FINAL REPORT

for

PILOT STUDY TO CALCULATE NUTRIENT AND HYDROLOGIC FLUXES IN A TREE ISLAND

Prepared for

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1.0 EXECUTIVE SUMMARY

In the Florida Everglades, tree islands are conspicuous as heterogeneous elements of the landscape. Tree islands are suggested to concentrate large quantities of nutrients that may otherwise be released to phosphorus (P) limited Everglades marshes. This function has likely been compromised because up to 60% of treed islands that once existed in the 1940's have been lost (WCA-3A). The goals of this project were to: 1) investigate the ecological significance of tree island loss by quantifying the contribution of tree islands to the nutrient balance of the Everglades and 2) contribute to our understanding of pre-drainage water quality and "getting the water right". We addressed the following overall questions. 1) What is the average standing stock of nutrients in an Everglades tree island; 2) Annually, what is the quantity of nutrients sequestered by a tree island? 3) What is the quantity of N & P that is available to Everglades marshes annually as a function of tree island loss?

This work provided some interesting results meriting further investigation. These results are as follows:

1. Wet head and Near Tail communities maintained relatively small differences in standing stocks of N and P.
2. The annual nutrients sequestered by tree island communities of Wet head and Near Tail were dependent on annual hydrology.
3. Annual variability in hydrology had a large affect on concentration gradients of TP, SRP and dissolved N between very short intervals along the soil profile (between 30cm & 60cm), were variable within and between Wet Head and Near Tail communities

4. Infiltration rates mediated relatively large average losses of total and dissolved nutrients.
5. Peat accretion rates and surface water loading were among the most important budget parameters, but reported with the greatest uncertainty
6. Plant uptake was another important parameter, but also could only be estimated
7. Despite the contribution of surface water loading, treed island loss has allowed phosphorus to be released to the marsh, approximating 8-22% of the annual TP input through atmospheric deposition
8. Based on soil concentration gradients in the Wet Head, High Head budgets & fluxes will yield important information about the source and fate of P

This work will aid in our understanding of the role of tree islands in landscape nutrient budgets and provide a comprehensive metric with which to assess tree island ecosystem responses to hydrologic change. Thus, this project addresses a critical science need by quantifying the P and net inorganic N standing stocks and retention of a characteristic tree island of the Water Conservation Area (WCA) 3A where DECOMP will occur. This work was only possible through the contributions of many District collaborators, most notably Steve Krupa. This report was dramatically improved by editorial comments provided by Fred Sklar, Colin Saunders, Dave Rudnick and Carlos Coronado-Molina.

2.0 INTRODUCTION

In the Florida Everglades, tree islands are conspicuous as heterogeneous elements of the landscape. Tree islands are suggested to concentrate large quantities of nutrients that may otherwise be released to phosphorus (P) limited Everglades marshes (Orem et al., 2002). This function has likely been compromised because up to 60% of tree islands that once existed in the 1940's have been destroyed (Water Conservation Area 3-A; Patterson and Finck, 1999). Tree islands appear to concentrate large quantities of P as shown by high soil P concentrations (Orem et al., 2002) and have been shown to have an important function in landscape sequestration of inorganic nitrogen (N) (Troxler Gann 2005). Enrichment of Everglades surface water with both P and N are of concern because P inputs have been documented to dramatically change the ecological structure and function of Everglades wetland communities (Newman et al. 1996; McCormick et al., 200; Gaiser et al., 2005) and nitrogen loading has been linked to algal blooms in more phosphorus enriched parts of Florida Bay (LaPointe et al., 1994). Thus, the goal of this project is to investigate the ecological significance of tree island loss by quantifying the contribution of tree islands to the nutrient balance of the Everglades landscape (Sklar and van der Valk, 2002). As the hydrologic restoration of upstream Everglades freshwater marshes occurs and tree islands are restored, the nutrient sequestration function of tree islands is likely to change as the tree island-marsh linkages will become more pronounced.

This pilot study will help to supports Everglades Restoration goals and objectives by addressing key science and management issues including “getting the water right” and tree island restoration targets. Similarly, this work will aid in our understanding of the role of tree islands in landscape nutrient budgets and provide a comprehensive metric with which to assess tree island ecosystem responses to hydrologic change. Thus, this project addresses a critical science need by quantifying the P and net inorganic N standing stocks and retention of a characteristic tree island of the Water Conservation Area (WCA) 3A where DECOMP will occur. Our goal was to address the following overall questions. 1) What is the average standing stock of nutrients in an Everglades tree island; 2) Annually, what is the quantity of nutrients sequestered by a tree island? 3) What is the quantity of N & P that is available to Everglades marshes annually as a function of tree island loss? Our main hypothesis followed that of van der Valk and Sklar (2002) and Wetzel et al (2005) where fixed tree islands in deep slough intercept nutrient sources, especially phosphorus, through mechanisms that accumulate and leach nutrients in upstream plant communities (in this study, the "wet head") to downstream plant communities which thus retain these nutrients ("near tail").

3.0 METHODS

The study site was the tree island 3AS3 in the Water Conservation Area 3-A (Figure 1). Here were present annual N and P budgets for each of the "Wet Head" and "Near Tail" plant communities for 2007 and 2008, and calculations of net ecosystem N and P flux.

2.1 Annual Standing Stocks of P and N in soil, microbes, plants and water

a. Plants

We used litterfall collections to estimate values for plant nutrient cycling, uptake and N and P accumulation in soils. In each of two communities, "high head" and "near tail", litterfall was collected monthly by District researchers from ten 0.5 m^2 traps (2000-2004). Litter collected from each trap was dried to constant weight at 70ºC, sorted (leaves by species, wood, reproductive parts, and miscellaneous parts), and weighed. A representative sample of mature green leaves from the species most commonly represented in each month's litterfall samples was collected in early 2007, processed in the District's nutrient analysis lab for CNP and also used for these calculations.

Litter standing stocks were quantified in (2006), collected from 5 0.5m^2 quadrats placed on the soil surface (excluding large woody debris >2.5 cm in diameter) in each of two communities ("High Head" and Near Tail"). Litter was sorted into leaf components, dried to constant weight at 70º C, and weighed in the District's laboratory facilities.

Subsamples from each component were compiled, ground to a homogeneous powder (<500 μm), and analyzed for total nitrogen, total phosphorus, and total carbon. Live leaf, litterfall and standing litter samples were analyzed in the District's nutrient analysis lab. Nitrogen and phosphorus content of litterfall and green leaves were used to calculate nutrient resorption efficiency (% nutrients withdrawn upon senescence of leaves; Chapin and VanCleve, 1989).

b. Soil and Water Standing Stocks

In each of five samplings conducted in months January, February, March, May, June and August, in years 2007 and 2008, 24 soil cores were collected, 12 of which were analyzed for inorganic soil nutrient concentrations (SRP, NH_4^+, and NO_3^-), bulk nutrient concentrations of surficial litter and soil, and N and P determinations of microbial biomass, and the remaining 12 used for analyses of N transformation rates.

For inorganic nutrient concentrations, total P and N, and N and P microbial biomass determinations, we were extracted two cores from each site with a 5.2 cm inner diameter PVC tube with a thin sleeve (~ 5 mm thickness). Each core was normalized to a constant core depth of 10 cm when possible. The cores were homogenized, and subsamples used for the following analyses. We determined inorganic and organic dissolved nutrient concentrations (soil porewater) from KCl and $NaHCO_3$ soil extractions for N and P analyses, respectively. Samples (~17 mL) were extracted in 25 mL, 2 M KCl, centrifuged at ambient temperature, and filtered through Supor ™ 0.45 µm membrane filters. Samples were analyzed for ammonium (NH_4^+) and nitrate (NO_3^-) on an auto-analyzer (Technicon model RFA), and soluble reactive phosphorus (SRP) was analyzed with the modified Solorzano method using a Shimadzu spectrophotometer (Solorzano and Sharp 1980). A third subsample was dried to a constant weight at 70 ºC, and used to determine moisture content (g wet - g dry/g dry), ground to a homogeneous powder (<500 µm), and analyzed for TC and TN with a Carlo Erba elemental analyzer and for TP using the modified Solorzano method (Solorzano and Sharp 1980). When surface water was present at sampling locations, we collected grab samples (bottles submerged to the middle of the water column) for analyses of SRP, NH_4^+, NO_3^- + NO_2^-, and NO_2^- concentrations on filtered water samples using a four-channel auto-analyzer (Alpkem model RFA 300)

We estimated the standing stock of organic N and P in soils using the soil N and P content and the dry weight of soil per m^2 of tree island. We calculated the mass of dissolved N and P m^{-2} using KCl and $NaHCO_3$ soil extracted concentrations (inorganic + organic). We estimated the mass of N and P in standing surface water m^{-2} using N and P concentrations and the average volume of water m^{-2} based on average water depth from well data for each of Wet Head and Near Tail communities.

c. Microbial Biomass

Nitrogen and phosphorus bound in microbial biomass were determined with chloroform fumigation following methods of Fierer et al (get citation) and Ivanoff et al. (1998), respectively.

For nitrogen, two sets of duplicates samples of 10 grams wet soil were weighed, and 2 mL chloroform added to one of two duplicate samples for each sampling location. The second duplicate is not fumigated (no chloroform added). Duplicate blanks were generated for each sampling location. Fumigated, unfumigated and blank samples were simultaneously extracted with 50 mL 0.5 M K_2SO_4, and samples are thoroughly mixed on shaker table set at 170 rpm for 4 hours at room temperature. Fumigated samples were then bubbled vigorously with air for one hour to remove any remaining chloroform. All samples were centrifuged at 3500 rpm for 10 minutes, and gravity filtered through a glass fiber filter (Whatman GF/F). Samples were then poured off into Whirpaks and frozen until analysis. Samples were analyzed for total dissolved phosphorous where TN was measured following digestions of the extract with HCl and potassium persulfate. The unfumigated total dissolved nitrogen was subtracted from the fumigated total dissolved nitrogen, and adjusted with blank concentrations, to calculate microbial nitrogen of the sample.

For phosphorus, two sets of duplicates samples of 5 grams wet soil were weighed, and 2 mL chloroform was added to one of two duplicate samples for each sampling location. The second duplicate was not fumigated (no chloroform added). Duplicate blanks are generated for each sampling location. Fumigated samples were incubated, covered by a paper towel, under the fume hood for 24 hours. For blanks and unfumigated samples, 100 mL 0.5 M $NaHCO_3$ was added, and samples were thoroughly mixed on shaker table set at 170 rpm for 16 hours at room temperature. Samples were then centrifuged at 3500 rpm for 10 minutes, and gravity filtered through a glass fiber filter (Whatman GF/F). Concentrated HCl was added to each sample after filtration to precipitate colloidal materials. Samples are then poured off into Whirpaks and frozen until analysis. Fumigated samples are bubbled vigorously with air for one hour to remove any remaining chloroform after the 24 hour incubation period, similarly processed and stored. Samples were analyzed for total dissolved phosphorous where TP was measured following digestions of the extract with HCl and potassium persulfate. The unfumigated total dissolved phosphorus was subtracted from the fumigated total dissolved phosphorus and adjusted with blank concentrations to calculate microbial phosphorus of the sample.

d. Plant Nutrient Demand Calculations

Using nutrient and biomass data obtained from live leaves, litterfall, standing litter, water, microbial biomass, soil, and root productivity we generated an ecosystem N and P budgets of bulk pools (plants, soils and water) and fluxes through those pools for tree island 3AS3 for wet head and near tail communities. We used six variables to calculate ecosystem (integrating both aboveground and belowground components) nutrient uptake requirement or demand (additional nutrients required for plant uptake to support annual primary production). First, we quantified the annual nutrient leaf standing crop based on annual litterfall production and nutrient content of live leaves of *C. icaco*, *S. caroliniana* and a pooled component of other species. *C. icaco* and *S. caroliniana* were the dominant species. Litterfall and nutrient content data were not available for wood or reproductive components and were excluded from litterfall-based budget estimates. Second, we estimated the nutrient flux to the forest floor by litterfall using the nutrient content of each litterfall component. Third, we estimated potential nutrient leaching (labile, < 1 month) from this litterfall using annual litterfall production values and rates of tree island *C. icaco* litter decomposition (i.e. fraction of mass loss after two weeks decomposition, 11% for *C. icaco*, Troxler and Childers 2008; assumed 11% for *S. caroliniana* and other species for both wet head and near tail communities). We also estimated that pool potentially available after one year of decomposition following estimates from Troxler and Childers, 2008; the product of average litterfall nutrient content and 29% for wet head and 14% near tail communities). Fourth, we estimated nutrient accumulation by litter and soil accretion in the detrital soil pool (peat). Nutrient accumulation from standing litter deposition (litter accretion) was calculated as the total nutrient pool contained in standing litter minus the litter available nutrients after one year of decomposition. Nutrient accumulated via peat accretion was estimated as the product of the peat accumulation rate (4 mm yr^{-1}; based on a value twice of that reported by Craft and Richardson 1998 for Everglades marsh), nutrient concentration of surface soil, and soil bulk density of 0.28 g cm^{-3}. Peat accretion, expected to be turnover of litter after litter accretion or generated by microbial assimilation was not used as a parameter to calculate plant nutrient demand, but as nutrient accumulated by peat accretion, assumed to be externally-derived. We assumed that the fraction of the nutrient pool left over after one year of decomposition was lost as refractory organic matter via infiltration or other export from the system (lateral surface flow to adjacent marsh), and did not include this fraction in the annual N and P uptake values. Fifth, we estimated internal cycling with an estimate of nutrient resorption (leaf standing crop * nutrient resorption efficiency). Finally, we estimated that contribution by root productivity and root decomposition to N and P budgets using data provided by District researchers. The nutrient flux required to support annual root production was calculated as the product of annual root production and nutrient content of live roots for each community. That contribution of decomposed roots to N and P nutrient budgets was calculated as the product of annual root production, nutrient content of dead roots, and an estimated value for root decomposition (based on leaf decomposition rates) for each community. We did not use dead root biomass harvested after one year. We estimated the amount of "new" N and P required for primary production, that is, nutrients required to support annual leaf standing crop from sources other than plant nutrient retention or via decomposition, as:

N and P Uptake = N and P leaf standing crop – N and P recycled by plants – N and P available via annual decomposition + N and P accumulation from litter deposition + N and P root production – N and P root decomposition.

2.2 Annual Rates of P and N in accumulated sediment

We estimated nutrients accumulated via sediment accretion as noted above, assuming all that was accreted was externally-derived nutrients. In the future, we intend to estimate peat accretion and surface elevation change using sedimentation-erosion table (SET) measurements and feldspar marker horizons with one benchmark pipe installed in both locations to represent wet head and near tail plant communities.

2.3 Nitrogen Transformation Rates

We utilized a pool dilution technique to quantify rates of N mineralization, nitrification, and N immobilization (DIN production, transformation, and consumption, respectively; Brooks, 1989; Davidson, 1990).

Cores to quantify rates of N mineralization, nitrification, and NH_4 and NO_3 immobilization for were extracted with a 6.1 cm inner diameter PVC "invertebrate sampler" tube with a thin sleeve (~ 5 mm thickness). This type of sampler was used as it created a suction that reduced soil compaction upon core collection. The tube was fitted with a saw blade to further minimize peat compaction. Each core was normalized to a constant core depth of 10 cm when possible. To determine gross mineralization rates, soil cores were collected at 3 locations in close proximity to interior island well clusters along each transect (in wet head and near tail communities). Soils extracted with the invertebrate sampler were then transferred in the field to soil core tubes. These tubes were constructed of 6.1 cm inner diameter, clear PVC tube, cut into 20 cm lengths with injection ports drilled at 1 cm intervals along the length of each tube, and filled with silicone. We collected peat cores after removing the surficial litter layer, and then fit each with a rubber stopper. The top of each core was left open to the atmosphere to ensure the preservation of possible oxygen gradients. Ambient water was collected along with peat soils when present. Cores were stored overnight at room temperature until processing (< 24 hours). When present, water from the tops of the cores was replaced with tree island surface water before processing. The cores were then injected with 2 μmol L^{-1}, 30 atom % $^{15}NH_4SO_4$ solution with 1cc syringes. Soil cores were incubated at 0 and 24 hours at room temperature. After incubation, cores were dropped into Ziploc bags containing 2M KCl at a 2: 1 soil: KCl ratio. Bags were shaken for one hour on a rotary shaker and centrifuged at 3400 rpm for 10 minutes. Soil extracts were poured off 1 L filter flasks, prefiltered through 1.0 micron GF/F filters, and final filtered through Supor ™ 0.45 μm membrane filters. Samples were transferred into Whirlpak™ bags. Subsamples were collected for inorganic nutrient analyses. Both samples for nutrient and isotope analyses were stored frozen until processing. Rates of mineralization were calculated using the model of Wessel and Tietema (1992). To determine gross nitrification rates, we used a similar procedure. The injection solution was 2 μmol L^{-1}, 30 atom % $K^{15}NO_3$. These cores were incubated at 0 and 2-3 hours, and samples were extracted at a similar soil: KCl extraction ratio.

We used the diffusion method of Brooks et al. (1989) to determine ^{15}N of soil extracts. Isotopic analyses of diffusion filters were conducted at the University of California, Davis Stable Isotope Laboratory. Samples were analyzed using an elemental analyzer coupled with an isotope ratio mass spectrometer. For $\delta^{15}N$, the stable isotopic ratio was calculated using standard δ notation where: $\delta^{15}N = (R_{smpl}/R_{stnrd} - 1) * 1000$ vs. air. R is the ratio of $^{15}N/^{14}N$ of the sample and standard (Martinelli, 1999). Production and consumption rates for NH_4^+ and NO_3^- (mmol m^{-2} hr^{-1}) were averaged for five monthly sampling periods (August samples not yet available) to estimate annual values (g m^{-2} yr^{-1}).

Denitrification and N fixation rates are considered negligible in these budget calculations based on values obtained from other Everglades peatland ecosystems (Rivera-Monroy and Twilley 2001, Troxler and Childers, in review), but should be verified as such for tree island 3AS3. Strong nutrient gradients in tree island 3AS3 may influence variation in denitrification and N fixation rates between wet head and near tail communities.

2.4 Hydrologic N and P fluxes

a. Surface Fluxes

We generated estimates of marsh surface water inputs to the wet head and near tail communities in tree island 3AS3 and mass fluxes of TN, N+N, NH_4, SRP and TP. We used the product of marsh water levels, marsh flow rates, and nutrient concentrations of marsh surface water collected in samplings in 2007 and 2008 to calculate marsh surface water loads. Hydroperiod (number of days inundated) values were obtained from well data from one well of Wet head and Near Tail locations by subtracting out the soft ground elevation level (obtained from survey data produced by Keith and Schnars). We considered only hydroperiod days as days with potential surface water flux when the water level was at least 10 cm. We measured water flow during 5 sampling periods at the upstream end of the island using fluorescein dye as a visible tracer. Specifically, surface water flow into to the tree island from the upstream marsh (L d^{-1}) was calculated as the product of average daily water level (cm), marsh surface water flow rate (cm s^{-1}), and tree island cross-sectional width (m). Total surface water input (m yr^{-1}) was thus calculated as the product of discharge (L d^{-1}) and island hydroperiod (d yr^{-1}), divided by island community area (m^2), and averaged over the sampling periods. Mass flux of N+N, SRP, TP, and NH_4^+ was determined from the product of marsh surface water concentration and the bimonthly surface water input ($g\ m^{-2}\ yr^{-1}$). Fluxes of total P and DIN were used in budget calculations.

Of the samplings of tree island surface water, no water was present in months May, June and August 2007, or in April and May 2008 for N and P standing stock calculations. Nutrients available in precipitation fluxes are also included. Here, we place five bottles fitted with funnels covered with nylon screen in three locations: marsh, "wet head" and "near tail". The samples are bulked and three replicate samples are obtained for analyses per location.

b. Sub-surface fluxes

We installed wells in two transects across Wet head (north) and Near Tail (south) communities (Figures 2-4). Wells were installed in five clusters across each transect, with two wells per cluster, installed to 30cm and 60cm below the soil surface. The well design was a 2" PVC slotted along 10 cm at bottom of pipe and fit with pressure transducer (*In-situ*) water level gauges. We installed the wells by excavating approximately 20cm diameter holes with a gas-powered hand auger. To ensure the wells did not migrate due to peat shrinkage or swelling, the pipes were installed with an anchor and well sections. The bore hole for each well was dug down to the limestone where the anchor section, attached to the well section, was rested. The slotted section of the well section was then 20-30cm and 50-60cm below the soil surface for shallow and deep wells, respectively. The annular area around the wells was then filled with betonite around the anchor section, filled with sand to completely cover the profile under and above the slotted section, and to include the slotted section. The annular area was then filled with betonite, sand, and capped with betonite. Wells were then surveyed relative to nearest benchmark by Keith & Schnars under a separate contract.

In six samplings conducted in months January, March, May, June and August of 2007 and 2008, sub-surface water samples were collected from wells installed at 30 and 60 cm depth below the soil surface, and analyzed for total and inorganic nutrient concentrations. Samples were collected from wells along both wet head and near-tail transects. Inorganic N and P concentrations were used in the calculation of sub-surface hydrologic nutrient fluxes.

Water depth (cm) was measured monthly in each well to calculate hydraulic head levels. The head levels were used to calculate Darcy's groundwater flux (q; m yr^{-1}):

$$q = \frac{Q}{A} = K \frac{(h_1 - h_2)}{\Delta l}$$

where Q/A is the volumetric flow rate (L d^{-1}) per unit cross-sectional area (the product of the well profile length (30 cm) and the well diameter; in m^2), K is hydraulic conductivity (cm s^{-1}), and $(h_1 - h_2)/\Delta l$ is the hydraulic gradient (Fetter, 1994). Values of hydraulic conductivity were determined using Hvorslev's slug tests following the equation:

$$K = \frac{A}{F} \frac{1}{t_2 - t_1} \ln \frac{H_1}{H_2}$$

where K is the hydraulic conductivity, A is the cross-sectional area of the well, F is a shape factor, and H_1 and H_2 are the water levels at t_1 and t_2 (Fetter, 1994). We calculated K utilizing a shape factor for a cased hole, where soil is flush with the bottom of the well ($F = 11*R/2$) and R is the radius of the well. A peristaltic pump was used to evacuate wells (remove the slug), and water level return was determined using installed pressure transducers. Water level and time were plotted on a log scale, and t_1, H_1, t_2, and H_2 were recorded. We verified the well levels using field depth-to-water measurements taken monthly.

Subsurface hydrologic fluxes were calculated for each well pair to obtain both horizontal and vertical fluxes. Annual subsurface mass flux (assuming advective flux is the main transport mechanism; Schwartz and Zhang 2003) was calculated following the equation $J_{adv} = nCv$ where J_{adv} is mass flux (g m^{-2} yr^{-1}), n is the porosity of the peat (approximated as 0.85 based on literature values and on the approximate fraction of soil moisture in this saturated peat; Radforth et al 1977), C is the concentration of N+N, NH_4^+ or TP (µmol L^{-1}), and v is the groundwater velocity vector ($q\ n^{-1}$). Depending on the spatial relationship of the wells within and between well clusters, we were able to obtain estimates of nutrients imported from or exported to the island at two depths as well as rates of infiltration and upwelling.

For vertical fluxes, we considered a flux "upwelling" when the head level was higher in the deep well than in the shallow well and "infiltration" when the head level was higher in the shallow well than the deep well of each well cluster. Infiltration fluxes were assumed as exports in the calculation of nutrient budgets because these were fluxes from 30 cm to 60 cm depth and assumed to not be intercepted by fine roots if the primary fine rooting depth is between 0 and 30 cm depth below the soil surface. However, deep root uptake (> 60cm) is a possible mode of P uptake by the tree island. For horizontal fluxes, we considered fluxes as imports following this protocol relative to the head level of wells with each cluster: N1>N2>N3<N4<N5 for the "wet head" and S6>S7>S8<S9<S10 for the "near tail". Exports followed the opposite protocol relative to head levels between well clusters: N1<N2<N3>N4>N5 for the "wet head" and S6<S7<S8>S9>S10 for the "near tail". This protocol accounted for variability in flux direction throughout the year by an operator included in our flux calculations. These assumptions may overestimate hydrologically-driven nutrient exports in our budget calculations in two ways. For infiltration fluxes, part of those nutrients that are lost below 60 cm depth may be utilized for uptake by fine roots that grow below that level, or otherwise used by means which we have not considered here in these budgets. For horizontal export fluxes, fluxes from well cluster N3 or S8 may be utilized for uptake as these are fluxes that occur within the tree island.

To attempt to account for bimonthly variability in nutrient concentrations and seasonal variability in hydraulic conductivity, we applied these seasonal data to calculate flux for TP, SRP, N+N and NH_4 for the wet head and near tail communities. The average of four locations, at two depths, was used to estimate horizontal imports and exports for each community. The average of five locations was used to estimate vertical imports and exports, or upwelling and infiltration, respectively. Total P and DIN fluxes were used in budget estimates.

2.5 Budget Calculations

a. Nitrogen

We determined net nitrogen flux in tree island 3AS3 utilizing results from the described N transformation studies in conjunction with surface water and tree island-island edge groundwater fluxes and biomass N pools and fluxes and data provided by District researchers. All soil pools and fluxes were normalized to a 10 cm soil depth. With the tree island-marsh interface as our boundary, our N budget followed the form:

$$[N_{dep} + N_{accretion} + N_{demand} + (N_{NH4imm} + N_{NO3imm}) - (N_{min} + N_{nit}) + N_{sw} + N_{ssw(IM)}] - N_{ssw(EX)} = \text{net ecosystem N flux}$$

where N_{dep} is N as atmospheric deposition, $N_{accretion}$ is soil accretion (assuming all is an annual input), N_{min} is gross mineralization, N_{nit} is gross nitrification, N_{sw} is surface water of DIN, N_{ssw} is subsurface water inputs of DIN, N_{NH4imm} is NH_4 consumption, N_{NO3imm} is NO_3 consumption, and N_{demand} is plant N required by external N sources (hydrologic imports) to meet minimum requirement to sustain canopy leaf standing crop and $N_{ssw(EX)}$ is subsurface water export of DIN. In this estimate, denitrification and N fixation were considered negligible (Troxler and Childers, in review). All units are in g m^{-2} yr^{-1}.

b. Phosphorus

We determined net phosphorus flux in tree island 3AS3 utilizing results from the described surface water and tree island-island edge groundwater fluxes and biomass P pools and fluxes and data provided by District researchers. All soil pools and fluxes were normalized to a 10 cm soil depth. With the tree island-marsh interface as our boundary, our P budget followed the form:

$$[P_{dep} + P_{sw} + P_{ssw(IM)} + P_{accretion} + P_{demand}] - P_{ssw(EX)} = \text{net ecosystem P flux}$$

where P_{dep} is P as atmospheric deposition, P_{sw} is surface water inputs/outputs of TP, $P_{ssw(IM)}$ is subsurface water import of TP, $P_{accretion}$ is soil accretion (assuming all is an annual input), P_{demand} is plant P required by external P sources (hydrologic imports) to meet minimum requirement to sustain canopy leaf standing crop and $P_{ssw(EX)}$ is subsurface water export of TP. All units are in g m^{-2} yr^{-1}.

4.0. Results

3.1 Annual Standing Stocks and Fluxes of P and N in soil, microbes, plants and water

a. Plants, soil, water and microbial biomass

We calculated N standing stocks (g N m^{-2}) of and N fluxes (g N m^{-2} yr^{-1}) between major components of the tree island (Table 1). We assumed that N cycling between components (TN) would be released into the system as inorganic N (DIN: NH_4 + NO_3/NO_2), and thus TN and DIN were comparable fluxes and pools. Nitrogen stocks and fluxes were generally higher for the wet head than the near tail community (Table 1). About 3 times as much N was internally recycled by N resorption in the wet head as compared with the near tail. As our standing stock data for plants were based on a previous data collections made by District staff plant stocks were the same in 2007 and 2008.

We also calculated P standing stocks (g P m^{-2}) of and P fluxes (g P m^{-2} yr^{-1}) between major components of the tree island (Table 2). We assumed that P cycling between components (TP) would be released into the system as inorganic P (SRP). For phosphorus, we found about 3 times more P in leaf standing crop in the wet head as compared with the near tail (Table 2), and thus more P had to be obtained to support this higher annual stock (and minimum plant requirement). Both the soil organic and microbial biomass pools were also estimated to contain more g P m^{-2} than the near tail community. Very little P was recycled by plants in the wet head community and thus the mass of P in litterfall approximated that which was found in live leaf standing crop. Conversely, the near tail recycled at least half of the P that was available in leaf standing crop P, and with this low standing stock, delivered less than a third to the forest floor as compared with the wet head. As our standing stock data for plants were based on a previous data collections made by District staff, plant stocks were the same in 2007 and 2008.

b. Plant Nutrient Demand Estimates

We estimated plant nutrient demand (net N uptake) using the model described previously. We found that 2.73 and 2.74 g N m^{-2} yr^{-1} were required to satisfy the minimum N necessary to sustain growth at steady state from sources not accounted for by remineralization or internal recycling of N in wet head and near tail communities in 2008, respectively. As much of this budget was based on previous data collected by District staff, this N was similar. In 2008, where 2.81 and 2.77 g N m^{-2} yr^{-1} were required to satisfy the minimum N necessary to sustain plant growth in wet head and near tail communities in 2008, respectively.

We estimated plant nutrient demand (net P uptake) using the model described previously, 0.515 and 0.133 g P m^{-2} yr^{-1} were required to satisfy the minimum P necessary to sustain growth at steady state from sources not accounted for by remineralization or internal recycling of P in wet head and near tail communities, respectively. As much of this budget was based on previous data collected by District staff, this P was similar. In 2008, where 0.520 and 0.134 g P m^{-2} yr^{-1} were required to satisfy the minimum P necessary to sustain plant growth in wet head and near tail communities in 2008, respectively.

3.2 Annual Rates of P and N in accumulated sediment

We used literature values of soil accretion to estimate annual rates of P and N in accumulated sediment. These values are presented in Table 1 for nitrogen and Table 2 for phosphorus.

3.3 Nitrogen Transformation Rates

Gross NH_4 and NO_3 production and consumption rates were calculated to estimate hourly fluxes. We extrapolated these hourly fluxes to annual rates per unit area (m^{-2}) based on core surface area. In 2007, average gross NH_4 production and consumption rates were 0.482 ± 0.209 and 0.153 ± 0.174 mmol m^{-2} d^{-1} in the wet head and 0.338 ± 0.115 and 0.350 ± 0.280 mmol m^{-2} d^{-1} near tail, respectively. In 2007, this corresponded to a net production of NH_4 of 1.681 g m^{-2} yr^{-1} and a net consumption of NH_4 of 0.063 g m^{-2} yr^{-1} in the wet head and near tail communities, respectively. In 2008, average gross NH_4 production and consumption rates were 0.622 ± 0.200 and 0.792 ± 0.120 mmol m^{-2} d^{-1} in the wet head and 1.285 ± 0.357 and 0.946 ± 0.225 mmol m^{-2} d^{-1} near tail, respectively. In 2008, this corresponded to a net consumption of NH_4 of 0.867 g m^{-2} yr^{-1} and a net production of NH_4 of 1.732 g m^{-2} yr^{-1} in the wet head and near tail communities, respectively. In 2007, gross NO_3 production and consumption rates were 0.836 ± 0.142 and 1.839 ± 0.260 mmol m^{-2} d^{-1} in the wet head and 1.324 ± 0.330 and 2.588 ± 0.413 mmol m^{-2} d^{-1} in the near tail, respectively. Thus, in 2007, there was net NO_3 consumption of 5.176 and 6.462 g m^{-2} yr^{-1} in the wet head and near tail communities, respectively. In 2008, gross NO_3 production and consumption rates were 0.613 ± 0.159 and 2.131 ± 0.426 mmol m^{-2} d^{-1} in the wet head and 0.552 ± 0.142 and 1.748 ± 0.316 mmol m^{-2} d^{-1} in the near tail, respectively. Thus, in 2008, there was net NO_3 consumption of 7.756 and 6.113 g m^{-2} yr^{-1} in the wet head and near tail communities, respectively.

3.4 Hydrologic N and P fluxes

a. Surface fluxes

In 2007, average surface water DIN input was about one third lower than average subsurface DIN input in the wet head community, but was almost 5 times the subsurface DIN input in the near tail community (Table 1). In 2008, surface water DIN load exceed subsurface DIN import in both wet head and near tail communities. For inorganic and total P, average surface water TP and SRP input was lower than average subsurface TP and SRP input in both the wet head and near tail communities in both 2007 and 2008 (Table 2).

However, the difference between surface and subsurface TP and SRP inputs was much higher for the wet head in 2007 and for the near tail in 2008 (Table 2).

b. Sub-surface fluxes

Inorganic N and total P concentrations are presented in Figures 2 - 4, and were used to estimate average hydrologic fluxes of TP, SRP, N+N, and NH_4. We summed average daily fluxes for the February 2007 – January 2008 period to represent 2007 and for the February 2008 – December 2008 period to represent 2008 providing an estimate of average annual flux per plant community per year. Overall, infiltration rates were the highest nutrient fluxes, followed by upwelling fluxes, and horizontal imports at 30cm below the soil surface, with variation among well locations. Table 3 presents values for site location, per year, for each plant community. Table 4 summarizes these values into average annual flux rates in g m^{-2} yr^{-1} for the wet head and near tail communities for 2007 and 2008.

3.5 Budget Estimates

Tables 5 and 6 summarize major flux rates for N and P in the wet head and near tail communities. We then estimated net ecosystem N and P flux for each community. We found that the wet head community lost 42.5 and 26.4 g DIN m^2 yr^{-1} in 2007 and 2008, respectively (Table 5). The near tail lost 26.1 g DIN m^2 yr^{-1} in 2007 but accumulated 39.2 g DIN m^2 yr^{-1} in 2008 (Table 5). In both 2007 and 2008, both the wet head and near tail communities lost inorganic P (Table 6).

As tree island communities mediated net uptake of both N and P, we estimated the ecological contribution of treed islands relative to their loss in the WCA-3A (Table 7; Patterson and Finck 1999). Treed island area in WCA-3A was 8911 ha in 1940 and 3434 ha in 1995. Based on the difference in aerial coverage of treed islands between 1940 and 1995, treed island loss mediated the potential release of $7.85 * 10^8$ g P over the 55 year period, or 14.27 Mg P yr^{-1}. This is 22% of the annual TP input to WCA-3A via atmospheric deposition of P (wet and dry deposition). With respect to N, treed island loss mediated the potential release of 238.5 Mg N yr^{-1} (Table 8).

5.0 Discussion and Conclusions

With these budget estimates, we present major N and P pool and fluxes for the wet head and near tail communities in years 2007 and 2008 for tree island 3AS3. District staff provided considerable data on the mass of material in litterfall, standing litter as well as root production and decomposition and associated nutrient data from 2000-2004 for the high head and near tail communities. The net P and N ecosystem fluxes for the wet head and near tail were based on these integrated datasets. While informative, more recent information on plant mediated pools and fluxes, and those specifically for the wet head, and nutrient budget information for the high head, will be needed to refine these nutrient budgets for the tree island 3AS3. However, hydrologic nutrient fluxes were the dominant tree island nutrient fluxes of these mass balance estimates.

In summary, based on our updated and refined estimates for P and N fluxes, both wet head and near tail communities are losing P, however, at a lower rate in the near tail, for both years in 2007 and 2008. For N, the wet head community lost N in 2007 and 2008, whereas the near tail community lost N in 2007, but accumulated N in 2008.

For phosphorus, variation in fluxes between wet head and near tail, and between years for these communities, still resulted in relatively similar differences in net ecosystem P fluxes. In 2007, the wet head had higher SRP exports and imports as compared with the near tail, with about 6.5 g m^{-2} yr^{-1} greater loss of P. In 2008, the near tail had higher imports but lower exports of P, with a slightly lower surface water load, resulting in about a 4 g m^{-2} yr^{-1} greater loss of P in the wet head. This consistently higher loss of P from the wet head reflects, in most part, higher SRP concentrations in the wet head subsurface water. Interestingly, high TP and SRP concentrations prove to hold at very elevated levels in the deep and shallow wells of the interior cluster in the wet head community throughout the year and from year to year. However, average TP and SRP concentrations at this location in the center of the wet head community are about ½ at 60 cm depth as compared to the shallower well at 30 cm depth. This concentration gradient varied within year as a function of hydrology.

Fluxes of nitrogen were the highest nutrient fluxes in tree island 3AS3, resulting in net ecosystem loss in both wet head and near tail communities in 2007. However, in 2008, we found net ecosystem loss of N in the wet head community, and net ecosystem accumulation in the near tail community. The main differences in fluxes between years were influenced: 1) by higher surface water loads of DIN to the tree island with higher DIN imports in the near tail in 2008 and 2) greater microbial assimilation of N in 2007 in the near tail community. This near tail import of DIN that was 20 times lower in 2007 than 2008 was a function of lower water levels in 2007 during April and September when DIN upwelling fluxes were highest in 2008.

The nutrient chemo-hydrodynamic theory of tree island maintenance hypothesizes that nutrients accumulate in the head of the tree island and leach or flow to downstream plant communities of the same tree island (van der Valk and Sklar 2004). This dynamic causes a nutrient gradient from high P in the head area of the tree island to the tail of the tree island. Our results suggest that this dynamic exists as P uptake is higher, with higher subsequent loss, in the "wet head" plant community and lower P uptake and subsequent loss of P in the "near tail" community. This dynamic would be expected to be even more pronounced including a comparison of the "high head", where soil nutrient concentrations have been reported to be as high as 10000 μg TP g^{-1} soil (Wetzel et al 2005). Our results also suggest that the TP source is concentrated in the center of the more upstream plant communities ("wet head") and is not expressed in downstream plant communities. The source of this TP is still unknown, but is likely due to leaching or flow from the high head as TP and SRP concentrations are highest at shallow soil depth, where hydraulic conductivity is highest. However, this does not preclude the possibility that much of this TP could be originating from biotic mechanisms that draw TP from below the surface and deposit it at more shallow depths (i.e. calcrete deposition) that is then available for remineralization and plant uptake.

6.0 Recommendations

We have attempted to provide a complete as budget for the contracted work as possible. Clearly, a complete nutrient budget is an exhaustive undertaking, and better estimates of some values could be improved with additional resources, sampling, equipment, software and analyses. This exercise identifies the most significant nutrient fluxes and pools for a tree island ecosystem nutrient budget, and poses some important questions suggesting where gaps may exist in the datasets. 1. What is the contribution of incorporating the High Head in the overall tree island nutrient budget? 2. What is the actual contribution of surface water inputs to N and P budgets? 3. How much of the infiltration flux is a nutrient input to the tree island N and P budgets i.e. recouped below 60cm depth? 4. Is dissolution of $CaCO_3$ in surface (or subsurface) soils an important source of P contributing to large concentration gradients in wet head communities in the dry season? 5. What other possible sources of P are there e.g. animal deposits? While this list is not exhaustive, exploring these questions with small, short-term experiments and less frequent, but more intensive data collections would help to fill potential gaps.

Some recommendations are thus provided here for consideration. 1. Increased spatial and temporal resolution of subsurface hydrologic fluxes to rectify variation among communities – high head will have a much different N & P budgets with implications for landscape significance of tree islands. 2. Assessment of plant nutrient demand estimates for high head, wet head and near tail. 3. SETs to measure peat accretion rates in head, wet head and near tail coupled with soil nutrient analyses. 4. A tracer study (fluoroscein dye) and comparison with regional hydrodynamics to evaluate contribution of seasonal surface water nutrient load to head, wet head and near tail. 5. Integration of datasets, and corollary measurements of ions, to incorporate spatial variability into tree island nutrient budget. 6. Utilizing a tracer study or other short-term experiment to evaluate shallow soil concentration gradients, fate of nutrients and importance of deep root uptake.

7.0 References

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TABLES

Table 1. Tree Island 3AS3 N standing stocks and annual fluxes in wet head and near tail communities in a. 2007 & b. 2008

a. 2007	Wet Head			Near Tail		
	TN	NO_3^-	NH_4^+	TN	NO_3^-	NH_4^+
STOCKS (g N m^{-2})						
Leaves	8.22			5.05		
Surficial Litter	2.80			2.75		
Surface Water	8.33	0.12	1.87	7.02	0.35	0.80
Soil Organic Pool (kg m^{-2})	39.4			38.9		
Soil Porewater (DIN)		6502			7124	
Microbial Biomass	5697			5809		
FLUXES (g N m^{-2} yr^{-1})						
Nutrients in Litterfall	3.70			3.34		
Labile (< 1 month)	0.42			0.38		
Labile (< 1 year)	0.81			0.38		
Accumulated in Soil						
Litter	1.99			2.36		
Sediment accretion	15.70			15.60		
Recycled by Plants	4.52			1.71		
Root Production	0.38			0.18		
Root Decomposition	0.10			0.02		
Soil N produced		4.27	2.46		6.77	1.73
Soil N consumed		9.45	0.78		13.23	1.79
Surface Water Load	451	1.36	46.40	417	1.26	42.91
Subsurface (DIN)						
Import		10.44			1.50	
Export		42.26			17.08	
Throughfall (DIN)	0.45			1.04		

b. 2008	Wet Head			Near Tail		
	TN	NO_3^-	NH_4^+	TN	NO_3^-	NH_4^+
STOCKS (g N m^{-2})						
Leaves	8.22			5.05		
Surficial Litter	2.51			2.56		
Surface Water	n/a	0.07	1.07	n/a	0.04	0.52
Soil Organic Pool (kg m^{-2})	35.3			33.1		
Soil Porewater (DIN)		2644			1613	
Microbial Biomass	2752			1830		
FLUXES (g N m^{-2} yr^{-1})						
Nutrients in Litterfall	3.70			3.34		
Labile (< 1 month)	0.42			0.38		
Labile (< 1 year)	0.73			0.36		
Accumulated in Soil						
Litter	1.78			2.20		
Sediment accretion	14.10			13.20		
Recycled by Plants	4.52			1.71		
Root Production	0.38			0.18		
Root Decomposition	0.10			0.02		
Soil N produced		3.13	3.18		2.82	6.57
Soil N consumed		10.89	4.05		8.93	4.83
Surface Water Load	n/a	3.91	437.34	n/a	3.32	371.81
Subsurface (DIN)						
Import		15.52			22.82	
Export		55.57			18.51	
Throughfall (DIN)	1.04			2.45		

Table 2. Tree Island 3AS3 P standing stocks and annual fluxes in wet head and near tail communities 2007 & 2008

	2007		2008	
	Wet Head	Near Tail	Wet Head	Near Tail
STOCKS (g P m^{-2})				
Leaves	0.643	0.291	0.643	0.291
Surficial Litter	0.126	0.099	0.108	0.089
Surface Water	8.50	7.86	16.28	13.84
Soil Organic Pool	1082	874	968	847
Soil Porewater	114.3	86.3	30.5	24.1
Microbial Biomass	176.3	119.0	90.3	55.0
FLUXES (g P m^{-2} yr^{-1})				
Nutrients in Litterfall	0.625	0.156	0.625	0.156
Labile (< 1 month)	0.071	0.018	0.071	0.018
Labile (< 1 year)	0.037	0.014	0.037	0.014
Accumulated in Soil				
Litter	0.120	0.104	0.120	0.104
Sediment accretion	4.40	3.52	3.89	3.41
Recycled by Plants	0.032	0.133	0.032	0.133
Root Production	0.037	0.009	0.037	0.009
Root Decomposition	0.025	0.0004	0.025	0.0004
Surface Water Load	8.50	7.86	16.28	13.84
Subsurface				
Import	0.24	0.07	0.19	0.40
Export	2.52	2.01	1.44	1.18
Throughfall (SRP)	0.02	0.16	0.04	0.37

Table 3. Subsurface Hydrologic Fluxes of NH_4, N+N, DIN, TN, SRP and TP at each site location at 30&60cm with sum, average and standard error of fluxes (g m^{-2} yr^{-1}). A. horizontal imports in wet head and near tail in 2007, b. horizontal imports in wet head and near tail in 2008, c. horizontal exports in wet head and near tail in 2007, d. horizontal exports in wet head and near tail in 2008, infiltration fluxes in e. 2007 and f. 2008 and upwelling fluxes in g. 2007 and h. 2008.

a. J adv (mg/m2/yr) - horizontal - imports

		30 cm				60 cm			
2007		**6-7**	**7-8**	**8-9**	**9-10**	**6-7**	**7-8**	**8-9**	**9-10**
Near Tail (South)	**NH4**	0.1	0.0	0.0	55.9	3.3	36.7	2.6	0.4
	sum	***56.0***				***43.0***			
	avg ± se	***14.0***	***14.0***			***10.7***	***8.7***		
	NN	0.0	0.0	0.0	4.4	0.4	1.1	0.1	0.0
	sum	***4.4***				***1.6***			
	avg ± se	***1.1***	***1.1***			***0.4***	***0.2***		
	DIN	0.1	0.0	0.0	60.3	3.7	37.7	2.7	0.4
	sum	***60.4***				***44.6***			
	avg ± se	***15.1***	***15.1***			***11.1***	***8.9***		
	TN	0.3	0.0	0.0	283.8	29.5	96.5	7.4	0.6
	sum	***284.2***				***134.0***			
	avg ± se	***71.0***	***70.9***			***33.5***	***21.9***		
	SRP	0.0	0.0	0.0	17.0	3.9	9.3	0.4	0.0
	sum	***17.0***				***13.7***			
	avg ± se	***4.2***	***4.2***			***3.4***	***2.2***		
	TP	0.0	0.0	0.0	23.4	7.0	11.6	0.8	0.0
	sum	***23.4***				***19.4***			
	avg ± se	***5.9***	***5.9***			***4.8***	***2.7***		
		1-2	**2-3**	**3-4**	**4-5**	**1-2**	**2-3**	**3-4**	**4-5**
Wet Head (North)	**NH4**	188.9	6.9	11.5	9.3	7.1	31.8	14.1	0.1
	sum	***216.6***				***53.0***			
	avg ± se	***54.1***	***44.9***			***13.3***	***6.8***		
	NN	2.9	0.6	1.9	0.4	0.1	1.0	0.1	0.0
	sum	***5.8***				***1.2***			
	avg ± se	***1.4***	***0.6***			***0.3***	***0.2***		
	DIN	191.8	7.4	13.4	9.7	7.2	32.8	14.2	0.1
	sum	***222.3***				***54.2***			
	avg ± se	***55.6***	***45.4***			***13.6***	***7.0***		
	TN	742.6	95.1	158.2	42.7	11.9	45.4	25.3	0.4
	sum	***1038.7***				***83.1***			
	avg ± se	***259.7***	***162.7***			***20.8***	***9.7***		
	SRP	9.7	1.5	6.1	2.7	0.8	3.1	0.0	0.0
	sum	***20.0***				***4.0***			
	avg ± se	***5.0***	***1.8***			***1.0***	***0.7***		
	TP	34.4	4.3	10.1	3.3	0.9	5.7	0.7	0.0
	sum	***52.1***				***7.3***			
	avg ± se	***13.0***	***7.3***			***1.8***	***1.3***		

b. J adv (mg/m2/d) - horizontal - imports

		30 cm				**60 cm**			
2008		**6-7**	**7-8**	**8-9**	**9-10**	**6-7**	**7-8**	**8-9**	**9-10**
Near	**NH4**	0.0	0.0	0.0	85.9	17.8	0.1	0.0	0.2
Tail	***sum***	***85.9***				***18.1***			
(South)	***avg ± se***	***21.5***	***21.5***			***4.5***	***4.4***		
	NN	0.0	0.0	0.0	17.5	1.3	0.1	0.0	0.0
	sum	***17.5***				***1.4***			
	avg ± se	***4.4***	***4.4***			***0.4***	***0.3***		
	DIN	0.0	0.0	0.0	103.4	19.1	0.2	0.0	0.2
	sum	***103.4***				***19.5***			
	avg ± se	***25.8***	***25.8***			***4.9***	***4.7***		
	SRP	0.0	0.0	0.0	43.1	7.8	0.1	0.0	0.0
	sum	***43.1***				***7.9***			
	avg ± se	***10.8***	***10.8***			***2.0***	***1.9***		
	TP*	0.0	0.0	0.0	25.9	6.3	0.1	0.0	0.0
	sum	***25.9***				***6.5***			
	avg ± se	***6.5***	***6.5***			***1.6***	***1.6***		
		1-2	**2-3**	**3-4**	**4-5**	**1-2**	**2-3**	**3-4**	**4-5**
Wet	**NH4**	17.5	202.7	10.2	275.4	4.3	3.7	4.8	3.5
Head	***sum***	***505.9***				***16.3***			
(North)	***avg ± se***	***126.5***	***66.7***			***4.1***	***0.3***		
	NN	1.8	18.6	0.3	7.4	1.3	2.5	0.1	0.1
	sum	***28.1***				***4.0***			
	avg ± se	***7.0***	***4.2***			***1.0***	***0.6***		
	DIN	19.3	221.3	10.6	282.8	5.6	6.2	4.9	3.6
	sum	***533.9***				***20.3***			
	avg ± se	***133.5***	***69.6***			***5.1***	***0.6***		
	SRP	3.0	21.2	1.5	35.5	0.7	0.6	0.0	0.2
	sum	***61.2***				***1.4***			
	avg ± se	***15.3***	***8.1***			***0.4***	***0.2***		
	TP*	5.9	6.5	3.1	25.2	1.5	1.8	0.1	0.4
	sum	***40.7***				***3.8***			
	avg ± se	***10.2***	***5.1***			***0.9***	***0.4***		

***estimated**

c. J adv (mg/m2/yr) - horizontal - exports

		30 cm				**60 cm**			
2007		**6-7**	**7-8**	**8-9**	**9-10**	**6-7**	**7-8**	**8-9**	**9-10**
Near	**NH4**	89.9	33.7	284.8	181.8	239.4	0.2	23.3	13.6
Tail	***sum***	***590.3***				***276.4***			
(South)	***avg ± se***	***147.6***	***55.0***			***69.1***	***57.0***		
	NN	14.5	6.2	54.4	21.8	8.1	0.2	0.5	0.6
	sum	***96.8***				***9.4***			
	avg ± se	***24.2***	***10.6***			***2.4***	***1.9***		
	DIN	104.4	39.9	339.2	203.6	247.5	0.4	23.8	14.2
	sum	***687.1***				***285.9***			
	avg ± se	***171.8***	***65.2***			***71.5***	***58.9***		
	TN	1336.5	352.3	3049.4	1128.5	687.0	8.2	50.8	51.7
	sum	***5866.8***				***797.7***			
	avg ± se	***1466.7***	***568.5***			***199.4***	***162.8***		
	SRP	32.6	7.3	63.4	19.9	61.5	0.2	0.4	1.8
	sum	***123.1***				***64.0***			
	avg ± se	***30.8***	***12.0***			***16.0***	***15.2***		
	TP	149.1	30.4	260.6	81.7	77.7	0.2	1.2	3.9
	sum	***521.8***				***82.9***			
	avg ± se	***130.4***	***49.7***			***20.7***	***19.0***		
		1-2	**2-3**	**3-4**	**4-5**	**1-2**	**2-3**	**3-4**	**4-5**
Wet	**NH4**	5.6	455.8	579.6	86.2	50.9	0.6	0.3	20.5
Head	***sum***	***1127.2***				***72.2***			
(North)	***avg ± se***	***281.8***	***139.5***			***18.0***	***11.9***		
	NN	0.4	1.1	1.5	11.9	2.3	0.0	0.0	0.2
	sum	***14.9***				***2.5***			
	avg ± se	***3.7***	***2.7***			***0.6***	***0.6***		
	DIN	6.0	456.9	581.2	98.1	53.2	0.6	0.3	20.6
	sum	***1142.1***				***74.6***			
	avg ± se	***285.5***	***138.5***			***18.7***	***12.4***		
	TN	85.5	287.9	324.6	682.7	85.7	0.4	0.2	37.9
	sum	***1380.7***				***124.2***			
	avg ± se	***345.2***	***124.2***			***31.0***	***20.3***		
	SRP	1.4	122.0	170.7	37.6	5.5	0.0	0.0	0.0
	sum	***331.6***				***5.6***			
	avg ± se	***82.9***	***38.7***			***1.4***	***1.4***		
	TP	3.9	130.9	152.5	45.8	9.0	0.0	0.0	0.9
	sum	***333.1***				***10.0***			
	avg ± se	***83.3***	***35.1***			***2.5***	***2.2***		

d. J adv (mg/m2/d) - horizontal - exports

		30 cm				**60 cm**			
2008		**6-7**	**7-8**	**8-9**	**9-10**	**6-7**	**7-8**	**8-9**	**9-10**
Near Tail (South)	**NH4**	91.9	140.9	1204.6	40.8	3.0	3.0	5.6	5.8
	sum	***1478.2***				***17.4***			
	avg ± se	***369.5***	***279.1***			***4.4***	***0.8***		
	NN	10.9	34.7	296.2	3.7	2.3	0.1	0.2	0.1
	sum	***345.5***				***2.7***			
	avg ± se	***86.4***	***70.3***			***0.7***	***0.5***		
	DIN	102.8	175.5	1500.8	44.5	5.3	3.1	5.8	5.9
	sum	***1823.7***				***20.1***			
	avg ± se	***455.9***	***349.3***			***5.0***	***0.7***		
	SRP	65.8	49.7	419.7	6.3	2.1	0.1	0.3	0.2
	sum	***541.4***				***2.6***			
	avg ± se	***135.4***	***95.6***			***0.7***	***0.5***		
	TP*	57.3	62.0	519.9	8.9	2.8	0.5	1.3	0.3
	sum	***648.2***				***4.9***			
	avg ± se	***162.0***	***119.9***			***1.2***	***0.6***		
		1-2	**2-3**	**3-4**	**4-5**	**1-2**	**2-3**	**3-4**	**4-5**
Wet Head (North)	**NH4**	429.4	904.7	693.1	67.3	3.5	0.0	0.6	12.7
	sum	***2094.5***				***16.8***			
	avg ± se	***523.6***	***180.5***			***4.2***	***2.9***		
	NN	62.1	4.2	3.2	1.8	2.6	0.0	0.0	0.2
	sum	***71.4***				***2.8***			
	avg ± se	***17.8***	***14.8***			***0.7***	***0.6***		
	DIN	491.6	908.9	696.3	69.1	6.1	0.0	0.6	12.9
	sum	***2165.9***				***19.6***			
	avg ± se	***541.5***	***179.0***			***4.9***	***3.0***		
	SRP	44.1	81.2	135.3	11.8	0.7	0.0	0.0	0.0
	sum	***272.3***				***0.7***			
	avg ± se	***68.1***	***26.5***			***0.2***	***0.2***		
	TP*	14.5	137.1	103.6	19.6	1.8	0.0	0.0	0.2
	sum	***274.8***				***2.1***			
	avg ± se	***68.7***	***30.6***			***0.5***	***0.4***		

***estimated**

e. J adv (mg/m2/yr) - INFILTRATION

2007		**6**	**7**	**8**	**9**	**10**
Near Tail (South)	**NH4**	2649.3	941.3	3633.3	4008.9	2890.8
	sum	***14123.6***				
	avg ± se	***2824.7***	***531.0***			
	NN	42.4	158.7	772.5	430.6	576.7
	sum	***1980.8***				
	avg ± se	***396.2***	***133.6***			
	DIN	2691.7	1100.0	4405.8	4439.4	3467.4
	sum	***16104.4***				
	avg ± se	***3220.9***	***621.6***			
	TN	6662.1	14377.9	41512.1	31480.9	32072.9
	sum	***126105.9***				
	avg ± se	***25221.2***	***6377.8***			
	SRP	556.2	306.3	866.8	965.3	771.4
	sum	***3466.0***				
	avg ± se	***693.2***	***118.1***			
	TP	663.4	1592.6	3439.8	2041.2	1554.1
	sum	***9291.2***				
	avg ± se	***1858.2***	***454.2***			

		1	**2**	**3**	**4**	**5**
Wet Head (North)	**NH4**	6445.9	366.6	28435.9	1124.1	6114.2
	sum	***42486.8***				
	avg ± se	***8497.4***	***5137.6***			
	NN	141.3	17.3	99.3	157.9	104.8
	sum	***520.6***				
	avg ± se	***104.1***	***24.3***			
	DIN	6587.2	383.9	28535.2	1282.1	6219.0
	sum	***43007.4***				
	avg ± se	***8601.5***	***5139.0***			
	TN	30664.1	2411.4	15409.7	12051.7	13036.9
	sum	***73573.8***				
	avg ± se	***14714.8***	***4561.5***			
	SRP	518.2	81.7	8518.0	634.1	504.9
	sum	***10256.9***				
	avg ± se	***2051.4***	***1619.4***			
	TP	1517.5	133.7	8637.8	999.6	906.3
	sum	***12195.0***				
	avg ± se	***2439.0***	***1565.4***			

f. J adv (mg/m2/d) - INFILTRATION

2008		**6**	**7**	**8**	**9**	**10**
Near	**NH4**	4045.8	1297.2	6688.8	192.4	2098.3
Tail	***sum***	***14322.5***				
(South)	***avg ± se***	***2864.5***	***1144.6***			
	NN	47.0	153.8	1637.3	47.3	457.8
	sum	***2343.2***				
	avg ± se	***468.6***	***301.7***			
	DIN	4092.8	1451.0	8326.1	239.7	2556.1
	sum	***16665.8***				
	avg ± se	***3333.2***	***1400.4***			
	SRP	1023.6	999.8	2391.6	41.5	1044.7
	sum	***5501.2***				
	avg ± se	***1100.2***	***374.7***			
	TP*	398.0	700.1	2930.8	52.9	980.0
	sum	***5061.8***				
	avg ± se	***1012.4***	***503.8***			
		1	**2**	**3**	**4**	**5**
Wet	**NH4**	676.2	9036.8	39109.7	235.5	4486.9
Head	***sum***	***53545.0***				
(North)	***avg ± se***	***10709.0***	***7274.8***			
	NN	67.6	484.6	181.2	10.3	111.9
	sum	***855.6***				
	avg ± se	***171.1***	***83.2***			
	DIN	743.8	9521.4	39290.9	245.8	4598.7
	sum	***54400.6***				
	avg ± se	***10880.1***	***7294.9***			
	SRP	112.9	909.0	6186.5	46.5	570.2
	sum	***7825.1***				
	avg ± se	***1565.0***	***1166.0***			
	TP*	231.0	203.2	5941.3	78.0	392.5
	sum	***6846.0***				
	avg ± se	***1369.2***	***1144.1***			

***estimated**

g. J adv (mg/m2/yr) - UPWELLING

2007		**6**	**7**	**8**	**9**	**10**
Near Tail (South)	**NH4**	85.6	979.4	0.0	279.8	23.7
	sum	***1368.5***				
	avg ± se	***273.7***	***183.2***			
	NN	6.7	8.2	0.0	7.8	5.3
	sum	***28.0***				
	avg ± se	***5.6***	***1.5***			
	DIN	92.2	987.7	0.0	287.6	29.0
	sum	***1396.4***				
	avg ± se	***279.3***	***184.1***			
	TN	508.8	1183.0	0.0	693.7	268.3
	sum	***2653.7***				
	avg ± se	***530.7***	***200.4***			
	SRP	59.0	43.6	0.0	13.8	52.4
	sum	***168.8***				
	avg ± se	***33.8***	***11.4***			
	TP	104.9	97.9	0.0	37.4	65.4
	sum	***305.6***				
	avg ± se	***61.1***	***19.5***			
		1	**2**	**3**	**4**	**5**
Wet Head (North)	**NH4**	21.2	930.1	2707.4	5883.8	6393.3
	sum	***10052.0***				
	avg ± se	***3187.2***	***1282.6***			
	NN	0.4	28.5	7.9	72.4	93.1
	sum	***129.9***				
	avg ± se	***40.5***	***18.2***			
	DIN	21.6	958.6	2715.3	5956.2	6486.4
	sum	***10181.9***				
	avg ± se	***3227.6***	***1299.1***			
	TN	70.7	1363.8	1383.9	12602.4	14157.7
	sum	***10311.8***				
	avg ± se	***5915.7***	***3066.5***			
	SRP	2.4	70.5	181.3	16.1	418.8
	sum	***672.9***				
	avg ± se	***137.8***	***77.0***			
	TP	2.1	146.9	140.4	199.0	637.0
	sum	***926.5***				
	avg ± se	***225.1***	***108.0***			

h. J adv (mg/m2/yr) - UPWELLING

2008		**6**	**7**	**8**	**9**	**10**
Near	**NH4**	9400.4	155.7	20.7	6854.7	4973.5
Tail	***sum***	***21405.0***				
(South)	***avg ± se***	***4281.0***	***1850.4***			
	NN	648.1	139.7	0.5	95.1	409.5
	sum	***1292.9***				
	avg ± se	***258.6***	***118.7***			
	DIN	10048.5	295.5	21.2	6949.8	5382.9
	sum	***22697.9***				
	avg ± se	***4539.6***	***1940.3***			
	SRP	1567.1	52.7	0.4	84.5	147.0
	sum	***1851.7***				
	avg ± se	***370.3***	***300.1***			
	TP*	1279.1	68.5	1.0	131.3	489.1
	sum	***1968.9***				
	avg ± se	***393.8***	***236.8***			

		1	**2**	**3**	**4**	**5**
Wet	**NH4**	422.5	73.2	10373.5	3247.1	4084.7
Head	***sum***	***18201.1***				
(North)	***avg ± se***	***3640.2***	***1854.3***			
	NN	130.3	60.5	14.5	45.5	96.0
	sum	***346.7***				
	avg ± se	***69.3***	***20.1***			
	DIN	552.8	133.7	10388.0	3292.6	4180.7
	sum	***18547.8***				
	avg ± se	***3709.6***	***1840.5***			
	SRP	67.2	12.2	66.7	14.5	162.2
	sum	***322.7***				
	avg ± se	***64.5***	***27.2***			
	TP*	154.9	30.7	233.1	59.5	416.1
	sum	***894.3***				
	avg ± se	***178.9***	***69.3***			

***estimated**

Table 4. Summary table of subsurface hydrologic fluxes of NH_4, N+N, DIN, TN, SRP and TP with net subsurface flux (g m^{-2} yr^{-1}). Individual values used are average flux for horizontal imports and exports and vertical imports and exports (n=5). See Table 3 for standard error values.

A. 2007		**IMPORTS horizontal**	**upwelling**	**EXPORTS horizontal**	**infiltration**	**NET I-E**
Near Tail (South)	**NH4**	**0.02**	**0.27**	**0.22**	**2.82**	**-2.74**
	NN	**0.00**	**0.01**	**0.03**	**0.40**	**-0.42**
	DIN	**0.03**	**0.28**	**0.24**	**3.22**	**-3.16**
	TN	**0.10**	**0.53**	**1.67**	**25.22**	**-26.25**
	SRP	**0.01**	**0.03**	**0.05**	**0.69**	**-0.70**
	TP	**0.01**	**0.06**	**0.15**	**1.86**	**-1.94**
Wet Head (North)	**NH4**	**0.07**	**3.19**	**0.30**	**8.50**	**-5.54**
	NN	**0.00**	**0.04**	**0.00**	**0.10**	**-0.07**
	DIN	**0.07**	**3.23**	**0.30**	**8.60**	**-5.61**
	TN	**0.28**	**5.92**	**0.38**	**14.71**	**-8.89**
	SRP	**0.01**	**0.14**	**0.08**	**2.05**	**-1.99**
	TP	**0.01**	**0.23**	**0.09**	**2.44**	**-2.28**

B. 2008		**IMPORTS horizontal**	**upwelling**	**EXPORTS horizontal**	**infiltration**	**NET I-E**
Near Tail (South)	**NH4**	**0.03**	**4.28**	**0.37**	**2.86**	**1.07**
	NN	**0.00**	**0.26**	**0.09**	**0.47**	**-0.29**
	DIN	**0.03**	**4.54**	**0.46**	**3.33**	**0.78**
	SRP	**0.01**	**0.37**	**0.14**	**1.10**	**-0.85**
	TP	**0.01**	**0.39**	**0.16**	**1.01**	**-0.77**
Wet Head (North)	**NH4**	**0.13**	**3.64**	**0.53**	**10.71**	**-7.47**
	NN	**0.01**	**0.07**	**0.02**	**0.17**	**-0.11**
	DIN	**0.14**	**3.71**	**0.55**	**10.88**	**-7.58**
	SRP	**0.02**	**0.06**	**0.07**	**1.57**	**-1.55**
	TP	**0.01**	**0.18**	**0.07**	**1.37**	**-1.25**

Table 5. Tree Island 3AS3 Net Ecosystem N Fluxes for a. 2007 and b. 2008 (g m^{-2} yr^{-1})

a.	Wet Head	Near Tail
Sediment Accretion	**15.70**	**15.60**
Plant Demand	**2.73**	**2.74**
Microbial Assimilation	**3.50**	**6.53**
Surface Water Load	**47.76**	**44.16**
Subsurface		
-import	**10.44**	**1.50**
-export	**42.26**	**17.08**
Throughfall	**0.45**	**1.04**
Net Ecosystem N Flux	**38.31**	**54.49**

b.	Wet Head	Near Tail
Sediment Accretion	**14.10**	**13.20**
Plant Demand	**2.82**	**2.77**
Microbial Assimilation	**8.62**	**4.38**
Surface Water Load	**441.25**	**375.13**
Subsurface		
-import	**15.52**	**22.82**
-export	**55.57**	**18.51**
Throughfall	**1.04**	**2.45**
Net Ecosystem N Flux	**427.77**	**402.24**

Table 6. Tree Island 3AS3 Net Ecosystem P Fluxes for a. 2007 and b. 2008 (g m^{-2} yr^{-1})

a.	Wet Head	Near Tail
Sediment Accretion	**4.40**	**3.52**
Plant Demand	**0.51**	**0.13**
Surface Water Load	**8.50**	**7.86**
Subsurface		
-import	**0.24**	**0.07**
-export	**2.52**	**2.01**
Throughfall	**0.02**	**0.16**
Net Ecosystem P Flux	**11.15**	**9.73**

b.	Wet Head	Near Tail
Sediment Accretion	**3.89**	**3.41**
Plant Demand	**0.52**	**0.13**
Surface Water Load	**16.28**	**13.84**
Subsurface		
-import	**0.19**	**0.40**
-export	**1.44**	**1.18**
Throughfall	**0.03**	**0.37**
Net Ecosystem P Flux	**19.48**	**16.98**

Table 7. Ecological contribution of tree islands to landscape cycling of phosphorus

	m^{-2}	$g\ m^{-2}\ yr^{-1}$	$g\ 55yr^{-1}$	$g\ yr^{-1}$	% of annual TP input
Area of WCA 3A	2361100000				
Tree island area 1940	89110000				
Tree island area 1995	34343000				
Annual TP input to WCA3A (Davis 1994)		65100000			
Average tree island P uptake -all SW inputs					
1940		14.3	1277391850		
1995			492306905		
TP lost due to tree island decline			785084945	14274272	22

Table 8. Ecological contribution of tree islands to landscape cycling of nitrogen

	m^{-2}	$g\ m^{-2}\ yr^{-1}$	$Mg\ 55yr^{-1}$	$Mg\ yr^{-1}$
Area of WCA 3A	2361100000			
Tree island area 1940	89110000			
Tree island area 1995	34343000			
Average tree island N uptake -all SW inputs				
1940		239.6	21351	
1995			8228	
N lost due to tree island decline			13122	238

FIGURES

Figure 1. Map of Florida and tree island 3AS3 study site (red star) in the WCA 3A (inset).

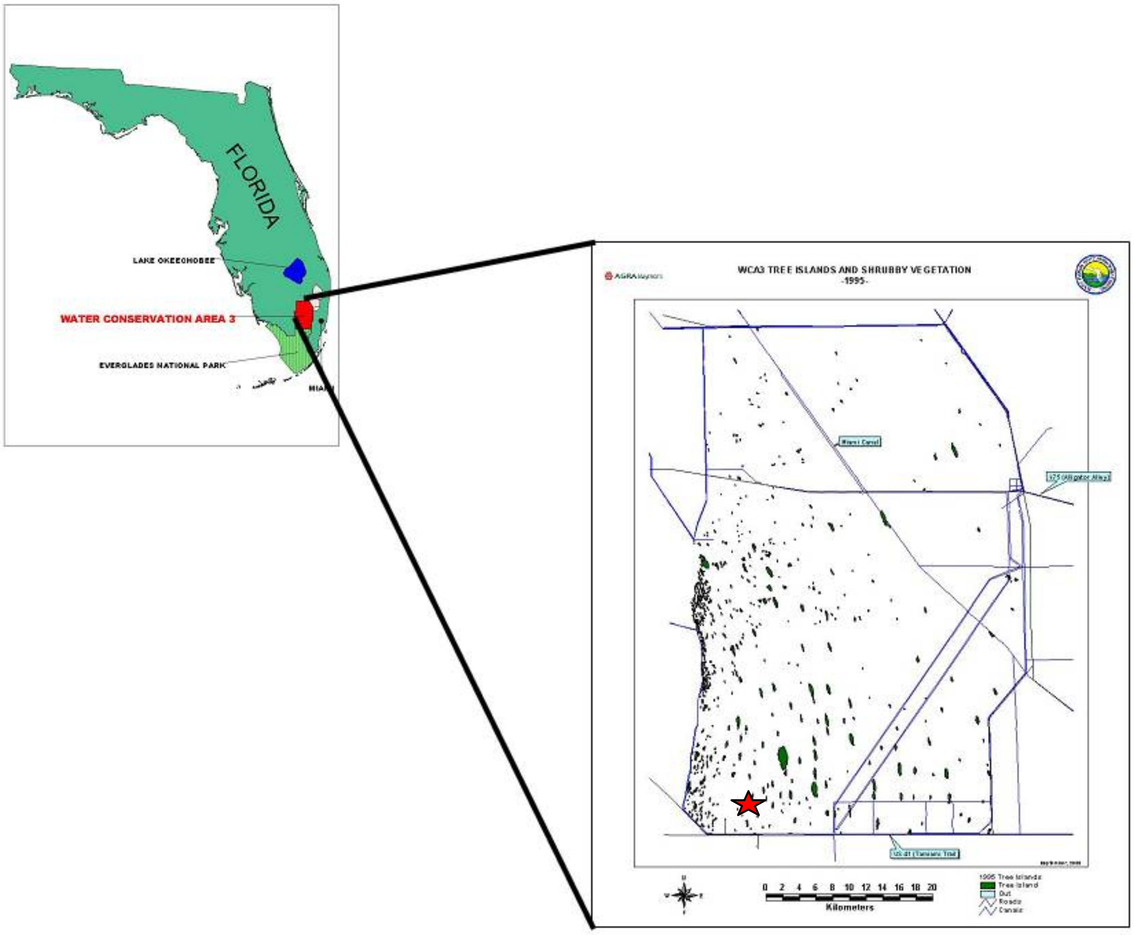


Figure 2. Conceptual figure of tree island 3AS3 with relative well locations identified

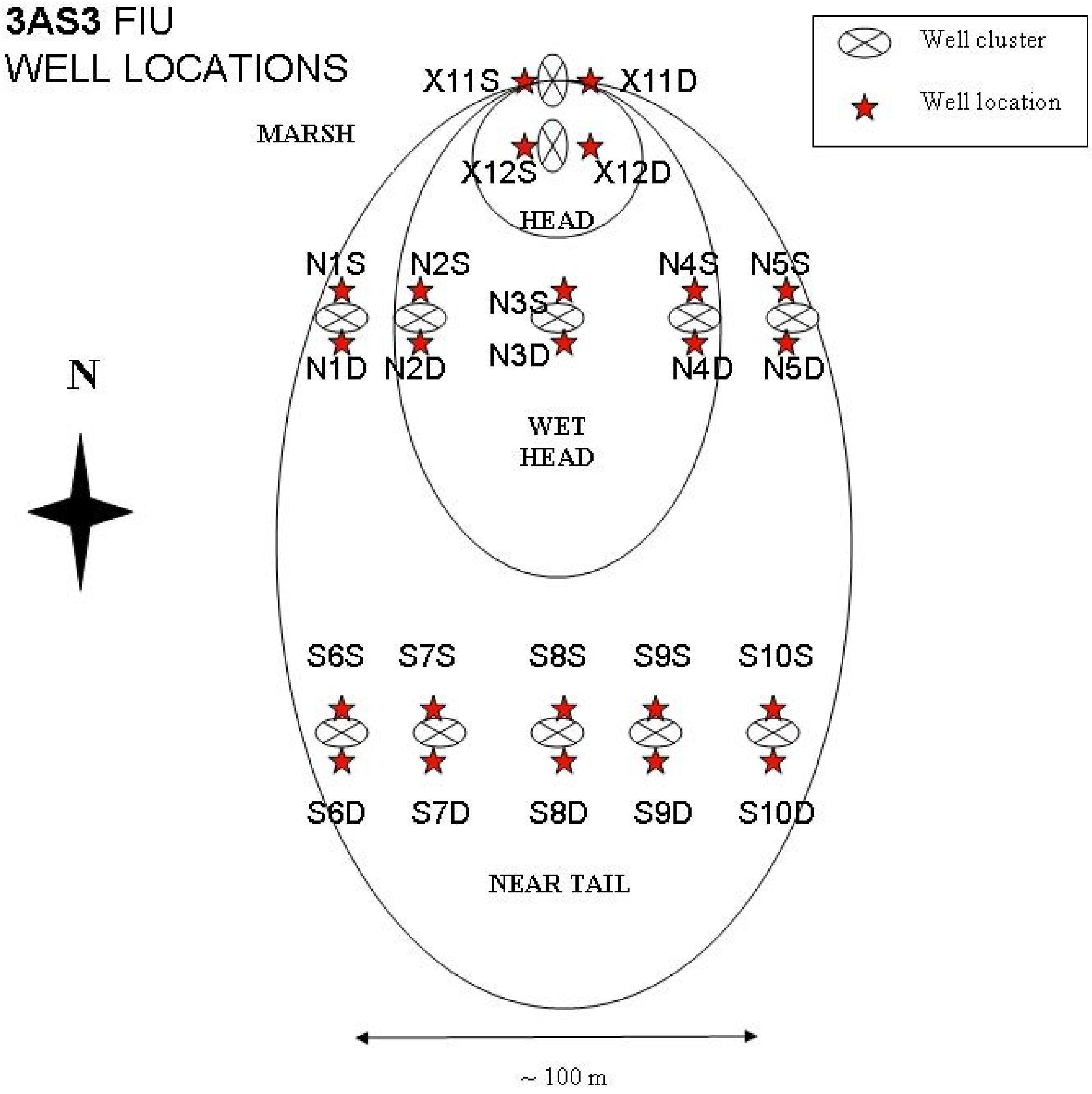


Figure 3. Map of georeferenced well locations in tree island 3AS3 with tree island outline drawn from aerial imagery (provided by Keith and Schnars under a separate contract).

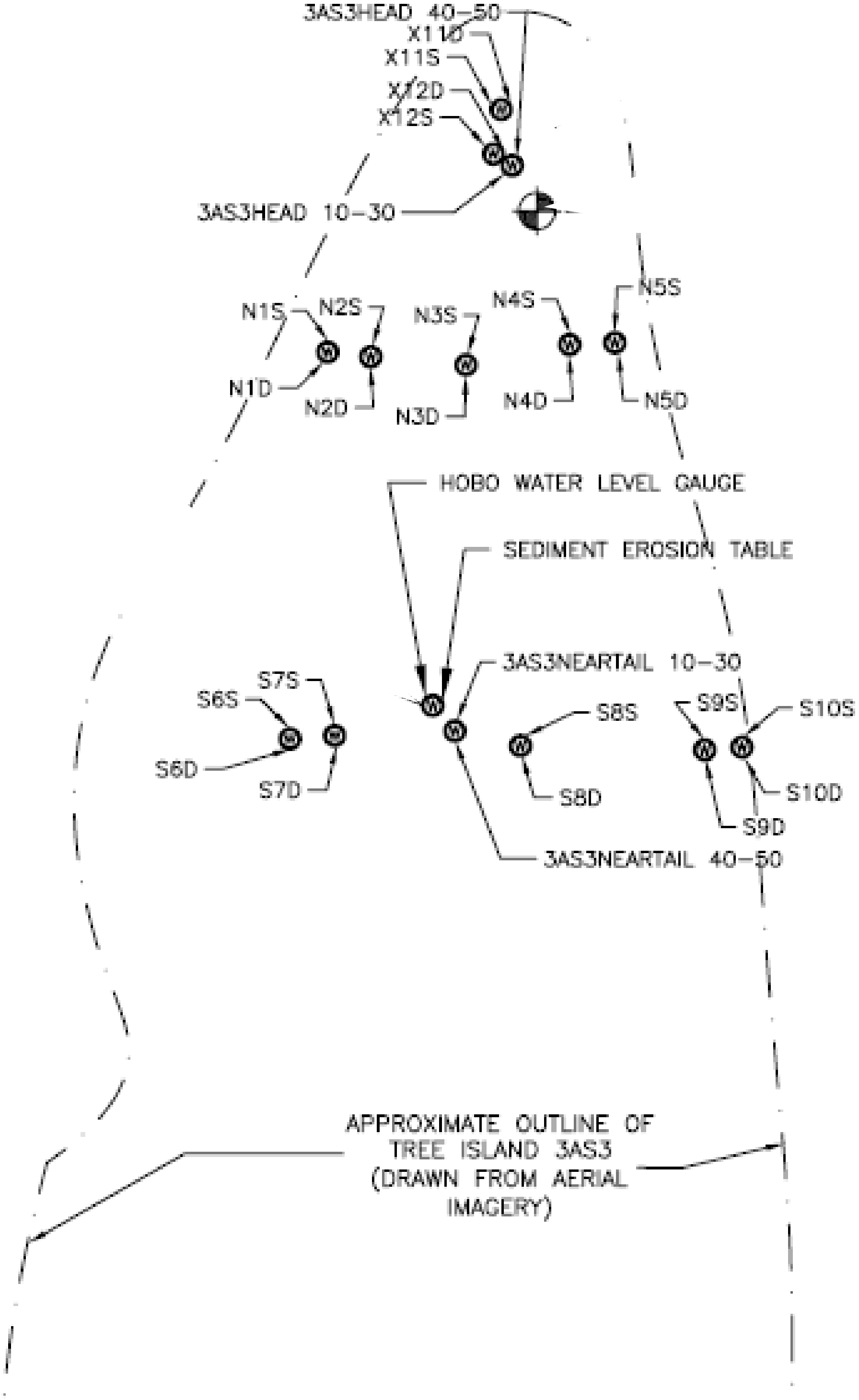


Figure 4. Aerial image of tree island 3AS3. Note the difference in vegetation cover along location of S transect where tree cover is greater on the E side, with greater shrub cover on the W side resulting in a discrete marsh-tree island boundary on the E side and a more transitional vegetation community on the W side. The N transect traverses a more uniform vegetation cover.

Figure 5. Spatial variability in TP concentrations among well clusters for wells installed at 30 cm and 60 cm depth (shallow and deep, respectively) in 2007 for Wet Head (N1-N5) and Near Tail (S6-S10). The 30 cm well characterizes the soil profile of 20-30 cm depth while the 60 cm well characterizes the soil profile of 50-60cm depth. Values are an average of five sampling months except for S10S (n=3), S10D (n=3), and S9S (n=3). Error bars represent standard error about the mean.

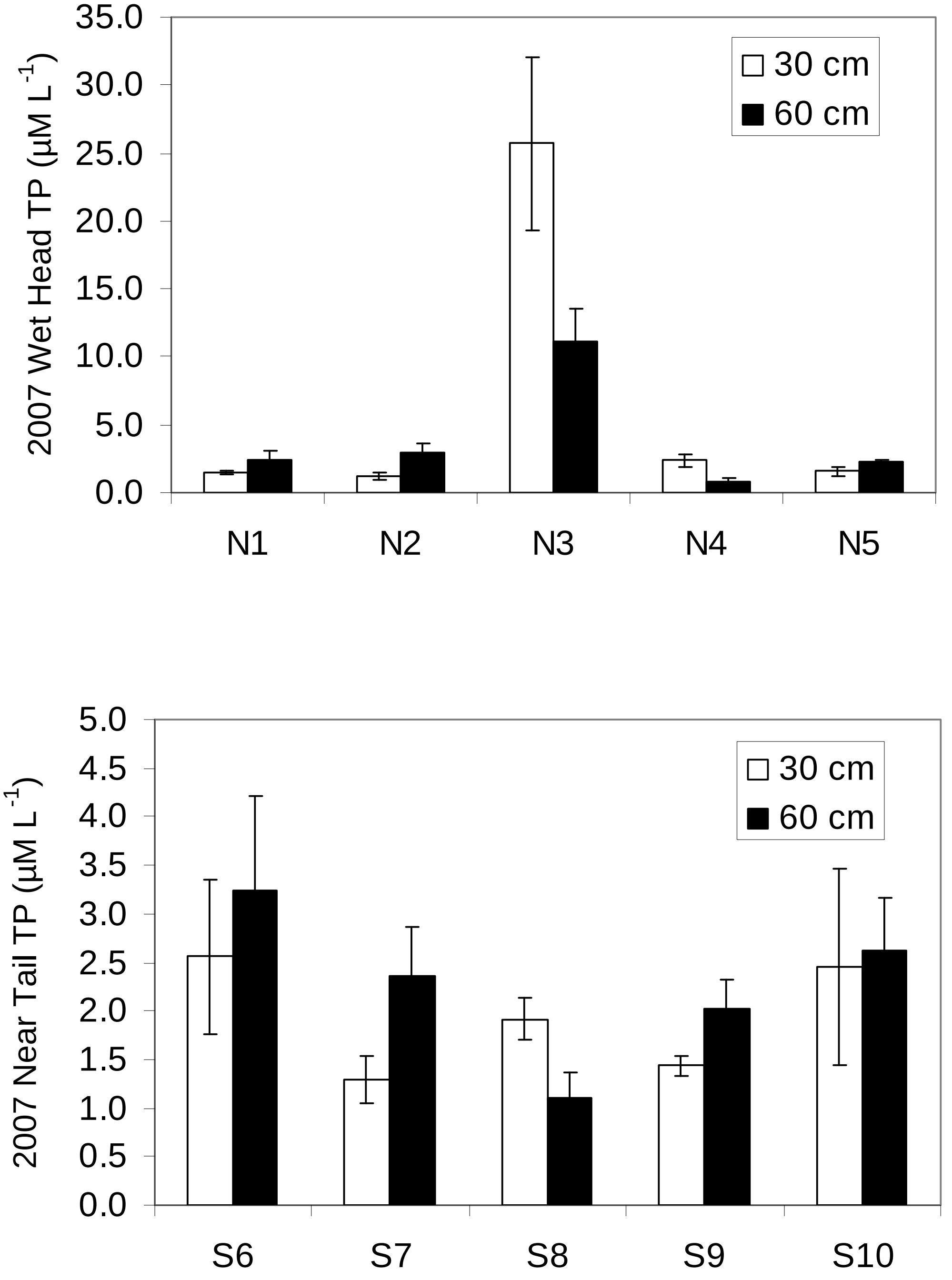


Figure 6. Spatial variability in TN concentrations among well clusters for wells installed at 30 cm and 60 cm depth (shallow and deep, respectively) in 2007 for Wet Head (N1-N5) and Near Tail (S6-S10). The 30 cm well characterizes the soil profile of 20-30 cm depth while the 60 cm well characterizes the soil profile of 50-60cm depth. Values are an average of five sampling months except for S10S (n=3), S10D (n=3), and S9S (n=3). Error bars represent standard error about the mean.

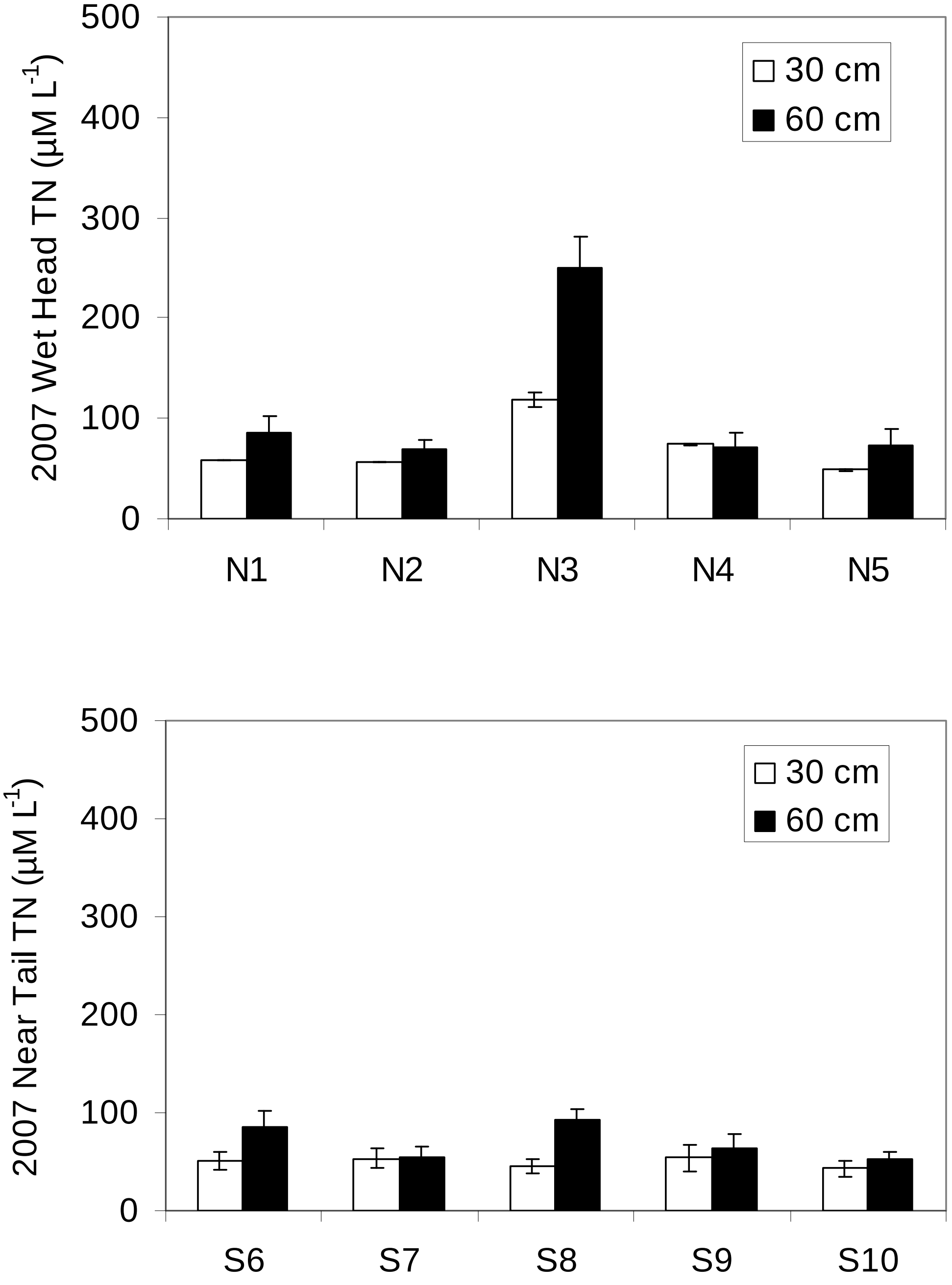


Figure 7. Spatial variability in SRP concentrations for among well clusters for wells installed at 30 cm and 60 cm depth (shallow and deep, respectively) in 2007 for Wet Head (N1-N5) and Near Tail (S6-S10). Values are an average of five sampling months except for S10S (n=3), S10D (n=3), and S9S (n=3). Error bars represent standard error about the mean.

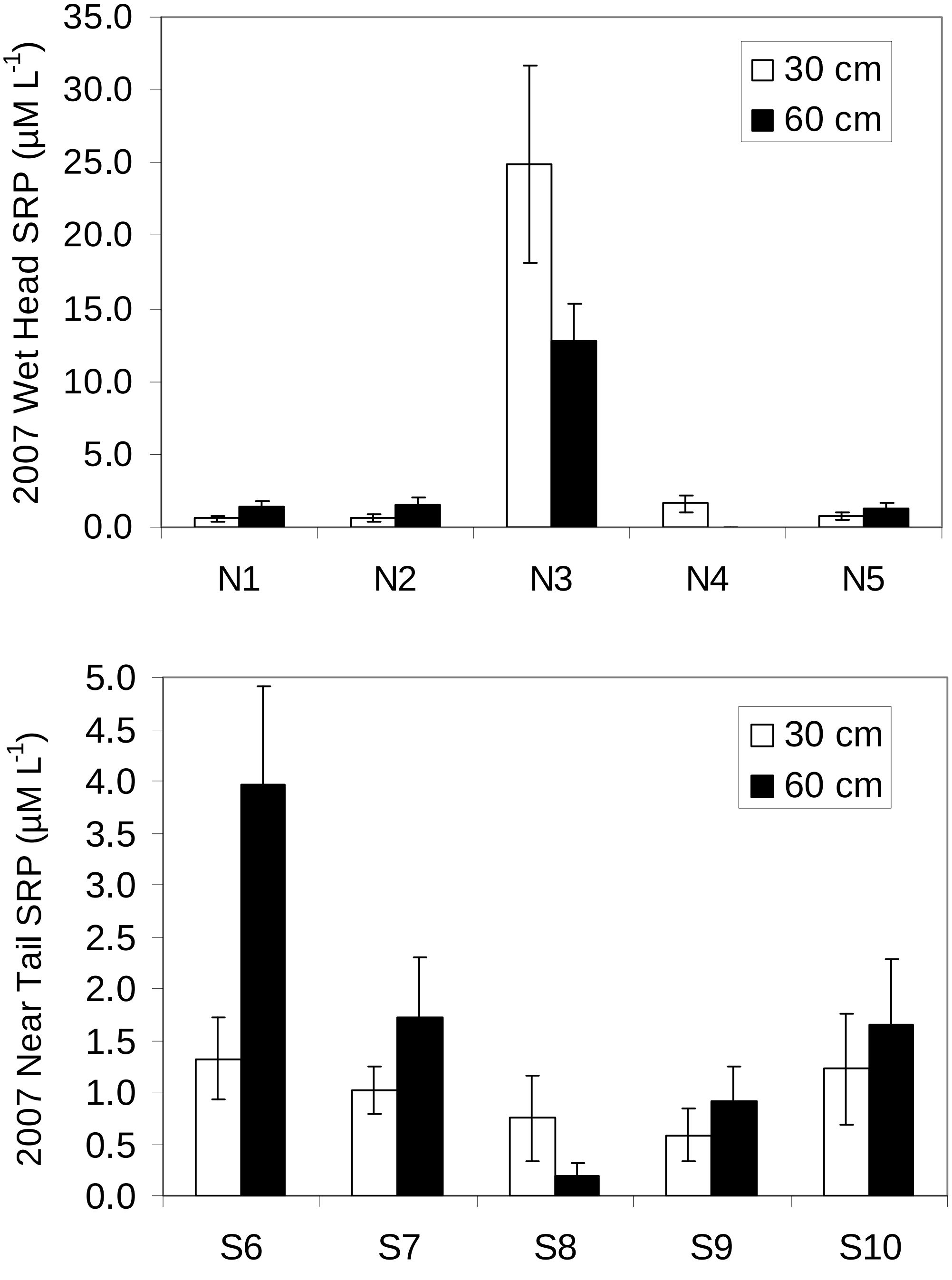
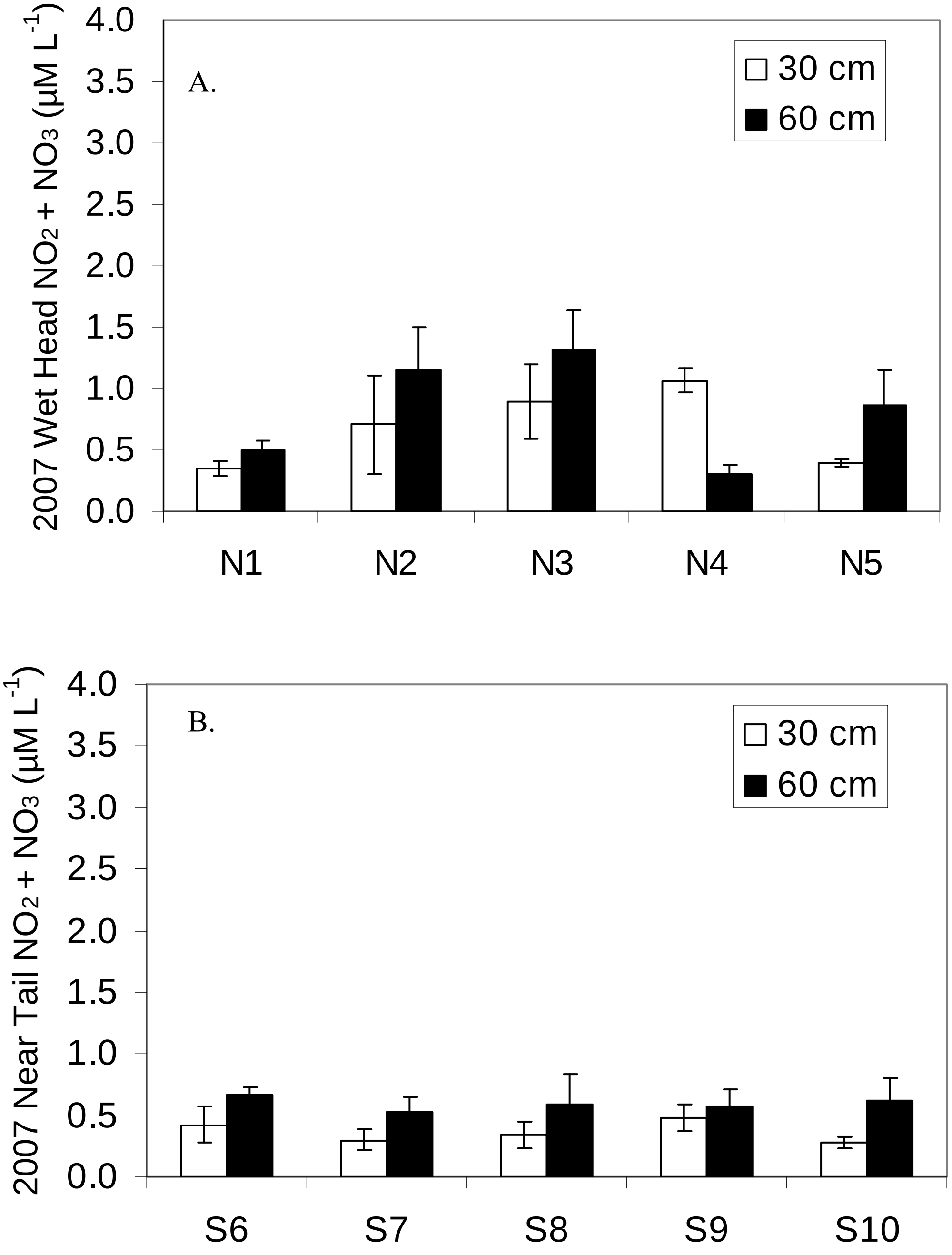
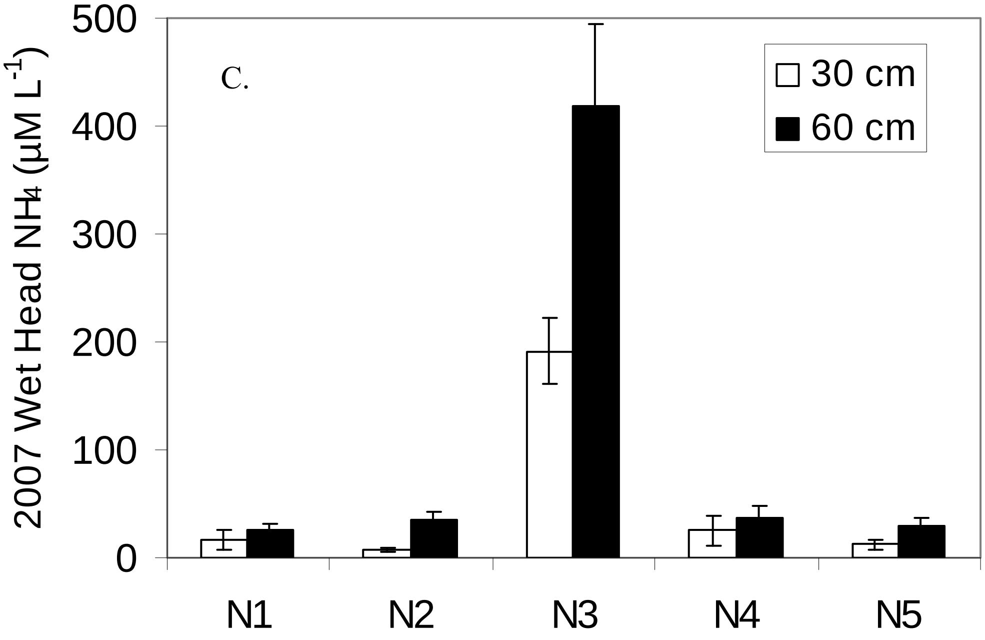


Figure 8. Spatial variability in N+N (A&B) and NH_4^+ (C&D) concentrations among well clusters for wells installed at 30 cm and 60 cm depth (shallow and deep, respectively) in 2007 for Wet Head (N1-N5) and Near Tail (S6-S10). Values are an average of five sampling months for N+N and NH_4^+ except for N3D (n=4) for NH_4^+. Error bars represent standard error about the mean.




C.
□ 30 cm
■ 60 cm
2007 Wet Head NH_4 (µM L^{-1})
500
400
300
200
100
0
N1
N2
N3
N4
N5

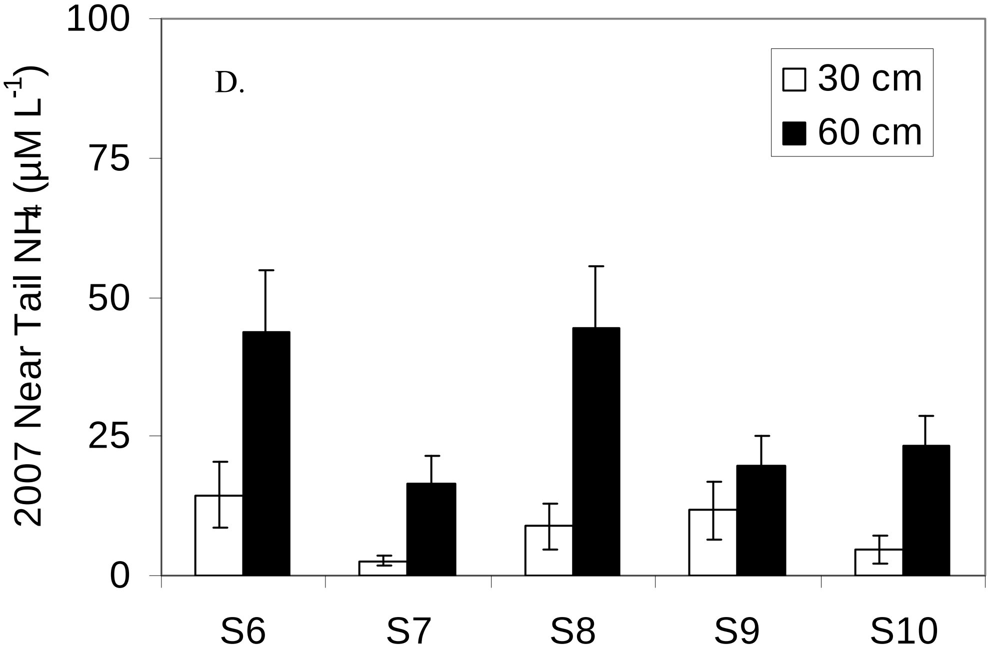

D.
□ 30 cm
■ 60 cm
2007 Near Tail NH_4 (µM L^{-1})
100
75
50
25
0
S6
S7
S8
S9
S10

Figure 9. Spatial variability in TP concentrations among well clusters for wells installed at 30 cm and 60 cm depth (shallow and deep, respectively) in 2008 for Wet Head (N1-N5) and Near Tail (S6-S10). The 30 cm well characterizes the soil profile of 20-30 cm depth while the 60 cm well characterizes the soil profile of 50-60cm depth. Values are an average of five sampling months except for S10S (n=3), S10D (n=3), and S9S (n=3). Error bars represent standard error about the mean.

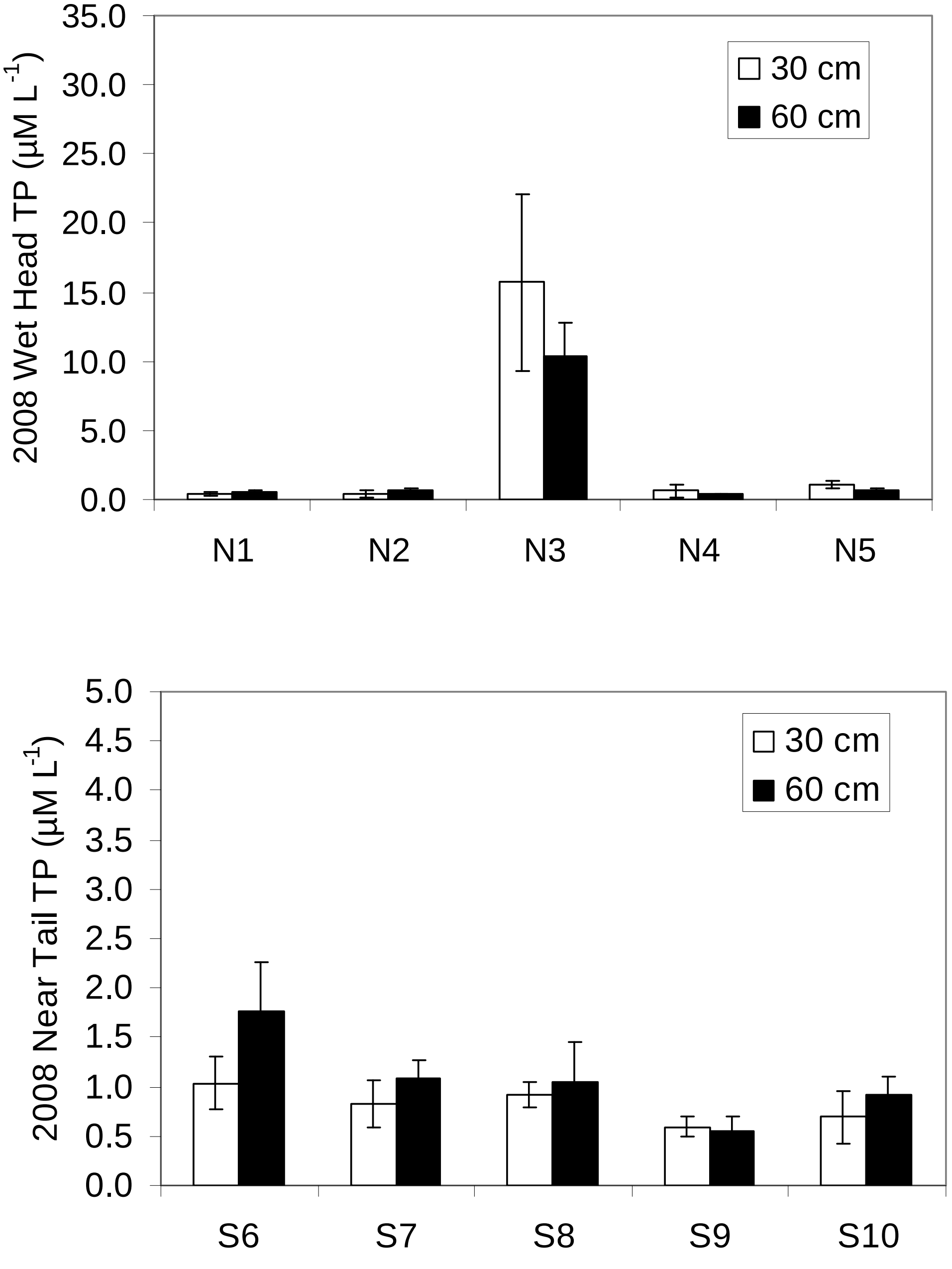
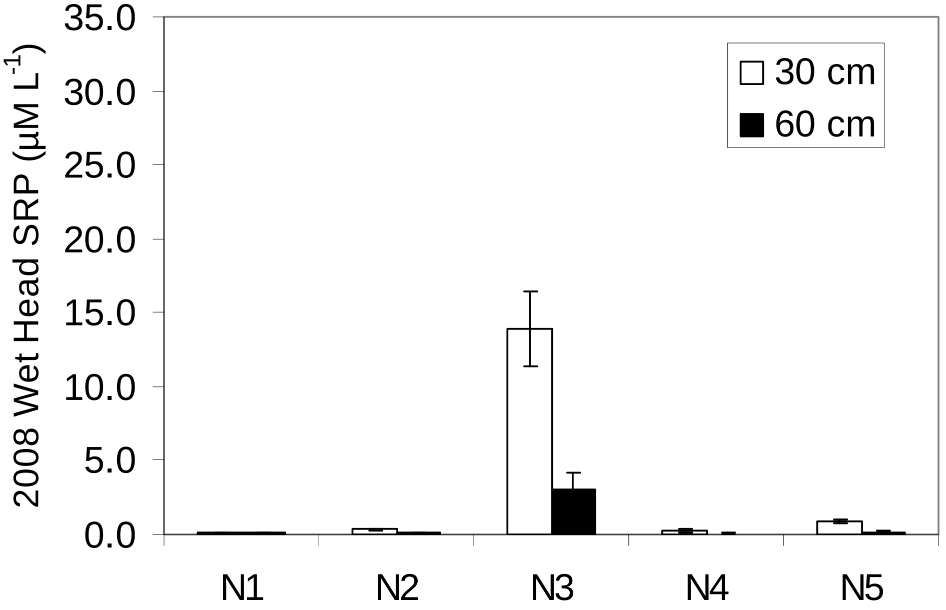


Figure 10. Spatial variability in SRP concentrations for among well clusters for wells installed at 30 cm and 60 cm depth (shallow and deep, respectively) in 2008 for Wet Head (N1-N5) and Near Tail (S6-S10). Values are an average of five sampling months except for S10S (n=3), S10D (n=3), and S9S (n=3). Error bars represent standard error about the mean.



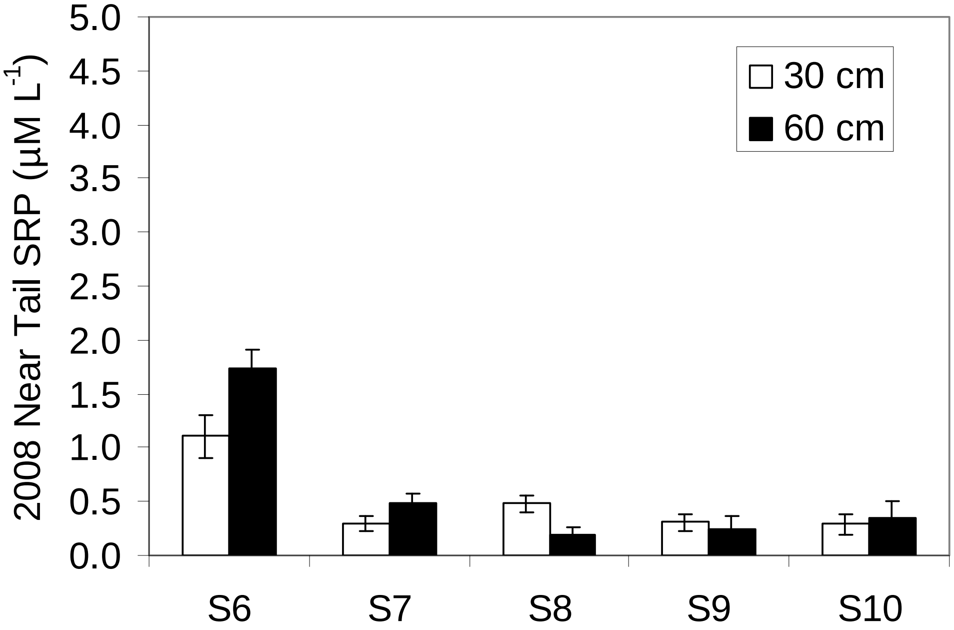
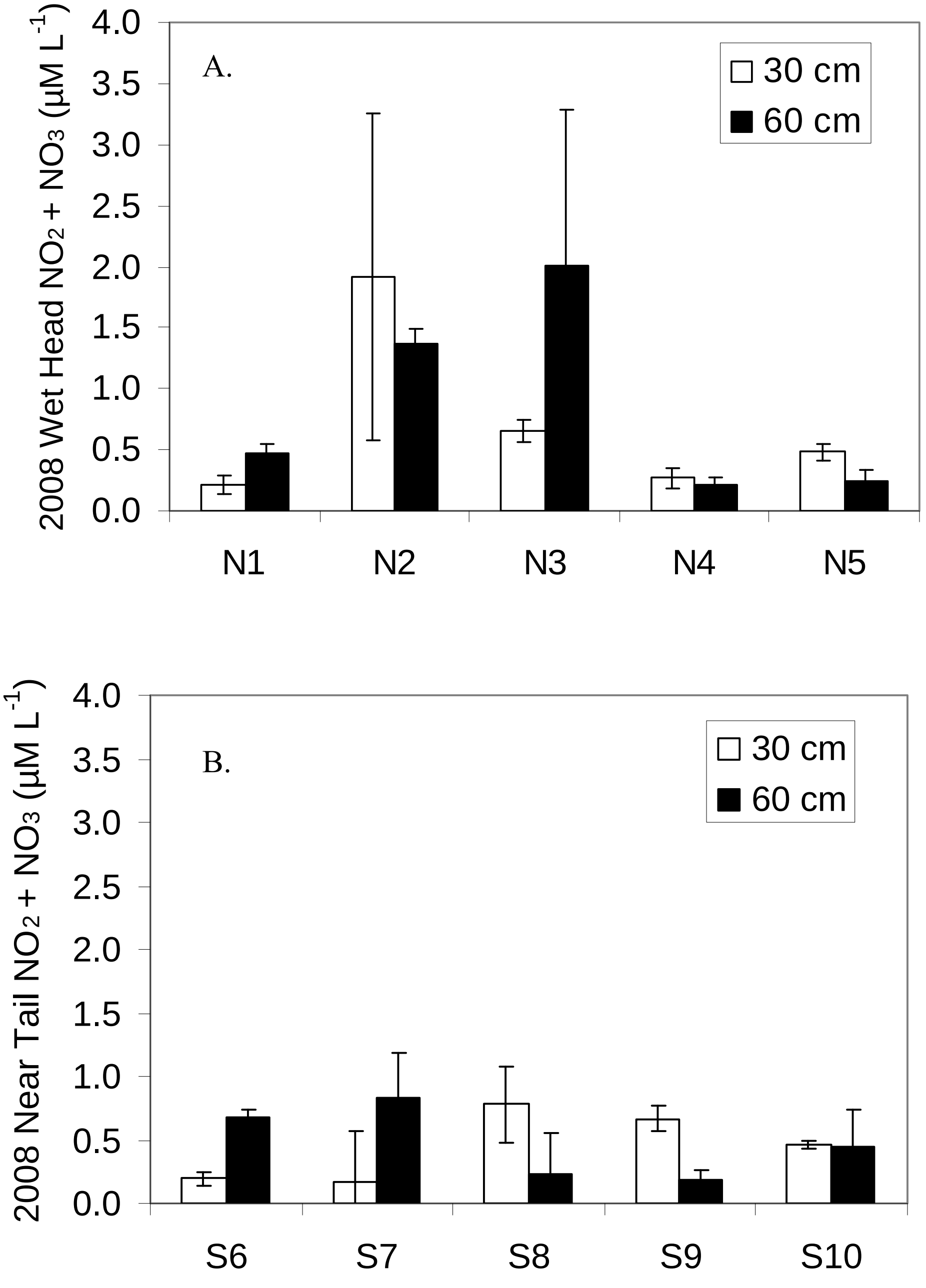
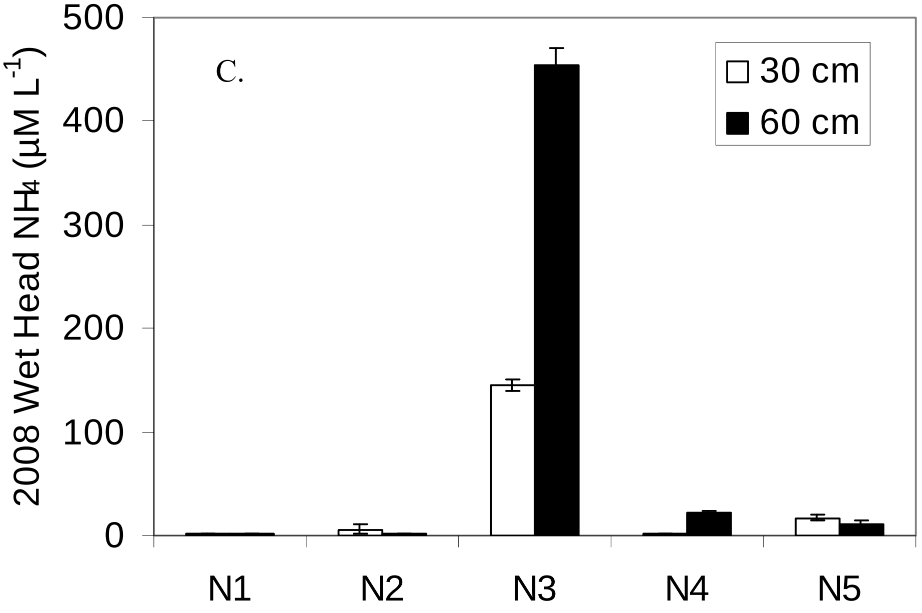


Figure 11. Spatial variability in N+N (A&B) and NH_4^+ (C&D) concentrations among well clusters for wells installed at 30 cm and 60 cm depth (shallow and deep, respectively) in 2007 for Wet Head (N1-N5) and Near Tail (S6-S10). Values are an average of five sampling months for N+N and NH_4^+ except for N3D (n=4) for NH_4^+. Error bars represent standard error about the mean.




C.
2008 Wet Head NH_4 (µM L^{-1})
500
400
300
200
100
0
N1
N2
N3
N4
N5
□ 30 cm
■ 60 cm

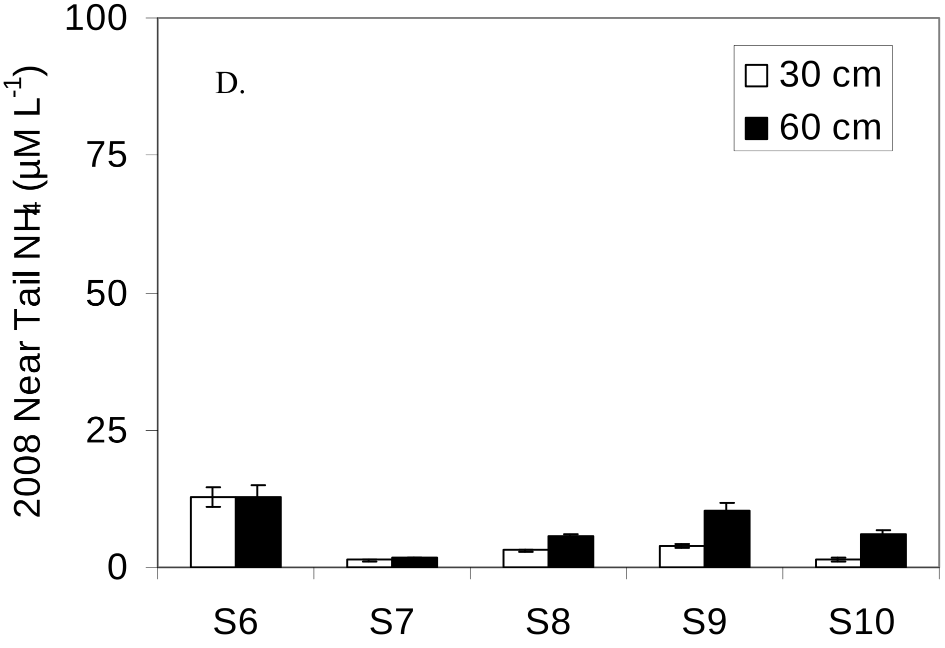

D.
2008 Near Tail NH_4 (µM L^{-1})
100
75
50
25
0
S6
S7
S8
S9
S10
□ 30 cm
■ 60 cm

Figure 12. Seasonal variability in SRP concentrations for wells installed at 30 cm and 60 cm depth in the central well cluster of the A. Wet Head (N3) and B. Near Tail (S8). Note the concentration gradient that increases as water levels start to decrease in the early dry season months, but with an order of magnitude difference between Wet Head and Near Tail.

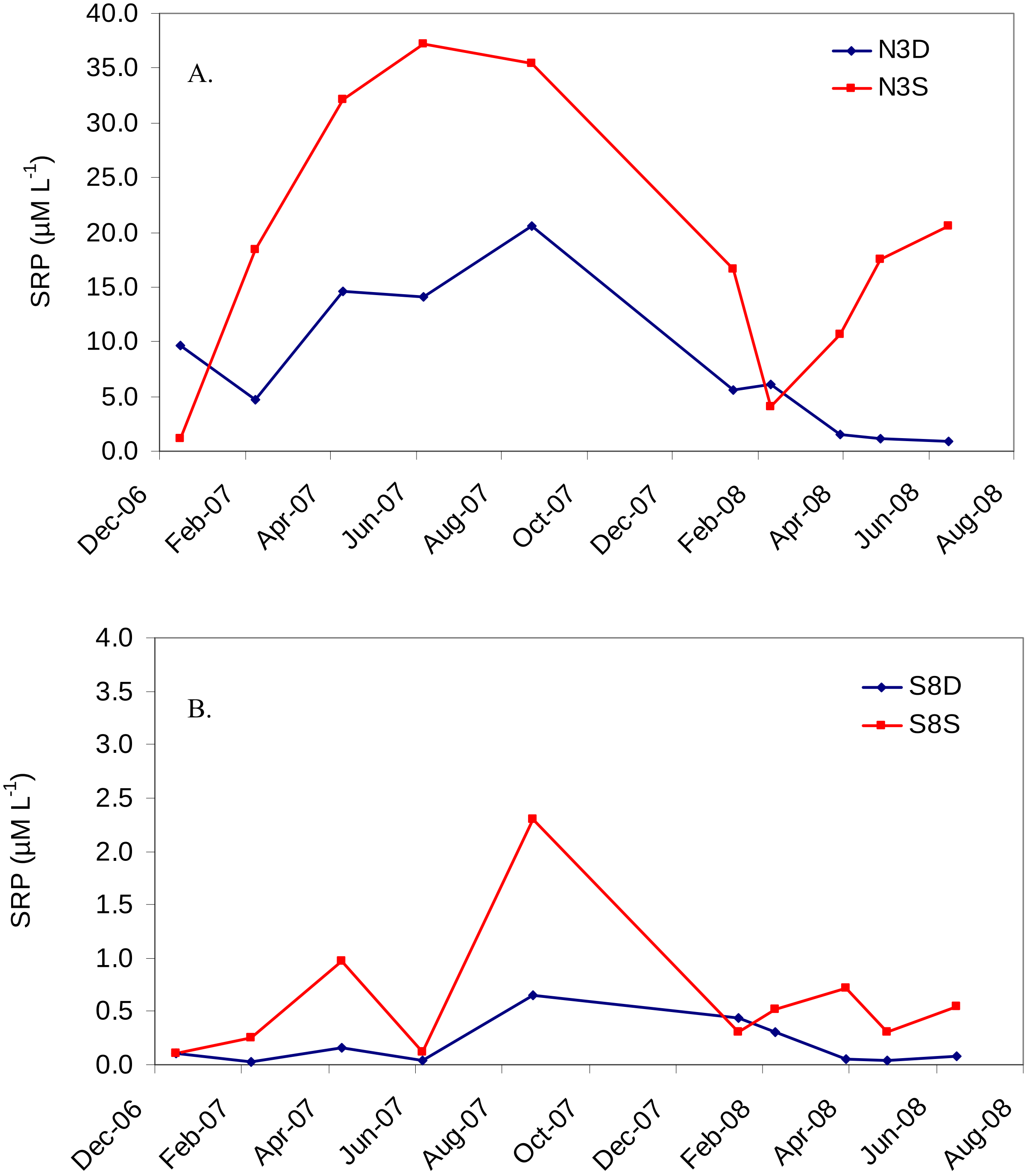


Figure 13. 2007 spatially explicit TP fluxes (mg m^{-2} yr^{-1}). Green arrows are imports, blue arrows are exports, with horizontal & vertical fluxes illustrated. Values less than 0.5 are reported as 0.

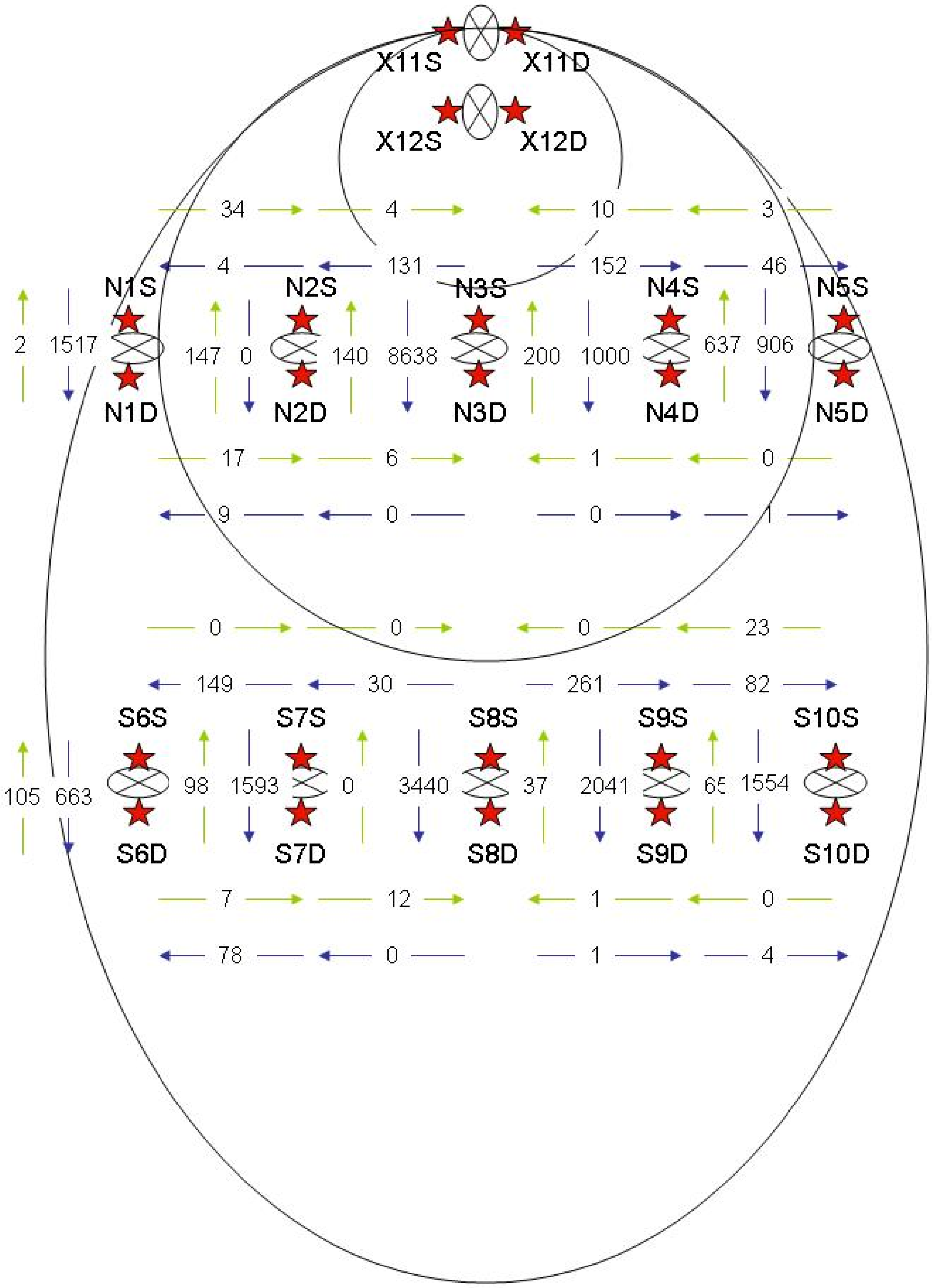


Figure 14. 2007 spatially explicit TN fluxes (mg m^{-2} yr^{-1}). Green arrows are imports, blue arrows are exports, with horizontal & vertical fluxes illustrated. Values less than 0.5 are reported as 0.

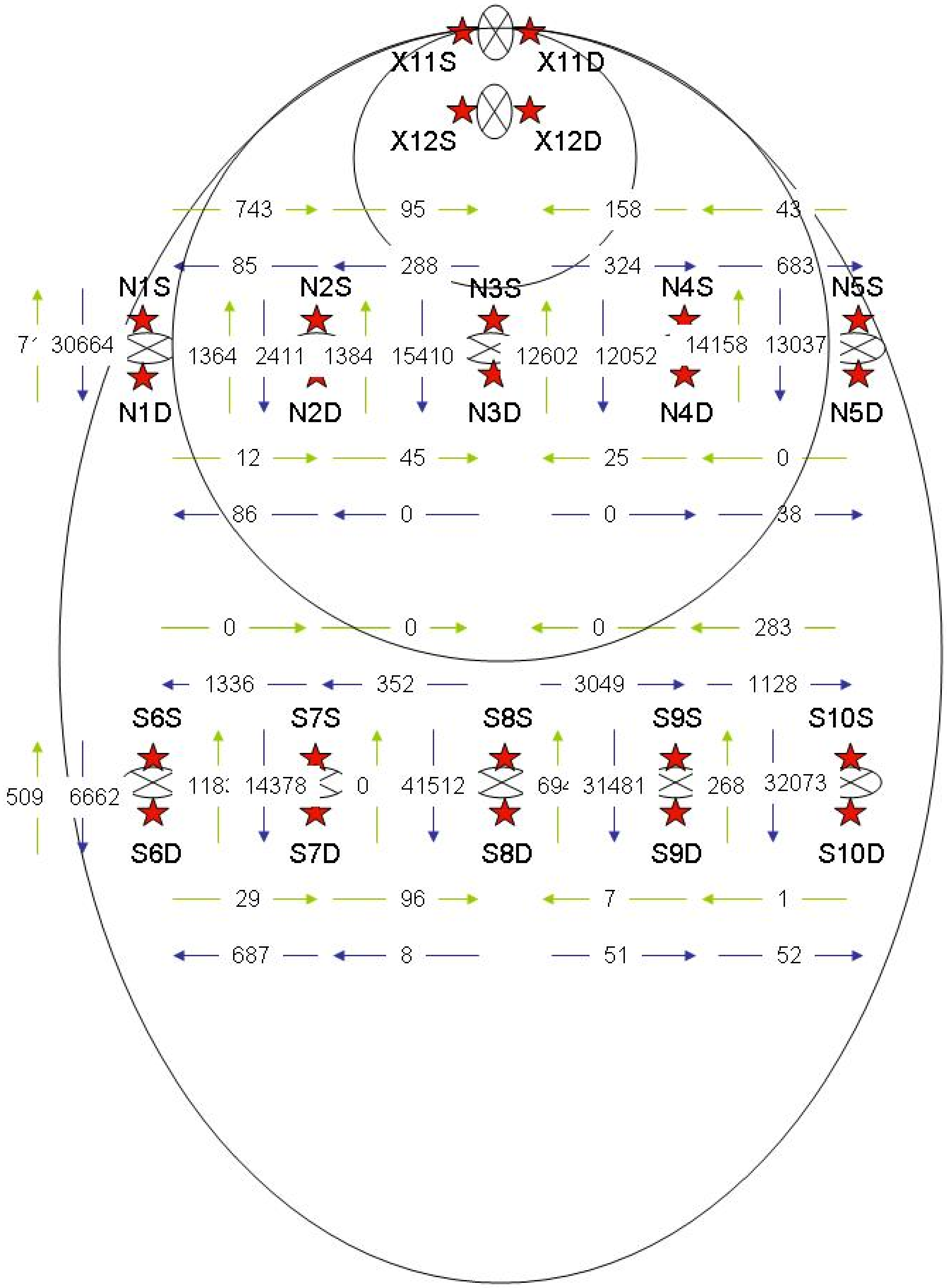


Figure 15. 2007 spatially explicit SRP fluxes (mg m^{-2} yr^{-1}). Green arrows are imports, blue arrows are exports, with horizontal & vertical fluxes illustrated. Values less than 0.5 are reported as 0.

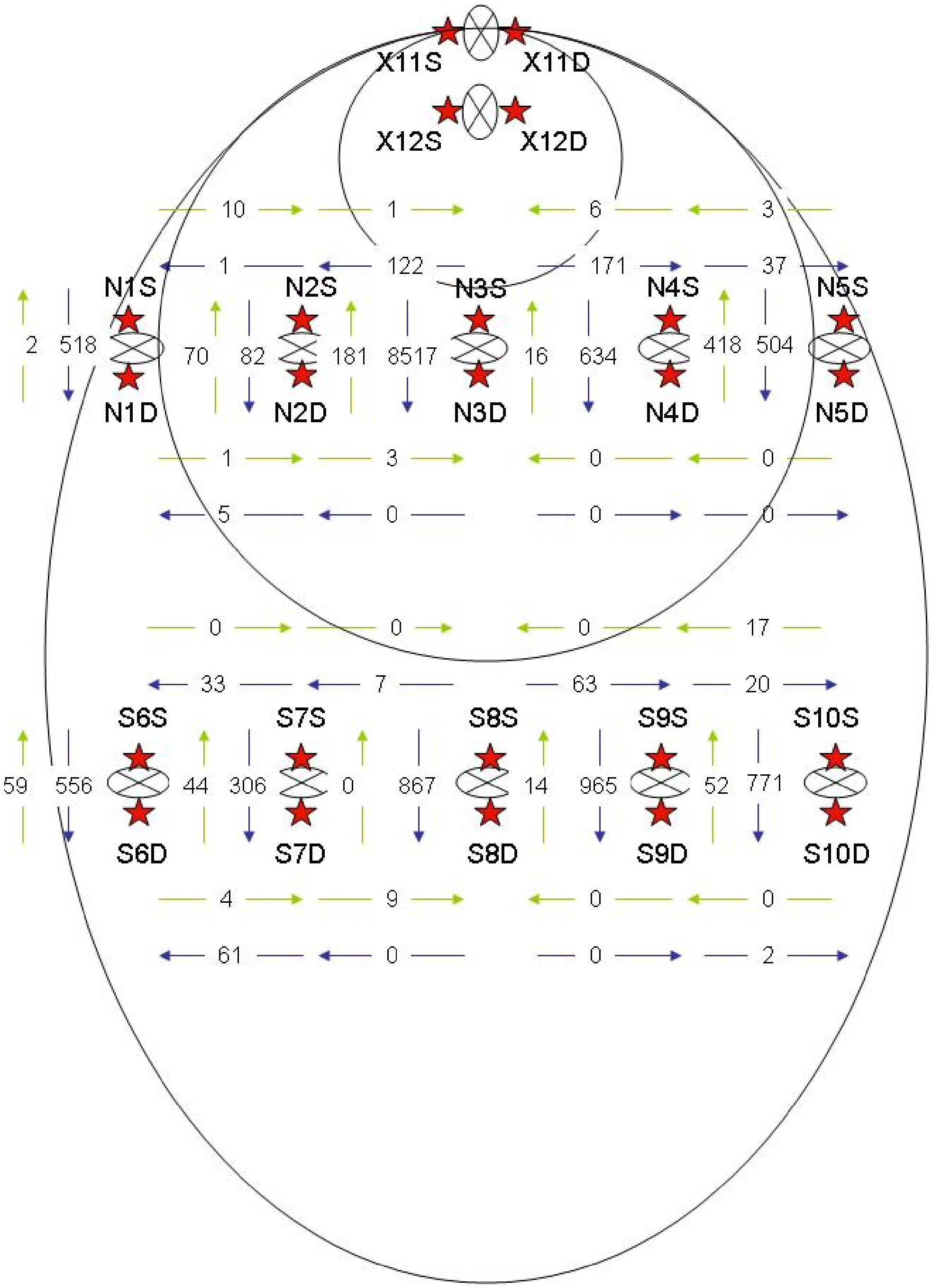


Figure 16. 2007 spatially explicit DIN fluxes (mg m^{-2} yr^{-1}). Green arrows are imports, blue arrows are exports, with horizontal & vertical fluxes illustrated. Values less than 0.5 are reported as 0.

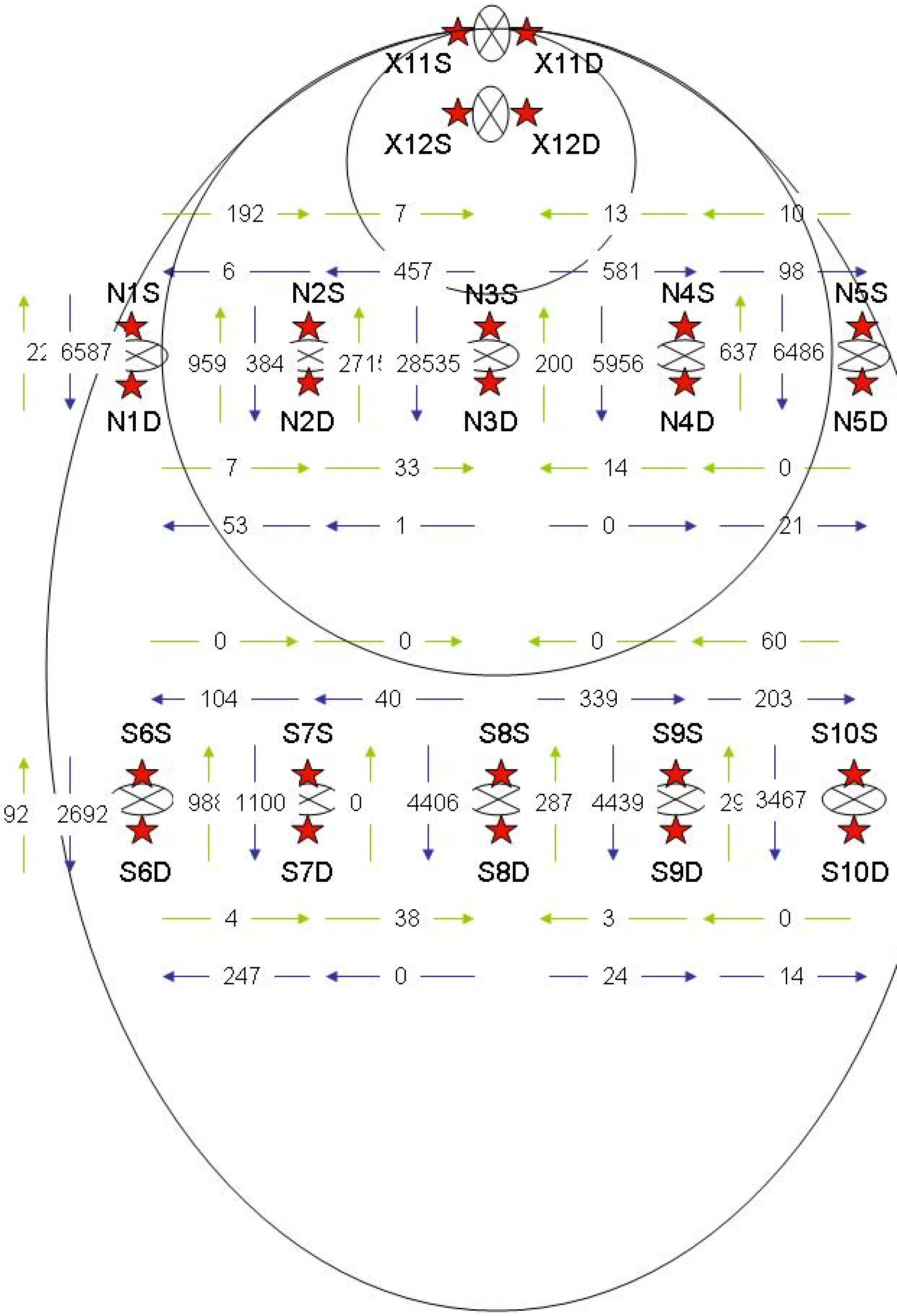


Figure 17. 2008 spatially explicit TP fluxes (mg m^{-2} yr^{-1}). Green arrows are imports, blue arrows are exports, with horizontal & vertical fluxes illustrated. Values less than 0.5 are reported as 0.

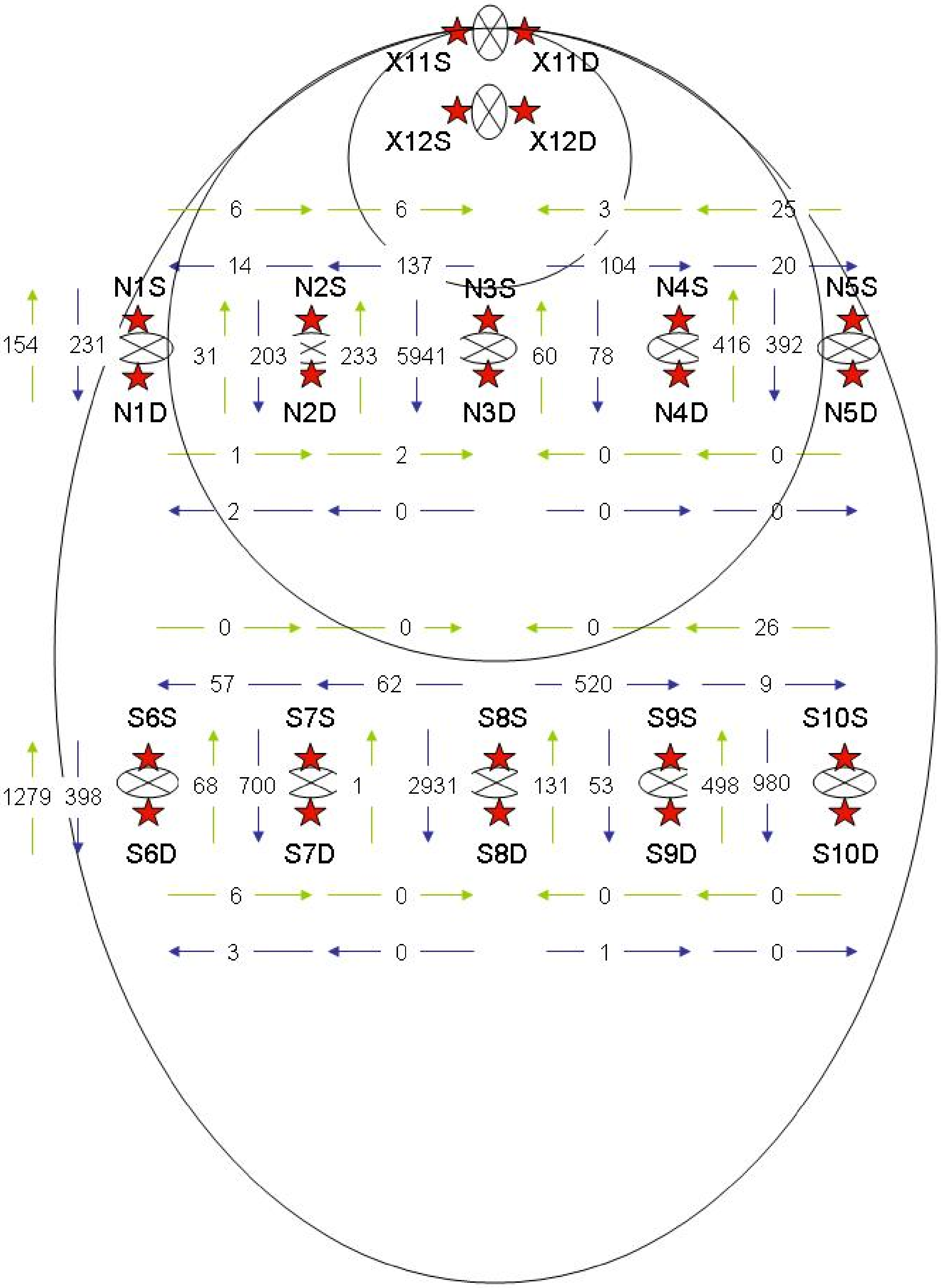


Figure 18. 2008 spatially explicit SRP fluxes (mg m^{-2} yr^{-1}). Green arrows are imports, blue arrows are exports, with horizontal & vertical fluxes illustrated. Values less than 0.5 are reported as 0.

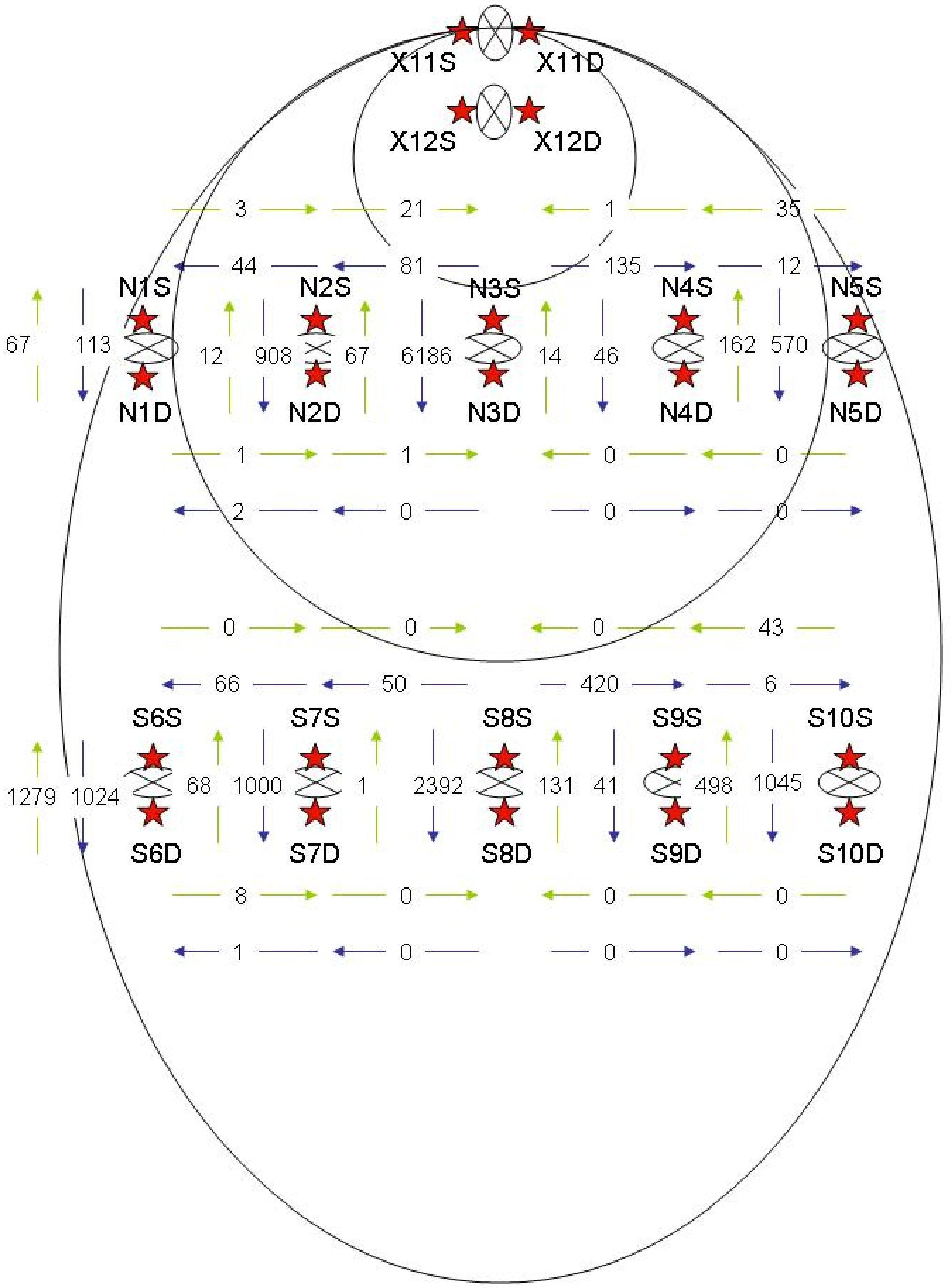


Figure 19. 2008 spatially explicit DIN fluxes (mg m^{-2} yr^{-1}). Green arrows are imports, blue arrows are exports, with horizontal & vertical fluxes illustrated. Values less than 0.5 are reported as 0.

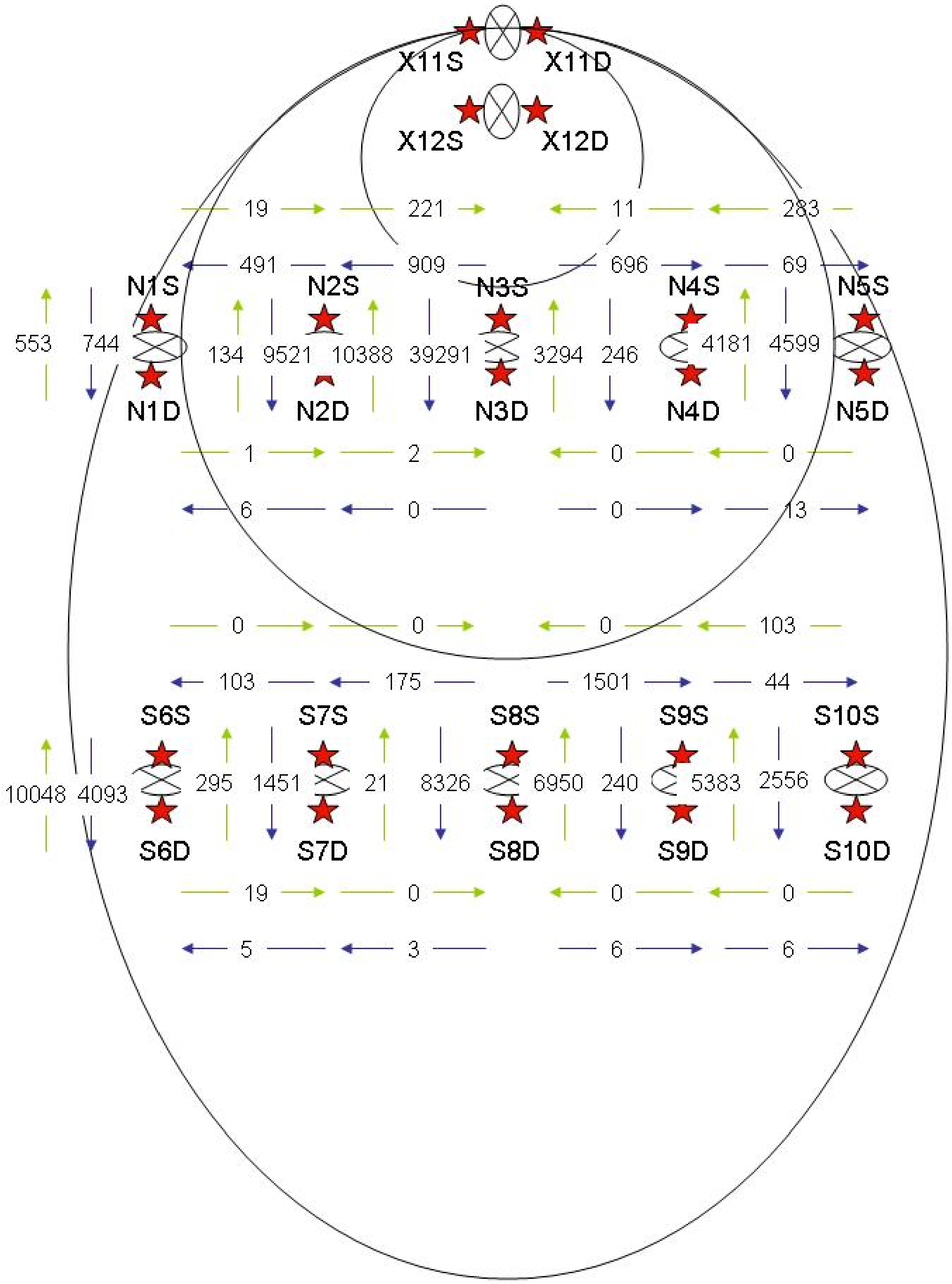


Figure 19. 2007 mass N budget for tree island 3AS3 for "Wet Head" community

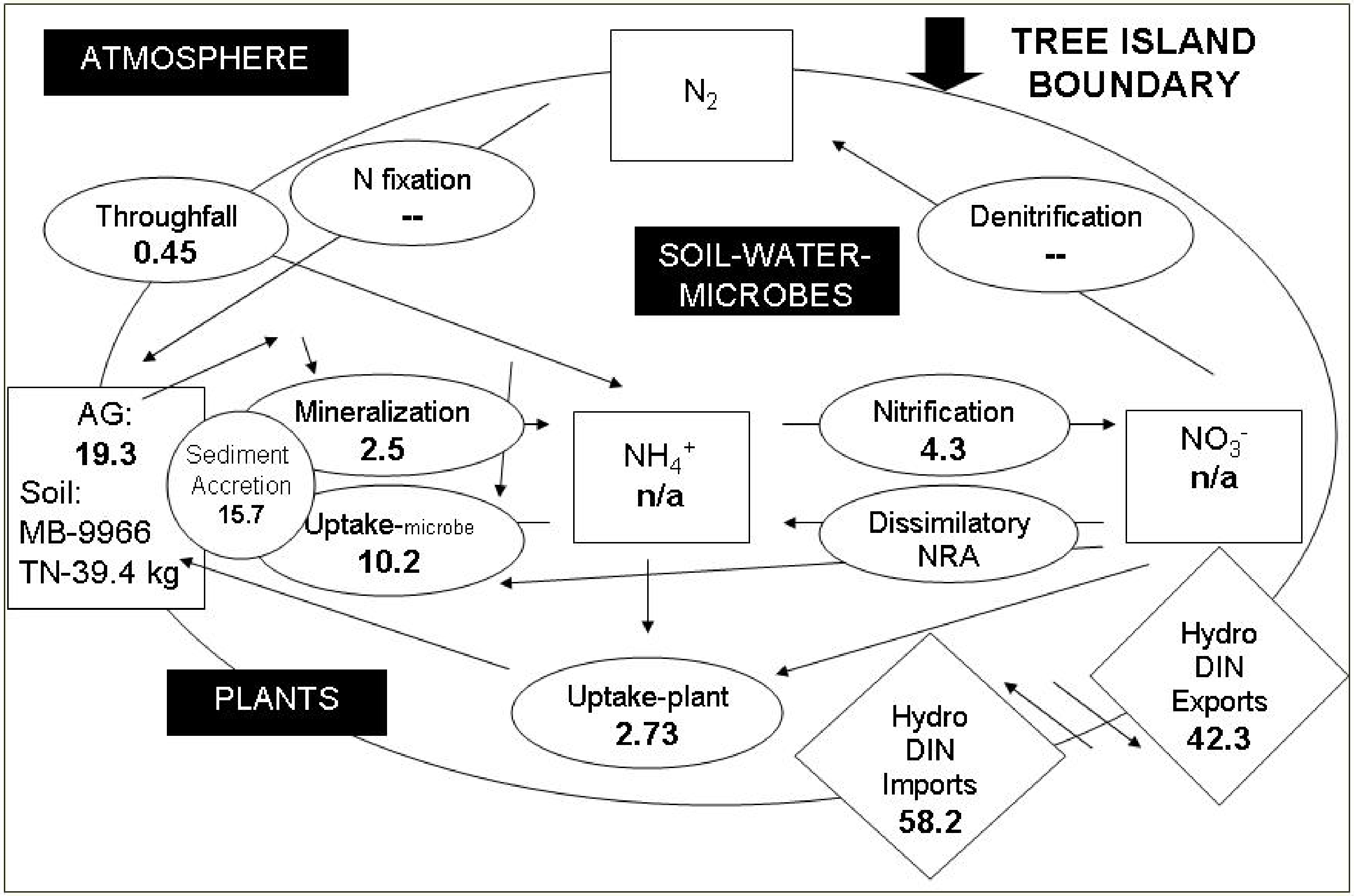


Figure 20. 2007 mass N budget for tree island 3AS3 for “Near Tail” community

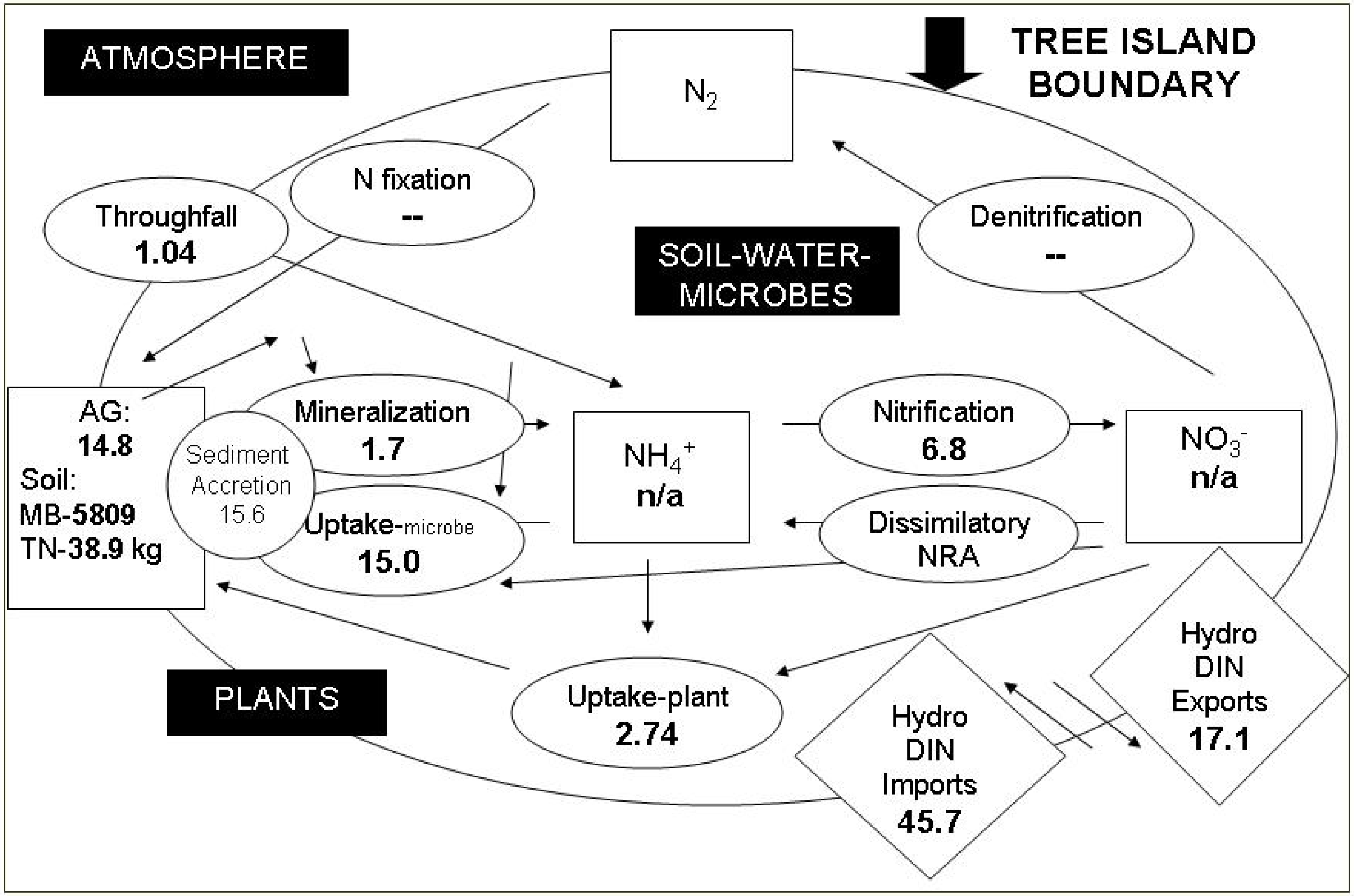


Figure 21. 2008 mass N budget for tree island 3AS3 for "Wet Head" community

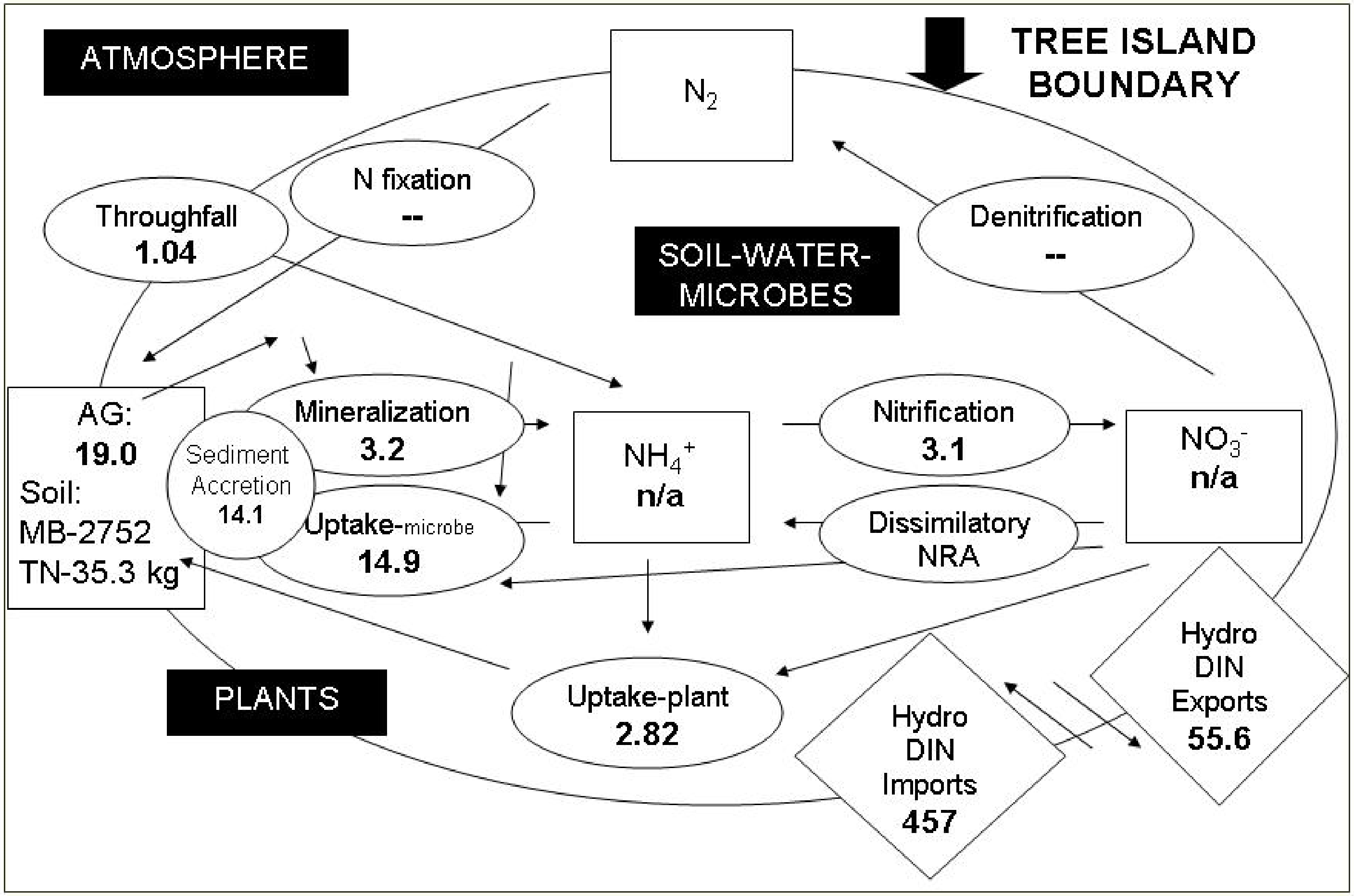


Figure 22. 2008 mass N budget for tree island 3AS3 for "Near Tail" community

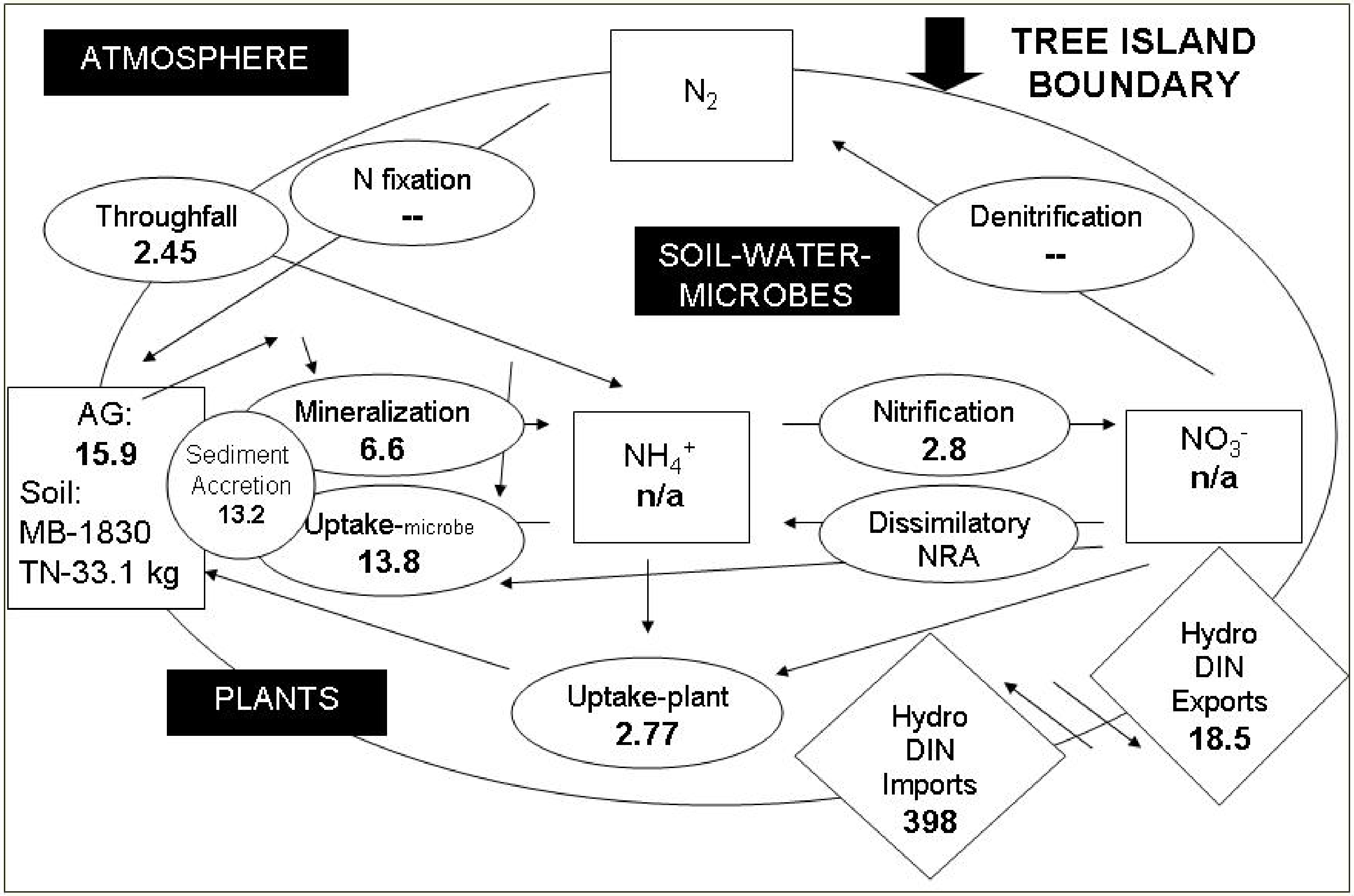
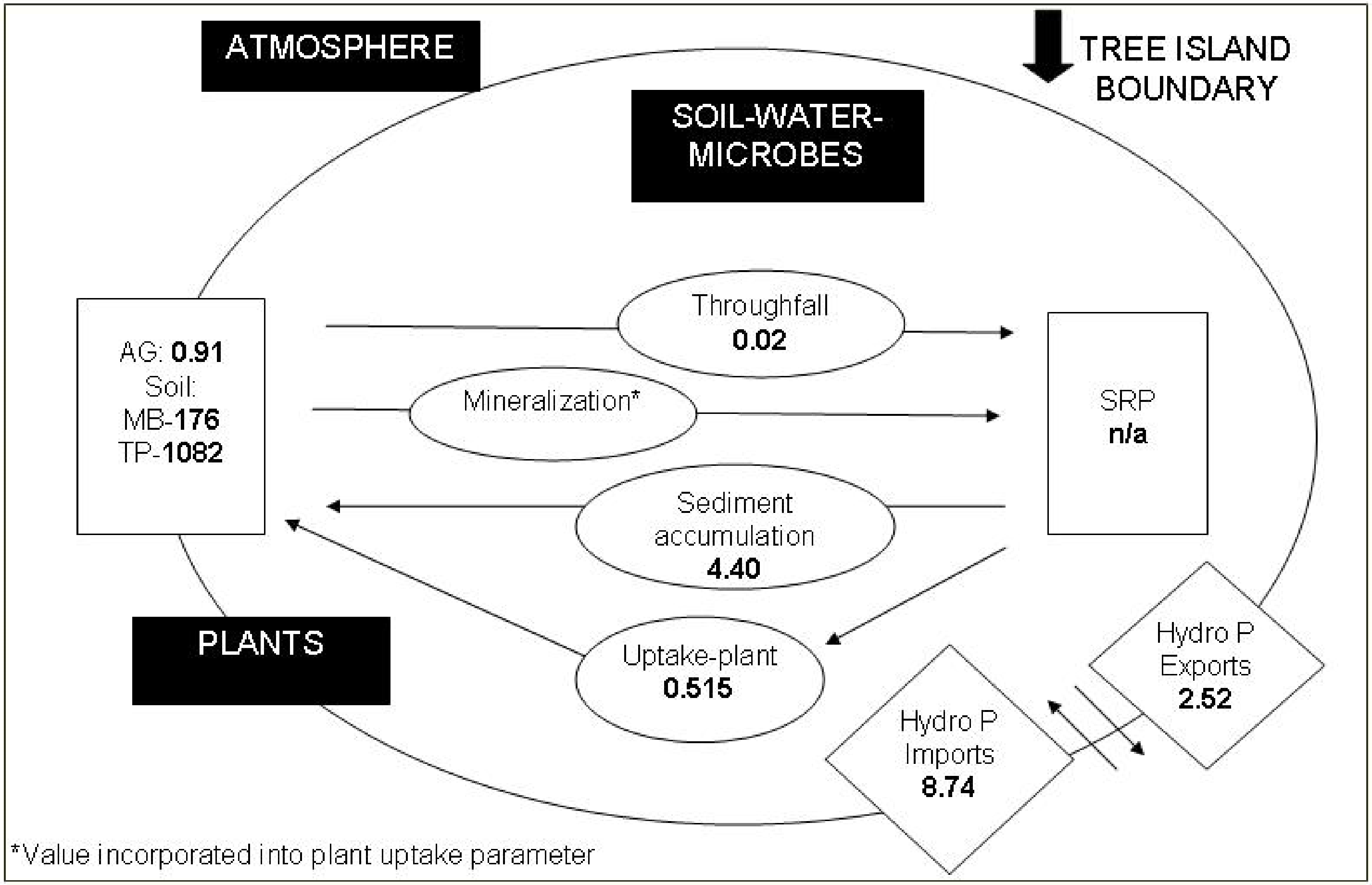
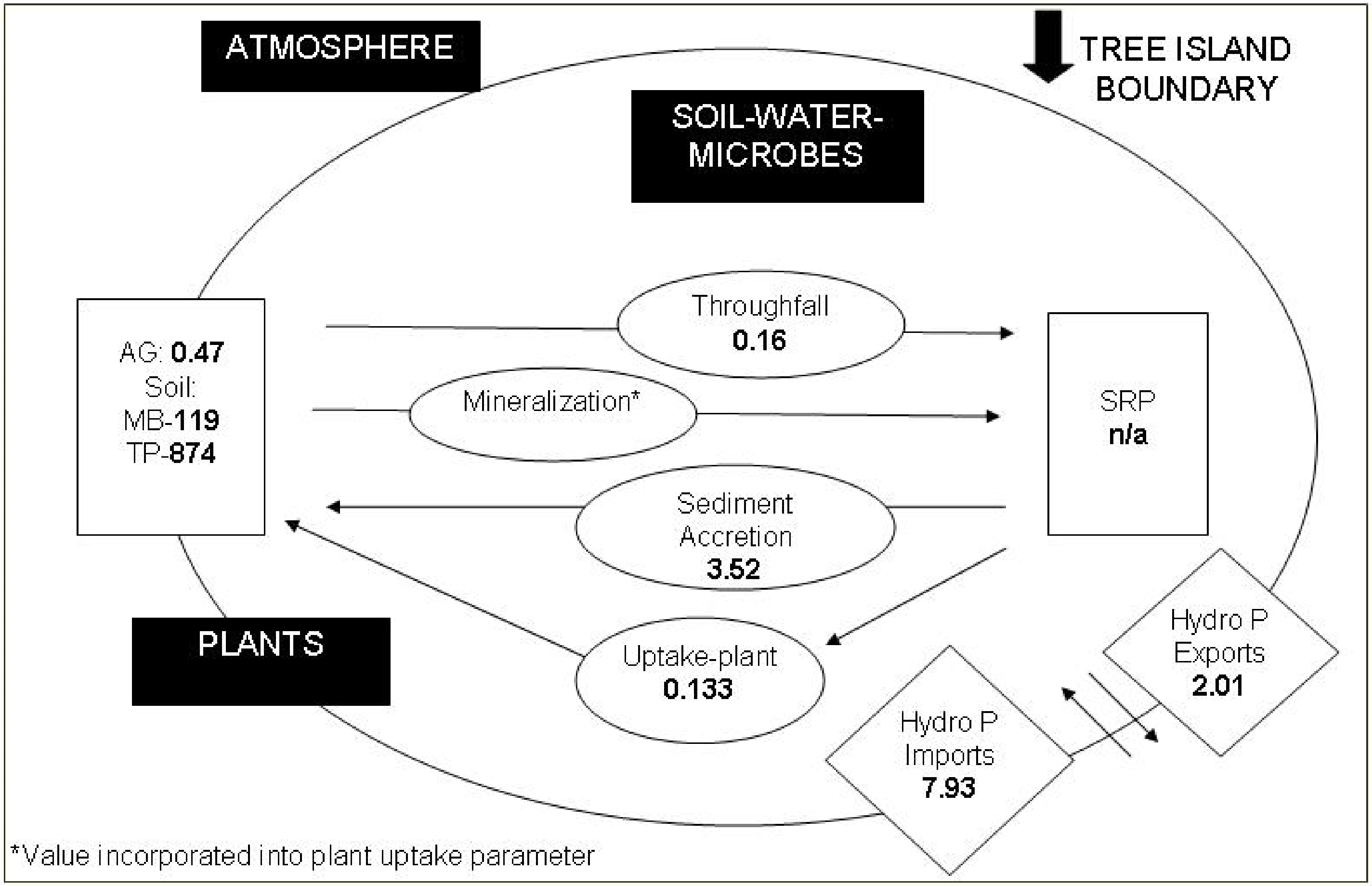


Figure 23. 2007 mass P budget for 3AS3 tree island in “Wet Head” community



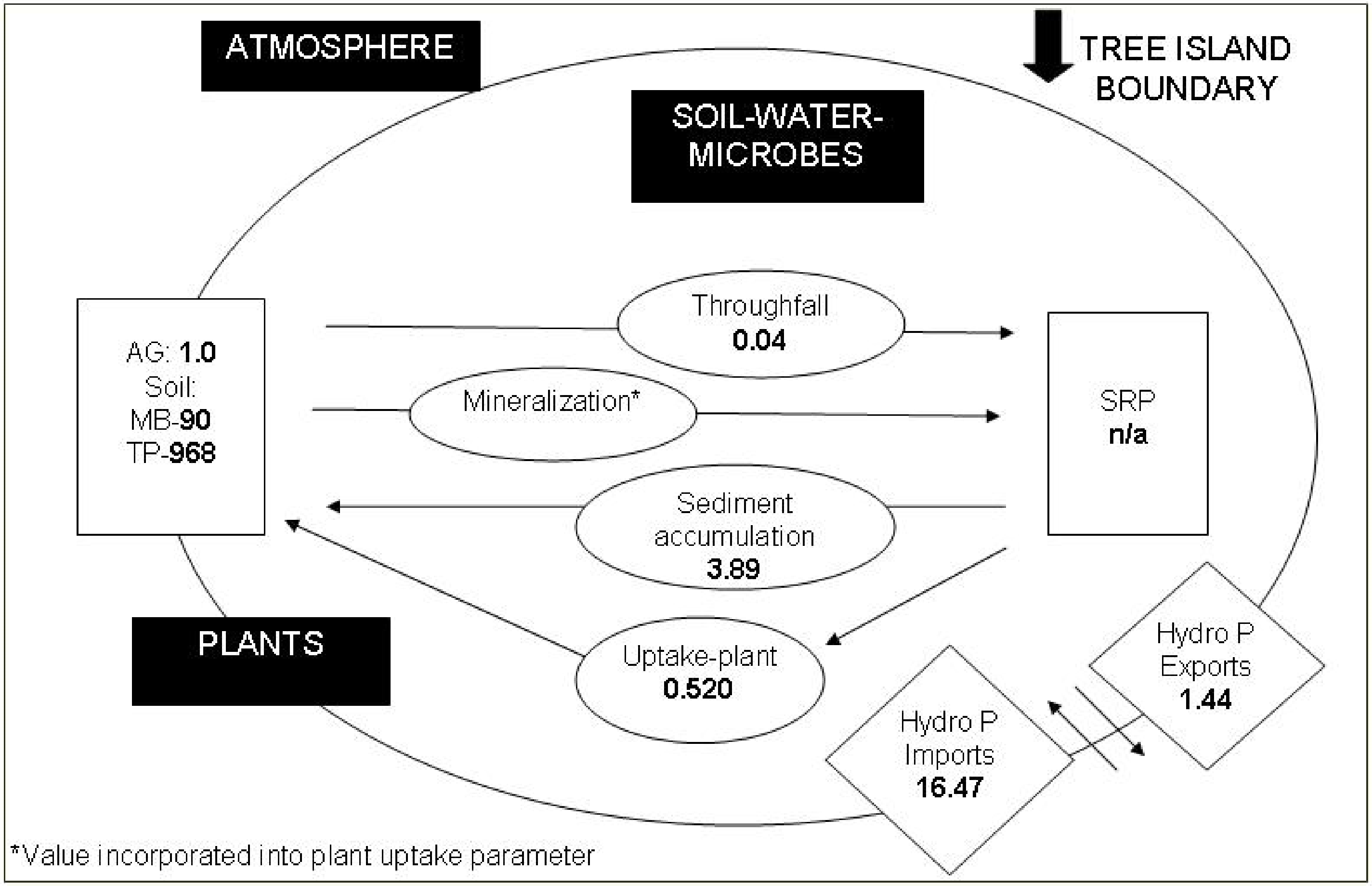
*Value incorporated into plant uptake parameter

Figure 24. 2007 mass P budget for 3AS3 tree island in “Near Tail” community



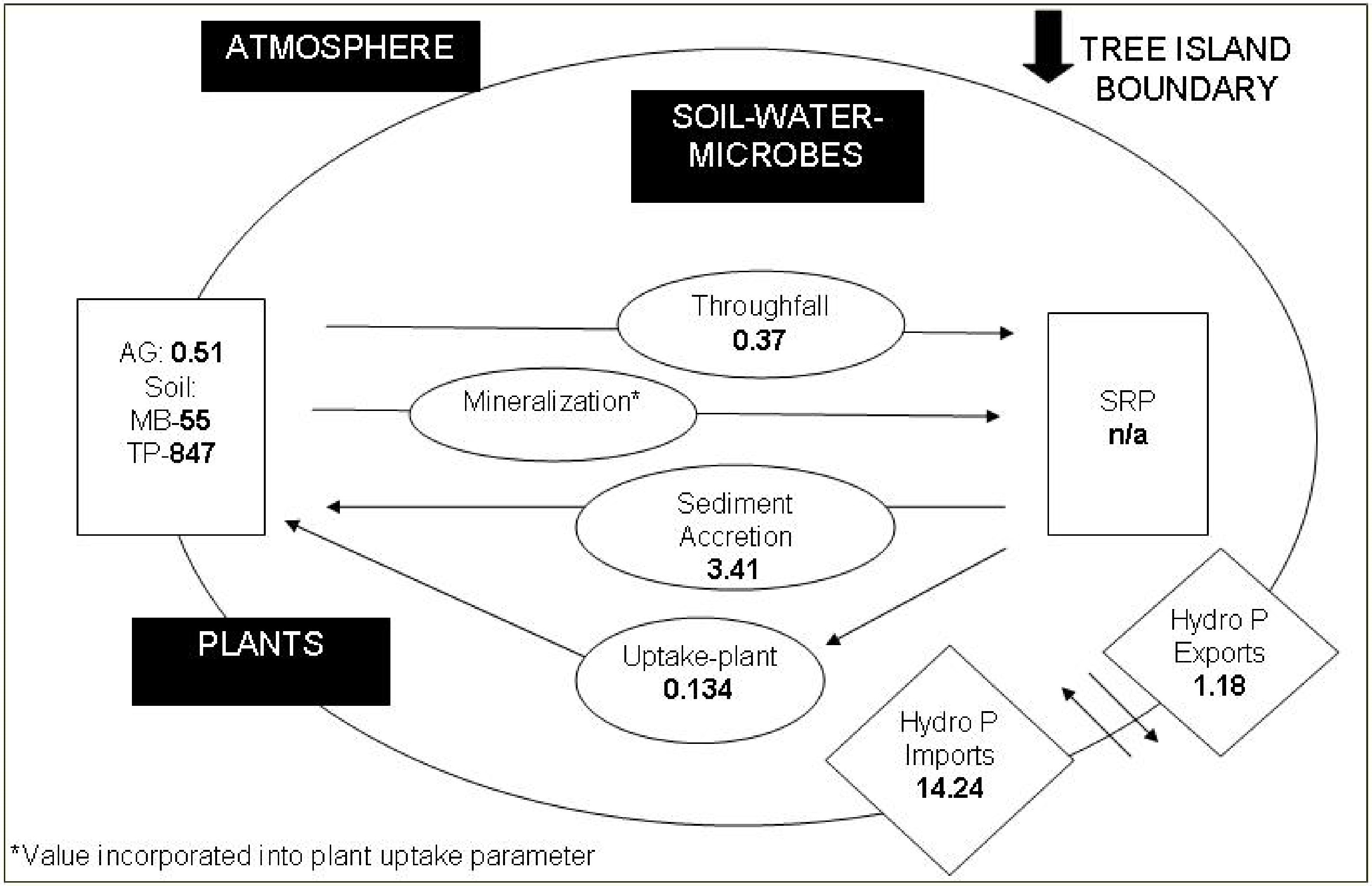
*Value incorporated into plant uptake parameter

Figure 25. 2008 mass P budget for 3AS3 tree island in “Wet Head” community



*Value incorporated into plant uptake parameter

Figure 26. 2008 mass P budget for 3AS3 tree island in “Near Tail” community



*Value incorporated into plant uptake parameter

Figure 27. 2007-2008 precipitation at tree island 3AS3. Total precipitation was 38.5 and 81.2 inches in 2007 and 2008, respectively.