ETF Final Report 2011

Effects of agricultural contaminants on wetland ecosystems in New Brunswick
(Project #100041)

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Rationale

Wetlands in New Brunswick provide invaluable ecological services including their capacity to improve water quality, stabilize shorelines, provide habitat for wildlife and act as reservoirs during flooding. They support a diverse array of vertebrates, including amphibians, and birds depend on these systems for food, habitat and breeding grounds. These systems are subject to numerous stressors including runoff of pesticides and fertilizers from agricultural, forestry and military applications that can affect the sustainability and value of wetland habitats through losses in their productivity, function and diversity of wildlife. New Brunswick introduced the Wetland Conservation Policy in 2002, making an explicit commitment to *no net loss* in wetland function. An understanding of the food web structure of these wetlands will help use to detect the impacts that herbicides and fertilizers can have on wetland species and function. This is particularly important in the face of worldwide declines in amphibian species, where it is hypothesized that agricultural chemicals are contributing to these declines.

Agriculture is a key component of New Brunswick's economy, with over 395,000 hectares of farmland producing $1.17B of food and beverage in 2007. Herbicide and fertilizer application is an integral practice in agriculture, and these contaminants frequently are detected in wetlands adjacent to areas of application. Small wetlands are ubiquitous in agricultural landscapes, and have considerable potential for contamination by both herbicides and fertilizers. Despite this, little is known about their combined effects on wetland communities. Glyphosate-based herbicides are the dominant herbicide used in agriculture in New Brunswick. It is used for pre- and post-emergence weed control in both agriculture and forest management (as well as in military operations) to reduce competing vegetation. Previous laboratory investigations indicated no adverse effects of glyphosate on wetland invertebrates and amphibians. However, the surfactants used during herbicide application have been shown to be harmful to amphibians and invertebrates. As well, non-target wetland plant species are sensitive to the herbicidal ingredients, and this can cause changes in wetland habitats that indirectly impact animal populations, including endangered species, diversity, and ecosystem functioning.

In this study, we are assessing the effects of glyphosate-based herbicides and fertilizers, as they are currently used in agriculture, on wetland food webs. The research is improving our understanding of the relationships among human land-use, aquatic ecosystems, and valuable ecological functions. Although glyphosate and fertilizers themselves are not generally toxic to amphibians, loss of habitat and food sources may be responsible for loss of these sentinel species. An understanding of food web structure would allow us to determine how changes in food sources and organism interactions caused by agricultural contaminants indirectly impact these organisms. We are determining how glyphosate and nutrient enrichment from fertilizers interact to affect the structure of the entire food web in an experimental system.

Although studies (mainly in the laboratory) have been done to examine some of the effects of stressors on the animals living in wetlands, few have examined the effects on the entire ecosystem. Short-term experiments in laboratories cannot capture all of the spatial, temporal and biological variability present in nature and, thus, extrapolations of lab results to real systems are unreliable. Whole-ecosystem experiments are increasingly accepted as the 'gold standard' for determining the effect of human activities on aquatic systems, and for the development of policies. However, these types of studies are rarely done because they require the manipulation of natural systems and the long term availability of a dedicated research facility for this purpose. Drs. Kidd and Houlahan at UNB Saint John, in partnership with the Department of National Defence (DND) at CFB Gagetown, established the *Long-term Experimental Wetlands Area* (LEWA) for conducting whole-ecosystem experiments. LEWA is a 4 km^2 area of CFB Gagetown containing more than 100 permanent and temporary ponds.

Sustainably managing and protecting NB's vast natural resources will ensure future economic prosperity and maintain the ecological integrity of the landscape. This research will help to identify sensitive indicators of changes in wetland ecosystems that can be used to guide policy regarding the acceptable use of agricultural chemicals, and the conservation of wetlands. The use of herbicides in forest and agricultural production, as well as in military sites is governed by an adaptive management framework that utilizes the best available science to maximize production and facilitate operations while mitigating potential risks to humans or wildlife. Results of this work will allow us to assess the environmental impacts of environmentally relevant concentrations of new glyphosate formulations in real wetland systems.

The objectives of this project were:

<u>1) Short-term objectives:</u>

a) To determine whether new glyphosate formulations, alone or in combination with fertilizers, at predicted and realistic environmental concentrations, will have significant effects on food web dynamics and stability in wetlands.

b) To assess the potential utility of nitrogen stable isotope signatures as tracers of anthropogenic sources of excess nutrients (which can lead to eutrophication of the system).

<u>2) Long-term objectives:</u>

a) To determine the effects of multiple stressors on aquatic systems, using whole-ecosystem experiments.
b) To conserve ecological integrity of wetlands, and protection of amphibian species.
c) To contribute to sustainable land management strategies used by the Canadian Forest Services and CFB Gagetown military training areas.
d) The provision of information to the public on appropriate uses of glyphosate-containing herbicides and fertilizers near wetland systems.

Methods

In August of 2008, impermeable plastic barriers were installed in 6 wetlands located on Canadian Forces Base Gagetown, near Oromocto, NB. See Table 1 for chemical, physical and biological characteristics of each pond. In the spring of 2009, one half of each pond was oversprayed with the glyphosate-based herbicide RoundUp WeatherMAX® in two separate treatments (mid-May and mid-June) to achieve either an environmentally realistic (0.21 mg active ingredient (a.e.)/L - 3 ponds) or worst case maximal aqueous concentration (2.89 mg a.e./L - 3 ponds) with the other half left untreated. All six ponds also received several applications of inorganic fertilizer nutrients (phosphoric acid and ammonium nitrate) to maintain two-fold higher aqueous nutrient concentrations.

Samples of wetland plants, periphyton, biofilm, phytoplankton and surrounding vegetation were collected from both sides of the ponds three times after spraying the ponds, in July, August and September 2009, in order to assess the effects of mixtures of herbicides and nutrients on the basal food resources. Wetland invertebrates, tadpoles of green frogs, spring peepers, yellow-spotted salamanders, as well as green frog metamorphs were also collected at these times. These samples were processed at the Canadian Rivers Institute at UNB Saint John in the summer of 2010, and analysed by the Stable Isotopes in Nature Lab at UNB Fredericton in the fall of 2010. Stable isotope analysis of carbon (measured as $\delta^{13}C$) and nitrogen (measured as $\delta^{15}N$) were used to create models of the food web structure of these wetlands. Carbon isotopes are used to determine unique food sources of a food chain (i.e.- terrestrial organic matter vs. aquatic detritus vs. algae). Nitrogen stable isotopes are used to determine the trophic level of a particular organism.

Water and sediment samples will be collected from both sides of each pond several times during the course of the summer so that we can determine concentrations of major ions, dissolved organic materials, pH, redox potentials and other factors that may affect the behaviour and availability of glyphosate in surface waters and sediments, and if these change as a result of treatment with glyphosate herbicides. Further analyses will help us to confirm treatment application concentrations, the actual impermeability of the dividing curtains. Most importantly, this will allow us to track the fate, concentration and degradation of glyphosate and its breakdown products.

Results

All field work and stable isotope analysis has been completed for this project. Analysis of aqueous glyphosate concentrations at Natural Resources Canada is ongoing. Determination of nutrient concentrations in the wetlands has been completed. Data analysis and manuscript writing are ongoing and we anticipate that Leanne Baker will use this research as part of her PhD thesis, to be completed in August of 2011.

The difference in aqueous nutrient concentrations between the sides of the ponds was variable throughout the course of the summer of 2009. Fig. 1 shows that we were able to increase the concentration of total phosphorus in the water on the treated sides of the ponds, but that total kjeldahl nitrogen remained variable. These results suggest that when nutrients were added to the ponds, they were quickly used by the primary producers. Generally, in the higher glyphosate-based herbicide treatments, all plants and algal food resources had decreases in carbon and nitrogen isotope ratios immediately post-treatment (July 2009) and an increase in both carbon and nitrogen by Sept 2009 (Table 2a). The decrease in both carbon and nitrogen is likely due to herbicide-induced toxicity to emergent plants and a shift in the algal community from smaller, more sensitive species to a community dominated by cyanobacteria.

Cyanobacteria are more resistant to herbicides and have lower carbon and nitrogen signatures than other algal species; this group also tends to become dominant in eutrophic systems. Late in the summer, the plant community would likely be responding to an increase in nutrients released from decomposing, senesced plant materials and continued fertilizer inputs. Inorganic nitrogen fertilizers are created using atmospheric nitrogen; therefore, the stable isotope ratio should not be significantly different from an atmospheric nitrogen source (atmosphere $\delta^{15}N$ 2-8‰, synthetic fertilizer -3-3‰). However, increasing the availability of nitrogen in the system results in greater denitrifcation in wetland sediments, and leads to enrichment in the $\delta^{15}N$ available for plants, so plants in eutrophic systems should have more positive $\delta^{15}N$ ratios than in nutrient- limited systems. The increase in nutrients also results in an increase in photosynthesis and growth rate in plants, and this can cause the $\delta^{13}C$ isotope ratio to increase in plant tissues.

In the low glyphosate-herbicide and nutrient treated ponds, many emergent plants and phytoplankton showed an immediate (in July 2009) enrichment in nitrogen stable isotope ratios without corresponding changes in the carbon isotope ratios (Table 2b). The nutrients may have increased the denitrification in the wetlands, and the increase in growth rate may not have been apparent yet. This lower concentration of herbicide did not appear have had the same effect on the plant and algal communities as the high glyphosate and nutrients treated ponds. The concentration of glyphosate added to these ponds was approximately ten times less than was added to the high glyphosate treated ponds, and is reflective of concentrations of glyphosate that have actually been measured in wetlands located in an agricultural landscape. By September of 2009 the carbon isotope ratios of most plants and algae were significantly higher on the treated sides of wetlands than on control sides. This is probably due to the increased growth rate from the nutrient additions and overall lower impacts from herbicides earlier in the summer.

Zooplankton closely mimicked the changes in the isotope ratios of their food source, phytoplankton, although these trend in the differences were not always significantly different from zero (Fig. 2). We had difficulty collecting a sufficient amount of green frog tadpoles from all wetlands, but they appear to also be fairly good integrators of the stable isotope ratios of their food sources, benthic and pelagic periphyton. The metamorphs of the same frog species also demonstrated stable isotope ratios that were similar to their food sources. Wetland communities are dominated by many generalist predatory invertebrates, such as the larvae of predacious diving beetles, damselflies and dragonflies. These organisms showed no significant differences in their isotope ratios (Table 2a and 2b) between the sides, this is likely because they eat prey from both the pelagic and benthic compartments of the wetland, which tended to have opposing changes in stable isotope ratios. These particular organisms would not be good indicator species for detecting eutrophication in small wetlands affected by agricultural contaminants. When the isotope ratios of organisms were averaged across treatment levels, lymnaeid snails and caddisfly larvae best demonstrated the long-term enrichment in wetland stable isotope ratios. These organisms are frequently used as baseline indicators of the basal food resources in other stable isotope food web studies, because they are long-lived and can incorporate changes in the benthic and epiphytic periphyton caused by eutrophication.

These results have been presented to the public at the Canadian Rivers Institute's "CRI day" in July of 2010, and to the scientific community at the Aquatic Toxicity Workshop, in Toronto, ON in October of 2010, resulting in a best platform presentation award. Final results of this research will be presented at the Ecological Society's annual meeting in Austin, Texas in August of 2011. We expect this data to be submitted for publication in a peer-reviewed journal this year. We have also provided information on the effects of glyphosate-based herbicides and nutrients to Health Canada's Pesticide Management Regulatory Agency for their pesticide re-evaluation program.

In summary, glyphosate-based herbicides and nutrients caused small, but statistically significant changes in the stable isotope ratios of carbon and nitrogen in wetlands supporting pond-breeding amphibians. These changes were visible in most primary consumers in the wetlands, but were difficult to detect in higher trophic levels. Higher concentrations of glyphosate-based herbicides led to depleted carbon and nitrogen isotope signatures early in the summer. This same effect was not apparent in the ponds treated with environmentally-observed concentrations of glyphosate-based herbicides, where there was an enrichment in both carbon and nitrogen isotope ratios. By the fall of 2011 we will have completed the analysis of food web models and that will allow us to better understand the changes that occurred in the wetlands, leading to the changes in stable isotope ratios. These findings will be correlated with data collected on changes in the gut contents, abundance, and development of important wetland organisms. In addition, results from this ETF-funded project are part of a larger multi-institutional program being conducted at LEWA and will be incorporated into a larger synthesis of how common stressors affect wetland communities.

Presentations of this study

Leanne F Baker**,** Dean G Thompson, Jeff E Houlahan, and Karen A Kidd (2010). The effects of glyphosate-herbicides on zooplankton communities and the emergence of adult insects from wetlands. Poster presentation: Aquatic Toxicity Workshop, Toronto, ON, October 3-6.

Leanne F Baker**,** Dean G Thompson, Jeff E Houlahan, and Karen A Kidd (2010). Modeling the effects of fertilizers and herbicides on wetland food web structure. Platform presentation: Aquatic Toxicity Workshop, Toronto, ON, October 3-6.

Leanne Baker, Jeff Houlahan, Dean Thompson, Karen Kidd, Vance Trudeau, Bruce Pauli, Megan Gahl, Laia Navarro-Martin, Chris Edge, Joe Mudge, Chantal Lanctot, Courtney Robertson. (2010) Whole-pond experiments to assess the effects of herbicides on wetland ecosystems. Platform presentation: Canadian Rivers Institute Day, Fredericton, NB, July 9.

Leanne F Baker, Dean G Thompson, Jeff E Houlahan, and Karen A Kidd (2009). Chemical mixtures in the environment: The effects of glyphosate-herbicides and fertilizers on the emergence of adult aquatic insects from wetlands. Poster presentation: Aquatic Toxicity Workshop, La Malbaie, QC, September 27-29.

Table 1. Physical and chemical characteristics of ponds sampled in the Long-term Experimental Wetlands Area of CFB Gagetown, NB.

Pond Name	Glyphosate concentration added	Treated side of Pond	Latitude	Longitude	Max Volume	Min Volume	Max Depth	Surface Area
(Units)			Decimal deg.	Decimal deg.	L	L	cm	m^2
Ag 07	2.89mg/L a.e.	N	45.66804405	-66.50871322	145,993	126,856	61	899
Ag 15	0.21mg/L a.e.	S	45.68432808	-66.49644496	182,292	99,919	53	998
Ag 20	0.21mg/L a.e.	E	45.6635516	-66.50604391	33,301	21,158	31	323
Ag 21	2.89mg/L a.e.	W	45.67205069	-66.51216748	318,596	240,494	61	878
Ag 26	0.21mg/L a.e.	W	45.69006088	-66.48558469	370,313	197,640	38	2433
Ag 36	2.89mg/L a.e.	W	45.67594031	-66.50375767	65,241	46,103	51	418

Pond Name	Max Perimeter	Shape (isoperimetric quotient)	Hydro period	Dominant Vegetation	Dominant Larval Amphibian	Dominant Amphib Predators	Trophic Status	Limiting Nutrient
(Units)	m	(1=perfect circle)						
Ag 07	198	0.29	Permanent	*Potamogeton sp.*	*L. clamitans*	Odonata larvae	Oligotrophic	P
Ag 15	157	0.51	Permanent	*Typha latifolia*	*L. sylvaticus*	Dytiscidae adults	Oligotrophic	N
Ag 20	94	0.46	Permanent	*Typha latifolia*	*L. clamitans*	Odonata larvae	Mesotrophic	P
Ag 21	119	0.78	Permanent	*Typha latifolia*	*L. clamitans*	Dytiscidae adults	Mesotrophic	P
Ag 26	271	0.42	Permanent	*Typha latifolia*	*L. clamitans*	Dytiscidae larvae	Oligotrophic	N
Ag 36	99	0.53	Permanent	*Typha latifolia*	*L. clamitans*	Dytiscidae adults	Oligotrophic	N

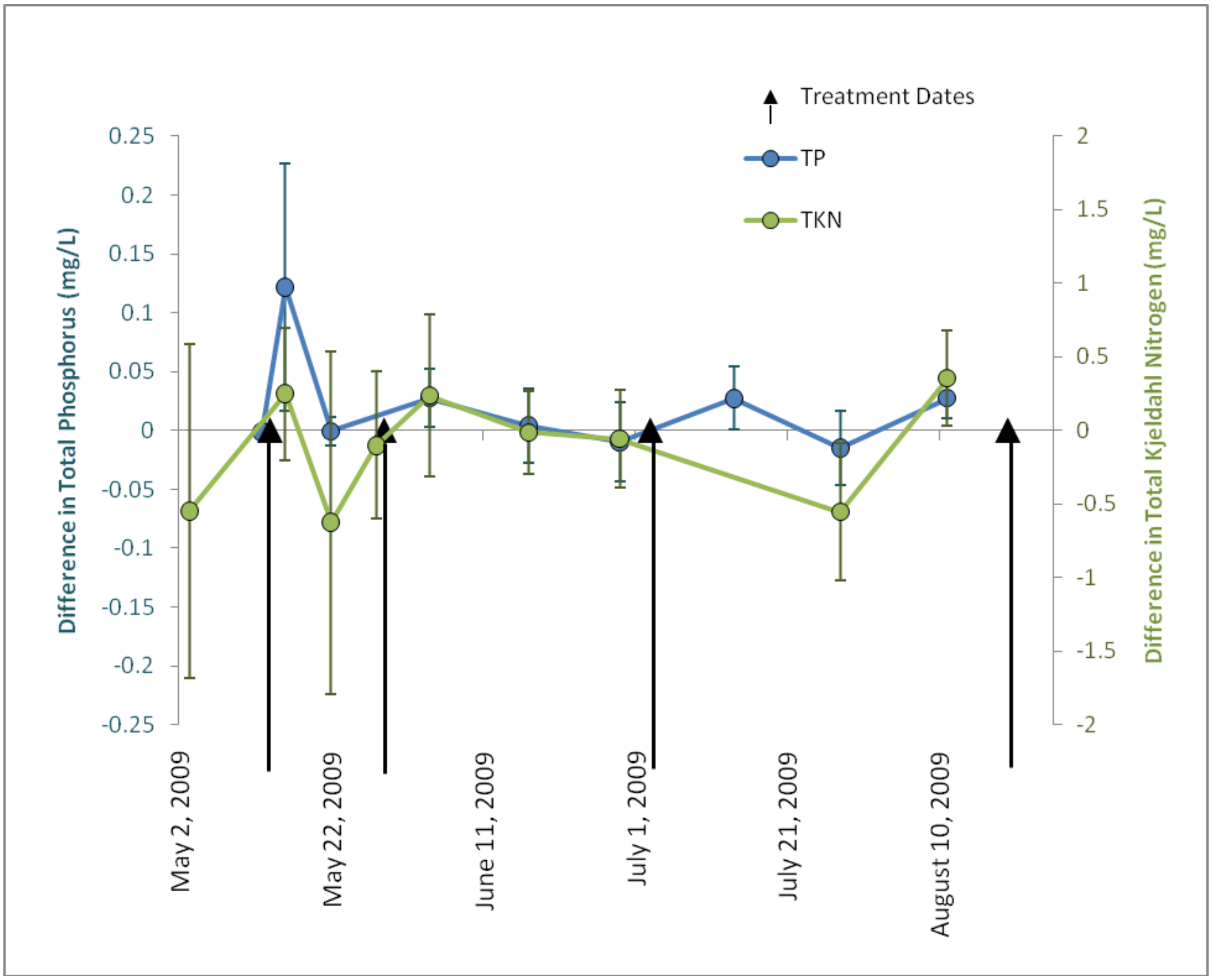

Figure 1. The average (+/-95% CIs) difference in aqueous concentrations of Total Phosphorus (TP-measured on left axis) and Total Kjeldahl Nitrogen (TKN-measured on right axis) in experimental wetlands. The value presented was calculated by subtracting the concentration measured on the control side of the pond, from that of the repective treated side for each pond. Values above the zero line indicate where the concentration would have been, on average, greater on the treated sides of the ponds than in their control sides.

Table 2a. Average differences (±SD) of the stable isotope ratios of food sources, invertebrates and amphibians collected from experimental wetlands in 2009, treated with the high concentration of the glyphosate-based herbicide (Roundup WeatherMax) and nutrients (H gly +N). Values presented were calculated by substracting the $\delta^{13}C$ and $\delta^{15}N$ of each species collected from the treated side of the pond from that measured in the same species collected from the respective control side of the pond. **Bold values** are those where the average difference is significantly different from 0.

				July 2009		August 2009		Sept 2009	
Treatment	Organism	Compartment	Trophic level	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
H gly +N	Phytoplankton	Pelagic	1^o producer	**-1.83‰±1.116**	-0.545‰±0.934	**1.015‰±0.993**	**0.701‰±0.642**	1.433‰±1.557	**-0.357‰±0.315**
H gly +N	Zooplankton	Pelagic	1^o consumer			-0.36‰±0.506	**0.549‰±0.367**	**1.697‰±1.119**	0.177‰±1.078
H gly +N	Damselfy larva	Pelagic	2^o consumer	**-0.939‰±0.278**	0.378‰±0.49	0.339‰±0.404	**-0.552‰±0.247**	1.085‰±1.435	0.257‰±0.472
H gly +N	Benthic periphyton	Benthic	1^o producer	0.642‰±1.506	0.266‰±0.713	-0.846‰±1.826	0.348‰±0.442	0.436‰±2.657	**1.266‰±0.112**
H gly +N	Epiphytic periphyton	Benthic	1^o producer	1.603‰±4.204	0.911‰±1.358	0.684‰±2.006	**0.81‰±0.645**	2.465‰±2.893	0.584‰±1.257
H gly +N	*L. clamitans* metamorph	Benthic	1^o consumer	**0.775‰±0.259**	**0.511‰±0.381**	0.871‰±1.774	0.545‰±1.224	1.307‰±3.562	**0.786‰±0.096**
H gly +N	Lymnaeid snail	Benthic	1^o consumer			0.273‰±2.21	0.098‰±1.246		
H gly +N	Caddisfly larva	Benthic	1-2^o consumer					**2.177‰±1.806**	**0.939‰±0.408**
H gly +N	Aeshnid dragonfly larva	Generalist	Predator	-0.341‰±2.107	-0.068‰±1.246	**1.779‰±0.984**	0.201‰±1.12	2.38‰±3.438	0.18‰±0.277
H gly +N	Libellulid dragonfly larva	Generalist	Predator	**-1.096‰±0.841**	-0.15‰±0.624	1.567‰±2.251	0.12‰±0.415	-0.005‰±0.449	0.29‰±0.794
H gly +N	Notonectidae	Generalist	Predator	1.569‰±2.371	0.12‰±1.152	-0.733‰±1.031	-1.072‰±0.527	-0.572‰±0.978	0.428‰±0.566
H gly +N	Water scorpion	Generalist	Predator			-1.095‰±5.867	**0.615‰±0.229**	**-0.823‰±0.53**	0.704‰±1.315
H gly +N	Sphagnum	Bryophyte	1^o producer	1.029‰±2.236	-0.148‰±0.491	-0.364‰±1.287	0.402‰±0.847	0.332‰±1.143	-0.036‰±0.397
H gly +N	*J. effusus*	Emergent plant	1^o producer	-0.077‰±0.381	**0.798‰±0.2**	0.872‰±1.058	0.125‰±0.503	1.827‰±2.444	-0.029‰±1.307
H gly +N	*S. cyperinus*	Emergent plant	1^o producer	-0.156‰±0.739	-0.565‰±0.85	-0.166‰±1.328	0.335‰±0.399	0.526‰±2.061	-0.039‰±2.39
H gly +N	*T. latifolia*	Emergent plant	1^o producer	-0.401‰±1.744	0.046‰±0.66	0.104‰±0.78	-1.047‰±2.08	0.702‰±1.765	-1.016‰±1.156
H gly +N	Corixidae	Emergent plant	1^o consumer	0.197‰±1.031	0.751‰±0.9	-0.017‰±1.224	**0.779‰±0.402**	1.291‰±1.991	0.893‰±1.137

Table 2b. Average differences (±SD) of the stable isotope ratios of food sources, invertebrates and amphibians collected from experimental wetlands in 2009, treated with the low concentration of the glyphosate-based herbicide (Roundup WeatherMax) and nutrients (L gly + N). Values presented were calculated by substracting the $\delta^{13}C$ and $\delta^{15}N$ of each species collected from the treated side of the pond from that measured in the same species collected from the respective control side of the pond. **Bold values** are those where the average difference is significantly different from 0.

				July 2009		August 2009		Sept 2009	
Treatment	Organism	Compartment	Trophic level	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
L gly +N	Phytoplankton	Pelagic	1° producer	-0.698‰±2.347	**0.477‰±0.432**	1.283‰±1.469	1.46‰±2.574	**2.827‰±1.133**	0.66‰±1.313
L gly +N	Zooplankton	Pelagic	1° consumer	**1.193‰±1.135**	-0.167‰±1.093	0.284‰±1.325	-0.212‰±0.406	**1.5‰±1.305**	-0.062‰±0.544
L gly +N	Chaoborus	Pelagic	2° consumer	-0.273‰±1.196	**0.79‰±0.342**				
L gly +N	Damselfy larva	Pelagic	1° consumer	0.289‰±0.967	0.178‰±1.677				
L gly +N	Benthic periphyton	Benthic	1° producer	-0.466‰±0.595	**-0.516‰±0.288**	0.837‰±1.241	0.121‰±0.146	**1.679‰±1.475**	0.371‰±0.849
L gly +N	Epiphytic periphyton	Benthic	1° producer	1.174‰±1.647	-0.53‰±0.869	**2.348‰±1.54**	-0.053‰±0.613	0.382‰±1.094	0.493‰±0.75
L gly +N	*L. clamitans* tadpole	Benthic	1° consumer			-0.522‰±1.229	0.708‰±0.897		
L gly +N	*L. clamitans* metamorph	Benthic	1° consumer	-2.653‰±5.297	0.867‰±1.233	**-1.129‰±0.152**	**0.615‰±0.245**		
L gly +N	Mayfly larva	Benthic	1° consumer					**1.731‰±0.23**	0.254‰±0.497
L gly +N	Chironomidae adult	Benthic	1° consumer	**1.008‰±0.139**	**0.394‰±0.36**				
L gly +N	Chironomidae larvae	Benthic	1° consumer			**1.137‰±1.472**	-0.523‰±2.289		
L gly +N	Caddisfly larva	Benthic	1-2° consumer					**2.961‰±0.544**	1.015‰±1.334
L gly +N	Aeshnid dragonfly larva	Generalist	Predator	1.183‰±1.19	0.788‰±1.04	**1.284‰±0.524**	0.011‰±0.05	0.749‰±1.258	-0.079‰±0.841
L gly +N	Libellulid dragonfly larva	Generalist	Predator	0.094‰±1.599	-0.517‰±1.047	1.057‰±2.929	-0.384‰±1.028	0.082‰±2.1	**0.248‰±0.219**
L gly +N	Notonectidae	Generalist	Predator	0.53‰±0.639	-0.242‰±1.18	1.263‰±1.49	-0.47‰±0.615		
L gly +N	Water scorpion	Generalist	Predator			0.302‰±1.31	0.303‰±0.36		
L gly +N	Sphagnum	Bryophyte	1° producer	0.907‰±1.53	-0.372‰±0.444	0.411‰±0.527	0.864‰±1.164	-1.122‰±1.8	**1.182‰±0.178**
L gly +N	*P. pusillus*	Submerged plant	1° producer					**5.154‰±2.893**	0.314‰±0.494
L gly +N	*J. effusus*	Emergent plant	1° producer	-0.349‰±1.032	**0.557‰±0.362**	-0.198‰±0.401	-0.683‰±2.9		
L gly +N	*S. cyperinus*	Emergent plant	1° producer	0.413‰±0.739	**1.348‰±1.262**	0.269‰±1.302	0.366‰±1.817	**1.181‰±0.447**	-0.337‰±1.636
L gly +N	*T. latifolia*	Emergent plant	1° producer	0.165‰±0.689	0.773‰±0.852	-0.115‰±0.883	0.511‰±1.337	0.264‰±0.392	0.5‰±0.843
L gly +N	Corixidae	Emergent plant	1° consumer	**-1.388‰±0.546**	0.625‰±0.759	-3.432‰±8.037	0.64‰±2.365	0.003‰±0.443	**2.08‰±0.671**

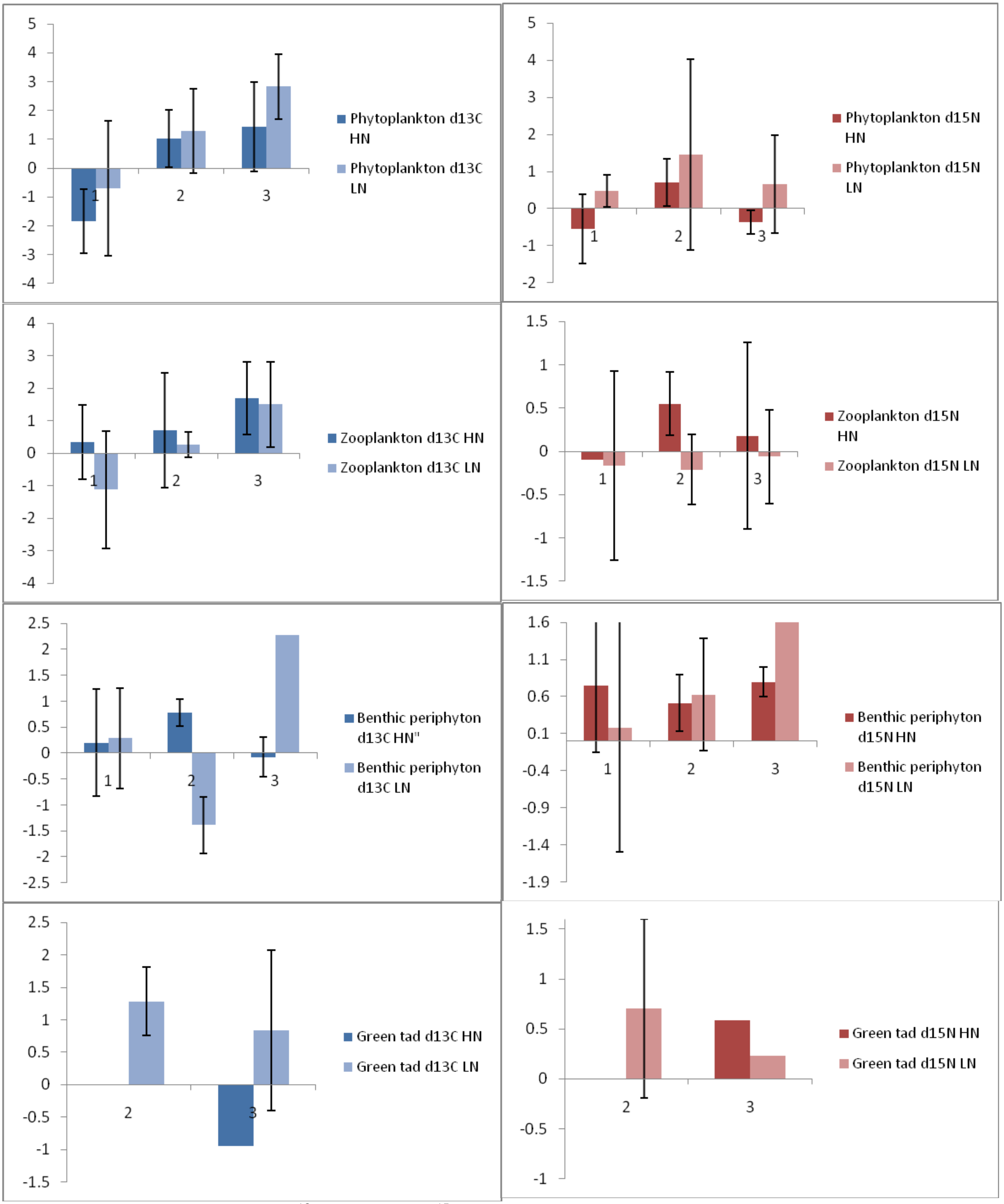

Figure 2. Difference (‰ ± SD) in $\delta^{13}C$ (d13C) and $\delta^{15}N$ (d15N) of selected basal food resources and primary consumers from treated wetlands.