Fish Health of the St. Lucie River Estuarine System in Relation to Canal Discharges and Water Quality

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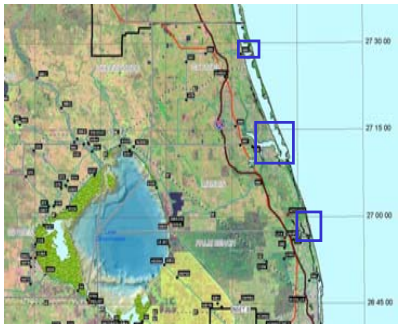


Map of the southeast coast of Florida showing the St. Lucie estuarine system (middle box) and the two reference systems, Ft. Pierce Inlet and the west side of the Indian River Lagoon at Taylor Creek (upper box), and Jupiter Inlet and the lower Loxahatchee River (lower box).

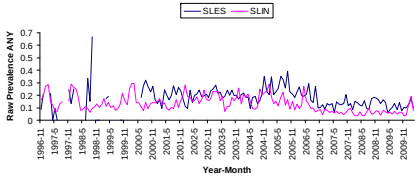
Abstract

Indicators of environmental quality are essential for assessing change in the support value of an estuary for fish and wildlife and for evaluating the effectiveness of hydrologic and water quality restoration efforts. We propose St. Lucie fish health, as reflected in the prevalence of fish with gross abnormalities, as an index of environmental quality for monitoring the progress of both local and regional restoration efforts. In an analysis of a 12+-yr dataset, we examined the prevalence of fish with any externally visible abnormality (ANY) in relation to potential causal factors--canal discharge (including Lake Okeechobee regulatory releases) and water quality. The discharge and water quality data were obtained from the South Florida Water Management District (downloaded from DBHydro) and summarized for analysis. The discharge data of three canals, C23, C24, and C44, were combined or used separately to calculate two variables for alternative use: the weighted mean cubic feet per second and proportion of days when flows were greater than the 75th percentile. These were lagged for various periods (7-day, 30-day, or 90-day) in the analysis. The water quality variables we included in our analysis were secchi disk visibility, color, chlorophyll-a, total suspended solids, volatile suspended solids, and salinity of the previous month or the previous three months, as measured in the St. Lucie near the discharge points of the three canals. In our multi-species database, species is a major factor determining abnormality prevalence; therefore, we used mixed-effects models and entered species into our models as a random effect to account for species variation. Since the water quality variables were cross-correlated to varying extents, we examined these variables in separate equations to prevent problems associated with multicollinearity. We created separate models for the middle estuary (SLES) and the Inlet (SLIN). When we treated the canal flows as separate variables, only C44 flow was statistically significant. Our results suggested that hydrologic variables affected ANY in SLES with a 90-day lag and ANY in SLIN with a 7- or 30-day lag. Those species that had the highest prevalence of ANY were the same species that were most sensitive to change in freshwater inflow. Where they occurred in both areas, the sensitive species were the same species in both SLES and SLIN. All water quality variables were significantly related to ANY in either SLES, SLIN, or both areas. In general, color, visibility, chlorophyll-a, and salinity were negatively related to ANY (the higher the variable, the lower ANY), and total and volatile suspended solids were positively related to ANY (the higher the variable, the higher ANY). In general, previous-3-month variables had stronger effects. The beneficial effect of color on fish health that is suggested by its negative relationship with ANY may be due to the sequestering of heavy metals such as copper. Our results suggest that both discharge volumes and water quality affect fish health in the St. Lucie system. The prevalence of fish with abnormalities can be a powerful indicator of the cumulative effects of local and regional restoration efforts.

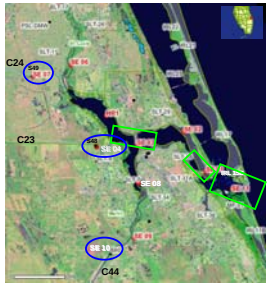
Sampling

Fish are sampled regularly for externally visible abnormalities in the St. Lucie and nearby reference systems (weekly sampling in the St. Lucie Inlet and the St. Lucie Estuary since June 2000 and regular sampling since November 1996 in the St. Lucie Inlet and intermittent sampling in the St. Lucie Estuary). Fish are captured on rod and reel (using dead shrimp for bait) and screened for abnormalities. All fish captured are recorded as normal or having one or more specific type of abnormality. "ANY" abnormality is the presence or absence of any of the abnormalities listed in the Table below in each captured fish, excluding what appear to be wounds (i.e., scrapes, cuts, tears, or bites) and healed ulcers. Nearly 59,000 fish from 63 species were captured and screened through March 2009 in the St. Lucie system.

Health status code	Description of externally visible abnormalities	Raw Prevalence (%) of St. Lucie sampled fish: St. Lucie Estuary	St. Lucie Inlet	St. Lucie system
O	Normal	80.22	85.78	84.42
CC	Chromatophore cluster, abnormal color spot or stain	0.05	3.92	2.98
DB	Deformed body	0.04	0.10	0.09
DDS	Deformed dorsal spine(s)	0.01	0.07	0.05
DE	Deformed eye	0.08	0.04	0.05
DF	Deformed fin other than dorsal	1.33	1.14	1.19
FR	Fin erosion (fin rot)	10.42	3.52	5.21
H	Bleeding on body and/or fins	0.83	0.67	0.71
HU	Ulceration that appears to have healed and left scar tissue	0.02	0.02	0.02
L	Lump (possible tumor)	0.01	0.04	0.03
LL	Lateral line abnormality	0.14	0.19	0.18
LR	Reddened, usually slightly raised skin area (live rot)	0.27	1.45	1.16
P	Severe parasite infestation	3.69	1.10	1.73
SBDS	Saddle back (depression) dorsal spines (fin area)	0.02	0.04	0.04
SBHA	Saddle back head area	0.00	0.07	0.06
SC	Scoliosis of backbone	0.00	0.00	0.00
SD	Scale disorientation	3.24	2.55	2.72
U	Ulceration (break in skin)	0.02	0.10	0.08
UNK	Unknown, does not fit into any other category	0.07	0.02	0.03
W	Apparent mechanical injury or bite	0.82	0.59	0.65

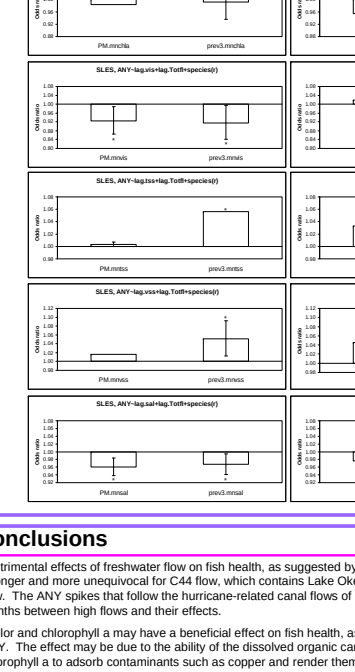


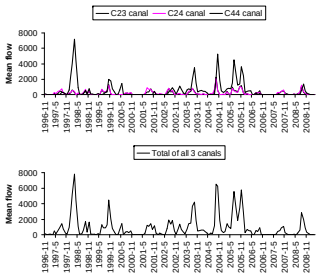
Hydrology and Water Quality



Map indicating SFWMD stations where freshwater flows are measured (S48, S49 and S80) and where water quality variables are measured (SE07, SE04, SE10). Other SFWMD water quality stations are also indicated.

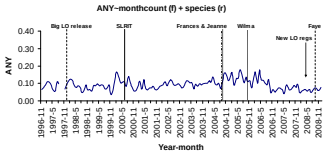
Time series of flow-weighted water quality parameters are shown to the right. Color and salinity show regular seasonal periodicity. Color generally peaks toward the end of the wet season with relatively little year-to-year variation. Salinity peaks toward the end of each dry season. Year-to-year variation is more pronounced in salinity. Chlorophyll-a shows large within- and between-year variation but less seasonal predictability than the other two factors, although its largest peaks tend to be mid-summer. Visibility also shows large between-year variation with marked decline in visibility since 2004. Total suspended solids and volatile suspended solids are similar in their temporal patterns, both having high concentrations in certain years. These years correspond to the large Lake Okeechobee releases and hurricanes. Low levels of tss and vss coincide with the 2000-2001 and 2006-2009 drought periods. Seasonality is muted in tss and vss.





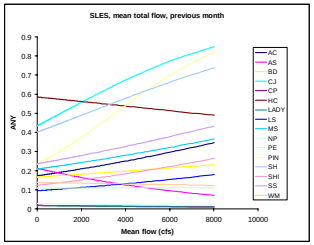
Seasonal periodicity is evident in all three canals with distinct peaks toward the end of the wet season. The C44 canal flow shows greater variation compared with the C23 and C24 canals, in part due to periodic releases from Lake Okeechobee. There are several periods of high total freshwater discharge into the St. Lucie during the winter dry season and there are periods of low total freshwater discharge during the summer wet season.

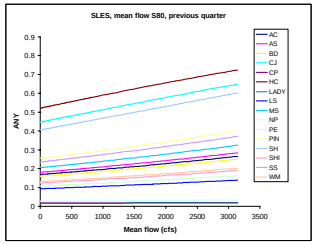
Statistical Modeling



A generalized mixed effects regression model of prevalence by consecutive month taking into account species differences in prevalence and abundance inequities (species as a random variable). High levels of prevalence are sometimes preceded by storm events (e.g., after the 2004 and 2005 hurricanes), and low levels of prevalence sometimes coincide with periods of drought (e.g., October 2006 through December 2008.)

Examples of two generalized mixed effects regression models of abnormality prevalence (ANY) with hydrology (mean total flow, previous month; mean C44 flow, previous quarter) and species (as a random variable) in the St. Lucie estuary (SLES). Species differences are apparent. The mean monthly flow model indicates some species with increasing prevalence with increasing flow, some species with decreasing prevalence with increasing flow and some with little change in prevalence with flow. The mean quarter flow from the C44 canal model shows a general increase in prevalence with increasing flow, although some species show little change.





Odds ratios, probability of a change in abnormality prevalence (ANY) with a change in flow-weighted water quality (WQ). Shown is the effect of PM (previous 30-day WQ) or prev3 (previous 90-day WQ). Significant odds ratios (indicated by asterisk) above 1.00 indicate increasing prevalence with an increase in WQ parameter; significant odds ratios below 1.00 indicate decreasing prevalence with an increase in WQ parameter.

Conclusions

- Detrimental effects of freshwater flow on fish health, as suggested by the positive relationship of ANY with flow, are stronger and more unequivocal for C44 flow, which contains Lake Okeechobee discharges, than for C23 and C24 flow. The ANY spikes that follow the hurricane-related canal flows of 2004 and 2005 suggest a delay of 3 to 5 months between high flows and their effects.
- Color and chlorophyll a may have a beneficial effect on fish health, as suggested by their negative relationship with ANY. The effect may be due to the ability of the dissolved organic carbon compounds associated with color and chlorophyll a to adsorb contaminants such as copper and render them biologically inactive. pH changes (as occurs with ingestion) may alter this effect.