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Coastal and Estuarine Data Archaeology and Rescue Program

1987 ECOSYSTEM VIEW OF MANAGEMENT RESEARCH IN THE MYAKKA RIVER

October 2006

US Department of Commerce
National Oceanic and Atmospheric Administration
Miami, FL

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Review of Phase I and Phase II Reports

Review of Draft Report on Evaluation of Water Quality Impacts
Review of Ecosystem Models on Estuarine Management Problems
Proposed Work

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COVER PHOTOGRAPH: The flooded Myakka River. Courtesy of Larry W. Arrington.

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PREFACE

[PREPARED IN 2006]

There are a significant number of documents and data related to the marine environment of South Florida that have never been published, and are thus not used by scientific community and academia. These documents and data are important because they can help characterize the state of the coastal environment in the past, and thus are essential when evaluating the current state of degradation and setting restoration goals. Due to the nature of the paper and electronic media on which they exist, and in some cases the conditions in which they are housed, the data and documents are in jeopardy of being irretrievably lost. These materials cannot be located using electronic and manual bibliographic searches because they have not been catalogued or archived in libraries.

The purpose of the Coastal and Estuarine Data Document Archeology and Rescue (CEDAR) for South Florida is to collect unpublished data and documents on the South Florida coastal and estuarine ecosystem; convert and restore information judged valuable to the South Florida restoration effort into electronic and printed form, and distribute it electronically to the scientific community, academia and the public. "Data Archaeology" is used to describe the process of seeking out, restoring, evaluating, correcting, and interpreting historical data sets. "Data Rescue" refers to the effort to save data at risk of being lost to the science community.

This report was originally prepared by the NOAA National Marine Fisheries Service to review and synthesize reports prepared at Mote Marine Laboratory concerning the Myakka River and to propose future ecosystem scale work building upon the previous work.

NOAA/National Ocean Service/National Centers for Coastal Ocean Science (NCCOS) is not responsible for the accuracy of the findings or the quality of the data in rescued documents.

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ABSTRACT [PREPARED IN 2006]

This memorandum has four parts. The first is a review and partial synthesis of Phase 1 and Phase 2 Reports by Dr. Ernest Estevez of the Mote Marine Laboratory to the Board of County Commissioners of Sarasota County, Florida.[1] The review and synthesis emphasizes identification of the most important aspects of the structure of the Myakka system in terms of forcing functions, biological components, and major energy flows. In this context, the dominant primary producers, dominant fish species and food habits, and major environmental variables were of particular interest. A major focus of the review and synthesis was on the river zonations provided in the report and based on salinity and various biological indicators. The second part of this memorandum is a review of a draft report by Mote Marine Laboratory on evaluation of potential water quality impacts on the Myakka River from proposed activities in the watershed. This Memorandumís third part is a review of resource-management related ecosystem models in the context of possible future models of the Myakka River Ecosystem. The final part of this memorandum is proposed future work as an extension of the initial reports.

REVIEW OF PHASE I AND PHASE II REPORTS

1. Introduction

The principal purpose of the Phase I and Phase II studies was to gain information for evaluating the potential impacts on river ecosystems and resources of decreased runoff to the Myakka River. Despite this emphasis, considerable information was collected that also will be useful in evaluating the potential impacts of Increasing the nutrient load of the Myakka River, which is another major management concern. The reports support the development of a conceptual framework with which to evaluate the response of the natural resources of the river to land use and water management changes of all types; they contribute to an understanding of the river as an ecosystem. Developing such an understanding should be the first step in evaluating impacts. The Phase I and Phase II reports suggested that salinity has a major influence on the

[1] Estevez, E. D. 1985. A wet-season characterization of the tidal Myakka River. Mote Marine Laboratory Tech. Rep. 095a. Submitted to Ringling MacArthur Reserve Project, Board of County Commissioners, Sarasota, FL. 281 pp.
Estevez, E. D. 1985. A dry-season characterization of the tidal Myakka River. Mote Marine Laboratory Tech. Rep. 095b. Submitted to Ringling MacArthur Reserve Project, Board of County Commissioners, Sarasota, FL. 171 pp.

distribution of benthic organisms and fish in the rive r— their occurrence and density. Future Investigative work In the river will benefit from the emphasis on the spatial distribution of plants, animals, and salinity that was given In the Phase I and Phase II reports

Clearly, salinity is an important variable affecting plant and animal distributions; this must be recognized in any analysis of the potential effect on the river of water management or land use changes. Salinity effects on biological organisms will have to be taken into account in examination of the effect of changes in nutrient load. The salinity profile of the river will help describe how nutrient concentrations change as river water mixes with Charlotte Harbor water. Physical conditions in the river such as turbulence, bottom scouring, and circulation and the mixing of water masses, undoubtedly change similarly to changes in salinity; correlation of these conditions with salinity will help us to describe their variation In the river over time and to evaluate possible impacts of these changes on river organisms.

Nutrients such as nitrogen are driving forces in primary production and the transfer of energy through aquatic food webs. Concentrations of nutrients may vary both as a function of river flow and Independently of it. These relationships, as well as salinity effects, need to be addressed in evaluating potential impacts of altering freshwater Inflow to the system.

My review of the Phase I and Phase II reports has been from the point of view of trying to learn the most important aspects of the structure of the system in terms of forcing functions, components (or compartments), and major energy flows. For this reason, I have been Interested in determining (1) dominant primary producers—types and species; (2) dominant species of fish and their general food habits; (3) density and biomass density of fish and invertebrate species and their variation over time and space; (4) major river zones and habitats; and (5) spatial and temporal variation in major environmental variables such as salinity and nutrient concentrations. Of major importance is the determination of how salinity and nutrient concentrations vary in relationship to river flow and, then, how the overall abundance and biomass of natural resources is affected by salinity and nutrient concentrations. Another topic of interest is how physical conditions in the river, such as scouring, turbulence, etc., vary with river flow and how plants and animals of the river respond to variation In physical conditions. Information on most of these subjects was contained In the reports at various levels of detail.

I obtained a general idea of food habits of dominant fish species of the river by a cursory literature review. Lacking biomass data, which was beyond the scope of the Phase I and Phase II studies, I used qualitative information on vegetation coverage and density estimates on fish and benthic Invertebrates to approach these topics.

Future work that I propose is based on the ecosystem perspective I have gained from the Phase I and Phase II reports and my ancillary investigative efforts. The work includes modeling. Although the study could be conducted without models, modeling can Integrate all the elements of the study and make results more meaningful. Quantifying a preliminary model is the best way I know to estimate in advance whether suspected effects are of sufficient magnitude to be important. Seen from the perspective that preliminary modeling might provide us, some elements of the study that I propose now may later prove to be of little relevance; therefore, I suggest an iterative approach in which Initial studies help to quantify a preliminary model to provide guidance on which are the most important next steps.

A model is a conceptual tool that Integrates a set of hypotheses about how the system works at a fundamental level. Such a tool can be used to guide research, refine our understanding of the system, facilitate communication between Investigators and managers, and, finally, combine a lot of diverse quantitative information about the system into. an evaluation of possible impacts. I envision relatively simple energy budgets of the major subsystems and simple growth models of one or two species (i.e., hogchoker and anchovies) for which we propose a different set of salinity optima, varying by life stage, and which we expose to various time varying salinity regimes simulating conditions in the various segments of the river under different water management options.

1.1. Primary Producers

A knowledge of the principal types of primary producers of the river - their areal coverage, requirements, growth dynamics, and nutrient uptake, storage, and release rates is essential to evaluating the possible response of the river to decreased flow rates or Increased Inputs of nutrients from the watershed. I have divided the primary producers into categories, as follows, based on certain characteristics of their connection with the river.

Upland plants: contribute organic detritus to river in runoff In proportion to rainfall, which Influences both the amount of plant biomass produced and the proportion of above-ground biomass transported to the river.

Bank or canopy: trees, vines, and shrubs on banks ordinarily not flooded. Canopy coverage of the river determines the direct input of leaf detritus and also the suppression of photosynthesis by phytoplankton and submerged plants.

Seasonally-flooded vegetation: contribute organic material to the river and take up nutrients from the water column only during the times of year when water levels are exceptionally high.

Intertidal emergent vegetation and periphyton: contributes to river food chains, is utilized as fish and macro in vertebrate habitat, and takes up nutrients only when it is flooded, which occurs only part of the day.

Continuously-flooded emergent vegetation and periphyton: contributes to river food chains, is utilized as fish and macro in vertebrate habitat, and takes up nutrients continuously.

Submerged plants and epiphytes: contribute to river food chains, take up nutrients continuously; light reception can be affected by canopy coverage and phytoplankton density.

Phytoplankton: contribute to river food chain and take up nutrients continuously; rate of sinking inversely proportional to river flow; rate of removal from river directly proportional to river flow; light transmission to submerged plants is inversely proportional to phytoplankton density.

Subdivisions within each of these categories separate the major growth forms (i.e. grasses and sedges from mangroves) and species.

Table 1 gives a very rough approximation of the percent river area covered by each of these vegetation types (except upland, of course) in each of the river zones. These are my very gross estimates from qualitative Information in the literature. A rigorous examination of information from the vegetation transects would yield more accurate estimates. Still more accurate estimates could be obtained by using the Information from the transects in combination with aerial photographs to map the river by vegetation type. A special project would be necessary to adequately map the seagrass beds of Myakka Bay and Upper Charlotte Harbor.

Table 1. Estimated percent river area covered by various primary producers, by zone.

Zone	Canopy	Seasonally Flooded Vegetation	Intertidal Vegetation	Continuously Flooded Veg.	Submerged Veg.	Tot Emergent Submerged Veg.	Phyto-plankton
1	10	1	1[a]	1[b]	1	4	90
2	0	10	20[c]	20[c]	0	50	100
3	0	0	2[d]	3[d]	20	50	100
4	0	1[e]	1	1	25	28	100

[a] *Spartina bakerii*
[b] *Scirpus*
[c] *Juncus*
[d] Red mangrove
[e] Black mangrove

Note: Zonation scheme is river width. Phytoplankton was calculated as total river area minus canopy area.

During the Phase II study, the concentration of chlorophyll a was highest in the lower part of the river (zone 4) and next highest in the upper river (zone 1). Lowest concentrations occurred in zone 2. Submerged vegetation is most prevalent below El Jobean (in Zone 4), and then only in very shallow water. The extent of coverage by bottom vegetation in Myakka Bay is not known and could be significant. Mangrove area is most extensive in zone 4. Emergent vegetation is most extensive in zone 3, which Includes the braided river section. There is no mangrove, little emergent vegetation, and only limited submerged vegetation in zone 1.

The area covered by different types of primary producers plays an Important role in the nutrient dynamics of the river. Knowing the relative coverage by various types of primary producers might help in interpreting nutrient data. For Instance, the observed decline in inorganic nitrogen concentrations between US. 41 and El Jobean noted in Phase II sampling might be due to the relatively high coverage of the river by emergent vegetation in the braided river section. Improving our estimates of areal coverage by the various primary producers is important in determining the possible response of the river to increased Inputs of nutrients and organic material that might result from an upstream waste water recycling facility.

Secondary productivity by the benthic community is fueled by organic material. The primary producers are the sources of organic material to the system. Table 2 shows my very gross estimates of the percent of total energy as organic material contributed to the river by primary producers of various types. These estimates suggest that the proportion of organic material contributed by the various types of primary producers probably differs by river zone. Some of the difference in the density of benthic organisms between zones may be due to the difference in sources and quantities of organic material available to the benthos in the various zones.

Submerged aquatic vegetation contributes to the dissolved oxygen of river bottom waters. Knowing the extent of coverage by SAV in each zone will help us to evaluate the importance of this contribution to the DO content of bottom waters in each zone.

Table 2. Estimated percent total organic matter from indicated source, by river zone.

Zone	Upland Detritus	Emergent Vegetation & periphyton	Submerged Vegetation & epiphytes	Phytoplankton
1	70	5	5	20
2	20	75	0	5
3	5	5	45	45
4	2	10	46	47

Note: Zonation scheme is river width.

1.2. Dominant Fish Species and Trophic Structure

The dominant fish species of the river during Phase I (wet season) and Phase II (dry season) sampling are shown in Table 3. The percent of total specimens in samples each represents is given. These species probably are the major higher consumers of the river, although some major consumers may not be Included here because they are difficult or impossible to catch in trawls. By determining the principal prey of these species, we can identify the major pathways of energy flow to the major consumers.

Stomach contents analysis was not included in either the Phase I or Phase II studies, however the dietary habits of many of these species In other areas is available from other studies. Table 4 lists the prey composition of Myakka dominants that were covered by Carr and Adams (1973) at Crystal River, Florida. Also included to fill gaps or provide additional perspective is information from Odum and Heald (1972) at North River in Everglades National Park and Darnell (1958) at Lake Ponchartrain, Louisiana. Included are pinfish, bay anchovy, spot, pigfish, hogfish, silver perch, sea catfish, hardhead catfish, spotfin mojarra, and striped mojarra. Pink shrimp is also Included. The table indicates that copepods and amphipods can be utilized by many of these species. Planktonic copepods are particularly important In the diets of very young fish, most of which feed in the water column. Caridean shrimp, polychaetes, and molluscan veliger larvae can be heavily utilized by some of these species.

Although *A. mitchilli* at Crystal River fed almost entirely on copepods and molluscan veliger larvae, this species consumed a wider variety of prey at North River and also at Lake Pontchartrain (Darnell, 1958) and at Tampa Bay (Springer and Woodbum, 1960). Mysids were an important component of the diet of bay anchovy at Lake Pontchartrain, making up from 28 to 52% of stomach contents by volume. Fish were important in the diet of larger individuals, comprising 33% of stomach contents volume of *A. mitchilli* 60-74 mm in length. Darnell concluded that the bay anchovy had two pathogenic feeding stages: very young fish feeding in the water column and older fish feeding on the benthos. Polychaetes, the principal benthic taxa found in the stomachs of other fish species, were absent from the stomachs of *A. mitchilli* taken in the Ten Thousand Islands by Colby *et al.* (1985). Zooplankton made up approximately 50% by weight of stomach contents of a large collection of *A. mitchilli* in a wide range of sizes.

Table 3. Major Fish Species of the Myakka River.

	Percent Total Fish Phase I Dry[a]	Percent Total Fish Phase II Wet[b]	Spawning Season
Trinectes maculatus (hogchoker)	30	81	Sum (May-Nov)
Leistomus xanthurus (spot)		6	
Micropogonias undulatus (croaker)		3	Win-Early Spr
Anchoa mitchilli (bay anchovy)		2	Win-Early Spr
Lagodon rhomboides (pinfish)		2	Win-Early Spr
Bairdiella chrysoura (silver perch)		1	
Cynoscion arenarius (sand seatrout)		1	Spr-Sum
Orthopristis chrysoptera (pigfish)		1	Win-Early Spr
Symphurus plagiusa (blackcheek tonguefish)		1	
Menticirrhus americanus (kingfish)			Spr & Sum
Arius felis (hardhead catfish)			
Bagre marinus (gafftopsail catfish)			
Diapterus sp.			
Eucinostomus argenteus (mojarra)			

[a] Total dry-season fish catch was 662 (30 species)
b Total wet-season fish catch was 1,241 (22 species)

The principal diet of hogchoker at Crystal River was polychaetes (Carr and Adams, (1973) (Table 4). Hildebrand and Schroeder (1928), examining 17 fish from Chesapeake Bay, concluded that *T. maculatus* fed primarily upon annelids, supplemented by occasional small crustaceans and strands of algae. Darnell (1958), finding three out of 10 hogchokers with recognizable food in their stomachs, determined that amphipods of the genus *Corophium* were present in all three and made up about 50 percent by volume of contents. Undetermined organic matter and detritus comprised the remainder. Examination of Intestinal contents revealed that the hogchokers had also consumed other microcrustaceans, chironomid larvae, foraminifera, and seeds. Reid (1954) examined the stomachs of eight hogchokers at Cedar Key but found all of them empty except for sand. In exclosure studies in Chesapeake Bay. Virnstein (1977) discovered that hogchokers had no appreciable effect on the density of an infauna consisting principally of polychaetes, but he based that conclusion on only one fish. The number of hogchokers in each of these studies was small. A larger sample and size range of hogchoker should be examined to adequately understand the diet of this species.

My review of stomach contents studies of both the bay anchovy and the hogchoker led me to the opinion that stomach contents studies of a species need to be conducted in an area where the species is most abundant as well as where it is scarce to adequately understand the diet of the species. If relative number of samples obtained for stomach contents analysis provide even a rough index of the relative abundance of a species, then hogchokers occurred in low abundance relative to other species in the areas where stomach contents studies were conducted. Certainly the abundance of this species relative to other species in the Myakka River is greater than in the areas where stomach contents analyses were conducted, and stomach contents analyses would have to be conducted here to adequately understand their diet in this system.

According to this cursory overview, all of the major fish species of the Myakka River feed on benthic invertebrates. At early life stages, many feed in the water column on copepods. Both infaunal organisms and epifaunal crustaceans appear to be important dietary items of the Myakka River fish species. Principal prey items of the Myakka River fish community, as suggested by examination of the same species in other areas, are summarized in Table 5. If the feeding habits of these species in the Myakka River are similar to their habits elsewhere, then the major pathway of energy flow to higher consumers of Myakka River is through the benthos.

1.3. Density and Biomass Density of Fish and the Benthos

Fish are a conspicuous component of the ecosystem, and fishing, both in the Myakka River and in Charlotte Harbor, are important commercial and recreational activities. Nine species during dry season and 14 species during wet season were identified in Phase I and Phase II reports as the dominant fish species of the river. The principal species is the hogchoker, which made up 80 and 30 percent of fish caught in dry-season and wet-season sampling, respectively. A comparison of the change in hogchoker distribution on various stages of the tide (Table 8) suggests that they do not move out Into Charlotte Harbor to feed-even during the season and tide when salinities are lowest there. Hogchoker densities were consistently lower at the Upper Charlotte Harbor station than at upstream stations throughout all tidal cycles. Lower densities of hogchoker at the mouth of the river may have been due to the fact that the bottom is anoxic at the river mouth during periods when salinities in Charlotte Harbor are lower than in the upper river (E. Estevez, pers. comm.). If, however, this species is primarily dependent upon the river, then hogchoker densities might provide a good index of the overall ecological well-being of the river. Seasonal variation in density due to spawning periodicity would have to be a consideration in using hogchoker densities as an Indicator of the environmental health of the river.

Table 4. Stomach contents as various prey taxa, specific to size of predator taxa, according to various indicated literature sources. Values are percent dry weight or percent volume.

	Algae	Plant Detri	Mollusc Veliger Larvae	Copepods	Harpact. Copepods	Mysids	Caridean Shrimp	Penaeid Shrimp	Amphi-pods	Iso-pods	Ostra-cods	Poly-chaetes
<u>Lagodon rhomboides</u>												
10-20 mm (a)				70-85								
21-35 mm (a)									30-40			
36-60 mm (a)	65-80											
61-80 mm (a)	20-35	5-15					--------10-25-------					
81-110 mm (a)	5-10	5-10										
<u>Anchoa mitchilli</u>												
15-23 mm (a)			50-74	26-50								
31-36 mm (b)		11			9	19			22		10	
<u>Leiostomus xanthurus</u>												
40-99 mm (f)		27(g)		6(h)	11	1			8	8	13	2(i)
100-149 mm (f)		27(g)			1	9			10		1	
150-203 mm (f)		38(g)							7	12		
<u>Orthopristis chrysoptera</u>												
16-30 mm (a)				45-65			40-50					
31-50 mm (a)							20-35		3-12			5-30
51-80 mm (a)								25-85				
<u>Trinectes maculatus</u>												
18-35 mm (a)		2-22										60-90
<u>Bairdiella chrysoura</u>												
6-15 mm (a)				100								
16-40 mm (a)				5-80			-------10-85					
41-160 mm (a)							50-95		2-5			
larvae (b)				50								
127-181 mm (b)						X						
<u>Arius felis</u>												
205-331 mm (b)						7			28			
<u>Bagre marinus</u>												
262-445 mm (b)												
<u>Eucinostomus argenteus</u>												
19-63 mm (b)												
dry season (b)		6			39	7			31			
wet season (b)		5				9			38		6	
<u>Diapterus plumieri</u>												
35-172 mm (b)		4			4	44			36		3	
<u>Penaeus duorarum</u> (e)				X					X	X		X

Table 4. (Continued)

	Xanthid Crabs	Blue Crab	Molluscs	Chiron. Larvae	Fish Larvae	Fish	Zoo-plank	Sand Grains	No. Stom with Food
Lagodon rhomboides									1,608
10-20 mm (a)									
21-35 mm (a)									
36-60 mm (a)									
61-80 mm (a)						10-20			
81-110 mm (a)						25-85			
Anchoa mitchilli									
15-23 mm (a)									73
31-36 mm (b)			8	5			16		17
Leiostomus xanthurus									
40-99 mm (f)			18(j)						18
100-149 mm (f)			29(j)			8			28
150-203 mm (f)			32(j)						20
Orthopristis chrysoptera									445
16-30 mm (a)					0-10				
31-50 mm (a)									
51-80 mm (a)	5-15								
Trinectes maculatus									17
18-35 mm (a)								10-15	
Bairdiella chrysoura									
6-15 mm (a)									
16-40 mm (a)									797
41-160 mm (a)						0-30			
larvae (b)					50				34
127-181 mm (b)						X(c)			14
Arius felis									
205-331 mm (b)	47(d)					4			62
Bagre marinus									
262-445 mm (b)		X				X			5
Eucinostomus argenteus									
19-63 mm (b)									
dry season (b)				4					42
wet season (b)				31					53
Diapterus plumieri									
35-172 mm (b)			3	6					
Penaeus duorarum (e)									

Table 4. (Continued)

(a) Values are percent dry weight from Carr and Adams (1973).
(b) Values are percent volume from Odum and Heald (1972).
(c) The fish was Anchoa mitchilli.
(d) The xanthid crab was Rithropanopeus harrisii.
(e) Non quantitative observations from Sastrakusumah (1971).
(f) Values are percent volume from Darnell (1958).
(g) Copepods that could not be identified to Harpacticoid or otherwise.
(h) Includes "undetermined organic matter" as well as "detritus".
(i) Identified only as "Annelid." Included with polychaetes in this table.
(j) Principally Rangia cuneata.

Table 5. Principal prey taxa of major fish species of the Myakka River.

Copepods
Harpacticoid copepods
Mysids
Caridean shrimp (Palaemonetes)
Penaeid shrimp
Polychaetes
Mollusc veliger larvae
Amphipods
Isopods
Plant detritus
Algae
Fish (*Eucinostomus* sp. and *Anchoa mitchilli*)

Table 6. Area of river, by zones of indicated width range, as estimated from width range and shoreline length in Phase I report.

Zone	Transect	Width Range (ft)	West Bank (ft)	East Bank (ft)	Width Used	Est. Area ft^2
I	1-15	0-250	29,852	31,875	50	1,492,600
II	17-34	250-1,000	40,221	37,654	250	9,413,500
III	35-44	1,000-3,500	34,013	36,640	1,000	34,013,000
IV	46-53	3,500-13,500	24,799	32,724	3,500	86,796,500

My analysis of the food habits of these species according to studies in other areas suggested that, beyond the planktonic postlarval stage, almost the entire energetic support of the fish community comes from the benthos. Meanwhile, benthic core sampling suggested that the density of benthic organisms was extremely low In the upper and braided portions of the river. The areas of these two river zones (1 and 2) are relatively small compared to that of the lower river (zones 3 and 4), which comprise Myakka Bay and Upper Charlotte Harbor. My rough estimates suggest that river area in zones 3 and 4 is at least 10 times greater than that in zones 1 and 2 (Table 6). The low benthic density coupled with the low areal coverage of the two upper river zones suggests that the fish community is strongly dependent upon the lower river for its food.

Benthic core samples at the five stations may not adequately represent benthic animal densities in any of the zones. Zone 2 contains considerable area of saltwater marsh, which probably was not covered by benthic core sampling. Zone 1 contains some freshwater marsh that is possibly Important in food chains, but this area probably was not covered either. On the other hand, the seagrass beds in zones 3 and 4 may not have been sampled with benthic cores in proportion to their areal coverage of these zones. Benthic sampling stratified by habitat is essential to making good estimates of the relative abundance of benthic organisms in the different sections of the river.

Fish densities and benthos densities in the river were not well correlated. Benthos densities were highest at station T-53, whereas fish densities were highest at station T-40. Fish densities at stations T-7 and T-19 did not reflect the low benthic densities there. Hogchokers, In particular, were found at fairly high densities at these stations particularly on flooding and high tides. Hogchoker densities are, in fact, as high at these stations as at T-40. Possibly the benthic core samples do not adequately represent relative density of benthos in Zone 1. Alternatively, perhaps high predation pressure by hogchokers is maintaining the benthic community in a state of low density and high productivity. But is this possible? Nichols (1977) and others have observed that the ratio of production to biomass in benthic communities is fairly constant at around 4.5. One would expect the ratio of production to density to be, if - anything, even more stable. Furthermore, fish density and, presumable predation pressure, was greater at T-40 than at stations T-7 and T-19, since fish density was greater at T-40, yet the density of benthic organisms was six times greater there!

Even if the food supply for fish in the braided and upper river zones is small in comparison to that of the lower river, these areas might be essential to the fish community if they contain critical habitat for fish at late postlarval and early settlement stages. Herke (1971), Hansen (1969), and others suggest that salt marshes and tidal creeks in extremely low-salinity (1-5 ppt) portions of estuaries may be critical habitat for estuarine-dependent fish when they first settle out of the plankton. Red drum, spot, snook, and Atlantic croaker are four species for which an occurrence of very small individuals in waters of salinities below 5 ppt can be documented. The size distribution of hogchokers and bay anchovy with distance upriver suggests that these species, too, use very low salinity parts of the river as nursery grounds.

The perpetuation of fish stocks in the river and possibly in Charlotte Harbor and offshore, as well, is dependent upon survival and growth of early life stages, which determines recruitment to their populations. The importance of various specific types of habitats in the braided and upper river zones to early life-stage fishes needs to be determined. An Investigation of the species composition and density of fish in the salt marshes associated with and connected to the braided and upper portions of the river may provide important information relevant to this question.

1.4. Zones and Zonation Schemes

The study group divided the river into zones based on several different sets of criteria. One approach to assimilating the Phase I and Phase II reports was to examine and compare the zones resulting from the different zonation schemes. Additionally, I use data from benthic core and trawl sampling to estimate zonations on the basis of relative densities.

The river was divided by river width into the following four zones:

Zone 1 (transects 1-15) 0-250': narrow, with steep banks

Zone 2 (transects 17-34) 250-1,000': "braided river", stretch having greatest associated marshes

Zone 3 (transects 35-44) 1,000-3,500': Myakka Bay (mangrove fringe)

Zone 4 (transects 46-53) 3,500-13,500': Upper Charlotte Harbor (mangrove fringe)

I found this scheme convenient to use since shoreline length and the range of river width in each of these zones was given in the Phase I report. I used this Information to obtain a rough estimate of the relative area of each zone (Table 6). Qualitative descriptions suggest that the proportionality of various aquatic habitats (i.e., submerged plants, emergent vegetation, mangroves) may be more similar within each of these zones than between them.

A zonation scheme roughly based on salinities was given as follows;

Upper river, usually < 1 ppt salinity during both wet and dry seasons.

Mid river, usually < 1 ppt during wet season and 1-10 ppt during dry season.

Lower river, usually 5-20 ppt during wet season and 15-22 ppt during dry season.

Delineation of these zones by the study team apparently is undergoing continuous revision as data from new monthly surveys is obtained. For this reason, precise boundaries are not given in the reports, making it difficult to compare this zonation scheme with others. The area of the river experiencing 1-4 ppt salinities during the wet season was not Included in this zonation scheme. Perhaps it should be identified as a separate zone.

Information on vegetation communities along the banks of the river were used to classify the river into three zones. In order to facilitate comparison with other zonation schemes, the zone numbers are changed from those given in the text.

Zone One, a riverine community - from river mile 13.0 to 21.0. (roughly. Transacts 1-9), rarely experiences salinities > 1 ppt.

Zone Two, a transitional community - from river mile 6.0 to 13.0. (roughly, Transects 10-33)

Zone Three, an estuarine/marine community - from river mile 2.3 to 6.0 (measured from Cattle Dock Point near the outlet to Charlotte Harbor) (roughly, Transacts 34-53), rarely experiences salinities < 1 ppt.

The vegetation zonation is on the basis of clustering vegetation communities from 20 sites from both sides of the river according to Czekanowski's index of percent similarity. Complicating factors in the analysis were caused by community differences on opposite sides of the river, possibly occurring due to discharges of freshwater from tributaries emptying primarily into the east side. The vegetation communities probably reflect long-term salinity conditions.

The river was also zoned according to communities of submerged aquatic vegetation (SAV). These zones were as follows:

Zone I, freshwater SAV, identified by presence of *Eleocharis baldwinii, Ceratophyllum demersum, Nitella* sp., or *Sagittaria subulata* and, possibly, the absence of *Vallisineria* (except in one oxbow.

Zone II, low salinity SAV, identified by presence of *Vallisineria*.

Zone III, brackish SAV, identified by the presence of *Ruppia maritima*.

Zone IV, marine SAV, identified by dominance of *Halodule wrightii*.

Zone I is discontinuous, interrupted by Zone II. The upper stretch of Zone I includes Transects 1-7. Its lower stretch encompasses Transects 18-25. The lower freshwater zone is apparently due to the inflow of water from Deer Prairie Creek. Zone II encompasses Transects 8-17. Zone III includes Transects 26-40. Apparently the freshwater inflows from Big Slough are not sufficient to create freshwater conditions in this stretch. Zone IV includes Transects 41-53. A transition SAV community from Transects 19-38 was identified.

According to anelid distributions during the wet season (September sampling) at five transect stations, the river can be divided into three zones:

Upstream, < 1 ppt salinity (T-7, T-19, T-27)

Mid region, 6-12 ppt (T-40)

Downstream, generally 6-18 ppt (T-53)

Based on mollusc distribution during both the wet and the dry season the river was divided into three zones. I have changed to an alphanumeric numbering to prevent confusion with other zonal designations.

Zone A, limnetic (< 1 salinity), (upstream of T-13)

Zone B, oligohaline to mesohaline (approximately 1-15 ppt) (roughly, T-14 through T-36)

Zone C, meso-polyhaline (approximately 15-25 ppt), (T-37 - T-53)

Zone A was said to be characterized by the presence of *Corbicula manilensis*. Zone B was identified as being the area of greatest osmotic stress, being subjected to the greatest salinity fluctuations. Two taxa, *Tagelus plebius* and *Polymesoda caroliniana*, may characterize this area. Zone C was characterized by a much higher diversity of mollusc taxa than was found at Zones A and B. The region between transects 5 and 34 exhibited very low molluscan diversity and a high proportion of empty mollusc shells, suggesting a dynamic community with respect to salinity and a region of transition between limnetic and "true" estuarine conditions. The empty mollusc shells suggested that the molluscan species shifted back and forth with changing salinity conditions on the inner boundaries of their salinity ranges.

Based on crustacean distributions during the wet season, the river was divided in the Phase II report into two zones, labeled zones B and C to conform to the zones defined by mollusc distributions. Zone B of the crustacean distribution extends into zone A of the mollusc distribution. Crustacean distributions indicated a "transition region" extending from station T-9 through T-44, the region from T-9 through T-25 appearing particularly "stressed".

Table 7, compiled from the Phase I report, shows the relative density of benthos, by major taxa, at five river stations, according to benthic cores, the only quantitative sampling method used on the benthos. If only these data are used, it appears that a zone of low benthic density from at least station T-7 through at least station T-27 can be distinguished. Benthic densities are approximately six times greater at T-40 and approximately 10 times greater at T~53 than at T-7, T-19, and T-27. Station T-53 Is In Upper Charlotte Harbor. T-40 is In Lower Myakka Bay. T-27 is in the braided river area. T-19 is in the "shallows" area upstream of Deer Prairie Park. T-7 is upriver near Snook Haven.

Also shown in Table 7 is the number of fish taken in otter trawls during September sampling at five stations corresponding to the location of the benthic core sampling. These data suggest that fish density is lowest at station T-27 and intermediate at T-7 and T-19. The highest fish density was found at T-40. Some fish species are found primarily downriver, whereas others are found primarily upriver. The hogchoker is found both upriver and downriver, densities being approximately equal at T-7, T-19, and T-40 (Table 8). Hogchoker are less abundant at the mid-river station, T-27, than at either upriver or downriver sites. Hogchoker densities drop sharply below T-40 and are extremely low at the mouth of the river (T-53). The distribution of hogchoker changes somewhat with the tide, and densities are higher upriver on

Table 7. Relative densities of benthos and fish from Phase I report.

A. Relative abundance of benthos, by major taxa, at five river stations? from benthic core sampling, September, 1985.

Taxa	1 (T-7)	2 (T-19)	3 (T-27)	4 (T-40)	5 (T-53)	Tot
Molluscs	10	1	15	73	145	244
Crustaceans	10	35	64	105	608	820
Annelids	38	6	10	144	420	668
Tot	58	42	89	322	1,173	1,732

B. Number of fish and macroinvertebrate individuals taken in trawls, September, 1985.

Day	482	54	65	1,586	279	2,466
Night	463	745	224	2,081	1,049	4,562
Tot	945	799	289	3,667	1,328	7,028

Table 8. Hogchoker catches in trawls during Phase I (September 1985) sampling.

Tide & Day or Night	1 (T-7)	2 (T-19)	3 (T-27)	4 (T-40)	5 (T-53)	Tot
Day ebb	20	9	5	35	1	70
Day flood	36	11	1	34	0	82
Day slack tide	81	4	9	26	0	120
Day slack low	159	3	0	43	0	205
Night ebb	75	70	27	168	25	365
Night flood	158	321	10	99	1	589
Night slack high	95	227	56	89	0	467
Night slack low	18	52	21	191	0	282
Tot	642	697	129	685	27	2,180

the high tide. But, regardless of tide, hogchoker densities are lower at stations T-27 and T-53 than elsewhere. The fact that densities are extremely low at the mouth of the river, even on outgoing tides during the wet season, suggests that this species may not leave the river. The spatial distribution of hogchoker may be worth examining more closely. If this species seldom or never leaves the Myakka River, it might an ideal organism to monitor as an Indicator of conditions in the river.

The river was divided into the following zones according to the distribution of fish eggs and larvae:

Upriver (<5 ppt), freshwater species

Transition, low diversity and abundance

Lower river (>= 5 ppt, estuarine species

The Tarpon Point station, which is located near Transect Station 33 (at river mile 8.7) was described as epitomizing the transition area. It seemed to be a dividing line between freshwater and estuarine forms during both the wet and the dry seasons. The area between Myakka Bay and Deer Prairie Creek, which encompasses the Tarpon Point station, was referred to as the "wet season estuary" with respect to larval fish. This designation was not explained. It seems to me that this region might more aptly be described as the "dry season estuary", because estuarine salinities extend further upstream during the dry season than during the wet season. Perhaps the "wet season" designation was a transpositional error in writing or typing the text.

Table 9 summarizes information on transition zones. Both the zones suggested in the Phase II report and zones suggested by relative density estimates from benthic core otter trawl sampling (Table 7) are Included. Transition zones defined by the different criteria do not exactly correspond. In particular, the transition zones defined in the report, which may be based primarily on species distributions and species diversity and include consideration of qualitative data from dredges and other sampling in addition to benthic core data, differ from

Table 9. Transition zones of the river suggested by indicated criteria.

Criteria	Transition Zone Limits by T Station	 Limits by River Mile
Taxonomic Distributions		
Annelids	? - 40 - ?	5
Molluscs	5 - 34	8.2 - 18.75
Crustaceans	9 - 44 9 - 25 (highly stressed)	2.5 - 16.53
Fish larvae	? - 33-34 - ?	- 18.75
Relative Density		
Fish	27	18
Hogchoker	7 - 27	10.6 - 18
Benthos	19	
Molluscs	7 - 27	10.6 - 18
Crustaceans	7 - 19	13 - 18
Annelids	7 - 27	10.6 - 18

the transition zones suggested by the benthic core data alone. In particular, they differ for annelids. Annelid densities were relatively high at station T-40, yet this was Indicated as a transition zone for annelids in the Phase I report. Annelid densities were lowest at T-7, T-19, and T-27. Mollusc densities also were extremely low at these three stations compared to elsewhere. Crustacean densities were lowest at stations T-7 and T-19 and Increased from T-27 through T-53. Based on benthic densities, the river can be separated into a low density and a high density zone, the high density zone covering Upper Charlotte Harbor and some portion of Myakka Bay and the low density zone including the braided river area and everything upstream.

Data presented in the two reports strongly suggest that salinity influences both the number and density of benthic species in various segments of the Myakka River, but it is not clear what aspect of salinity is determining the presence or absence of species and their density. In the Phase II report it was suggested that the transition zones distinguished by benthic species distributions may be the area of greatest salinity fluctuations. Table 10 summarizes information on areas of greatest salinity fluctuations between tides at the three times of salinity measurement: mid dry season (April 14-15, 1987) and wet season (September 10 and 24, 1985). During both wet and dry season sampling, between-tide salinity fluctuations were greater at station T-40 (lower Myakka Bay) than anywhere else that benthic core sampling was conducted; yet this station had benthic densities second only to that at T-53 and the highest densities of fish. This suggests that the areas of lowest benthic densities do not correspond to the areas of greatest between-tide salinity fluctuations.

According to Remane and Schlieper (1971), the lowest number of species on a salinity gradient often is found somewhere between 1 and 5 ppt. Boesch (1977) found that benthic densities in Chesapeake Bay were lowest in the region of Chesapeake Bay experiencing salinities of about 1 to 5 ppt. The Myakka River zone of low density appears to extend further upriver than the area that experiences salinities between 1 and 5 ppt most often.

Perhaps the zone of low density best corresponds to the stretch of the river that frequently experiences salinities of less than 1 ppt and occaslonally experiences salinities of greater than 1 (or 5?) ppt. This fits the description of the mid-river zone of the second zonation scheme, described above and presented in the Phase I and Phase II report.

Another possibility is that the zone of low benthic densities corresponds to the segment of the river that experiences the greatest variation in salinities between seasons. Benthic species may be able to adapt better to frequent short-term changes in salinity than to longer-term changes in salinity that occur seasonally. Further examination of data in the Phase I and Phase II reports and new data collected in more recent monthly surveys could possibly pinpoint the aspect of salinity variation in the river that best describes the variation In benthic species distributions and densities.

1.5. Spatial and Temporal Variation and Management Changes

The primary objectives of the Phase I and Phase II studies were to determine baseline conditions in the river with which to evaluate possible effects of water management actions and land use changes on the productivity of the river. Water management actions that have been proposed include (1) a proposed project to use the Ringling McArthur Preserve to treat and recycle secondary sewage waters, which could affect the nutrient load of the river; (2) a proposed project to divert up to 5X the flow of the Myakka River for upstream uses, which

Table 10. Stretches of the river experiencing greatest change in salinity of bottom waters, by date, as interpolated from graphs in Phase I and Phase II reports.

Change in Salinity	ID	Date: Apr 14,15,'86	Sep 10,'85	Sep 24,'85
< 2	River Mile	-2 - 13.1	-2 - 6.2	0.7 - 7.1
	T-Station	53 - 18	53 - 38	50 - 36
	Description	mouth - near SHW	mouth - UMB	CHH - near UMB
2 > 5	River Mile	5.2 - 10.8	0.5 - 5.2	1.8 - 4.3,5.9
	T-Station	40 - 26	50 - 40	46 - 41,38
	Description	LMB - WMS	CHH - LMB	Tippecanoe Bay LMB,UMB
5 > 8	River Mile		0.4 - 4.8	2.9
	T-Station		(49,50) - 40	(43 - 44)
	Description		CHH - LMB	

Salinity Change	Distance of Indicated Salinity Change (miles): Apr 14,15,'86	Sep 10,'85	Sep 24,'85
> 2	15.1	8.2	6.4
2 < 5	4.6	5.7	2.5
5 < 8		4.4	

Note: River mile measurement starts at Cattle Dock Point. -2 is two miles downstream from Cattle Dock Point. 5 is five miles upstram from Cattle Dock Point.

Mean discharge rates: March, 1986 = 137.3 cfs
April, 1986 = 43.5 cfs
Sept, 1985 = 656.0 cfs

LMB - Lower Myakka Bay
CHH - Charlotee Harbor
WMS - Unknown
UMB - Upper Myakka Bay
SHW - Shallows

might alter the salinity structure of the river; and (3) a proposed project to plug the Curry Canal, which also could affect the salinity structure of the river. Changes In land use, such as conversion from pasture to citrus, or changes in on-site water management practices could affect the river by affecting salinity structure or nutrient concentrations. The Phase I and Phase II reports help us to understand the dimensions of variation In these important variables and their ramifications.

2. Freshwater Inflow Effects

The relationship of freshwater Inflow to estuarlne productivity is complicated by many dimensions of variability In causal and responding agents. Furthermore, the impact of changes is difficult to evaluate because impacts occur at several levels. Freshwater flow Influences salinities, nutrient concentrations, and exchange with oceanic waters; and it is probably through these factors that changes in the flow of fresh water affect estuarlne productivity and nursery value. Determining the Impact of altering freshwater flow is difficult due to the complications that impede establishment of the fundamental relationships.

Variability is due to many factors. Salinity varies with distance from the river mouth; then, at every location within the river, salinity varies continuously with the tide as well as by season and across years. Furthermore, salinities in Charlotte Harbor, which are affected by the flow of the Peace River, affect salinities in the Myakka River, at least downstream.

Mixing within the river is strongly influenced by freshwater flow, but the relationship is nonlinear. Increases in freshwater flow enhance mixing up to a point, beyond which vertical mixing is inhibited and stratification occurs. The point at which freshwater flow causes stratification differs not only by estuary but also due to temperature, wind effects, and other factors. When stratification occurs, salinity varies with depth, and bottom isohalines are positioned differently in the river than surface isohalines.

Salinity in estuaries and tidal rivers is directly related to freshwater flow and its variation over space and time has an Influence on the survival and growth of estuarlne organisms, but the exact mechanisms for this Influence are not known and may even differ by species. The physiological and ecological requirements regarding salinity differ by species. Within a species, these requirements even differ by size or age group. The survival and growth of a certain species and age group at various salinities not only depends upon the physiological requirements of that organism but also upon the physiological requirements of its predators, its prey, and the food of its prey. For this reason, indicators of survival and growth of even one species reflect the Integration of multiplicative interactions with the environment. Furthermore, variation In trophic structure between ecosystems may cause differing responses of the same species to salinity in two different systems.

An environmental change can cause a shift in dominance from one group of species to another and yet cause little change at the ecosystem level. If the extant dominants have a recognized value to human society and their replacements do not, then society realizes a loss from the change, despite the lack of major impact on the ecosystem. On the other hand, when environmental change results in a loss of productivity, a reduction in energy flow, and a reduction in biomass, the effects of the environmental change are felt at the ecosystem level. These ecosystem-level changes can mean conversion from a highly productive system to a relatively barren one. Because of differences in trophic structure among ecosystems, differences in their dominant species and their species pools, these ecosystems' potential responses to changed conditions - their abilities to adapt - may differ.

We ultimately must be concerned with how the ecosystem is affected by alterations. But primary responses are made at the level of species, with different responses occurring at different developmental stages. For this reason, we certainly have to determine effects at the level of species and age groups within species. In doing this, we should concentrate on the species that presently are dominant in the system, for their abundance relative to other species suggests that their metabolism represents major flows of energy through the system. We should not, however, ignore the possibility of measuring ecosystem-level parameters that might differ In relation to salinity-benthic metabolism, for Instance.

What aspects of salinity control the survival and growth of organisms in the tidal river and estuary? In a paper with Don Moore (Browder and Moore 1981), I proposed that survival and growth In estuaries is a function of the area of overlap of certain structural features of the habitat that are important to a species (i.e. bottom depth, shoreline length, or vegetation cover) with water within a certain salinity range that is somehow favorable to that species. The concept was founded on the range management concept that habitat differs in quality and acreage of habitat, by quality type, limits production. In a study in Faka Union Bay, John Wang and I (Browder and Wang, 1987) showed that variation in the relative abundance of several species of fish and macroinvertebrates over time was significantly related to area of the bay within certain salinity bands. Studies by Hansen (1969), Herke (1971) and others, as well as Information presented in the Phase I and Phase II reports, suggest that both the habitat features and the salinity ranges favorable to a species may differ according to size or life stage.

Other aspects of salinity may also strongly Influence organismic survival and growth. For some species, minimum salinities or the duration and frequency of lower salinities may be governing. For other species, maximum salinities may be limiting. Differences in survival and growth are reflected as differences in abundance and biomass.

Tidal river and estuarlne organisms can be divided into four groups that, because of basic differences in their behavior and habitat, can be expected to be Influenced differently by salinity variation and to reflect this influence differently in their abundance and biomass. These are benthic sessile organisms, benthic motile organisms, demersal-feeding motile organisms, and pelagic species. Salinity-related differences In abundance in the first group are relatively easy to detect. The responses of the second and third group are much more complex and our ability to detect their responses much more difficult. It is difficult to distinguish between true abundance and mere changes In relative density as animals move around. It can be done, however, by sampling by type of habitat, knowing the area of each habitat type, and sampling intensively in space and time.

The entry of new young organisms into the system complicates the analysis of variation in abundance in relation to environmental variables. It is imperative to understand the seasonal cycle of reproduction and recruitment in order to evaluate temporal changes in abundance. Immigration of older organisms to higher-salinity environments is another factor that complicates the Interpretation of change in abundance over time.

The Phase I and Phase II reports have provided especially lucid two-dimensional descriptions of how salinity varies in the Myakka River. The view of tidal excursions in which isohalines are shown moving up and down the river with each tidal cycle is a particularly interesting one that I have never previously encountered. I think that a study from this viewpoint promises to yield more useful information on the distribution of macro in vertebrates and fish in relation to salinity than any antecedent. I have found the Phase I and Phase II reports very exciting to review for this reason. These reports and the extension of these studies will pave the way for determining specific relationships between salinity and the distribution and abundance of organisms, which should facilitate reliable predictions of potential Impacts on natural resources of altered land uses, local water management practices, and large-scale management actions.

Physical conditions such as turbulence, bottom scouring, and the circulation and mixing of water masses also vary with freshwater flow and may affect the survival and growth of fish and benthic organisms. We need to gain more insight on these physical conditions-how they vary with freshwater flow, how they differ in various segments of the river, and how they affect various organisms. Little information on these aspects of river influence were covered in the Phase I and Phase II reports.

3. Nutrient Concentrations

Although the two studies placed less emphasis on nutrient dynamics and the variation In nitrogen concentrations in time and space than they did on salinity variations, they did identify several aspects of river ecology that may have great bearing on how the river might respond to Increased nutrients from a wastewater recycling facility, pastures, or agricultural fields. First, nitrogen, as opposed to phosphorus, is the limiting factor to primary productivity in the Myakka River. Second, dissolved oxygen levels In bottom waters sometimes fall below Florida water quality standards, possibly suppressing benthic secondary productivity. Levels below 4 mg/L commonly occur upriver (near Snook Haven), and, under stratified conditions, also are found downriver (in Zones 3 and 4). Third, the area of emergent vegetation in the Myakka River relative to the surface area of the river is extremely limited. Fourth, submerged vegetation in upstream portions of the Myakka River may be light-limited due to color In the water. The water is clearer downstream, possibly because of the flocculation and precipitation of color compounds when freshwater mixes with salt water (the Phase I and Phase II reports suggest that in the Myakka River, this occurs at a salinity of about 6 ppt). Simple dilution of river water with clearer waters from Charlotte Harbor may also improve water clarity. The Phase I and Phase II reports suggest that extensive seagrass beds occur in downriver portions of the Myakka; but that they are found only in shallower areas, indicating that these beds may be existing at minimum light levels now.

Here we have several elements of concern: Nitrogen inputs can be expected to increase primary productivity. The potential for emergent vegetation to take up nitrogen may be extremely limited. Submergent vegetation in the upper river probably will not be able to absorb additional nutrients. Of all the primary producers, phytoplankton in the lower river may have the greatest potential to Increase in response to Increased nitrogen. If this occurs, light transmission to the grassbeds in the lower river could be reduced, causing a loss of these beds. To the extent that nutrient concentrations are above ambient at the mouth of the Myakka River, grassbeds in Charlotte Harbor could also be affected. An ecosystem model of Chesapeake Bay by Kemp *et al.* (1983) suggested that the stimulation of phytoplankton productivity by added nutrients was the leading cause of the loss of seagrass beds there and that the seagrass losses could be responsible for observed declines In stocks of fish, crabs, and oysters in Chesapeake Bay.

If water-column primary productivity increases and bottom vegetation decreases, benthic biomass, secondary productivity, and the value of the river-estuary as a nursery ground for fish and invertebrate species is likely to diminish for several reasons. First, bottom vegetation is an important habitat for the young of many species of fish and shrimp, who are found in higher concentrations in these beds than elsewhere. Survival of these organisms would likely be affected for this reason alone if seagrass area decreased. But perhaps of even greater concern, increased phytoplankton production would add to the biological oxygen demand of bottom waters at the same time the production of oxygen in bottom waters by seagrasses was depressed. The possible importance of seagrasses in contributing dissolved oxygen to bottom waters through photosynthesis should not be overlooked. Although the area of coverage by submerged aquatic vegetation in the upper river may be small, this, too, may be playing an important role in supplying oxygen to bottom waters. Both benthic organisms and demersal fish are detrimentally affected by low DO. Although fish can move to other areas to avoid an oxygen depletion event, moving may affect their survival potential by Increasing fish densities and the intensity of competition in substitute living and feeding areas. Furthermore, benthic organisms, many of which do not move, can be killed by low oxygen events. This can depress benthic secondary productivity, which equates directly with food availability to demersal-feeding fish. According to the Phase I and Phase II reports and my trophic analysis, this includes all the major species of fish in the Myakka River.

An increase in nutrients in the watershed may not only Increase nitrogen inputs to the river but also the load of organic matter the river receives from the watershed. Land spreading of waste water, the wastes of domestic animals, and commercial fertilizers stimulate primary production in the watershed, resulting in an Increase in organic matter in runoff. Inputs of organic matter have a direct effect on BOD. This is of particular concern in the upper river, where DO levels already are often below state standards. Belanger (1985) has noted that low DO levels are a chronic condition of highly colored waters of Florida. Because DO levels in these waters are naturally low, they may be extremely vulnerable to increased inputs of organic matter.

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REVIEW OF DRAFT REPORT ON EVALUATION OF WATER QUALITY IMPACTS

My comments concern primarily the monthly regression equations used for prediction of salinities and salinity change with flow reduction at Snook Haven, Port Charlotte, and El Jobean.

I question whether Peace River discharge rates should have been left out of these final equations. Peace River discharge must have a strong affect on salinities in Charlotte Harbor, and Charlotte Harbor waters are the waters that mix with local freshwater inflow to determine Myakka River salinities. Unfortunately, the multiple correlation coefficients were not included with the final predictor equations, so I can not use this to compare them with the original equations, for which multiple correlation coefficients were Included. Multiple correlation coefficients for the final predictor equations should be Included In the final report.

Can I assume that the salinities used to develop the equations were "high tide" salinities? This was not Indicated in the report, however tide stages used in the equations were high tide stages.

The tide stage data were for St. Petersburg. The table on description of data sets Indicated that the St. Petersburg data extended into 1985. Are these data still being collected? If not, it is not very useful to future work to have equations that are dependent upon them. Can comparable long term data on tidal stage be collected In Charlotte Harbor or, perhaps preferably, the ocean outside Charlotte Harbor in the future?

Two aspects of the predictive equations suggest that variables not included in the equations may strongly affect salinity In the Myakka River. First, the regression coefficients differed considerably among months.

Secondly, the multiple correlation coefficients for the original equations were below 0.7 (equivalent to 49% of variance in the dependent variable explained by the equation) for all months except June, August, September, and October. I suggest that, in addition to Including Peace River discharge In the final equations, some effort be made to find the other controlling variables. I believe wind speed is the most likely. I suggest the equations be rerun using the following four variables: Wind speed northern sector, wind speed southern sector, wind speed eastern sector, and wind speed western sector. If this gives a poor fit, I suggest you try wind speed northwestern sector, wind speed northeastern sector, wind speed southwestern sector, wind speed southeastern sector. There is a good chance that one or a combination of these will improve the prediction capability.

Another possible reason for low multiple correlation coefficients and poor correspondence of regression coefficients among months is that salinity may not be linearly related to freshwater Inflow. As a matter of fact, Wang and Browder (1986) found an Inverse hyperbolic relationship between salinity and freshwater inflow in Faka Union Bay, Florida.

The equations probably could be improved considerably if additional data on salinity were collected and if stage data were collected at the three stations at the time of each salinity collection. Data should be collected at high stage, low stage, and mid stage.

In addition to improving these equations, the following needs should be addressed in future work:

1. Prediction of low-tide salinities at the three stations.

2. Prediction of the spatial distribution of high tide and low tide salinities between the three stations.

3. Prediction of between-tide salinities at the three stations and locations in between.

Although the equations can probably be improved with no additional data collection, I strongly recommend that additional data be collected and that data to predict low tide salinities, between-tide salinities, and salinities between stations also be collected.

REVIEW OF ECOSYSTEM MODELS ON ESTUARINE MANAGEMENT PROBLEMS

A review of ecosystem models applied to management questions in other estuaries, particularly in Florida, may provide Insight to aid In planning a study to evaluate potential impacts of management options concerning the Myakka River. I am going to confine my discussion to models that have actually been quantified and executed. To my knowledge, there are only two such models - that by Boynton (1977) for the Apalachicola estuary and that by Kemp (1977 and 1980) for Crystal River. I am also going to discuss three estuarlne ecosystem models for areas outside of Florida that seem relevant to the problems of concern in the Myakka River.

Modeling was part of a regional study to evaluate the potential effect of a proposed dam on the Apalachicola River on the oyster beds of Apalachicola Bay and the possible consequences for the economy of Franklin County. On the basis of 24 hour measurements of dissolved oxygen (DO), Boynton estimated primary productivity (daytime change in DO) and respiration (nighttime change in DO) In five types of habitats. He found that the P/R ratio was greater than 1 over grassbeds and in a medium salinity plankton system (the type of system occurring over oyster beds). The P/R was less than 1 in boat basins and In an oligohaline system. Highest rates of photosynthetic activity were over grassbeds. His model of the medium salinity plankton system suggested that photosynthesis by phytoplankton was a more Important source of oxygen to the water column than either advection or reaeration. Nevertheless, if reaeration were surpressed, mimicking decreased turbulence or stratification, then early morning DO concentrations fell to about 3 ppm, approaching the level where mobile species might leave the area and many sessile benthic organisms might be stressed.

The oxygen compartment was eliminated in future work with the model, in which he coupled it to a model of the oyster subsystem. The oyster model was not described in the text, but Fig. 1 from Boynton Indicates that it has three compartments-juvenile oysters, adults, and oyster predators. Fresh water entering the system is shown to have a negative Impact on juvenile oysters and predators and no direct effect on adults except through the effect of river flow on the availability of detritus to both juvenile and adult oysters. The main effect of the river on the coupled plankton-oyster system is to carry nitrogen and detritus, to lower salinities, and to stimulate turbulance. Nitrogen has a positive effect on primary productivity by phytoplankton. Detritus has a positive effect on growth of juvenile and adult oysters. Salinity, which is, of course, inversely related to freshwater inflow, has a negative effect on juvenile oysters and oyster predators. The net result of these effect is apparent in simulations testing the effect on oyster blomass of (1) reducing the amplitude of the seasonal pulse of water flow, (2) Increasing the total annual flow, and (3) decreasing the total annual flow. Adult oyster biomass Increased with river flow patterns having seasonal pulses of lower amplitude than the control pulse but the same amount of freshwater input. Substantial increases or decreases in the total annual freshwater Input produced smaller than normal oyster stocks. Details of the oyster model need to be examined more closely in order to evaluate the model and its implications.

This model is an Interesting example of an extremely simplified ecosystem model used to evaluate potential effects of proposed man-induced changes in freshwater flow. It does not make any attempt to compare oyster harvests In years of varying freshwater inflow. The Interfacing of river flow with biological activity is highly simplistic, possibly because it was not supported by a physical model relating salinity, mixing, and nitrogen concentrations to river flow. I am not sure how accurately the relationship of freshwater to oyster predators and juvenile oysters were defined, since no details of quantification of these relationships was described. This model will be a useful reference in conducting a systems study of the Myakka River, but it should not be copied because the systems are different and the questions being addressed are different.

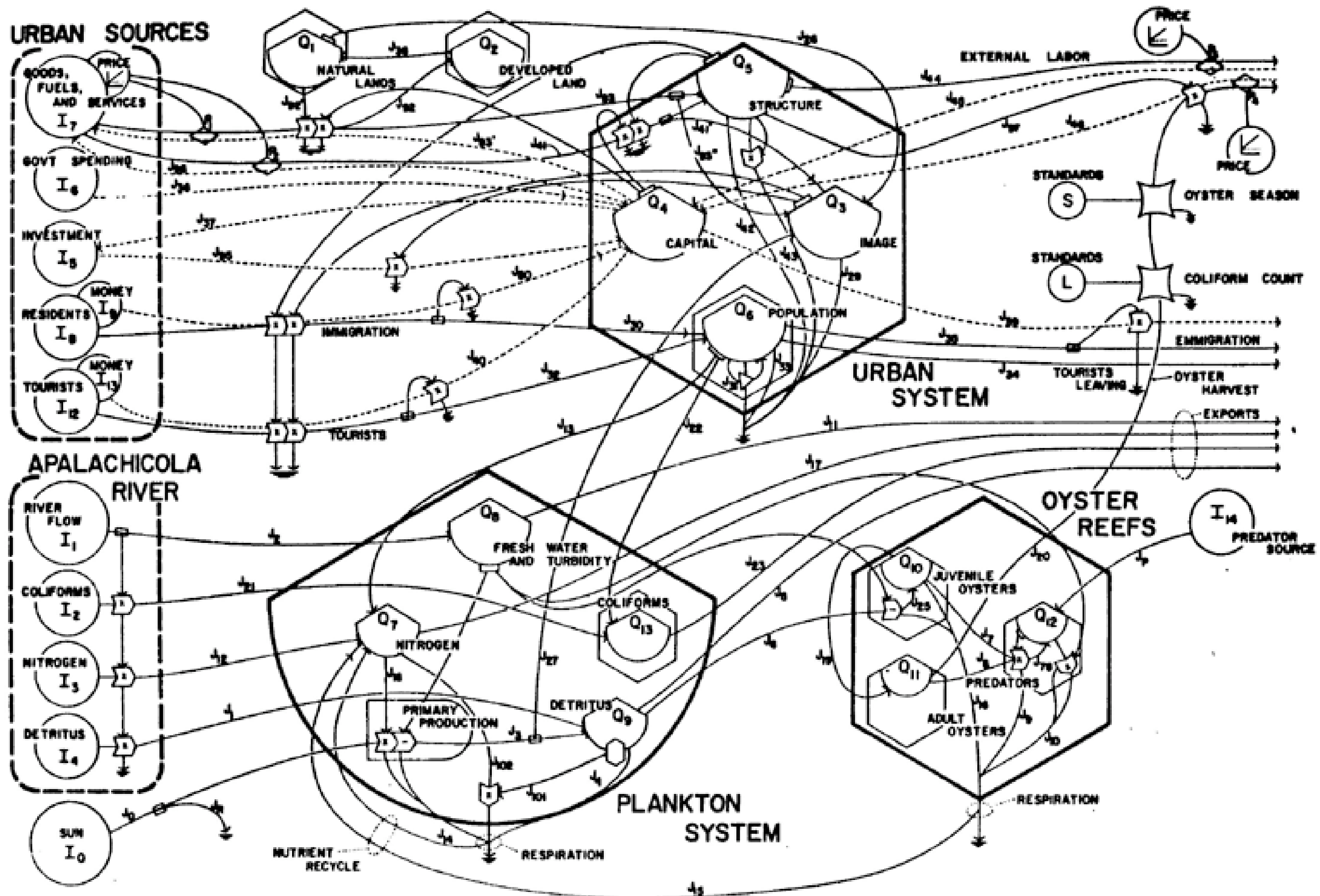


Fig. 1. Regional model of Franklin County and Apalachicola Bay, Florida (from Boynton 1977).

Kemp (1977 and 1980) conducted an ecosystem analysis to evaluate the effect of a power-plant cooling canal on the Crystal River estuary. A trophic analysis was a component of the study (Fig. 2). One feature of his analysis was a technique for collapsing a food web into several food chains by partitioning flows according to their trophic distance (number of links) from the food chain base (the primary producer or detritus) (Fig. 3). A number of taxa are either wholly or partially incorporated Into each consumer compartment. Those taxa that feed at several trophic levels or are supported by several primary sources are included in more than one consumer compartment. This technique allows him to easily express, in terms of energy embodied at the primary production level, the energy cost or benefit of various management options that affect the production and biomass of fish and shellfish.

The structure of the simulation model developed by Kemp (1977) for the Intake canal and discharge basin of the Crystal River power plant is shown in Fig. 4. He distinguished water column detritus (POC) from bottom detritus and separated macroinvertebrates into suspension feeders and deposit feeders, feeding on POC and organic sediments respectively. He also distinguished nekton from benthos. The nekton were vulnerable to entertainment in the power plant condenser and the benthos were not.

A model of the system was calibrated based on field measurements at a nearby coastal site not affected by the power plant. Conditions representing the power plant (entralnment and heated effluent) were then imposed and the biomass of fish and shellfish were simulated. The simulated output was then tested against sampling data from the power plant site. The model was used to separate the effects of turbidity and temperature as aspects of the discharge plume, to examine the potential impact of adding a third power generating unit, modifying the circulation rate, and utilizing closed-cycle cooling. An accompanying hydrodynamic model made it possible to apply the spatially averaged ecosystem model to the entire affected area.

Kemp (1977) estimated primary productivity (P) and respiration (R) over a seagrass community based on diurnal (24 hr) oxygen measurements. His calculations were complicated by stratification. His discussion of his problems and solutions may be applicable to the Myakka situation in which stratification sometimes occurs downriver.

Browder developed an energy flow model for the Calcasieu Lake estuary in Louisiana (Dow *et al.*, 1987) The model treats the open estuary as representative of the entire system and makes offshore harvests of shrimp, menhaden, and bottom fish functions of inshore biomass densities. New recruits to the populations are Injected into the node! in seasonal pulses estimated on the basis of what is known about the seaaonality of spawning of the major species in each trophic group. Growth rates of inshore populations are dependent not only upon available food but also on average bay temperature and salinity, which vary seasonality. Food availability is fundamentally dependent upon nutrient concentrations In the estuary, which are assumed to be a function of river flow, and on detrital imports from extensive marshes bordering the estuary. Monthly average nutrient concentrations, which stimulate primary production by phytoplankton, are assumed to be proportional to the flow of the Calcasleu River. Monthly estimates of detrital input were provided by David Dow (NASA, Bay St. Louis, pers. comm.), who is working on a production capacity model to estimate long-term detrital export from the marsh as a function of areal coverage by marsh vegetation and the pattern of land and water in the marsh. Ultimately, the estuarine ecosystem model and the marsh productive-capacity model will be coupled, and the coupled models will be used to evaluate the effect of marshland loss on fishery harvests. The ecosystem model presently is being calibrated with one year of harvest data. Its predictions will be tested against a second year of harvest data; however a close correspondence between simulated and actual data is not expected due to numerous Insufficiencies In the input data.

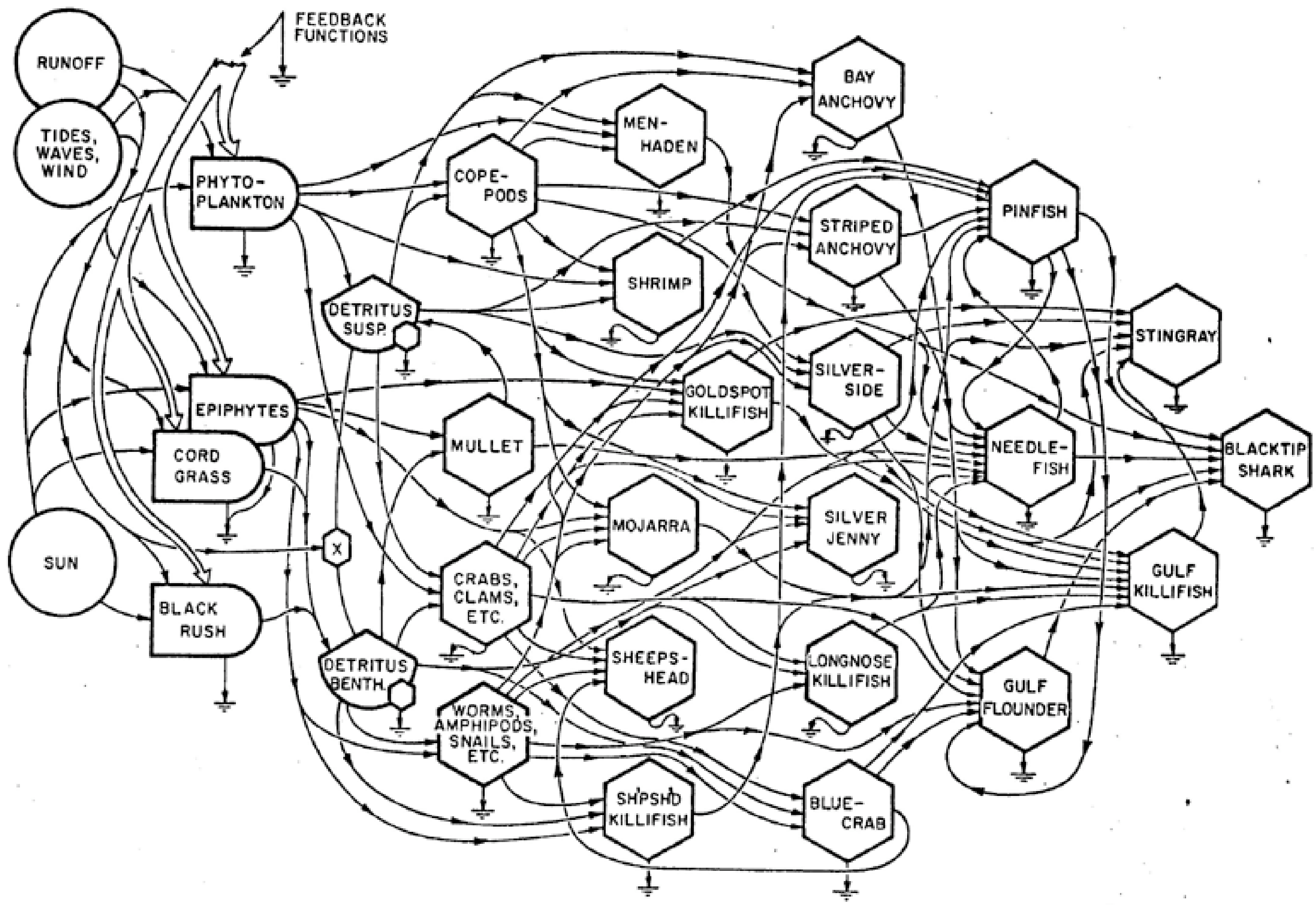


Figure 2. Food web of Chrystal River ecosystem. (from Kemp 1977).

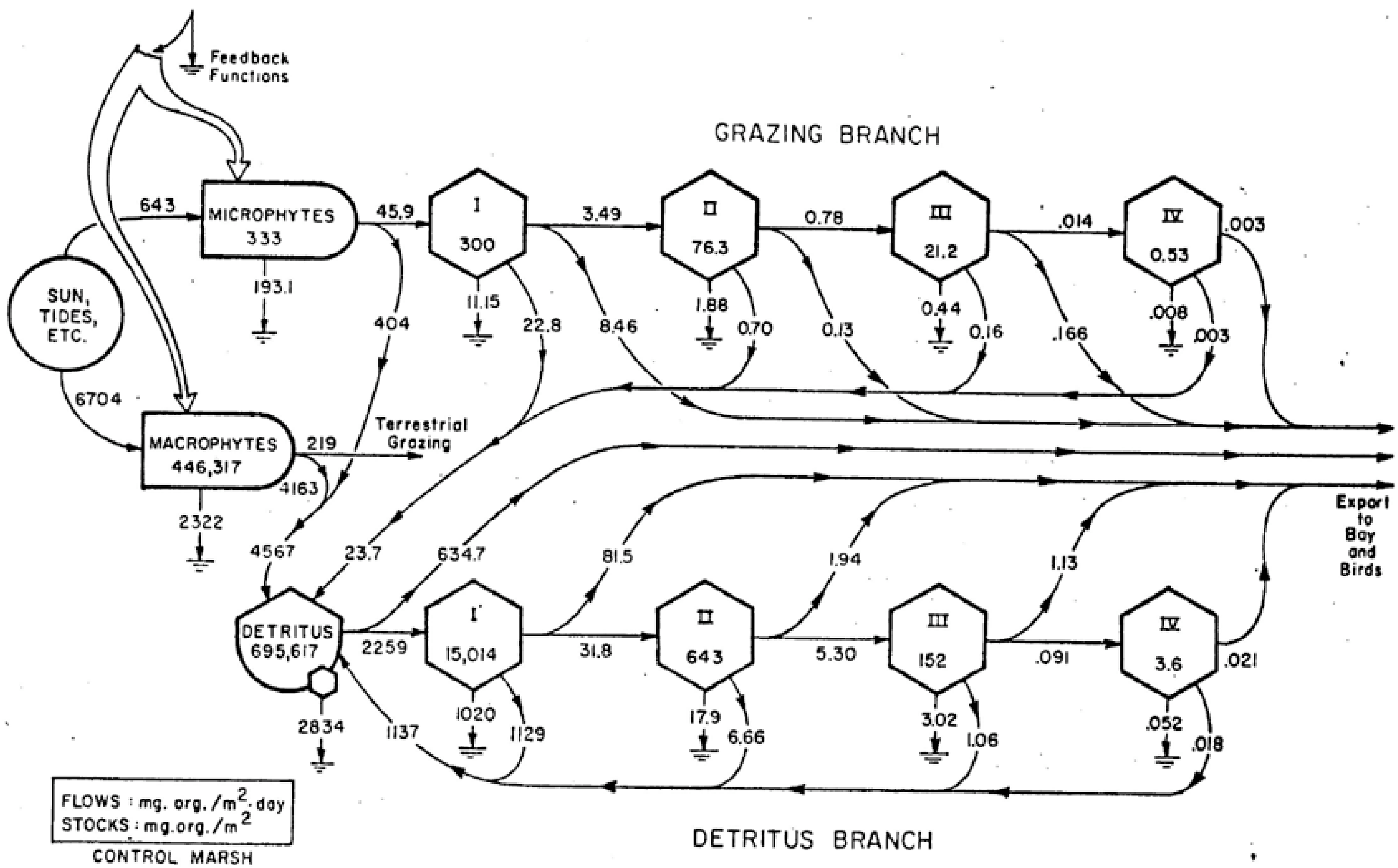
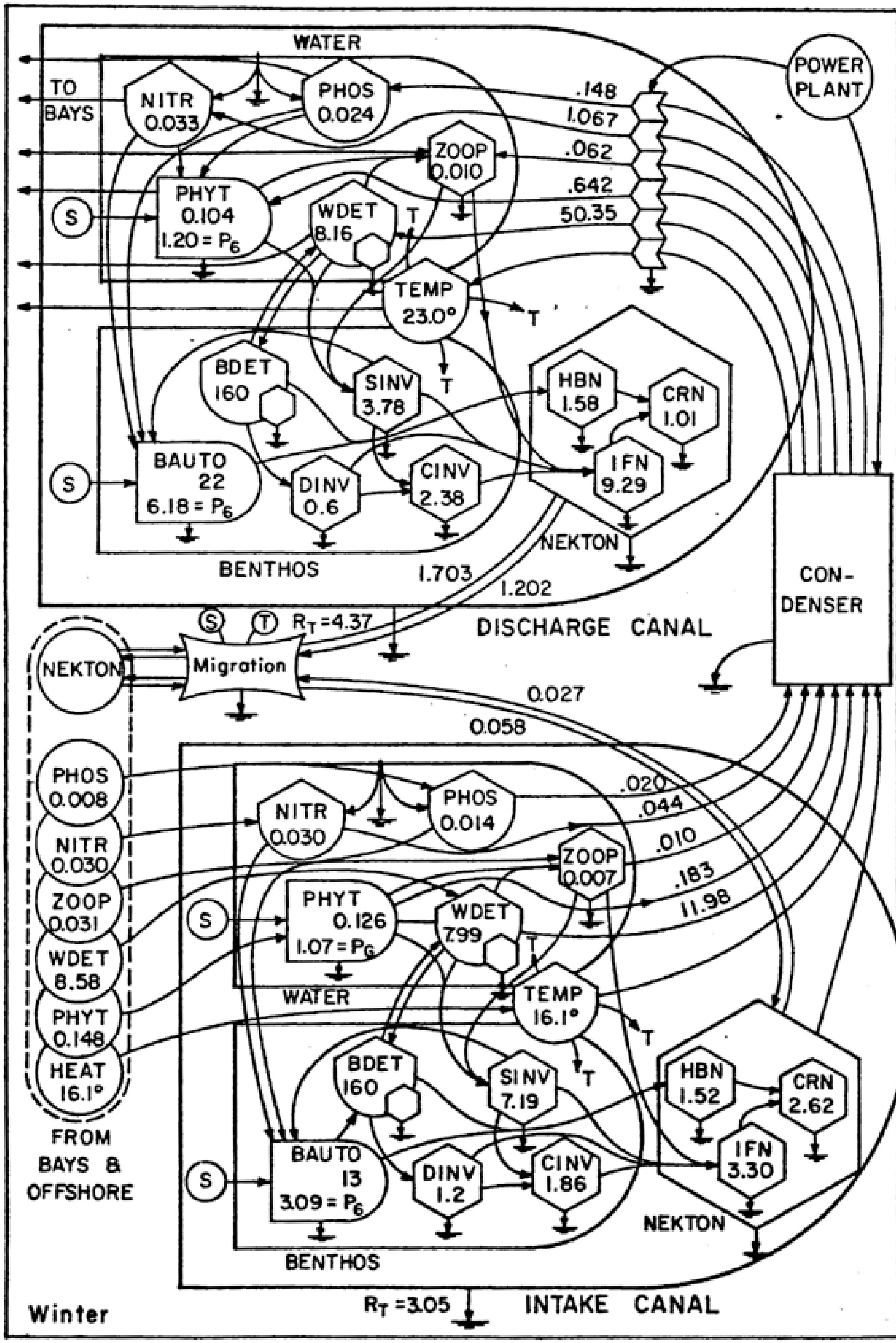


Figure 3. Food chains derived from Crystal River food web (from Kemp 1977).


WATER
TO BAYS
NITR 0.033
PHOS 0.024
POWER PLANT
.148
1.067
.062
.642
50.35
ZOOP 0.010
PHYT 0.104 1.20 = P6
WDET 8.16
TEMP 23.0°
BDET 160
SINV 3.78
HBN 1.58
CRN 1.01
IFN 9.29
BAUTO 22 6.18 = P6
DINV 0.6
CINV 2.38
NEKTON
BENTHOS
1.703
1.202
CON- DENSER
R_T = 4.37
DISCHARGE CANAL
NEKTON
Migration
0.027
0.058
PHOS 0.008
NITR 0.030
ZOOP 0.031
WDET 8.58
PHYT 0.148
HEAT 16.1°
FROM BAYS & OFFSHORE
NITR 0.030
PHOS 0.014
.020
.044
.010
.183
11.98
ZOOP 0.007
PHYT 0.126 1.07 = P6
WDET 7.99
WATER
TEMP 16.1°
BDET 160
SINV 7.19
HBN 1.52
CRN 2.62
IFN 3.30
BAUTO 13 3.09 = P6
DINV 1.2
CINV 1.86
NEKTON
BENTHOS
Winter
R_T = 3.05
INTAKE CANAL

The models of Apalachicola Bay, Crystal River, Chesapeake Bay, and Calcasieu Lake are all of the same general type. They are "energy circuit" or "energy flow" models of a basic construct Introduced by Odum (1982). Structurally, the model is a set of compartments representing biomass connected by lines representing flows of energy and/or materials. Energy flows through the system from prey to predator and is lost from the system as respiration or through harvesting. Nutrients cycle through the system, being Incorporated into organic matter through photosynthesis and being released through respiration. The rate of biomass flow from prey to predator usually is proportional to the product of prey biomass and predator biomass. The general modeling approach allows for feedback effects and thus these models can be highly nonlinear. They are not solved analytically but rather by numerical integration over time. This general scheme has variations. For Instance, to calibrate his model, Kemp (1977 and 1980) calculated the energy required to support a measured level of predator biomass and partitioned the flow of energy from alternative prey according to an analysis of contents of the predators' stomachs, rather than making feeding proportional to prey biomass.

In the Calcasieu model and a model of the offshore Gulf of Mexico (Browder, 1983), Browder estimated feeding rates based on energy requirements using an iterative "top down" flow balancing procedure in which calculations began with harvest levels and standing stocks of the top predators. Biomass flows to each predator were apportioned among prey according to their relative biomass density. A "weighting" function was utilized to approximate selectivity or accessibility, making it possible for the model to reflect the tendency of animals to feed on certain prey items over others at a greater rate than would be expected from their relative biomass densities in the environment. For example, there is a tendency of many benthic feeding animals who eat both benthic organisms and detritus to feed more heavily on the organisms than on the detritus relative to the biomass density of both. The weighting factor usually can only be grossly estimated for lack of field studies in which the relative biomass density of alternative prey is measured in both the predator's stomach and the habitat in which it was feeding.

I discuss these details of the preceding four models because I am next going to describe a model that, though it shares the food web structure of the previous models. Is in some ways very different from them.

Bigelow *et al.* (1977) prepared a model to evaluate the potential effect of a planned conversion of the Oosterschledge estuary In the Netherlands "into a freshwater lake by the construction of a dam across its connection to the North Sea. The dam was seen as a solution to the problem of disastrous flooding from the sea.

For modeling purposes, the system was subdivided In two ways. First, the 2,400 species of living organisms found in it were divided into ecological groups based on their general ecology. Secondly, space was divided into homogeneous units defined by where the ecological groups live and feed. The modelers defined 18 ecological groups, beginning with photosynthetic organisms and ending with benthos-eating birds (see Table 11). The four segments defined for the Oosterschelde were pelagic (water column); oyster banks and mussel beds; tidal flats and shallow bottoms, from mean high water level down to 3 m below mean low water; and deep bottoms, more than 3 m below low water (deep benthic segment).

The model basically is an accounting system that uses ash free dry weight as the accounting unit. Both the energy available to a consumer and the energy expended in respiration are roughly equivalent to ash-free dry weight. A food web forms the structure of the accounting network. Three types of groups were defined: one for photosynthetic organisms, a second for detritus, and a third for heterotrophs. Each of these is handled slightly differently in the accounting system.

Table 11. Ecological groups defined for the Oosterschelde estuary ecosystem (from Bigelow *et al.*, 1977).

1. Photosynthetic organisms (phytoplankton, benthic diatoms, sea grasses, and seaweeds).
2. Detritus (dead organic material), bacteria, micro and meiofauna.
3. Zooplankton and planktonic larvae of various creatures (oysters, mussels, cockles, lugworms, all have planktonic larvae).
4. Oysters and mussels.
5. Cockles and limpets.
6. Selective deposit feeders having planktonic larvae.
7. Shrimp, shore crab.
8. Sea stars.
9. Deposit feeders having nonplanktonic larvae, and filter-feeding worms.
10. Omnivores and infaunal predators.
11. Benthic grazers (e.g., periwinkles).
12. Planktivorous fish (e.g., anchovy, herring, sprat).
13. Benthos-eating fish (e.g., eel, plaice, sole, dab, flounder).
14. Fish-eating fish (e.g., mackerel, cod, whiting).
15. Plant-eating fish (e.g., mullet).
16. Fish-eating birds (e.g., grebe).
17. Plant-eating birds (e.g., mallard, teal).
18. Benthos-eating birds (e.g., oystercatcher, plover).

The model selects a single, unique "ecostate". Ecostate is a special condition of steady state. A system is in steady state when system Inflows equal system outflows and the weight of each ecological group is neither increasing or decreasing. Ecostate, as defined by Bigelow *et al.* (1977) is the unique steady state that satisfies an "ecological minimum principle". Computationally, this state is attained by means of a "Gibbs function", which is based on Gibbs free energy concept. Solution Involves estimation of the coefficients that determine the amount of energy each predator takes from alternative prey. Within certain physiologically based constraints, the model solves for the steady state condition In which there is a net energy gain to each predator from its predation. There is usually only one solution or a clustered group of solutions that fit within a narrow range. Feeding rates are assumed to be proportional to the product of the biomass of the predator and the prey. This is another approach to determining feeding rates and apportioning predation flows from several prey types to the same predator.

An advantage to this modeling approach is that it is computationally simple and requires very little computer time. A disadvantage is that It looks only at long term averages, ignoring seasonal variation.

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PROPOSED WORK

The Phase I and Phase II reports were used as the basis for the design of an ecosystem study to address major questions about the river that will improve our ability to determine the most likely responses of river ecosystems to various expected or proposed land use or water management changes in the Myakka basin. I propose a study of five elements: (1) modeling, (2) mapping, (3) field studies, (4) a laboratory microcosm study, and (5) statistical analysis.

1. Modeling

Ecosystem modeling should be done in five steps.

A. First, a conceptual model should be designed to aid in communication between Investigators and managers and to help in Initial study design. The model should include the major features of the river system that might be expected to be affected, either directly or indirectly, by changes In water flow or nutrient concentrations.

B. Second, a simplified version of the conceptual model should be quantified based on existing information, making gross estimates, where necessary, and utilizing information from other areas to fill gaps where no information on the Myakka River is available. Model quantification and simulations can provide perspective with which to evaluate the Initial assumptions used to design the field studies, giving guidance on how to fine tune them.

C. Following acquisition of data from proposed mapping and field studies, the model would be refined and requantifled.

D. To test the model, simulation results would be compared with actual data not used in the model. Collection of two years of periodic (preferably monthly) data will allow coefficients to be set with the first year of data and the model to be tested with the second year of data.

E. The tested model should then be used to predict how the river ecosystems may respond to Increased concentrations of nitrogen and organic detritus.

One aspect of the model would emphasize relationships between nitrogen concentration, primary productivity, oxygen evolution and uptake, and benthic secondary production. In integrating the various types of Information, the principle concerns will be (1) the effect on phytoplankton of increased or decreased nitrogen concentrations, (2) the effect of Increased or decreased nutrient and organic detritus levels on submerged aquatic vegetation, both upstream and downstream, and dissolved oxygen (DO) levels in bottom waters; (3) the effect of Increased or decreased oxygen levels on benthie biomass; and (4) the effect of increased or decreased benthic biomass on fish, particularly the hogchoker.

Another aspect of modeling work would emphasize relationships between river flow, salinity, benthic species and biomass, and fish species and biomass. Several dimensions of salinity will have to be considered and quantified in terms of freshwater inflow. These include (1) maximum and minimum salinities occurring within the river on low tide and high tide (2) the portion of the river and area of each habitat experiencing each salinity on each excursion of the tide, (3) minimum and maximum salinities experienced by each location and habitat on each excursion of the tide, and (4) minimum and maximum salinities experienced by each location and habitat from wet season to dry season. We need to quantify for each location the cumulative exposure to each salinity over the annual reproductive and growth cycle.

A third aspect of modeling might look at current patterns and mixing as they affect salinity distributions, nitrogen concentrations, and the transport and distribution of phytoplankton, larval fish, and both submerged and emergent vegetation.

The data collected in suggested field studies will be subjected to statistical analysis and will be integrated with models. Tentatively, I recommend an energy flow model of three linked subsystems: upstream detritus and SAV, midstream saltmarsh, and downstream seagrass-phytoplankton. Primary production and nutrient cycling should be emphasized in the marsh submodel. Primary production and oxygen dynamics should be emphasized In the two submodels of submerged systems. Such models could improve our ability to evaluate (1) the capability of the emergent vegetation to absorb nutrients and (2) the sensitivity of bottom-water oxygen concentrations to the combination of loss of seagrass and Increased Inputs of organic material.

Simple modeling work to guide the design of field studies. Integrate data, and generate a holistic view of the river as a ecosystem could be valuable to the study effort. I used a conceptual ecosystem model as a framework for reviewing the Phase I and Phase II reports and for determining the elements of proposed work. The development of simple energy budgets based on ecosystem models of each major habitat would be helpful in evaluating various hypotheses about the system that are the basis for some suggested work. For Instance, which vegetation communities of the river take up sufficient quantities of nitrogen to be Important to the nitrogen concentrations of the river? Do any submerged aquatic vegetation communities have an Important effect on the dissolved oxygen of bottom waters, and under what conditions (day, night, stratified, mixed, etc.)? Once mapping of the vegetation communities is completed and acreage data obtained, simple models preliminarily quantified with additional data from other locations can be used to address these questions. Answers based on the preliminary data can improve the effectiveness of field work by ruling out some hypotheses and supporting others, allowing research resources to be redirected accordingly. Improved data from field work can then replace preliminary estimates used In models to Improve the reliability of modeling results.

In addition to the ecosystem model, I suggest the development of a model that predicts salinities at each location in the river on each stage of the tide for incremental freshwater Inflow rates ranging from zero to the highest recorded flow in the river. The output of this model should be used as input to population models for one or two species of fish in which growth and survival are functions of salinity, each species having a different set of salinity optima that vary by life stage. Initially, these models would be entirely theoretical and based on hypothetical data. Tests should then be made of the theoretical effect on abundance and biomass of reducing or Increasing river Inflow to various extents.

2. Mapping

The first essential step in gathering additional Information is a project to map and quantify the different habitats of the river by vegetation type and depth. The map should be restricted to vegetation that is flooded at least seasonally. It should Include all marsh vegetation connected to the river during at least some time of the year. The location and areal extent of the seagrass beds in the lower river should be precisely determined. Also, a good estimate of the percent coverage of river bottom by submerged aquatic vegetation should be obtained by half mile river zone (or area between existing transects) throughout the river. Aerial photography and the vegetation transects developed during the Phase I study could serve as the basis for the map. Additional field measurements would be necessary to adequately map seagrasses in the lower river. Some field work may also be needed to map SAV in the upper river.

3. Sampling

The sampling strategy should be to take advantage of spatial and seasonal variation to estimate (1) how salinity varies as a function of freshwater Inflow and other variables; (2) how phytoplankton concentrations change as a function of freshwater Inflow and nitrogen concentration; (3) how bottom dissolved oxygen changes as a function of salinity (or stratification), phytoplankton concentration, organic content of sediment, particulate concentration of water, and coverage and biomass of SAV: (4) how SAV varies as a function of salinity, phytoplankton concentration, color, and POC; (5) how benthic invertebrate density and biomass (and possibly, growth rate) vary as a function of salinity, habitat, and dissolved oxygen DO in bottom waters; and (6) how fish abundances vary as a function of salinity and benthic Invertebrate biomass. Careful location of stations and a sampling intensity that adequately covers the spatial and temporal variation in these factors will be important to the success of the study. The background of Information provided by the Phase I and Phase II studies will be particularly valuable in selecting stations and scheduling sampling.

Station locations in the river should coincide with those used in Phase I and Phase II studies and should be chosen to represent the various sections of the river defined in these studies. Additional sampling stations should be established in the tributaries to Myakka River such as Deer Prairie Creek, Big Slough, Warm Mineral Springs, and the tributary near Warm Mineral Springs that is adjacent to a sewage disposal site. Present variation In nitrogen concentrations and other conditions between tributary and river sites will help us to evaluate effects of nitrogen concentrations. Future differences between tributary and river sites may serve as an index of management effects on the river. Determining the relationship between nitrogen concentrations and river flow rates or rainfall could help us separate the effect of man's activities from natural variation. POC and color, as well as nitrogen. In the tributary and river sites should be compared. The tributary near the sewage disposal site may provide the opportunity to evaluate conditions in an area that presently has higher nitrogen concentrations than the river or the other tributaries. To the extent possible, an effort should be made to select tributary and river sites that experience approximately the same salinity regimes. This will minimize possible confounding effects of salinity differences when attempting to determine relationships between the other parameters.

To the extent possible, sampling and measurement of all required parameters should take place synchronously to facilitate the determination of relationships between them. Sampling of all living organisms should be on a unit area basis. Ash-free dry weights should be obtained for all major biological components sampled. At least three samples or measurements of each type should be taken on each station visit to facilitate statistical analyses. To adequately investigate variation within the year, sampling should be conducted monthly, or at least bimonthly. Sampling should be conducted for at least two years and, preferably, three years.

Continue and expand salinity sampling conducted for the Phase I and Phase II reports so that the length and position of tidal excursions and the variation In salinity at each location is determined for many Myakka River flow rates. Peace River flow rates, and, possibly, wind speeds. Measure salinity and stage on both high and low tides and at Intermediate tides. Measure currents (speed and direction at several depths) over the tidal cycle at key stations.

Insure that monitoring of sea stage is continued at St. Petersburg or initiate sampling at an ocean station near Charlotte Harbor-preferably one that is not affected by local freshwater inflow. A recording stage station in Charlotte Harbor also would be desirable.

Determine how nitrogen concentrations vary over time at river and tributary sites. Sample once a month or every other month to determine seasonal variation. Sample at least twice within each month to determine the effect of spring and neap tides. Sample over the tidal cycle. Sample in conjunction with phytoplankton collections. Measure all species of nitrogen, as in Phase I and Phase II studies. Measure salinity concurrently.

Determine how phytoplankton concentrations and gross taxonomic composition (count cells by size fraction) vary over time at river and tributary stations. Sample every month or every other month. Sample twice within each sampling month to determine how concentrations change with spring and neap tides. Sample over tidal cycle. Collect phytoplankton samples in conjunction with nitrogen measurements.

Determine change in DO over time with light and dark bottle experiments at sites of phytoplankton and nitrogen measurements. Estimate primary productivity and respiration in the water column on basis of light dark bottle measurements.

Light transmission should be measured concurrently with phytoplankton sampling. Color and POC should also be measured so that a light extension coefficient can be estimated as a function of color, POC, and phytoplankton cell concentrations.

Note: In analysis, nitrate-nitrite and ammonia should be examined separately for their effects on primary productivity, because Sklar (1976), working at the mouth of the Mississippi River, found that phytoplankton primary productivity was significantly related to nitrate-nitrite-nitrogen but not to ammonia-nitrogen.

Determine how the biomass and gross taxonomic composition of zooplankton varies in time and space relative to the biomass of phytoplankton by sampling at the same time and place as phytoplankton sampling.

Sample ichthyoplankton concurrently with phytoplankton and zooplankton sampling.

In phytoplankton, zooplankton, and ichthyoplankton tows, standardize tow speed and time towed and use flow meters to estimate volume of water filtered.

Conduct a primary production and nutrient cycling study of principal species of emergent macrophytes (*Juncus*, possibly also *Scirpus* and *Typha*). Locate sampling plots at different sites relative to river flow (for, Instance at the upper and lower ends of the braided river area) so that sections possibly exposed to different concentrations of nutrients can be compared.

Conduct a primary production and oxygen evolution study of principal species of seagrasses (*Halodule wrightii*) in Lower Myakka Bay or Upper Charlotte Harbor. Include ambient light and light transmission as measured variables. Measure oxygen levels over a 24-hr period.

Conduct a primary production, oxygen evolution, and nutrient uptake and cycling study of SAV in upper river. Measure oxygen levels over 24~hr period. Take replicate samples to facilitate statistical analysis to separate the effect of different variables and to compare differences among sites.

Conduct sampling to determine the relationship between the benthos (density, blomass, taxonomic composition, respiration rate, etc) and bottom DO concentrations in bottom waters. Include 24-hr measurements of dissolved oxygen at sites of sampling. Consider water flow rates, type of tide (spring or neap), and tidal stage as possible Influencing factors. Measure salinity to cover another Important factor Influencing benthos. If feasible, separate benthic organisms into deposit feeders and filter feeders and obtain separate ash-free dry weights on the two groups.

Conduct sampling to determine the variation in benthic density, blomass, and gross taxonomic composition, by habitat (salt marsh, seagrass, "oyster bed, etc.), in the different sections of the river (upriver, braided river, Myakka Bay, Upper Charlotte Harbor). Organic content in sediments at the site of benthic sampling should be determined. This Investigation and the previous one (i.e., determination of relationship between benthos and DO) can be Integrated by a sampling design that covers the spectrum of habitats and a range of DO levels occurring within each of one or more habitats (i.e., bare bottom and grass bottom). Replicate samples should be taken. Analysis can then separate oxygen and habitat effects.

Determine the species composition and density of fish (and possibly also macro crustaceans) In marsh habitats, such as the oxbows and the braided river section. It is especially important to determine the use of this type of area by early settlement stages of recreationally and commercially important fish and macrocrustaceans.

Determine the food habits of the hogchoker, *Trinectes maculatus*, in the Myakka River. Although mentioned in food habits studies, this species has not been well covered, principally because so few specimens were caught in these studies and also because a very high proportion of those caught had empty stomachs. Since this species makes up such a high proportion of the fish community in Myakka River and, additionally, because it appears to be entirely dependent upon the river environment for its food, it is important to better determine what it is eating in the river.

Conduct standardized trawl sampling at least five general locations in the river, as in the Phase I and Phase II studies. Conduct sampling at night on the new moon, as in the previous studies. Sample around high tide. Measure cross-sectional area of trawl and distance swept at a known throttle setting so that catch can be expressed on a unit area basis. Because hogchoker are so abundant in the river and also because they are entirely dependent upon the river, hogchoker densities in the river can be used as an Index of the well-being of river ecosystems as they presently exist. Sample once monthly for at least two years.

Set up a regular monthly schedule for co-monitoring nitrogen (all species) and salinity. Increase the number of locations where nitrogen is measured. Locate stations relative to stands of various types of marsh and submerged vegetation, so that nitrogen concentrations upstream and downstream of stands of vegetation can be compared as one estimate of uptake by the various types of vegetation. Conduct this type of monitoring for at least two years. The nitrogen data will allow us to determine the principal locations where uptake occurs. The salinity data will allow determination of the effect on nitrogen concentration of mixing of river and Charlotte Harbor waters. Additionally, the salinity data will allow effects of salinity to be separated from effects of other variables of interest such as nitrogen on biological parameters.

Nutrient concentrations are a function of uptake and mixing. Salinity is an index of the degree of mixing and can be used to estimate the change in the concentration of a nutrient that occurs In response to mixing alone. Therefore, salinity monitoring will enhance the study of nitrogen dynamics. The Phase I and Phase II studies have suggested that salinity, particularly over the long term, has an Important Influence over both vegetation and the benthos. It will be necessary to know the history of salinity at each site to separate the effects of salinity from (1) the effects of oxygen on benthic biomass, (2) the effect of SAV coverage on dissolved oxygen levels, and (3) the effect of marsh vegetation type on nutrient uptake.

Ideally, the same sampling stations established In the Phase I and Phase II studies should be used, providing the sites of benthic sampling and primary productivity studies are included in these. Table 1 summarizes suggested field studies, listing the parameters that should be measured and suggested frequency of measurements and indicating those parameters that should be measured synchronously.

Stratification of the river is a major factor affecting bottom oxygen. It is important to determine under what circumstances stratification occurs and the location and areal extent of its occurrence. What river flow rate initiates stratification? What conditions must exist in Charlotte Harbor in order for stratification to occur? How often does it occur? Is it a frequent or unusual event? What locations are anoxic during a stratification event? What acreage of bottom water is affected at each site? Are the same sites affected repeatedly? We need to know more about this phenomenon. A special ancillary sampling effort in conjunction with the sampling design outline may be needed to gain this information. Once locations and times of low oxygen are Identified, special sampling should be conducted to determine areal extent and duration. There also is a need to know the localized affect of bottom scouring and turbulence on the benthos. This would help us better understand the distribution of the benthos and also might help us better evaluate the effect of changes in water flow. Some special sampling for benthos at the mouths of tributaries might help us gain this information.

4. Laboratory Microcosm Study

Conduct a laboratory microcosm study with water from various locations in Myakka River. Add controlled quantities of nitrogen and measure system response in terms of phytoplankton cell concentrations, gross taxonomic composition, and transparency. Distinguish effects of inorganic aid organic forms of nitrogen. Distinguish effects of ammonia and nitrate-nitrite. Determine the relationship between light transmission and phytoplankton concentration. Measure color as a variable also affecting light transmission.

5. Statistical Analyses

Statistical analysis is an essential element of the study to determine whether measured parameters differ significantly in space and time and how they vary relative to each other. For example, statistical tests are needed to determine whether benthic biomass differs significantly among habitats, whether nitrogen concentrations differ significantly among different segments of the river and between the river and its tributaries, whether dissolved oxygen concentrations are significantly higher over seagrass beds than over bare bottom, etc. To make such comparisons it is important not only to measure within each space-time strata but also to have two or more repetitions within each strata.

Regression analyses should be used to test and quantify relationships between variables for which relationships are hypothesized. Both linear and non-linear relationships should be explored. It nay be possible to find a clear statistical relationship between nitrogen concentrations and phytoplankton biomass or dissolved oxygen. A relationship between benthic biomass and dissolved oxygen is likely. Two years of salinity measurements, coupled with data on Myakka River flow. Peace River flow, and sea-level height, could probably be used to develop multiple regression equations that could hind cast the salinity history (i.e., frequency at each salinity) for every sampling site where the salinity measurements were taken. A report by Wang and Browder (1986) describes how this type of estimation was made for stations In Fakka Union Bay in southwest Florida. Statistical analysis of the data collected in the study elements suggested above will help build a better understanding of the system and will provide information to quantify models to generate further understanding.

Table 1. List of parameters to be measured in proposed work and indication of temporal and relative spatial intensity.

	PARAMETERS													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Stage	A				X				X			X		
Depth a	A									X		X		
Velocity	A		X				X		X					
Salinity	A		X		X				X			X		
Nitrate	A		X		X					X			X	
Nitrite	A		X		X					X			X	
Annonia	A		X		X					X			X	
Organic nitrogen	A		X		X					X			X	
Organic carbon														
Particulate	A		X		X					X			X	
Dissolved	A		X		X					X			X	
Color	A				X					X			X	
Phytoplarkton														
Gross taaanomic composition	A		X		X					X			X	
Cell count?	A													
Relative volume, by major														
taxanomic group	A		X		X					X			X	
Dry welghL/vol. water filtered b	A		X		X					X			X	
Chlorophyll a	A		X		X					X			X	
Photosynthesis														
Light and dark. bottle	A		X				X		X					X
or														
C^{14} uptake														
Dissolved oxygen	A			X				X		X		X		
Biological Oxygen demand														
Water oolunn		A			X					X			X	
Top 1 cm substrate		A								X			X	
Top 1 cm substrate														
Dry welght/sq. m		A								X			X	
Ash free dry welght/sq. m		A								X			X	
Bottom vegetation														
Species composition		A									X		X	
Dry weight/sq. m		A									X		X	
Photosynthesis		A									X			X
Benthos														
Taxonomic composition		A								X			X	
Number/sq. m		A								X			X	
Ash free dry weight/sq. m		A								X			X	
Respiration		A									X			X
Fish														
Species composition		A	X							X			X	
Nuriber/sq. m		A	X							X			X	
Ash free dry KBi^ht/sq. m		A	X							X			X	

Table 1. List of parameters to be maasured in proposed work and indication of temporal and relative spatial intensity (cont.).

A	H
B	I
C	J
D	K
E	L
F	M
G	N

[a] Parameters indicated with the same letter should be measured synchronously or near-synchconously.

[b] Actual water depth, needed to convert from concentration to unit area basis (nitrogen, phytoplarkton, etc).

[c] Fish weights could he estimated from length-wet weight relations and vet wai^hL-dry weight relations obtained by the study.

6. Priorities

Based on my present view of the system, I have tentatively given the field investigations itemized above the following priorities:

Priority Number One

The first priority is to complete the description of the spatial and temporal pattern of salinities in the river as a function of Myakka River flow and other variables. The approach initiated in the Phase I and Phase II directly approaches questions that must be answered to adequately evaluate effects of land use and water management changes on natural resources of the river, but data collection needs to be expanded to cover at least spring and neap tides of each month for at least two years to be used to understand the distribution of benthic organisms or to predict the effects of changes in freshwater inflow. Sampling on four tidal cycles each month rather than just two would be desirable. Velocities were not measured in the Phase I and Phase II studies but should be added in follow-up studies in order that a detailed view of the current pattern of the river can be obtained.

Priority Number Two

A map of the river aid quantification of the different types of habitat, by river section, is extremely necessary for three reasons:

(1) to estimate the potential uptake of nitrogen by rooted vegetation, as opposed to phytoplankton.

(2) to estimate the importance of SAV and seagrasses to the dissolved oxygen budget of bottom waters in different segments of the river.

(3) to establish a baseline from which to monitor change in area covered by SAV and seagrasses, by river section.

Priority Number Three

A detailed study of nitrogen concentration in the river as it changes over time and space in relation to salinity, POC, color, near-bottom DO, BOD, and sediment organic content (refractile and labile) is a second high priority necessity. Using statistical analysis, the variation In nitrogen concentrations over time should be examined in relation to the variation In river flow or, possibly, rainfall at the nearest recording station In the watershed. Such a study will show us:

(1) the extent to which nitrogen concentrations vary spatially and temporally In the river now

(2) the relationship between river flow rate (or rainfall) in the watershed and nitrogen concentrations

(3) sections of the river and its tributaries where nitrogen concentrations are presently the highest

(4) how the river compares to its tributaries as nitrogen concentrations in both change over tine

(5) whether near-bottom DO concentrations are correlated with nitrogen concentrations

(6) the extent of potential dilution as water flows downriver and is mixed with Charlotte Harbor water by the tide

(7) specific sections of the river where major uptake occurs, possibly indicating an important effect of vegetation

At the least, this effort will provide a baseline for future monitoring of the effect of waste-water recycling. Increased pasture runoff, Increased fertilizer application, upstream water withdrawals, etc. Since the Phase II study suggested that nitrogen concentrations are affected by rainfall and, presumably, river flow, it is necessary to quantify this relationship in order to evaluate the effect of land use and water management changes on nitrogen concentrations. Knowing the quantitative relationship between nitrogen concentrations and river flow or rainfall would allow us to separate natural variation from man's effects. Comparing the relationship between river concentrations and tributary concentrations now and after the facility is operational also may provide an index of the effect of man's activities on the river. It will be instructive to compare nitrogen concentrations near the Warm Mineral Springs package treatment facility to those in other parts of the river.

Finding a statistically significant relationship between nitrogen concentrations or organic matter concentrations and near-bottom dissolved oxygen concentrations would strongly suggest that DO concentrations would decline if nitrogen or organic material were added to the river. We could even estimate the amount of decline for each incremental increase.

Priority Number Four

A detailed Investigation of the relationship of benthic numerical density, biomass-density, and gross taxonomic composition to near-bottom DO concentration, BOD, sediment organic matter, and habitat is fourth on my list of priorities. Benthic densities varied tremendously among the various segments of the river, according to the Phase I study. Salinity was a likely cause of much of the variation, but bottom DO concentration might have been a second determining factor. Low DO concentrations might, for example, explain the low benthic densities in the upper part of the river. Variation in benthic densities among habitats exposed to the same salinity regime was not examined in the Phase I study. This source of variation must either be explored or avoided; otherwise, it will not be possible to understand relationships between the benthos and DO. We could avoid the issue of habitat effects by sampling only on bare bottom, as was done in the Charlotte Harbor study by Estevez. But I think we need to determine variation among existing habitats for several reasons:

(1) near-bottom DO concentration may be much greater over vegetated bottom;

(2) benthic density and biomass-density may be much greater on vegetated bottom, as Yokel (1975) and Weinstein *et al.* (1977) have found densities to be elsewhere;

(3) coverage by bottom vegetation may decline due to shading by phytoplankton when nitrogen concentrations in the river become elevated.

To the extent possible, benthic sampling sites should coincide with sites where nitrogen *et al.* are being measured.

Examination of the benthos should be emphasized In future work. The species diversity, numerical density, and blomass density of the benthos probably will be sensitive Indicators of the response of the river ecosystem to changes In land use practices or water management. For instance, increased concentrations of nitrogen and organic matter would be likely to depress bottom DO concentrations and lead to a decline In coverage by SAV. On-site retention of pasture and agricultural runoff, which would decrease nitrogen concentrations in the river, might lead to lower nitrogen concentrations in the river and Increased coverage by SAV. Benthic blomass density would likely decrease if bottom DO concentrations or SAV coverage decreased, whereas increases in these variables might lead to Increased benthic blomass density. My trophic analysis suggests that the density and productivity of fish would likely be affected by changes In benthic biomass.

In most benthic studies of taxonomic composition, diversity, and, sometimes, density are examined; but measurements of benthic biomass density are neglected. This is unfortunate if one wants to relate the benthos to fish abundance and biomass, because the biomass density of the benthos relates directly to energy availability to benthic-feeding fish. Benthic diversity or numerical density are poor Indicators of energy availability. Diversity indicates how many species are available but not how much food energy is available. Even numerical density is an Inadequate index of food energy availability, because of the wide variation in the sizes of benthic organisms. Biomass density is the main quantity that should be measured to evaluate potential impacts of changes in the benthos on the fish community. Obtaining ash-free dry weights is important, particularly where shells make up a considerable part of the mass.

Priority Number Five

An understanding of how phytoplankton responds to nitrogen in river water In the existing range of color and salinity gets fourth priority in my view. In "Proposed Work", I recommended complimentary field and laboratory Investigations. Preferably, phytoplankton collections should be made at the same site as measurements of nitrogen, etc.

These following Investigations should be Initiated In the first phase of new work. Results of these investigations, preferably integrated with other information in a preliminary model, could provide a good quantitative indication of whether the other investigations recommended In Proposed Work are really needed. For instance, they could tell us:

(1) whether emergent vegetation in any section of the river could possibly take up a sufficient quantity of nitrogen to be important in moderating nitrogen concentrations in the water column

(2) whether upriver SAV substantially increases near-bottom DO concentrations;

(3) whether upriver SAV supports substantially higher benthic biomass densities than adjacent habitats and whether this makes a substantial difference to the overall biomass offered to fish by the river segment;

(4) whether downriver seagrasses substantially increase near-bottom DO concentrations;

(5) whether downriver seagrasses support substantially higher benthic biomass densities than adjacent habitats and whether this makes a substantial difference to the overall blomass offered to fish by the river segment.

Area of coverage and rates of photosynthesis and net production will be important factors in making these evaluations.

7. References

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