shrubs, liana, herbs, and tree species. The riverbank area along Surabaya River is bordered by earth dykes with riverbank boundary markers can be found along the dyke toe at certain kilometer distance from Mlirip Water Sluice. There were 18 accelerated eroded sites identified along 7 km section from Mlirip to Lebaniwaras. The length of eroded bank was range from 50 m to 200 m, and the river bank height was range from 1.5 m to 3 m. The bank slope at restored sites before ECO-RIPRAP model application was range from 41,3 - 60 degrees indicated that most part of eroded banks were steep and unstable. The bank morphology profile in Wringinanom and Klubuk is shown in Figure 3 and the condition of bank erosion is shown in Figure 4. River bank erosion occurs in Fish Sanctuary Area due to bank instability, increased

of discharge and near bank velocity during rainy season. Stream bank erosion is natural process that eroded banks also occurs in most stable river systems, although the erosion rate in stable river is much slower and at smaller scale than those occurs in unstable river systems. Flooding can trigger bank erosion, as well as land use and river modification. Removal of stream bank vegetation and stream channelization can promote accelerated rates of bank erosion. The main process of stream bank erosion generally is bank scour and mass failure. Bank scour is direct removal of bank materials by physical action of flowing water that mostly dominant in smaller streams. Mass failure includes bank collapse and slumping due to unstable bank materials topple into the stream, that mostly dominant in the lower reaches of large stream that often associate with scouring of lower banks (Brisbane City Council, 2004).

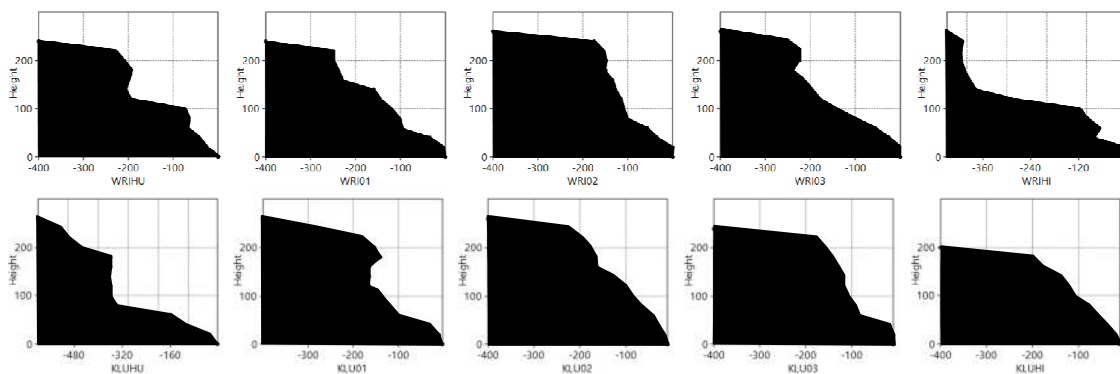


Figure 3. River bank morphology profile at eroded site in Wringinanom (top) and Klubuk (bottom)

Severe bank erosion at low land rivers induces stream bank retreats, changes bed topographies, and increase water turbidity. Bank failure in nature occurs frequently influenced by interaction of hydrodynamic conditions near bed velocity and non-cohesive banks in meandering and straight rivers. No bank failure occurs at bank angle smaller than critical value, a function of a dimensionless parameter which is proportional to the square of flow velocity near river bed and inversely proportional to the median diameter of bank materials. The critical angle reduces with flow velocity and is higher in meandering river than in straight river at the middle and lower reaches of Yangtze river (Yu et al., 2015). Conventional groynes and revetment were used to mitigate erosion in Bangladesh but it did not provide expected results that groyne modifications needed to improve its performance to stabilize bed topography at low flow and provide protection

during high flood (Pizzuto and Meckelnburg, 1989). Riparian vegetation has strong influence on occurrence and progress of streambed riverbank erosion. Re-establishing or maintaining native riparian vegetation will prevent erosion and preserve complex variety of in-stream and riparian habitat, thus it become recent riparian management practice in Australia. Presence of native riparian forest significantly reduce the likelihood of erosion by mass failure due to tree root hold the soils reinforcement and reduce likelihood of mass failure that maintain stability of channel cross-section. Some native tree species evolved roots that seek the deeper permanent summer water table in order to survive prolonged dry season. This root systems are particularly effective to reduce mass failure due to rooting depths are more than 5 m to 20 m (Simon and Pollen, 2006).



Figure 4. Riverbank condition before and after application of ECO-RIPRAP bank protection model in Wringinanom (top) and Klubuk (bottom)

River Hydrology

The graph in Figure 5 shows that discharge of Surabaya River during 2009 to 2016 indicated rainy season period occurred on December to May with average monthly discharge above 50 m³/s, range from 57.5 to 74.6 m³/s. Dry season occurred on June to November with average monthly discharge was less than 50 m³/s, discharge range from 31.52 to 48.33 m³/s. The highest average discharge was 94.21 m³/s that occur on January 2013 and lowest average was 20.58 m³/s that occur on October 2014. In year 2013, 2015 and 2016, the highest average discharge in rainy season was recorded above 90 m³/s. In 2013 and 2016, the average low discharge was above 40 m³/s that indicated less significant dry season.

River regime coefficient (Q_{id}) of Surabaya River was calculated by comparing maximum discharge to minimum discharge (Q_{max}/Q_{min}) during 2009 to 2015, that given ratio score 2.1 – 4.5. This Q_{id} value indicated that Surabaya River sub basin fall into good quality category. The riparian condition mostly was covered by natural vegetation that served as flood retention zone to localize floods in the floodplain area and reduce floods to downstream area. Riparian area with natural vegetation in Fishery Sanctuary Area of Surabaya River from Mlirip to Legundi need to be protected by government regulation to control human activity and to prevent conversion of riparian area into impermeable structures.

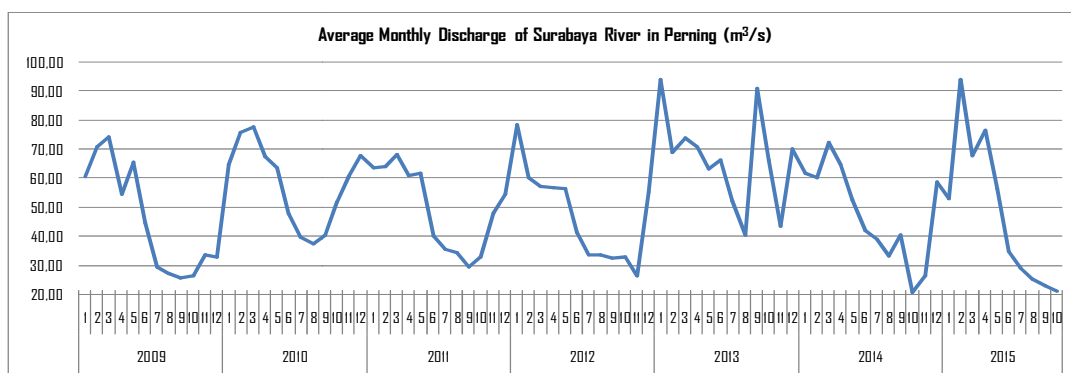


Figure 5. Hydrograph of Surabaya River in Perning

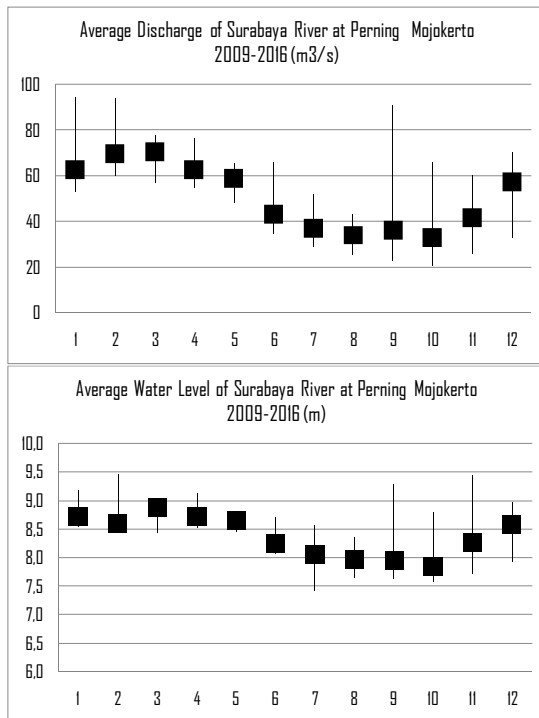


Figure 6. Average discharge and water level of Surabaya River 2009-2016

Figure 6 indicates that average monthly water discharge fluctuation in 2009 - 2016 has the same pattern with water level fluctuation. The wet season occurred in December to May, while dry season occurred in June to November. The water elevation in Kali Surabaya was range from 7.4 to 9.5 meter that maximum water level fluctuation was 2.1 meter. During wet season, water level increase causes periodic floods in riverbank area as natural entity that maintain balance of hydrological cycle in river ecosystem. The floods also create littoral habitat extension for fish and river organisms as refuge area from fast current. Flood management in some developed countries has been shifted from flood control to flood adaptation approach. The flood control relies on structural measures is not a sustainable solution for flood management. Indonesia has 5.590 main rivers, about 600 rivers have been severely flooded that leads to social problems and economic losts. The integrated flood management should adopt ecosystem-based disaster risk reduction. Ecosystems, such as wetlands, forests, riparian and coastal systems can reduce physical exposure of natural hazards. Restoring catchment vegetation along the riverbank reduces surface runoff that will reduce flood damages, particularly in smaller events. Natural green belt serves as natural protective barriers or buffers and thus mitigating hazard impacts of floods (PEDRR, 2010).

Littoral Habitat

The data summary on littoral habitat parameters is shown in Table 2. Data analysis showed that application of ECO-RIPRAP bank protection model had positive impacts on bank stability and improve water quality of littoral water. Addition of *riprap* or boulder placement at the bank toe and groyne triangle structure of large woody debris protects bank toe from shear scours that prevent undercut bank and reduce the risk of bank failure, as well as creating new microhabitat conditions for river organisms. The bank slope degree at eroded sites decreased significantly and became less steep after application of ECO-RIPRAP bank protection structures.

Application of ECO-RIPRAP model successfully improve bank stability that eroded bank at restored sites were gradually shifted to sedimented bank. The ECO-RIPRAP bank protection model reduced bank slope degree to less than 30 degrees, while rock toe reinforcement at bank base reduced the near bank current velocity that reduce bank erosion at restored sites. The near bank current velocity at post-restored site was significantly slower than both pre-restored and unrestored sites, as shown by Mann Whitney pairwise test results. The rock toe enforcement and reprofiled bank slope effectively stabilize eroded bank. The percentage of littoral plant cover increased significantly at post-restored sites compared to pre-restored and unrestored sites. Tree species that grow well in the treatment sites that can cope with drought and floods in the floodplain area are *Ipomoea aquatica* and *Pistia stratiotes*, *Ipomoea carnea*, *Pluchea indica*, *Saccharum spontaneum*, *Arundo donax*, *Ficus glomerata*, *Bambusa arundinacea*, *Dendrocalamus asper*, *Bambusa vulgaris*, *Ficus benjamina*, *Dillenia indica*, *Psidium guajava*, *Arthocarpus camansi*, *Arthocarpus elasticus*, *Hibiscus mutabilis*, *Nauclea sp.*, *Inocarpus edulis*, and *Syzygium polyanthum*. The water temperature at post-restored sites significantly lower than those at unrestored and pre-restored sites. The lower temperature at restored sites was caused by increase of vegetation cover in littoral water and increase of shade from multi-strata vegetation on bank slope. The dissolved oxygen at post-restored sites significantly higher that those at pre-restored sites. This was caused by turbulence created by rock toe reinforcement at the bank base, log spur dykes and littoral vegetation along the restored banks. The materials also provide new habitat for algae and moses to grow that increase oxygen release into water through photosynthesis by water plants grown in littoral zone.

Table 2. Mean and standar deviation for data analysis

Location	Habitat Condition			Water Quality			Macroinvertebrate			
	Bank Slope (Degree)	Plant Cover (%)	Near Bank Velocity (ms ⁻¹)	Temperature (°C)	Dissolved Oxygen (mg l ⁻¹)	Turbidity (NTU)	Taxa_S	Shannon_H	Margalef	%EPT
Perning1	46.37±2.84	38.33±7.64	0.33±0.06	27.73±0.25	5.83±0.29	8.40±0.70	14.00±1.00	1.53±0.25	2.20±0.10	5.67±2.79
Perning2	44.30±3.97	41.67±6.51	0.33±0.12	27.43±0.06	6.20±0.10	8.97±2.01	14.67±2.52	1.40±0.10	2.47±0.45	13.00±5.81
Sumber1	41.85±0.64	22.50±3.54	0.25±0.07	29.90±0.28	5.00±0.31	17.35±1.48	9.00±1.41	1.20±0.28	1.25±0.21	0.10±0.14
Wringin1	50.82±2.44	15.33±5.16	0.25±0.025	30.52±0.88	4.75±0.26	17.87±0.77	13.33±1.51	1.25±0.12	2.07±0.20	1.03±1.11
Wringin2	33.82±3.84	37.67±5.24	0.05±0.05	27.55±0.72	5.37±0.15	17.00±1.67	15.50±1.76	1.52±0.19	2.50±0.26	3.53±1.17
Penam1	43.90±3.58	31.33±4.04	0.20±0.06	31.13±0.25	4.53±0.06	15.77±4.92	11.67±1.15	1.50±0.10	1.83±0.25	0.20±0.35
Penam2	40.77±7.07	30.67±7.51	0.17±0.12	27.20±0.36	5.73±0.06	14.87±0.67	13.00±1.00	1.53±0.15	2.10±0.30	0.30±0.52
Klubuk1	50.80±6.32	18.00±3.61	0.27±0.06	29.37±1.94	5.23±0.46	18.47±1.70	10.67±1.15	1.33±0.15	1.73±0.23	1.63±0.99
Klubuk2	36.50±2.12	26.50±2.12	0.15±0.07	27.85±0.49	5.28±0.11	17.65±1.91	13.50±0.71	1.45±0.07	2.25±0.21	3.95±1.20
Lebani1	39.57±3.19	22.33±6.81	0.17±0.06	32.47±0.55	4.37±0.06	13.20±3.82	13.00±2.00	1.40±0.10	2.03±0.32	0.67±1.15

The water turbidity at post-restored sites was not different significantly with those at unrestored and pre-restored sites. The water turbidity was caused by high sediment loads from upstream due to forest degradation and land use change in the upper drainage area that could not be reduced by ECO-RIPRAP structures that only occupied limited area of riverbanks at restored sites.

Biotic Community

There were 30 families of macro invertebrate in Surabaya River, mostly dominated by moderately sensitive taxa Atyidae and pollution tolerant taxa Corixidae, Chironomidae and Tubificidae. Some of macro invertebrate taxa that sensitive to water pollution and indicate good river quality are shown in Figure 7. The application of ecohydraulic bank stabilization model in Surabaya

River increased of taxa richness, EPT taxa richness, %EPT and %Atyidae, and decreased of %Chironomidae in macro invertebrate community (Figure 8). The fish community at restored sites in Wringinanom and Klubuk reach showed increased of taxa richness, increased of fish abundance by 54,2%, increased of abundance of *Pangasius micronemus* by 25,6%, and increased of abundance of *Hemibragus nemurus* by 6,3 % in Wringinanom - Klubuk reach (Figure 9). The rare fish species also found at treatment area in Wringinanom - Klubuk reach, namely *Oxyeleotris marmorata*, *Mastacembelus unicolor*, *Hampala macrolepidota* and *Notopterus notopterus*. Fish larvae and juveniles were spotted under log groynes, boulder and water plant's roots in the edge water column.



Figure 7. Macro invertebrate specimen that were found in Surabaya River

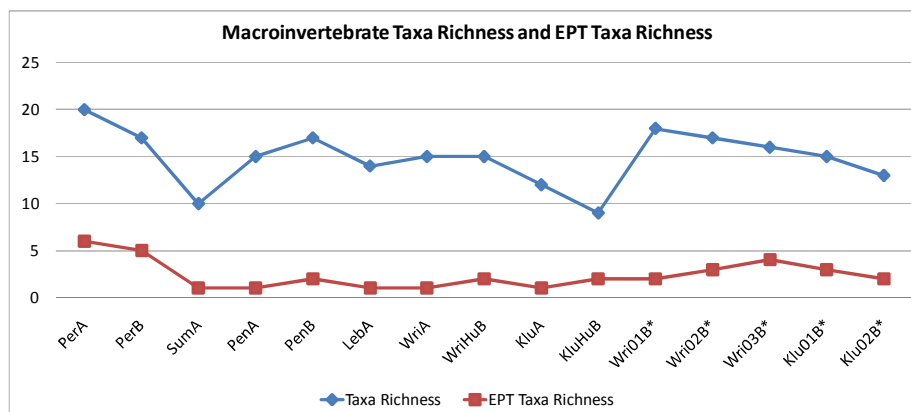


Figure 8. Taxa richness and EPT taxa richness in macroinvertebrate community

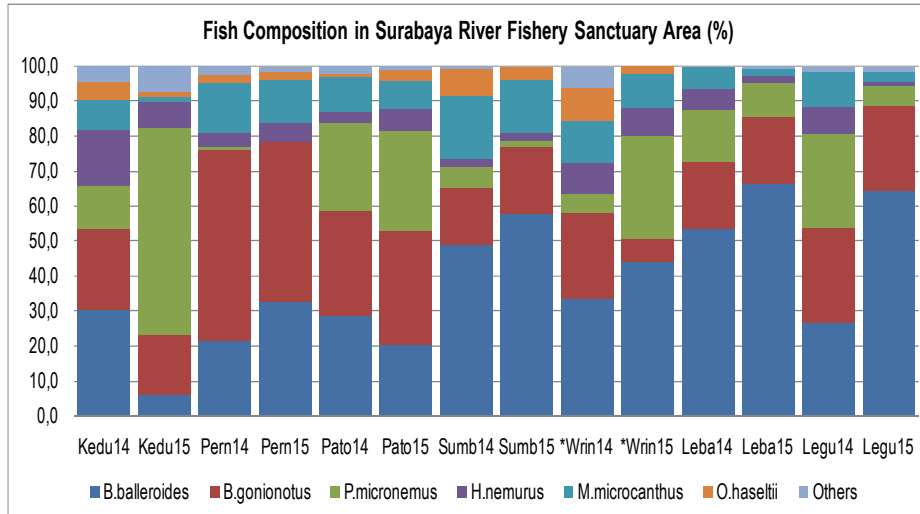


Figure 9. Composition of Fish Species in Surabaya River

Multivariate Principal Component Analysis

The Principal Component Analysis (PCA) was applied to identify the dominant hydraulic and habitat components that correlated with macro

invertebrate attributes. The results shown there were three groups of site distribution that complement with research site groupings as shown in Figure 10.

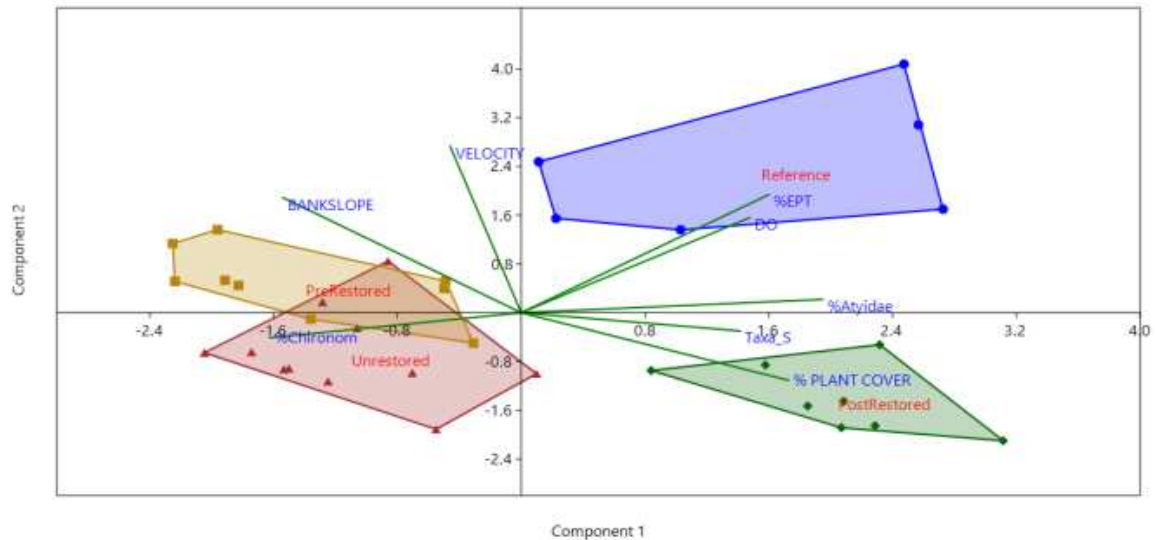


Figure 10. PCA Analysis result

The reference group laid at upper right quadrant, the post-restored group laid at lower right quadrant, and the unrestored laid through pre-restored at middle left quadrant. The important parameters at reference sites were near-bank velocity, Dissolved Oxygen (DO) and %EPT. Those parameters at reference sites are significantly higher compared to other groups. Dissolved oxygen was strongly correlated with %

EPT. The important parameters at post-restored sites were % littoral plant cover, Margalef's richness index and % Atyidae. Those parameters in post-restored sites were significantly higher than other group sites. These results suggested that ecohydraulic bank stabilization at post-restored sites changed the bank morphology and macro invertebrate community. The ECO-RIPRAP bank protection model effectively

improved bank stability and provide new micro-habitat for macro invertebrate in littoral zone of riparian habitat in Surabaya River Fishery Sanctuary Area. Important changes that indicated littoral habitat improvement after application of ECO-RIPRAP structures were increased of % littoral plant cover, decreased of bank slope degree, increased of Margalef's richness index, increased of %Atyidae moderately pollution sensitive taxa and decreased of %Chironomidae pollution tolerant taxa.

Conclusion

Application of ECO-RIPRAP model succeed to restored eroded banks to gradually shifted to sedimented bank. The ECO-RIPRAP bank protection model effectively improved bank stability and provide new micro-habitat for macro invertebrate in littoral zone of riparian habitat in Surabaya River Fishery Sanctuary Area. ECO-RIPRAP structures increased % littoral plant cover, decreased bank slope degree, decrease near bank current velocity, increased Margalef's richness index, increased %Atyidae and decreased %Chironomidae. The fish community in Wringinanom - Klubuk reach showed increase of taxa richness, fish abundance was increased by 54,2%, abundance of *Pangasius micronemus* was increased by 25,6%, abundance of *Hemibragus nemurus* was increased by 6,3 %. The rare fish species thrive back at restored area, namely *Oxyeleotris marmorata*, *Mastacembelus unicolor*, *Hampala macrolepidota* and *Notopterus notopterus*.

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