Senator George J. Mitchell Center for Environmental & Watershed Research Annual Technical Report FY 2010

Introduction

Introduction

The Maine Water Resources Research Institute (MWRRI) is the locus of activity to sustain water science in the state through its support of research, graduate studies, and outreach. These fundamental and essential functions, which would not exist without Congressional authorization and appropriations, are not duplicated in any other form. The federal money that supports the Water Resources Research Institute is highly leveraged with other funds provided by stakeholders, universities, and researchers. Research project proposals are evaluated by peer-review and approved by our Research Advisory Board composed of members from the U.S.G.S. Water Science Center, State Environmental Agencies, U.S. EPA, academia, and industry. During the FY10 period, the Maine Institute supported eight research projects, including five student-directed projects: (1) Estimation of benthic dissolved organic carbon flux from wetland sediments using a novel technique; (2) Permaculture-design research initiative; (3) Fish scales as non-lethal biosensors of surface water contaminants; (4) Database development to support spatio-temporal analysis of coastal Maine mercury data; (5) Phosphorus dynamics in Androscoggin Lake, Wayne and Leeds, Maine; (6) Vegetation response to potential increased tidal marsh inundation in Northern New England; (7) Atlantic salmon (Salmo salar) as an indicator of habitat quality in tributaries; and (8) Microorganisms that can alter groundwater chemistry in an arsenic enriched aquifer. The MWRRI also supported Information Transfer activities, in addition to directly conducted activities, one additional information transfer projects was supported- Improving access to well water information: A pilot information transfer project. These projects directly provided support to six graduate students and three undergraduate students.

The Maine Institute Director, John Peckenham, also serves as the Assistant Director of the Senator George J. Mitchell Center for Environmental and Watershed Research. The Mitchell Center provides the administrative home for the Institute. This structural association greatly enhances our efforts to have the Maine Institute increase the breadth and accessibility of water research in Maine. The Mitchell Center is the recipient of a five-year EPSCoR grant from the National Science Foundation to develop the Sustainability Solutions Initiative. This grant is fostering even greater multi-institutional interdisciplinary research, including several projects related to water resources.

The 16th annual Maine Water Conference was held in March and continues to be a very important regional event for the water community. The number of people and organizations who support and contribute to this conference reflects the importance of water to the people of the State of Maine. Through the hard work of Institute staff, the Conference Steering Committee, and major supporters, we have been able to address the important water issues in Maine and to bring together diverse interest groups. The Water Resources Research Institute's affiliation with the Mitchell Center gives us the ability to support small projects that address important local needs. It also provides us leverage to develop and attract funding from other agencies. This program is strongly supported by our Vice-President for Research who has contributed $50,000 to the 104b research projects. In FY10, the Maine Institute had projects funded by municipalities, state agencies (e.g. Department of Inland Fish and Wildlife, Department of Environmental Protection), federal agencies (e.g. Fish and Wildlife, Environmental Protection Agency, National Oceanic and Atmospheric Agency), and foundations. None of these projects would be possible without the support of the federal Water Resources Research Institutes program and the U.S. Geological Survey.

Research Program Introduction

The Maine Water Resources Research Institutes supports research and information transfer projects using 104b funds. Projects are awarded on a competitive basis using a two-stage selection process. The Research Advisory Committee, comprised of the Institute Director, Regional U.S.G.S. Chief Scientist, State and Federal Agencies representatives, and Water Resources Professionals, set the research priorities based on current state needs and issues. The Institute issues a call for pre-proposals in the spring. The pre-proposals are reviewed by the Executive Committee (5 individuals) and full proposals are solicited for 150% of available funds. Full proposals are sent out for external review (out of state reviewers are required). The full Research Advisory Committee (12 members) reads the proposals and reviews to provide the Institute Director with a selection of proposals to fund. Much effort is made to solicit suggestions for themes, to diversify the types of projects funded, and to include researchers from the small colleges and universities in the state. Preference is given to support new faculty and projects directly involving students. Investigators are encouraged to collaborate with state and federal agencies and to seek additional contributions for their projects.

A special student competition was initiated in FY09 to fund summer research. A call for proposals is issued in March and reviewed by the Research Advisory Committee Executive Committee. Student project budgets are allowed up to be up to $5,000 and a total of $20,000 is allocated for this program. Response to this student-centered program has been strong and it will be continued.

Estimation of benthic dissolved organic carbon flux from wetland sediments using a novel technique

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Final Project Report Submitted to the Water Resources Research Institute

ASSESSMENT OF BENTHIC DISSOLVED ORGANIC CARBON FLUX USING THE EDDY CORRELATION TECHNIQUE

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Abstract:

Dissolved organic carbon (DOC) is a water quality concern, as DOC facilitates mobilization of metals and organics and leads to toxic disinfection byproducts during water treatment. Sediments in freshwater and estuarine systems are important sources of DOC, the export of which can vary with changing environmental conditions, including land use change, changes in temperature, wetland restoration, and rising sea levels. Therefore, it is important to quantify DOC flux across the sediment-water interface (SWI). Existing DOC flux measurement techniques are intrusive to the sediment environment and usually underestimate flux by only capturing certain flux contributions. In this research, a method for estimating benthic DOC flux using the eddy correlation technique was developed and implemented at three estuarine mudflats and one freshwater wetland throughout Maine and New Hampshire. The eddy correlation technique is a non-intrusive, *in situ* method based on measurement of fluctuations in turbulent velocity and a scalar, such as solute concentration or temperature. The method developed in this research utilized high frequency fluctuations in vertical velocity vectors obtained with an acoustic Doppler velocimeter (ADV) and DOC concentrations approximated with a chromophoric dissolved organic matter (CDOM) fluorometer, the time-averaged product of which produced the vertical benthic DOC flux. DOC flux values obtained using eddy correlation were compared with results from porewater extraction. Eddy flux values were typically an order of magnitude higher than the diffusive fluxes calculated from porewater gradients, which are thought to underestimate flux, as turbulent eddy diffusion dominates vertical transport in these aquatic systems. Reasonable flux estimates are a function of adequate trend removal to separate turbulent fluctuations from mean flows and wave-induced fluctuations.

1. INTRODUCTION

Dissolved organic carbon (DOC) is a water quality concern in freshwater and coastal environments. Sediments in these environments can be major sources of DOC, which can bind and mobilize toxic metals and organics (e.g., Kalbitz et al., 1997). In addition, DOC in source waters can lead to the formation of toxic disinfection byproducts during the drinking water treatment process (Fleck et al., 2007). There is a potential for increases in DOC export from sediments due to wetland restoration, dam removal, land use change, changes in acid deposition, rising temperatures and rising sea levels. Therefore, it is essential to be able to reliably quantify sedimentary DOC flux in different environments. Carbon cycling in the benthic boundary layer involves complex biogeochemistry. DOC in aquatic environments can originate from a variety of sources and accumulate in the benthic zone (Carlson, 2002). Since, in many sediments, porewater DOC concentrations are an order of magnitude higher than concentrations in the overlying water, the sediments can serve as a DOC source to the water column via diffusive transport (Burdige, 2006).

Various methods are currently used to measure benthic DOC flux. Some methods, such as equilibrium dialysis (peepers) and porewater extraction, rely on porewater concentration gradients to estimate solute flux (Burdige, 2006). These techniques, however, only capture flux due to molecular diffusion, thus underestimating net flux. Alternatively, benthic chambers rely on temporal measurement of properties in the overlying water, but do not adequately replicate physical aquatic conditions that facilitate turbulent transport. In addition, these methods are intrusive and result in disturbance of the sediment environment. Calculating flux from porewater gradients relies heavily on diffusion coefficients, which depend on DOC molecular weight and sediment porosity. Diffusion coefficient also changes with temperature and from site to site and

may be difficult to accurately estimate (Alperin et al., 1994). Due to long equilibration times peepers cannot be used to examine short-scale temporal variations in flux. This raises concerns about effectively capturing short-term changes in solute transport caused by bioturbation, bioirrigation, and sediment resuspension. Benthic chambers are used to measure temporal release of DOC from sediments into the overlying surface water. While both laboratory and *in situ* benthic chambers do attempt to reproduce advective flow using stirring rods or disks, these chambers do not take into account the same turbulent flow induced by horizontal currents present in tidal or riverine systems (Janssen et al., 2005).

The eddy correlation technique provides a non-invasive, *in situ* method for measuring and monitoring changes in flux over time. This technique has been used in atmospheric sciences for many years and more recently has been adopted to measure solute flux across the sediment-water interface (SWI) in aquatic systems (Berg et al., 2003; Kuwae et al., 2006). Eddy correlation principles involve the separation of turbulent fluctuations from mean flow. Turbulent fluctuations of velocity and those of a scalar, such as heat, O_2, or DOC concentration, can be correlated to estimate the vertical benthic flux due to turbulent eddy diffusion, which is expected to dominate vertical transport through the water column, provided that there is no significant vertical advective flow (Berg et al., 2003).

The research presented here illustrates the first known attempt to quantify benthic DOC flux using the eddy correlation technique. Eddy correlation instrumentation was deployed at three estuarine mudflats and one freshwater wetland in northern New England in August and September of 2009. An acoustic Doppler velocimeter (ADV), which utilizes acoustic backscattering of suspended particles as a proxy for water velocity, was used to measure three-dimensional velocity vectors. A chromophoric dissolved organic matter (CDOM) fluorometer

was used to estimate DOC concentration. The data collected with these two instruments were processed and correlated to obtain estimates of vertical DOC flux across the SWI.

2. MATERIALS & METHODS

2.1. Eddy correlation

Eddy correlation is a process by which flux of a variable across a plane can be estimated from the covariance of two variables; i.e., vertical velocity and a scalar or horizontal velocity (Glickman, 2000). In benthic systems, eddy correlation provides a method by which vertical solute flux can be estimated by measuring properties in the water column (e.g., Berg et al., 2003; Kuwae et al., 2006).

Eddy correlation measurement is facilitated by the Reynolds decomposition, in which vertical fluid velocity (*w*) and contaminant concentration (*C*) at a specific depth can be broken down into mean and temporally fluctuating values (Tennekes & Lumley, 1972),

$$w = \overline{w} + w' \tag{1}$$

$$C = \overline{C} + C' \tag{2}$$

where, $\overline{w}$ and $\overline{C}$ represent mean values, and *w'* and *C'* represent fluctuations about the mean. The correlation between velocity and concentration can be established by the covariance, or the product of the fluctuating components averaged over a length of time, $\overline{w'C'}$ (Everitt, 2006). If this product does not equal zero, the two variables are considered correlated (Tennekes & Lumley, 1972).

In turbulent conditions the total vertical diffusive flux at a given depth of a solute (*j*) is described by (Boudreau, 2001),

$$j = -D\frac{\partial C}{\partial z} + \overline{w'C'} \tag{3}$$

where, D is the molecular diffusion coefficient. The first term is representative of molecular diffusion, and the second term is representative of eddy diffusion due to turbulent fluctuations. In water columns where vertical transport is dominated by turbulent fluctuations (Berg et al., 2003), the molecular diffusion term can be neglected such that the covariance of vertical velocity and solute concentration is representative of the total vertical flux at a given depth:

$$j = \overline{w'C'} \tag{4}$$

In this work, DOC flux is calculated from the turbulent fluctuations of vertical velocity and DOC fluorescence measured in the water column a short distance above the SWI.

In the first use of eddy correlation to quantify flux of a dissolved species across the SWI, Berg et al. (2003) coupled a fast response O_2 microelectrode with an ADV to capture O_2 uptake by marine sediments. The results of the study illustrated the potential for eddy correlation to be used for O_2 flux measurement, as well as for other dissolved analytes for which fast-response sensors exist. Here we use this method to estimate the vertical DOC fluxes to/away from the SWI.

2.2. Acoustic Doppler velocimeter

A Vector ADV (Nortek AS, Rud, Norway) was used to obtain water velocity measurements. The ADV uses Doppler principles to measure particle velocities in three dimensions via acoustic backscattering, and the particle velocity measured by the ADV is used as a proxy for water velocity. Velocity measurements are taken within a cylindrical volume approximately 2 cm^3, located 15.7 cm from the instrument's transmit transducer. The ADV has a maximum sampling rate of 64 Hz, but 8 Hz was used throughout this project due to the limitations of the fluorescence sensor, as described in the next section. Note that the vector does not strictly measure flow velocity but that of particle, hence a small vertical velocity component

associated with sinking particles is often observed (e.g. Fugate and Friedrich, 2002). Since in the subsequent analysis the mean vertical velocity is removed, this should not affect the flux estimates.

2.3. Fluorometer

An ECO-FL chromophoric dissolved organic matter (CDOM) fluorometer (WETLabs, Philomath, OR, USA) was used to measure in situ CDOM concentration, which is an indicator of DOC concentration (e.g., Blough & Del Vecchio, 2002). The ECO-FL utilizes excitation and emission wavelengths of 370 nm and 460 nm, respectively, corresponding to the fluorescence characteristics of CDOM. The fluorometer measures CDOM concentration at approximately 2 cm from the face of the optics head. Unlike some other fluorometers, the ECO-FL is not a flow-through device, thus reducing the chance of contaminating velocity measurements by pumping. This instrument has a maximum sampling rate of 8 Hz.

The ECO-FL was calibrated in the laboratory using multiple concentrations of water collected from a field site. The ECO-FL was connected as an analog through the ADV, and both were powered by an external marine battery with a backup internal battery pack to emulate the power and data collection conditions used in the field (The dark current of Eco sensor is often sensitive to the) . During calibration, the ECO-FL was placed in an acid-washed plastic tank, which was entirely concealed with aluminum foil to prevent light from entering the system.

For each dilution, the ECO-FL collected 3 min of data. Each 3-min set of data was then averaged to obtain a single mean fluorescence count for each dilution. Immediately following each data collection period, a 120-mL sample of water was collected in an acid-washed plastic bottle. Each sample was filtered through 0.45-μm filter paper and preserved with 4 drops of a 1:1 18M sulfuric acid and DI water solution. Samples were stored at 4˚C until DOC

concentration measurement with a 1010 Total Organic Carbon (TOC) Analyzer (OI Analytical, College Station, TX, USA). The resulting DOC concentrations exhibited R^2=0.98 with respect to the fluorometer digital counts.

Since the CDOM fluorescence to DOC relationship can be affected by site-specific (Blough and Del Veccio, 2002), laboratory DOC calibrations should ideally be performed on samples collected *in situ* during the deployment. For the purposes of this study, however, all CDOM data were converted to DOC using a single laboratory calibration obtained using water collected from one project site. While this increases the uncertainty of flux calculations of DOC, it does not detract from our ability to evaluate the eddy-correlation technique, the primary purpose of this study.

2.4. Deployment setup and sites

For deployments, the two instruments were attached to an A-frame aluminum step ladder (Fig. 1), similar to the setup previously used by Kuwae et al. (2006). The ADV was mounted vertically and held in place by a bracket clamped to a ladder rung. The ADV was easily adjustable to the desired measuring height, and the bracket's rigidity prevented excessive wind and wave-induced movement of the instrument. The ECO-FL was mounted to a lower ladder rung using a different bracket that allowed the instrument to be oriented pointing downward at 45° to minimize the instrument's influence on the water flowing through the ADV's measurement volume.

Due to restrictions of the instruments' sizes and orientations, the two instruments did not share exactly the same measurement volume. For a typical field deployment, the ADV and fluorometer measurement volumes were located as much as 2 cm apart. This distance was acceptable, however, since smaller eddies that would not be captured due to the difference in

measurement volumes, do not contribute significantly to momentum and solute transport compared with larger eddies (Tennekes and Lumley, 1972). To minimize disturbance to the flow, the ladder was positioned so that the primary direction of flow occurred between the ladder's legs and orthogonal to the face of the fluorometer.

Four study sites were chosen for deployments: (1) Frankfort Flats, Frankfort, ME; (2) Squamscott River, Stratham, NH; (3) Piscataqua River, Kittery, ME; and (4) Burton Bog, Old Town, ME. The first three sites, which are all intertidal mudflats, were the subjects of concurrent and prior research, and the sediments at these sites are well-characterized, including the DOC porewater gradients (Brown, 2010).

2.5. Data Analysis

Data analysis was performed using the MATLAB programming environment. CDOM counts provided by the ECO-FL were converted to concentration of DOC in ppm. The ADV provides continuous pressure measurement, indicating the depth of water above the pressure sensor on the instrument. Pressure was added to the measured height of the sensor above the SWI in order to obtain the total water depth at any given time during the deployment.

Sections of data for preliminary analysis were selected by visual inspection. Bursts of data at least 10 min in length that were relatively stationary in w and C in comparison to the rest of the data were selected, as mean flow must be statistically stationary in order to facilitate adequate trend removal (Tennekes & Lumley, 1972).

2.5.1. Velocity vector rotation

Since the ADV is not mounted perfectly orthogonal to the sediment surface, the three-dimensional velocity vectors require transformation to represent true horizontal and vertical velocities. The ADV provides measurements of pitch and roll, which could be used to translate

the velocity vectors (West & Oduyemi, 1989). However, translations would be dependent on the accuracy of the tilt sensor. Therefore, another approach was used. By assuming that variance is minimized in the z-direction, the following relationships were used to develop angles of rotation and transform each velocity vector:

$$\begin{aligned} \phi &= \frac{1}{2}\tan^{-1}\left(\frac{\sum 2u_1u_2}{\sum u_1^2 - \sum u_2^2}\right) \\ u_{1new} &= u_1\cos\phi + u_2\sin\phi \\ u_{2new} &= -u_1\sin\phi + u_2\cos\phi \end{aligned} \tag{5}$$

where, u_1 and u_2 are velocity vectors (Emery & Thomson, 2004). This two-dimensional rotation is performed three times to correct all three velocity directions. The validity of these transformations was tested by comparing the correlation between *C* and both the corrected and uncorrected values of *w*.

2.5.2. Averaging window selection

It is necessary to determine an averaging window size for velocity and concentration trend removal such that the turbulent eddies that contribute to flux are captured in the flux calculations. To accomplish this, blocks of data ranging in length from 10 min to 60 min were analyzed for correlation between *w* and *C* at varying filter lengths ranging from 3 s to 10 min. Digital filtering was performed using the *filtfilt* function in MATLAB. This function provides a zero-phase filter by filtering in both forward and reverse directions. The *corrcoef* function was used to calculate the correlation coefficient *R* at varying filter lengths:

$$R(y) = \boxed{} \tag{6}$$

where, *y* corresponds to the filter length, and $0 \le R \le 1$.

The technique used here is similar to the method used by Berg et al. (2003) and McGinnis et al. (2008) in which flux was calculated directly for varying averaging windows. In this study, however, the correlation is based on the covariance of *wC* rather than *w'C'*. In order to analyze *w'C'*, trends must first be removed from *w* and *C*. The goal of examining correlation in this study is to directly determine from velocity and concentration the window lengths over which to establish these trends.

The optimum window sizes for block or running trend removal were determined by examining the change in correlation plotted over the change in filter length. Optimum window size was established as the filter length at the first local maxima on the correlation plot, indicating a likely shift from small-scale turbulent eddy-induced flux to large-scale advective flux (Berg et al., 2003). In cases where local maxima or minima did not exist due to continuously increasing correlation with filter length, the optimum window size was taken as the filter length at the first inflection point of correlation plot (Swett, 2010). Inflection points were determined by taking the second derivative of a polynomial fit ($R^2 > 0.999$) to the correlation plot.

2.5.3. Trend removal

Once an optimum averaging window was determined for a burst of data, two different methods were used to establish the trends, $\overline{w}$ and $\overline{C}$: (1) moving average, and (2) linear regression. The moving average technique has been used by Berg et al. (2003) and McGinnis et al. (2008). The moving average was carried out using the *filtfilt* function in MATLAB. The beginning and end portions of each burst corresponding to one half the length of the averaging window were used in calculating the moving average, but were not included in flux calculations,

as the data used to calculate the trend for these portions were outside the initial burst. The resulting $\overline{w}$ and $\overline{C}$ values were subtracted from *w* and *C* to obtain *w'* and *C'*.

Block averaging using the statistical mean of *w* and *C* has been utilized previously to establish trends over a burst of data (e.g., Kuwae et al., 2006). The statistical mean, however, does not provide an adequate trend if there is noticeable long-term change or drift in the velocity or concentration over the length of the averaging window. Such conditions were observed in the data collected for this research. Therefore, a linear regression technique, which has been used previously by Brand et al. (2008) and Berg et al. (2009), was adopted. Each burst of data from a particular deployment site was broken down into smaller blocks corresponding to the size of that burst's optimum averaging window. Least squares linear regression was applied to a block of data, producing a "best-fit" line, and the resulting trend was removed to obtain *w'* and *C'*.

2.5.4. Flux calculation

Following trend removal of both *w* and *C*, instantaneous flux was calculated by multiplying *w'* by *C'*, and averaging in time. As shown by Kuwae et al. (2006), large variations in *w'* and *C'* can be reduced by eliminating values greater than three standard deviations above or below the mean for a given block or averaging window. This method was applied to the data in this study, but it was found that despite the removal, large variations in *w'C'* over a block of time still existed, leading to possible artifact in cumulative flux over the given period. Therefore, rather than remove the variations prior to correlation, variations greater than three standard deviations were removed from *w'C'*.

The basis of using three standard deviations was also investigated. According to Laws (1997), data falling within a certain number of standard deviations from the mean can be removed as outliers. Based on a *t* distribution function, 95% percent of the data should fall

within a certain standard deviation range, which varies with sample size. Following this methodology, a data set of only 50 points would require use of a three standard deviation cutoff. Therefore, the use of three standard deviations provides a conservative analysis, since the smallest averaging window used in this study included 1440 data points.

Once instantaneous flux was obtained for a burst of data, the cumulative flux over the entire burst was calculated using a trapezoidal numerical integration method. Assuming stationary, the cumulative flux over a given period can be extrapolated to estimate average daily flux.

2.5.5. Spectral analysis

Spectral analysis was performed on all blocks of flux data to examine the behavior of the data in the frequency domain. This representation shows the distribution of eddy sizes that contribute to the total flux. The MATLAB *periodogram* function was used to obtain power spectral densities for each burst of data. The resulting spectra were cumulated, normalized, and plotted against the log of frequency (Kuwae et al., 2006). Spectra were also produced for flux calculated using uncorrected velocity and for flux calculated with no removal of bad data in order to examine the potential effects of these transformations on the data.

3. RESULTS AND DISCUSSION

3.1. Data processing

3.1.1. DOC concentration

The CDOM to DOC calibration utilizes the fluorometer's dark current value and the first three data points obtained from the calibration. These four points were fit with a linear trend allowing conversion to DOC concentrations up to 6 ppm. Data at higher concentrations deviated from this trend, as CDOM counts began to level off with increasing DOC concentration. This deviation from linearity is likely due to attenuation in the 4-cm light path length between the source and detector. Absorption and scattering interactions can be attributed to bulk optical properties, including chlorophyll, suspended solids, and dissolved organics. For instance, suspended particulate matter are known to have an effect on volume reflectance across the CDOM emission wavelength (Bukata et al., 1995). Other studies have used flow-through fluorometers with in situ filters to measure optical properties in aquatic systems (e.g., Saraceno et al., 2009). Using flow-through fluorometers is not possible in this study, since it will induce advective velocities that interfere with flux measurements. Additional measurements of absorption and backscatter would be required to correct for these issues (e.g., Chen et al., 2004).

3.1.2. Velocity vectors

The validity of the velocity vector rotations was tested by comparing the correlation between C and both the corrected and uncorrected values of w. Correlation was calculated and plotted as a function of filter length, as described for the averaging window determination in Section 3.5.2.

The corrected velocity vector was more correlated with concentration for all but one of the deployment bursts. The ADV pitch and roll data were examined for that burst to determine if there were any anomalies that led to a less correlated corrected velocity for the second burst. However, the mean and standard deviation of the angle of rotation determined from pitch and roll were reasonable.

3.2. Data selection

Visual inspection yielded a total of five bursts from three of the sites for further analysis. The selected bursts account for only 10% of the total data collected during the four deployments. This low percentage of quality data reflects the overall variability in the CDOM concentration as measured with the fluorometer with time in a given measurement volume. High DOC variability (most likely due to advection) over scales shorter than 10 min was typically the controlling factor in eliminating data from further analysis.

The Frankfort and Squamscott deployments took place directly in river channels, where the flow was subject to both tidal influence and continuous current flow. In Kittery the instruments were deployed in a sheltered tidal inlet, and the actual input of freshwater was small in relation to tidal inundation, so riverine currents were not as prevalent as at the other two estuarine sites. There was also no vegetation in the tidal range at the Kittery site, while the banks at the other two estuarine sites were heavily populated by *Spartina* spp., which became inundated at high tide. The Kittery deployment produced the longest periods of steady DOC concentration, which accounted for 28% of that deployment.

The Burton Bog deployment site was characterized by very low horizontal velocities. Low-velocity deep ocean systems have been studied with success (Berg et al., 2009), but these systems exhibited stationary O_2 concentration, which made establishing trends and calculating

O_2 flux feasible. At Burton Bog, DOC concentration was highly variable, suggesting that DOC was controlled by factors other than release from sediment (e.g., due to density driven flows).

3.3. Averaging windows

By examining the correlation between *w* and *C* at different filter window lengths, the window length that will adequately capture turbulent eddies can be estimated. Since the eddy correlation technique depends on the correlation between the two parameters, the correlation coefficient is an indicator of flux contribution, and the filter window length is an indicator of the size of eddies contributing to flux (Tennekes & Lumley, 1972).

Figure 2 shows two typical plots of correlation coefficient vs. filter length. In Figure 2a, correlation reaches a local maximum and then begins to decrease with increasing filter length. In Figure 2b, a local maximum is never reached, so the first inflection point was taken as the optimum filter length. We hypothesize that the inflection point is indicative of a shift in flux contribution from small-scale turbulent eddies to large-scale advective flow. The increase in correlation coefficient at longer filtering lengths beyond the inflection point is likely due to large-scale advection contributing to positive correlation. Similarly, correlation plots that reach a local maximum and then begin to decline illustrate a negative correlation contribution by large-scale advection. By choosing the filter length at the inflection point or local maximum, we attempt to preclude this large-scale influence from the calculation of turbulent eddy flux.

The resulting optimum averaging window lengths for each of the five bursts ranged from 100 s to 337 s, indicating high variability between bursts in the size of eddies contributing to flux. The averaging windows obtained for each burst were utilized to remove trends using linear regression and moving averages, as described in Section 3.5.

3.4. Flux calculation

Following trend removal, cumulative flux was calculated for each data set. Figure 3 shows representative plots of cumulative flux over time for two deployments, calculated both with linear regression and moving average techniques. The cumulative fluxes from each burst were extrapolated to obtain values of average daily flux that are reported in Table 1.

With the exception of the second Frankfort burst, the fluxes calculated for each site using linear regression and moving average techniques are within about 20% agreement with one another. In all cases, trend removal using the moving average technique led to lower flux estimates. Kuwae et al. (2006) noted that block averaging techniques can also lead to errors in flux by omitting low-frequency contributions. The large discrepancy between values for the second Frankfort burst illustrates the inability of the moving average technique to adequately model trends over short blocks of data.

The bursts from Frankfort and Squamscott resulted in net negative flux (Table 1). If correct, negative flux, indicating transport of DOC from the water column into the sediment, could be indicative of a DOC sink at the sediment surface. A potential mechanism for exchange of DOC from the water column into the sediment is adsorption to sediment Fe(III) hydroxide. The data from Brown (2010) show that Fe(III) hydroxide was present at Kittery and Squamscott at the sediment surface and at depth. Cores collected at Frankfort in 2006 by Merritt (2007) also showed Fe(III) hydroxide at the surface and at depth.

It is evident from plots of w and C that even though the three bursts of data from Frankfort and Squamscott were selected by visual inspection, they are not as stationary as the data from the two Kittery bursts (Swett, 2010). This could lead to artifacts in flux calculations if

trends were not adequately calculated. As mentioned previously, the Frankfort and Squamscott deployment sites were characterized by a high degree of heterogeneity. Extensive vegetation in the intertidal zone was inundated at high tide, releasing DOC into the water column. Riverine flow likely carried terrestrial DOC from upstream sources not indicative of sediment release. In addition, the Frankfort and Squamscott sites are characterized by significant sediment transport. During preliminary Frankfort test deployments, substantial buildup of sediment occurred on the face of the fluorometer. ^{7}Be isotope data showed a high degree of sediment mixing at the Squamscott site (Brown, 2010).

During the Kittery flow burst, there are distinct periods of both positive and negative flux within the hour-long burst, as evident from Figure 3. A possible explanation for the changes between positive and negative flux is that the instrumentation is actually measuring the contribution to flux from different areas of sediment. Berg et al. (2007) determined analytical expressions for estimating the upstream elliptical sediment surface area that contributes to the O_2 flux based on surface roughness, water depth, and the height of the instrument. It has been shown that both horizontal and vertical velocities change over time and space in estuarine systems during tidal cycles (Sylaios and Boxall, 1998). Changes in upstream conditions and flow direction would lead to changes in the contributing surface area over time. In addition, Berg et al. (2007) showed that water depth has a significant influence on the size of the contributing footprint, especially at relatively shallow depths such as those present during the Kittery deployment. Therefore, the continuous change in water depth and flow direction due to tides would lead to a varying area of flux contribution. The changes from positive to negative flux seen during the Kittery tidal flow period could be attributed to the contributing sediment surface area changing from net sources of DOC to net sinks.

Kuwae et al. (2006) found that detrending can drastically change total O_2 flux estimates. Results of that study showed that in one case, detrending led to a 94% decrease in flux vs. removal of the statistical mean only. In another case, net flux changed from negative to positive with trend removal. The severity of these discrepancies suggests that not only is trend removal itself important, but the accuracy in establishing the trend for removal is just as crucial (Kuwae et al., 2006). Sharp changes in DOC concentration that occur in the middle of a selected block may be caused by a change in mean concentration, rather than turbulent fluctuations, and therefore will not be adequately removed by linear regression or a moving average. This could lead to significant artifact in flux estimates. As noted previously, mean velocity and concentration must be stationary in order for trends to be adequately removed (Tennekes & Lumley, 1972).

DOC flux estimates captured using eddy correlation for Kittery are an order of magnitude higher than flux values calculated from porewater gradients at that site (Brown, 2010). As mentioned previously, porewater gradients are thought to underestimate the total flux, as they capture only diffusive flux. The results illustrate the ability of eddy correlation to capture contributions to total flux, such as bioturbation, bioirrigation, and porewater advection. Due to the cohesive nature of the sediments at the three estuarine study sites, porewater advection was likely not a contributing factor to DOC release from between sediment grains. However, advection-induced pressure changes may have led to DOC release from burrows at the sediment surface at Kittery. In addition, bioturbation and bioirrigation are likely large contributors to DOC release, as evidence of macrofauna was found throughout the sediment column at this site.

3.5. Spectral analysis

Some studies have used spectral analysis to examine flux measurements in the frequency domain (Brand et al., 2008; Kuwae et al., 2008; Gerbi et al., 2008). For the purpose of this study, spectral analysis was performed on the data, and flux calculations were reassessed based on the resulting spectra. Other studies generally show that frequencies higher than 1 Hz do not contribute significantly to the benthic O_2 flux (Berg et al., 2003; Berg et al., 2009).

However, spectral analysis of DOC flux obtained in this study typically showed significant contribution above ~ 1 Hz (Fig. 4). This high-frequency contribution is indicative of high-frequency noise and not representative of actual flux. Further investigation of the frequency series of the individual components contributing to flux (*w'* and *C'*) showed that the high frequency contribution was from *C'*, while the majority of frequency contribution from *w'* was less than 1 Hz (Swett, 2010). The high signal power in the high-frequency range of *C'* indicates a contamination of the spectrum, likely due to particulate matter in the fluorometer's light path. Additionally, some contribution to signal power of both *C'* and *w'* at frequencies above ~ 1 Hz could be indicative of high-frequency instrument noise, which was determined to be randomly distributed. Uncorrelated noise does not contaminate flux estimates.

Another approach to examining the frequency domain of flux contribution is to perform spectral analysis on *w* and cospectral analysis on *w* and *C* to better illustrate the characteristics of turbulent transport (Brand et al., 2008). The spectrum of *w* was filtered and plotted on a log-log scale to determine the frequency range corresponding with the inertial subrange (Fig. 5a), and the cospectrum of *w* and *C* was accumulated from the high-frequency end (Fig. 5b). The inertial subrange includes frequencies that represent eddies of intermediate length scales that are smaller

than energy-containing eddies and larger than viscous eddies. The velocity spectrum in this subrange is expected to have a -5/3 slope as per Komolgorov's power law (Glickman, 2000). Viscous stress is expected to be small in comparison with Reynolds stress at high Reynolds numbers (Tennekes & Lumley, 1972).

The significant difference between cumulative cospectra for *w'C'* (Fig. 4) and *wC* (Fig. 5b) could illustrate a failure of linear regression to adequately remove trends from DOC concentration data, since spectra for *w'* and *w* were similar to each other. The inertial subrange of the velocity spectrum corresponds with the frequency range of ~ 0.2 to 1.7 Hz. The cospectrum of *w* and *C* shows the majority of contribution in a similar frequency range. The peaks in the velocity spectrum occurring around 0.6 Hz and 1.1 Hz may be due to wave contamination (Gerbi et al., 2008). Removing the points associated with these jumps greatly increased the correlation between the spectrum and the -5/3 slope. This wave contamination may have led to artifact in flux calculation.

To remove the effects of particle-induced high-frequency noise, raw data were low-pass filtered, and flux values were recalculated using linear regression. Since the cutoff of the inertial subrange for *w'* and the beginning of high-frequency C' noise both occurred at ~ 1.7 Hz, flux was calculated for data low-pass filtered to both 1 Hz and 2 Hz. Results are compared with flux obtained from unfiltered data (Table 2). The flux calculated at 2 Hz is expected to include the influence of noise from ~ 1.7 Hz to 2 Hz, which may be highly correlated judging from the considerable differences between flux values at each sampling rate. The flux calculated at 1 Hz is likely omitting some true flux contribution in the 1 Hz to ~ 1.7 Hz range. Representative plots of cumulative flux from the Kittery deployments calculated using 1 Hz data are shown in Fig. 6.

Spectral analysis was also used to look for differences between corrected and uncorrected velocity. Both corrected and uncorrected vertical velocity produced spectra with a similar range of frequencies in the inertial subrange. In addition, the potential effects of the removal of outliers were tested for by computing cumulative cospectra for *w'C'* with no outliers removed. The removal of outliers appeared to have little effect on the cumulative cospectra.

4. CONCLUSIONS

The results of this study demonstrate the potential of the eddy correlation technique for measurement of DOC flux from estuarine sediments. Results also indicate that benthic DOC flux may vary considerably over short time scales. Eddy correlation provides a method for monitoring short-term dynamics of flux, as well as variations on diurnal and seasonal scales. The magnitudes of DOC flux calculated using the eddy correlation technique were an order of magnitude larger than those calculated from porewater gradients obtained from sediment core centrifugation. These values are reasonable, since porewater gradients, which only capture diffusive flux, are expected to underestimate total benthic flux. Moreover, flux estimated from the porewater gradient reflects one location, whereas flux estimated from the eddy correlation technique reflects an average over a larger area.

In heterogeneous environments such as the systems studied here, it is important, yet challenging, to decouple turbulent eddy flux from large-scale advective flux, as advective flow carries DOC from non-benthic sources into the instrument measurement volume. Therefore, the instrumentation captures DOC inputs not only from sediment release, but also from upstream sources, which contaminate the eddy flux measurements. This is especially the case in tidal systems, where inundation of estuarine vegetation can lead to increased production, which might not be indicative of sediment DOC release. The Kittery deployment site was characterized by less heterogeneity than the other estuarine sites, and DOC concentrations were relatively stationary over significant periods of time, making eddy correlation more feasible. Flux estimates may have also been contaminated by suspended particles contributing to noise in CDOM fluorometer measurements.

Since this is the first study to use eddy correlation for benthic DOC flux estimation, further development is necessary to improve methods and verify flux measurements. To this end, the benthic DOC flux obtained using the eddy correlation technique could be validated in laboratory flume simulations. In addition, the effect of suspended particulate matter on the signal attenuation of the CDOM fluorometer should be investigated to determine its influence on eddy flux estimates. Measurement techniques could also be modified to reduce the influence of particles on CDOM readings.

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Table 1. Average daily DOC flux estimates determined using eddy correlation.

Project Site	Time Range (counts)	Window Length (s)	Average Daily Flux (mg m^{-2} d^{-1})	
			Linear Regression	Moving Average
Frankfort	76900-81700	100	-323.3	-352.7
Frankfort	88000-92800	207	-62.6	-304.7
Squamscott	103000-107800	170	-248.9	-299.7
Kittery	8700-37500	174	60.4	55.1
Kittery	127000-141400	337	174.3	143.6
Burton Bog	no acceptable range	-	-	-

Table 2. Values of average daily flux calculated from data at original sampling frequency and lower frequencies.

Project Site	Time Range (counts)	Window Length (s)	Average Daily Flux (mg m^{-2} d^{-1}) Calculated Using Linear Regression		
			8 Hz	2 Hz	1 Hz
Frankfort	76900-81700	100	-323.3	-252.3	-235.0
Frankfort	88000-92800	207	-62.6	-37.6	-66.8
Squamscott	103000-107800	170	-248.9	22.9	94.0
Kittery	8700-37500	174	60.4	-73.7	12.0
Kittery	127000-141400	337	174.3	33.3	118.6
Burton Bog	no acceptable range	-	-	-	-

Figure Captions

Figure 1. Eddy correlation instrumentation setup.

Figure 2. Typical plots of filter length vs. correlation: (a) Plot for Kittery tidal ebb burst showing local maximum (•) at filter length of 337 s; (b) Plot for Kittery tidal flow burst showing inflection point (•) at filter length of 174 s.

Figure 3. Plots of cumulative flux calculated using linear regression and moving average techniques for (a) Kittery flow period burst and (b) Kittery ebb period burst.

Figure 4. Cumulative flux for Kittery flow period burst calculated using linear regression. Trend lines are fit to periods of increasing and decreasing flux.

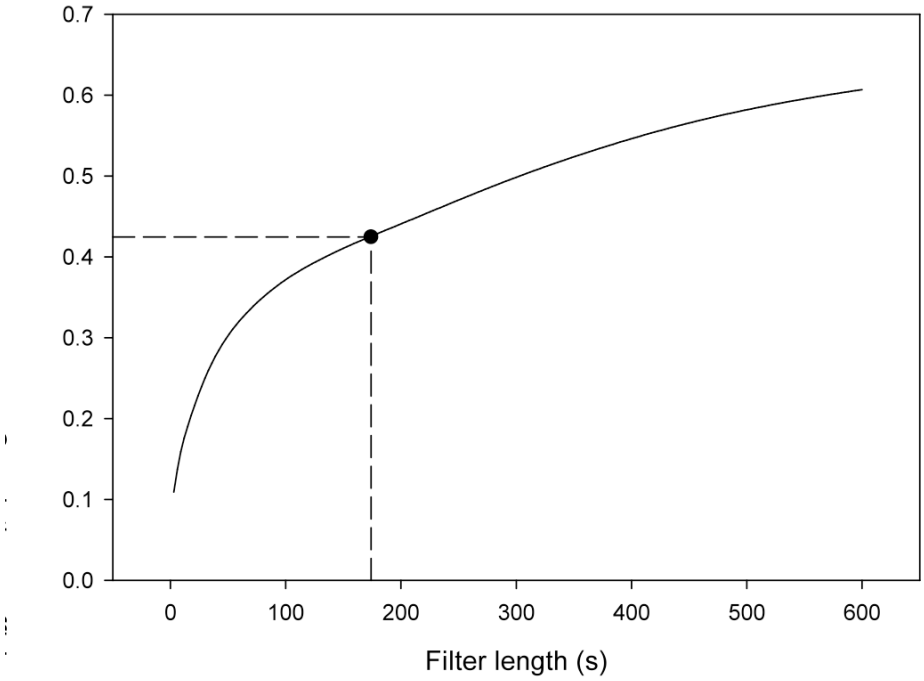
Figure 5. Typical normalized cumulative cospectrum (cumulated from the high-frequency end) of w' and C' for a 174-s block of data from the Kittery tidal flow period in which mean values were removed via linear trending.

Figure 6. (a) Smoothed power spectral density of w, shown with slope of inertial subrange; and (b) normalized cumulative cospectrum of w and C, cumulated from the high-frequency end.

Figure 7. Plot of cumulative flux for (a) Kittery flow period burst and (b) ebb period burst at 1 Hz calculated using linear regression. The value reported at the end of the plot is the cumulative flux for the duration of the burst.

Figure 1.

a.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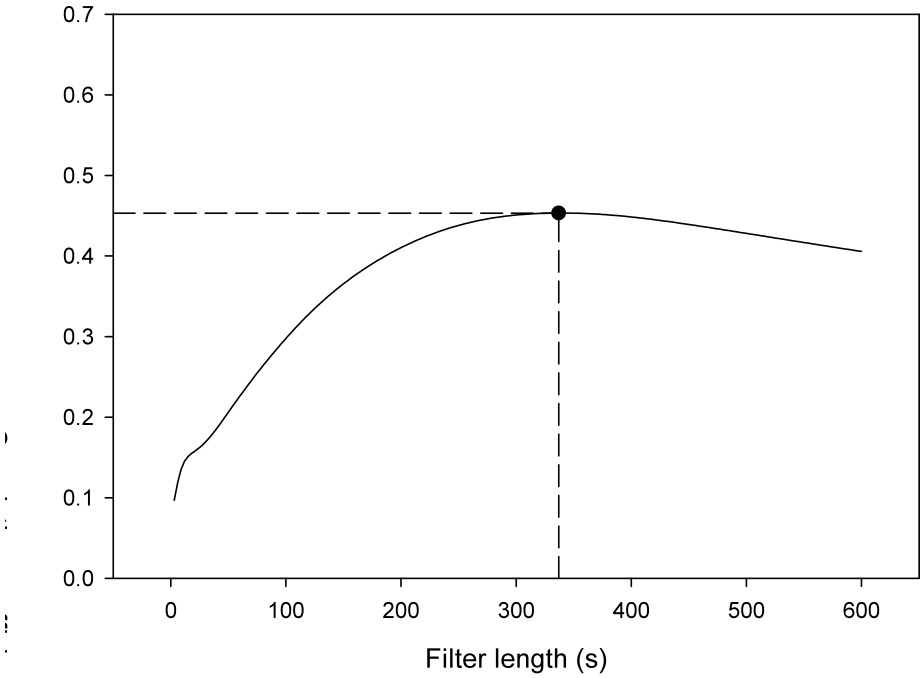
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
100
200
300
400
500
600
Filter length (s)

b.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0.6
0.5
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200
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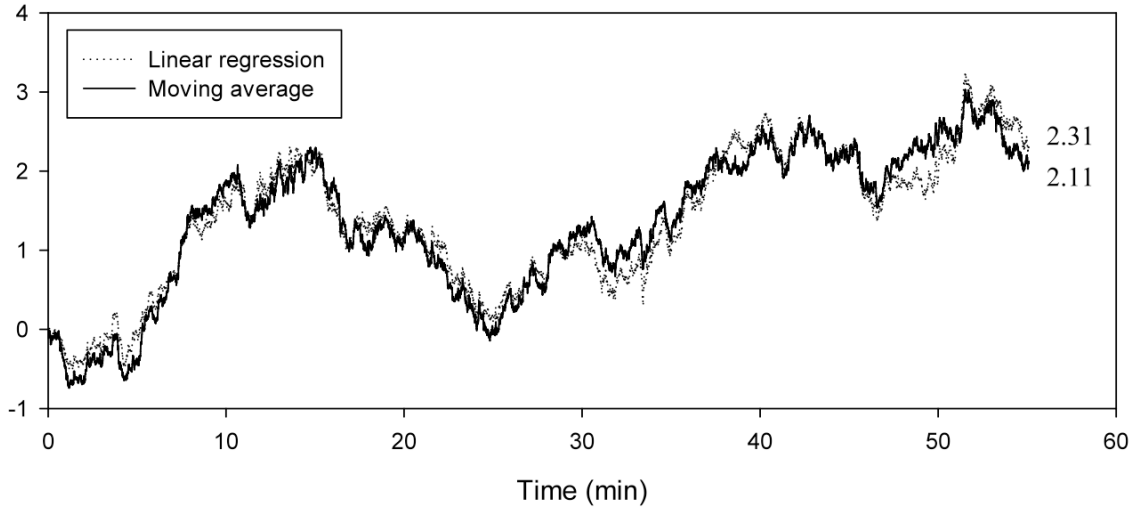
400
500
600
Filter length (s)

Figure 2.

a.


Linear regression
Moving average
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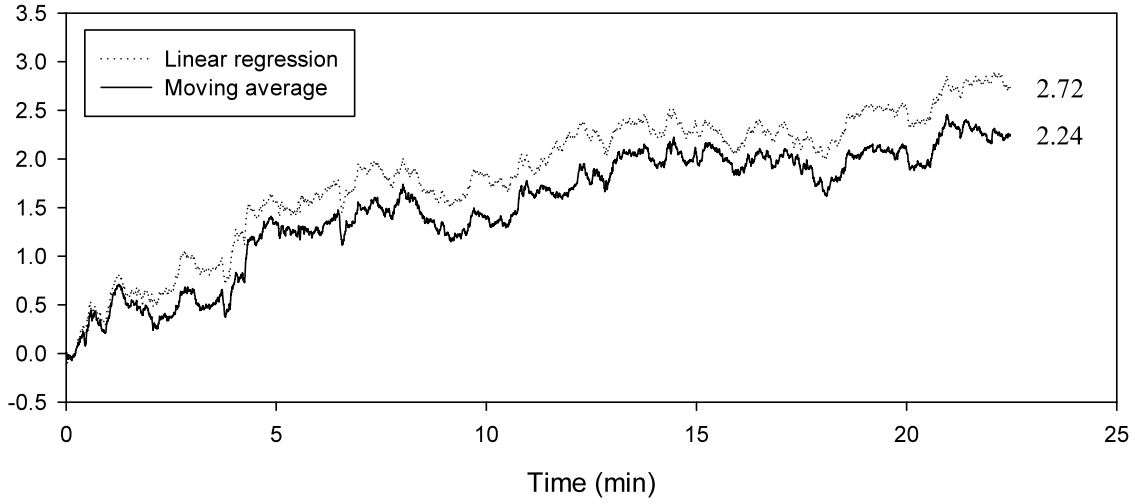
2.11
Time (min)

b.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Moving average
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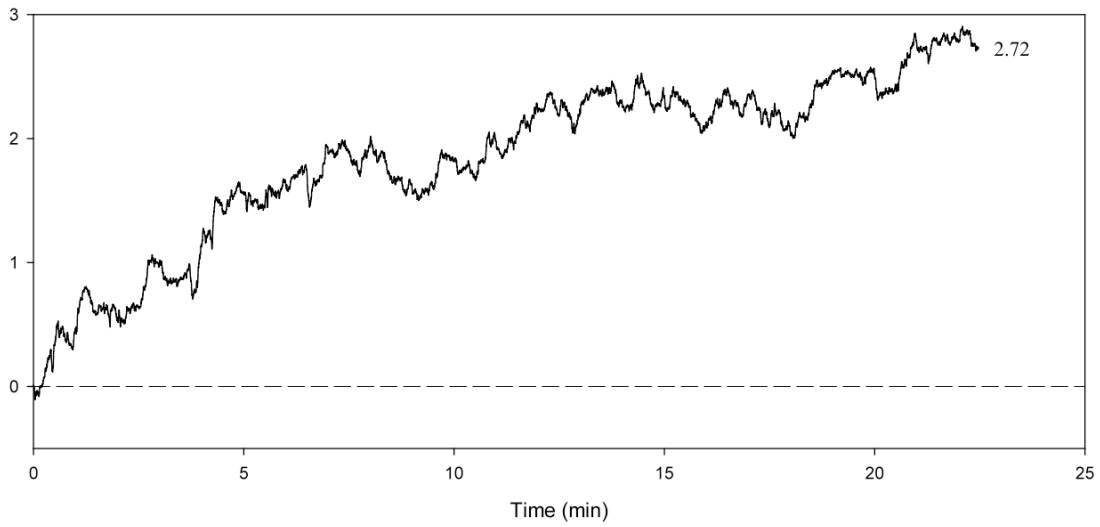
2.24
Time (min)

Figure 3.

a.



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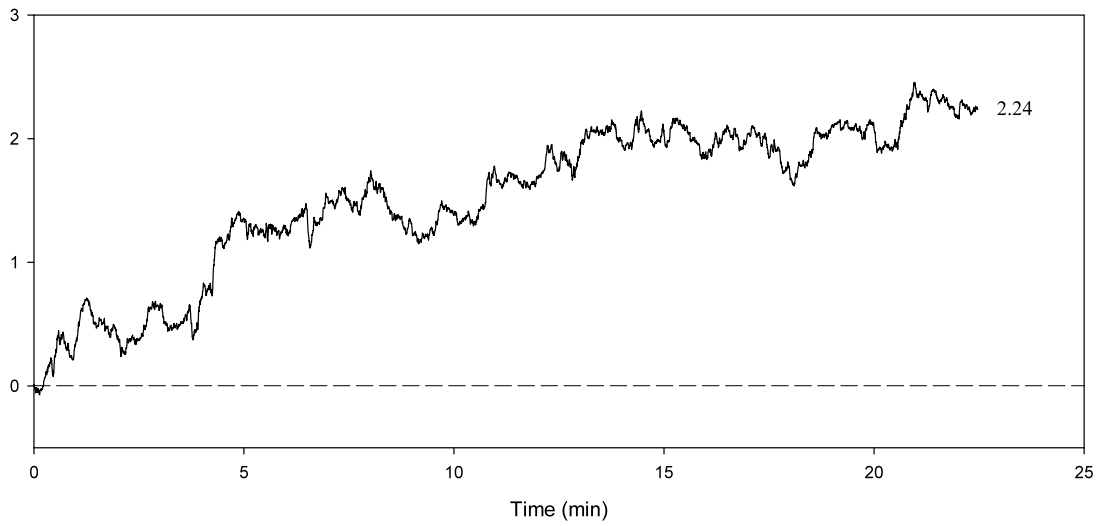

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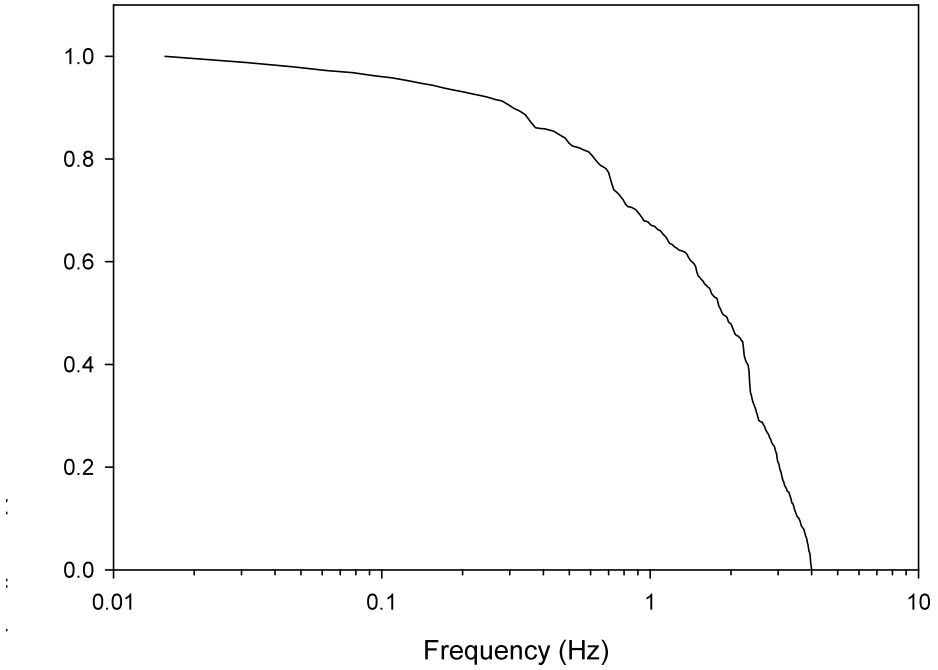

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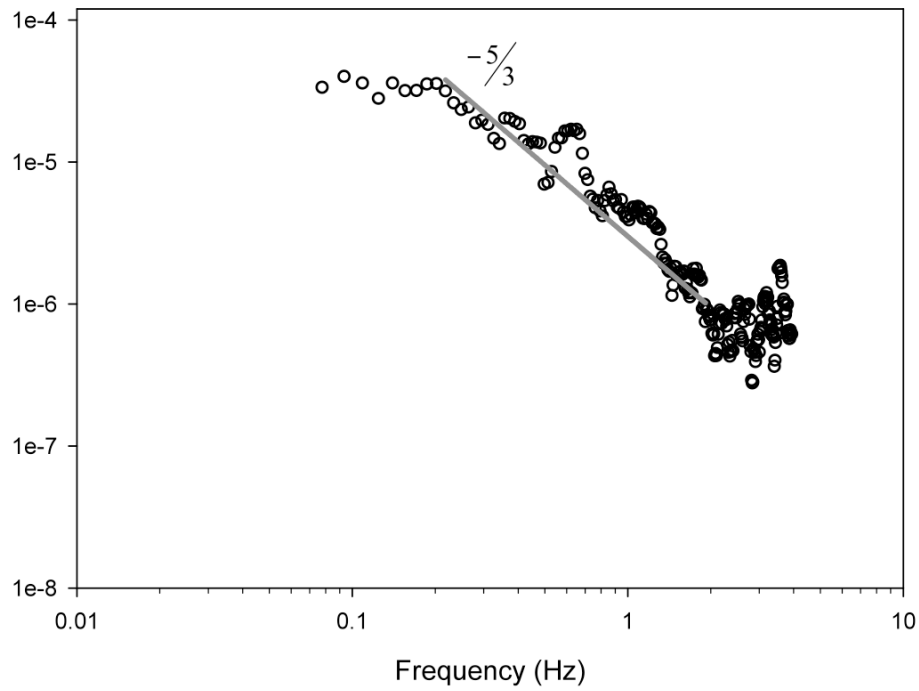
a.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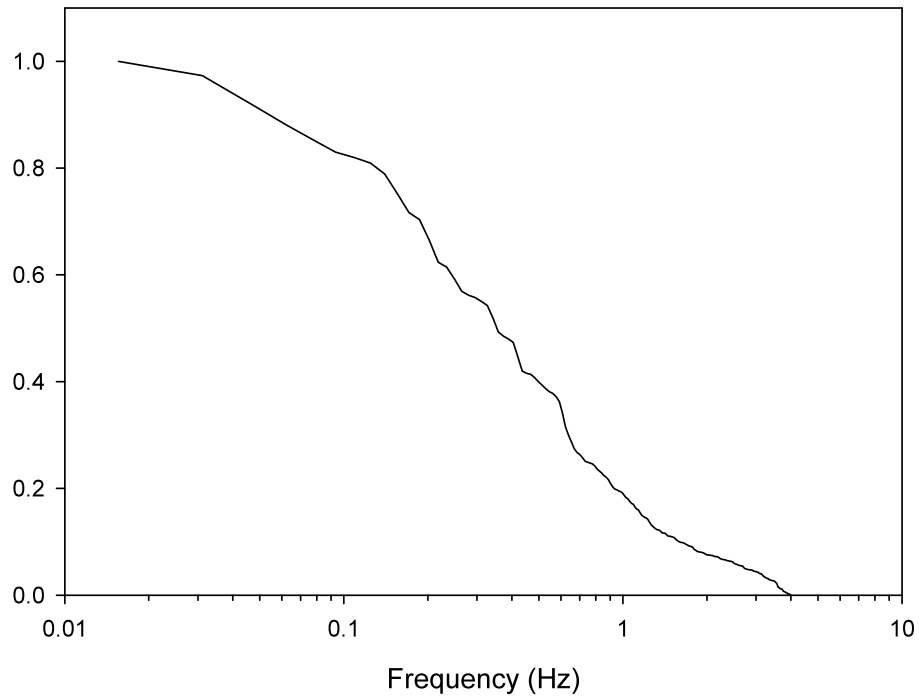
1e-6
1e-7
1e-8
0.01
0.1
1
10
Frequency (Hz)
−5/3

b.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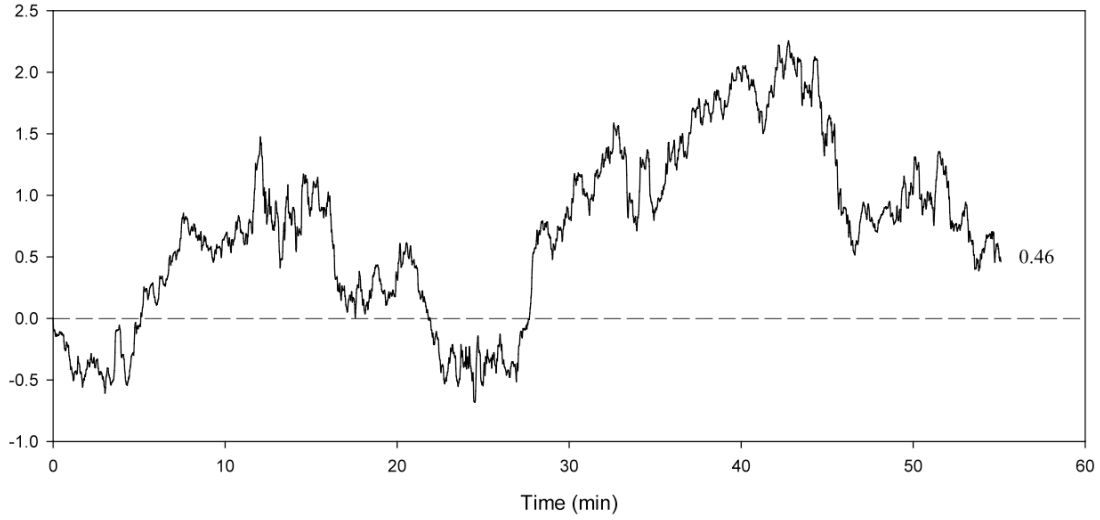
0.8
0.6
0.4
0.2
0.0
0.01
0.1
1
10
Frequency (Hz)

Figure 6.

a,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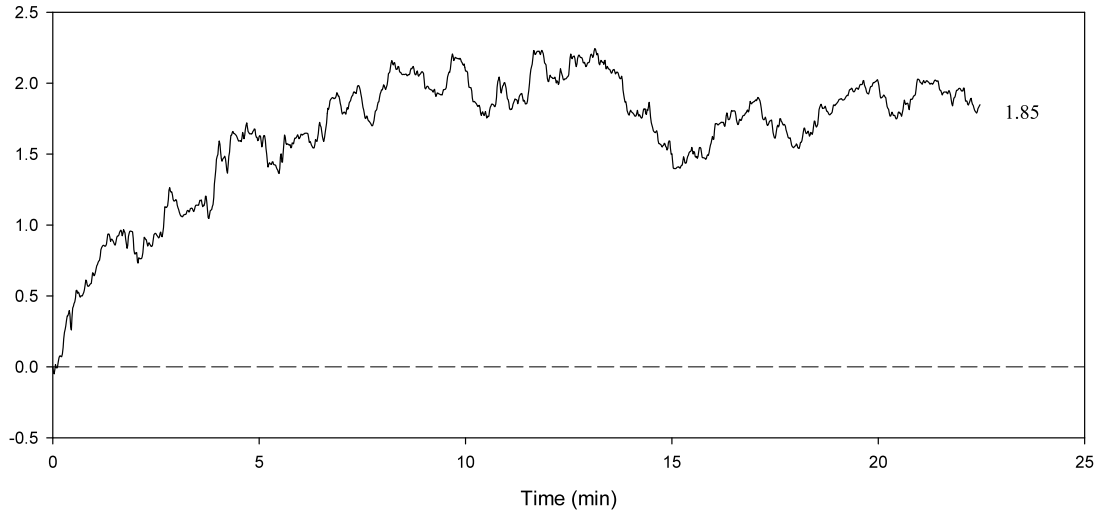
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
10
20
30
40
50
60
Time (min)
0.46

b.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2.0
1.5
1.0
0.5
0.0
-0.5
0
5
10
15
20
25
Time (min)
1.85

Figure 7.

Permaculture Design Research Initiative

Basic Information

Title:	Permaculture Design Research Initiative
Project Number:	2010ME204B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	Second
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Water Quality, Ecology
Descriptors:	None
Principal Investigators:	Joline Blais, Owen Smith

Publications

There are no publications.

MWRRI Report
Permaculture Research Design Initiative

PI: Prof. Joline Blais
Grad Student: William Giordano

Backyard UMaine stormwater infiltration at 5 Chapel due to broken conduit, April 2011

1. Problem and Research Objectives

Maine's DEP guidelines for stormwater management and design through Low Impact Development (LID) provide invaluable incentives towards effective site-specific retrofits that have stimulated the practice of restoration ecology and non-point source pollution control. However, many factors make the implementation and Best Management Practices (BMPs) burdensome to implement. Despite many documented successes in stormwater management and restoration ecology through interdisciplinary design research and community based initiatives, Maine boasts minimal efforts aimed at local citizen stakeholders and low tech collaborative practices that are the hallmark of permaculture practices. Permaculture techniques and local stakeholder involvement, along with educational and artistic approaches, provide alternative entry points to addressing these problems. The objective of our research was to synthesize these elements and produce a low-cost model of an educational, artistic and permaculture-based solution to ecological issues that arise with non-point source stormwater infiltration. We wanted to lay the groundwork for a distributed network of citizen scientists on a small scale, working in tandem with experts to address their backyard ecological issues.

2. Methodology

Permaculture is a design system for sustainable human habitats based on ecological patterns and cycles. (Holmgren 2002) Along with ecological benefits, this interdisciplinary approach to designing resilient ecosystems has the potential for socio-economic and cultural benefits within the human community. No matter the outlook on non-point source pollution, every household has at least one stakeholder. Therefore the majority of stakeholders are not professionals or academic researchers in the field; yet they represent a critical population able to play a vital role in protecting water resources. Permaculture design systems (like vegetative buffers and edible forest gardens) prioritize the natural system/human system interface, and design strategies that incorporate such

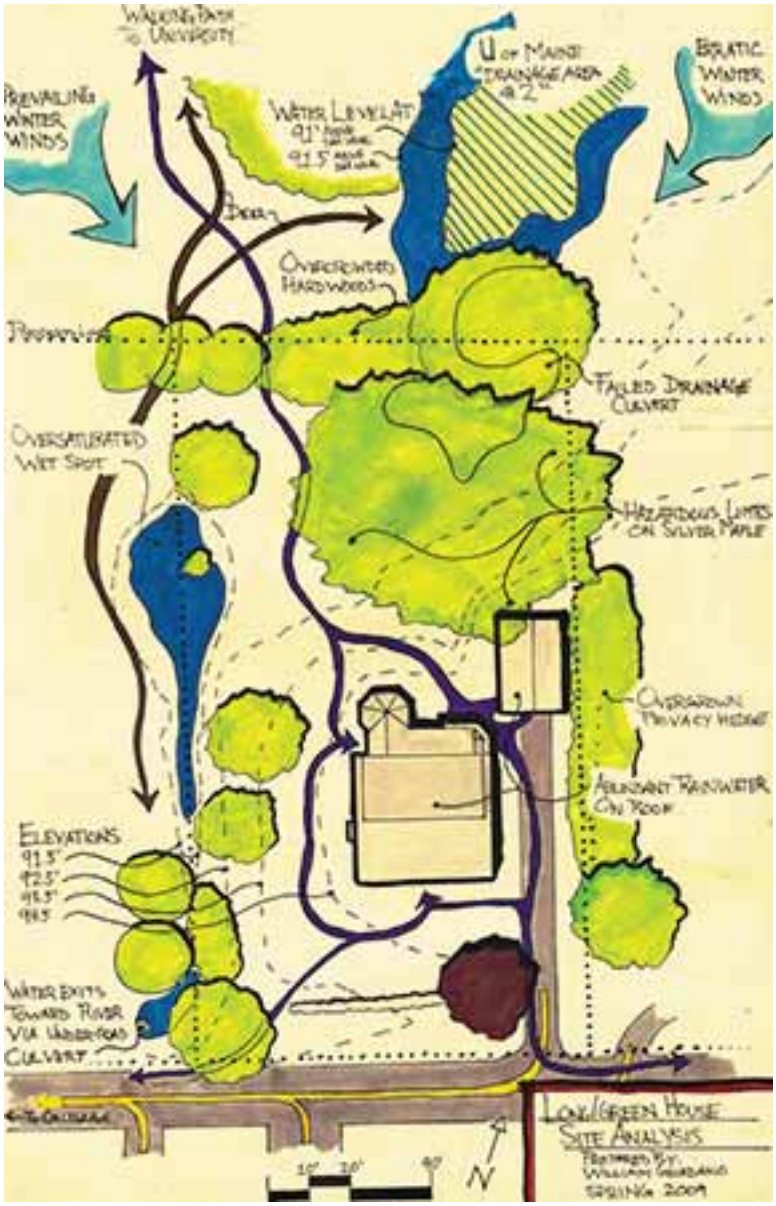
practices to meet a myriad of biological needs while maintaining a “restoration for resilience” methodology. (Mollison 1997)

The *LongGreenHouse* (LGH) project offered a site burdened with stormwater issues, but with a history of permaculture education initiatives designed to address the landscape needs in a holistic way. Past LGH strategies have included public eco-charettes, multi-age elementary school and community workshops, university courses and projects tied to community assets, and advising and teaching by Wabanaki elders. Over the past year we have continued to engaged our local community--from UMaine undergraduate journeypersons to UMaine Intermedia art students, from neighbors affected by stormwater infiltration to engineers with tools to help address the potential solutions.

In the fall, with our live-in journeypersons, we offered a series of community workshops, and invited local neighbors into a discussion with students, engineers and artists. Through the winter, we synthesized research about soil composition, wind patterns, zone sectors, filter plant properties and needs, and human uses. In consultation with our permaculture consultants Charles and Julia Yelton, we created a permaculture design document that outlines strategies for effective vegetative buffers and edible forest food production designed to address both the site stormwater issues and educate students and community members. In the winter, to bring more attention to this work, a team of Intermedia artists (grad students in the IMFA program) launched *Aurono Borealis*, a public art performance including storytelling by a snow-encircled bonfire, an interactive LED light and music performance engaging guests, and a "slow food" potluck dinner featuring local produce. In the spring, we presented the permaculture design document at the 2011 Maine Water Conference in Augusta, the Peace & Justice Center of Eastern Maine's *Hope Festival* in Orono, and we also published it on our blog: http://longgreenhouse.org/permaculture/ . Finally, we held three "April Garden days" on site to initiate the implementation of the permaculture design.

In addition to neighbors with backyards affected by university stormwater, stakeholders who became involved with our project on varying levels include *Sustainable Orono*, one of over a hundred world-wide Transition Town-based initiatives; *Still Water Permaculture Guild*, a UMaine journeyperson program involving 7 students; UMaine work-study students; UMaine New Media undergraduates; UMaine Intermedia graduate students; UMaine *Permaculture Club*; members of UMaine's *Green Team*; and a local YMCA garden program. In addition to gathering feedback during our live sessions, we documented our process and solicited feedback on our blog. Our goal was not just to distribute information generated by our team of experts, but also to inspire local 'backyard stakeholders' to experiment with some of our techniques and suggestions and generate feedback, creating a small scale *distributed* network of citizen scientists.

3. Principal Findings and Significance

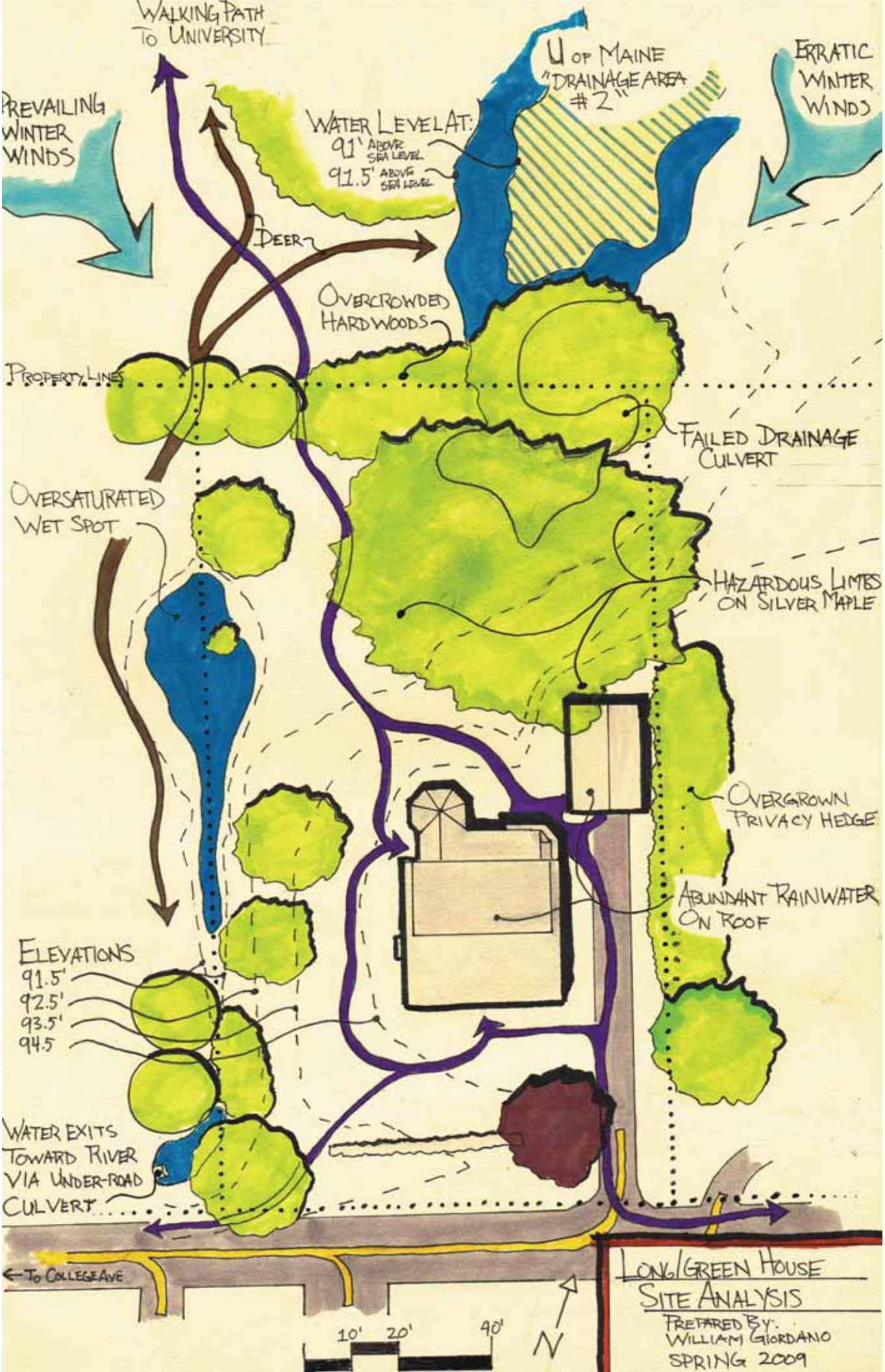


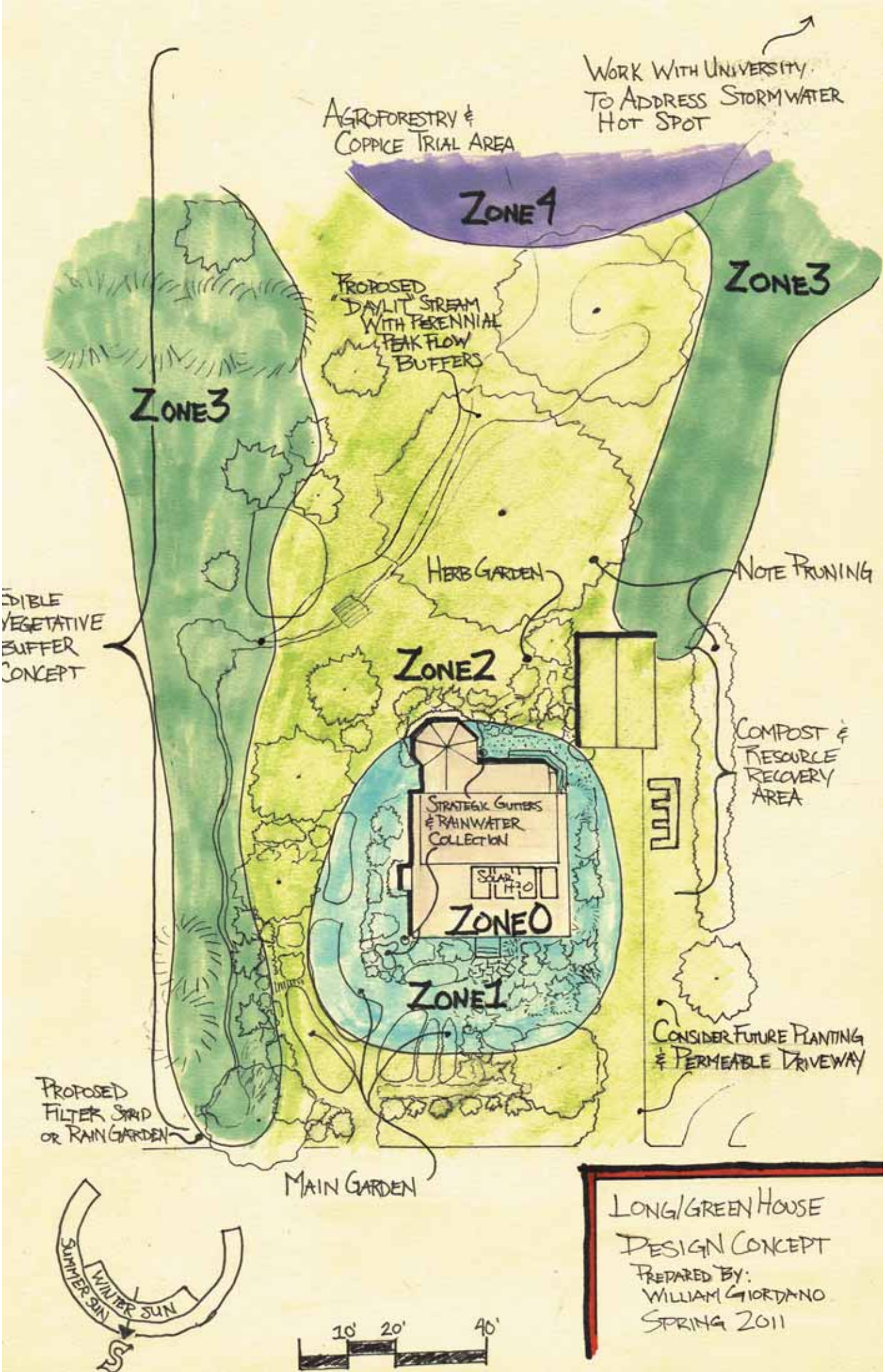
Site Analysis of Long GreenHouse area showing stormwater zone

The PDRI design (see attached) documents the strategic relationships at play in a localized ecology, and suggests LID strategies that steward the overall health of the area. The design document consists of detailed landscape drawings, site maps, site analysis (soils, plants, water issues, sun angles, wind, and climate concerns), recommended plants, timeline for implementation, materials list, cost analysis, and detailed instructions for the transformation of an unmanaged stormwater wetland zone into a water filtration and food production zone. Of specific interest are two LID strategies: 1) using food producing plants as vegetative buffers, and 2) planting grassed filter strips for stream restoration. Both respond to over saturated areas with seasonal stream flow. The combination of these two highlighted LID strategies has created a variety of interdisciplinary potentials that may be the focus of future project phases.

The focused methodology and outcome described above assumes the agent is the community, not the developer. The PDRI design published on our blog thus outlines low-cost, easy to implement solutions, and conveys permaculture zone systems to help the audience better understand how much interaction takes place in certain area. The 'Site Analysis' documents research that was completed on site and takes into consideration the pattern and “programs of use” overlapping in the landscape.

Based on the interest we received from lay and expert stakeholders alike, our work confirmed that edible forest gardens can be an engaging tool for managing stormwater and overall watershed health by successfully balancing human need with ecological integrity. Well established permaculture principles can create incentives for landowners and grassroots community groups to address localized issues that have a negative impact on watershed health. This could be considered a specific type of LID that may help address negative impact on a small scale. Some such issues could be improper storm-water design, over-saturation of residential areas due to development, lack of vegetation, and storm-water "hot-spots" that contribute to degraded health of water bodies, etc. The team theorizes that the process of permaculture design for distributed solutions would be of benefit for any projects, landowner, affinity group etc. where there is interest in addressing watershed health while balancing cultural, economic and ecological incentives. We hope that this research will inspire not only educators but also administrators at UMaine to support permaculture and citizen stakeholder approaches to address their multiple point stormwater issues, and that a variety of similar projects can address the need for *distributed* solutions to the many "backyard watershed issues" in our community and across the state.


WALKING PATH TO UNIVERSITY
U OF MAINE "DRAINAGE AREA #2"
ERRATIC WINTER WINDS
PREVAILING WINTER WINDS
WATER LEVEL AT:
91' ABOVE SEA LEVEL
91.5' ABOVE SEA LEVEL
DEER
OVERCROWDED HARDWOODS
PROPERTY LINES
FAILED DRAINAGE CULVERT
OVERSATURATED WET SPOT
HAZARDOUS LIMBS ON SILVER MAPLE
OVERGROWN PRIVACY HEDGE
ABUNDANT RAINWATER ON ROOF
ELEVATIONS
91.5'
92.5'
93.5'
94.5
WATER EXITS TOWARD RIVER VIA UNDER-ROAD CULVERT
← TO COLLEGE AVE
10' 20' 40'
N
LONG/GREEN HOUSE
SITE ANALYSIS
PREPARED BY:
WILLIAM GIORDANO
SPRING 2009


WORK WITH UNIVERSITY TO ADDRESS STORMWATER HOT SPOT
AGROFORESTRY & COPPICE TRIAL AREA
ZONE 4
ZONE 3
PROPOSED "DAYLIT" STREAM WITH PERENNIAL PEAK FLOW BUFFERS
ZONE 3
HERB GARDEN
NOTE PRUNING
EDIBLE VEGETATIVE BUFFER CONCEPT
ZONE 2
COMPOST & RESOURCE RECOVERY AREA
STRATEGIC GUTTERS & RAINWATER COLLECTION
SOLAR H2O
ZONE 0
ZONE 1
CONSIDER FUTURE PLANTING & PERMEABLE DRIVEWAY
PROPOSED FILTER STRIP OR RAIN GARDEN
MAIN GARDEN
SUMMER SUN
WINTER SUN
S
10' 20' 40'
LONG/GREEN HOUSE DESIGN CONCEPT
PREPARED BY: WILLIAM GIORDANO
SPRING 2011

PLANT LIST CONT'D

24. CHAMOMILE
25. NETTLE
26. HYBRID HAZELNUT
27. HIGHBUSH CRANBERRY
28. BLACK BEAUTY ELDER
29. JOSTABERRY
30. STRAWBERRY
31. ANNUAL VEGETABLES
32. PERENNIAL VEG.
33. ROSA RUGOSA
34. BEACH PLUM
35. FLOWERING QUINCE
36. EVERBEARING RASPBERRY
37. HIGHBUSH BLUEBERRY
38. BUTTERFLY BUSH
39. SOLOMON'S SEAL
40. HYSSOP
41. TRAILING SAGEBRUSH
42. WINTERBERRY
43. MAXIMILLIAN SUNFLOWER

10' 20' 40'

LONG/GREEN HOUSE
2011 PLANTING DESIGN
PREPARED BY: WILLIAM GIORDANO

SECTION 1 OF 3

PLANT LIST CONT'D

4. CHOCOLATE MINT
5. ARNICA
6. PURPLE CONEFLOWER
7. YARROW
8. KAGA PLUM
9. MAYPOP VINE
10. HORSERADISH
11. MARJORAM
12. ST. JOHN'S WORT
13. AZALEA
14. ROSEMARY (POTTED)
15. HARDY KIWI VINE
16. THYME
17. PEAR
18. RED WILLOW
19. PUSSY WILLOW
20. AMERICAN PLUM
21. SIBERIAN PEASHRUB
22. APPLE
23. LILAC

* - PLANT REFERENCE IN SECTION 3

PLANT LIST

1. BUTTERNUT
2. MIXED PLANTING:
   - BEE BALM
   - COREOPSIS
   - PURPLE CONEFLOWER
   - GOLDENROD
3. WILD GINGER

Fish Scales as Non-Lethal Biosensors of Surface Water Contaminants

Basic Information

Title:	Fish Scales as Non-Lethal Biosensors of Surface Water Contaminants
Project Number:	2010ME214B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	second
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Methods
Descriptors:	None
Principal Investigators:	Rebecca Van Beneden, Sharon L Ashworth, Adria Elskus, Julie Ann Gosse, Brian Perkins

Publications

There are no publications.

WRRI FY10 FINAL REPORT

Title: Fish Scales as Non-Lethal Biosensors of Surface Water Contaminants

Principal Investigators:

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ABSTRACT

There is great need for non-lethal, biologically relevant screening tools for assessing the effects of surface water contaminants on threatened or endangered fish species. Typical screening procedures are highly invasive or lethal to the fish. Recent studies show that fish scales biochemically respond to a range of contaminants, including toxic metals, organic compounds, and endocrine disruptors. Fish scales can be collected rapidly and non-lethally from fish, and are regularly collected by state and federal agencies, such as NOAA, DMR, and IFW. The overall goal of our work is to evaluate fish scales as non-lethal biosensors for pharmaceuticals, organic contaminants, endocrine disruptors, metals, and contaminant mixtures. In this study we used cytochrome P4501A (CYP1A) as a biomarker for exposure to organic contaminants (Meyers, 2009; van der Oost et al. 2003; Quiros et al. 2007). Our hypotheses were that 1) biomarkers in fish scales can be used as contaminant biosensors and 2) these biomarkers are reliable in contaminant mixtures. We used Atlantic salmon (*Salmo salar*) as the test species. Atlantic salmon are an endangered diadromous fish, the smolts and adults of which migrate through polluted areas. Our project objectives were to 1) establish protocols for fish scale collection, storage, and biochemical analyses, and 2) evaluate biomarker induction in scales of *S. salar* exposed to contaminants. We have determined that the pollutant biomarker, cytochrome P4501A (CYP1A)) is 1) inducible in scales of Atlantic salmon (*Salmo salar*) parr aqueously exposed to polychlorinated biphenyls and polynuclear aromatic hydrocarbons, 2) is expressed in the epidermal covering of these scales as well as in scale osteocytes, and 3) is reliably and sensitively measured using RNA isolated from fish scales that can be stored indefinitely after scale collection. We optimized isolation of high quality RNA from fish scales for use in quantitative (real-time) reverse-transcriptase polymerase chain reaction (qRT-PCR) assays to detect fish exposure and biochemical response to chlorinated and polynuclear aromatic hydrocarbon contaminants. The strength of the scale assay is that it provides an *in vivo*

biosensor of fish response (e.g. scales from wild-caught or caged fish can be used as first pass sensors to evaluate water quality in a given habitat). This technique could be used with any scale-bearing fish species. Screening for contaminants using fish scales provides a rapid, inexpensive, non-lethal and biologically relevant first pass indicator of water quality for sensing the presence of bioactive chemicals in surface water and the exposure to such compounds by endangered and threatened fish species.

INTRODUCTION

Recent nationwide surveys report a wide spectrum of xenobiotics in US surface waters, including toxic metals, chlorinated organics, polynuclear aromatic hydrocarbons and pharmaceuticals (Kolpin et al. 2002; Brigham et al. 2009). Pharmaceuticals are of particular concern because of their extraordinary potency at very low concentrations (Triebskorn et al. 2007), with aquatic organisms at the greatest risk because of their chronic, lifelong exposure to these chemicals. The US EPA has recognized the potential for suborganismal biomarkers as surrogates for chronic toxicity testing (Sanderson et al. 2009).

The sensitivity of fish to trace concentrations of contaminants, including pharmaceuticals, is well documented. In a 7-year whole-lake dosing study low pptrillion (5-6 ng/L) levels of ethinylestradiol (EE2), a potent xenoestrogen used in birth control and hormone replacement therapy, led to the complete collapse of a resident fish population (Kidd et al. 2007). The anti-depressant fluoxetine disrupts feeding in fish at pptrillion concentrations with acetycholinesterase activity likely inhibited at concentrations far lower (Stanley et al. 2007; Gaworecki et al. 2008). The anti-inflammatory, diclofenac, induces kidney lesions and gill necrosis in trout and carp at environmentally relevant concentrations (Triebskorn et al. 2007). The main source of pharmaceuticals to surface waters is through wastewater (Fent et al. 2006), and Maine, as do many states, bases its effluent limits on EPA's National Recommended Water Quality Criteria, criteria that currently do not include pharmaceuticals, despite their bioactivity, constant input via effluents, and their ability to bioaccumulate in fish, including fluoxetine (Brooks et al. 2005).

Mercury (Hg) levels in Maine surface waters approach, and in some instances exceed, those associated with adverse health effects in fish. Although these levels (0.09-7.01 ng total Hg/L) (MDEP 1999) are well below US EPA freshwater water quality criteria for Hg (1400 ng/L (acute) and 770 ng/L (chronic)), the state regulates on much lower standards (0.3 ng/L - 0.8 ng/L) (MDEP 2001). Moreover, Hg levels in fish in Maine rivers (0.07 – 0.11 mg/kg wet weight for brook trout, 0.23 - 0.87 mg/kg for bass (Mierzykowski et al. 1998)), approach and in some species exceed, the 0.2 mg/kg wet weight 'tissue threshold effect level' for mercury considered protective of adult and juvenile fish (Beckvar et al. 2005).

Surface waters commonly contain mixtures of chemicals (Kolpin et al. 2002), an important consideration in biosensor testing as chemical co-exposure can alter contaminant-specific

responses. For example, arsenic inhibition of estrogen-responsive vitellogenin upregulation (Davey et al. 2007), and cadmium and methylmercury suppression of estrogen receptor expression in fish scales (Suzuki et al. 2004), indicate interactive effects between water-borne metals and hormones are likely. However, mixture effects are notoriously difficult to study due to the innumerable combinations and concentrations of chemicals.

Atlantic salmon have been in serious decline for the past 100 years. The last remaining wild stocks in the United States are in Maine where they are endangered (NationalResearchCouncil 2004). Their decline is likely due to several stressors, including toxicants (NationalResearchCouncil 2004). Fish-based, non-lethal biosensors that detect trace levels of both legacy and emerging chemicals (e.g. pharmaceuticals) and could be used with threatened and endangered species would provide powerful first-pass tools for rapid evaluation of potential water quality issues.

We evaluated the response of scales collected non-lethally from an endangered Maine species, Atlantic salmon (*Salmo salar*), exposed to aquatic contaminants commonly found in surface waters in the US, polychlorinated biphenyls and polynuclear aromatic hydrocarbons. We demonstrate that CYP1A mRNA is a highly sensitive indicator of fish exposure to water-borne, toxic organic pollutants which can be measured with very high sensitivity, and non-lethally, using scales from exposed fish.

APPROACH

Materials

All solvents were high purity, pesticide-grade from Fisher Scientific (Pittsburg, PA) and clear polyethylene bags used for fish exposure were purchased from VWR (West Chester, PA). Co-star and Nunc microtiter plates were obtained from Fisher Scientific, 7-ethoxyresorufin, resorufin ethyl ether, and all buffers and biological reagents were obtained from Sigma-Aldrich (St. Louis, MO). Tricane methanesulfate was obtained from Argent (Redmond, WA). Beta-naphthoflavone and 3,4,3’,4’,5’-pentachlorinated biphenyl (PCB126) were obtained from Ultra Scientific, Inc (N. Kingstown, RI). All reagents used for PT-qPCR were obtained from Qiagen, Inc. (Valencai, CA).

Fish: Source and Maintenance

Juvenile land-locked Atlantic salmon (*Salmo salar*) were obtained from Grand Lake Stream hatchery (Maine) and maintained at the University of Maine Aquaculture Research Center. Fish were held in flow-through tanks at seasonally appropriate temperatures and light cycles and fed daily with trout chow provided by the hatchery. Fish were anesthetized with buffered tricaine (MS222) prior to removal of scales using a small, dull-edged metal spatula. MS222 does not affect the activity of biotransformation enzymes in fish, including CYP1A (Kolanczyk et al.

2003). The ability to store scales indefinitely in RNALater™ for molecular assays (e.g. RT-PCR) makes scales ideal for field-collection (manufacturer's protocol).

Fish Exposure

Atlantic salmon parr were exposed to the organic contaminants 3,4,3',4',5-pentachlorobiphenyl (PCB126) and β-naphthoflavone (βNF). In each experiment, fish were statically exposed in 20 L aerated bags to aqueous doses of PCB126 (0.3, 3.27 and 32.7 ppb), βNF (330 ppb), vehicle (40 ppb acetone) or no treatment for 48 hours with 3 to 5 fish per bag per dose, depending on the experiment.

Endpoints

We used three endpoints to evaluate CYP1A in fish scales: enzyme activity, protein location, and gene (mRNA) expression. Catalytic analysis of scale CYP1A is the most rapid way to determine if the induction of CYP1A is successful prior to conducting more time consuming analyses. To confirm the induction of CYP1A enzyme activity, we used the ethoxyresorufin-o-deethylase (EROD) assay, with 15 scales per well, 3 wells per fish in a 96-well plate format, using 7-ethoxyresorufin as the substrate, essentially as described (Elskus et al. 1999).

To determine whether CYP1A is expressed in fish scale osteocytes or the epidermal covering of the scale, we used immunohistochemistry (IHC) analysis. We collected three 2 cm^3 skin samples and one small snip of liver tissue, fixed these in formalin and had them paraffin embedded and sectioned (5 micron thick) by the University of Maine's Aquatic Animal Health Diagnostics Laboratory. We performed the IHC analyses at the Woods Hole Oceanographic Institution in the laboratory of Dr. John Stegeman under the supervision of Bruce Woodin. Three sets of slides were cut, and stained with hematoxylin and eosin (to establish tissue architecture), probed with MOPC 31 (non-specific antibody), or MAb 1-12-3 (CYP1A specific antibody), essentially as described (Kloepper-Sams et al. 1987; Elskus et al. 1999). The H&E stained tissue layers were identified using Amin et al. 1992. The anti-body probed sections were examined under a light microscope and antibody signal was scored for "Occurrence" (0-3) and "Intensity" (0-5) of staining, with final scores calculated as "Occurrence X Intensity" (0-15), as described (Elskus et al. 1999).

To measure scale CYP1A gene (mRNA) expression, we used quantitative real time polymerase chain reaction (qRT-PCR). Scales removed from treated fish were placed in RNAlater™, which allows indefinite storage at -20 C. We extracted RNA from the scales (30+ scales per sample per fish) and reverse transcribed the RNA to cDNA. We identified *S. salar* specific primers and optimized qRT-PCR parameters for *S. salar* (CYP1A and β-actin primer concentration and cDNA template concentration). Amplified scale CYP1A cDNA was quantified using the method of Pfaffl (Pfaffl 2001).

RESULTS

Scale Architecture

The scales are arranged in an imbrication pattern, each partially encased in an epidermal 'pocket' that is partially retained when the scale is removed (Fig 1). *CYP1A catalytic activity*

CYP1A activity

As expected, CYP1A enzyme activity was induced over controls in the scales of βNF- and PCB126-treated fish, with a strong dose-response evident in PCB126-treated fish (Fig 2). This established CYP1A response in the fish scales, allowing us to proceed with IHC and qPCR analyses.

CYP1A protein location

CYP1A protein staining was present in all skin tissue layers (epidermis, scale, dermis, fat, and muscle) and in the liver of βNF- and PCB126-treated fish (data not shown). CYP1A protein staining was strong and consistent in the epidermal covering of the scale (Fig. 4). Although we observed staining in the vicinity of the scale bone in some samples, we believe this to be a staining artifact, due to physical 'trapping' of stain precipitate by the circuli of the scales, with only a few osteocytes exhibiting true binding of the CYP1A Ab. The quantification of the CYP1A signal in the osteocytes is thus artificially high as we could not reliably distinguish 'trapped' antibody from true staining (Fig. 4).

Scale CYP1A mRNA expression

We identified 30 as a sufficient number of scales for extracting good quality, high yield RNA from salmon scales. An earlier paper (Quiros et al. 2007) used 1 – 3 scales per fish, however our trials with fewer scales (1 – 10) produced low yield, poor quality RNA (data not shown).

Scale CYP1A gene expression was elevated in all treated fish relative to the controls, with a strong dose-response in the scales of PCB126 treated fish (Fig. 5).

DISCUSSION

Scale CYP1A enzyme activity is readily inducible in PCB126- and βNF-treated fish and is easily measured using the EROD assay, but ultimately EROD is not a field friendly assay. Meyers (2009) reported rapid (hours) and sustained (34 days) induction in scales from *S. salar* exposed to PCB126 for 24 hours. We confirmed rapid induction of scale CYP1A activity by organic contaminants. Unfortunately, the need for rapid analysis of enzyme activity (within 24 h of scale collection, Meyers, 2009) makes scale CYP1A enzyme activity unsuitable for field-collected samples.

The strongest CYP1A signal in scales is clearly in the epidermal tissue surrounding the scales and not in the scales themselves. The aryl hydrocarbon receptor (AhR), which regulates CYP1A induction, is expressed in the osteocytes of mouse bone cells (Wejheden et al. 2010), but AhR expression in fish scale osteocytes is unexplored. We observed unmistakable CYP1A staining in many scale osteocytes of contaminant-treated fish, indicating that like mouse bone, it is likely AhR is expressed in the osteocytes of fish scales. Work in fathead minnows identified CYP1A expression in chondroid cells (hyaline cartilage), which are associated with skeletal formation (Lindstromseppa et al. 1994; Iwata et al. 2000), but we know of no other work investigating CYP1A or AhR expression in fish bone cells.

We demonstrated that CYP1A gene expression in scales is strongly induced by organic contaminants. Scale CYP1A mRNA expression was elevated 1,500-4,000 fold over controls in juvenile salmon aqueously exposed for 48 hours to 330 ppb βNF using 30 scales/sample. In the only other comparable study published to date, scale CYP1A mRNA expression was induced 10 to 50 fold over controls in goldfish (*Carassius auratus*) injected intraperitoneally with 50 mg βNF/kg (50,000 ppb) with signal measured 8-72 h post-exposure using 1-3 scales/sample (Quiros et al. 2007). This difference could be due to species, route of exposure, exposure time, dose, number of scales extracted, and quality of the RNA extracted. Our work is the first to report scale CYP1A mRNA induction by a chlorinated inducer (PCB126) and demonstrates strong dose-response to this toxicant.

Our work demonstrates that scale CYP1A mRNA is a sensitive indicator of fish exposure to organic contaminants that is non-lethal, field-friendly (i.e. scales can be stored indefinitely prior to processing), and easily measured.

We are continuing this project and will next evaluate CYP1A mRNA expression in scales of Atlantic salmon exposed to the pharmaceutical fluoxetine (Prozac). To evaluate scales as biomarkers for other prominent contaminant classes we will evaluate scale biomarkers for endocrine disruptors (estrogen receptor (ER) mRNA, Pinto et al. 2009) and toxic metals (metallothionein (MT) mRNA, Suzuki et al. 2004)).

Because fish are exposed to mixtures of contaminants, which can alter the expression of biomarkers in various ways, we will evaluate mixture effects on scale CYP1A, ER, and MT mRNA expression. We will evaluate our mixture results based on published interactions that indicate metals can inhibit ER mRNA expression (Suzuki et al. 2004) and estrogens can inhibit CYP1A mRNA expression (Navas et al. 2001).

Chemical-specific biomarkers do not currently exist for any pollutant, and thus can only be used to identify the likely classes of chemicals in contaminated waterbodies. We selected CYP1A as a biomarker based on its low, nearly non-detectable expression level in un-impacted fish. In isolation, this endpoint, like any biomarker, is not necessarily indicative of toxic effects. Rather, induction points to potential problems with water quality, triggering in-depth water chemistry

analysis targeting the chemical classes inducing these endpoints. Scale biosensors are not meant to identify contaminant concentrations, except in a relative sense (absence/presence, low/high concentrations). While biochemical responses to toxicants may differ among tissues, the strength of any sensor lies in its ability to respond to the chemicals of interest.

Fish scale CYP1A mRNA assay developed here provides a new tool for water quality assessment by providing a rapid, non-lethal and biologically relevant toxicant biosensor that can be readily used by a broad variety of researchers. Many agencies, including NOAA Fisheries and the Maine Department of Marine Resources, routinely collect scales for aging and other purposes, a subset of which can be stored cryogenically for later analysis of contaminant exposure. Because scale biosensors could potentially be used with any scale-bearing fish, they could allow rapid identification of which fish species are being exposed to contaminants, in what part of their geographic range, and, for diadromous fishes, whether exposure is occurring during migration to-, or return from-, the sea. Field-verification of the scale CYP1A mRNA biosensor is needed before this sensor is truly 'field-ready' for detection of specific locations and species as 'hot-spots' that can be targeted for more expensive chemical analyses.

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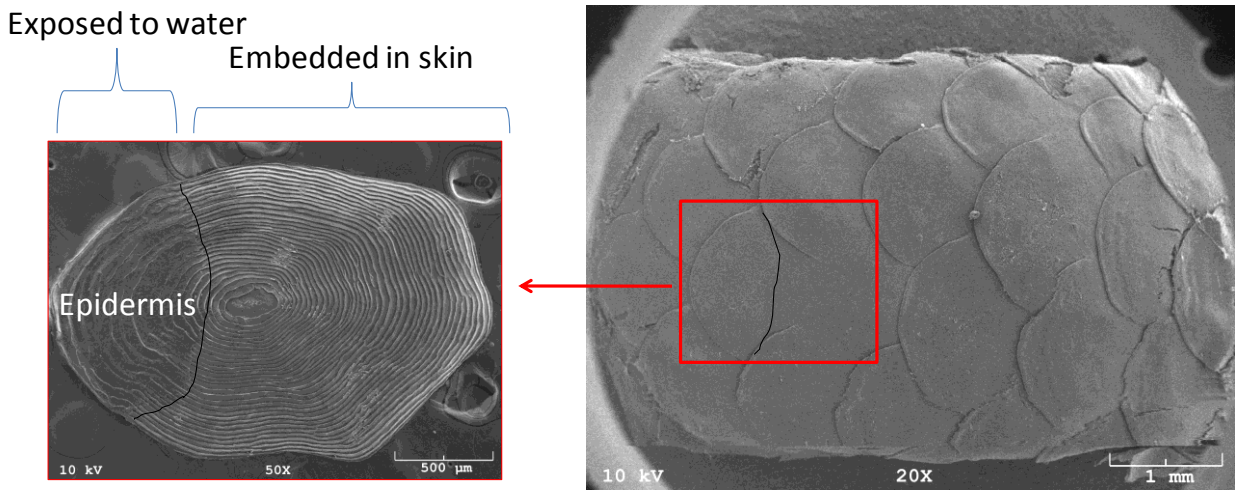


Figure 1. Light microscope (left) and scanning electron microscope (right) images of *S. salar* scale (left) and skin sample (right) . Black line indicates extent of epidermal covering left on scale after removal. Images courtesy of E. Kelly, University of Maine.

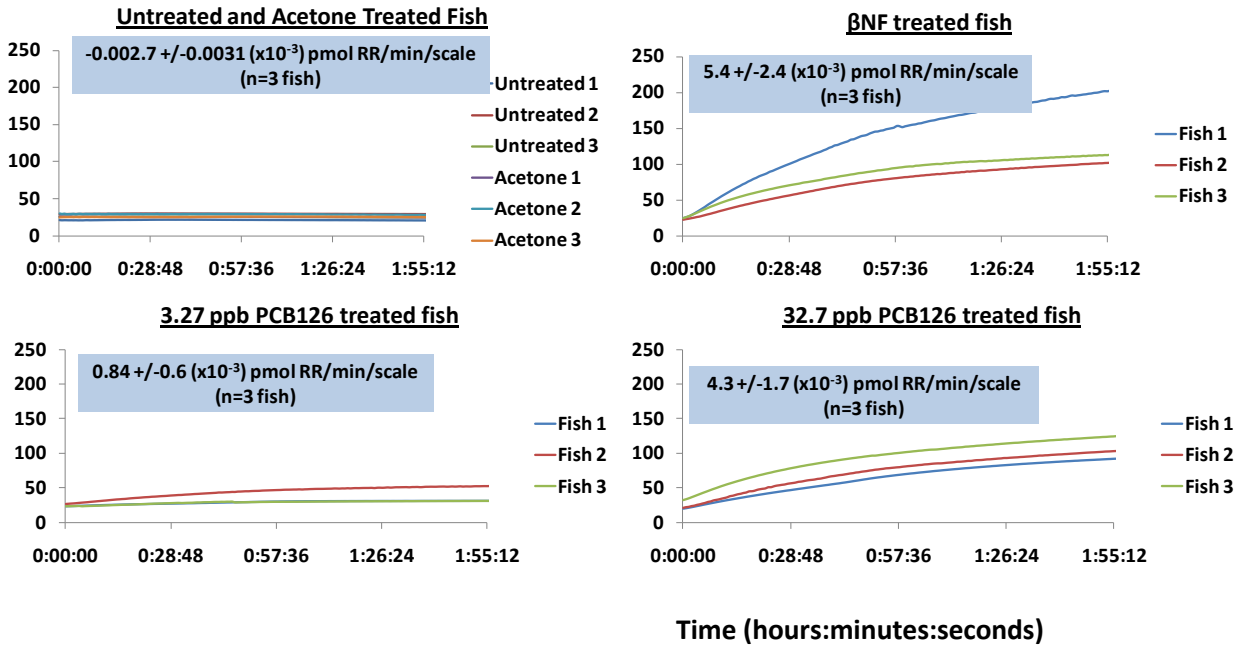


Figure 2. Representative CYP1A activity profiles of *S. salar* scales (15 scales/well; 3 wells/fish) from fish exposed for 48 hours to vehicle (acetone), PCB126 (3.27 or 32.7 ppb) or BNF (330 ppb) in the water. Y-axis is relative fluorescence units x 1000.

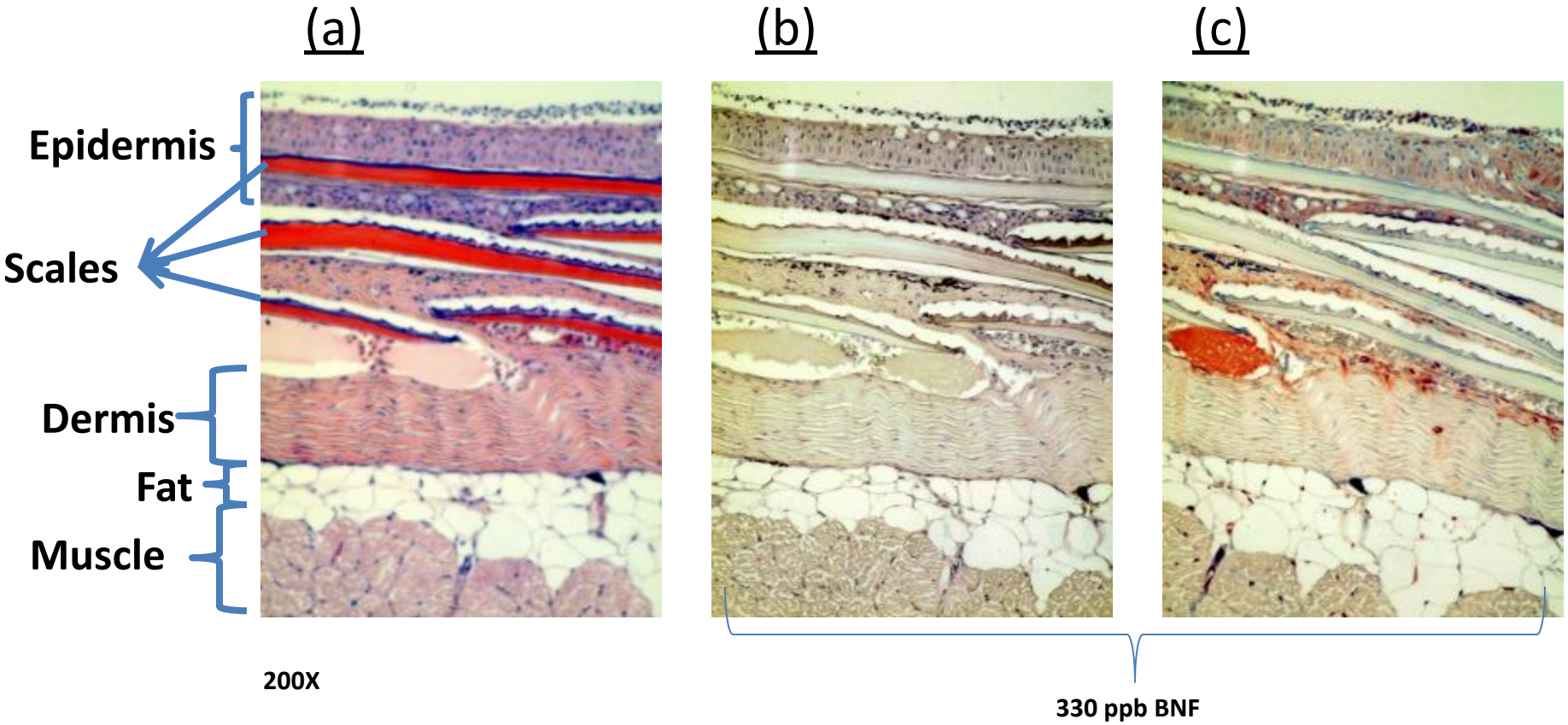
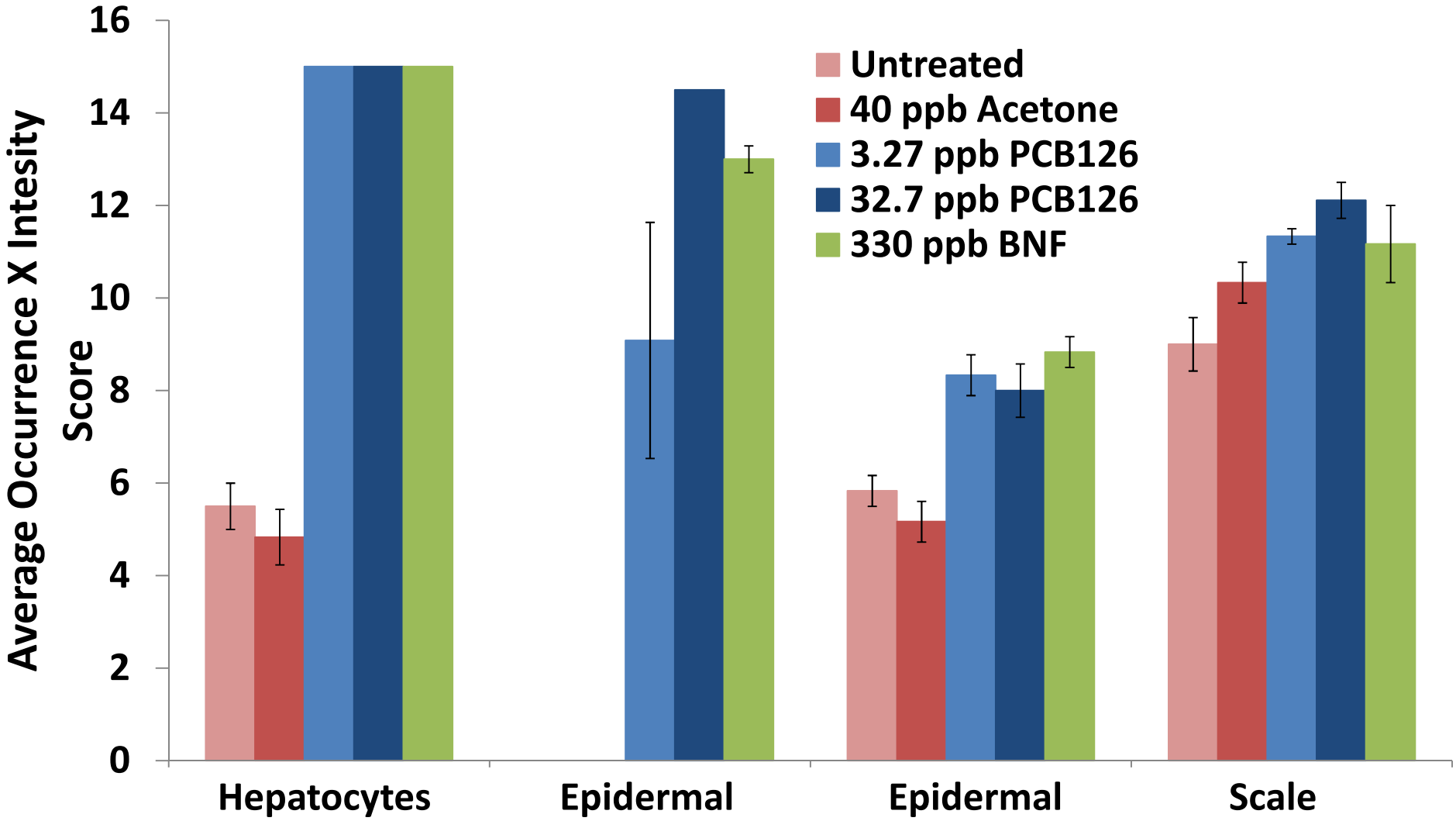


Figure 3. Histology sections (5 microns) of skin of salmon exposed to 330 ppb BNF. (a) hemotoxlin and eosin stain, (b) non-specific antibody MOPC31, (c) CYP1A specific antibody Mab 1-12-3.

IHC quantification



Mean +/- SEM (n=3)

Figure 4. Quantitation of CYP1A immunohistochemical signal in select tissue layers from skin of salmon statically exposed to waterborne chemicals for 48 hours . Means +/- SEM (n=3 fish).

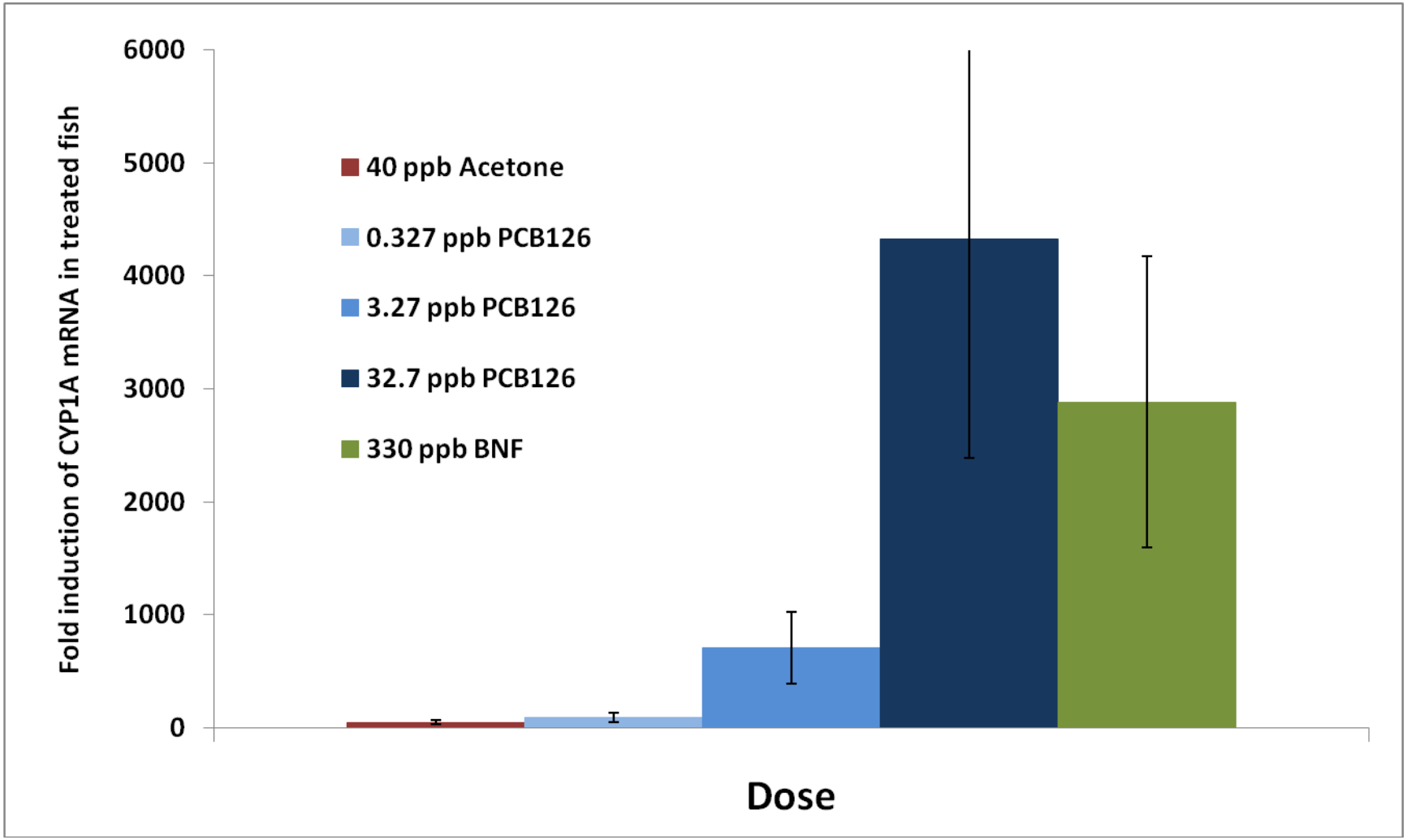


Figure 5. CYP1A mRNA expression fold induction in treated fish relative to controls. CYP1A mRNA values normalized to β-actin mRNA using the Pfaffl (2001) method. Mean +/- SE (n=5 fish).

Database development to support spatiotemporal analysis of coastal Maine mercury data

Basic Information

Title:	Database development to support spatiotemporal analysis of coastal Maine mercury data
Project Number:	2010ME216B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2nd
Research Category:	Water Quality
Focus Category:	Geochemical Processes, Toxic Substances, Non Point Pollution
Descriptors:	None
Principal Investigators:	Kate Beard, Melinda Diehl

Publications

There are no publications.

WRRI FY2010 Final Report

Database development to support spatiotemporal analysis of coastal Maine mercury data

Project duration. March 1, 2010 to February 28, 2011

Principle investigators

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Abstract.

The project funds supported a PhD student for the development of a database that synthesized two decades of coastal Maine mercury (Hg) research across many different sample media. Numerous studies on Hg have been carried out in Maine with widely varying spatial and temporal scales. These disparate, legacy data sets are valuable resources from which Hg sinks and sources across multiple ecosystem pools can be identified and potentially quantified. With thorough metadata development, data contextualized with landscape and climatological factors, and GIS integration of spatial features, we are now equipped to explore spatiotemporal patterns and test hypotheses relating to patterns among upland and estuarine ecosystem Hg. Outcomes of this research include the populated database available for future Hg assessments, public resource brief summarizing coastal Maine Hg monitoring efforts, means to define effective monitoring strategies for Hg, and the basis for expanding this spatiotemporal analysis beyond the coastal area.

Problem Summary and Research Objectives

Sources of Mercury (Hg) to Maine's water and soils have been reduced due to effective environmental regulations, but Hg contamination is still considered a significant problem. Hg concentrations in Maine aquatic biota are still among the nation's highest due in part to the global transport of Hg in the atmosphere. The threat of Hg exposure to human health has prompted widespread fish consumption advisories across most of the United States and Canada.

For decades, high amounts of Hg in Maine prompted research on Hg in atmospheric deposition and in the landscape. Monitoring changes in Hg levels in the environment has been complicated by a lack of historical data, differences in methods and experimental design among projects, and the differences in Hg concentrations across different scales. Numerous studies on Hg have been carried out in Maine with widely varying spatial and temporal scales. These disparate, legacy data sets are valuable resources from which Hg sinks and sources across multiple ecosystem pools can be identified.

Due to the creation of a geospatial database of legacy abiotic and biotic Hg samples, questions on spatiotemporal patterns within Hg legacy data can be explored. Additionally, this project provided the foundation of a PhD student's research and will provide data to support future funding prospects.

The proposal's objectives were to:

1. Develop, compile, and standardize metadata for available legacy Hg datasets
2. Contextualize Hg data spatially and temporally by landscape, climatological, and time factors to aid in comparison among multiple ecosystem Hg pools
3. Characterize the spatiotemporal patterns in Hg concentrations by landscape and seasonal contexts
4. Test hypotheses using the coordinated database, particularly relating to patterns among upland and estuarine ecosystem Hg.

Methodology

This project compiled, contextualized, characterized and analyzed the legacy Hg data on local (MDI) and regional scales. We assembled and georeferenced data from several independent research projects including Hg samples from precipitation, throughfall, streams, soils, litterfall, invertebrates, amphibians, fish and birds. These data form the basis for estimated Hg pools in specific landscape settings.

UMaine facilities used for the this project were the Geographic Information Science (GIS) computer lab in the Department of Spatial Information Sciences and Engineering, and the Sawyer Environmental Chemistry Research Laboratory. ArcGIS software and spatial analysis toolboxes. Matlab, S-PLUS, and MS Access were utilized.

<u>1. Develop, compile, and standardize metadata.</u> The Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata (CSDGS) was implemented for the available data where it had not yet been done. Because of the legacy Hg data source diversity, there were a few special considerations. Much of the landscape data for the area were referenced using UTM Zone 19N, NAD 1983, and thus data were converted to the UTM coordinate system.

Laboratory and field methods for Hg analysis that changed during 1990-2010 were noted within the database. To date, several project leaders and research authors have been contacted regarding the quality of the available Hg information, leading to the reclassification, correction, or exclusion of some data. Gathered QA/QC information on particular sample sets was incorporated as CSDGS compliant metadata for each included data set.

2. Contextualize Hg data spatially and temporally. This project collated available Hg data for the MDI region, with the understanding that while not immediately relevant to the project objectives, the inclusion of data will ensure availability in a common format. Hg sample data loaded into a GIS database included sample data properties (time stamps, original project name, research personnel, and ancillary data associated with a particular measurement). For example, a record of a fish from Jordan Pond contained data on fish length, which tissue was sampled, what time of year it was caught and the concentration of Hg. We linked the sample to the lake and catchment layers within the GIS database. Data on land use, fire history, climatic events (drought, storms), seasonal and annual cycles will be added to the GIS database to help build a spatial and temporal contextual framework for the sample data. Thus by extension the fish sample was linked to catchment events such as fire history.

3. Characterize spatiotemporal patterns. Once the database was populated with the Hg data sets, we began to assess the spatial extent and density of samples. Our investigation confirms that sample locations of available data are spatially non-random and clustered, in part by individual experimental designs. Appropriate statistical techniques (not requiring random, normally-distributed data) are currently being assessed.

4. Hypothesis Testing. Previous research relating abiotic Hg concentrations to those in fish and birds used correlation and linear regression models to explain spatial variation and predict Hg concentrations. Soil and lake Hg data was related to fish, bird, and amphibian data collected on MDI using non-parametric and multivariate statistics to analyze variables extracted from our relational database. By defining the mobility of Hg from atmospheric deposition, through the terrestrial and aquatic landscapes and into wildlife, we have provided a tool for hypothesis testing with legacy data.

Principle & Significance

We have applied an informatics approach to a geochemical problem: while more data is always better, we were able to gain more information than we had already from the data we already had. Recent work in creating spatiotemporal datasets for Hg has illustrated the difficulty in selecting comparable data within particular or across several ecosystem Hg pools. Data from monitoring networks are often standardized in some way to limit sampling method bias, resulting in the potential underestimation or changes in the variance of Hg contamination. Many times, data that don't "fit" are discarded in larger databases. Strategies (such as adding a Z-score property for each datum, providing the basis for comparison across scales) were implemented in our work to increase the flexibility of data management.

Student training

This proposal funded co-investigator Melinda Neville's PhD research, specifically providing the basis for thesis chapters and defining data gaps for future research. During the WRRI funding period, Melinda achieved PhD Candidacy by passing her oral and written

comprehensive exams. We are currently preparing a research proposal to better define the sensing parameters of commonly used Hg biosensors as a result of the WRRI funded work.

Accomplishments

- Metadata development for disparate spatial and temporal Hg data for coastal Maine, thereby increasing the information usability and potential.
- Georeferenced database combining the legacy Hg data contextualized with landscape and climatic factors that may influence Hg concentrations across multiple ecosystem Hg pools.
- Journal article and thesis chapters in preparation discussing the effectiveness and limitations GIS-based tools to identify spatio-chemical and temporal patterns in Hg data.
- Foundation for continued research on effective, GIS-compatible monitoring of Hg contamination in Maine

Citations resulting from this work

Neville, M. and Beard, K. 2010. Mercury flux estimation in the coastal North Atlantic using bivalves as *in vivo* bioindicators. Oral presentation at the NSF IGERT Summer Institute, University of Maine, Orono ME. June 10, 2010.

Neville, M. and Beard, K. 2011. Spatiotemporal database integration of mercury research in Maine. Oral Presentation at the Maine Water Conference, Augusta, ME. March 16, 2011.

Neville, M. and Beard, K. 2011. Geospatial analysis of mercury data in coastal catchments. Accepted Abstract for the 10th International Conference on Mercury as a Global Pollutant (ICMGP), Halifax, Nova Scotia, Canada, July 24, 2011.

Neville, M. and Beard, K. 2001. Analysis of mercury contamination in a coastal ecosystem using geospatial tools. Ecosystems (in preparation).

Phosphorus Dynamics in Androscoggin Lake, Wayne and Leeds, Maine

Basic Information

Title:	Phosphorus Dynamics in Androscoggin Lake, Wayne and Leeds, Maine
Project Number:	2010ME225B
Start Date:	6/14/2010
End Date:	8/13/2010
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Nutrients, Sediments, Surface Water
Descriptors:	None
Principal Investigators:	John M. Peckenham

Publications

There are no publications.

Phosphorus Dynamics in Androscoggin Lake, Wayne and Leeds, Maine

Start Date: June 14, 2010
End Date: August 13, 2010

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Faculty Advisor: Peter Lea
Bowdoin College Geology Department
plea@bowdoin.edu

Congressional district: Maine 1st District

Final Report: Preliminary data from Bowdoin College studies in the past two years suggest that Androscoggin Lake and its watershed are dynamic, with significant stratification/mixing events within the water column and variations in through-flow of water that influence TP concentrations directly, and potentially indirectly by impacting rates of internal loading from bottom sediments. Data collected for this project confirm this suggestion. Temperature records taken using HOBO data loggers show that in the deep central basin of Androscoggin lake the water column was stratified (Figure 1) while in the shallow northwest basin of the lake the water column was mixed for the majority of the summer during which this project was conducted. Bi- weekly sampling with a YSI 6600 water-quality sonde gives a more detailed, but less-frequently sampled view compared to the submersible temperature loggers, of stratification and of oxygen concentrations near the lake bottom (Figure 2). In the deep central basin of Androscoggin lake water reached anoxic conditions in the late summer. Secchi depth readings, taken bi-weekly, coupled with Chlorophyll data from the YSI give a better understanding of possible chlorophyll activity in the central deep basin (Figure 3). In the Northwest basin the Secchi disc was visible to the bottom of the water column for nearly all measurements.

Sediment cores were collected from the lake, and duplicate cores were incubated under lake water to measure phosphorus fluxes: one set with air gently bubbled into the overlying water, and another set with nitrogen gas to induce anoxia (cf. Steinman et al., 2004, *Journal of Environmental Quality* 33, 2040-2048). By the end of the summer proper methodology was resolved for inducing oxygenated and anoxic conditions, and for removing overlying water with the given conditions, soil types, and tools. They remain intact for upcoming research on the lake.

This project has provided insight into phosphorus dynamics in Androscoggin Lake by coupling measurements of water quality and phosphorous concentrations and by deriving a technique for measuring phosphorus release rates under controlled conditions at Bowdoin College. Further work on this project will allow for investigation of the lake's responses to weather and storm flow variations in the area and of the movement of water bodies and of phosphorous throughout, and in and out of the lake.

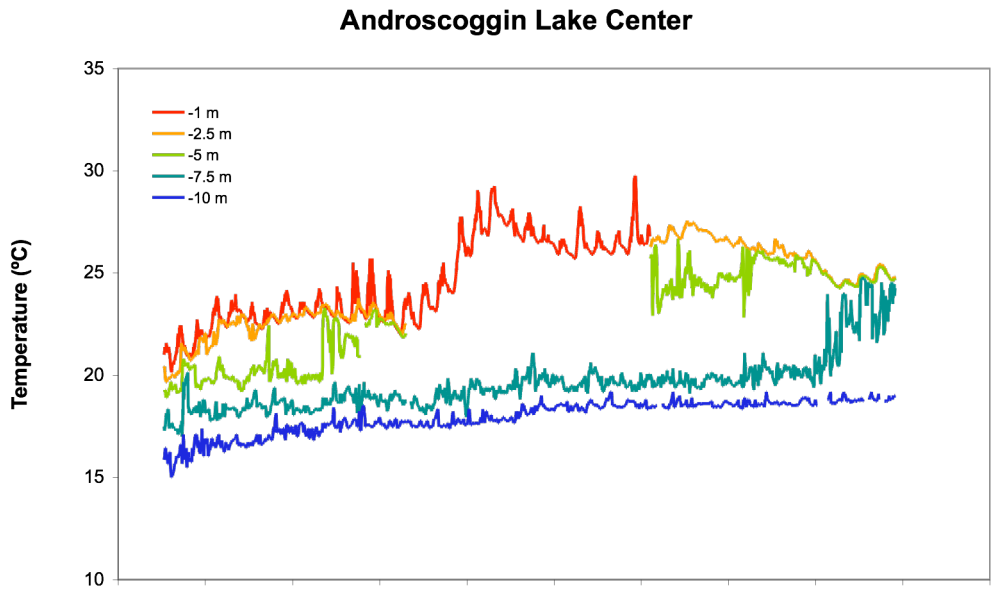


Figure 1. Temperature records (15-minute intervals, June - August) in the central deep basin of Androscoggin Lake from Hobo dataloggers attached to a sediment trap.

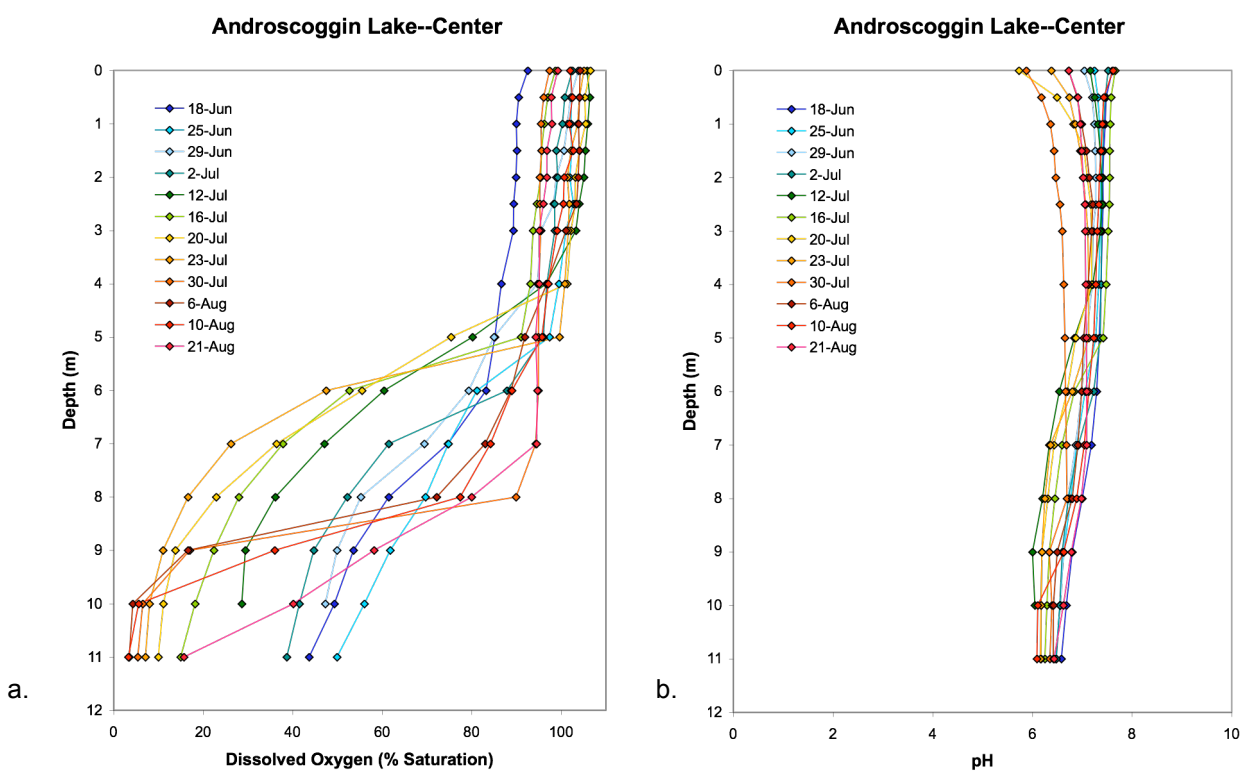
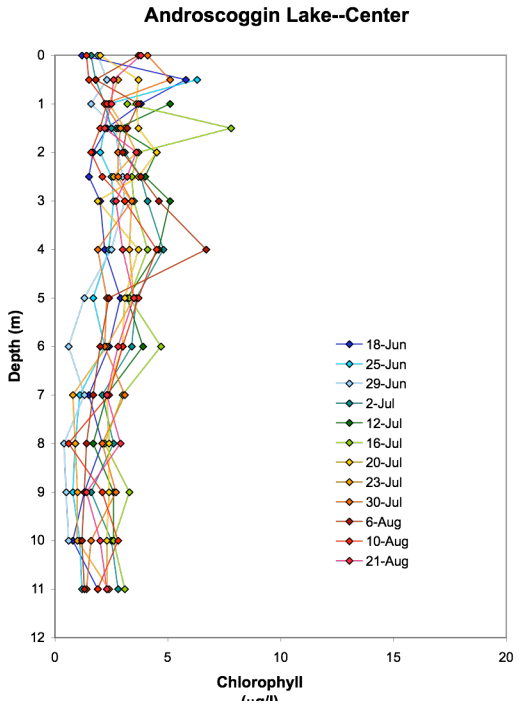


Figure 2. Dissolved Oxygen (% Saturation) (a.) and pH (b.) plots in the central deep basin of Androscoggin Lake taken bi-weekly with a YSI 6600 water-quality sonde.

a.



b.

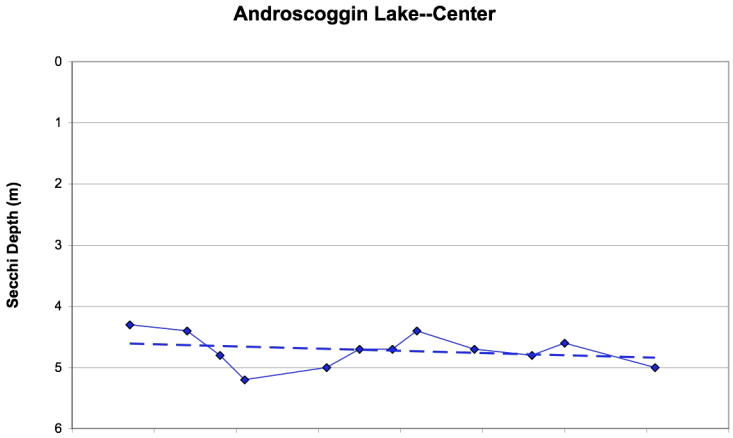


Figure 3. Chlorophyll (µg/l) (a.) and Secchi Depth (June-August, dashed blue line indicates average values) (b.) plots in the central deep basin of Androscoggin Lake taken bi-weekly with a YSI 6600 water-quality sonde.

Vegetation Response to Potential Increased Tidal Marsh Inundation in Northern

Basic Information

Title:	Vegetation Response to Potential Increased Tidal Marsh Inundation in Northern
Project Number:	2010ME226B
Start Date:	5/1/2010
End Date:	10/31/2010
Funding Source:	104B
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Conservation, Ecology, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	John M. Peckenham

Publications

There are no publications.

Vegetation Response to Potential Increased Tidal Marsh Inundation in Northern New England Brackish Marshes

Elizabeth E. Mitchell
M.S. Biology Candidate
University of Southern Maine

Abstract

Brackish marsh vegetation distribution is strongly controlled by inundation and salinity, and is likely to be impacted by climate change and sea level rise due to changes in the periodicity and magnitude of freshwater and salt water inputs. With increases in sea level, shifts in dominant marsh species would be expected, altering typical brackish marsh plant diversity and moving these systems towards saltier marsh vegetation. Yet little is known about the effects of these hydraulic regimes on brackish marsh floral communities in northern New England. Quantifying vegetation response in these systems to inundation and salinity will lead to stronger predictions of change when considering long-term protection and conservation of these fragile habitats. The goal of this study is to construct a model as a guide for predicting vegetation response to inundation and salinity along a brackish gradient using experimentally obtained information on plant responses to these different regimes.

Introduction

Estuaries are important biological habitats in the Gulf of Maine, providing nursery grounds for commercially important species, and habitat for many or endangered species. Estuarine marshes provide a natural filter that keeps excessive nutrients and discharge from entering our rivers, lakes, and oceans (Maine DEP 1996; NECIA 2007). Between the ocean and our bodies of freshwater lay marshes that experience salinities at both ends of the spectrum, seasonally or tidally (Odum 1988; Touchette 2006). These brackish marshes experience significant mixing of freshwater and seawater inputs, and salinities can sometimes reach fresh conditions (Tiner 1987). These marshes are likely to be highly impacted by climate change and sea level rise due to changes in the periodicity and magnitude of freshwater and seawater inputs. They share many characteristics of freshwater wetlands, like plant species (Meyerson et al. 2000; Latham et al. 1994; Gallagher and Kibby 1980). For our study, we will focus on these brackish marshes, which range from mesohaline marshes (5-18 PSU) to oligohaline marshes (0.5-5 PSU) (Odum 1988). Brackish marsh vegetation patterns are strongly controlled by their hydraulic regime (Meyerson et al. 2000). Within the estuary, salinity is typically considered the determining factor for most plant species' distribution (Odum 1988; Meyerson et al. 2000)**.** However, sediment anoxia (brought on by periods of inundation) is a greater stress on brackish and freshwater marsh plant species (Stribling et al. 2006). Understanding these succession dynamics across salinity and tidal inundation gradients in marsh systems is critical for restoration/management efforts (Weiher and Keddy 1995; Crain et al. 2004; Konisky and Burdick 2004).This fact is particularly true in context of predicted rises in sea level (Solomon et al. 2007; NECIA 2007), because gradients in salinity and inundation change species' composition and environmental characteristics of estuarine marshes (Weiher and Keddy 1995; Crain 2008; Crain et al. 2008; Cooper 1982). Plant-water relationships under current changing conditions are crucial to expand what we know about salinity resistance in plants (Touchette 2006).

Structuring of species interactions and marsh plant community composition and abundance by environmental gradients is well known for salt marshes (Bertness 1991; Weiher and Keddy 1995; Crain et al. 2004; Crain et al. 2008). However, these dynamics have not been well characterized for brackish marshes, as few experiments have tested increased salinity and

inundation on growth limits, and are limited in their scope (Bertness and Ellison 1987; Burdick et al. 1989; Hellings and Gallagher 1992; Konisky and Burdick 2004; Meert and Hester 2009). Predictive models are important for understanding species interactions in the context of community structure and physical environments across natural abiotic gradients (Paine and Levin 1981; Sousa 1984; Brooker 2006; Gedan et al. 2009). To address the increasing difficulty of understanding what changes (retreat of habitat, species composition, etc) to expect with rising sea levels or a resource management change in tidal hydrology, a broader view is necessary to understand relationships between hydrological and elevation characteristics and vegetation change. Konisky and Burdick 2004 address this question for marshes along a gradient from mesohaline to polyhaline marshes. In the face of predicted sea level rise (or changes in hydrology due to management actions), the question is: how will changes in hydrology (i.e., tidal inundation and soil salinity), impact vegetation distribution in Maine brackish marshes? In this project, I propose to determine interactions of hydrology and vegetation in brackish systems across a gradient of soil salinities from mesohaline to oligohaline and create a model that details interactions for restoration and resource management purposes. I hypothesize that increases in salinity and increases in tidal inundation should have a negative impact on plant growth, but I expect that increased tidal inundation will have the greatest effect on high marsh plant species of either salinity regime.

Methods

Experimental sites were chosen in May based on average soil salinities (Konisky and Burdick 2004). There were two sites, stratified by expected salinity, with four plots placed in low and high marsh areas. Inundation and salinity effects were measured.

Intact plants of two common mesohaline species (*Spartina alterniflora*- low marsh; *Spartina patens*- high marsh) and two common oligohaline species (*Agrostis stolonifera*- low marsh; *Scirpus robustus*- high marsh) were transplanted into each plot, with pore water salinity wells placed between each plot at 5 to 20 cm belowground to measure localized soil salinity for each site (Neckles et al. 2002). Species were randomly paired to assess competitive interactions under different salinity and inundation regimes. Three individuals of each species were measured for initial height, then collected, dried, and weighed to estimate initial aboveground biomass. Every other week from May–September, plots were monitored and weeded. I also measured pore water salinity, number of additional shoots, shoot height, and shoot survival. In September, surviving plants were extracted, dried and weighed for final aboveground biomass.

Inundation depths, duration, and temperature were quantified with in-situ dataloggers at each site over 1-3 neap/spring cycle(s) (Neckles et al. 2002). Loggers were suspended at 1 m depth. Elevation of each logger station (and plot) were collected with DGPS. An iButton temperature datalogger were placed in each plot, and are an effective indirect measure of tidal inundation (Gjerdrum et al. 2008). These measurements will be used to estimate a tidal curve, determining duration/depth of tidal inundation of each site. Soil redox potential was measured to account for the controlled effect of competitive interaction, as well as length of time of anoxic conditions (periods of inundation) (Stribling et al. 2007).

Preliminary Results

Figure 1. These are the values for the mean salinity across plots for each site high marsh only, at each sampling trip throughout the growing season. On average, the salinities across both sites were higher than previously recorded, but still show a strong differentiation across the system. July through August brought sustained periods of high temperatures, which may be reflected in these salinity values, though a comparison to the actual temperatures still needs to be run. These higher salinity conditions across sites means that the transplants had to cope with not just resettling stress, but less favorable growing conditions overall.

Figure 2. Here is a comparison of the mean final biomass of each species for both sites, high marsh only. All species tended to do well in the growing conditions of the oligohaline site. Though most species in the mesohaline site on average did less well than the other species in the oligohaline site, *Spartina alterniflora* did significantly well, perhaps reflective of its evolutionary adaptation to higher stress environments. At the mesohaline site, the two representative species did better, and at the oligohaline site, those species performed the same if not better than the oligohaline representative species, perhaps because they are stronger competitors and better adapted to changing environmental conditions.

Figure 3. We measured biweekly stem heights of the transplants across the growing season. Here are depicted the values for the high marsh only. Initial dips in stem height represent dieback and regrowth, most likely a result of transplant stress. *Spartina alterniflora* on average, adjusted to the transplantation, and continued to grow. However, its mesohaline cohort, *Spartina patens*, experienced significant regrowth towards the beginning of the growing season, but in the latter half of the summer continued to experience dieback and regrowth in the mesohaline site, and in the oligohaline site took well to the transplanting and continued to grow. *Carex vesicaria* did well after initial dieback, but may have responded poorly to the higher salinities it experienced in the later part of the growing season at the mesohaline site (salinities were approaching that of a salt marsh- this being a fresh-brackish water species). *Schoenoplectus pungens* had a harder time recovering from the initial transplant dieback, particularly in the atypical environment of the mesohaline site. There was a high rate of mortality for this species in the mesohaline site.

Future Work

The final samples for the low marsh plots are currently being processed, and once they are done, data comparisons will be made between the high marsh plots and low marsh plots. Competition factors, tolerance factors, relative aboveground biomass, and repeated measures ANOVAs will be run on the weight data. DGPS elevational data collected this fall will be correlated with the inundation data collected from the data loggers this summer. The cumulative compilation of processed data will be added and explained in a Master's thesis, and will be defended this spring (most likely end of April). As well, the final results will be presented in a poster at the Maine Water Conference in March.

Conference Proceedings

Oral presentation. New England Estuarine Research Society, Spring Meeting, May 2010. Vegetation Response to Potential Increased Tidal Marsh Inundation in Northern New England Brackish Marshes: A proposal. Authors: Elizabeth E. Mitchell, Karen A. Wilson.

Oral presentation. New England Estuarine Research Society, Fall Meeting, October 2010. Vegetation Response to Potential Increased Tidal Marsh Inundation in Northern New England Brackish Marshes: Preliminary results. Authors: Elizabeth E. Mitchell, Karen A. Wilson.

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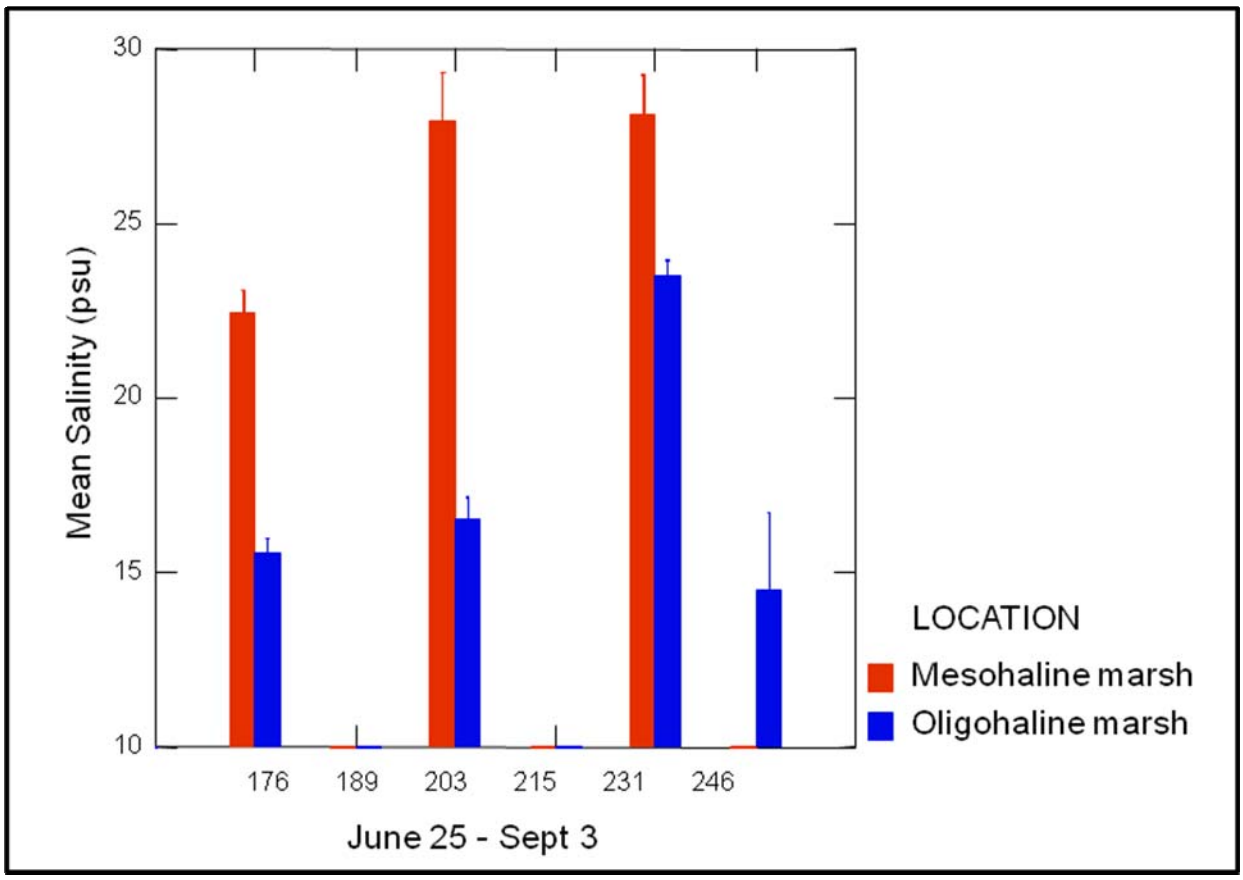

Figure 1. Salinities measured in practical salinity units, for the high marsh plots at the mesohaline and oligohaline marsh sites. Days are Julian dates, and absent values represent dry wells, where no ground water was present.

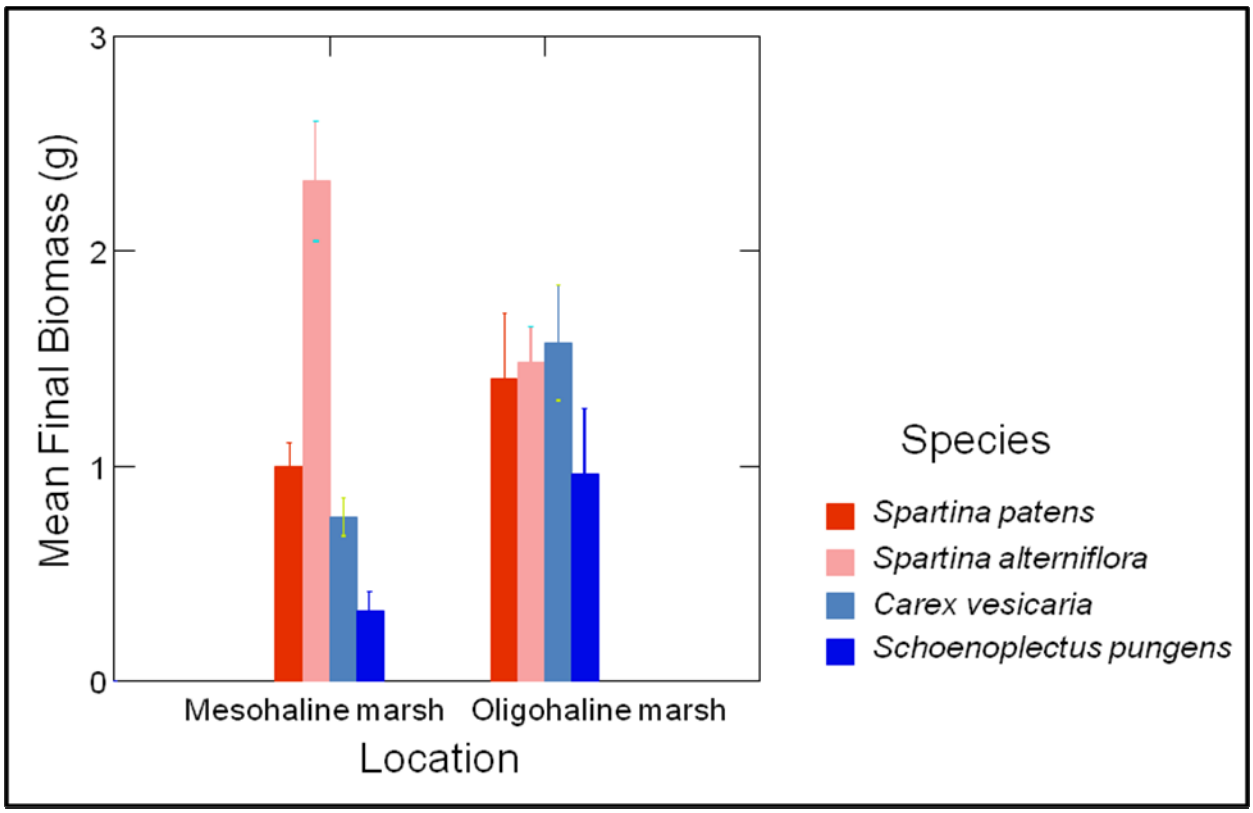

Figure 2. Mean final biomass (grams) for each species across all high marsh plots at the mesohaline and oligohaline marsh sites. Error bars represent one standard error.

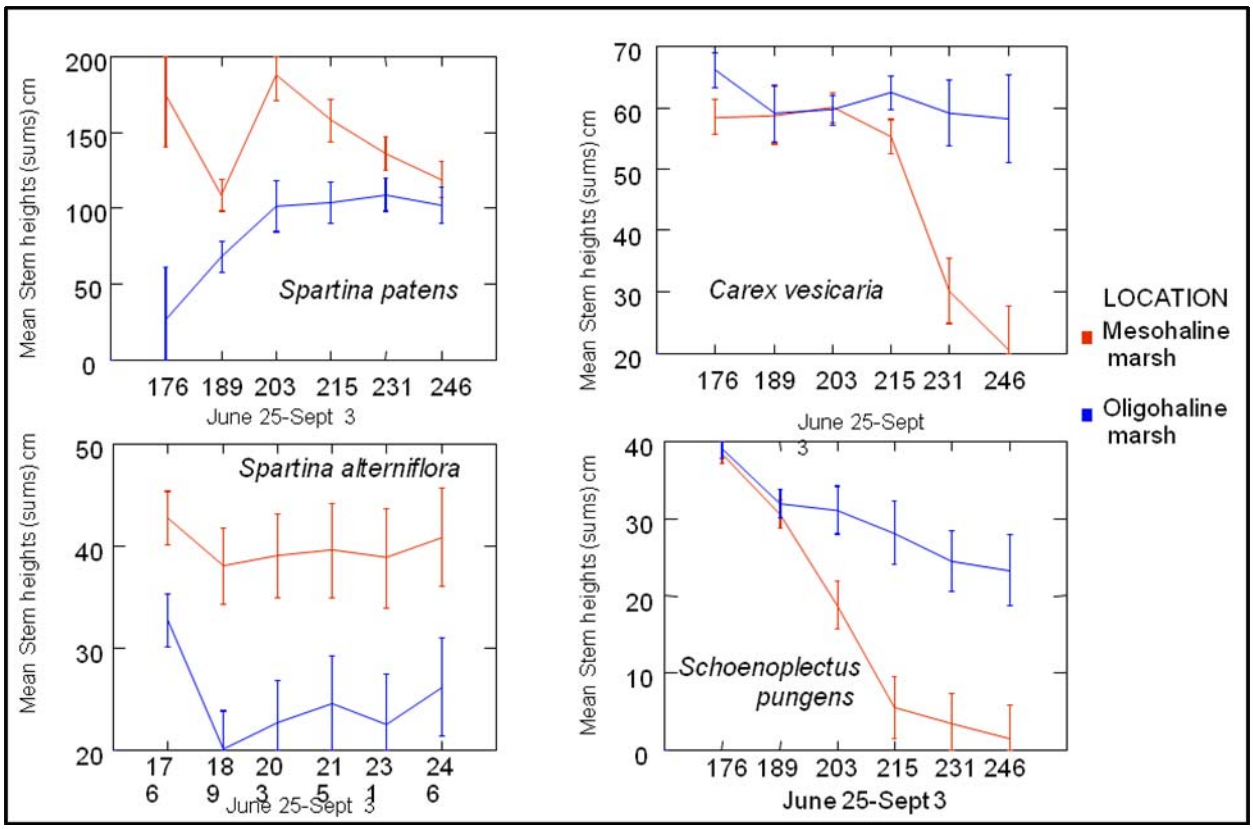

Figure 3. Mean stem heights in centimeters (summed to account for mortality and new growth), for each species across all high marsh plots in the mesohaline and oligohaline marsh sites. Error bars represent one standard error.

Atlantic salmon (Salmo salar) as an indicator of habitat quality in tributaries

Basic Information

Title:	Atlantic salmon (Salmo salar) as an indicator of habitat quality in tributaries
Project Number:	2010ME227B
Start Date:	5/1/2010
End Date:	9/1/2010
Funding Source:	104B
Congressional District:	
Research Category:	Biological Sciences
Focus Category:	Conservation, Ecology, Management and Planning
Descriptors:	None
Principal Investigators:	John M. Peckenham

Publications

There are no publications.

Student Investigator: Wes Ashe
Graduate Advisor: Stephen Coghlan
WRRI Summary Report
Due: 12/31/2010

Atlantic salmon (*Salmo salar*) growth and survival as an indicator of habitat quality in tributaries of the Machias River watershed

INTRODUCTION

The Machias River, located in downeast Maine, harbors one of the few remaining wild populations of anadromous Atlantic salmon in the U.S. This study focuses on Atlantic salmon habitat in 1st and 2nd order streams of the Machias River watershed. Atlantic salmon are a charismatic sentinel species with strict habitat requirements, whose presence and success indicate excellent stream quality for native, coldwater fishes. However, over the past century, the Machias River watershed has experienced much alteration due to anthropogenic disturbance. These activities, mainly the construction of roads for timber harvest and log driving, have disrupted the structure and function of the river and its tributaries. The extensive network of logging roads required the construction of dozens of culverts on many of these headwaters streams. Many of these culverts are poorly designed and malfunctioning, and thus impede the movement of juvenile Atlantic salmon into a network of small tributaries that comprises upwards of 70% of the total stream area in the watershed, and that historically provided critical nursery and rearing habitat. These productive habitats are essential to the growth and survival of juvenile Atlantic salmon, as they provide thermal refuge, protection from predators, and abundant food supply. However, current management of Atlantic salmon in the Machias River involves stocking fry in larger tributaries because many of these smaller tributaries are blocked by culverts and thus would be inaccessible to returning adults. Therefore, we will investigate the importance of these smaller tributaries to Atlantic salmon fry by meeting three objectives.

- Quantify differences in growth and survival of juvenile Atlantic salmon among1st and 2nd order stream reaches and across multiple environmental gradients.
- Determine the relative importance of measured habitat features to juvenile Atlantic salmon growth and survival.
- Compare the production potential of headwater streams to the main stem and other previously-stocked tributaries.

METHODS

Twenty, 100-meter reaches on 1st and 2nd order tributaries in the Machias River watershed were selected prior to the 2010 field season to serve as study sites for this project. On May 1, 2010, directional traps were installed up and downstream on three representative reaches in order to quantify fry movement during the first summer of life. On May 7, approximately 30,000 Atlantic salmon fry, averaging 22.0 ± 0.6 mm (mean ± 2 S.E.) in length and 0.16 g in mass obtained from the Craig Brook National Fish Hatchery were scatter-stocked in all sites at a density of 1 fry/m^2. The same density stocked by the Maine Department of Marine Resources in their Atlantic salmon restoration program. Salmon were stocked within each study reach, as well as in100m-long "buffer reaches" upstream and downstream of each site.

Several biotic and abiotic habitat factors were measured throughout the field season at each of the 20 reaches and at two separate timeframes. We conducted habitat measurements twice in order to quantify some of the seasonal variation within the stream. Habitat analyses began in May and included measurements on pH, temperature, stream velocity, substrate composition, shelter availability, water depth, wetted width, riparian composition, forest canopy, invertebrate food supply (benthic and drifting), and large woody debris. These environmental variables were selected and measured based on their inclusion in many literature sources emphasizing their importance upon the growth and survival of Atlantic salmon fry.

We estimated mean wetted width from twenty equally-spaced transects within each of the 20 sampling reaches. Mean substrate size and size distributions were measured by selecting forty substrate samples within a randomly placed 25 cm diameter hoop along each of the twenty transects, and were classified based on the Wentworth scale. In those reach transects that measured greater than three meters in width; two hoops with 30 substrate samples were sampled. Substrate shelter availability was quantified by visually identifying potential interstitial spaces using a flexible PVC tubing method. We recorded half-hourly water temperature at each site using remote data loggers, and monitored pH intermittently at the upstream and downstream boundaries of the study sites. We measured mean velocity and mean depth at three locations within each of the twenty transects using the 0.60 depth method with a velocity-meter. Canopy cover was estimated at each of the 20 transects using a spherical densitometer, and species composition and DBH (of trees > 3 cm) was estimated along five, 25 m transects located at 0m, 25m, 50m, and 75m, and 100m of each stream reach. The abundance, length, and DBH of all large woody debris (LWD; DBH ≥ 10 cm) were measured within each of the 100m study sites. Five benthic invertebrate samples per reach were collected using electro-shocking techniques. Two drift nets were set upstream of the reach for 2-hour increments during the daylight hours in order to estimate drifting invertebrates. The invertebrate samples were stored in 80% ethanol to be later processed in the laboratory for identification and enumeration.

Electro-fishing was conducted in mid- to late August to estimate abundance, mass, length, density, biomass, and apparent survival of Atlantic salmon fry as well as the presence of competitor/predator fish species within the twenty reaches. All collected salmon, as well as other fish species, were measured for length and mass and released back into the reach.

RESULTS

ATS fry migration-

Only downstream fry migration was observed throughout the field season. Of the 86 fry that either immigrated into or emigrated out of the reaches, 87% of this movement occurred within 14 days of stocking. Additionally, 84 % of all movement was recorded at one directional trap where fry seemed to be moving away from habitat typically characterized as poor quality for juvenile salmon (i.e. slow-flowing, detritus substrate). The directional fry traps remained structurally sound throughout the entire field season and seemed to capture moving fry adequately; however, 94.8% of fry stocked within the three representative reaches were unaccounted for. These fry either migrated through the fry traps without detection (e.g. during extreme spates) or were mortalities within the reach.

ATS fry apparent survival, growth (mass, length), density, biomass, and competitors-

Three-pass depletions of 40m reaches extrapolated fry abundance per reach at 43 ± 0.085 (mean ± 2 S.E.), and ranged from 0 to 200 fry per 100m (Table 1). Two sites yielded no fry. Apparent survival of salmon fry over the summer months averaged between 0 and 18.8%, with a mean value of 7.3% averaged across all study sites. Mean length of fry at time of capture was 53.9 ± 0.8 mm and ranged from 35.0 to 78.0 mm, and mean mass per fry was 1.4 ± 0.1 g and ranged from 0.3 to 5.2 g. Mean size of fry varied significantly among stream reaches for both length ($p < 0.0001$) and mean mass ($p < 0.0001$). Mean density was 0.20 ± 0.01 fry/m^2 and ranged from 0.00 to 0.68 fry/m^2 per reach, whereas mean biomass was 0.30 ± 0.18 g of salmon tissue/m^2 and ranged from 0.00 to 0.84 per reach. Brook trout (*Salvelinus fontinalis*), the dominant fish throughout the study area, were collected in 85% of study reaches, and were the only other fish species (besides Atlantic salmon) present in 70% (14 of 20) of the tributaries. Other fishes present in six of the 20 study reaches were brown bullhead (*Ameiurus nebulosus*), white sucker (*Catostomus commersoni*), creek chub (*Semotilus atromaculatus*), and eastern blacknose dace (*Rhinichthys a. atratulus*).

ATS fry habitat analyses-

Among the twenty sites, temperatures during the study ranged from 4.8 to 28.2˚C and averaged between 10.9 and 20.2 ˚C. Mean pH was 6.2 and ranged between 5.7 and 7.0. The average wetted width among the twenty reaches was 1.9 m, and varied from 1.0 to 4.3 m. Mean stream depth was 0.12 m and ranged from 0.06 to 0.19 m. Mean water velocity ranged from 0.02 to 0.13 m/s, and averaged 0.07 m/s

across all sites. Interstitial spaces available as potential shelter for salmon fry, averaged 0.0 to 2.1 spaces per 5 m of stream length (mean shelter was 0.8 per 5m across all twenty sites)(Table 2).

Spherical densitometer readings of % canopy cover ranged from 19.4 to 92.4% and averaged 83.7% across all reaches (Table 2). In reference to riparian composition among the twenty sites, conifers (averaged 58.1%) were more abundant than deciduous trees (27.9%), while snags (14.1%) comprised a smaller percentage of the forest community. The abundance of large woody debris (LWD) ranged from 18 to 120 pieces, while the mean abundance was approximately 46 per reach. Mean LWD length was 4.5m per study site, while it ranged from 2.7 to 8.1m across all study sites. The diameter at breast height (DBH) of LWD varied from 14.3 to 20.0 cm and averaged 17.2 cm among the twenty reaches (Table 2).

Substrate composition among the 20 reaches was heterogeneous in content; pebbles (2 – 64 mm)(49.8%) comprised approximately half of all substrate composition, while the combination of silt/sand (< 2mm)(14.6%), detritus (14.2%), boulder (> 256 mm)(14.1%), and cobble (90-256 mm)(8.2%) comprised the other half (Table 2).

DISCUSSION & CONCLUSION

Due to a drought during August and September, the 2010 field season wasn't completed until much later than originally anticipated, and we are still analyzing data. Therefore, exhaustive statistical analyses are currently underway to provide the following deliverables:

- Differences in growth and survival of juvenile Atlantic salmon among1st and 2nd order stream reaches and across multiple environmental gradients
- A statistical analysis determining the relative importance of measured habitat features to juvenile Atlantic salmon growth and survival

The following deliverables will be completed at the conclusion of the investigator's graduate degree program:

- Comparisons of the productive capacity between headwaters and main stem rearing habitats
- A bioenergetics model useful in comparing fish performance across a gradient of sites
- A Habitat Suitability Index based on stream reach habitat variable data
- A means by which impaired culverts can be systematically removed from not only tributaries of the Machias River watershed, but from watersheds throughout the entire state

Table 1. Variation in abundance, apparent survival, mean mass, mean length, mean density, and mean biomass of stocked Atlantic salmon fry collected from study reaches in August 2010 (± standard errors are given in parentheses). Sites in which no fry were collected are not shown.

Site	n	Apparent Survival (%)	Mass (g)	Length (mm)	Density (# of fry/m²)	Biomass (g/m²)
43 Washout	67	17.9	1.19 (0.17)	53.23 (2.21)	0.59 (0.03)	0.70 (0.52)
5th Lake #1	17	3.6	0.94 (0.21)	47.43 (3.32)	0.11 (0.01)	0.10 (0.06)
5th Lake #2	20	5.0	1.09 (0.22)	49.67 (3.00)	0.10 (0.01)	0.10 (0.05)
Burntland #2	7	1.5	0.55 (0.50)	40.50 (3.00)	0.05 (0.01)	0.03 (0.04)
Colson	15	3.5	2.70 (0.54)	70.40 (4.80)	0.10 (0.01)	0.26 (0.12)
Elwell	25	9.2	1.10 (0.23)	51.00 (2.75)	0.16 (0.13)	0.18 (0.12)
Four-Wheeler	12	2.9	0.79 (0.27)	45.17 (4.87)	0.09 (0.01)	0.07 (0.07)
Hadley	90	17.6	1.62 (0.16)	56.85 (1.20)	0.40 (0.01)	0.65 (0.38)
Honeymoon	50	7.9	1.97 (0.24)	59.05 (2.37)	0.20 (0.01)	0.39 (0.21)
Honeymoon Trib.	25	3.7	0.86 (0.18)	46.56 (2.65)	0.16 (0.01)	0.32 (0.09)
Ingalls	10	1.0	2.33 (0.33)	64.33 (4.67)	0.05 (0.01)	0.12 (0.03)
Intersection	30	5.8	1.25 (0.29)	50.60 (2.83)	0.18 (0.01)	0.23 (0.17)
Laupher	120	18.8	1.24 (0.14)	52.95 (1.67)	0.68 (0.02)	0.84 (0.61)
Libby	15	2.6	1.02 (0.26)	49.60 (3.44)	0.10 (0.01)	0.10 (0.06)
North Dead	200	17.6	0.93 (0.05)	48.51 (0.77)	0.47 (0.01)	0.44 (0.21)
Patience	22	-	1.86 (0.32)	60.00 (4.24)	0.16 (0.01)	0.30 (0.15)
Thompson	55	9.6	2.11 (0.23)	61.33 (2.08)	0.19 (0.01)	0.10 (0.20)
Thompson 42	75	9.6	2.51 (0.38)	63.96 (2.51)	0.26 (0.01)	0.67 (0.52)

Table 2. Various habitat measurements for all 20 study streams in the Machias River watershed.

	MISC. HABITAT								RIPARIAN							SUBSTRATE				
Site	Min Temp (°C)	Max Temp (°C)	Mean Temp (°C)	pH	Mean WW (m)	Mean Depth (m)	Mean Velocity (m/s)	Mean Shelter (per 5m)	Mean Canopy Cover	# of LWD	Mean LWD Length (m)	Mean LWD DBH (cm)	% Conifer	% Deciduous	% Snag	% Detritus	% Silt/Sand	% Pebble	% Cobble	% Boulder
Four-Wheeler	-	-	-	6.3	1.3	0.07	0.09	0.5	89.5	28	6.8	19.0	40.0	51.8	8.2	5.8	16.8	63.7	4.4	9.4
43-Washout	12.2	23.3	17.0	6.6	1.1	0.10	0.04	1.4	88.1	28	4.0	16.1	15.3	65.9	18.8	2.2	0.7	71.9	6.3	18.9
Bullmoose	8.1	19.6	14.3	6.6	1.0	0.06	0.02	0.6	88.2	33	2.9	14.3	51.5	34.1	14.4	20.8	9.9	57.6	2.2	9.5
Burnland #1	5.1	18.4	13.4	6.2	1.1	0.06	0.03	0.6	85.1	40	4.1	17.5	84.2	11.2	4.6	30.4	12.2	40.7	3.4	7.3
Burnland #2	5.7	14.6	10.9	6.2	1.4	0.07	0.12	0.1	90.0	51	5.7	19.7	43.7	42.5	13.8	19.3	21.4	55.6	0.4	3.4
Colson	6.2	23.4	13.3	6.4	1.6	0.17	0.10	0.0	78.2	72	4.1	15.6	74.4	13.7	12.0	32.3	30.9	36.8	0.0	0.0
Elwell	5.1	24.2	16.0	6.0	1.5	0.07	0.06	2.1	88.2	22	2.7	15.2	51.5	22.1	26.5	8.5	2.7	52.5	8.1	28.3
Fifth Lake #1	10.1	21.7	15.5	6.5	1.6	0.10	0.03	0.2	88.8	53	4.0	19.2	42.3	46.5	11.2	8.9	15.5	37.7	24.3	13.6
Fifth Lake #2	5.3	19.5	13.6	6.1	2.1	0.13	0.06	0.4	89.4	87	4.1	17.2	44.1	47.1	8.8	12.2	31.2	26.5	11.6	18.5
Hadley	6.0	20.8	15.1	6.1	2.3	0.12	0.08	1.8	88.2	24	8.1	20.0	66.7	10.8	22.5	22.5	6.9	59.2	12.1	21.8
Honeymoon	12.1	24.8	18.8	6.3	2.5	0.11	0.13	1.7	84.1	18	5.0	17.3	41.1	48.7	10.2	12.1	3.3	22.1	41.3	21.2
Honeymoon Trib.	8.2	18.5	14.4	5.7	1.5	0.12	0.03	0.2	83.5	33	3.7	16.0	44.2	45.9	9.9	25.4	29.9	19.0	11.2	14.5
Ingalls	5.3	21.9	13.6	6.0	1.9	0.19	0.06	1.0	89.4	77	5.2	16.1	80.5	6.9	12.6	12.9	11.7	44.5	4.0	27.0
Intersection	4.8	18.5	12.8	5.9	1.6	0.13	0.03	0.6	90.0	39	2.9	16.3	83.9	7.7	8.4	11.1	14.9	56.6	3.7	13.7
Lapham	12.4	26.3	18.6	6.8	1.8	0.08	0.12	1.0	88.2	45	4.2	18.6	52.1	42.4	5.5	2.4	16.6	66.9	6.4	7.7
Libby	4.9	19.9	13.5	5.7	1.5	0.14	0.06	0.2	92.4	40	3.3	15.2	67.1	27.3	5.6	7.6	14.5	68.7	1.9	7.3
North Dead	13.5	25.2	18.7	6.2	4.2	0.15	0.05	1.3	72.4	25	3.7	19.2	81.8	10.8	6.8	1.0	15.8	72.2	10.5	3.3
Patience	10.2	20.0	15.6	5.8	1.4	0.14	0.11	0.7	91.8	54	4.6	16.5	72.7	12.1	15.2	6.4	5.1	53.7	3.3	31.6
Thompson	11.9	28.2	20.2	6.0	2.9	0.19	0.09	0.7	88.8	41	4.4	17.4	77.2	6.9	15.8	11.6	15.7	48.1	5.8	18.8
Thompson #2	9.9	19.9	15.2	7.0	2.9	0.19	0.10	0.4	19.4	120	6.0	18.1	47.0	3.0	50.0	31.1	16.5	42.5	3.1	6.9

Microorganisms that can alter groundwater chemistry in an arsenic enriched aquifer

Basic Information

Title:	Microorganisms that can alter groundwater chemistry in an arsenic enriched aquifer
Project Number:	2010ME228B
Start Date:	5/1/2010
End Date:	10/31/2010
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Groundwater, Hydrogeochemistry, Geomorphological Processes
Descriptors:	None
Principal Investigators:	John M. Peckenham

Publications

There are no publications.

Title: Microorganisms that can alter groundwater chemistry in an arsenic enriched aquifer located in Northport, ME.

Focus Categories: G&G, GW, HYDGEO, TS, WQL
Keywords: 15, 19, 90, 101, 111, 252, and 266

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Project Dates and Duration: 5/1/2010-10/31/2010

Project Synopsis:
An aquifer in Northport, Maine has naturally occurring elevated levels of arsenic. Microorganisms may release arsenic in groundwater by reducing bedrock surface coatings or by altering arsenic speciation, thus affecting the sorption of arsenic. Currently there is competing evidence whether microbially mediated iron or arsenic reduction is more important for arsenic release. This work will determine the relative importance of iron and arsenic reduction within the Northport aquifer. Clone libraries for two sampling dates are being constructed to examine changes in the composition of the microbial communities between low arsenic recharge wells and high arsenic discharge wells to assess the impact microorganisms may have on the groundwater chemistry of the aquifer. Since little is known about the long term stability of microbial community structure in a groundwater environment this work will examine the temporal shifts in the microbial communities within the Northport aquifer. The importance of microbial arsenate reduction and arsenite oxidation is will be examined culturing techniques.
Introduction:
Hundreds of millions of people around the world have been exposed to arsenic through contaminated groundwater drinking sources. In Maine, 5-6% of the state's residents may use groundwater sources with arsenic concentrations that exceed the US EPA's Maximum Contaminant Level (MCL) of 10µg/L (Loiselle et al., 2002).

Adsorption of arsenic to iron oxyhydroxides and arsenic speciation can each affect arsenic mobility in groundwater. The relative importance of these two activities needs to be studied further.

In a fractured bedrock aquifer located in Northport, Maine there are naturally occurring elevated levels of arsenic (Lipfert et al, 2006). An arsenate respiring microorganism, *Sulfurospirillum* species NP4, was isolated from a well in the Northport aquifer and the proportion of it in groundwater samples correlated well with the arsenite concentration in the groundwater (Weldon and MacRae, 2006). Another probe which was designed to detect a genus of iron reducing bacteria, *Geobacter,* showed a correlation between *Geobacter* and the total arsenic concentration in groundwater samples (Weldon and MacRae, 2006).

Preliminary results from the clone library study show there is an increase in the proportion of microbial clones identified as δ proteobacteria when comparing the low arsenic recharge well R to the high arsenic discharge wells D1 and D2 (Fig. 1). This shift points to the reduction of iron as an important activity in the aquifer. Within δ proteobacteria there are many organisms that are capable of iron reduction, for example *Geobacter sulfurreducens (*Caccavo et al., 1994). Microbial reduction of iron has been linked to an increased retention of arsenate in the solid phase which, indicates that organisms capable of reducing arsenate may play a key role in arsenic mobilization while iron reduction is occurring within an aquifer (Kocar et al., 2006).

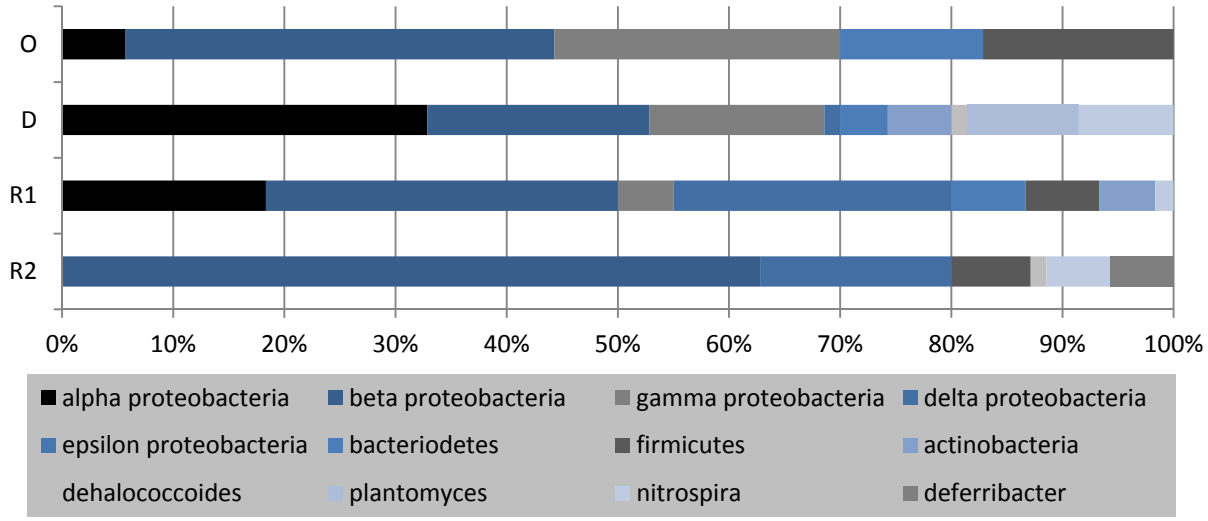
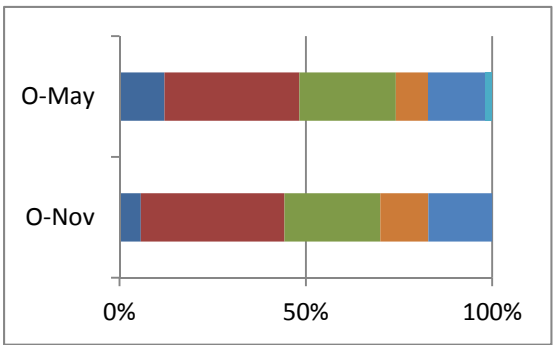
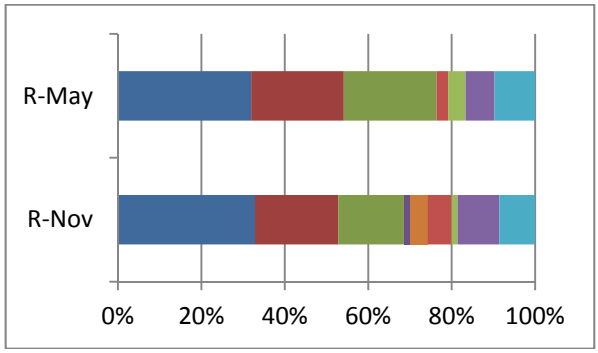


Figure 1: Complete microbial community analysis for groundwater wells in Northport, ME.

The shift of the microbial population in the discharge wells toward β and δ proteobacteria could be relevant for arsenic cycling and release within the aquifer system (Fig. 1). Many β proteobacteria species such as *Hydrogenophaga* species CL3 and *Azoarcus* species DAO1 are capable of oxidizing arsenite to arsenate, either aerobically or anaerobically (Rhine et al., 2005). Conversely δ proteobacterial species such as *Enterobacter* sp GS4, *Citrobacter* species TSA-1, and strain MLMS-1 are capable of dissimilatory arsenate reduction (Rhine et al., 2005). Based on the dominance of microorganisms from both β and δ proteobacteria in the high arsenic discharge wells of the Northport aquifer, there could be microbially mediated arsenic speciation and cycling in this system.

Additional sequence data was combined with the preliminary results to and similar shifts in the microbial populations were observed. Minor changes in the community composition of less than 5% were observed in some of the wells but the predominant trends remained the same. While the overall shifts in the microbial populations were similar there was an improvement in the statistical significance of the combined results over the preliminary analysis. These results point to the potential importance of iron reduction and possibly arsenic reduction within the Northport aquifer.





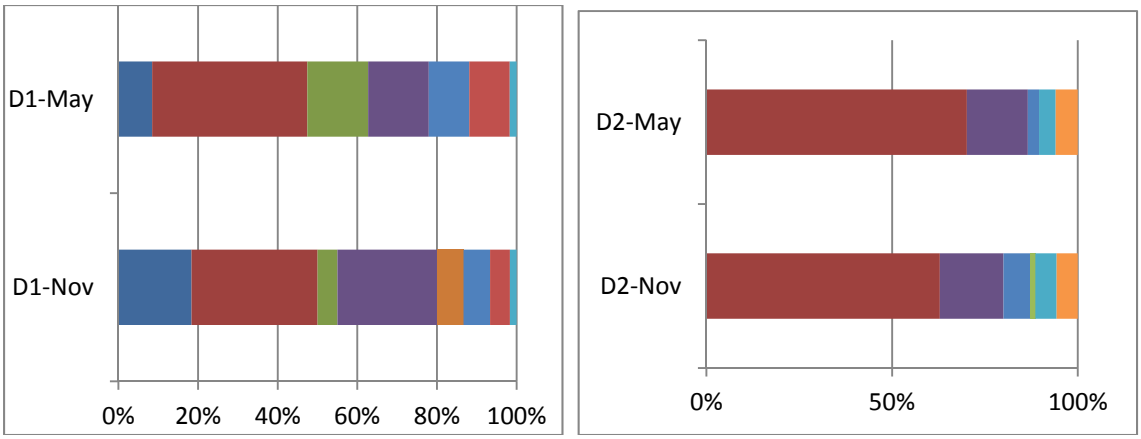


Figure 2: Microbial community composition for each well for samples from May and November of 2007.

In addition to an increased number of sequence data from 1 sampling date sequence data was obtained for a second set of samples to observe temporal shifts in the microbial population. The overall shifts in the microbial population composition observed between the wells remained. Also, the microbial community appears to be relatively stable with only minor shifts in the populations within individual wells in a six month period.

Methods outline:

A generalized approach that does not target specific microbes, the construction of clone libraries, was used to examine the composition of the microbial community. The libraries were constructed from samples from 4 observation wells installed in the aquifer. Two of the wells have low arsenic levels: one was in the overburden materials, well O, and the other well, R, is in the recharge region of the aquifer. The other two observation wells are located in the high arsenic discharge region of the aquifer, wells D1 and D2.

Previously a limited number of clones were sequenced. Prior to sequencing restriction fragment length polymorphism, RFLP, patterns which were frequently observed in individual libraries were reanalyzed using a second pair of enzymes to ensure the proper classification of the most frequent clone types. The additional data was used to improve the statistical significance of the results from the original clone library. To test the temporal stability of the community structure, cloned PCR products from a second time point were purified and sequenced. The sequence data obtained will be aligned using Clustal W and classified using phylogenetic trees constructed using Mega®. The relevance of observed differences between microbial populations will be statistically tested using mothur and Arlequin software packages.

Arsenite oxidizing bacteria were isolated using groundwater enrichments with added arsenite and nitrate. Colonies from solid media enrichments have been picked and transferred back into liquid media.

Expected publications:

- A peer reviewed journal article describing the observed microbial community changes is being prepared.
- Two chapters in Jennifer Weldon's dissertation are being completed.
- An annual report submitted to the Mitchell Center
- A presentation at the 2011 Maine Water Conference

Caccavo et al. 1994. Appl. Environ. Microb. 60(10): 3752-3759.
Kocar et al. 2006. Environ. Sci. Technol. 40: 6715-6721.
Lipfert et al. 2006. Appl. Geochem. 21: 528-545.
Loiselle et al. 2002. Arsenic in New England: A Multidisciplinary Scientific Conference. May 29–31.
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Weldon and MacRae. 2006. *Chemosphere*. 63: 440-448.

Information Transfer Program Introduction

Information Transfer activities for the Maine Institute can be assigned to four categories: (1) Maine Water Conference; (2) Web-based information; (3) Participation on state-wide boards and committees; and (4) Direct response to inquiries. The Maine Water Conference is the primary water event in the state and brings together a very broad array of interest groups. This conference is very popular and continues to be the most important information transfer event for the Maine Institute. The Maine Institute's web page is the location to find information for current issues, activities, and publications. The web page is updated on a regular basis to include project outputs such as publications and presentations. Also, it serves as a notice board for meetings, student opportunities, and calls-for-proposals.

The Water Institute Director serves on several state-wide boards and committees. This activity provides a direct method to discuss relevant institute-sponsored research and education. Also, it provides a process to collect information about the concerns and challenges of water resources in the state. This activity helps keep the Maine Institute in the core of water resources in the state. Finally, the Water Institute receives public inquiries on a regular basis. Typically, someone is either looking for the results from a project or they have a water-related problem. Responding to these inquiries is important and we make every effort to help citizens in finding answers and solutions to their problems.

Improving Access to Wellwater Information: A Pilot Information Transfer Project

Basic Information

Title:	Improving Access to Wellwater Information: A Pilot Information Transfer Project
Project Number:	2010ME199B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2
Research Category:	Not Applicable
Focus Category:	Groundwater, Water Supply, Education
Descriptors:	None
Principal Investigators:	Laura R Wilson, John Jemison, Jessica Leahy, John M. Peckenham, Andy Tolman

Publications

There are no publications.

Improving Access to Wellwater Information (Pilot Information Transfer Project)
Submitted by Laura Wilson, University of Maine Cooperative Extension
May 5, 2011

Introduction: Over 40% of Maine's population obtains their water from a private source, and it is estimated that due to naturally occurring contaminants alone, up to 20% of private wells are not safe for drinking. No agency regulates or monitors private well water - well owners are responsible for ensuring that they have a safe source of drinking water. Obtaining a private well water test is essential, therefore, to ensure that families are consuming safe water. The process that a homeowner needs to go through to ensure the safety of their well water includes multiple steps, including choosing a testing lab, deciding what analytes to test for, obtaining the proper test kit, properly obtaining a water sample, and paying for that sample to be analyzed. Once the sample has been analyzed, the homeowner needs to understand the results, and if the water is deemed unsafe, take corrective action (sometimes difficult and costly action). The process is long, complicated, and can be prohibitively costly.

Currently, there is no statewide coordinated outreach effort designed to encourage private well owners to test their wells, though multiple groups have individually attempted to reach the well owner. The task is to get the right materials into the homeowners' hands, at the right time, in the right place.

Opportunities for outreach exist, including providing wellwater education to adults through GET WET! (a school-based groundwater education program) student presentations, local health fairs, and well water workshops through adult education programs. Our goal with this pilot information transfer project was to determine which, if any, of these methods of communicating with well owners were successful at motivating the well owner to have their private well tested.

Problem and Information Transfer Objectives: Our objective was to develop, deliver and evaluate multiple outreach methods to convince adults in Maine to test their private wells. These methods included participation in local health/community fairs, and offering wellwater workshops through adult education programs.

Methods: The project partners developed an outreach and evaluation plan, including the different types of outreach activities mentioned above (adult education programs, GET WET student presentations, community events/fairs). Student research assistants coordinated the project, scheduled programs, and conducted a final evaluation. The primary evaluation method was to follow-up with program participants. All evaluation materials were approved by the University of Maine's Human Subjects Review Board prior to data collection.

For this project, both a wellwater display (for use at community events) and a wellwater workshop presentation (in PowerPoint) were developed. An events database was created, which catalogs local events in municipalities within 100 miles of Orono that have a significant proportion of the population obtaining their drinking water from a private source.

Communities were then targeted for a wellwater display at appropriate local events, and/or a workshop through the local adult education program.

Principle findings and significance
Our primary finding is that small scale efforts such as these are ineffective in changing well owner behavior. None of the individual methods listed above generated much interest from the target audience, and even if a well owner did attend a workshop/visit a booth at a local fair, they were still not likely to have their well tested.

The wellwater display was at the following events (the brochure mentioned is the Maine CDC guidelines for well testing):

Maine COLA (Congress of Lake Associations) Conference: 44 Brochures distributed. This audience already knows and trusts the University of Maine Cooperative Extension for lake information – however, only eight people gave contact information for follow-up.

Penobscot River Revival: 23 Brochures, a lot of people came up to chat and ask questions, especially about where/how to get their well tested.

Lincoln Homecoming: Very little interest in booth, only 12 brochures, a few people expressed interest in how to get their well tested. Majority of people where there for food and the parade, not health.

Piscataquis River Festival in Guilford: 27 brochures, a lot more people stopped by to either chat or grab a brochure for later reference. More people stopped and asked questions but not necessarily needed a brochure.

China Community Days: a total fail because of very few people attending, of those very few stopped by to look at the poster and only gave out about 5 brochures. I was also situated in a corner at the end of vendors so not much traffic.

Hermon Sumer Sizzler: Several people were very interested, handed out about 16 brochures. There wasn't a big crowd though, very little traffic by the booth.

Wellwater Workshops through Adult Education Programs were held in Ellsworth (15 participants), Bucksport (6 participants), Hampden (6 participants), Orono (4 participants) and Steuben (7 participants). Of these 38 participants, 14 agreed to allow us to contact them at a later date to determine if they had acted on our recommendations.

A total of 22 people gave contact information to allow us to follow up with them (eight from the COLA conference, 14 from adult education workshops). At the time of follow-up (3 – 6 months after the contact was made), only three had tested their water. Eleven indicated that they will test their water in the future, and one will not be testing his water.

At this time, an analysis of the GET WET! program shows that delivery of well testing messages from students to parents is also not an effective method of delivering the well testing message.

Student involvement
Three students were involved with this project. Phoebe Peckenham (George Washington University) developed the initial wellwater display and conducted the outreach at community events. Brittany Carle (University of Maine) delivered the phone survey, and Ryanne Nason (University of Maine) conducted a literature review and presented a poster at the Maine Water Conference. For Ms. Nason, this project also served as an internship to meet her graduation requirement in the University of Maine Communications Department.

Longer-term outcomes and implications: As a result of this effort, we have determined that a larger-scaled community based outreach effort should be developed. Therefore, as a subcontract to a Columbia University NIH grant, a proposal has been made to further develop community engagement methods, determine who should deliver the well testing message within communities, and work collaboratively with local, state and federal partners to deliver and evaluate well testing messages.

On a shorter-term timeline, our efforts will continue to reach municipal officials in locations where well testing is most essential (as determined by number of residents self-supplied). The University of Maine Cooperative Extension's Water Quality team has developed the #UMaineWater twitter feed, and has begun #wellwaterwednesday information posts. Municipal staff will be invited to follow these posts, which will include information on common contaminants, well facts, and timely resources. This information will be shared at the 2011 Northeast Private Well Symposium.

Maine Information Transfer

Basic Information

Title:	Maine Information Transfer
Project Number:	2010ME222B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2
Research Category:	Not Applicable
Focus Category:	Education, Law, Institutions, and Policy, Management and Planning
Descriptors:	None
Principal Investigators:	John M. Peckenham, John M. Peckenham

Publications

There are no publications.

Publications

Peer Reviewed Publications

Fingerut, J., D. Hart, and J. Thomson. 2011. Larval settlement in benthic environments: The effects of velocity and bed element geometry. Freshwater Biology

Hart, D. and A.J.K. Calhoun. 2010. Rethinking the role of ecological research in the sustainable management of freshwater ecosystems. Freshwater Biology 55:258-269

Schilling, E.G., C.S. Loftin, and A.D. Huryn. 2009. Effects of introduced fish on native macroinvertebrate communities in two physiographic types of historically fishless lakes. Biological Conservation 142:3030-3038.

Whitmer, A., L. Ogden, J. Lawton, P. Sturner, P.M. Groffman, L. Schneider, D. Hart, B. Halpern, W. Schlesinger, S. Raciti, N. Bettez, S. Ortega, L. Rustad, S.T.A. Pickett and M. Killelea. 2010. The engaged university: Providing a platform for research that transforms society. Frontiers in Ecology and the Environment 6: 314-321.

Godsey, S.E., J.W. Kirchner, M. Palucis, H. de Wit, B.L. Skjelkvale, W. Aas, C. Neal, M. Neal, S.J. Nelson, S. Kahl, S. Norton, I. Fernandez, I. Malcolm, D. Tetzlaff, C. Soulsby, I. Dennis, T. Clair. 2010. Generality of Fractal 1/f Scaling in Catchment Tracer Time Series, and its Implications for Catchment Tracer Time Distribution. *Hydrological Processes* 24(12):1660-1671.

Navrátil, T., S.A. Norton, I.J. Fernandez, S.J. Nelson. 2010. Twenty-year inter-annual trends and seasonal variations in precipitation and stream water chemistry at the Bear Brook Watershed in Maine, USA. *Environ. Monit. Assess*. 171:3-21.

Nelson, S.J., I.J. Fernandez, J.S.Kahl. 2010. Mercury concentration and deposition in snow in eastern temperate North America. *Hydrological Processes* 24: 1971-1980.

Invited Scholarly Papers and Talks

MacRae, J.D., J.-S. Kim, Shaleen Jain. 2010. User-driven data exploration of a managed lake system: first steps toward integrated watershed modeling and management tool in support of decision making and community education. The Sixth International Conference on Sustainable Water Environment: Water Infrastructures in Time of Climate Change. University of Delaware, Newark, DE, USA, 29-31 July 2010. (*Invited presentation).

Nelson, S.J., 2010. Finding mercury in Maine: Local, regional, and global influences. Husson University Environmental Club lecture series, March 30, 2010.

Presentations

Amirbahman A., B.A. Lake, and S.A. Norton, “Seasonal phosphorus dynamics in the surficial sediment of shallow temperate lakes: A combined DET and 31P-NMR study,” Paper presented at the American Society of Limnology and Oceanography (ASLO), Aquatic Sciences Meeting, Puerto Rico, February 2011.

Beard, K. IGERT Sensor Science, Engineering and Informatics. Invited Presentation, University of Arkansas, Little Rock. October 21-22. 2010. Visualizing and Exploring Events from Sensor Networks. SIE- NCGIA Seminar Series, Orono, ME.

Kirstin Ditzler, Jasmine Saros, Kevin Simon, Michael Kinneson. 2010. Impacts of White Perch Introductions on Food Web Dynamics: Paleolimnological and Experimental Analysis of Zooplankton Grazing and Nutrient Cycling. 16th Annual Maine Water Conference, Augusta, ME. March 17, 2010.

Feurt, C. Sustainable Lawn Care Practices. Kennebunk Conservation Commission Community Forum on Lawn Care Practices to Sustain Water Quality

Hart, D. SSI Overview, Research-Extension Partnerships in Sustainability Science: Bridging Research-Based Knowledge with Client-Based Needs. Day-long workshop at UMaine, Orono.

Hart, D. Maine's Sustainability Solutions Initiative: Novel strategies for strengthening connections between knowledge and action. Invited seminar, Dept. of Natural Resources and the Environment, University of New Hampshire.

Hart, D. Maine's Sustainability Solutions Initiative: Partnerships for Linking Knowledge with Action. 40th Annual Maine Lakes Conference. June 26, 2010.

Hart, D. SSI Overview and Update. Maine EPSCoR State Conference, University of Maine, Orono, ME. November 8, 2010.

Jain, S., J. Peckenham, A. Reeve, and D. Hart (2010) Defining Problems for Sustainable Solutions: Typology of Source Water Protection in Maine, University Council for Water Research Annual Conference, July 17, 2010.

Jain, S. Emerging hydroclimatic regimes in a changing climate: Understanding the nature of decadal variability and secular trends for resource management and decision-making. Conference on Decadal Predictability at the International Centre for Theoretical Physics Trieste, Italy, 16 - 20 August 2010.

Jain, S., Adaptive water allocation and instream flow standards in a changing climate: Maine's Chapter 587. Northeast Climate Change & Bioassessment Workshop, USEPA - New England Regional Lab (NERL), North Chelmsford, MA, September 29-30, 2010

Lee M. Demi, Kevin S. Simon, Stephen M. Coghlan, Rory Saunders, Dennis Anderson. Top-down trophic cascades and their influence on phytoplankton biomass in lakes along a trophic gradient. Annual Meeting of the North American Benthological Society.

Loftin, C., A. Calhoun. S. Nelson (presenter), A. Elskus, K. Simon. Does mercury bioaccumulate in amphibians developing in vernal pools? Northeastern/Southeastern Geological Society of America meeting, Baltimore, MD, March 13-16, 2010.

Madeleine Mineau, Kevin Simon, Damon Ely, Regina Rancatti, Ivan Fernandez, Steve Norton, Maury Valett. Effects of chronic N enrichment and acidification on coupled N and P cycling in streams: insights from multiple spiraling techniques. Annual Meeting of the North American Benthological Society.

Nelson, S**.,** B. Zoellick, E. Lindsey, E. Sherman. Dragonfly larvae as indicators for mercury in the Northeast: interdisciplinary citizen science research. Dragonfly Society of the Americas 2010 Annual Meeting, June 24-27, 2010.

Nelson, S.J., 2011. Finding mercury across the Northeast: local, regional and global influences. Stevens High School. Claremont, NH, January 28, 2011.

Nelson, S.J., Soukup, M., Lindsey, E. 2010. WERU Radio – Talk of the Towns. Community Science: Schoodic Education and Research Center links researchers, school teachers and students. November 12, 2010. Available: http://archives.weru.org/talk-of-the-towns/talk-of-the-towns-111210.

Nelson, S**.,** P. Vaux, B. Zoellick. No such thing as pristine: mercury in Maine waters and northeast National Parks. Maine Water Conference, Augusta, ME, March 17, 2010.

Parr, T., C. Cronan, T. Ohno and K. Simon. Patterns of dissolved organic matter composition along an Urbanization Gradient in Maine. Annual Meeting of the North American Benthological Society. May 2011
Peckenham, J. (2010) Changing Climate and Water Resources- Guidance for Drinking Water Utilities. U.S. Environmental Protection Agency SRF/ARRA/GPR Workshop, Kennebunk, ME.

Peckenham, J., J. Pinto, C. Proctor, Q. Wang, and H. Patterson. (2010) Real-Time Algae Monitoring For Drinking Water Security, North American Lake Management Society Annual Meeting.

Simon K., C. Rigsby, D. Ely, M. Mineau, T. Ohno, I. Fernandez, S. Norton, H.M. Valett. Microbial response to altered dissolved organic matter chemistry arising from watershed nitrogen enrichment and acidification. Annual Meeting of the North American Benthological Society. Providence, RI, USA

Zoellick, B., S. Nelson, T. Johnston, Y. Davis. Making sense of observations and data: Integrating explicit instruction in working with data into science education. Maine Center for Research in STEM Education, 2010 National Summer Conference, June 21, 2010.

Zoellick, B., T. Johnson, S. Nelson**.** Making Sense of Observation and Data (Graphs are Not Just for Math Class): Integrating explicit instruction in working with data into science education. Integrating Science and Mathematics Education Research into Teaching National Conference. University of Maine, Orono, Maine. June 21, 2010.

Reports

James-Pirri, M.J., S.J. Nelson, and P.D. Vaux. July 2010. Natural Resource Assessment for Saugus Iron Works National Historic Site. Natural Resources Report NPS/NER/NRR-2010/248. National Park Service. Boston, MA, in press.

Kahl, J.S., W. McDowell, S. Nelson, K. Webster. 2010. Determining the effectiveness of the Clean Air Act and Amendments on the recovery of surface waters in the northeastern US (IAG 06HQGR0143). Annual Report to USGS WRD WRRI, Reston, VA; US EPA, CAMD, Washington DC; and US EPA, ORD, Corvallis OR, March, 2010.

Nelson, S.J**.** 2010. The Acadian Internship in Regional Conservation and Stewardship: Large landscape conservation training and service for the next generation of public, private and non-profit conservation leaders. Report to Quebec-Labrador Foundation/Atlantic Center for the Environment, August 2010. 61 pp.

Ranco, D., J. Daigle, R. Lilieholm, J. Neptune and T. Secord. 2010. Kolunkayowan Wikpiyik: Protecting the Ash for Future Generations Symposium Report. Orono, ME: George Mitchell Center, University of Maine. 23 pgs.

Vaux, P., S.J. Nelson. 2010. KnowledgeBase On-Line Bibliographic and Dataset Catalogue: Maintenance and Update of AcadiaScience.org Web site. Report to National Park Service, December 2010.

Vaux, P., S.J. Nelson, M.J. James-Pirri, and G. Giese. 2010. Assessment of natural resource conditions in and adjacent to Cape Cod National Seashore, Massachusetts. Natural Resource [Technical] Report NPS/NRPC/WRD/NRR—2008/069. National Park Service, Fort Collins, Colorado. in final prep.

Zoellick,B., S.Nelson, Y.Davis. 2011. Professional Partnership and Praxis: A program to connect teachers and working scientists in support of citizen science and student inquiry. Report to Maine Department of Education - Year Three, January 26, 2011.

Zoellick, B., B. Bisson, S. Nelson, 2010. Acadia B-WET: a partnership to help teachers engage students in sustained, project-oriented investigations of the American eel (*Anguilla rostrata*) in Gulf of Maine watersheds. NOAA Office of Education Semi-Annual Project Progress Report, December 2010.

Other Publications

Waterlines…in brief

Mitchell Center newsletters are distributed via email on a regular basis to the Mitchell Center's mailing list of over 2,000 people. The newsletter is also posted on-line (http://www.umaine.edu/WaterResearch/outreach/waterlines.htm) and includes news and information on current activities at the Mitchell Center, Maine's Sustainability Solutions Initiative and Maine WRRI.

Waterlines in brief. Web-based news sheet, February 16, 2011

Waterlines in brief. Web-based news sheet, February 7, 2011

Waterlines in brief. Web-based news sheet, January 1, 2011

Waterlines in brief. Web-based news sheet, October 14, 2010

Waterlines in brief. Web-based news sheet, October 5, 2010

Waterlines in brief. Web-based news sheet, May 7, 2010

Waterlines in brief. Web-based news sheet, March 1, 2010

doSSIer

doSSIer is the team newsletter of Maine's Sustainability Solutions Initiative, a program of the Mitchell Center. The newsletter is published bi-weekly and provides news and updates for the SSI team. It is e-mailed to 150 participating faculty and students and posted to the SSI web site.

DoSSIer Issue No. 25, 2/16/2011
www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_02_16_11.html

DoSSIer Issue No. 24, 2/2/2011
www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_02_02_11.html

DoSSIer Issue No. 23, 1/12/2011
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_01_12_11.html

DoSSIer Issue No. 22, 12/20/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_12_20_10.html

DoSSIer Issue No. 21, 12/2/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_12_02_10.html

DoSSIer Issue No. 20, 11/17/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_11_17_10.html

DoSSIer Issue No. 19, 11/3/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_11_03_10.html

DoSSIer Issue No. 18, 10/18/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/dossier/dossier_10_14_10.html

DoSSIer Issue No. 17, 9/22/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/pdfs/dossier/doSSIer_no_17.pdf

DoSSIer Issue No. 16, 8/12/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/pdfs/dossier/doSSIer_no_16.pdf

DoSSIer Issue No. 15, 7/20/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/pdfs/dossier/doSSIer_no_15.pdf

DoSSIer Issue No. 14, 6/9/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/pdfs/dossier/doSSIer_no_14_small2.pdf

DoSSIer Issue No. 13, 4/28/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/pdfs/dossier/doSSIer_no_13.pdf

DoSSIer Issue No. 12, 4/14/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/pdfs/dossier/doSSIer_no_12_small.pdf

DoSSIer Issue No. 11, 4/1/2010
http://www.umaine.edu/sustainabilitysolutions/faculty_resources/pdfs/dossier/doSSIer_no_11_small.pdf

Poster Presentations

Arter, Barbara. Diadromous Species Restoration Research Network: A Five-Year Collaborative Research Effort. 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Bacon, Linda C., Aria Amirbahman, Stephen Northon, Kathleen P. Bell, Kevin Simon, Ivan Fernandez, Dave Courtemanch, Barry Mower. Linking Knowledge with Action: Refining Maine's Mercury Fish Consumption Advisory (Phase I). 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Baker, B., Hutchins, K., Leahy, J., Lindenfeld, L, Quartuch, M.R., and Silka, L. Sustainability Problems and Engaged Solutions: Opportunities for New Interdisciplinary Approaches, 11th Annual National Outreach Scholarship Conference, October, 2010, Raleigh, N.C.

Ball, William, John Jemison, Laura Wilson, Christopher Brewer, Mark Ward, Wendy Warren. Reducing Pollutants to Urban Streams through "Business Friends Program". 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Barton, Andrew, Chris Bennett, Daniel Buckley, Ronald Butler, Mellisa Clawson, Julia Daly, Wendy Harper, David Heroux, Rebecca Kurtz, Cathleen McAnneny, Nancy Perlson and Shelby Rousseau. 2010. Sustainability and Landscape Change in the Rangeley Lakes. Poster presented at the Maine EPSCoR State Conference, University of Maine, Orono, ME, November 8.

Becker, Amy, Bell, K.P., Budzinski, C., Hall, D.M., Hutchins, K.K., Kacer, N., Leahy, J., Lindenfeld, L.A., Lyons, P., McGreavy, B., Post, D., Quartuch, M., Silka, L., Smith, H., Richards, M., Thornbrough, L. 2010. Poster. Linking Knowledge and Action Systems: Creating Solutions-Oriented Partnerships for a Sustainable Future in Maine. Maine EPSCoR Conference, University of Maine, Orono, ME, November 8.

Cole, F. R., P. J. Nyhus, S. Hart, and I. McCullough. 2010. Investigating Resilience and Change in the Belgrade Lakes Watershed. A Delicate Balance: Sustaining Maine Lakes. 40th Annual Maine Lakes Water Conference, June 26, 2010, Waterville, Maine.

Cosley, B., McCoy, S. K., Noblet, C., Teisl, M., & Wellman, J., (2010). Persuaded by the status quo: The role of economic stress in persuasion for environmental messages. Maine EPSCoR conference, Orono, ME.

Harvey, Amanda. Behrooz Zekavat, Mahsan Miladi, Touradj Solouki. Improving the Detection of Disinfection Byproducts in Drinking Water: Utilizing GC/FT-I CR MS Combined with GC/FID. 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Johnson, Dustin, Amanda Olsen, Aria Amirbahman, Stephen Norton. Influences of dissolved organic carbon and iron photochemistry on phosphorus cycling in surface waters: Implications of particle size distribution. 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Johnson, M.L., R.J. Lilieholm, C.S. Cronan, S.R. Meyer, J. Tremblay, and J. McCloskey. 2011. Analysis of alternative futures of the Maine landscape using stakeholder-derived spatial models. Association of American Geographers Annual Meeting.

Johnson, T.R. and G. Zydlewski. 2010. Maine Tidal Power Initiative: Linking Knowledge to Action for Responsible Development. Maine EPSCoR State Conference, Wells Conference Center, University of Maine, Orono, Maine. November 8, 2010.

Killarney, James, Howard Patterson, John Peckenham, Adria Elskus, Lawrence Leblanc, Gregory Hall. Fluorescence Spectroscopy as a Rapid, Cost-Effective Method to Monitor and Analyze Low Levels of Pharmaceuticals and Personal Care Products in Environmental Water Samples. 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Kong, Lina, Benjamin Shasa, Lynne Lewis. Measuring and Incorporating Stakeholder Values into River Restoration Decisions: A Socio-Economic Analysis. 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Lillieholm, R., Cronan, Judd, Wilson, Gallandt, Hornsby, McCloskey, Tremblay, Johnson, Meyer, Mallory Glidden. 2010. Analysis of Alternative Futures of the Maine Landscape using Spatial Models of Coupled Social and Ecological Systems. 2010 Maine State EPSCoR Conference, University of Maine, Orono.

Lilieholm, R., Jansujwicz, Hunter, Ryan, Cline, Bell, Levesque, Morgan, Popescu, Calhoun, Loftin . 2010. Population Persistence in Complex Landscapes: Vernal Pools as a Model System. 2010 Maine State EPSCoR Conference, University of Maine, Orono.

Lilieholm, R.J., C.S. Cronan, J. McCloskey, S.R. Meyer, M.L. Johnson, J.Tremblay, R. Judd, J.S. Wilson, E.R. Gallandt, S.J. Hornsby, E. Mallory and T. Glidden. 2010. Analysis of Alternative Futures in the Maine Landscape Using Spatial Models of Coupled Social and Ecological Systems. Maine EPSCoR State Conference. Orono, Maine. November 8, 2010.

McCullough, I., S. E. Hart, D. Homeier, P. J. Nyhus, and R. Cole. 2010. Historic and Future Residential Development in the Belgrade Lakes Watershed. A Delicate Balance: Sustaining Maine Lakes. 40th Annual Maine Lakes Water Conference, June 26, 2010 (Poster).

McCullough, I., S. E. Hart, D. Homeier, P. J. Nyhus, and R. Cole. 2010. The Impact of Land Use and Land Cover Patterns on Phosphorus Loading in the Belgrade Lakes. A Delicate Balance: Sustaining Maine Lakes. 40th Annual Maine Lakes Water Conference, June 26, 2010 (Poster).

Meyer, S.R., R.J. Lilieholm, C.S. Cronan, M.L. Johnson, J.T. McCloskey, J.W. Wilson, E.G. Gallandt, ,J. Tremblay, T. Glidden, R. Judd, S. Hornsby, and E. Mallory. 2011. Using Bayesian Belief Networks to Model Future Land Use in Maine. Poster presentation to Maine EPSCoR Conference. Orono, ME. April 15, 2011.

Meyer, S.R., R.J. Lilieholm, C.S. Cronan, M.L. Johnson, and J.T. McCloskey. 2011. Using Bayesian Belief Networks to Model Future Land Uses in Maine. Poster presentation at United States-International Association of Landscape Ecology Symposium. Portland, OR. April 3-7, 2011.

Morgan, Dawn E., and A.J.K. Calhoun. 2010. Conserving Maine Vernal Pools through Collaborative Local Initiatives. Poster at: Maine EPSCoR State Conference, University of Maine, Orono, ME.

Morgan, Dawn E., and A.J.K. Calhoun. 2010. Conserving Maine Vernal Pools through Collaborative Local Initiatives. Poster at: North East Partners in Amphibian and Reptile Conservation, Schoodic, ME.

Owen, D., Cronan, C., Lindenfeld, L., Silka, L., Simon, K., Hall, D., Hutchins, K., and Parr, T., 2010. Poster. Sustaining and Restoring Urban Streams in Maine. Maine EPSCoR Conference, University of Maine, Orono, ME, November 8.

Parr, T., C. Cronan, T. Ohno, and K. Simon. 2011. Patterns of dissolved organic matter composition along an urbanization gradient in Maine. NABS annual meeting.

Straub, Crista, Teresa Thornton, Jessica Leahy, John Peckenham, Laura Wilson, John Jemison, Jean MacRae. A Pilot Study: Human Dimensions of Private Well Testing. 16th Annual Maine Water Conference. March 17, 2010. Augusta, Maine.

Supple, W.R., and C.R. Bevier. 2010. The Maine Vernal Pool Mapping and Assessment Project. Poster presentation, Colby Undergraduate Summer Research Retreat. July 2010.

Teisl, M., McCoy, S. K., Noblet, C. L. (2010). Modeling stakeholder acceptance of environmental problems. Maine EPSCoR conference, Orono, ME.

Thiele, Josie, Katherine Murray. 2010. The Impact of Thermal Structure and Mixing on Nutrient Dynamics and Plankton Abundance in Intermediate Depth Lakes in Maine. Presented at the Maine Lake Association Annual Conference, Waterville, Maine. June 2010.

Wilson, J.S., E.M. Simons, K.R. Legaard, S.A. Sader, and J. E. Leahy. Spatial forest planning to meet multiple natural resource goals. Maine EPSCoR Conference. University of Maine, Orono, ME.

Conferences and Annual Meetings

Maine Water Conference 2010

The 2010 Maine Water Conference took place on Tuesday, March 17 at the Augusta Civic Center in Augusta, Maine. Sessions topics included drinking water, urban streams, regional partnerships for watershed planning, and public outreach and education. Plenary speakers were Art Gold, Director of the

URI Water Quality Extension Program, and Andrew Reese, Vice President of AMEC Earth & Environmental.

The Maine Water Conference is the largest environmentally-related conference in Maine attracting over 350 water resource professionals. It provides unprecedented opportunities to promote both the Mitchell Center's and UMaine's role in environmental research and problem-solving throughout Maine and to build stronger relationships with state and federal agencies, NGOs, and the private sector. The MWC Steering Committee is made up of key water resource stakeholders from across the state.

Sponsorship for the 2010 Maine Water Conference was provided by: U.S. Geological Survey, Senator George J. Mitchell Center for Environmental and Watershed Research and the Maine Water Institute, Maine Drinking Water Program/Dept. of Health & Human Services, Aqua Maine, Maine Dept. of Environmental Protection, Maine WasteWater Control, Maine Coastal Program, Maine Geological Survey, Maine Water Utilities Association, Maine Congress of Lake Associations, University of Maine Cooperative Extension, and Maine Volunteer Lake Monitoring Program.

Public Service

Media/Press
Life Science. Scarborough Leader, June 4, 2010
http://blog.scarboroughleader.com/2010/06/04/life-science--june-4-2010.aspx

Committees and Service

David Hart
- Member, Science and Technical Advisory Committee, American Rivers
- Member, Sustainable Oceans, Coasts, and Waterways Advisory Committee, Heinz Center for Science, Economics, and the Environment, 2004 – present.
- Member, President's Advisory Committee on Water Information (representing the Ecological Society of America), 2003 – present.

John Peckenham
- Board Member (New England Regional Representative), National Institutes for Water Research.
- New England Private Well Initiative – Water Quality Extension and US EPA Region 1
- Source Water Collaborative and American Water Works Association Source Protection Committee
- New Business Development – Maine Water Security LLC (managing partner), Mainely Sensors
- LLC (consultant), Zeomatrix (consultant)
- Penobscot River Keepers (~500 students on the river)
- GET WET! (~125 students, water quality testing).
- River Flow Advisory Commission- Drought Task Force
- Maine Water Conference Organizing Committee
- Maine Water Utilities Association- Water Resources Committee
- Sustainable Water Withdrawal- Land and Water Resources Council
- Maine Waste Water Control Association- Residuals Management Committee
- Penobscot River and Bay Institute- Board of Directors
- Northern Maine Children's Water Festival
- DEP-Consulting Engineers of Maine Task Force
- New England Water Quality Extension Advisory Board

Sarah Nelson
- Convener, Mercury in Acadia and northeast protected areas. In collaboration with NPS-ARD, NPS-Acadia, SERC Instititute
- Lead scientist, Acadia Learning project, 2007-present

- Steering committee member, Acadian Internship in Regional Conservation and Stewardship, 2010-present
- Steering committee member, Downeast and Acadian Inititative, 2010-present
- Maine Water Conference, Science Program Chair, 2010-2011
- Acadia Web Portals working group, coordinator, 2009-2010
- Scientist-teacher liaison, Acadia Learning project, 2007-present
- MDI Water Quality Coalition student mentor, 2006-present
- Appalachian Trail Environmental Monitoring Program, Water Quality Working Group
- Coordinator, University of Maine Mercury Research Group, 2006-present
- Board member, Maine Lakes Conservancy Institute 2007 - 2010
- Maine Water Conference Organizing Committee

Peter Vaux

- Board member and Treasurer, Maine Volunteer Lake Monitoring Program
- Development of databases and on-line data resources Union River Watershed

Workshops and Other Activities

Maine's Sustainability Solutions Initiative (SSI) at the Mitchell Center

In July 2009, the Senator George J. Mitchell Center was awarded a $20 million, five-year grant by NSF EPSCoR to support Maine's Sustainability Solutions Initiative. Synergy between SSI and the Maine WRRI program provides important leveraging opportunities for water resource projects across the state. A key component of the SSI project is its partnership with 12 other educational institutions across Maine. All of these institutions are funded to conduct research under the SSI program – many related to water resources in Maine. WRRI Director John Peckenham acts as liaison between SSI and the partner institutions building relationships that also strengthen the WRRI program. It is also important to note that many faculty who have been funded under the WRRI research program are key collaborators on the SSI project.

SSI partner institutions include: Bates, Bowdoin, Colby, Unity, University of New England, College of the Atlantic, University of Southern Maine, University of Maine at Farmington, University of Maine at Augusta, University of Maine at Machias, University of Maine at Presque Isle, University of Maine at Fort Kent.

Introduction to Maine's Sustainability Solutions Initiative

Producing knowledge and linking it to actions that meet human needs while preserving the planet's life support systems is emerging as one of the most fundamental and difficult challenges for science in the 21st century. There is growing consensus that traditional methods of generating and using knowledge must be fundamentally reorganized to confront the breadth, magnitude, and urgency of many problems now facing society. Maine's Sustainability Solutions Initiative seeks to transform Maine's capacity for addressing these scientific challenges in ways that directly benefit Maine and other regions. The program of research will also help Maine increase economic activity and technological innovation in ways that sustain the State's remarkable "quality of place".

Maine's Sustainability Solutions Initiative Research Projects

The following funded projects provide direct linkages with the Maine WRRI program. Opportunities for further collaborations that enhance both research programs will be actively pursued in the future.

- Linking Knowledge with Action: Refining Maine's Mercury Fish Consumption Advisory
  Team Leader: Aria Amirbahman, Civil & Env. Engineering, University of Maine
- Protecting Natural Resources at the Community Scale: Using population persistence of vernal pool fauna as a model system to study urbanization, climate change and forest management

Team Leader: Aram Calhoun, Wildlife Ecology, University of Maine

- Decision tools to support water resources sustainability of managed lake systems
  Team Leader: Andy Reeve, Dept. of Earth Sciences, UMaine
- Adaptation Strategies in a Changing Climate: Maine's Coastal Communities and the Statewide Stakeholder Process
  Team Leader: Shaleen Jain, Civil & Env. Engineering & Climate Change Institute, UMaine
- Analysis of Alternative Futures in the Maine Landscape using Spatial Models of Coupled Social and Ecological Systems
  Team leader: Rob Lilieholm, Forest Resources
- Sustaining and Restoring Urban Stream Resources in Maine
  Team leader: Dave Owen, School of Law, University of Southern Maine
- Researching Knowledge-to-Action Linkages to Promote Stakeholder and Community Engagement
  Team leaders: Laura Lindenfeld, Communication and Linda Silka, Margaret Chase Smith Center for Public Policy
- Modeling Stakeholder Acceptance of Solutions to Environmental Problems
  Team leaders: Mario Teisl, Shannon McCoy, University of Maine
- Spatial forest planning to meet multiple natural resource goals: Developing geospatial tools to forecast management outcomes across a diverse landscape of ownership types and stakeholder interests
  Team leader: Jeremy Wilson, University of Maine
- The Maine Tidal Power Initiative: Linking knowledge to action for responsible tidal power development
  Team leaders: Teresa Johnson, Gayle Zydlewski, University of Maine
- Ecological and economic recovery and sustainability of the Kennebec and Androscoggin Rivers, estuary and nearshore environment
  Team leader: John Lichter, Bowdoin College, Bates College, University of Southern Maine
- Sustaining Quality of Place in the Saco River Estuary through Community Based Ecosystem Management
  University of New England
- Modeling Resilience and Adaptation in the Belgrade Lakes Watershed
  Team leader: Whitney King, Colby College
- Modeling evolving ecological, cultural, and economic systems of the Aroostook River watershed of northern Maine for sustainable development (Planning Grant)
  Team leader: Jason Johnson, University of Maine at Presque Isle (UMPI)
- Planning for Watershed-based Sustainable Development: Bridging the Belgrade and Rangeley Lakes Regions
  Team leader: Wendy Harper, University of Maine at Farmington (UMF)

Senator George J. Mitchell Lecture on Sustainability

Conventional wisdom holds that only large-scale solutions can address global problems, and that smaller efforts are ineffective. Among the leading scholars challenging this assumption is Nobel Laureate Elinor Ostrom, whom SSI invited to present the Senator George J. Mitchell Lecture on Sustainability on October 21, 2010.

The first woman to win the Nobel Prize in Economic Sciences, Ostrom has shown how groups of people around the world have sustainably managed shared local resources such as fisheries and grazing land. Her findings challenge the widespread economic belief that these and other "commons" can only be managed through privatization or regulation. A political economist and professor at Indiana University and Arizona State University, she is the author of books including the seminal *Governing the Commons: The Evolution of Institutions for Collective Action.*

Ostrom presented her insights on “a polycentric approach to climate change,” to an audience of more than 450 attendees, including students, faculty and the general public. She described how diverse local efforts can cumulatively help reduce greenhouse gas emissions, especially when successful approaches are shared and spread through networks. Ostrom illustrated this concept with innovative initiatives, including the Sacramento Municipal Utility District’s program to encourage electricity conservation by showing customers how their energy use compares to that of their neighbors, and the Berkeley First program, which provides financing incentives to help families purchase renewable and solar technologies.

Instead of “one global remedy” to climate change and other sustainability challenges, Ostrom urged the application of polycentric theory to develop complex “political-economic social systems to cope with complex, multi-level ecological systems.”

She emphasized the importance of local engagement in complex challenges like climate change. “Current research on ecosystem services is getting technologically more sophisticated, but local knowledge and local commitment are also important components of effective policies,” Ostrom said.

Water Words that Work (Workshop)
Co-sponsored with Maine NEMO and the University of Maine Cooperative Extention, the “Water Words that Work” training enabled water professionals and faculty to improve their ability to inform citizens about conservation, pollution control and water use, and to inspire action on those issues. The two-day workshop was attended by more than 75 people representing various state agencies, schools and non-profits.

Mitchell Center and SSI Seminars
In order to meet its mission and goals, the Mitchell Center offers related seminars and workshops each semester. Following is a list of relevant seminars for FY10.

March 18, 2010
Richard Judd
Environmental Justice in New England: Race, Class, and Environment in Regional Perspective

Thursday, April 15
Bettina Boxall
A conversation with Bettina Boxall, Pulitzer-prize winning journalist on natural resource and environmental issues

April 16, 2010
Jessica Leahy, Jeremy Wilson, Rob Lilieholm
New forestry research under the Sustainability Solutions Initiative

April 27, 2010
Jim Levitt, Author of "Conservation Capital in the Americas"
Innovation in Conservation Finance: Past, Present & Future

September 27, 2010
Damon Hall, SSI Post-doc
Useful knowledge for sustainability science: place-based research on the Yellowstone River

October 4, 2010
Zachary Easton, Cornell University
“Non-point” from Non-point Source Pollution.

October 13, 2010
Kathleen Boomer, Smithsonian Environmental Research Center
Using Multiple Watershed Models to Link Science and Land Management

October 18, 2010
Adam S. Ward, Penn State University
When Science is Not Enough: Restoring Functions of Streams Beyond the Banks

October 20, 2010
Sean Smith, Maryland Dept of Natural Resources
Ecosystem Restoration Services
Closing the Gaps Between Sediment Budgeting, Watershed Modeling, and Stream Rehabilitation

December 3, 2010
Robert Kates, Presidential Professor of Sustainability Science
Sustainable Development: Can It Be Done in This or Any Century?

January 18, 2011
SSI Integration Discussion Group Series
Bridie McGreavy, University of Maine
Attitudes to Vernal Pools

February 1, 2011
SSI Integration Discussion Group Series
Tim Waring, University of Maine
Evaluating Coupled Socio-Ecological Systems

February 15, 2011
SSI Integration Discussion Group Series
Brian McGill, University of Maine
Is climate change an example of a coupled natural human system?

Environmental Seminars at UMaine
As part of a larger initiative to have the Mitchell Center become the focus of environmental initiatives on campus, Center staff worked with other departments and institutes to put together a comprehensive list of all the environmentally-related seminars taking place at UMaine each semester. This initiative has been very well received by staff, faculty and students, and several faculty members noted that this was an important role for the Mitchell Center.

Web Sites
The Mitchell Center hosts two Web sites, the main Mitchell Center Web site (http://www.umaine.edu/WaterResearch/) and the new SSI Web site. WRRI program information is available on the Mitchell Center web site and includes updates on funded projects, grant programs and related conferences and grant opportunities. The site is updated weekly.

The SSI Web site was launched in 2009 (www.umaine.edu/sustainabilitysolutions) and is designed to assist with SSI communication efforts. The site contains information covering many aspects of the initiative including current research projects, faculty and student involvement, student opportunities and recruitment materials, resources, and news and events.

GET WET!
Groundwater Education through Water Evaluation and Testing (GET WET!) is an experiential project to raise community awareness about groundwater quality and to provide data for a study of gravel mining and water quality. There are three key objective categories: science, community, and education.

Scientific goals include:

- Create long-term water quality databases in towns through annual well monitoring and sampling.
- Utilize students to sample. The wells sampled are located in, over, or next to the sand and gravel
- aquifer.
- Include in the database: 1) Water chemistry of nitrate, alkalinity, chloride, conductivity, and
- turbidity. 2) Locations of wells mapped into a GIS program. 3) Operational excel spreadsheets
- with all information gathered. 4) Statistics and charts to graphically represent information.

Community goals include:

- Increase awareness, understanding, and interest in water resources within towns.
- Involve local citizens in the sampling, monitoring, and maintenance of water quality within their town.
- Generate a water quality database that can be used by the community to formulate productive choices in planning, management, and development.

Education goals include:

- Create an interdisciplinary study focusing on natural resources water and development.
- Employ all grades and educators involved in chemistry, geology, geodesy, mapping, GIS, statistics, computer programs, and environmental studies.
- Encourage student development in: 1) Field sampling techniques. 2) Laboratory skills. 3) Computer competence. 4) Internet research capabilities. 5) Mapping abilities in both interpolation of hard copy topographic maps and interpretation of computer based topographic maps. 6) Recognition and identification of locations by latitude and longitude on topographic maps. 7) Comprehension in terminology and function of water chemistry testing for nitrates, alkalinity, chloride, conductivity, and turbidity. 8) Understanding of why conservation and commitment to a healthy environment takes an entire community. 9) Public presentation.

Waterlines…in brief mailings
The Mitchell Center has moved its newsletter almost exclusively to an on-line format (http://www.umaine.edu/waterresearch/outreach/waterlines.htm) with e-mail notification to its subscription list. An effort has been made to keep newsletter content shorter which enables mailing on a more frequent basis. This allows us to provide readers with updates on upcoming seminars, conference and event information, proposal notification and more in a more timely fashion. A total of six “Waterlines…in brief” were distributed in FY10 to a mailing list of over 2,000 readers.

Professional Partnership and Praxis
Sarah Nelson is participating as a partner in the project “Professional Partnership and Praxis: Connecting Teachers, Working Scientists, and College Education Faculty to Attain New Learning Results” through Maine Title II, Mathematics and Science Partnerships program. Although Nelson is involved with all goals of the project through collaboration with Acadia Partners for Science and Learning and other partners, her primary activities relate to planning and design sessions, lesson and research program planning and design, direct engagement between students, teachers, and working scientists, and statewide outreach and invitation to participate.

Research Coordination Network: Diadromous Species Restoration Research Network
The Diadromous Species Restoration Research Network (DSRRN) is an NSF-funded network whose goal is to advance the science of diadromous fish restoration and to facilitate interactions among scientists, managers, and stakeholders. A web site for the network has been established at http://www.umaine.edu/searunfish and a full-time Science Information Coordinator was hired in March 2009. In November 2008, a Stakeholders Workshop was convened to introduce the Network and to

gather information to identify research questions and restoration goals. Over 30 stakeholders attended and discussed potential impacts and changes as a result of the anticipated dam removals on the Penobscot River.

In 2010, the Network hosted two gatherings of the Penobscot Science Exchange. The spring meeting was held in March while the fall meeting was held in October. The purpose of the Exchange is to meet biannually to share information regarding research and monitoring in the Penobscot Watershed. Each researcher was asked to provide a two-minute update describing his/her research on the Penobscot. There were also presentations on the NOAA Restoration Monitoring Plan, Penobscot Trust Project and DSRRN Activities. In addition, the Coordinator reviewed the recently updated Penobscot Science Exchange Research Summary, a database which describes recent research on the Penobscot. Information about both the Stakeholders Meeting and the Science Exchange Meeting can be found at http://www.umaine.edu/searunfish/research/Penobscot-exchange.htm

The first DSRRN workshop was held in April 2010. Titled **'**Resilience of North Atlantic Diadromous Fish Assemblages: a Restoration Perspective," the goal of this workshop was to develop a synthesis paper which will identify and synthesize factors and species interactions that contribute to North Atlantic diadromous fish assemblage resilience in the context of restoration. Two other workshops are scheduled for May 2011 and May 2012.

Northern Maine Children's Water Festival

The Mitchell Center plays a key role in the Northern Maine Children's Water Festival that is held every two years at the University of Maine. Over 700 students and teachers from 14 middle and elementary schools all over northern Maine convened on campus on October 12, 2010 for the 10th biennial festival. The festival is a fun-filled way for students to learn about the value of clean water and healthy habitats, and to provide teachers with materials and lessons that they can use for years to come. At the festival, water resource professionals from Maine and other parts of New England provide presentations and interactive displays about water, wetlands, human health and aquatic life.

This experience is provided at no cost to the participants, and the Festival budget includes funding to help schools pay for the cost of transportation to the University of Maine for the day. Festival attendance is limited, and schools are selected to attend on a competitive basis.

The Northern Maine Children's Water Festival is sponsored by the Maine Department of Environmental Protection, the Senator George J. Mitchell Center and Water Research Institute, Maine CDC Drinking Water Program, University of Maine Cooperative Extension and Conference Services, and Maine Sea Grant.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	2	4
Masters	6	0	0	16	22
Ph.D.	2	0	0	1	3
Post-Doc.	0	0	0	0	0
Total	10	0	0	19	29

Notable Awards and Achievements

Maine's Sustainability Solutions Initiative (SSI) at the Mitchell Center

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Water Resource-Related SSI Projects

The following funded projects provide direct linkages with the Maine WRRI program. Opportunities for further collaborations that enhance both research programs will be actively pursued in the future.

- Protecting Natural Resources at the Community Scale: Using populations persistence of vernal pool fauna as a model system.
  Team leader: Aram Calhoun, UMaine.
- Decision Tools to Support Water Resources Sustainability of Managed Lake Systems
  Team leader: Andrew Reeve, UMaine
- Researching Knowledge-to-Action Linkages to Promote Stakeholder and Community Engagement
  Team leaders: Laura Lindenfeld and Linda Silka, UMaine.
- Sustaining and Restoring Urban Stream Resources in Maine
  Team leader: Dave Owen, University of Maine School of Law
- Linking Knowledge with Action: Refining Maine's Mercury Fish Consumption Advisory
  Team leader: Aria Amirbahman, UMaine.
- Ecological and Economic Recovery and Sustainability of the Kennebec and Androscoggin Rivers and their Common Estuary and Nearshore Marine Environment.
  Team leader: John Lichter, Bowdoin College
- Modeling Resilience and Adaptation in the Belgrade Lakes Watershed
  Team leader: Whitney King, Colby College
- Sustaining Quality of Place in the Saco River Estuary through Community Based Ecosystem Management
  Team leader: Pamela Morgan, University of New England
- Modeling Evolving Ecological, Cultural and Economic Systems of the Aroostook River Watershed of Northern Maine for Sustainable Development
  Team leader: Jason Johnson, University of Maine at Presque Isle
- Promoting Watershed-based Sustainable Development through Ecological and Socio-economic Research and Educational Initiatives
  Team leader: Wendy Harper, University of Maine at Farmington
- Application of an Integrative Decision Support Tool and Spatial Modeling to Assess the Implications of Future Growth Scenarios on Sensitive Aquatic Resources in Maine
  Team leader: Rob Lilieholm, UMaine

Senator George J. Mitchell Lecture on Sustainability

Conventional wisdom holds that only large-scale solutions can address global problems, and that smaller efforts are ineffective. Among the leading scholars challenging this assumption is Nobel Laureate Elinor Ostrom, whom SSI invited to present the Senator George J. Mitchell Lecture on Sustainability on October 21, 2010.

The first woman to win the Nobel Prize in Economic Sciences, Ostrom has shown how groups of people around the world have sustainably managed shared local resources such as fisheries and grazing land. Her findings challenge the widespread economic belief that these and other "commons" can only be managed through privatization or regulation. A political economist and professor at Indiana University and Arizona State University, she is the author of books including the seminal Governing the Commons: The Evolution of Institutions for Collective Action.

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Publications from Prior Years

1. 2007ME152B ("Response of a linked lake-stream system to dam removal and restoration of migratory fish.") - Dissertations - Demi L. (2010) Anadromous alewives in linked lake-stream ecosystems: Can trophic interacations in lakes influence streams? Thesis (M.S.) in Ecology and Environmental Science.