RELATIONSHIPS BETWEEN ALGAL BIOMASS AND DIVERSITY WITH STREAM SIZE AND ADJACENT LAND USE

RACHEL A. HABEGGER AND JORDAN M. MARSHALL*
DEPARTMENT OF BIOLOGY, INDIANA UNIVERSITY-PURDUE UNIVERSITY FORT WAYNE, FORT WAYNE, INDIANA

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CORRESPONDING AUTHOR

* Jordan M. Marshall
marshalj@ipfw.edu

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- runoff

ABSTRACT

Land use adjacent to waterways, such as development or agriculture, alters hydrological patterns leading to increases in runoff and nutrient input. Forests and wetlands, as natural land cover types, reduce water movement and allow infiltration into soil. We measured algal biomass and diversity in order to quantify the influence neighboring land cover types have on streams in Northeastern Indiana. In the study area, cultivated crops were the dominant land cover type, with open development and deciduous forest following. Emergent wetland area had the greatest influence on algal biomass, with increases in wetland area decreasing biomass. However, open development, low intensity development, grassland, shrub, and forested wetlands added to increases in biomass. Conversely, forested wetlands reduced algal richness, while open development and pastures increased richness. Because open development (i.e. dominated by turf grass, lawns, parks, golf courses) was the second most common land cover type and positively influenced both algal biomass and richness, management of those properties will likely have direct impact on nutrient flow into streams. Additionally, adding functional wetlands dominated by emergent herbaceous plants will directly impact future algal biomass.

INTRODUCTION

Land use and cover types can directly influence water infiltration and runoff patterns within a watershed (22). Decreases in natural vegetation often results in increases in surface runoff (15). Additionally, the complexity of layers within the vegetation cover can influence infiltration of water into soil (26). Developed land cover types have decreased in tree cover in the U.S., while increasing in impervious surfaces (18). Both changes in tree and impervious land cover have direct impacts on runoff volume and soluble nutrient content (2). Assessing the anthropogenic changes to land cover types may be important in identifying potential water quality issues (20).

In addition to decreases in infiltration and increases in runoff, there is a resultant increase in sedimentation and nutrient content associated with anthropogenic land cover changes (i.e. simplified vegetative structure, impermeable surfaces) (7,15,17,23). Degradation of freshwater has been clearly linked to increased nitrogen and phosphorous fertilization (24). Increases in human population densities have resulted in increases in nitrate and suspended solids within streams (1). While agricultural fertilization may add to eutrophication, urban development imparts major influence on biologically available phosphorus (4). Increased nutrient content within streams leads to human and environmental health issues including increases in disease vector populations and toxic algal blooms (11,13,16).

In the Midwest region of the United States, agricultural land dominates the land cover types, with cultivated crops and pasture lands making up 80-90% of land cover (6). In Indiana major changes in land cover between 2001 and 2006 were focused around the state's larger urban areas (i.e. Indianapolis, Fort Wayne, Evansville) (8). While there is minimal change in land cover types in Indiana, those persistent land cover types adjacent to streams may have sustained and continual influence on water quality. The objectives of this study were to 1) quantify algal diversity and biomass within streams in Northeastern Indiana, 2) compare the influence of stream channel size and land use on algal communities, and 3) test the hypothesis that neighboring land use types influence algal diversity and biomass.

MATERIALS AND METHODS

We selected thirteen sites in Adams, Huntington, and Wells Counties, Indiana, based on size and access from public property (i.e. road crossings; Fig. 1). Each stream was measured at the sampling location from bank to bank. Six small streams (< 8m channel width), four medium streams (≥ 8 and < 20m width) and three large streams (≥ 20m width) were selected (Fig. 1). Monthly from May to August 2013, we collected 40 mL of water from the center of the channel for each stream. Samples were immediately separated into 20 mL containers, each for chlorophyll a biomass and diversity assessments.

We used methods described by EPA (5) for chlorophyll a extraction. Briefly, the 20 mL samples were centrifuged (9000 RPM, 20 minutes), aqueous layer decanted, and 10 mL of acetone was added and mixed with the pellet on a vortex. The acetone solution was stored for 24 hours at 5°C, centrifuged (7000 RPM, 5 minutes), and aqueous layer decanted for spectrophotometry. Using the equation presented by EPA (5), we calculated µg/L of chlorophyll a in the streams. For diversity, we identified algal morphospecies as a rapid assessment tool within three random microscope views per sample (100 µL per slide, 100x magnification). Morphospecies were defined based on shape (i.e. spherical, filamentous), motility (i.e. non-motile, flagellated), and colonial status (unicellular, colonial). We used morphospecies richness (counts of different morphospecies) as a measure for algal diversity.

Land use adjacent to the stream were assessed using 2011 National Land Cover Data (10). In ArcMap (version 10.1, ESRI Inc., Redlands, CA), land use were categorized in a 0.5 km buffer around the stream channel 2 km upstream from the sample location (including all tributaries within the 2 km buffer). The area of land within the assessment buffers for each land use type were calculated. Additionally, the number of tributaries within the assessment buffer were counted for each stream.

Stream size classes were compared using one-way analysis of variance (ANOVA) for total land area within assessment buffers and number of tributaries, as well as repeated measures ANOVA for algal richness and biomass. Tukey HSD was used as a post-hoc multiple comparison test. Pearson correlations were used to identify relationships between algal richness, algal biomass, and number of tributaries. Multiple regression with reverse variable selection was used to identify relationships between stream size and land use types, with biomass and morphospecies richness. All analyses were conducted in R (version 3.1.1, The R Foundation for Statistical Computing, Vienna, Austria).

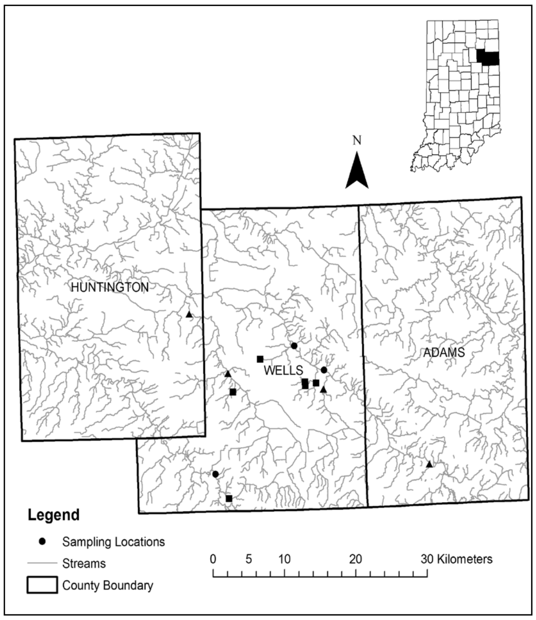

Fig. 1. Sampling locations within Adams, Huntington, and Wells Counties, Indiana. Squares indicate small stream sampling locations (<8 m channel width), triangles indicate medium streams (>8 and <20 m width), and circles indicate large streams (>20 m width).

RESULTS

Large streams had significantly more tributaries within the 2 km upstream from the sampling location than small streams (F2,10 = 8.19, p = 0.008). However, the total area within the assessment buffers were not significantly different between the size classes (F2,10 = 1.06, p = 0.382). Stream size classes were not significantly different in chlorophyll a biomass (F2,6 = 1.59, p = 0.279, Table 1) using repeated measures over the months. However, stream sizes were significantly different in monthly algal richness, with large and medium streams having greater numbers of morphospecies than small streams (F2,6 = 13.48, p = 0.006, Table 1). Algal biomass and richness were not significantly correlated (r = 0.34, p = 0.259). Mean algal biomass was significantly correlated with number of tributaries upstream (r = 0.61, p = 0.026), while richness was not correlated with tributaries (r = 0.36, p = 0.223). Using different models defining the relationship between algal biomass and total phosphorus (12,25), estimated mean phosphorus ranged from 0.003 (± 0.002) to 0.057 (± 0.018) mg/L.

We encountered thirteen of the 20 land cover types in the land assessment buffers (Table 2). Cultivated crop agriculture dominated the land cover types accounting for 77.2% of the area within the study. Open development and deciduous forest lands were distant second and third in area, accounting for 6.7% and 6.5%, respectively. Land cover types provided significant multiple regression models for both algal richness and biomass

(Table 2). For algal richness, open developed land and pasture had positive influence, while woody wetlands had negative influence. For algal biomass, open and low developed land, grass, shrubs, and woody wetlands had a positive influence. Emergent wetlands had the strongest influence and negatively impacted algal biomass.

Table 1. Algal biomass measured in μg/L chlorophyll a (SE) and species richness (SE) per size class over four sampling periods.

	May		June		July		August	
Size	Biomass	Richness	Biomass	Richness	Biomass	Richness	Biomass	Richness
Small	15.32	0.00	20.63	0.67	23.32	0.67	19.63	0.67
	(4.34)		(10.48)	(0.33)	(8.09)	(0.21)	(2.83)	(0.21)
Medium	54.20	1.00	39.35	2.00	27.86	0.67	20.66	2.67
	(39.72)	(1.00)	(17.63)	(1.00)	(6.25)	(0.33)	(5.13)	(0.33)
Large	246.19	1.50	23.28	2.25	39.99	1.75	48.39	2.00
	(142.14)	(0.65)	(13.39)	(0.48)	(2.82)	(0.48)	(11.45)	(0.91)
All	105.24	0.83	27.75	1.64	30.39	1.03	29.56	1.78
	(41.32)	(0.14)	(2.08)	(0.20)	(1.54)	(0.08)	(2.58)	(0.22)

DISCUSSION

Land use cover type changes can greatly influence runoff and fertilization of local streams (2,15,18,22,26). The majority of changes occur as shifting from natural land cover with complex vegetative layers to simplified layers (17,20,23). Within the study area in Northeastern Indiana, little land cover has changed recently; agriculture has dominated. Dominance of both agricultural and developed land, both anthropogenic simplifications of the natural land cover, greatly alter stream nitrogen and phosphorus contents (1,7,24).

Stream size classes were designated as arbitrary categories based on channel width at the sampling location. As evidenced by the significant correlation between algal biomass and number of tributaries two km upstream from the sampling point, a categorical index based on tributaries may have been a more appropriate size category. The land cover/tributary interaction on the landscape can have substantial impact downstream (19). However, since our buffer production began with a 500 m buffer around all streams and then used a two km buffer, the area of land that was potentially draining into the sample stream channel didn't differ between size classes. The tributary influence would have been included in the arbitrary size class categorization (large streams with more tributaries than small).

While nitrogen and phosphorous are im-

Table 2. Land use types occurring within stream buffers (0.5 km x 2 km upstream) with mean number of tributaries (SE) and mean ha area (SE) for small (< 8 m), medium (≥ 8 m, < 20 m), and large (≥ 20 m) width streams.

Stream Size	Count of Tributaries	Land Use Cover Types*												
			Developed				Forest				Planted/Cultivated		Wetlands	
		Water	Open	Low	Medium	High	Deciduous	Evergreen	Shrub	Grass	Pasture	Crops	Woody	Emergent
Small	1.2	0.64	13.20	1.61	1.04	1.03	11.69		0.07	2.91		224.68	0.19	0.17
	(0.3)	(0.26)	(1.84)	(1.35)	(0.95)		(4.55)			(0.79)		(35.17)		(0.11)
Medium	3.5	2.84	27.95	2.04	0.46		26.21		0.59	5.46	26.93	365.12	8.58	1.89
	(0.9)	(1.75)	(6.87)	(1.58)			(10.43)		(0.49)	(1.23)	(16.77)	(22.75)	(8.05)	(1.13)
Large	5	4.18	45.15	23.69	8.16	4.16	46.79	2.79	0.80	13.95	4.85	316.27	5.31	7.36
	(1.1)	(2.10)	(9.65)	(16.54)		(3.83)	(31.64)	(2.52)	(0.44)	(9.08)		(84.87)	(2.76)	(2.66)
All	2.8	2.14	25.11	6.84	2.50	1.43	24.26	0.64	0.40	6.24	9.40	289.03	3.96	2.36
	(0.6)	(0.77)	(4.61)	(4.26)	(1.89)	(0.98)	(8.17)	(0.60)	(0.19)	(2.24)	(5.85)	(29.61)	(2.53)	(1.02)

Table 3. Multiple regression equations for predicting algal richness and biomass with adjacent land cover type area within a 0.5 km wide buffer 2 km upstream from sampling location.

Dependent	Equation	F	df	P-value	R^2
Richness (count)	1.05 + 0.06*DevelopedOpen + 0.08*Pasture – 0.20*WetlandsWoody	8.11	3,9	0.006	0.73
Biomass (µg/L)	7.11 + 2.91*DevelopedOpen + 1.76*DevelopedLow + 2.79*Grass + 6.73*Shrub – 10.57*WetlandsEmergent + 2.14*WetlandsWoody	33.69	6,6	< 0.001	0.97

portant nutrients in driving algal population size, phosphorus is considered the more important of the two in freshwater systems (3). Because of this, we wanted to use published models for predicting algal biomass to inversely estimate stream phosphorus content. Due to differences in systems and model techniques, we estimated a very broad range of phosphorus (0.003-0.057 mg/L) (12,25). Even with this broad range, the estimated phosphorus content of the streams were well below the benchmark values set by the Indiana State Department of Agriculture of 0.3 mg/L (9). While there are limitations to interpreting this conversion of algal biomass to estimated total phosphorus, it does indicate that the streams we sampled were well below the State's benchmark value.

In our study area, combined agriculture (pasture and cultivated crops; 80% of area) and combined development (open, low, medium, and high; 10% of area) were the clearly dominant land cover types. However, agriculture was not included in either algal richness or biomass models. Likely this is due to the ubiquitous nature of agriculture as a dominant land cover within the buffers for every stream. Changes in open developed land for algal richness, as well as both open and low intensity for algal biomass, significantly added positively to the multiple regression models. While phosphorus is often intentionally added to agricultural fields, total biologically available phosphorus during baseline flow rates in agricultural streams appears similar to urban streams (1,4,24). Increasing urban development dramatically increases coverage of impermeable surfaces, decreasing water infiltration, and increases total biologically available phosphorus in streams (2,4,17,20). The influence of open and low intensity land use in the two models fits with an expectation of a potential increase in phosphorus with increasing area.

The effect of wetlands on algal biomass and richness may be explained through absorption of nutrient-rich runoff from the dominating agricultural land use. However, emergent herbaceous wetlands have limited phosphorus retention capacity, while forested wetlands may serve as phosphorus sinks (14,21). Our results may indicate interactions between natural systems: stream channel and natural wetlands. The two strongest influences within both models were negative associations with woody and emergent wetlands. Both are common wetland types, when wetlands occur, within the study region. Within our buffers, wetlands only accounted for 1.7% of land area. Even though they were not a dominant land type, wetlands play a substantial and dramatic role in the algal richness and biomass responses within the study streams.

Our results highlight the importance of responsible land management near waterways to maintain high water quality. As part of the Indiana Nutrient Reduction Strategy (9), there is a focus on urban residential fertilizer application in addition to the typical focuses on agriculture and sewer management. Open development land use (i.e. dominated by turf grass, lawns, parks, golf courses) has strong positive influence on algal richness and biomass, which could have future water quality implications if land uses change with increases in urban and suburbanization within the region.

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