Final Report

SFP2002: Nutrient Mass Flux Between Florida Bay and the Florida Keys National Marine Sanctuary

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Joseph N. Boyer and Patrick J. Gibson

Southeast Environmental Research Center
Florida International University
OE 148
University Park Campus
Miami, FL 33199
Phone: 305-348-4076
Fax: 305-348-4096
boyerj@fiu.edu

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Joseph N. Boyer, Principal Investigator

Abstract

This report presents results from a 2 year study of water volume and nutrient mass transport through Long Key Channel in the Middle Keys. This channel is the principal conduit for exchange between the two federally protected ecosystems of Florida Bay (part of Everglades National Park) and the Florida Keys National Marine Sanctuary (FKNMS). Annual estimates of nutrient flux are reported along with a comparison to other recent studies of nutrient inputs to the area.

Executive Summary

Florida Bay is the midpoint of the hydrological continuum of South Florida, connecting the systems of the freshwater Everglades to the north and the Florida Keys reef tract in the Atlantic to the south and east. Changes in the hydrologic regime and water quality parameters in upstream sections of this continuum may have direct or indirect impacts on downstream systems of Florida Bay and the reef tract (Lapointe & Barile 2004). Rapid development of both the mainland and island communities of South Florida have drastically altered natural water transport processes of the area through the constructions of canals, levees, water control structures, and wastewater management practices. As the Everglades are entering an era of ecosystem rehabilitation as part of the Comprehensive Everglades Restoration Plan (CERP), close attention must be paid to the downstream effects of restoration efforts with special attention of water flow, quality, and nutrient loading.

At the distal end of the South Florida hydrological continuum lies the Florida Keys reef tract. The coral reef community stretches discontinuously along the length of the Keys island chain between Hawk Channel and the Atlantic Ocean. Like many coral reef communities around the world, the Florida Keys reef tract has experienced a decline in health in the past few decades. Porter et al. (2001) report an overall loss of coral cover in the Keys of 38% from 1996 to 2000. Although likely the result of several environmental factors, some scientists speculated that outwelling of waters from Florida Bay might contribute to coral reef decline (Lapointe & Clark 1992). The tidal passes of the Keys island chain serve as a point of exchange for waters from Florida Bay, the Southwest Florida Shelf and the Gulf of Mexico with the waters of the Atlantic coastal environment. One scenario is that bay waters affect the reef by delivering relatively nutrient rich, hypersaline, turbid, hot, or cold waters to the offshore reef environment (Pitts 1994).

Nutrient mass flux through the Keys tidal channels has never been measured directly. The purpose of this study was to quantify the exchange of water and nutrients through one of the largest flow paths, Long Key Channel, using long-term, high resolution mass flow measurements combined with periodic tidal-scale collections of nutrient concentrations. Observations were made using an acoustic Doppler current meter coordinated with collections from an underwater autosampler engineered specifically for this project.

The results of this study describe a net annual export of nutrients from Florida Bay to the Florida Keys National Marine Sanctuary. The study found an estimated annual net flux through Long Key Channel of 3850 metric tons of TN and 63 metric tons of TP from Florida Bay to the Atlantic. Inorganic constituents accounted for 6% and 17% of the TN and TP pools, respectively. This export is driven principally by water transport, as flow accounted for about 90% of nutrient load. Nutrient concentration values varied seasonally but no significant difference was detected in the flow weighted mean concentration of inflowing or outflowing waters. If Long Key Channel is taken to represent 70% of Middle Keys outflows (Smith & Lee 2003), the results can by extrapolated to estimate net flux through all Middle Keys passes, such as Channel 5 and Channel 2, northeast of Long Key. Thus, the annual net flux from Florida Bay through the Middle Keys is approximately 5500 metric tons of N and 90 metric tons of P. Since studies have found that the passes of the Upper Keys show relatively little net transport (Lee & Smith 2002), and that passes west of Long Key Channel are outside the bounds of Florida Bay, the Middle Keys estimates can be taken as the total direct mass flux between Florida Bay and the Atlantic. These findings are about half of previous estimates of nutrient export from Florida Bay through the Keys passes by Rudnick et al. (1999) of 12000 MT TN and 180 MT TP.

Dispersal of bay waters in Hawk Channel and out into the greater Atlantic is likely great enough inhibit the accumulation of biologically available nutrients on the reef tract. The input of Florida Bay nutrients to the Keys coral reef community is minimal when compared to evidence of offshore tidal bores washing upon the reef. A recent study conducted by Leichter et al. (2003) in the upper keys produced evidence of relatively cool, nutrient rich subsurface waves upwelling onto the Keys reef tract. These waters contained an average of 4.0 μM NO_3^- and resulted in an estimated annual input of over 5000 metric tons of NO_3^- to reef tract waters. The estimated DIN export from Florida Bay through all the channels in the Middle Keys is only 330 metric tons; well under 10% of the NO_3^- input from offshore tidal bores. The results of this study indicate that if the coral reefs of the Florida Keys are suffering from nutrient eutrophication, Florida Bay waters are not the culprit.

Purpose

Rapid development of both the mainland and island communities of South Florida have drastically altered natural water transport processes of the area through the constructions of canals, levees, water control structures, and wastewater management practices. As the everglades are entering an era of ecosystem rehabilitation as part of the Comprehensive Everglades Restoration Plan (CERP), close attention must be paid to the downstream effects of restoration efforts with special attention of water flow, quality, and nutrient loading.

At the distal end of the South Florida hydrological continuum lies the Florida Keys reef tract. The coral reef community stretches discontinuously along the length of the Keys island chain between Hawk Channel and the Atlantic Ocean (Fig. 1). Like many coral reef communities around the world, the Florida Keys reef tract has experienced a decline in health in the past few decades. Porter et al. (2001) report an overall loss of coral cover in the Keys of 38% from 1996 to 2000. Although likely the result of several environmental factors, some scientists speculated that outwelling of waters from Florida Bay might contribute to coral reef decline (Lapointe & Clark 1992). The tidal passes of the Keys island chain serve as a point of exchange for waters from Florida Bay, the Southwest Florida shelf and the Gulf of Mexico with the waters of the Atlantic coastal environment. One scenario is that bay waters may affect the reef by delivering relatively nutrient rich, hypersaline, turbid, hot, or cool waters to the offshore reef environment (Pitts 1994). The purpose of this study was to quantify water volume transport and total nutrient flux between Florida Bay and Hawk Channel through Long Key Channel in the Middle Keys. The flux of nutrients through the Key's tidal channels has never been directly measured. Long Key Channel accounts for 70% of all Middle Keys transport, with the remaining flow passing through Channel 5 and Channel 2. Moser Channel, the principle conduit under the 7-Mile Bridge is larger in terms of magnitude of flow than Long Key Channel, however this passage is west of the 81° 05 meridian defining the western extent of Florida Bay. As there is relatively little exchange taking place in the tidal channels of the Upper Keys, Long Key Channel is the principle point of exchange between Florida Bay and the Florida Keys National Marine Sanctuary.

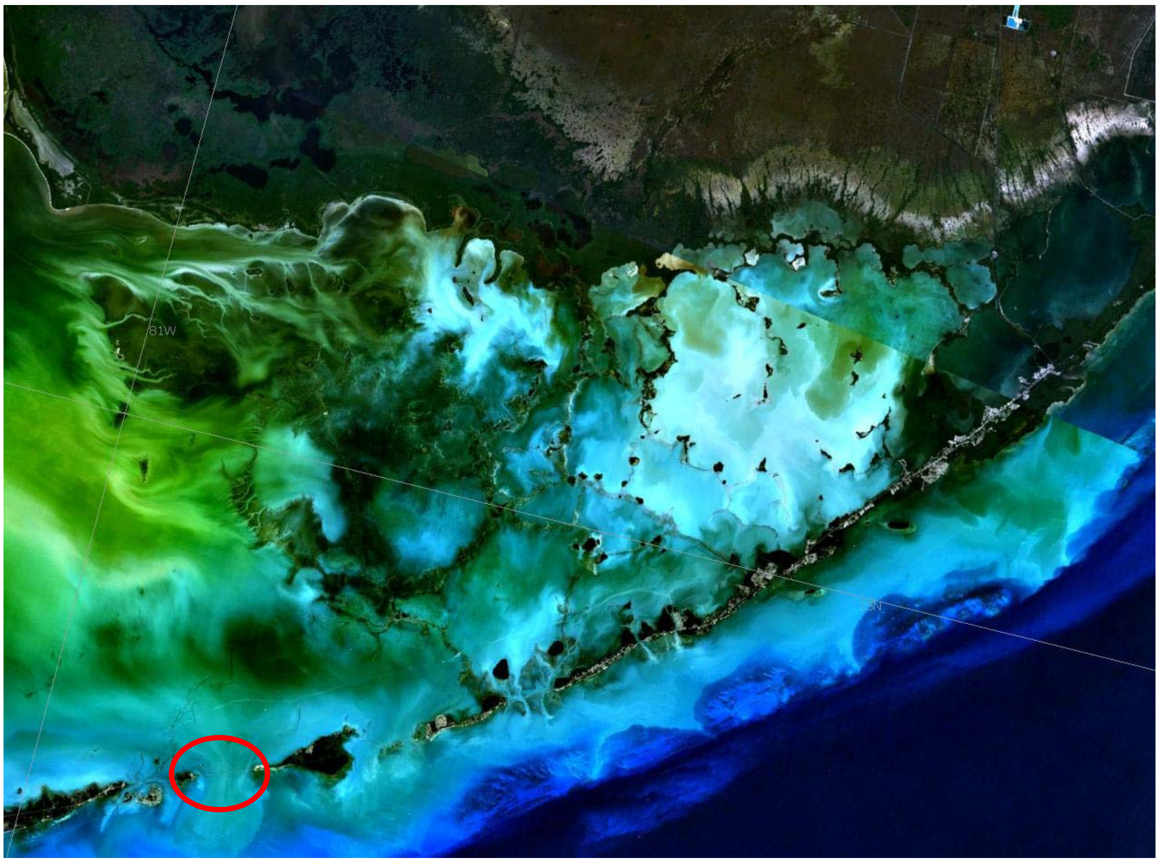

Figure 1. Map of Florida Bay showing internal bank morphology as bounded by the Florida Keys. The sampling site in Long Key Viaduct is shown in red.

Methods

Site Description

Previous studies of Florida Bay circulation have identified Long Key Channel as the primary avenue of exchange between the bay and Hawk Channel (Smith 1994, 1998, 2004). Moser Channel under the Seven Mile Bridge has overall greater exchange but is outside the western boundary of what is generally considered Florida Bay, and was not addressed in this study. Long Key Channel is located on the southwest end of Long Key and connects the waters of western Florida Bay to Hawk Channel (Fig. 1). Smith & Lee (2003) have described Long Key Channel as being responsible for 70% of cross-keys water transport in the Middle Keys (excluding Moser Channel), with Channel 2 and Channel 5 evenly representing the remaining 30%. Long Key Channel is approximately 3767 m across, has an average depth of 2.85 m and is oriented along a roughly 160/340 degree heading. The channel bottom is composed of limestone hardbottom spotted with solution holes, soft corals, a few sponges, and scattered small hard corals. A few shallow banks are present in the channel giving the bottom varying topography. The channel topography has been thoroughly characterized in previous studies (N. P. Smith, personal communication). The monitoring station for this study was established approximately mid-channel, bay side of the Long Key Viaduct Bridge at 24° 47.857 N and -80° 52.225 W, which corresponded with historical measurements by N. P. Smith.

Instrumentation

Three instruments were positioned on site, deployed, and serviced at varying intervals. A SonTek Argonaut acoustic Doppler current meter was deployed for three extended time periods: April 9, 2003 to July 16, 2003; August 27, 2003 to May 28, 2004; and July 17, 2004 to November 18, 2004. For each sampling period, current velocity (cm/s) was measured and averaged for a period of 120s every hour, along with measurements of pressure and temperature. A total of 11,721 current meter data points were directly measured for the study. Also deployed at the station was a YSI 6600 EDS environmental sensor. This instrument obtained a measure of temperature (°C), salinity (practical salinity scale), depth (m), dissolved oxygen (mg l^{-1}), pH, and turbidity (NTU) every 15 minutes of its deployment. This instrument was deployed sporadically for a total of 141 of the 213 days between February 17, 2004 and September 17, 2004. Data from the YSI were binned to the nearest hour for analysis, to a total of 3,385 data points per parameter measured.

The third instrument used for monitoring in this study was an underwater autosampler engineered specifically for this project (Fig. 2). The pump based device was mounted to the seafloor and programmed to collect and store water samples at various intervals, typically every 6 hours. The instrument was deployed at irregular intervals throughout the study period and collected a total of 165 individual water samples. The sampler has a purging method to insure sample water consists of a distinct aliquot from the appropriate time. The underwater autosampler can retain a maximum of 24 individual samples for any given deployment period. The unit may be programmed to collect distinct samples at any time interval or to create a composite sample by pumping water from multiple time points into a single collection vessel.

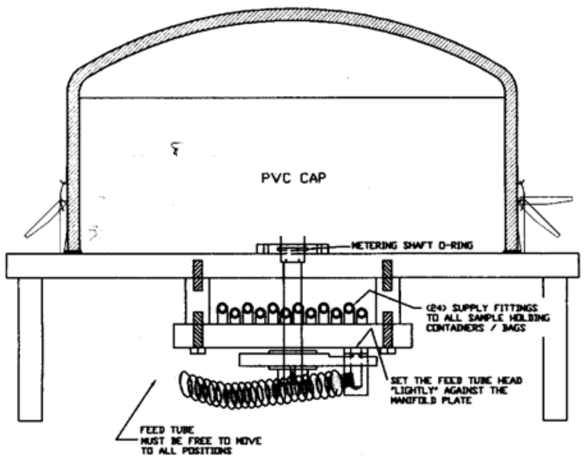

Figure 2. Schematic of underwater autosampler design. Pump and control unit is inside the PVC cap.

Volume Transport

Calculations of water volume transport through the channel were obtained from current velocity measurements, depth, and channel calibration coefficients determined from previous studies (N. Smith and T. Lee, personal communication). The calibration coefficients were used to extrapolate velocity values from the single mid-channel sensor to the entire width of Long Key Channel. These constants varied slightly with inflow and outflow due to channel topography. Thus, the calculations are as follows: Current speed ($m\ s^{-1}$) was multiplied by a correction factor of 0.9856 to account for the seafloor boundary layer not detected by the acoustic current meter (N. Smith, personal communication). This value was then multiplied by the instantaneous channel depth (m) for the speed of a vertically integrated 1m wide slice of the water column in $m^2\ s^{-1}$. This value was then multiplied by 2790.8 m for inflows and 2917.0 m for outflows to obtain whole channel water transport in $m^3\ s^{-1}$. These numbers represent effective channel area and differ with inflows and outflows due to variations in channel morphology on with side of the bridge. This result was the volume of flow used to calculate nutrient flux in further calculations. Long Key Channel lies at a general heading of 160°/340°. All water movements along a heading between 70° and 250° were considered exports from the bay, and were assigned negative values. All other headings, from 250° to 70°, were taken to be imports to the bay and assigned positive values.

Nutrient Concentrations

Upon servicing the autosampler, water samples were stored in a cooler at ambient temperature until returned to the lab at Florida International University. The water from the samples was transferred from the autosampler storage vessel to sample rinsed HDPE bottles and refrigerated at 4°C prior to nutrient analysis by the Southeast Environmental Research Center at FIU for concentrations of total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC). Additional nutrient data were obtained from a cross channel survey of five sites parallel to the Long Key Viaduct. The sites were nearly equally spaced across the channel and were used to detect spatial variability of water masses passing through the channel at any given time. The midpoint of this cross channel survey was directly above the benthic mounted instrument site where the autosampler collects water from the water column. If water quality data from each of the five cross channel sites was found to be equivalent, then our single mid-channel sampler could be used as a representative sample of all waters passing through the channel. This cross channel survey was conducted on most visits to the site for instrument maintenance, with a total of 16 collections between September 2003 and January 2005. The cross-channel samplings consisted of a SeaBird CTD cast and grab samples of surface waters for analysis of total nutrients (TN, TP, TOC) as well as dissolved constituents DOC, NO_3^- $+NO_2^-$ (NO_x^-), NO_2^-, NH_4^+, soluble reactive phosphorus (SRP), and chlorophyll a (CHL*a*).

All nutrient analyses were conducted using standard methodology by the Southeast Environmental Research Center at Florida International University according to NELAC standards (Boyer 2005). Sample water was submitted unfiltered for TOC, DOC, TN, and TP analysis in sample rinsed 120ml high-density polyethylene (HDPE) bottles. TOC measurement was by direct injection onto hot platinum catalyst in a Shimadzu TOC-5000 after first acidifying to pH<2 and purging with CO_2-free air. TN was measured using an ANTEK 7000N Nitrogen Analyzer using O_2 as carrier gas (Frankovich and Jones, 1998). TP was determined using a dry ashing, acid hydrolysis technique (Solarzano and Sharp, 1980). DOC was measured in the same way as TOC, only this water was filtered through a Whatman GF/F immediately after sampling then analyzed using the TOC method described. Water for dissolved nutrient analyses including SRP, NO_x, NO_2^-, and NH_4^+ was filtered by hand through a sample rinsed 25mm GF/F into acetone-washed and sample rinsed 60ml HDPE bottles. These concentrations were obtained by flow injection analysis (Alpkem model RFA 300). The filters from the dissolved constituents were placed in 2 ml plastic centrifuge tubes with 90% acetone for CHL*a* analysis. These tubes were kept at –20°C for a minimum of 4 days to complete extraction before being analyzed using a Gilford Fluoro IV Spectrophotometer (excitation = 435nm, emission = 667nm) as compared to a standard curve of pure CHL*a* (Sigma). Three N parameters were not measured directly but rather calculated by difference. NO_3^- was calculated as $NO_x^- – NO_2^-$; DIN is calculated as $NO_x^- + NH_4^+$; and TON was defined as TN – DIN. Concentrations from various samplings were all binned to the nearest hour to coordinate with current meter and environmental sensor time series.

Water quality concentration data rarely achieves normal distribution. Outliers persistently appear on the upper range of concentrations but low outliers are rarely observed. For the purposes of concentration comparisons, median values were used in lieu of mean values due to lack of normality in concentration distributions. This nonparametric approach is often applied to water quality monitoring data (Christian et al. 1991). Wilcoxon and Kruskal-Wallis test (equivalent to AVOVA in parametric analyses) were used to compare differences between two level sample and multiple level comparisons, respectively (Sokal and Rohlf 1995).

Nutrient Flux

The primary objective of this study was to calculate the flux of N and P between Florida Bay and Hawk Channel. This mass transport was derived from measurements of water flow and nutrient concentration using the formula:

$$f_i = q_i \times c_i \qquad (1)$$

Where *f*, *q*, and *c* are instantaneous flux, flow, and concentration values. For instantaneous nutrient flux calculations, concentrations of TN and TP were converted from µM to kg N or P m^{-3}. These values were then multiplied by the instantaneous water volume transport at that time ($m^3\ s^{-1}$) to find nutrient flux in kg s^{-1}. These observed estimates of instantaneous mass transport of N and P are the basis for extrapolation of nutrient loading estimates for larger time scales.

The study generated far more data points for water volume transport through the channel than nutrient concentrations associated with those water masses. In order to estimate nutrient flux values for points in time where flow was known but concentration data was missing, Beale's Ratio Estimator (BRE) was used (Richards 1998). In this approach, the mean instantaneous flux estimate was calculated from flow and observed nutrient concentrations. This value was adjusted by a flow ratio obtained by dividing the mean flow of all observed values during the study period by the mean flow of points in time associated with observed nutrient concentrations. This estimate calculation also incorporates a bias correction factor that is designed to compensate for the effects of correlation between discharge and flux. The formula for the Beale's Ratio Estimator is:

$$\hat{F} = \overline{Q} \times \frac{\bar{f}}{\bar{q}} \times \left(\frac{1 + \frac{\mathrm{cov}_{fq}}{n \times \bar{f} \times \bar{q}}}{1 + \frac{\mathrm{var}_q}{n \times \bar{q}^2}} \right) \qquad (2)$$

Where for any given time period for any: $\hat{F}$ = estimated flux, $\overline{Q}$ = mean flow for all observed points, $\bar{f}$ = mean flux for points with observed nutrient concentrations, $\bar{q}$ = mean flow for points with observed nutrient concentrations. For the purposes of this study, the BRE approach was slightly modified by using the median nutrient flux instead of the mean, with the above formula adjusted accordingly. The calculated estimates of median N and P load were then applied to each time step of missing concentration values. The summation of these fluxes gave the net load for the total time period in question.

Another metric useful for comparison in flux studies is the flow-weighted mean concentration (FWMC). This value represents the amount of a nutrient in a volume of water but takes into consideration possible concentration or dilution effects from high or low flow values. FWMC allows comparisons of data from periods of different flow regimes or between inflows and outflows through the channel. For any given period of time, the formula for calculating FWMC is:

$$FWMC = \frac{\sum_{i=1}^{n}(c_i \times q_i)}{\sum_{i=1}^{n} q_i} \qquad (3)$$

FWMC is calculated in this study as concentration (*c*) times flow (*q*), *i.e.* nutrient load (kg), divided by volume flow (*q* as m^3). This value is generally scaled down to more traditional units for nutrient concentrations of µM. Whereas the BRE method is effectively flow weighted by incorporating the load over flow term, FWMC is not designed to estimate missing values, only to provide a relative concentration for a given time period.

Results

Volume Transport

In the course of this investigation a total of over 488 days of hourly current velocity, bottom pressure, and temperature data was collected between 4/9/2003 and 11/18/2004. When taken as a whole, the mean long term net transport of water was out of Florida Bay at -384 (± 39) $m^3 s^{-1}$ (negative values represent exports from the bay; standard error in parenthesis). Short periods of net inflow driven by wind forcing were observed but generally persisted for only a few days (Fig. 4). Peak observed flows were 7894 $m^3 s^{-1}$ into the bay and -9799 $m^3 s^{-1}$ out towards the Atlantic. Mean volume transport varied significantly between inflows and outflows, with respective values of 3455 (± 19) $m^3 s^{-1}$ and 4231 (± 27) $m^3 s^{-1}$. Median current speed was 39.02 cm s^{-1}, while the maximum observed speed was 99.57 cm s^{-1}. Depth at the sampling location varied with tide and spanned a range from 3.03 to 4.08 m, with the median value of 3.55 m. Seasonal variability was present in the volume transport data with respect to magnitude of mean flow. Due to bias of unequal numbers of data points between seasons, the long-term net transport value may be misrepresentative of an annual period by overemphasizing spring and fall flow conditions. To account for this seasonal sampling bias and to acquire a representative annual mean flow estimate, a random subset of the data was taken at the rate of 2000 hourly samples per quarter. 2000 hourly samplings cover 83.33 days of a 91 day quarter, or about 91% of all flows and should be representative. This unbiased subset of data from 2003-2004 generated a mean long term net transport of -447 (± 47) $m^3 s^{-1}$. This value is greater than but on the order of previous reported values for Long Key Channel of -250 m^3s^{-1} and -400 m^3s^{-1} (Smith 1998, Smith & Lee 2003).

Long term net flows displayed strong seasonal patterns. Winter periods exhibited the strongest outflow with a mean of -737 m^3s^{-1}, while summer mean flows were small, -253 m^3s^{-1} out of the bay. This discrepancy is likely due to prevailing seasonal wind patterns driving cross-key sea level slope differences. The passage of winter and spring cold fronts increases frequency of winds from the west and northwest which is capable of causing sea level set up in Florida Bay relative to the Atlantic (Lee & Smith 2002).

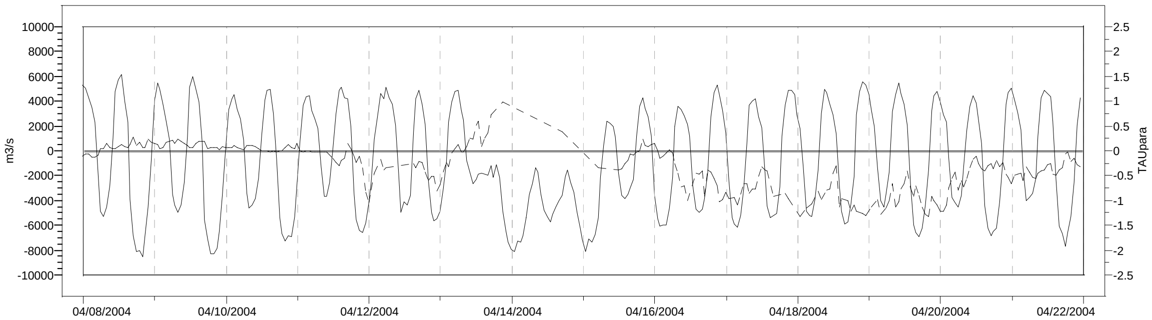

Figure 4: Flow pattern and wind stress from a 2 week period in April 2004 displaying persistent net outflow (solid line) in response to elevated wind stress at the 071 heading (broken line).

Nutrient Concentrations

Water samples collected by the underwater autosampler and were only analyzed for TN, TP, and TOC. Due to a time interval of up to a week or more between collection by the autosampler and sample preparation for nutrient analysis, dissolved nutrients could not be accurately determined in these samples. Surface grab samples from the autosampler site and four other cross-channel locations were analyzed for total and dissolved nutrient constituents as described above.

Total Nitrogen

Concentrations of TN ranged from 8.75 µM to 39.07 µM, excluding a single outlier at 55.66 µM. Mean TN value was 20.08 (±0.58) µM while the median value was 18.15 µM (Fig. 5). Seasonal variability was present as fall median TN concentrations were elevated (23.60 µM *includes outlier*) compared to winter, spring, and summer (13.73 µM, 13.30 µM, 14.66 µM, respectively). There was no difference detected between the 5 cross-channel survey sites (Kruskal-Wallis, $p = 0.91$), indicating that the mid-channel sampling site was representative of TN concentrations in the entire channel. There was no difference in TN concentration detected between the mid-channel surface grab sample and the water column sample collected by the autosampler. No differences in median TN between inflowing and outflowing water masses was detected (Wilcoxon, $p = 0.41$).

Total Phosphorus

Mean concentration of TP observed during this study was 0.201 (±0.008) µM, with a range from 0.069 µM to 0.816 µM and a median value of 0.174 µM (Fig. 5). Summer TP concentrations were significantly higher than other seasons with a median value of 0.312 µM compared to Fall, Winter and Spring mean concentrations at 0.234 µM, 0.150 µM, and 0.070 µM, respectively. Median TP did not vary by inflow or outflow (Wilcoxon, $p = 0.37$). The cross-channel survey revealed no significant differences between surface water TP concentrations (Kruskal-Wallis, $p = 0.74$), indicating out mid-channel site was representative of the entire channel.

Total Organic Carbon

Concentrations of TOC spanned a range from 116.58 µM to 858.33 µM. The mean concentration was 296.84 (±8.81) µM while the median was 279.25 µM. TOC concentrations were significantly higher in the summer, with the season median of 411.46 µM compared with the respective fall, winter and spring values of 273.33 µM, 270.58 µM, and 135.00 µM. There were no significant differences in median TOC with respect to inflows and outflows (Wilcoxon, $p = 0.14$), nor did TOC vary significantly between the 5 cross-channel survey sites (Kruskal-Wallis, $p = 0.56$).

Dissolved Nutrients

Inorganic constituents of N and P comprised only a small fraction of the total pools. DIN values had a median concentration of 0.80 µM, or about 4.4% of the TN pool. Of this inorganic component, NO_3^- was dominant with a median concentrations of 0.44 µM, followed by NH_4^+ with a mean of 0.27 µM, and NO_2^- at a mean of 0.08 µM (Fig. 5). Analysis of a long term data set of nutrient concentration in Western Florida Bay places the inorganic constituent at about 6.1 % of the TN pool, slightly higher but on order with the ratio found in this study. The inorganic form of P was measured as SRP in this study. SRP was found to have a median concentration of 0.030 µM, representing about 17% of the TP pool. This value nearly equivalent to that of the long term water quality data set of about 18%.

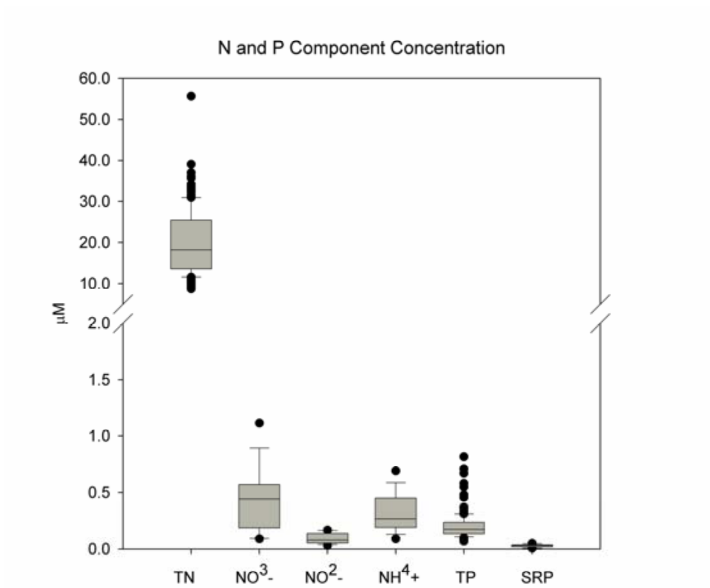

Figure 5: N and P concentration box-plot representation of measured nutrient species.

Nutrient Loading

Cross-key transport of TN and TP through Long Key Channel were estimated using measurements of water flow and nutrient concentration as described above. Observed instantaneous nutrient loading for TN and TP had median values of -0.123 kg and -0.0021 kg respectively. When these median loads were extrapolated to represent an entire year, the annual nutrient flux is estimated to be 3.88×10^6 kg N (3880 metric tons) and 6.62×10^4 kg P (66 metric tons). These estimates were derived solely from directly measured values of flow and concentration and did not include loading values estimated by extrapolation. The directly measured concentration values were colleted across the range of measured flow values with good representation of all flow magnitudes.

The BRE method was used to estimate loading values for points in time where only flow was measured. The method produced mean instantaneous loading values of -0.122 kg N and -0.002 kg P. When incorporated with the observed nutrient loading values, the annual estimated flux equals 3.85×10^6 kg N (3850 metric tons) and 6.31×10^4 kg P (63 metric tons).

If Long Key Channel is taken to represent 70% of Middle Keys outflows, the results can by extrapolated to estimate net flux through all Middle Keys passes, such as Channel 5 and Channel 2, northeast of Long Key. If the N and P loading estimates generated using the BRE method are used, the annual net flux from Florida Bay through the Middle Keys results in approximately 5500 metric tons of N and 90 metric tons of P (Table 1). Since studies have found that the passes of the Upper Keys show relatively little net transport (Lee & Smith 2002), and that passes west of Long Key Channel are outside the bounds of Florida Bay, the Middle Keys estimates can be taken as the total direct mass flux between Florida Bay and the Atlantic.

Table 1: Estimated Annual TN and TP Inputs to FKNMS.

Study Location	Source	Volume Flow	TN conc. (μM)	TP conc. (μM)	TN Load/yr (metric tons)	TP Load/ yr (metric tons)
Long Key Channel	This study	447 m^3/s 1.41×10^{10} m^3/yr	18.152	0.174	3850	63
All Middle Keys Passes	This Study	638 m^3/s 2.01×10^{10} m^3/yr	18.152	0.174	5500	90
All Keys Passes	Rudnick et al. 1999	2.28×10^{10} m^3/yr	???	???	12000	180
Reef Tidal Bores	Leichter et al. 2003	1.08×10^9 m^3/bore	4.00 NO^{3-}	0.30	5190	861
Keys WW+SW	Kruczynski & McManus 2002	???	9.14 to 49.46	0.032 to 1.74	499	163

Conclusions

There is a net discharge of water and nutrients through Long Key Channel from Florida Bay to the Florida Keys National Marine Sanctuary. There has been speculation that this water and its constituents may be contributing to the loss of coral cover on the Florida Keys Reef tract over the past few decades. There has also been some speculation that changes in freshwater flow in the upstream Everglades ecosystem associated with the Comprehensive Everglades Restoration Plan may exacerbate this phenomenon. The results of this study indicate that although there is a net flux of approximately 3850 metric tons of TN and 63 metric tons of TP, the concentrations of these nutrients flowing out of Florida Bay is the same as that flowing in. This implies that no significant nutrient enrichment is occurring in the waters of the FKNMS in the vicinity of Long Key Channel. Dispersal of bay waters in Hawk Channel and out into the greater Atlantic is likely great enough inhibit the accumulation of biologically available nutrients on the reef tract. However, the transport of water and material across Hawk Channel has not been studied thoroughly and more research is required to quantify the direct impact of Florida Bay waters on the offshore coral reef community.

The impact of Florida Bay nutrients on the Keys coral reef is also opposed by evidence of offshore tidal bores washing upon the reef (Leichter et al. 2003). A study conducted by Leichter et al. (2001, 2003) in the upper keys produced evidence of relatively cool, nutrient rich subsurface waves upwelling onto the Keys reef tract. These waters contained an average of 4.0 µM NO_3^- and resulted in an estimated annual input of over 5000 metric tons of NO_3^- to reef tract waters (Table 1). The estimated DIN export from Florida Bay through all the channels in the Middle Keys, is only 330 metric tons; well under 10% of the NO_3^- input from offshore tidal bores. If the coral reefs of the Florida Keys are suffering from nutrient eutrophication, Florida Bay waters are not the culprit.

Acknowledgements

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