Chapter 8. Future Efforts

This study has made significant contributions to the level of knowledge regarding nutrient dynamics in southwest Florida tidal creeks. Perhaps the most important scientific finding of the study was that nutrient addition was common in the estuarine portion of the creeks. It was beyond the scope of this study to identify the sources of nutrients in the creeks. Malkin et al., 2010 used stable nitrogen isotope analysis of fish tissue collected from southwest Florida tidal creeks to identify sources of nitrogen in some of these systems. Nitrogen inputs from row crops, tree crops, and wetlands were principal determinants of nitrogen in fish muscle tissue with those inputs considered to be exporting more nitrogen to nearby aquatic systems than their relative areas would suggest (Malkin et al., 2010). However, few of the watersheds in our study contained agricultural acreage and Greenwood et al., 2008 found fish isotopic signatures in creeks with more residential land uses presented a seasonally variable mix of influences including septic tanks, fertilizer application, and soil redistribution. Wet season and dry season results differed with more homogenized influences during the wet season when hydrologic connectivity was high and more influence of septic tanks during the dry season though other sources were also considered to contribute. In particular, *in situ* nitrogen recycling and decomposition of organic material were posited as additional potential contributing sources of nutrients. Allen et al. (2013) conducted a series of powerful field experiments in a South Carolina tidal salt marsh dominated creek and found that nekton (i.e., fish and shrimp) can contribute greatly to the concentration of dissolved nutrients in tidal creeks. Tidally controlled patterns of nekton movements and feeding result in retention and reintroduction of nutrients to the upper reaches of the intertidal basins. Allen et al. (2013) conclude that nekton can be important and underappreciated contributors of dissolved nutrients in tidal systems. Nutrient outwelling from mangrove communities can also contribute nutrients to tidal creeks (Wolanski, 2007; Gleeson et al., 2013) and are more likely than salt marsh to be a contributing source of nutrients in the creeks we sampled. Again, sourcing nutrient inputs in these creeks was beyond the scope of this study but the results of other studies summarized above illustrate the complexity in attributing nutrient conditions to particular sources in these systems. More study is needed to identify critical thresholds of anthropogenic nutrient inputs that lead to adverse effects and this study has provided evidence that considering nutrients as a conservative substance in these creeks is overly simplistic and will lead to misclassification of healthy waterbodies as impaired.

Investigating nutrient mixing properties in these systems should be strongly considered in future studies evaluating the link between the incoming source water concentrations and concentrations in the tidal creeks. Nutrient budgets should consider the potential internal loads of the estuarine portions of the systems, where those nutrients were derived and how they contribute to the potential impairment of the designated use of the waterbody.

The need for the unified management framework proposed in this report is in part due to the highly complex interactions observed between watershed stressors, instream processes and biological responses during the study. No single study of such a diverse assemblage of estuarine environments would provide a definitive guide to optimize the stewardship of these important resources. However, the proposed management framework will serve to unify future efforts dedicated towards identifying science-based management outcomes leading to a more efficient and effective accumulation of knowledge towards the effective stewardship of southwest Florida tidal creeks. There is a great deal left to learn regarding the role of nutrients in governing tidal creek function. Disparate studies can sometimes lead to conflicting results. A unified management framework can help guide research leading to more effective science necessary to identify the site-specific attributes of tidal creeks that optimize their productivity within the larger estuary. The management framework we proposed included both stewardship and management components and the strength of future scientific results can affect both of these components of the management process in an adaptive management strategy. For example, the effects of landscape development on the productivity of tidal creeks has been well studies in the southeast United States (Mallin 2004; Holland et al., 2004; Sanger et al., 2008, Sanger et al., 2011; Greenwood et al., 2008; Krebs et al., 2013) but the results have been mixed. Holland et al., found significant negative effects of landscape development intensity on tidal creek integrity in South Carolina tidal creeks while Greenwood et al. (2008) and this study found limited evidence of any adverse impact based on landscape development intensity. Krebs et al., 2013 found some evidence to suggest that urbanization of creek watersheds may increase the energetic reserves of some resident fish species. These seemingly conflicting results can be unified by the fact that both Greenwood et al., 2008; Krebs et al., 2013 and this study suggest that near field effects such as riparian buffer and instream water quality conditions may be more important than more landscape level attributes in determining fish community composition in southwest Florida tidal creeks. The proposed unified management framework provides a vehicle to accelerate the science needed to further these individual hypotheses to inform management decisions and encourage local participation in the stewardship process.

There are no known long term monitoring efforts of fish and water quality in small tidal creeks in southwest Florida to provide results in the context of inter-annual variation in these metrics; however, in Tampa Bay's larger river systems there are both long term fisheries and water quality data collection programs ongoing. It would be highly beneficial to evaluate data from these larger rivers to provide additional information on inter-annual variability in both water quality and fish recruitment in these larger systems whose tidal portions also seem to currently fall under the narrative criteria. More work is needed to understand the effect of inter-annual variation which is why this report also includes the recommendation for future efforts to forward the science in this regard in a subset of southwest Florida tidal creeks. In particular, we recommend that each county maintain an existing water quality monitoring station in one of their tidal creeks and commit to additional water quality sampling within the tidal portion of the creek using a design scheme similar to that used in this study. This would allow for a better understanding of the inter-annual variability in these creeks and help to better define the relationship between the source water nutrient concentrations and nutrients in the tidal portion of the creeks. Additional fisheries collections in these creeks would be a valuable addition to this effort and considerations are provided in these recommendations for the development of a set of potential fish indices that can provide valuable information with limited effort to enhance our understanding of the relationships described above.

The chlorophyll content of the benthic sediment layer was also investigated as a response endpoint in an effort to capture estimates of production of the benthic microalgae (BMAC). Intuitively, benthic chlorophyll content makes sense as an endpoint because it integrates nutrient conditions over time and serves as a seasonally important source of primary productivity to higher trophic levels in southwest Florida tidal creeks (TTHI 2008). The FDEP also recognizes the importance of sediment periphyton as an indicator of stream condition for Florida freshwater streams and springs. However, our results did not support benthic chlorophyll as a unifying indicator of the relationships between nutrients, benthic chlorophyll concentrations, fish assembles, and the potential for identifying adverse effects though we still feel that this parameter is both an important trophic pathway and a potential indicator of trophic state in these creeks. Based on our study, water column chlorophyll production did not appear to be sufficient to limit availability of the benthic pathway on the scale in which we measured it. Unfortunately, there are no known reliable tools currently available to derive an integrated estimate of the "whole creek" benthic productivity in tidal creeks. Site-specific values were highly variable, contributing to uncertainty in our stressor-response relationships. In addition, site-specific conditions such as canopy cover and water clarity can mediate the relationships between nutrients and sediment primary production. Despite these limitations, future efforts should consider the importance of sediment phytoplankton as a source of trophic transfer and pursue alternative methods to quantify the contribution of benthic primary production to the food web in tidal creeks.

Consideration of the effects of organic matter decomposition as a mediating factor in the relationship between dissolved oxygen and fish community structure also warrants more investigation. This study found that despite using DO expressed as percent saturation, there was still a relationship between temperature and DO indicating biological processes related to decomposition likely play a role in the observed DO conditions in the creek and therefore seasonally variable DO criteria may be warranted. The microbial (or detrital) loop is well known as a significant source of productivity in estuarine systems increasing the complexity and production of the food web but also putting additional demands on DO. This detritus may come from phytoplankton, plant growth and decay, outwelling from wetlands, and rivers (Wolanski, 2007). Conrads et al., (2002) found that salt marsh loadings over tidal cycles contribute significantly to diel variation in dissolved oxygen concentrations. For mangrove dominated tidal creeks such as those in southwest Florida, the contribution of organic rich soils and fine sediments can increase detrital community and are likely to result in similar effects on DO to that described above. Thereby, estimates of the effects of decomposition of organic material on dissolved oxygen are another attribute worthy of future scientific investigation.

While the nutrient concentrations observed during the study did not appear to be deleterious to the biological integrity of these creeks, a host of interrelated factors complicate this interpretation. For example, physical and hydrologic alterations to individual waterways may have a profound influence on tidal creek integrity but this was only partially quantified in this study based on land use characteristics. Land use analysis suggested increased urbanization may actually have negative effects on productivity as measured by chlorophyll concentrations. For example, the percent impervious surface of the watershed, as well as the proportion of urban land use within the creek buffer area were negatively correlated with median chlorophyll concentrations, while the proportion of natural wetland vegetation (i.e. mangroves and marshes) within the buffer area was positively correlated with water column chlorophyll concentrations (Figure 39). Natural wetland vegetation within the buffer area was also correlated with a higher likelihood of exceeding existing state DO criteria for estuaries. This suggests that the underlying conceptual model currently applied using existing state DO and chlorophyll standards to evaluate these creeks under the narrative criterion may need to be reconsidered. This will require more research and sampling, to test the influence of anthropogenic alterations to the physical and hydrologic environment of the creek. Dredging creeks have been shown to result in negative effects on tidal creek biomass (Bilkovic and Roggero (2008); Bilkovic, 2011) and (Christian and Allen (2014) found that shallow wide tidal creeks lead to greater trophic efficiency that deeper creeks. These results support the conceptual models developed during this study (Janicki Environmental, 2013) that nutrients are only one of several important factors contributing to tidal creek integrity.

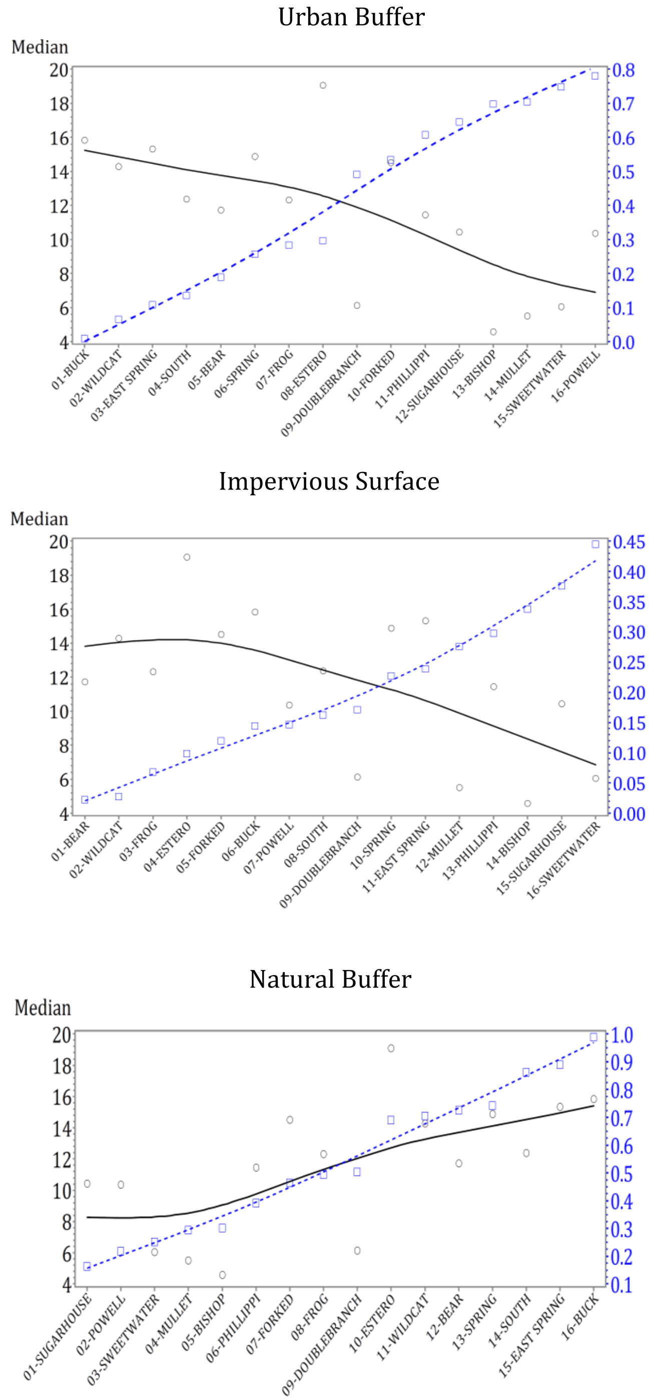

Figure 39. Plots of median water column chlorophyll concentrations (left) as a function of the proportion of urban land use in the buffer area (top), impervious surface (middle), and natural wetland vegetation (bottom). Plots are oriented with increasing watershed metric (x axis).

Trophic efficiency is an important concept that needs more investigation in southwest Florida tidal creeks. Nutrient concentrations measured in this study did not represent dystrophic conditions to tidal creek biological integrity but there was evidence that some creeks were more efficient in converting nutrients to biomass than others. For example, Mullet Creek had the second highest biomass of Snook in our study but only ranked 6th in terms of the total number of Snook (Table 9). Conversely, the most Snook were caught in South Creek but it was not the highest in terms of total biomass. Sugarhouse and Frog Creek had the highest geometric average nutrient concentrations but also had high numbers and high biomass of Snook. This reflects the high level of complexity in evaluating the relationship between nutrients and fish community response. We used length frequency distributions and biomass estimates as potential metrics to evaluate tidal creek condition for fish communities. Lipid storage reserves (Weinstein et al., 2012; Krebs et al., 2013) and length weight ratios (Greenwood et al., 2008) have been used locally as other metrics of fish condition in efforts to differentiate landscape development impacts to these estimates of fish community function with mixed success but the hope is that as more efforts are conducted there will be a convergence of the science needed to use indices such as these to evaluate tidal creek condition in southwest Florida.

Table 9. Snook biomass ranks with associated total number caught, and geometric average TN and TP concentration ranks (larger number=more).

Creek	Biomass	Number	TN	TP
East Spring	1	1	1	8
Powell	1	1	9	7
Forked	3	5	4	12
Doublebranch	4	4	14	3
Estero	5	3	6	1
Spring	6	6	13	2
Phillippi	7	9	10	14
Bear	8	7	8	5
Bishop	9	8	2	10
Sweetwater	10	11	3	6
Sugarhouse	11	14	15	15
South	12	16	7	11
Wildcat	13	12	12	13
Frog	14	13	16	16
Mullet	15	10	5	9
Buck	16	15	11	4

In some instances higher nutrient concentrations were positively correlated with fish species diversity. However, these results are complicated by instream processes such as the flow regime, amount of natural wetland vegetation within the creek, canopy cover, and degree of physical alteration. The degree to which natural habitat features can mask the potential deleterious effects of nutrients in tidal creeks is currently unknown. In theory, more natural habitat features within the estuarine portion of the creeks should increase species diversity, thereby masking the potential negative consequences of nutrient inputs. However, these same natural habitat features (e.g. mangroves) may, at times, limit the effectiveness of gear utilized in sampling, resulting in reduced species abundance and diversity. This is, in part, why we relied on fish length-frequency distributions as a metric of biological integrity. We propose estimates of recruitment and survival of estuarine-dependent fish as an index for identifying healthy creeks. The estuarine dependent species tend to be the more directly related to the recreational or commercial fisheries that drive large economic impacts to southwest Florida. Many of these species recruit as newly hatched juveniles to tidal creeks during certain portions of the year. This would allow for an index period sampling effort to evaluate the recruitment and success of these select taxa as an estimate of creek biological integrity in an ecosystem based management framework. Evaluating creeks in this way is directly tied to the biological communities that represent key ecological attributes for southwest Florida tidal creeks. Over the millennia, fish species have adapted reproductive strategies to maximize their potential for success. Temporal resource partitioning (Ross 1986) is one such mechanism by which these species maximize their probability of success by utilizing the same resource (tidal creeks) over different temporal (seasonal) patterns. An example of this is shown in Figure 40 which displays the recruitment windows for several important fish species in southwest Florida tidal rivers. Tidal creeks that are able to support higher recruitment and survival rates for multiple species throughout the year contribute to the integrity and resilience of the larger estuaries to which they connect. The index would need to be refined to include considerations of the individual species reproductive strategies, inter-annual variation in year class strength, and potential for emigration, but the occurrence of multiple size classes of a particular estuarine dependent species that is identified as a key ecological attribute is in itself an indication that the creek is meeting it's identified designated use.

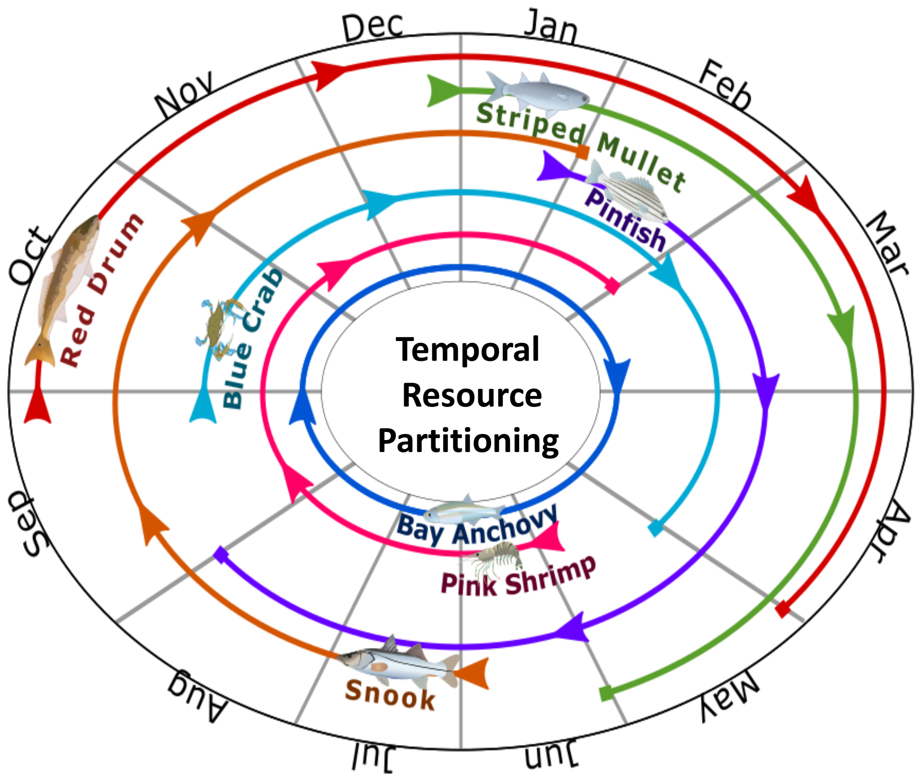

Figure 40. Temporal resource partitioning of estuarine dependent fish taxa utilizing southwest Florida tidal creeks.

Using these concepts, the methodology applied to this study could be used towards the development of a management system that could be generalized to other systems throughout Florida and beyond. For example, Red Drum recruit throughout Florida's Gulf Coast and this species could serve as a valuable indicator in the same manner in which Snook were used in this study. Inter-annual year class strength hinders the reliance on any one species and therefore there is a need to consider multiple species for this type of ecosystem-based management approach within the larger nutrient management framework. Southwest Florida is unique in that the FIM program has a long term monitoring program established in all three estuaries that can be used to provide indices of inter annual recruitment that may be correlated to tidal creek recruitment.

In conclusion, this study made important contributions to the development of a protective nutrient management strategy for southwest Florida tidal creeks. The strategy provides management guidelines and actions to be implemented that minimize the potential for these creeks to become eutrophic or dystrophic, while also minimizing the probability that a tidal creek waterbody will be designated as impaired due to naturally occurring water quality conditions. Natural resource managers and state and federal regulators can easily apply the proposed management strategy as an effective means of evaluating tidal creeks in a systematic manner and report the results within the context of other metrics used to evaluate tidal creek impairments (e.g., DO and Chla). The local governments of Southwest Florida are in a unique position to capitalize on the contributions of the three contiguous National Estuary Programs that have Comprehensive Conservation and Management Plans with specific actions addressing the stewardship of tidal creeks. This management framework will allow for the three Estuary Programs, and the six counties within their geographic boundaries to work cooperatively to achieve the common goals of the Estuary Programs, the local governments, and state and federal regulators to protect these vital ecotones that contribute greatly to the ecological productivity and resilience of their respective coastal estuaries.