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SEBASTIAN RIVER SALINITY REGIME

Report of a Study

Part I. Review of Goals, Policies, and Objectives

Part II: Segmentation

Parts III and IV: Recommended Targets

(Contract 92W-177)

Submitted to the:

St. Johns River Water Management District

by the:

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EXECUTIVE SUMMARY

This is the third and final report of a project concerning desirable salinity conditions in the Sebastian River and adjacent Indian River Lagoon. A perception exists among resource managers that the present salinity regime of the Sebastian River system is undesirable. The St. Johns River Water Management District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the Sebastian River and adjacent waters of the Indian River Lagoon. The District can then calculate discharges needed to produce the desired salinity regime, or conclude that optimal discharges are beyond its control.

The values of studying salinity and making it a management priority in estuaries are four-fold. First, salinity has intrinsic significance as an important regulatory factor. Second, changes in the salinity regime of an estuary tend to be relatively easy to handle from a computational and practical point of view. Third, eliminating salinity as a problem clears the way for studies of, and corrective actions for, more insidious factors. Fourth, the strong covariance of salinity and other factors that tend to be management problems in estuaries makes salinity a useful tool in their analysis.

Freshwater inflow and salinity are integral aspects of estuaries. Major, largely unnoticed changes in these factors have been underway for decades. In Florida, as elsewhere in the world, these changes are likely to accelerate. Implications for estuarine productivity and management are critical. Existing data are seriously incomplete. At the present time, no comprehensive literature reviews exist of ecological impacts in estuaries resulting from altered freshwater inflow or salinity. Part of the reason for this situation is that inflows can be altered in many direct and indirect ways. Such alterations include increases or decreases in the quantity of inflow, changes in the short-to-long period temporal variations of inflow, inflow location, etc. Another reason is that truly comprehensive ecological studies of estuaries are few and have tended to be made in relatively pristine, rather than altered, estuaries. Scientists and policy analysts agree that a coherent and transferable science is needed to determine the freshwater inflow and salinity requirements of estuaries. This report presents the results of one attempt to systematically determine a restorative and protective salinity regime for the Sebastian River and adjacent Indian River Lagoon.

Not counting basin alterations and augmented river flows, the salinity trend of the Indian River Lagoon during the past few centuries and especially the 20th Century has been one of increase. Sea level rise, island breaching, and inlet stabilization have been working to increase the connection between the Lagoon and Atlantic Ocean. The increased connection has altered water levels and circulation, sedimentation, salinity, and the numbers and kinds of plants and animals inhabiting the Lagoon. During this period, the major source of natural variation was probably related to the incidence and severity of tropical storms and hurricanes.

Large changes have occurred to inflows of both fresh and salt water to the River and Lagoon near Sebastian. Discharge of the Sebastian River has been increasing for decades because (1) gaps in the coastal ridge were closed, (2) wetlands in the basin were diked and filled, (3) drainage canals and laterals were dug, (4) the deepest canals increased drainage of the non-artesian aquifer, (5) deep wells pumping the Floridan aquifer added groundwater to surface waters, especially as agricultural runoff, and (6) urbanization has increased stormwater runoff. During the same period, Sebastian Inlet has been open and stabilized. Thus, the Sebastian area has become a mixing zone for higher freshwater inflows and higher salt water inflows than occurred historically.

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The first component of this project was an analysis of existing goals for the study area, emphasizing those that directly or indirectly related to the question of salinity. The first report assessed existing laws, policies and objectives at federal to local government levels for insight to official expectations for the Sebastian River or Indian River Lagoon, and found:

1. There is an overall intent to reduce fresh water inflows to the River and Lagoon. A reduction of inflow will result in higher salinities in both the River and Lagoon.

2. At the same time, there is a perceived need to provide base flows for certain oligohaline species and their habitats. A base flow will result in the establishment of permanent, tidal fresh water and low salinity areas.

3. Inflows and salinities should vary according to seasonal or daily or other cyclic patterns. At the same time, the rate of change of inflows, and consequently of salinity variations, should be moderated. Given the concern for acute changes, guidelines for rates and ranges of salinity variation are as important as average salinity conditions.

4. The peaks of inflow should coincide with the natural wet season runoff of the basin, meaning that low salinities caused by regulated inflows should coincide with low salinities caused by natural runoff. Natural seasonality of salinity variation is sought.

5. The area and duration of low salinities caused by natural runoff should not be made significantly larger or longer because of regulated inflows, in order to protect seagrasses, shellfish, and other estuarine biota in the Lagoon.

6. Additional constraints to salinity are believed needed in the Lagoon near the mouth of the River in order to restore and enhance seagrasses, and may be needed within 2.5 miles of the River mouth to protect hard clams or oysters.

7. A minimum of 20 parts per thousand is presently in use as an interim salinity standard during hard clam spawning seasons of spring and fall.

It is noteworthy that these findings already exist in official program and policy documents affecting the study area. Findings are instructive insofar as the appropriate direction for future salinity alterations is suggested, but they are incomplete. In order to add detail to these findings, additional research was undertaken.

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The second component addressed the geographical segmentation of the study area. Pertinent reports and data were used to divide the study area into discrete geographical units called segments (Figure I). The Indian River Lagoon near Sebastian, and the Sebastian River, were subdivided according to physical, chemical and biological boundaries and other natural transitional zones. Management boundaries (shellfish areas, aquatic preserves, etc.) were also used to define segments. Segments formed the basis for additional analyses and the formulation of recommended salinity conditions, called targets. The second project report defines the boundaries of each segment.

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This third and final report recommends salinity targets based on community and habitat requirements (Task 3 of the project) and individual species of ecological or economic concern (Task 4). Potential salinity targets were compiled through literature reviews, analysis of salinity data, and interviews. Summary reports were prepared for (1) freshwater inflow and estuarine productivity, (2) an overview of small coastal rivers of peninsular Florida, (3) case studies of altered inflow and salinity, (4) environmental setting, early conditions, and changes in the study area, (5) salinity, (6) seagrasses, (7) hard clams, (8) oysters, (9) fish, (10) species at risk, and (11), recapitulation of past task findings. In each review, the findings, salinity targets, and recommendations potentially pertinent to a salinity regime for the Sebastian River were identified. A total of 56 potential guidelines was compiled from these sources. The potentially useful findings were then compiled and evaluated in a synthesis. Final salinity recommendations (targets) were inferred from the list of potentially useful findings, plus additional considerations.

Salinity targets were organized around a spatial or landscape framework. A geographic or landscape approach to formulating salinity recommendations is possible because of the availability of spatially-referenced information. Sufficient information exists to support general salinity characteristics from marine to oligohaline waters, including intermediate mixing (estuarine) waters. Sufficient information also exists to specify the nature of salinity where the Sebastian River enters the Indian River Lagoon. Information regarding temporal variation was added to this spatial framework to address particular habitat or species requirements.

Separate targets are identified for each of 11 geographic segments or specific locations (Table I). Values are given for means, standard deviations (S.D.), coefficients of variation (C.V.), minima, maxima, and ranges of salinity recommended for each area. In general, these salinity targets resemble the existing salinity structure of the system, but there are several important differences:

1. Salinity targets at Segment S-157 are substantially lowered, from a present-day mean of 10.4 ppt to less than 1 ppt. The new S.D. is less than 2 ppt compared to 9.1 ppt. Maximum salinity is reduced greatly, from 29 ppt to 3 ppt.

2. The maximum recommended salinity target in Segment C-54 (15 ppt) is reduced by almost half from the Segment's existing maximum salinity (29 ppt).

3. The C.V. of salinity in the South Prong is increased from 87% to 133%.

4. Maximum recommended salinity is decreased in the North Prong, from 30 ppt to 20 ppt.

5. Seeming contradictions are proposed for the River Segment: (A) salinity range is contracted by raising minimum and lowering maximum salinity targets, while (B) mean salinity targets are unchanged but (C) S.D. is doubled and C.V. is increased by 50 percent.

6. Minimum salinity targets in the River Mouth and Inlet Segments are increased from 0 to 10 ppt and from 9 ppt to 28 ppt, respectively.

This set of recommended values address surface waters only because surface data are more numerous than data at depth. Once the relationship of bottom salinity to surface salinity is evaluated analytically for the study area, separate recommendations may be sought. For now, these recommended targets for surface salinity imply a given salinity structure near the bottom, and no specific problems resulting therefrom are known. Where possible, specific targets for bottom salinity in particular segments are presented below.

Weekly or bi-weekly sampling is recommended as a reasonable interval between sampling events employing grab samples. Continuous recording instruments should be deployed at stations in the River and River Mouth Segments.

Because the duration targets pertain to neighboring segments, it may be possible to employ just one such instrument in the vicinity of the U.S. 1 bridge. Because the critical targets reflect summer and/or high discharge periods, instrument use could be restricted to times and conditions when duration limits were most likely to be exceeded.

Taken as a whole, the recommended target salinities should have the following effects. First, salinity gradients across the landscape will be stabilized, with a stronger longitudinal signal from the ocean to freshwaters. Second, the low salinity reaches of the landscape will be insulated more from incursions of high-salinity water, in the past as high as 29 ppt. Third, lagoonal landscapes will be protected from excursions of low-salinity waters, at least insofar as the Sebastian River is their source. Fourth, and perhaps of greatest potential benefit, the largest range and variation in salinity within the landscape will be moved out of the Indian River Lagoon and into the confluent reach of the Sebastian River.

This last action has two benefits. Waters of highly variable salinity will be sheltered from the dispersive effects of winds. Also, highly variable salinity will be "registered" to a reach of river naturally associated with such conditions.

Ecological consequences of these targets are mostly beneficial. In the Lagoon, mean salinity requirements of hard clams and seagrasses would be met all of the time in the Inlet Segment, and much of the time in the River Mouth Segment. Extreme salinity stress would be reduced greatly. All other things being equal, the seagrass, Halodule, and the hard clam, Mercenaria, should successfully persist in close proximity to the River mouth. The chances of this happening are improved by additional targets defined for particular species of value (Table II).

If clams are the focus for salinity management in the Indian River Lagoon, then oyster areas may be restricted to the Sebastian River. Oysters in the River would not be safe to eat but they could serve to demonstrate the attainment of target salinity regimes. Oysters also accumulate a wide array of pollutants and are useful as indicator species. More importantly, oyster reefs are an important habitat for a wide variety of associated organisms. Small crabs, fish, shrimp, sponges, other mollusks, and numerous polychaete species are all typical inhabitants of healthy oyster reef communities. An increase of oyster habitat in the tidal reaches of the Sebastian River would increase the River's overall levels of biodiversity and productivity.

Recommended salinities should not have adverse effects on three fish species of economic interest, the red drum, snook, and spotted seatrout. The salinity requirements of these species are not completely known, but recommended salinities fall within the envelope of known, protective salinities. By the same token, recommended salinities will preserve tidal freshwater and low salinity environments required by several fish species officially listed as threatened. Recommendations for flowing fresh waters also will perpetuate habitat requirements of the West Indian manatee.

We found very little useful information concerning the maximum rates of salinity change tolerable by estuarine or marine organisms. The only finding, for hard clams, results in the fastest possible rate of salinity change that is measurable. Without better data on real-time rates of salinity change near Sebastian, an additional precaution is recommended, to make the limits contingent upon a comparison to "background" rates of change. A definition of background is offered but it does little to change our view that this target should be advisory rather than certain.

In the event that all salinity targets cannot simultaneously be met, the following priorities are suggested. Minimum targets are more important than maximum targets. In upstream waters, maintenance of low mean salinities is more important than the maintenance of salinity variation. In marine waters, low variation is probably more important than the mean salinities they accompany. Achieving targets for the River and River Mouth Segments, and letting salinity vary as needed in other segments, will do significant good. And as long as problems of low salinity stress remain a problem, bias in sampling programs toward low tide conditions is justified.

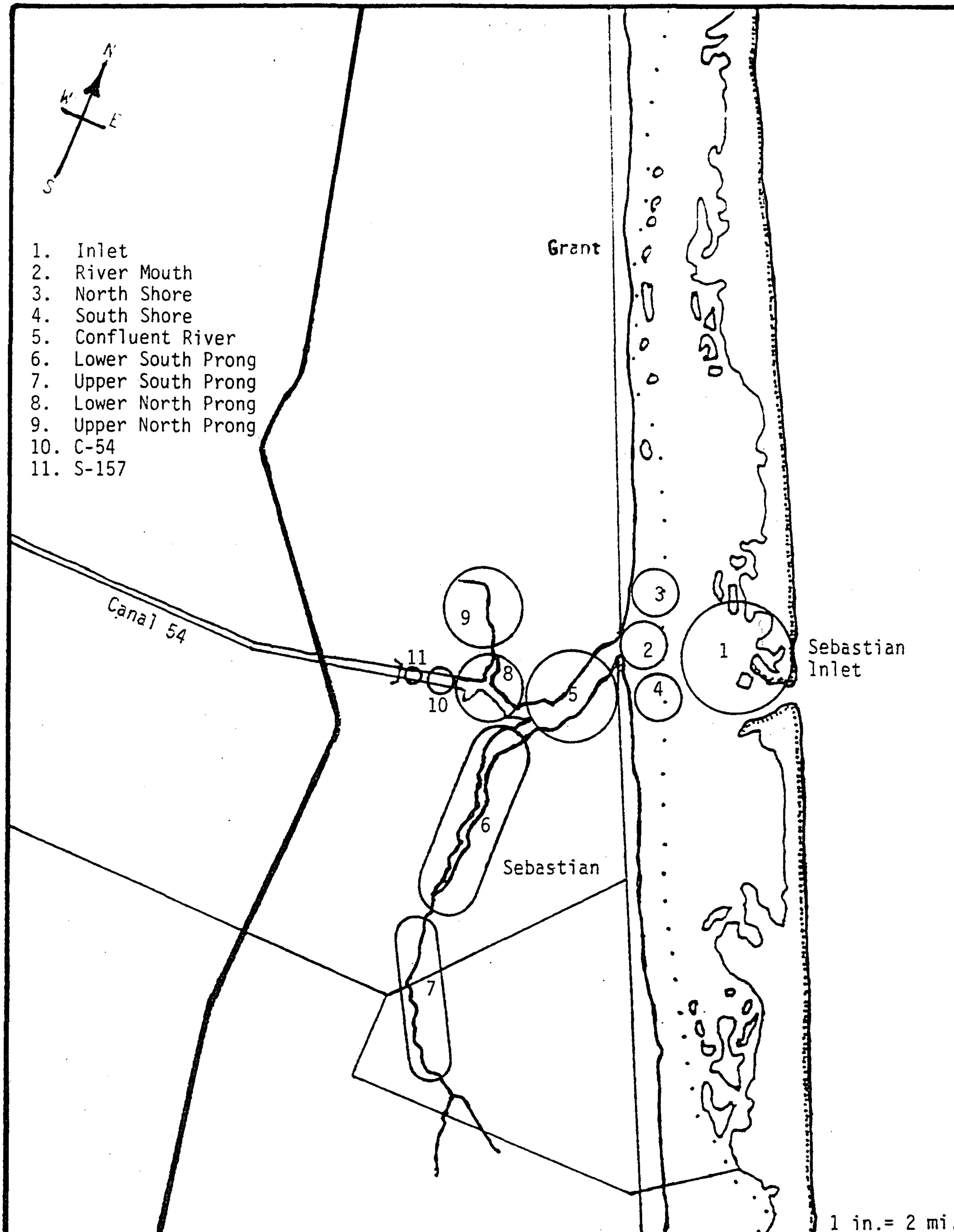

Figure I. Salinity Segments. See Table 1 in Section 14 for definitions.

Table I. Surface Salinity Targets by Segment or Site (parts per thousand). Segment names are in quotes and the names of geographic points are in parentheses.

"Segment"(Site)	Mean	Standard Deviation	C.V.[1], %	Minimum	Maximum	Range
(Sebastian Inlet)	33	5	15	28	--	--
"Inlet"	30	5	17	28	--	--
(ICW[2])	25	5	20	20	--	--
"River Mouth"	20	10	50	10	--	--
"River"	15	15	100	5	30	25
"Lower Prongs[3]"	6	8	133	0	20	20
"C-54"	5	8	160	0	15	15
"Upper Prongs[3]"	1	2	200	0	4	4
"S-157"	0.5	<2.0	--	0	3	3

[1]/Coefficient of variation
[2]/At county line
[3]/North and South Prongs

Table II. Additional salinity (S.) targets, in parts per thousand (ppt.).

Target	Resource	Affected Segments	Reference[1]
Mean bottom S = 25.0 ppt ± 10 ppt or less	Halodule (seagrass)	River Mouth	[25]
0 ppt duration at bottom < 24 hr.	Syringodium (seagrass)	River Mouth	[26]
Annual mean bottom S > 20 ppt.	Mercenaria (hard clam)	River Mouth	[27]
Minimum bottom S ≥ 10 ppt.	Mercenaria	River Mouth	[28]
Summer mean bottom S > 20 ppt ± 5 ppt or less	Mercenaria	River Mouth	[29]
Duration of summer mean bottom S < 15 ppt ≤ 7 days	Mercenaria	River Mouth	[29]
Non-summer mean bottom S ≥ 25 ppt ± 5 ppt or less	Mercenaria	River Mouth	[30,31]
Duration of S < 6 ppt < 14 days	Crassostrea (oyster)	River	[34]
Duration of S < 2 ppt < 7 days	Crassostrea	River	[34]
Provide flowing/ falling freshwater	Listed fish species and manatees	S-157; Lower N. Prong	[39]

1/ See list of findings and recommendations in Section 13.

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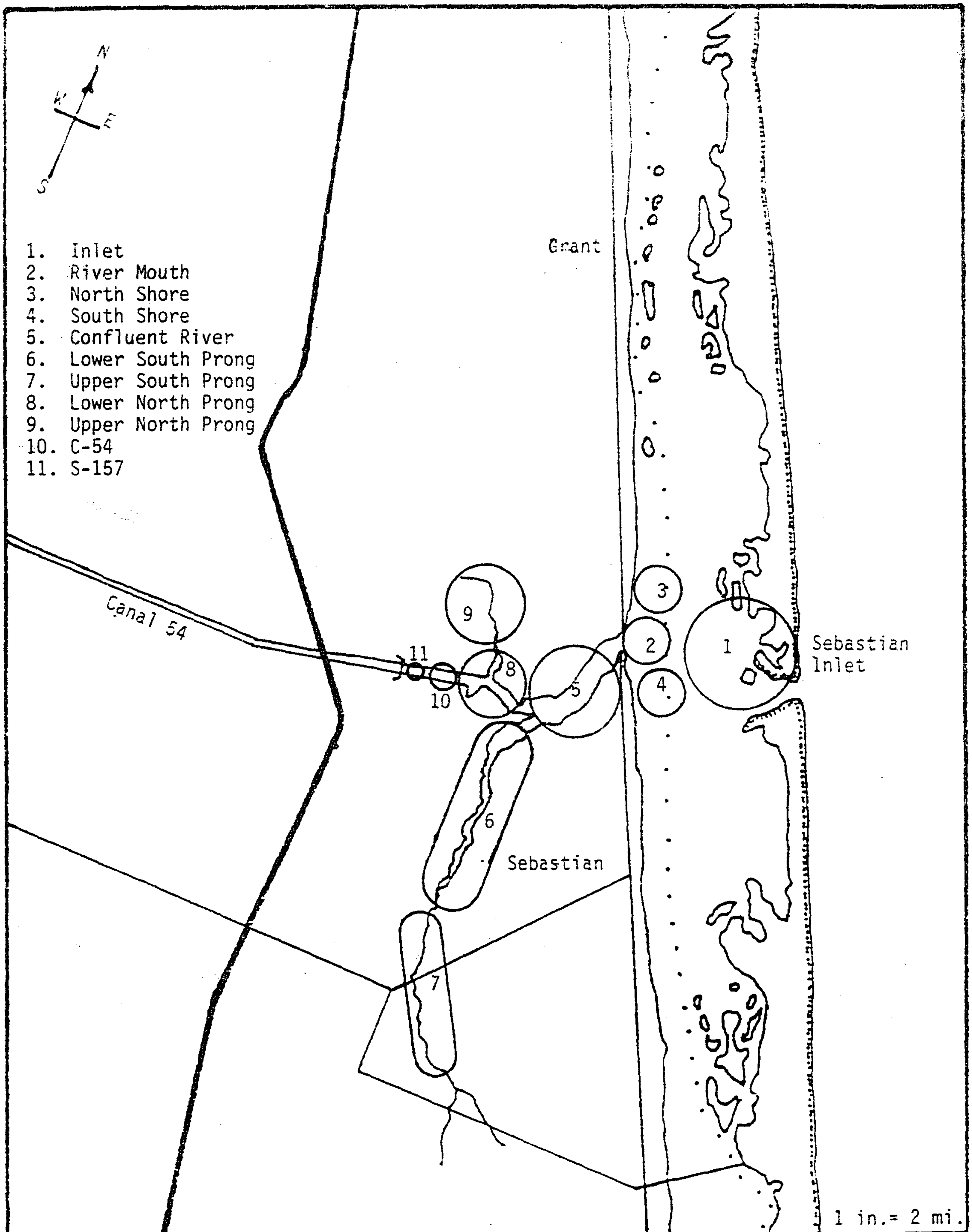

Figure 28. Salinity Segments. See text for definitions.

PART I

SEBASTIAN RIVER SALINITY REGIME

Part I. Review of Goals, Policies, and Objectives

(Contract 92W-177)

submitted October 1992 to:

St. Johns River Water Management District

by the:

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Mote Marine Laboratory Technical Report Number 275

EXECUTIVE SUMMARY

This is the first report of a project concerning desireable salinity conditions in the Sebastian River and adjacent Indian River Lagoon. The St. Johns River Water Management District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the study area. Because of the known importance of salinity in estuarine productivity, considerable interest has arisen in salinity optimization: the process of remedying problems attributable to changes in natural patterns of fresh water inflow to estuaries. This report addresses a key task in salinity optimization, namely the formal analysis of legal and official statements of governments and resource management agencies concerning the desired outcomes or results of resource management programs. In this report, attention is drawn to existing "goals" for the River and Lagoon that inform the process of salinity optimization. Goal statements for the natural resources of the River and Lagoon were sought in a number of sources. As used here, "goals" were interpreted broadly in 40 documents compiled from agency libraries and other sources. Twenty nine of the 40 documents were considered relevant to this project. More than half (nineteen) are federal or state-level guidance. Half deal with salinity, fresh water inflow and/or living resource targets directly, and half do so indirectly. Most (twenty one) contain language that in some way indicates living resource targets or management end-points. About half refer to surface waters (eleven) or fresh water inflow issues (ten). Only seven contain language that in some way refers to salinity per se. A synthesis was made of the explicit salinity goals plus salinity goals that may be inferred from less direct sources reviewed in this report. All are already present in existing regulatory and management programs. No priorities or relative importance were discernable among them. The guidelines will be considered in subsequent phases of the project, but methods and data yet to be introduced may result in their modification. 1. There is an overall intent to reduce fresh water inflows to the River and Lagoon. A reduction of inflow will result in higher salinities in both the River and Lagoon. 2. At the same time, there is a perceived need to provide base flows for certain oligohaline species and their habitats. A base flow will result in the establishment of permanent, tidal fresh water and low salinity areas. 3. Inflows and salinities should vary according to seasonal or daily or other cyclic patterns: at the same time, the rate of change of inflows, and consequently of salinity variations, should be moderated. Given the concern for acute changes, guidelines for rates and ranges of salinity variation are as important as average salinity conditions. 4. The peaks of inflow should coincide with the natural wet season runoff of the basin, meaning that low salinities caused by regulated inflows should coincide with low salinities caused by natural runoff. Natural seasonality of salinity variation is sought. 5. The area and duration of low salinities caused by natural runoff should not be made significantly larger or longer because of regulated inflows, in order to protect seagrasses, shellfish, and other estuarine biota in the Lagoon. 6. Additional constraints to salinity are believed needed in the Lagoon near the mouth of the River in order to restore and enhance seagrasses, and may be needed within 2.5 miles of the river mouth to protect hard clams or oysters. 7. A minimum of 20.0 parts per thousand is presently in use as an interim salinity standard during hard clam spawning seasons of spring and fall.

PREFACE

This is the first report of a project concerning desireable salinity conditions in the Sebastian River and adjacent Indian River Lagoon. A perception exists that the present salinity regime of the Sebastian River system is undesirable. Based on studies in nearby estuaries (Haunert and Startzman, 1985) discharges of interbasin canals such as the Fellsmere Canal and C-54 are implicated as a component of the problem. The District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the Sebastian River and adjacent waters of the Indian River Lagoon. The District can then calculate discharges needed to produce the desired salinity regime, or conclude that optimal discharges are beyond its control.

This project is one of several activities concerning resource planning and management in the Sebastian River and Lagoon region. The St. Johns River Water Management District has undertaken a basin runoff modeling project to determine the quantity of water entering the Sebastian River from various sources. Results of this effort will be used as input to a circulation and salinity model of the area, being produced for the District by the U.S. Geological Survey. The USGS modeling effort will be coordinated with a model of the Indian River Lagoon from the Sebastian River north to, and including, Turkey Creek, being produced by the Florida Institute of Technology.

The final results of this project will be used in concert with the three modeling efforts described above to estimate the attainability of improvements to fresh water discharge and overall ecological conditions in and near the Sebastian River.

Acknowledgements

Robert Virnstein, Joel Steward, John Higman and Fred Morris of the St. Johns River Water Management District have been very helpful in providing reports and data, maps, and general guidance during the initiation of this project. Each also provided comments on early drafts of this report. Diane Barile and staff of the Marine Resources Council volunteered much unique data and insight on the Sebastian River area and its management issues. The

Indian River National Estuary Program, Merritt Island (Pelican Island) National Wildlife Refuge office, Florida Departments of Environmental Regulation and Natural Resources, and the libraries of Florida Institute of Technology and Harbor Branch Oceanographic Institution were very responsive to requests for assistance. Jean MaGuire, Mote Marine Librarian, performed valuable electronic literature searches.

Style

"Fresh water" and "seagrass" are terms of choice used in this report, although "freshwater" and "sea grass" are given where either appears as part of a quote or paraphrasing of text reviewed in the Appendix. References are noted by two systems. Literature appearing in the References section is cited within the text by Author (date), whereas literature appearing in the Appendix is cited within the text by sequential number.

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INTRODUCTION

Estuaries vary greatly in terms of size and shape, fresh water inflow and tidal range, and ecological characteristics. In Florida, estuaries vary over six orders of magnitude in terms of their sizes and fresh water inflows. Florida estuaries may be highly stratified where fresh water inflows greatly exceed tidal prism volumes. Or they may be vertically homogeneous or prone to hyper-salinity if tidal prisms and evaporation are greater than inflows, and wind effects are significant. The natural Indian River Lagoon is an example of the latter case.

Fresh water inflow is essential to estuaries for a number of reasons (Snedaker and De Sylva, 1977; Cross and Williams, 1981; Estevez et al., 1984; Browder, 1991). Chief among these is the effect of inflow on salinity. Tidal fresh waters and reaches of progressively higher salinity are necessary for the existence of unique communities (Odum et al., 1982) and the successful completion of fish and invertebrate life cycles (Bulger et al., 1990). The area of wetlands and quantity of fresh water inflow broadly control overall estuarine productivity of many species (Deegan et al., 1986). The abundance of some species (pink shrimp -- Browder, 1985; oysters -- Wilbur, 1992) in a given year may be a function of dry season inflow and salinity during the previous year. As a consequence of the known importance of salinity in estuarine productivity, considerable interest has arisen in salinity optimization.

Salinity optimization refers to the process of remedying problems attributable to changes in natural patterns of fresh water inflow[1] to estuaries. It is a developing science that bears a similarity to the determination of instream flows for rivers and streams. More methods have been developed and tested to estimate the flow needs of rivers, than estuaries, but a growing body of theory and case studies offers much promise for progress in estuarine settings. Optimization is in some ways a misleading term in that it presumes knowledge of the conditions required for maximizing system components; as normally used it refers instead to

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[1]/ Or circulation.

ameliorating or mitigating obvious harm to an estuary resulting from changes to its fresh water inflow.

Several methods are at least potentially available for establishing optimal fresh water inflows to estuaries. As used here, optimization is not meant to imply that the actual events and processes of an estuary are necessarily maintained at maximum levels because of a particular inflow regime. Instead, the term is used inclusively to refer to the types of decisions facing resource managers in the real world, such as how much must flow be reduced to eliminate a certain problem. The determination of optimal salinities takes two general forms:

> Case 1. By how much can the discharge of a natural and free-flowing stream be changed (increased or decreased) without causing significant salinity-related impacts of estuarine nature?
>
> Case 2. By how much must the discharge of a regulated stream be changed (increased or decreased) in order to eliminate significant salinity-related impacts of estuarine nature?

Florida examples of Case 1 include the Apalachicola, Suwannee, Alafia, Myakka and Peace Rivers, and west-coast spring runs. Case 2 examples include the Hillsborough, Manatee, and Loxahatchee Rivers, where too little water is or was released (Estevez et al., 1991a and 1991b). The Caloosahatchee and St. Lucie Rivers, the C-111 canal to Florida Bay, and the Golden Gate Estates canal to Faka Union Bay are Case 2 examples where too much water is or was released.

Techniques available to address these two cases are affected by several constraints. Techniques are easier to apply where management goals are relevant to salinity and the goals are unambiguously stated (Estevez, 1991). Techniques are easier to apply when historic data (rainfall, discharge, salinity, valued living resources) are abundant. Case 2 techniques are easier to apply where significant impacts have been well documented.

Optimization techniques for Case 2 (excess flow) may involve the comparison of existing salinity regimes in a system to:

-Historic (pre-settlement) salinity regimes;

-The salinity regime of a comparable but unregulated system;

-Known salinity requirements of specific communities, habitats, species, life stages or other biological attributes, and/or salinity regimes associated with beneficial social uses.

-*A priori* salinity conditions based on general ecological theory and knowledge of estuarine structure and function.

In all of these cases, however, four broad principles can be offered. First is recognition that the characteristics of each estuary are unique and must be considered in developing inflow recommendations. Second is recognition that, though insufficient as an analytical or diagnostic tool for certain problems or estuaries, salinity has come to be regarded as one of the most important independent variables affecting natural resources of value in estuaries. A third principle is perhaps the most important, that there is no better alternative method for optimization than long-term, simultaneous measurement of inflows, salinity, and the status and trends of valued resources within the affected estuary. Regrettably, these are the rarest of actual optimization attempts.

The last principle is the importance of goal statements for the affected estuary. Few goals exist for estuarine management that are intrinsically derived from a given science. From biology the goal of avoiding species extinction is generally accepted as intrinsically meaningful. But on the whole, goals and objectives for estuaries and natural resources generally are statements of ambition for the resources that originate in broader social and legal contexts.

This report addresses the fourth consideration in salinity optimization, namely the legal and official statements of governments and resource management agencies, both public and private, concerning the desired outcomes or results of resource management programs. In this report, attention is drawn to existing "goals" for the Sebastian River and Indian River Lagoon that inform the process of salinity optimization.

METHODS

Goal statements for the physical, chemical and biological resources of the Sebastian River and Indian River Lagoon were sought in a number of sources. As used here, "goals" were interpreted loosely so as to include legislative intent, statements taken from Florida Statutes and the Florida Administrative Code, policies and objectives from regional and local government comprehensive plans, resource management plans, and other sources.

A total of 40 documents was compiled from agency libraries and other sources. Three sources of information that were particularly useful were Marine Resources Council (1987), *"Analysis of Management Agencies and Jurisdictions of the Indian River Lagoon"*; White and Busby (1990), *"Assessment of Management Strategies for the Indian River Lagoon"*; and Gilbrook (1992), *"Inventory and Analysis of Management and Regulatory Programs Affecting the Indian River Lagoon."*

A synopsis of each document's authority, scope, contents and applications is given in Appendix 1. Documents in Appendix 1 are arranged beginning with federal sources and ending with local government and private sources. The Appendix quotes passages that make specific references to salinity, fresh water inflow, or living resources that may be affected by these physical parameters. Interesting background information is included, as well. All pertinent "goal statements" are reported in each synopsis. Each synopsis also contains a brief analysis of how the goal statements pertain to the primary issue of salinity or secondary issues of fresh water inflow, valued species, or related resources.

RESULTS

Twenty nine of the 40 documents were considered relevant to the Sebastian River salinity project (Table 1). In general terms the documents may be summarized as follows:

1. More than half (nineteen) are federal or state-level guidance.
2. Half deal with salinity, fresh water inflow and/or living resource targets directly, and half do so indirectly. Many laws and rules, for example, reserve the right of an agency to become involved with these issues but do not make direct references to them, or offer explicit goal statements.
3. Most (twenty one) contain language that in some way indicates living resource targets or management end-points. About half refer to surface waters (eleven) or fresh water inflow issues (ten). Only seven (Items 7,9,12,16,20,22, and 23 in Table 1) contain language that in some way refers to salinity per se.

A variety of pertinent requirements and recommendations arose from the review. Some, especially the more recent management documents specific to the Indian River Lagoon, speak directly to the issues of salinity and fresh water inflow. Others produce interesting results when applied to or interpreted in terms of the issues of salinity and fresh water.

Direct Guidance

The most direct statement of expectations for salinity in the Lagoon, near the Sebastian River, exists as an interim or incipient salinity standard developed by the St. Johns River Water Management District (Item 23 in Table 1). In 1989, the District analyzed historic data, and measurements made during three surveys, to establish a salinity standard for the Lagoon near the mouth of Turkey Creek. The standard calls for a minimum salinity of 20 parts per thousand (ppt) at a distance of 1000 meters from the mouth of the creek, during March-May and September-November. This standard, "must be maintained to ensure viable [hard] clam populations and survival of their progeny," according to the District report. The same salinity standard has

Table 1. Laws, rules, programs and plans reviewed for their relevance to fresh water inflow and salinity targets.

Federal

1. Endangered Species Act of 1973
2. Marine Mammal Protection Act of 1972
3. Clean Water Act of 1987
4. Draft Management Plan -- Pelican Island National Wildlife Refuge
5. Central and Southern Florida Project for Flood Control

Federal - State

6. Indian River Lagoon National Estuary Program Management Conference Agreement
7. Indian River Lagoon NEP: Annual Work Plans 1991-1993

State

8. Chapter 373 Florida Statutes -- Water Resources Act
9. Chapter 17-40 Florida Administrative Code -- Water Policy
10. Chapter 17-43 Florida Administrative Code -- S.W.I.M. Rule
11. Chapter 403 Florida Statutes -- Environmental Control
12. Chapter 17-302 Florida Administrative Code -- Surface Water Quality
13. Chapter 16-20 Florida Administrative Code -- Aquatic Preserves
14. Indian River -- Malabar to Vero Beach Aquatic Preserve Management Plan
15. Chapter 17-4 Florida Administrative Code -- Permits
16. Governor's Nomination of the Indian River Lagoon to the National Estuary Program
17. Indian River Lagoon System Management Plan
18. Hutchinson Island Resource Planning and Management Plan

Regional

19. Rules of the St. Johns River Water Management District
20. SWIM Plan for the Indian River Lagoon
21. Draft Rules and District Programs in Progress
22. Sebastian River Salinity Regime -- RFP and Related Guidance
23. Effects on Lagoon Salinity from WCDSB Canal 1 Discharges
24. Regional Comprehensive Policy Plan

Local and Private

25. Brevard County Comprehensive Plan
26. Indian River County Comprehensive Plan
27. City of Sebastian Comprehensive Plan
28. Management Plan and Implementation Strategy for the IRL Systems
29. Brevard County Aquaculture Task Force Recommendations

been applied to the Lagoon near the mouth of the Sebastian River since the summer of 1990, serving to inform regulation of C-54 discharges.

Other direct references to salinity are less detailed. For example, one goal of the S.W.I.M. Plan for the Indian River Lagoon is "To attain and maintain water and sediment of sufficient quality (Class III or better) in order to support a healthy, macrophyte-based, estuarine lagoon ecosystem." In the context of that goal the Plan identifies undesirable salinity fluctuations as a major issue and states an objective of managing fresh water inflows from point and nonpoint sources to minimize their impacts on salinity. The Plan identifies the development of a Sebastian River Management Plan as a priority project, in which "the primary element of this plan is the regulation of fresh water discharges and improvement of water quality in the river and lagoon." The Plan does not, however, indicate the specific features of a desirable salinity regime.

In another example, Chapter 17-40 F.A.C. (Water Policy) provides that water management programs, rules and plans shall seek to establish minimum flows and levels to protect water resources and the environmental values associated with marine, estuarine, fresh water and wetlands ecology. The rule states that a primary goal of the state's stormwater management program is "...to maintain the appropriate salinity regimes in estuaries needed to support the natural flora and fauna...".

Indirect Guidance

While state water policy quoted above speaks directly to salinity goals for estuaries, other rules do so only indirectly. Chapter 13-302 F.A.C. (Surface Water Quality) governs the amount of change in specific parameters allowed by discharges. Among the guidance it provides is:

- "In predominantly marine waters the chloride content shall not be increased more than ten percent (10%) above normal background chloride content, and that normal daily and seasonal fluctuations in chloride levels shall be maintained";
- "Specific conductance shall not be increased more than 50% above background or to 1,275 micromhos per centimeter, whichever is greater, in predominantly fresh waters"; and

o For Classes I, II and III waters, biological integrity cannot be reduced to less than 75% of background. ("Biological integrity" is defined in the rule as the Shannon-Weaver diversity index and "background" is defined as condition of a water body in the absence of an activity or pollutant.)

These criteria were meant to apply as limits to the effects of a point source of pollution but suggest the amounts of change considered tolerable by the state.

A related but more complicated example of how a rule may be interpreted in the context of salinity occurs with respect to Chapter 17-4 F.A.C. (Permits), on the subject of discharges and mixing zones of pollutants. The rule allows for mixing zones but states that "no mixing zone...shall be allowed to significantly impair any of the designated uses of the receiving body of water." Some of the considerations for mixing zones include:

1. Condition of the receiving body of water including present and future flow conditions and present and future sources of pollutants;
2. The nature, volume and frequency of the proposed discharge including any possible synergistic effects with other pollutants or substances which may be present in the receiving body of water;
3. A mixing zone shall not include a nursery area of indigenous aquatic life or any area approved by the Department of Natural Resources for shellfish harvesting;
4. In lakes, estuaries, bays, lagoons, bayous, sounds and coastal waters, the area of a mixing zone shall not exceed 125,600 square meters, and all mixing zones shall not exceed 10 percent of an estuary's area;
5. The maximum concentration of wastes in the mixing zone shall not exceed the amount lethal to 50 percent of the test organisms in 96 hours (96 hr LC_{50}) for a species significant to the indigenous aquatic community.

Although largely a procedural rule, it does provide some guidance useful to the present Sebastian River case, although it should be noted that board-approved works of a water management district are probably exempted from the permit requirements of this rule. Furthermore, the rule does not appear to speak to the discharge of fresh water per se. Nevertheless, the rule provides insight to limits the state seeks in permitting new sources of pollutants to surface waters and these features may be instructive for the Sebastian River study.

Considering fresh water as a pollutant, for example, the rule requires that the nature, volume and frequency of the proposed [fresh water] discharge including any possible synergistic effects with [fresh water already] present in the receiving body of water be considered. Likewise, a mixing zone [of fresh water] shall not include a nursery area of indigenous aquatic life or any area approved by the Department of Natural Resources for shellfish harvesting.

The rule states that in estuaries [and] lagoons the area of a mixing zone shall not exceed 125,600 square meters, and all mixing zones shall not exceed 10 percent of an estuary's area. It is presently not known whether 10 percent of the Indian River Lagoon's total surface area is affected by the "mixing zones" of canals. On the other hand, 125,600 square meters as a maximum mixing zone is equal to about 31 acres, or an area of the Lagoon enclosed by a radius of 935 feet from the mouth of the Sebastian River.

Some sources specify targets for surface water management or the specific regulation of fresh water discharges which have value in the context of salinity. The Indian River -- Malabar to Vero Beach Aquatic Preserve Management Plan contains a major policy directive to, "Require, through the efforts of DER, water management districts, and mosquito control districts for (sic) the maintenance of the naturally high water quality of the estuary [and] to ensure the natural seasonal flow fluctuations of freshwater into the estuary."

Another example of indirect guidance for salinity optimization exists in Chapter 40C-4 (Management and Storage of Surface Waters within the St. Johns River Water Management District) which states, "It is an objective of the District to, where practical, curtail diversions of water from the Upper St. Johns River Hydrologic Basin into coastal receiving waters." The ambition to reduce inter-basin diversions of water into coastal receiving waters implies that the timing and/or amounts of inflow to the Indian River Lagoon should be changed, with an overall effect of increasing salinity.

The Treasure Coast Regional Comprehensive Policy Plan makes an interesting distinction between policies for water management in wet and dry years. Policy 8.1.1.2 states, "For normal, average rainfall years, water availability, use, allocation and management plans shall recognize that provision of sufficient water to maintain the functions and values provided by natural systems is the first priority and shall reserve sufficient water to meet the essential demands of fish and wildlife and the ecological systems that support them." Policy 8.1.1.3 states, "Water use allocation and management plans for emergency drought and flood situations shall avoid irreversible impact on ecological systems and minimize long term impacts on all sectors."

By these policies, then, natural systems have first priority in average years and no permanent damage and only minimal long term damage to natural resources are allowed. With respect to the diversion of excess waters (flood situations), the plan implies that discharges must cause no permanent damage to the Indian River Lagoon. Such an impact is more difficult to imagine than long term impacts, which are to be minimized.

The seasonality and even the event-based characteristics of salinity may be inferred from other documents. For example, the Indian River County Comprehensive Plan contains a conservation element which notes, "A certain volume and frequency of freshwater inflow are required to maintain the overall health and stability of the Indian River Lagoon. Controlled discharges to the lagoon can mimic natural storm-related discharges." These recommendations imply that some measure of base-flow is desirable and that managed discharges can simulate natural ones. A similar idea is expressed in Policy 6-1.2.2 of the City of Sebastian Comprehensive Plan, that "Land development regulations shall include stipulations that agricultural activities shall...maintain natural drainage patterns."

Although not stated as a goal or policy, the Management Plan and Implementation Strategy for the Indian River Lagoon Systems prepared by the Marine Resources Council observed that C-54 canal output has been reduced but there is definitely still a diversion problem: "Freshwater is being inappropriately diverted to the lagoon. Pulsing is an effective way to mitigate damage and more closely match *historical* conditions" (emphasis added).

DISCUSSION

"A plan cannot be developed without direction or targets. Meaningful and realistic goals need to be defined."

Joel VanArman, 1987.

In the process of developing a desirable salinity regime for the Sebastian River and Indian River Lagoon it has been instructive to consider the content of existing goal statements, policies and objectives held by other regulatory and resource management programs. It is clear that many points of detail remain to be determined but the review of existing programs has revealed much of general use. It would be wrong to rely excessively on these sources in defining an ecologically-based salinity regime. While not sufficient for such purposes, however, it is necessary that the content and purposes of existing programs be considered. A recommended salinity regime should be as consistent as possible with the management objectives of existing programs. In this light, consistency represents an element of desirability.

There are two shortcomings to the approach employed in this review. The first is the interpretation of the intent of provisions in some sources as guidance for the issue of salinity optimization. Is it meaningful to interpret surface water quality or permit rules that address allowable concentrations of pollutants, or mixing zones, in the context of fresh water discharge? This report has done so to discover the implications of such language in unintended applications, but is aware of the limitations that doing so entails.

The second pitfall is widespread in natural resource management and concerns the reference to "nature," "natural conditions," "natural function," or "health" of ecosystems or valued resources, in defining the desired end-point or product of a regulatory or management program. Twelve of the reviewed sources employed terms of this type in goals, policies or objectives. The practice was most common in resource management and comprehensive plans and least common in federal and state laws. In four cases, meaningful definitions were provided for "optimum sustainable populations" (Item 2 in Table 1); "natural background levels" (Item 12);

"essentially natural conditions" (Item 13) and "existing, ambient water quality" (Item 15). The District RFP Guidance Memorandum (Item 22) provided minimum criteria for an environmentally desirable salinity regime and one source (Item 27) was the only one to specify historical conditions as the desired end-point for reform of inflow regulation.

Although such terms as "fish and wildlife," "native flora and fauna," and "species of special concern" were often used without definition, there is less uncertainty regarding the biota for which a new salinity regime should seek to protect. Emergent and submergent vegetation, especially seagrasses, have very high priority for their own sake and for their roles as habitat for species of economic value, ecological value, or endangerment. Invertebrates and fishes of recreational, commercial, aquacultural, or scientific significance should be considered. Species listed as threatened or endangered are also priority concerns, including the West Indian Manatee. Unfortunately, none of the reviewed sources offered indications of what salinities such biota require.

A synthesis of the explicit salinity goals plus salinity goals that may be inferred from less direct sources reviewed in this report is given in Table 2. This list of guidelines reflects an interpretation and synthesis of the goals, policies and objectives already present in existing regulatory and management programs. All are derived directly or with some editorial license from the list of sources in Table 1 and the Appendix, but none originates solely from any other source. The list does not account for every guideline found during the review, and several similar ideas have been condensed for brevity. No priorities or relative importance is meant by the order of their listing. The guidelines will be considered in subsequent phases of the project, but methods and data yet to be introduced may result in their modification.

Two concluding observations are made. First, it was apparent during this review of regulations and management programs that federal and state level goals were concerned most with the provision or protection of minimum estuarine inflows. Regional and especially local goal statements addressed the issue of maximum inflow regulation. Second, goal statements at all levels of government gave far more attention to water quality than to inflow or salinity as estuarine management issues. Water quality was cited many times in programs specific to the Indian River Lagoon or Sebastian River, but water quality was not included in this review. Water quality, and parameters affecting seagrasses and some valued fauna in particular, are affected greatly by fresh water inflow and the salinity of receiving waters. In this report, the interaction of salinity with such water quality parameters was not considered.

Table 2. Salinity and inflow targets contained in existing goal statements. Numbers in parentheses refer to sources listed in Table 1 and the Appendix.

1. There is an overall intent to reduce fresh water inflows to the Sebastian River and Indian River Lagoon (Items 9,17,19,20, and 25). A reduction of inflow will result in higher salinities in both the River and Lagoon.

2. At the same time, there is a perceived need to provide base flows for certain oligohaline species and their habitats (Items 1,2,6,9, and 25). A base flow will result in the establishment of permanent, tidal fresh water and low salinity areas.

3. Inflows and salinities should vary according to seasonal or daily or other cyclic patterns: at the same time, the rate of change of inflows, and consequently of salinity variations, should be moderated (Items 9,12,14, and 20). Given the concern for acute changes, guidelines for rates and ranges of salinity variation are as important as average salinity conditions.

4. The peaks of inflow should coincide with the natural wet season runoff of the basin, meaning that low salinities caused by regulated inflows should coincide with low salinities caused by natural runoff (Items 13,20,26, and 27). Natural seasonality of salinity variation is sought.

5. The area and duration of low salinities caused by natural runoff should not be made significantly larger or longer because of regulated inflows, in order to protect seagrasses, shellfish, and other estuarine biota in the Indian River Lagoon (Items 15 and 20).

6. Additional constraints to salinity are needed in the Lagoon near the mouth of the Sebastian River in order to restore and enhance seagrasses, and may be needed within 2.5 miles of the river mouth to protect hard clams or oysters (Items 15, 20, and 22).

7. A minimum of 20.0 parts per thousand is presently used as an interim salinity standard during hard clam spawning seasons of spring and fall, for Lagoon waters near the mouth of the Sebastian River (Item 23).

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Appendix I

Synopsis of Pertinent Goals, Policies, and Objectives

I. Federal Guidance

1. Endangered Species Act of 1973

Prepared by: United States Senate and House of Representatives

In 1973, Congress adopted an act to protect species in danger of extinction throughout all or a significant part of their range. The Act also addresses species threatened by the likelihood of extinction. The Act has been revised several times. It provides for the determination of status, land acquisition, prohibition of certain activities, and penalties and enforcement among other considerations.

The stated purposes of the Act are to:

1. Provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved;

2. To provide a program for the conservation of such species, and

3. To honor national and international treaties and conventions.

Conservation of species is defined as methods and procedures necessary to remove a species from endangered or threatened status, as provided by the Act.

Reasons for designation of a species may include habitat alteration, over-utilization, disease or predation, inadequacy of existing regulations, and other natural or manmade factors. Management of these problems is to be addressed through the adoption of recovery plans for each listed species.

Analysis

Congress makes no specific reference to fresh water inflows or salinity alterations but reserves the ability for such issues to be considered in the designation of a species as endangered or threatened, or in the development of recovery plans.

2. Marine Mammal Protection Act of 1972

Prepared by: United States Senate and House of Representatives

Congress established and has revised a Marine Mammal Protection Act. The Act provides for moratoria and prohibitions; regulations on the taking of marine mammals; permits and penalties; federal and international cooperation; and appropriations. Goals of the Act are:

1. To protect and encourage [marine mammals] to the greatest extent feasible commensurate with sound policies of resource management;

2. To maintain the health and stability of the marine ecosystem, and

3. To obtain an optimum sustainable population keeping in mind the carrying capacity of the habitat.

"Optimum sustainable population" is defined as the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element.

The Act primarily regulates the taking of marine mammals. "Taking" is defined as the act or attempt to harass, hunt, capture, or kill.

Analysis

The Act is narrowly restricted to the issue of taking and does not speak to actions that may have adverse direct or indirect effects on marine mammals, other than taking. Thus the Act offers no guidance to the questions of inflow or salinity optimization.

3. Clean Water Act of 1987

Prepared by: United States Senate and House of Representatives

Congress established and has revised a national Clean Water Act. The Act provides for research and training; grants for construction of treatment works; standards and enforcement; water quality inventories; permits and licenses; and a state water pollution control revolving fund. In addition, Section 320 establishes the National Estuary Program.

The objective of the Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Goals of the Act include:

1. To eliminate the discharge of pollutants into navigable waters;

2. Until discharges are eliminated, to achieve an interim goal of water quality which provides for the protection and propagation of fish, shellfish and wildlife;

3. To prohibit the discharge of toxic pollutants in toxic amounts;

4. To provide federal financial assistance to construct publicly owned waste treatment works;

5. To develop and implement area-wide waste treatment management plans and technology;

6. To develop and implement controls of nonpoint sources of pollution.

Analysis

The main aim of the Clean Water Act is to curtail the discharge from point and nonpoint sources of pollutants such as domestic waste waters, sewage sludge, thermal pollution, oil at sea, and similar constituents. The Act does not address fresh water or salinity as pollutants *per se*. It is noteworthy, however, that impoundment effects are noted as follow (Sections 102.a and .b):

> Due regard shall be given to the improvements which are necessary to conserve such waters for the protection of fish and aquatic life and wildlife, recreational purposes, and the withdrawal of such waters for public water supply, agricultural, industrial and other purposes...The [EPA] Administrator is authorized to make joint investigations with any such agencies of the condition of any waters in any state or states, of the discharge of any sewage, industrial wastes, or substance which may adversely affect such waters...In the survey or planning of any reservoir by the Corps of Engineers...or other federal agency, consideration shall be given to inclusion of storage for regulation of streamflow...The need for and the value of storage for regulation of streamflow (other than for water quality) including but not limited to navigation, salt water intrusion,

> recreation, esthetics, and fish and wildlife shall be determined by the Corps of Engineers...or other federal agencies.

These passages reserve the right of Congress, through EPA and the Corps of Engineers, to consider ecological effects of reservoirs and stream flows on affected biota, including effects of salt water intrusion.

4. Draft Management Plan - Pelican Island National Wildlife Refuge

Prepared by: U.S. Department of the Interior, Fish and Wildlife Service (Merritt Island National Wildlife Refuge, Titusville)

In 1903, President Theodore Roosevelt issued an executive order protecting Pelican Island as a "preserve and breeding grounds for native birds." Sixteen federally listed endangered or threatened species occur on the refuge including the shortnose sturgeon, several species of sea turtles, the wood stork and southern bald eagle, and the West Indian Manatee.

The management plan states four goals for the Refuge.

1. To preserve, restore, and enhance in their natural ecosystems (when practicable) all species of animals and plants that are endangered or threatened with becoming endangered.

2. To perpetuate the migratory bird resource.

3. To preserve a natural diversity and abundance of flora and fauna on refuge lands.

4. To provide an understanding and appreciation of fish and wildlife ecology and man's role in his environment, and to provide refuge visitors with high quality, safe, wholesome, and enjoyable recreational experiences oriented toward wildlife to the extent these activities are compatible with the purposes for which the refuge was established.

Outputs of these goals are species of specific interest, wildlife "diversity," and certain visitor experiences. Strategies to achieve these goals and outputs are stated but none addresses fresh water inflow or salinity. One strategy utilizes monitoring of biological resources.

The plan recognizes that "areas of particularly high importance to manatee are the deeper waters of Canal 54 and the Sebastian River for aggregation, and the submerged grass beds near the confluence of the Sebastian River and Indian River Lagoon where feeding occurs." Fresh water inflows or salinity are not identified as management problems facing the manatee, and no management needs addressing these parameters are cited.

A proposal exists to expand Refuge boundaries. The enlarged refuge would include barrier island buffer areas and the Indian River Lagoon between the barrier island and mainland from Roseland north to near Micco (Brevard County). Refuge boundaries would parallel the entrance to the Sebastian River and could include upriver reaches of the South and North Prongs.

Analysis

The Plan recognizes shoreline loss as the major management problem facing the Refuge.

By virtue of Goal 3 (To preserve a natural diversity and abundance of flora and fauna on refuge lands) the Refuge has expressed a concern for and interest in the number and kinds of plants and animals in the managed area. The Refuge thereby reserves the opportunity to become involved with issues affecting natural conditions, such as inflow or salinity. "A natural" diversity and abundance is open to interpretation compared to "the natural" diversity and abundance. The plan makes no explicit reference to inflows or salinity but does not exclude these as parameters of future concern.

5. Central and Southern Florida Project for Flood Control

Prepared by: U.S. Army Corps of Engineers

Part III of this document concerns the upper St. Johns River basin and related areas, including the Indian River Lagoon. Supplement 2 is a general design memorandum for the upper St. Johns River basin and Addendum 3 is the associated environmental impact statement (draft).

The document describes the region and identifies major problems of surface water management. It states,

> "The need exists to determine the significance of potential freshwater discharges from C-54 upon ecological conditions within the Indian River and to develop operational schedules for discharges that will accomplish project purposes with minimum long-term negative impacts upon receiving waters."

The document states that the U.S. Fish and Wildlife Service performed an environmental impact study dealing primarily with the impact of fresh water discharges through Canal C-54 into the Indian River. The document also states that the Service mapped 1,472 acres of seagrass (mostly Halodule) within 3 miles north and south of the Sebastian River, and that about 13 percent of the Lagoon bottom in that area was covered by seagrasses.

The document notes that Gilmore (1984 personal communication) observed that "the fishery in the portion of the Indian River affected by freshwater releases from C-54 was not damaged by the freshwater discharge in 1979." Elsewhere, the document notes that SJRWMD staff "observed that some oysters and many hard clams died during the release."

Analysis

This document does not provide goals or objectives for the Lagoon or its resources per se but is included for its recognition of the potential impacts of C-54 discharges and citation of varying responses of Lagoon resources to the 1979 discharge event.

II. Federal - State Guidance

6. Indian River Lagoon National Estuary Program Management Conference Agreement

Prepared by: U.S. Environmental Protection Agency and the State of Florida

The Indian River Lagoon was designated part of the National Estuary Program based upon a Governor's Nomination in 1990. In 1991 an agreement was made between the U.S. Environmental Protection Agency and the State of Florida to begin a management conference as provided by Section 320 of the Clean Water Act.

The Agreement provides for an assessment of trends in water quality, natural resources, and uses; determination of the causes of changes through data collection, characterization and analysis; evaluation of point and non-point loadings; a comprehensive conservation and management plan that indicates priority actions; implementation of the plan; monitoring to assess the effectiveness of implementation; and review of federal programs for consistency.

The Agreement identifies four preliminary goals for the Indian River Lagoon NEP:

1. To attain and maintain water and sediment of sufficient quality to support a healthy estuarine Lagoon system.

2. To attain and maintain a functioning, healthy ecosystem which supports endangered and threatened species, fisheries, commerce, and recreation.

3. To achieve heightened public awareness and coordinated interagency management of the Indian River Lagoon ecosystem.

4. To identify and develop long-term funding sources for prioritized projects and programs to preserve, protect, restore and enhance the Indian River Lagoon system.

The Agreement lays forth a plan to identify and rank priority problems; develop a data and information management system; inventory relevant agency programs; produce a characterization report for the study area; prepare a financing plan for the final recommendations; and adopt a comprehensive conservation and management plan.

Analysis

The general thrust of the conference agreement is one of preservation of existing resource values and benefits, and restoration of these qualities where they have declined. Restoration of conditions is implied for most resources although a literal reading of the agreement also implies that the maintenance of endangered or threatened status for species at risk would be acceptable, as opposed to their removal from such status. Recovery plans adopted for particular species presumably would have priority over NEP.

The conference agreement does not refer to fresh water inflow or salinity alterations as problems facing the management conference. However, the first two goals (To attain and maintain water and sediment of sufficient quality to support a healthy estuarine Lagoon system; and To attain and maintain a functioning, healthy ecosystem which supports endangered and threatened species, fisheries, commerce, and recreation) clearly reserve the opportunity to consider these parameters if characterization or other tasks identify them as issues. The terms "health", "healthy", and "functioning" are not defined operationally.

7. Indian River Lagoon NEP : Annual Work Plans 1991-1993

Prepared by: Indian River Lagoon NEP Project Office

Three workplans describe annual activities of the NEP. The 1991 Workplan identified 11 priority problems facing the Lagoon. The 1991 draft identified hydrodynamics and salinity of the Sebastian River as a planned project, noting, "In 1987, following several incidents of large releases of freshwater from Turkey Creek to the Indian River Lagoon which appeared to cause severe impacts on the shellfish industry in this section of the Lagoon, this sub-basin was selected as a high priority area of concern," and "the first hydrodynamic modeling effort by the SWIM Program will concentrate on salinity problems in the Indian River Lagoon between Turkey Creek and the Sebastian River."

The 1992 Workplan "Adopted submerged aquatic vegetation (SAV) as a symbolic "theme" for the technical and educational efforts of the program." The Turkey Creek/Sebastian River Hydrodynamics and Salinity Model was also proposed.

Preliminary drafts of the 1993-1995 Workplan do not refer to the Turkey Creek or Sebastian River projects.

Analysis

The 1991 and 1992 Workplans refer to the hydrodynamic modeling effort by the SWIM Program on salinity problems in the Indian River Lagoon between Turkey Creek and the Sebastian River, but these projects do not appear in subsequent workplans. Also, it is noteworthy that the 1991 list of priority problems facing the Lagoon does not mention fresh water inflow or salinity perturbations.

III. State Guidance

8. Chapter 373 Florida Statutes -- Water Resources Act

Prepared by: Florida Senate and House of Representatives

The following summary is adapted from Wade and Tucker (1991), which should be consulted for a thorough analysis of the Act as it pertains to the fresh water requirements of estuarine and marine fisheries.

The Water Resources Act was based to a large extent on A Model Water Code developed by the University of Florida College of Law.

The Act gives general supervisory authority over water management districts to the Florida Department of Environmental Regulation, which was directed to produce an "integrated, coordinated plan for the use and development of the waters of the state." The plan is to be part of the state comprehensive plan which, together with water quality standards and classifications, represent the Florida Water Plan.

The Act directs water management districts to set minimum flows and levels for surface waters, among other actions, using the criteria of reasonable and beneficial uses. The Act defines minimum flow as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."

A policy of the Act is "to preserve natural resources, fish and wildlife." The Act directs the DER to consider "existing and contemplated needs and uses of water for protection and procreation of fish and wildlife" in preparing the state water use plan. In the administrative rule accompanying the Act[2] a general state water policy is to establish "minimum flows and levels to protect water resources and the environmental values associated with marine, estuarine, freshwater, and wetlands ecology." Minimum flows are to provide for recreation, fish and wildlife habitats and the passage of fish, estuarine resources, transfer of detrital material, and water quality, as well as other reasonable/beneficial uses.

The Act authorizes DER and water management districts to reserve from permitted uses "water in such locations and quantities, and for such seasons of the year, as in its judgement may be required for the protection of fish and wildlife or the public health and safety."

Analysis

State water policy does not explicitly state that historically impounded streams will have minimum flows established to tidal waters. The Act authorizes but does not require consideration of seasonal needs of estuaries in the establishment of minimum flows. Likewise, the Act authorizes but

[2]/ Florida Administrative Code Rule 17-40.310 (11) (1990).

does not require protection of nonconsumptive uses including the timing, quantity and distribution of inflows to estuaries, in establishing minimum flows.

The Act's general tone and intent address the problem of water use, consumption, or diversion. It focuses on management of the impacts of water extraction and does not explicitly refer to the impacts of excess water. However, recognition of timing, amount and location as critical flow parameters clearly leaves open such considerations.

There is no uncertainty that estuarine and marine considerations are to be made in water planning and management. On the other hand, the Act is silent with regards to the impacts of impoundments *per se* on estuaries. To the extent that such structures are regulated by DER or water management districts, the implication may be justified that estuarine impacts are to be considered.

The present Act does not require the DER or water management districts to consult federal agencies on minimum flow decisions affecting estuaries. However, the Act does not address state involvement in federal projects affecting fresh water inflow.

On balance, the Act declares that state water management shall protect estuarine living resources but offers no more specific goals that can be interpreted with meaning for the Sebastian River project. Several programs are authorized by the Act for implementation through water management districts, such as consumptive use permitting, district water management plans, minimum flows and levels, and Surface Water Improvement and Management (SWIM) Plans. These are discussed separately in this review, as programs of the St. Johns River Water Management District.

9. Chapter 17-40 Florida Administrative Code -- Water Policy

Prepared by: Florida Department of Environmental Regulation

This rule implements provision of the state water policy (see above). It states that waters of the State should be managed to conserve and protect natural resources and scenic beauty and to realize full beneficial use of the resource.

The rule provides that water management programs, rules, and plans shall seek to:

1. Reserve from use that water necessary to support essential non-withdrawal demands, including navigation, recreation, and the protection of fish and wildlife.

2. Utilize, preserve, restore and enhance natural water management systems and discourage the channelization or other alteration of natural rivers, streams, and lakes;

3. Mitigate adverse impacts resulting from prior alteration of natural hydrologic patterns and fluctuations in surface and ground water levels;

4. Establish minimum flows and levels to protect water resources and the environmental values associated with marine, estuarine, freshwater and wetlands ecology.

The rule specifies conditions to be considered in the establishment of minimum flows and levels.

The rule states that a primary goal of the State's stormwater management program is "...to maintain the appropriate salinity regimes in estuaries needed to support the natural flora and fauna..."

Analysis

This rule implements provisions of state water policy within DER and water management districts. It makes explicit reference to appropriate salinity regimes in estuaries as a primary goal for stormwater management. "Stormwater" is defined by the rule as the water which results from a rainfall event.

Similar to the State's water policy, the rule addresses minimum flows but not maximum flows. These may be inferred from references to natural hydrological parameters and appropriate salinity regimes.

10. Chapter 17-43 Florida Administrative Code -- S.W.I.M. Rule

Prepared by: Florida Department of Environmental Regulation

This rule enacts the Surface Water Improvement and Management Act (Chapter 373.451 Florida Statutes). General goals of the Act are to manage waters so as to provide aesthetic and recreational pleasure; provide habitat for native plants, fish and wildlife, including endangered and threatened species; providing safe drinking water; and attracting visitors and accruing other economic benefits.

The rule authorizes water management districts to prioritize waters in each district with respect to preservation and restoration. Districts are to prepare and triennally revise surface water plans for priority water bodies. Criteria for ranking and elements of the surface water plans are given. Arrangements for funding and DER review are provided.

The "Indian River Lagoon Basin" is named in an advisory table of approved surface water priority lists.

Analysis

Although the SWIM Act provides some general guidance, the SWIM rule is notably silent as to the state's ambitions for surface waters. It implies that some are to be preserved and others restored, "to meet Class III standards or better." The rule's intent states that it is the duty of the State...to enhance the environmental and scenic value of surface waters, but no other goals or policies are given other than administrative ones. The rule refers to the Indian River Lagoon *Basin*, and the legislature's intent that a SWIM plan for the *Lagoon* itself is needed is inferred. The listing of the system does not indicate whether it is to be preserved, restored, or both.

11. Chapter 403 Florida Statutes -- Environmental Control

Prepared by: Florida Senate and House of Representatives

This Act addresses pollution control, electrical power plant siting, resource recovery and management, drinking water, and other environmental issues. The Legislature declared as public policy to conserve the waters of the state and to protect, maintain, and improve the quality thereof for public water supplies, the propagation of wildlife and fish and other aquatic life, and for domestic, agricultural, industrial recreational and other beneficial uses and to provide that no wastes be discharged into any waters of the state without being given the degree of treatment necessary to protect beneficial uses.

The Act defines contaminant as any substance which is harmful to plant, animal, or human life. Waste is defined as sewage, industrial waste, and all other liquid, gaseous, solid, radioactive or other substances which may pollute waters of the State. Pollution is defined as the presence of any substances, contaminants, noise, or man-made or man-induced impairment of air or waters or alteration of the chemical, physical, biological or radiological integrity of air or waters in quantities or levels which are or may be potentially harmful or injurious to human health or welfare, animal or plant life, or property.

The Act permits the Environmental Regulation Commission to designate the Indian River -- Malabar to Vero Beach Aquatic Preserve as Outstanding Florida Waters if the natural attributes of such waters are of exceptional ecological or recreational significance. The Act prohibits mixing zones for point source discharges in Outstanding Florida Waters, but states "Discharges of water necessary for water management purposes which have been approved by the governing board of a water management district and, if required by law, by the [DER] secretary" are exempt from OFW standards.

Analysis

The Act seeks to control pollution of the environment and establishes conditions and exceptions. It allows that the Indian River -- Malabar to Vero Beach Aquatic Preserve is eligible for OFW designation and provides criteria for same.

Definitions in the Act make it possible to interpret fresh water as a contaminant or waste subject to the Act. The Act exempts board-approved discharges of fresh water from OFW standards. This exemption implies a recognition that non-degradation standards of OFW are or may be violated by fresh water discharges. The Act does not, however, exempt board-approved discharges of water from its general provisions not involving Outstanding Florida Waters.

12. Chapter 17-302 Florida Administrative Code -- Surface Water Quality

Prepared by: Florida Department of Environmental Regulation

This rule provides definitions; anti-degradation standards for surface water quality; a classification system for surface waters; minimum and general criteria; specific criteria; and protection for special areas.

Definitions of interest include "exceptional ecological significance," meaning that a water body is part of an ecosystem of unusual value; "natural background" means the condition of waters in the absence of man-induced alterations; and "nursery area of indigenous aquatic life" means beds of submerged aquatic vegetation or other areas used in early development or growth.

A chloride concentration in surface waters of 1,500 milligrams per liter is used to distinguish "predominantly fresh water" from "predominantly marine water."

The rule categorizes all waters of the State into one of 5 classes. Class II is for shellfish propagation and harvesting. Class III is for propagation and maintenance of a well-balanced population of fish and wildlife.

The rule provides general criteria which apply to all surface waters except in mixing zones. One criterion states that in predominantly marine waters the chloride content shall not be increased more than ten percent (10%) above normal background chloride content, and that normal daily and seasonal fluctuations in chloride levels shall be maintained.

Another general criterion states that specific conductance shall not be increased more than 50% above background or to 1,275 micromhos per centimeter, whichever is greater, in predominantly fresh waters.

For Classes I, II and III waters, biological integrity cannot be reduced to less than 75% of background. (Biological integrity is defined in the rule as the Shannon-Weaver diversity index and Background is defined as condition of a water body in the absence of an activity or pollutant.)

The rule designates all waters of the State as Class III except as specified. The Indian River Lagoon corresponding to the Malabar to Vero Beach Aquatic Preserve is designated as Class II waters. The rule also designates aquatic preserves as Outstanding Florida Waters, for which it is Department policy to afford the highest protection. The Sebastian River upstream of U.S. Highway 1 is not designated as OFW but is part of the aquatic preserve, and is a Class III water body. The Pelican Island National Wildlife Refuge is also designated as OFW.

Analysis

Although never applied to cases of inflow or salinity alteration, the rule states that in predominantly marine waters the chloride content shall not be increased more than ten percent (10%) above normal background chloride content, and that normal daily and seasonal fluctuations in chloride levels shall be maintained. It also states that specific conductance shall not be increased more than 50% above background or to 1,275 micromhos per centimeter, whichever is greater, in predominantly fresh waters. These criteria were meant to apply as limits to the effects of a specific point source of pollution but suggest the amounts of general change considered tolerable by the state.

By the same token, the rule prohibits biological integrity to be lowered by more than 25%. This criterion would have to be applied separately in fresh water, estuarine, and marine segments of the Sebastian River and Indian River Lagoon to be useful as a constraint on inflows or salinity change.

Careful reading of this Chapter reveals that (a) the Indian River Lagoon is a Class II water body in Brevard County and also in Indian River County, east of the Intracoastal Waterway, (b) all of the Indian River Lagoon is an Outstanding Florida Water, including the mouth of the Sebastian River west to U.S. Highway 1, but not further west, (c) the Indian River Lagoon and the Sebastian River are part of a state aquatic preserve, (d) the preserve includes waters north of Highway 512 on the South Prong, and all navigable waters on the North Prong, and (e) the Sebastian River west of U.S. Highway 1 is a Class III water body.

13. Chapter 16-20 Florida Administrative Code -- Aquatic Preserves

Prepared by: Florida Department of Natural Resources

Florida law (73-534, Sections 258.39 -258.393) creates a system of aquatic preserves implemented and administered by this rule. Goals of the rule are to:

1. Maintain essentially natural conditions, propagation of fish and wildlife, and public recreation including hunting and fishing;

2. Continue the preserves' essentially natural or existing condition so that their aesthetic, biological, and scientific values may endure for the enjoyment of future generations;

3. Preserve, protect, and enhance these exceptional areas of sovereignty submerged lands by reasonable regulation and a comprehensive management program;

4. Protect and enhance the waters of preserves so that the public may continue to enjoy traditional recreational uses;

5. To coordinate with other agencies of government and to use their programs to assist in managing preserves;

6. To encourage the protection, enhancement or restoration of [preserve values] when reviewing applications and implementing management plans;

7. To preserve, promote, and utilize indigenous life forms and habitats, including but not limited to sponges, soft coral, hard coral, submerged grasses, mangroves, salt water marshes, fresh water marshes, mudflats, estuarine, aquatic and marine reptiles, game and non-game fish species, estuarine, aquatic and marine invertebrates, estuarine, aquatic and marine mammals, birds, shellfish, and mollusks;

8. To acquire additional title interests in lands to promote preserve values;

9. To maintain those beneficial hydrologic and biologic functions, the benefits of which accrue to the public at large.

The rule also provides consistency with the requirements and authority of other governmental agencies. The rule applies to all preserves except Boca Ciega Bay, Pinellas County and Biscayne Bay Aquatic Preserves. The rule includes the Indian River -- Malabar to Sebastian preserve. The rule establishes a zoning system for preserve management in the form of three Resource Protection Areas. The protection areas are to be used in decisions affecting docking facilities in aquatic preserves.

The rule defines "essentially natural condition" as "those functions which support the continued existence or encourage the restoration of the diverse population of indigenous life forms and habitats to the extent they existed prior to the significant development adjacent to and within the preserve."

The rule defines "beneficial hydrological functions" as "interactions between flora, fauna, and physical geological or geographical attributes of the environment, which provides benefits that accrue to the public at large, including retardation of storm water flow, storm water retention, water storage, and periodical release."

Analysis

The tone of the rule clearly advocates the maintenance of existing, desireable conditions and benefits in preserves, and encourages restoration and enhancement. In defining essentially natural conditions the rule states that natural means pre-development, but one goal allows for existing conditions as an alternative to natural conditions.

Although ambiguous in application within the rule, the rule makes explicit reference to beneficial hydrological functions, and the definitions refer directly to retardation of storm water flow, water storage, and periodic releases. These actions are critical elements for the Sebastian River study.

Overall, the rule presents several goals regarding the desired outcome of management for estuarine conditions and is cognizant of the impacts of surface water management. Because the waters of the Indian River Lagoon in the vicinity of the Sebastian River are designated as a Florida Aquatic Preserve, this rule provides much useful guidance for the design of a desireable salinity regime.

14. Indian River -- Malabar to Vero Beach Aquatic Preserve Management Plan

Prepared by: Florida Department of Natural Resources

In 1986 the Board of Trustees of the Internal Improvement Trust Fund adopted a management plan for the Indian River -- Malabar to Vero Beach Aquatic Preserve, in a resolution stating "that the primary management objective of the [aquatic preserve] will be the maintenance of this ecosystem in an essentially natural state."

The management plan identifies the preserve and lands seaward of mean high water, including the Sebastian River, between Malabar on the north and Vero Beach on the south.

The plan reviews statutory and administrative authority affecting aquatic preserves. In addition to citing the Aquatic Preserve Rule (see above) and its enabling legislation, the plan also notes provisions of Chapter 16Q-21 F.A.C., a rule governing management of sovereignty submerged lands. Among the intents of the rule, as quoted by the plan, is to:

1. Manage, protect, and enhance sovereignty submerged lands so that the public may continue to enjoy traditional uses including but not limited to navigation, fishing, and swimming;

2. To manage and provide maximum protection for all sovereignty lands, especially those important to public drinking water supply, shellfish harvesting, and fish and wildlife propagation and management.

The plan notes the non-degradation goal of Outstanding Florida Waters designation.

The plan states 26 "major program policy directives," from which those pertinent to the present study are listed below. (The plan's original codes are retained.)

A. Ensure the maintenance of essentially natural conditions to ensure the propagation of fish and wildlife, and public recreational opportunities;

D. Protect and, where possible, enhance threatened and endangered species habitat within the aquatic preserve;

E. Prohibit development activities within the preserve that adversely impact upon grassbeds and other valuable submerged habitat [within limits of a public interest test];

S. Require, through the efforts of DER, water management districts, and mosquito control districts for (sic) the maintenance of the naturally high water quality of the estuary, to ensure the natural seasonal flow fluctuations of freshwater into the estuary and the greatest interaction possible of mosquito impoundments with the Indian River Lagoon;

Z. Recognize that successful shellfish culture and harvesting efforts in the aquatic preserve are dependent upon pollution prevention and abatement programs and careful comprehensive planning.

The plan describes the resources of the preserve, stating that "the major problems in the continued health of the lagoon are the large amounts of fresh water released by several man-made drainage systems..." and that "qualitative evaluation of the aquatic preserve resources has been hampered by a lack of data on the exact effects of the above problem..." Elsewhere the plan states that the volume of water discharged influences the preserve's water quality.

The plan recognizes the high incidence of manatees in the Sebastian River.

The plan describes the presence of shell middens, mostly oyster, in the Malabar to Grant areas. Elsewhere it states that there are at least 81 shellfish leases in the preserve and that, in 1986, "the majority of leases were issued for growing oysters but most lease holders are shifting to clam cultivation."

The plan defines on-site management objectives and cites Chapter 16Q-20 FAC provisions regarding cumulative impacts.

<u>Analysis</u>

Given the definition of essentially natural condition provided by the Aquatic Preserve Rule (16-20 F.A.C. -- see above), the Trustees' resolution adopting the management plan for this aquatic preserve may be interpreted to mean that impacts created by settlement and development in and adjacent to the preserve, which have altered its original condition, need to be corrected. As such, the resolution implies that large discharges of fresh water into the preserve could be rectified as part of a preserve management program. However, the resolution (and plan, for that matter) lack authority to cause changes to existing fresh water inflow or salinity patterns. Drawing from a rule on sovereignty lands, the plan has authority to provide maximum protection for all sovereignty lands, especially those important to ...shellfish harvesting and fish and wildlife propagation and management.

Despite awkward construction, Directive S seeks to ensure natural seasonal flow fluctuations of fresh water into the estuary, which is useful in the present context of salinity optimization. Grassbeds are recognized as a valuable submerged habitat, as are shellfish, although the shellfish directive is not driven by a tangible goal.

15. Chapter 17-4 Florida Administrative Code -- Permits

Prepared by: Florida Department of Environmental Regulation

This rule creates a permitting system for construction and operation of air and water pollution sources and dredging and filling. It provides anti-degradation requirements for Outstanding florida Waters and Outstanding National Resource Waters. It provides for temporary permits and mixing zones.

This rule establishes the procedures and fees for permit application. Anti-degradation criteria in the rule include whether a proposed discharge will adversely affect (a) conservation of fish and wildlife, including threatened or endangered species or their habitats, and (b) fishing or water based recreational values or marine productivity.

In OFW, the discharge must have a mixing zone as prescribed by 17-3.050 (1) (f) ii and by this rule (see below) and must singly or in combination with other discharges cause significant degradation of existing ambient water quality. Existing ambient water quality is defined as the best case between (a) that which, based on the best scientific information available, could be reasonably expected to have existed in the year of the OFW designation, or (b) that which existed in the year prior to the permit application. Either source shall include "daily, seasonal, and other cyclic fluctuations."

The rule allows for mixing zones but states that "no mixing zone...shall be allowed to significantly impair any of the designated uses of the receiving body of water." Some of the considerations for mixing zones include:

1. Condition of the receiving body of water including present and future flow conditions and present and future sources of pollutants;

2. The nature, volume, and frequency of the proposed discharge including any possible synergistic effects with other pollutants or substances which may be present in the receiving body of water;

3. A mixing zone shall not include a nursery area of indigenous aquatic life or any area approved by the Department of Natural Resources for shellfish harvesting;

4. In lakes, estuaries, bays, lagoons, bayous, sounds and coastal waters, the area of a mixing zone shall not exceed 125,600 square meters, and all mixing zones together shall not exceed 10 percent of an estuary's area;

5. The maximum concentration of wastes in the mixing zone shall not exceed the amount lethal to 50 percent of the test organisms in 96 hours (96 hr LC_{50}) for a species significant to the indigenous aquatic community.

Analysis

Although largely a procedural rule it does provide some guidance useful to the present Sebastian River case, although it should be noted that board-approved works of a water management district are probably exempted from the permit requirements of this rule. Furthermore, the rule does not appear to speak to the discharge of fresh water per se.

Nevertheless, the rule provides insight to limits the state seeks in permitting new sources of pollutants to surface waters and these features may be instructive for the Sebastian River study.

Considering fresh water as a pollutant, for example, the rule requires that the nature, volume and frequency of the proposed [fresh water] discharge including any possible synergistic effects with [fresh water already] present in the receiving body of water be considered.

Likewise, a mixing zone [of fresh water] shall not include a nursery area of indigenous aquatic life or any area approved by the Department of Natural Resources for shellfish harvesting.

The rule states that in estuaries [and] lagoons the area of a mixing zone shall not exceed 125,600 square meters, and all mixing zones shall not exceed 10 percent of an estuary's area. It is presently not known whether 10 percent of the Indian River Lagoon's total surface area is affected by the "mixing zones" of canals. On the other hand, 125,600 square meters as a maximum mixing zone is equal to about 31 acres, or an area of the Lagoon enclosed by a radius of 935 feet from the mouth of the Sebastian River.

16. Governor's Nomination of the Indian River Lagoon to the National Estuary Program

Prepared by: Florida Department of Environmental Regulation in cooperation with the Marine Resources Council of East Florida

This document replies to EPA guidance for the nomination to NEP of the Indian River Lagoon. It defines the Lagoon's national significance and geographic scope; estuarine resources and problems; need for the management conference; and program analyses. The Nomination provides a goal for the Lagoon as stated by the Indian River Lagoon Field Committee,

To protect, maintain, restore and enhance the resources and functions of the Indian River Lagoon.

Objectives issuing from this goal were to:

1. Establish and fund an integrated research and inventory effort to achieve greater understanding of the Lagoon system;

2. Establish and fund an integrated effort for the management of the Lagoon system;

3. Achieve water quality parameters identified as necessary to protect, maintain, restore and enhance the resources and functions of the Lagoon;

4. Identify freshwater inputs into the Lagoon system and manage these inputs in a manner consistent for the system and its resources;

5. Protect viable native populations and enhance habitats of species which have been determined to be endangered, threatened or of special concern;

6. Encourage development practices which maintain viability of the Lagoon system while providing for economic opportunity;

7. Recognize the multiple uses of the Lagoon's resources and provide for their balanced coexistence, and

8. Increase public awareness of the Lagoon system and its resource requirements through education.

The Nomination notes that, [Fresh water] "flow from these point discharges[3] contribute 50 percent of the annual water budget and are responsible for major freshwater pulses and pollution loads to the lagoon in the most restricted reaches of the lagoon" (page 7). Fresh water inflows are not identified as a major problem facing the Lagoon elsewhere in the Nomination although in summary (page 33) the report states, "Large scale drainage projects have increased the size of the watershed contributing surface water to the Lagoon and hastened discharge during storm events. Drainage projects

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[3]/ Point discharges are identified in the report as canals.

impact the salinity balance of the Lagoon and the life cycles of estuarine and marine organisms." Issues listed by the report (Table 7) include nonpoint (stormwater) runoff; fresh water control; and water quality; but salinity is not listed.

Analysis

Although the Nomination does not say more about the issues of fresh water and salinity, it contains numerous references to these as problems and one of eight objectives speaks to them in explicit terms. An appendix describes the Sebastian River area and its resources, and states, "This portion of the lagoon is the major clam harvest area of the Indian River Lagoon. Five clam depuration plants operate on the shoreline and large areas of the lagoon bottom lands are leased for clam cultivation and harvest."

The goals and objectives of the Field Committee and Nomination are different than those of the Management Conference Agreement, with one relevant change being the deletion of references to fresh water inflow.

17. Indian River Lagoon System Management Plan

Prepared by: The Indian River Lagoons Field Committee

The State's Coastal Management Program is supervised by an Interagency Management Committee (IMC) which in 1985 was chaired by the Secretary of the Department of Environmental Regulation. The Secretary established an advisory committee to the IMC called the Indian River Lagoons Field Committee (IRLFC) and charged that group with formulating a management strategy for the Lagoon.

The IRLFC recommended lagoon-wide and watershed-specific management initiatives.

The goal recommended for the Lagoon and the program was to protect, maintain, restore and enhance the resources and function of the Lagoon system.

Objectives relevant to the present study included:

1. Establish and fund an integrated research and inventory effort to achieve a greater understanding of the Lagoon system;

2. Establish and fund an integrated effort for the management of the Lagoon system;

3. Achieve water quality and quantity parameters identified as necessary to protect, maintain, restore and enhance the resources and function of the IRL system;

4. Protect viable native populations and enhance habitat of species which have been determined to be endangered, threatened, or of special concern.

5. Identify freshwater inputs to the Lagoon system and manage these inputs in a manner consistent for the system and its resources.

Policies were provided for each objective. In the case of the last objective, on fresh water, policies include the elimination of agricultural runoff into canals where possible; establish water management schedules consistent with the Lagoons' natural functions; and revise interbasin diversions into the Lagoon system to protect resources of the system.

Analysis

The Field Committee's management recommendations for species at risk encourages the enhancement of their habitat.

The report includes an objective dealing specifically with fresh water inflow, and the associated policies call for the elimination of agricultural runoff and reduction of interbasin transfers to the Lagoon. These actions would have the effect of raising salinity in the Lagoon.

18. Hutchinson Island Resource Planning and Management Plan

Prepared by: Hutchinson Island Resource Planning and Management Committee

In 1983 the Hutchinson Island Resource Planning and Management Committee ("Committee") submitted a report to the Department of Community Affairs, in response to a charge by the Governor of Florida (under authority of Section 380.045 Florida Statutes) to organize a voluntary and cooperative resource management program for the barrier island system from Sebastian Inlet south to the St. Lucie Inlet. The report is treated as state guidance because the Committee was appointed by the Governor.

The Plan identifies environmentally sensitive resources and resource issues; provides policy statements; and makes recommendations for transportation and capital improvements. Objectives of the Plan include:

1. To maintain and, where appropriate, reestablish productive natural ecosystems and related coastal components of the Indian River and Atlantic Ocean...and maintain their contribution to the quality of life and economic well-being of the region.

Analysis

The Plan identifies waters of northern Indian River County, east of the Intracoastal Waterway, as Class II waters of the state and also Outstanding Florida Waters. The Lagoon west of the Waterway is shown as Class III waters. This 1983 classification conflicts with the designations set forth in Chapter 17-302 Florida Statutes.

IV. Water Management District Guidance

19. Rules of the St. Johns River Water Management District

Prepared by: St. Johns River Water Management District

Rules appearing in the Applicant's Handbook -- Management and Storage of Surface Waters, were reviewed as a group. Highlights of selected rules are noted below for their applicability to the present project.

Ch. 40C-4: Management and Storage of Surface Waters states that it is the policy of the District to foster agricultural, commercial, industrial and residential growth in a manner consistent with the District's objectives. Applicants for permits must provide reasonable assurance that activities will not, among other concerns,

A. Be inconsistent with the maintenance of minimum flows and levels;

B. Cause adverse impacts to receiving water quality;

C. Adversely affect natural resources, fish or wildlife; or

D. Induce saltwater or pollution intrusion.

Ch. 40C-41: Surface Water Management Basin Criteria states that:

1. A system may not result in an increase in the amount of water being diverted from the Upper St. Johns River Hydrologic Basin into coastal receiving waters, and

2. It is an objective of the District to, where practical, curtail diversions of water from the Upper St. Johns River Hydrologic Basin into coastal receiving waters.

Analysis

The rules of the District serve to implement statutory mandates and offer little in the way of substantive intent for water resources or water dependent resources that can be used as guidance in the present study.

Ch. 40C-41 does state an ambition to reduce diversions of water from the Upper St. Johns River Hydrologic Basin into coastal receiving waters, implying that the timing and/or amounts of inflow to the Indian River Lagoon should be changed, with an overall effect of increasing salinity.

20. SWIM Plan for the Indian River Lagoon

Prepared by: St. Johns River Water Management District and the South Forida Water Management District

To comply with the Surface Water Improvement and Management (SWIM) Act, the St. Johns River and South Florida Water Management Districts issued a SWIM Plan for the Indian River Lagoon in 1989, with 8 appendices. A revised plan is presently in review by district staff. This analysis is based on the 1989 edition, which was the result of a Memorandum of Understanding between the districts. Among others, the Memorandum states as a guideline that the development of a SWIM Plan should "improve the overall health of the water resources of the Lagoon."

The plan reviews statutory requirements and states goals for the IRL SWIM Plan:

1. To attain and maintain water and sediment of sufficient quality (Class III or better) in order to support a healthy, macrophyte-based, estuarine lagoon ecosystem.

2. To attain and maintain a functioning macrophyte-based ecosystem which supports endangered and threatened species, fisheries, and recreation.

3. To achieve heightened public awareness and coordinated interagency management of the Indian River Lagoon ecosystem that results in the accomplishment of the two aforementioned goals.

The Plan identifies lagoon-wide problems, including two major activities responsible for impacts to habitats and species diversity. One is alteration in the natural patterns of circulation in the Lagoon and fresh water flow into the Lagoon. The plan notes,

> "Ten of the major canals have a combined peak discharge of over 20 billion gallons per day..."
>
> "Sustained high volume stormwater discharges can directly impact estuarine dependent organisms and their habitats and can produce biologically undesirable reductions in salinity..."
>
> "These same drainage systems can effectively curtail freshwater flows to the lagoon during dry seasons. This can elevate salinities, impacting habitats and their indigenous organisms dependent on brackish or freshwater areas for at least part of their life cycles."

The Plan identifies the Sebastian River sub-basin as a critical problem area and notes that the North Prong does not meet Class III criteria.

With respect to the first goal, the Plan identifies undesirable salinity fluctuations as a major issue and states an objective of managing fresh water inflows from point and nonpoint sources to minimize their impacts on salinity.

The Plan identifies the development of a Sebastian River Management Plan as a priority project, in which "the primary element of this plan is the regulation of freshwater discharges and improvement of water quality in the river and lagoon." The stated objectives for the Sebastian River Management Plan (p. 61) are "further refinement of the C-54 regulation schedule as well as improved management of agricultural discharges to the South Prong."

Salinity is named as a major issue for 7 of 21 projects that should be continued or initiated immediately.

An Appendix to the Plan states as one objective for a 4 to 5 year Sebastian River program:

"Assess biological impacts from high-discharge events. This will be primarily limited to impacts on submerged aquatic vegetation habitats in the lagoon proper, and possibly the macrobenthic and fish communities associated with SAV. Impacts of low salinity on specific organisms (e.g. hard clams) are better determined by reviewing published physiological tolerance studies and relating the studies' results to modeled salinity patterns."

Analysis

Neither the Florida Statutes or Administrative Code provide sediment criteria for Class I-V waters of the state, so the SWIM goal's reference to sediment quality implies that sediment quality should be attained or maintained so as to indirectly contribute to the achievement of surface water objectives.

A macrophyte-based...ecosystem implies that the majority of primary productivity and/or biomass within the Lagoon should be associated with submerged aquatic vegetation, primarily seagrasses. Taken literally, multicellular drift or attached algae also constitute macrophytes, and the Plan is moot on this point. In either case, the goal seeks to minimize the role of phytoplankton in primary production and community respiration.

The Plan does not clarify the meaning of an "estuarine lagoon."

On face value, the Plan seeks to "support" population levels of certain species that are presently responsible for their designation as endangered or threatened, but does not state an ambition for their improvement.

The Plan places greater emphasis on changes in salinity than on long-term or average patterns of salinity. Several parts of the Plan refer to abrupt increases or decreases of salinity as major issues. The Plan does state that prolonged periods of high salinity can be injurious to brackish and fresh water species or life stages.

The detailed plan for the Sebastian River Management Program (Appendix F) focuses on the impact of high discharge events on seagrasses and possibly its associated fauna. The scope implies that SAV impacts could be determined through new field study, insofar as it limits the treatment of low salinity on specific organisms to literature reviews. These data are to be merged with the results of runoff models, circulation models, salinity models, and other concurrent studies or studies that have not yet begun.

21. Draft Rules and District Programs in Progress

Prepared by: St. Johns River Water Management District

This section reviews draft rules and certain programs and projects of the District, in terms of their application in the present project. Text and some interpretations are taken from Wade and Tucker (1990).

Draft Rule 40C-8 will provide for minimum surface water levels and flows. The governing board "must consider, and at its discretion provide for, the protection of non-consumptive uses, including navigation, recreation, and the preservation of natural resources, fish and wildlife." At the present time, the rule provides for minimum flows for only the Wekiva River and Blackwater Creek.

According to District staff (Deanna Adams, personal communication) Rule 40C-8 was adopted on September 16, 1992 and is presently in effect. If warranted by a review of the rule, this entry will be revised to recognize final rule provisions.*

The District is in the process of preparing a water management plan as required by Section 373.036 Florida Statutes. It will identify needs and sources of water. Water needs will be projected for several use categories but not resource-based or habitat-based needs.

Analysis

The science of determining the instream flow requirements of fresh water systems is much more advanced than estuarine inflow optimization. Theoretically, can the minimum flows of a stream determined by such methods be interpreted with meaning as the minimum inflow requirements of its associated estuary? Even if so, the method will not guide decisions regarding maximum amounts of inflow that an estuary can tolerate.

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*/ Rule Ch. 40C-8 F.A.C. was studied and found to contain nothing of direct relevance to the present study.

22. Sebastian River Salinity Regime -- RFP and Related Guidance

Prepared by: St. Johns River Water Management District

The request for proposals reveals intent of the District with respect to the Sebastian River and Indian River Lagoon. "The District desires to regulate structurally controlled freshwater inflows in an environmentally sensitive manner" because "there may be times when too much or too little water is released..."

The District states "the objective of this project is to determine an environmentally desirable and acceptable salinity regime..." from which "the amount of freshwater required to maintain acceptable salinities...can be calculated."

In guidelines for establishing a salinity regime for the study area the District states "the guidelines are intended to achieve a complementary blend of, or an equitable balance between, ecological concerns and fishery industry concerns." An environmentally desirable salinity regime would minimally support:

1. Macrophyte based primary productivity;

2. A variety of native macrophyte communities over a full salinity range;

3. Significant macrophytic habitats of species at risk and economically important species;

4. Species at risk and species of recreational or commercial economic importance;

5. Hard clams within 2.5 miles of the Sebastian River, and blue crabs.

Analysis

The RFP and guidance memorandum are useful in establishing the geographic area of concern, including tidal fresh waters. The guidance memorandum lists specific processes and resources considered to be of value.

23. A Preliminary Assessment of the Effects on Salinity of the Indian River Lagoon from WCDSB Canal 1 Discharges (1989).

Prepared by: St. Johns River Water Management District

Concerned by the possibility of adverse estuarine impacts caused by discharges of Canal 1 through Turkey Creek to the Indian River Lagoon, District staff produced an analysis of flow and salinity relationships based upon historic data and measurements made during three periods in 1989.

The report notes that clam harvesting and mariculture depend on good water quality, including salinity, and states, "Proper salinity ranges in the lagoon must be maintained to ensure viable clam populations and survival of their progeny."

The report concludes, "Discharges from Canal 1 that exceed 1000 cfs can decrease the salinity of the Indian River Lagoon below 20 ppt[5], the incipient standard adopted by SJRWMD staff. *It is desirable to maintain salinities at or above 20 ppt during the hard clam spawning seasons of spring and fall.* A maximum threshold of approximately 1000 cfs for Canal 1 appears necessary to meet the 20 ppt standard." (Emphasis added.)

The report defines the spring as March-May and the fall as September-November. The 20 ppt salinity is meant to apply in Lagoon waters 1000 meters from the mouth of Turkey Creek.

Analysis

This analysis and canal operation schedule apply to Turkey Creek, not the Sebastian River. However, Joel Steward (SJRWMD, memorandum of November 30, 1992) writes, "This same 20 ppt standard has also been applied to the Sebastian R./IRL area and the regulation of C-54 discharges since the summer/fall of 1990." The standard presumably applies in spring and fall, at a 1000 m distance from the mouth of the Sebastian River.

The statement that, "Proper salinity ranges in the lagoon must be maintained to ensure viable clam populations and survival of their progeny" has two implications. The first is that Lagoon salinity ranges can be maintained. The second is that viable [hard] clam populations are a desired end-point or outcome of inflow and salinity management, as opposed to oysters, for example.

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[5]/ Parts per thousand.

V. Comprehensive Plan Guidance

Introduction: Laws (Section 163.317 F.S.) and rules (Chapter 9J-5.012 F.A.C.) of the State establish policies and objectives; require regional and local government plans addressing specified issues; require vertical consistency of plans; and provide for administration, implementation, and amendments to plans. Relevant State goals include:

1. Florida shall assure the availability of an adequate supply of water for all competing uses deemed reasonable and beneficial and shall maintain the functions of natural systems and the overall present levels of surface and ground water quality. Florida shall improve and restore the quality of waters not presently meeting water quality standards;

2. Florida shall protect and acquire unique natural habitats and ecological systems such as wetlands...and restore degraded natural systems to a functional condition.

24. Regional Comprehensive Policy Plan

Prepared by: Treasure Coast Regional Planning Council.

The Regional Plan contains text for each required element, including:

Regional Goal 8.1.1: To assure that the Region's water supply is managed to provide for 1) protection of fish and wildlife values, 2) protection of natural systems and their values and function, 3) agriculture, 4) power development and 5) domestic, municipal and industrial needs on a sustainable basis.

Policy 8.1.1.2: For normal, average rainfall years, water availability, use, allocation and management plans shall recognize that:

> 1. Provision of sufficient water to maintain the functions and values provided by natural systems is the first priority and shall reserve sufficient water to meet the essential demands of fish and wildlife and the ecological systems that support them.

Policy 8.1.1.3: Water use allocation and management plans for emergency drought and flood situations shall avoid irreversible impact on ecological systems and minimize long term impacts on all sectors.

Analysis

The plan has separate policies for average and extreme water years. Natural systems have first priority in average years and no permanent damage and only minimal long term damage to natural resources are allowed.

With respect to the diversion of excess waters (flood situations), the plan implies that discharges must cause no permanent damage to the Indian River Lagoon. Such an impact is more difficult to imagine than long term impacts, which are to be minimized.

25. Brevard County Comprehensive Plan

Prepared by: Brevard County

This plan addresses all mandatory elements. Only pertinent language is cited.

The plan contains "Directives" in addition to goals, policies and objectives. Pertinent directives are:

1. No new structures designed to control the stage and/or flow of waters of the state shall be constructed except where such structures are necessary to...restore the function of the natural water-dependent ecosystem and no practical non-structural alternative exists.

2. All practical steps shall be taken to minimize adverse impacts to biological attributes of the water resources and water-dependent natural systems.

3. Brevard County should support a program to retrofit large drainage canals with water control structures to hold canal stages high during the dry season.

Goal: Protect, conserve, enhance, maintain and appropriately use natural resources and their environmental systems, maintaining their quality and contribution to the quality of life and economic well being of Brevard County.

Goal: Establish growth management strategies that will allow growth to continue within the coastal zone which does not damage or destroy the function of coastal resources... .

Policy 1.1. Brevard County shall develop a master surface water management plan which identifies areas within the Indian River Lagoon of poor and fair water quality as priority areas.

Analysis

The plan recognizes that "changes in water quality (increased nutrients, sedimentation, and high turbidity) have negative impacts on sea grasses" but the list of changes does not mention fresh water or salinity. The plan does not state why it is desirable to hold canal stages high during the dry season.

26. Indian River County Comprehensive Plan

Prepared by: Indian River County

This plan addresses all mandatory elements. Only pertinent language is cited.

Coastal Management Goal: To protect, maintain and enhance coastal resources and provide for the enjoyment of the social, economic and natural benefits of these resources, while reducing the potential loss of life, and public and private expenditures in the coastal zone.

Objective 2. By 1995, Indian River County will improve overall estuarine water quality to the Florida DER guidelines of Class II Waters -- shellfish propagation and harvesting.

Policy 2.1. The County shall immediately adopt the state classification of Class II as the minimum acceptable standard for existing water conditions, and shall target improvement efforts to those areas failing to meet this standard.

Policy 2.6. Indian River County shall improve the quality and reduce the overall amount of freshwater inflow to the Indian River Lagoon.

The plan contains a conservation element, which notes,

"A certain volume and frequency of freshwater inflow are required to maintain the overall health and stability of the Indian River Lagoon. Controlled discharges to the lagoon can mimic natural storm-related discharges. However, with respect to volumes, quality, and seasonality, some discharges [may] lead to changes in the ecosystem which could potentially be detrimental to estuarine organisms and water conditions."

Conservation Goal: To protect, conserve, enhance or appropriately use the county's natural resources in a manner which maximizes their natural functions and values.

Objective 2. By 1995, water quality throughout the Indian River Lagoon and the St. Sebastian River shall meet state Class II and Class III water quality standards, respectively, and the County will protect and appropriately use these and other surface waters to maximize their natural functions and values.

Policy 2.1.e. No point-source discharge shall be allowed to enter the St. Sebastian River or Indian River Lagoon when such discharge is of poorer quality than state Class II water quality parameter standards.

Objective 7. There will be no reduction in the critical habitat of endangered or threatened plant or animal species occurring in Indian River County... .

("Critical habitat" is defined in the plan as the minimum required sum of environmental conditions in a specific area necessary to sustain a given species.)

Analysis

The plan recognizes that "the county's principal surface water discharge into the lagoon is from the south prong of the Sebastian Creek (River) and from the north, main and south canals of the Indian River Farms Water Control District" and that "the overall average water quality of the creek and south prong was classified as fair." Taken literally, the County's objective to raise estuarine water quality to Class II standards could apply to those tidal waters of the County in the south prong of Sebastian Creek. The conservation element clarifies this point, stating that the water of St. Sebastian River will meet Class III standards but that point-source discharges to the stream must meet Class II standards.

27. City of Sebastian Comprehensive Plan

Prepared by: Solin and Associates, Inc.

This plan also addresses all mandatory elements. Only pertinent language is cited.

Goal 5-1. Restrict development activities that would damage or destroy coastal resources and protect human life...

Objective 5-1.1. Protect coastal resources, wetlands, estuary, living marine resources, and wildlife habitats.

Policy 5-1.1.2. Protect the Indian River Lagoon [in part by preventing pollution and controlling surface water runoff].

Policy 5-1.1.5. Manage impacts of coastal development on tidal flushing and circulation patterns.

Goal 6-1. The coastal community of Sebastian shall conserve, protect and appropriately manage the city's natural coastal resources in order to enhance the quality of the natural systems within the community.

Policy 6-1.2.2. Regulate agricultural activities to preserve water quality. Land development regulations shall include stipulations that agricultural activities shall...maintain natural drainage patterns.

Policy 6-1.2.10. Protect and conserve lakes and estuarine areas.

Objective 6-1.8. Protect fisheries, wildlife and wildlife habitats.

Analysis

This small community has a thorough plan that speaks, in some cases, to issues that are larger or more general than the city may be able to address. On the other hand, it depicts a commitment to protection of the natural coastal environment.

The policy that agricultural runoff shall maintain natural drainage patterns implies that the location, amount and timing of drainage will not be different than historic conditions, because of agriculture.

VI. Other Local Government and Private Guidance

28. Management Plan and Implementation Strategy for the IRL Systems

Prepared by: Marine Resources Council, Florida Institute of Technology

The Florida Legislature and Florida Sea Grant Program funded a project by the Marine Resource Council to develop a management plan and implementation strategy for the lagoon. The project drew from scientific symposia, Indian River Lagoon American Assemblies, and other technical and public sources. It incorporates recommendations of the Field Committee (reviewed above). The report describes the resources of the region, establishes goals and objectives, provides an analysis of legal jurisdictions, and proposes management alternatives.

The report states that the American Assemblies reached consensus on the three major problems facing the lagoon, which include the need to reduce the amount and peak flow of fresh water entering the system.

Goals presented in this report are the same as those listed in Item 17 (Indian River Lagoon System Management Plan prepared by the Field Committee) and only one is restated here.

> Identify freshwater inputs to the lagoon system and manage these inputs in a manner consistent for the system and its resources.

As noted earlier, the Field Committee report includes an objective dealing specifically with fresh water inflow, and the associated policies call for the elimination of agricultural runoff and reduction of interbasin transfers to the Lagoon. These actions would have the effect of raising salinity in the Lagoon.

The report analyzes legal jurisdictions affecting the Lagoon, and possible management alternatives. The report recommends that water control and water management districts work to regulate discharges of fresh water to the Lagoon.

Results of the 1985 American Assembly are reported.

Analysis

The only new items presented in this synthesis are the jurisdictional analyses and the American Assembly. The jurisdictional analysis did not cite specific goals or objectives of agencies and the relationship of same to fresh water or salinity was not presented. The Assembly report did not present goals or objectives for lagoon management. The same is true of the report on the 1991 Assembly, introduced here for the record. The 1991 report did note:

1. C-54 canal output has been reduced;
2. C-44 canal discharges [are] better managed;

3. There is definitely still a diversion problem. Freshwater is being inappropriately diverted to the Lagoon.
4. Pulsing is an effective way to mitigate damage and more closely match *historical* conditions (emphasis added).

No explanation was given as to why fresh water diversion is inappropriate. Is diversion of any kind inappropriate, or are specific aspects of diversion (such as quantity, rate of change, duration, location, timing, etc.) inappropriate?

29. Brevard County Aquaculture Task Force Recommendations

Prepared by: Brevard County Aquaculture Task Force

The growing number of shellfish and aquaculture leases in Brevard County led to the formation of an Aquaculture Task Force, comprised of industry and agency representatives. Their purpose was to make recommendations to the Board of Brevard County Commissioners regarding overall management of marine aquaculture development.

Goals of the Task Force were to:

1. Maintain and enhance the beauty, productivity and economic viability of the Indian River Lagoon;

2. Maintain the water quality of the Lagoon for public recreation and fisheries productivity; and

3. Enhance public safety for both aquaculture and navigation.

The report identified a number of issues and needs, including "protection of the lagoon from inappropriate...freshwater inputs..."

Analysis

The Task Force's goals, particularly the second one, actually call for the maintenance of Class III water quality standards (maintenance of fish and wildlife, contact recreation, etc.) rather than the Class II standards needed for the propagation or harvesting of shellfish. "Fisheries productivity" was probably meant to mean propagation or harvesting of shellfish by that fishery.

In context of the report, the public safety aspect of the third goal refers to accident prevention rather than shellfish sanitation.

PART II

SEBASTIAN RIVER SALINITY REGIME

Part II: Segmentation

(Contract 92W-177)

submitted April 1993 to:

St. Johns River Water Management District

by the:

Mote Marine Laboratory
1600 Thompson Parkway
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Michael J. Marshall, Ph.D.
Principal Investigators

Mote Marine Laboratory Technical Report Number 286

EXECUTIVE SUMMARY

This is the second report of a project concerning desirable salinity conditions in the Sebastian River and adjacent Indian River Lagoon. A perception exists that the present salinity regime of the Sebastian River system is undesirable. The St. Johns River Water Management District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the Sebastian River and adjacent waters of the Indian River Lagoon. The District can then calculate discharges needed to produce the desired salinity regime, or conclude that optimal discharges are beyond its control. The first component of this project was an analysis of existing goals for the study area, emphasizing those that directly or indirectly related to the question of salinity. This second component addresses the geographical segmentation of the study area.

Segmentation refers to the geographic subdivision of an area for purposes of resource management. Criteria for the subdivisions vary according to the end use of the segmentation system. Objectives of this effort are to: (1) Review existing segmentation systems and geo-referenced data for the study area; and (2) Establish a segmentation system for salinity guidelines and recommendations for new data collection. Literature and other sources were consulted for information on existing segmentation systems and geo-referenced data in the Sebastian River and nearby waters of the Indian River Lagoon. Findings were sorted according to segmentation systems, boundaries, and geo-referenced data for the Indian River Lagoon and for waters within the Sebastian River.

A total of 33 segmentation systems or other sets of geographic data were obtained, of which 26 pertained to the issues of fresh water inflow, salinity, or estuarine ecosystem structure. The most significant of these is the line between Brevard and Indian River Counties. The county line has been used to define a number of federal, state, regional and local regulatory and resource management programs. Despite its widespread use, this line is not helpful in the present task of defining a desirable and ecologically acceptable salinity regime for the study area because it divides the River and Lagoon artificially. Four systems pertain in some way to shellfish, and the Intracoastal Waterway is an integral part of these and other systems. Based on these considerations, the study area is divided into segments and 2 specific sites, as follows:

Sebastian Inlet: Mid-channel of the Inlet at A1A bridge.

"Inlet" Segment: Indian River Lagoon west of Sebastian Inlet and east of the Intracoastal Waterway, extending 2.0 km north and south of the Brevard/Indian River County line.

Intracoastal Waterway: Mid-channel at the intersection of the Intracoastal Waterway and the Brevard/Indian River County line.

"River Mouth" Segment: Indian River Lagoon west of the Intracoastal Waterway to the mainland shore and U.S. 1 bridge, between ICW daymarks "R58" and "R62".

U.S. 1: Mid-channel of the River at U.S. 1 bridge.

"River" Segment: Sebastian River west of U.S. 1 bridge to mouths of North and South Prongs.

"Lower South Prong" Segment: South Prong from its entry to the River Segment, upstream to a point near 27°46'50" N. latitude.

"Upper South Prong" Segment: South Prong upstream of 27°46'50" N. latitude.

"Lower North Prong" Segment: Canal 54 upstream of the River Segment to and including the North Prong from its confluence with C-54, upstream to a point near 27°50'45" N. latitude.

"Upper North Prong" Segment: North Prong upstream of 27°50'45" N. latitude.

"Canal 54" Segment: Canal 54 west of the mouth of the North Prong Segment, to and including the outlet of Fellsmere Canal.

"Structure 157" Segment: Canal 54 west of Canal 54 Segment to S-157.

The general location of these segments is illustrated in Figure I.

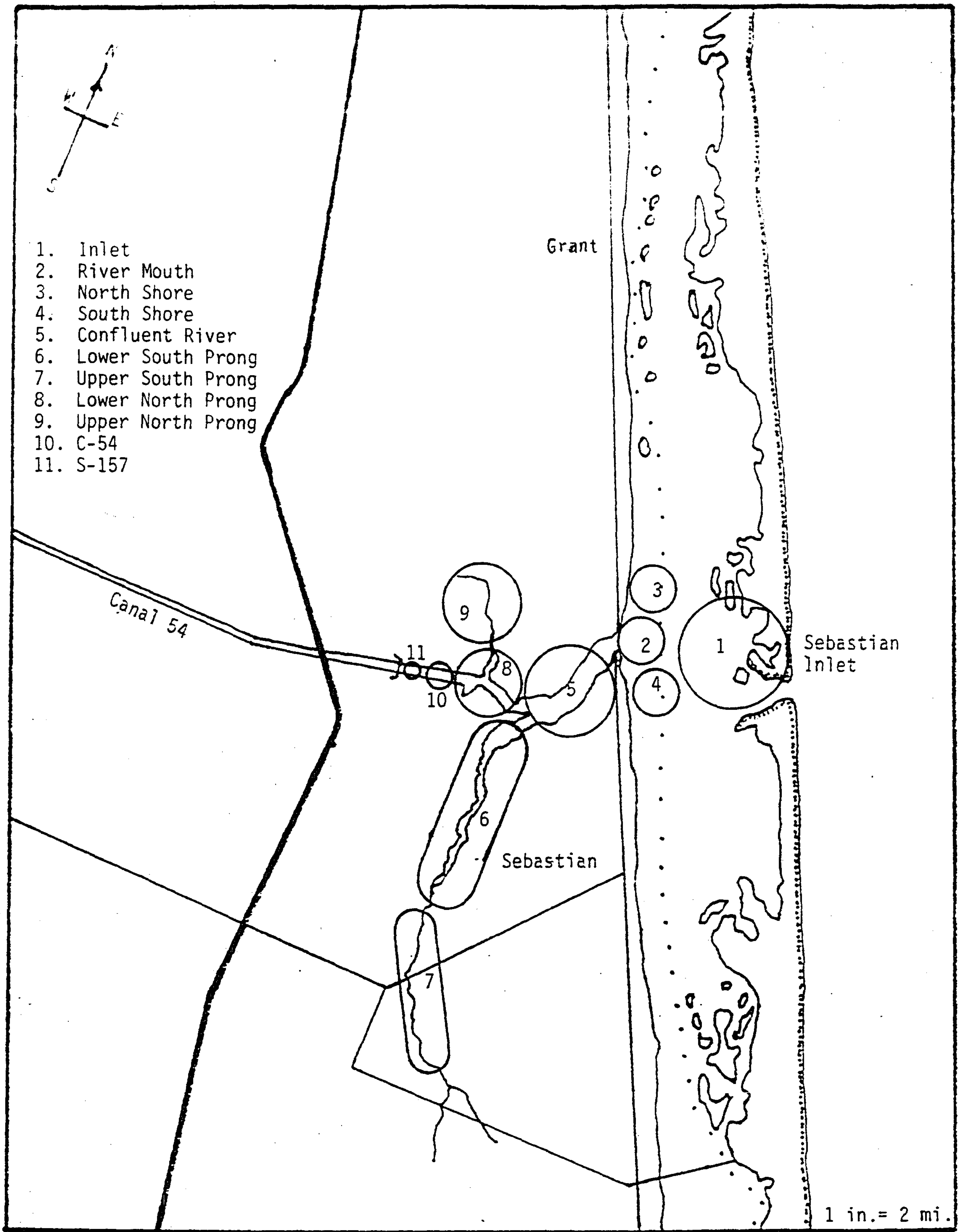

Figure I. Salinity Segments.

PREFACE

This is the second report and component of a project concerning desirable salinity conditions in the Sebastian River and adjacent Indian River Lagoon. A perception exists that the present salinity regime of the Sebastian River system is undesirable. Based on studies in nearby estuaries (Haunert and Startzman, 1985) discharges of C-54 are implicated as a component of the problem. The District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the Sebastian River and adjacent waters of the Indian River Lagoon. The District can then calculate discharges needed to produce the desired salinity regime, or conclude that optimal discharges are beyond its control.

The first component of this project was an analysis of existing goals for the study area, emphasizing those that directly or indirectly related to the question of salinity. Goal statements were sought from federal and state laws, agency rules, resource management plans, local government comprehensive plans, and other sources. This second component addresses the geographical segmentation of the study area. The third and final components will recommend salinity guidelines for the River and adjacent Lagoon.

This project is one of several activities concerning resource planning and management in the Sebastian River and lagoon region. The St. Johns River Water Management District has undertaken a basin runoff modeling project to determine the quantity of water entering the Sebastian River from various sources. Results of this effort will be used as input to a circulation and salinity model of the area, being produced for the District by the U.S. Geological Survey. The USGS modeling effort can be coordinated with a model of the Indian River Lagoon from the Sebastian River north to, and including, Turkey Creek, being produced by the Florida Institute of Technology.

The final results of this project can be used in concert with the three modeling efforts described above, when they are completed by 1995, to estimate the attainability of improvements to fresh water discharge and overall ecological conditions in and near the Sebastian River.

Acknowledgements

For their assistance by providing data, reports, or helpful information we are grateful to D. Basta, NOS Strategic Environmental Assessments Division; B. Poole, Florida Department of Natural Resources (FDNR) Aquatic Preserve Office; D. Witmore and J. Carroll, U.S. Fish and Wildlife Service; B. Browning, FDNR; D.C. Heil, FDNR Bureau of Marine Resource Regulation and Development; J. Steward and F. Morris, St. Johns River Water Management District; D.S. Knight, Knight, McGuire and Associates, and B. Frease and D. Barile, Marine Resources Council. Mote Librarian J. McGuire handled numerous, often obscure literature requests and L. Franklin assisted with report preparation.

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INTRODUCTION

Segmentation refers to the geographic subdivision of an area for purposes of resource management. Segmentation systems enhance research and management. An area may be segmented as part of the design phase of a data collection program, to insure geographic balance of effort. Segments may be used for data compilation and analysis, as in the cases of pattern or trend analysis. Segments can also improve the reporting of results.

The process of segmentation involves the geographic subdivision of an estuary into two or more areas. Criteria for the division vary according to the end use of the segmentation system. For general resource management, estuaries may be divided into "problemsheds" (D. Basta, NOS Strategic Environmental Assessments Division, personal communication): these are centers or foci of management problems and the surrounding area(s) they affect. Boundaries between foci may be "soft" or "hard" depending on the nature of issues, data density, and the physical structure of the estuary.

Segmentation has been used widely in the Environmental Protection Agency. All coastal waters have been divided into water bodies for purposes of reporting on water quality under Section 305(b) of the Water Quality Act, and EPA has issued guidelines to states on segmentation procedures. Segmentation is also used in EPA's National Estuary Program (NEP). A segmentation system for the Sarasota Bay NEP was developed by Estevez (1990). The National Oceanic and Atmospheric Administration has made extensive use of segmentation for characterization purposes. Klein and Orlando (1992) proposed a geographic subdivision of the Florida Keys National Marine Sanctuary, and NOAA previously developed segmentation systems for the Estuarine Living Marine Resources (ELMR) Program, Gulf of Mexico Program (GOMP), and Coastal Oceans Program.

Segmentation is meaningful in data-poor estuaries because the process causes a review of existing information and identification of data gaps; provides a mechanism for the equitable distribution of new sampling and measurement effort; and embodies hypotheses about ecosystem structure that may be tested at a later date. In data-rich systems, segmentation is easier to perform but sometimes less useful because actual foci and boundaries can be identified within the known structure of the ecosystem. Patterns of estuarine circulation, mixing, and flushing are examples of data that lead directly to estuarine segmentation. Segmentation systems may be retired once the circulation of an estuary is known completely.

<u>Objectives</u>

The Sebastian River and nearby waters of the Indian River Lagoon are segmented for the purpose of recommending ecologically favorable salinity regimes. Objectives of this report are to:

(1) Review existing segmentation systems and geo-referenced data for the study area;

(2) Establish a segmentation system for salinity guidelines and recommendations for new data collection.

METHODS

Literature and other sources were consulted for information on existing segmentation systems and geo-referenced data in the Sebastian River and nearby waters of the Indian River Lagoon. Findings were sorted according to segmentation systems, boundaries, and geo-referenced data for the Indian River Lagoon and for waters within the Sebastian River. Findings were sorted further according to whether each was an example of a segmentation system used by government agencies, a system used for monitoring or scientific study, or a naturally occurring break in the geographic distribution of resources. Only findings that are or may be pertinent to the issues of fresh water inflow, salinity, or estuarine ecosystem components within the study are presented.

RESULTS

A total of 33 segmentation systems or other sets of geographic data were obtained, of which 26 pertained to the issues of fresh water inflow, salinity, or estuarine ecosystem structure (Table 1).

I. Regional Systems

The geographic coverage of a regional system or feature greatly exceeds the study area for the present project.

I.A. Governmental Units

The most significant of these is the line between Brevard and Indian River Counties (Figure 1). The Sebastian River and adjacent Indian River Lagoon were part of St. Johns County established in 1821. Not counting short-lived counties that no longer exist, the study area became part of Mosquito County (1840) and Brevard County (1860), where it remained until 1920. Then, St. Lucie County was created so as to include all of the south prong of the Sebastian River, leaving the north prong and all of the confluence area in Brevard County. Indian River County was divided from St. Lucie County in 1940. At that time, the southern boundary of Brevard County was moved to divide a short reach of the south prong and all of the confluence area between the two counties. The boundary runs east from the River across the lagoon and into the Atlantic Ocean through the middle of Sebastian Inlet (Fernald, 1981).

The county line has been used to define a number of federal, state, regional and local regulatory and resource management programs. Although not complete, the following list identifies examples of the ways in which the county line has been utilized to divide:

1. Northeast and southeast areas of the Jacksonville District Office, Army Corps of Engineers;
2. EPA and DER federal air quality control regions;
3. Districts of the U.S. Fish and Wildlife Service;
4. Districts of the U.S. Soil Conservation Service;
5. DER's St. Johns River and South Florida Environmental Districts;
6. Planning Districts within the Florida Department of Transportation;
7. Regional Planning Councils;
8. 208 water quality planning districts;
9. Florida Sea Grant Extension Offices.

Additional examples affecting segmentation are described in more detail, below.

Other regional systems include the State's aquatic preserve boundary and Outstanding Florida Waters designated area. The Malabar/Vero Beach Aquatic Preserve essentially runs throughout the study area (Figure 2), but has local boundaries at Sebastian Inlet and at County Road 512 (Fellsmere Road) on the South Prong (Brian Poole, FDNR Aquatic Preserve Office, personal communication). Outstanding Florida Waters likewise cross the study area (Figure 3) and end at the inlet, but do not extend west of U.S. Highway 1.

Finally, the State of Florida authorized establishment of the Sebastian Inlet Tax District. Boundaries of this district (not illustrated) are outside of the study area although all of the study area falls within the district. The southern boundary of the district crosses the Indian

River Lagoon approximately 9 miles south of the Sebastian River mouth. The north district boundary crosses the Lagoon about 17 miles north of the River (Gilbrook, 1992).

I.B. Regional Science

Nearly all of the earlier regional investigations crossing the study area have been hydrological and chemical in nature. Hydrological and chemical data influenced the geographic subdivision of the Indian River Lagoon into four major segments (Figure 4) and the subdivision of each into sub-basin drainage areas (Figure 5). This segmentation system was created for SWIM planning and analysis (Steward and Van Arman, 1987) and has been incorporated into IRLNEP planning. Major segments and sub-basin boundaries utilize the Brevard/Indian River County line, Sebastian River, and Sebastian Inlet as divides.

I.C. Natural Features

One physical feature of the Indian River Lagoon that exhibits an interesting change in the vicinity of the study area is the amplitude of principal tidal constituents (Figure 6). In particular, the amplitude of the M_2 constituent, or semidiurnal tide, is less than 5.0 cm north of Sebastian River and Inlet, but is much larger and increases with distance south of the River and Inlet (Smith, 1987).

II. Local Systems within the Indian River Lagoon Study Area

The geographic coverage of a local system or feature is equal to or smaller than the study area for the present project.

II.A. Governmental Units

1. Federal

The Pelican Island National Wildlife Refuge (Figure 7) is defined along its north, east, and west boundaries by lines falling within the present study area. Waters west of the Intracoastal Waterway are excluded from the Refuge, as are waters in Brevard County and a small part of Indian River County south of the Sebastian Inlet approach channel. An expansion of the Refuge has been proposed (Fish and Wildlife Service, 1991) and early versions of the proposal would extend the Refuge further west, north and south. The Sebastian River would become part of the Refuge under the original proposal, which is presently being revised (D. Witmore, personal communication).

2. State

The Intracoastal Waterway also serves as part of the divide between Class II and Class III waters of the State. Class II waters allow for shellfish propagation and harvest, whereas Class III waters do not. Class III waters include the Sebastian River and the Indian River Lagoon off the mouth of the River and west of the Intracoastal Waterway in Indian River County (Figure 8). The Intracoastal Waterway therefore represents the boundary between shellfish propagation and harvest, and general fish and wildlife management.

Another segmentation system involving shellfish affects the study area. As part of Florida's shellfish sanitation program, waters of the state are classified according to their ability to support safe harvests (Figure 9). The mainland shore immediately north of the mouth of the Sebastian River, and in the vicinity of Grant, is closed to harvesting. The waters of Indian River County outside of the Refuge are unapproved, meaning that harvests are not allowed by default. Refuge waters are open to harvest based on conditional state approval. An area of the Lagoon in Brevard County, north of the Inlet, is designated as a relay area and the Lagoon north of that is conditionally approved. The county line and Intracoastal Waterway are utilized in this segmentation system. Changes to the system have been proposed but have not been adopted (B. Browning, Florida Department of Natural Resources [FDNR], personal communication).

Another form of governmental segmentation related to shellfish concerns the award of leases for shellfish operations. These include shellfish leases and aquaculture leases. These leases tend to honor the shellfish sanitation classification system described above, but shellfish leases may be much older than the current shellfish classification system in use. The location of 47 leases and 2 proposed shellfish leases in the vicinity of the study area was determined from records of the Florida Department of Natural Resources (D.C. Heil, FDNR Bureau of Marine Resource

Regulation and Development, personal communication). Locations of all leases were mapped and are summarized in Figure 10, in which no recorded or proposed shellfish leases were identified between the two bold lines. Comparable data on aquaculture leases were requested from FDNR on October 7, 1992 but no information has been received as of this writing.

Another state system involving the regulatory delineation of a geographic area in the vicinity of the Sebastian River concerns manatees. According to the joint study report of the South and St. Johns River Water Management Districts (Steward and Van Arman, 1987), an irregular polygon between Sebastian River and Sebastian Inlet is a designated manatee over-wintering habitat and protection area (Figure 11). Additionally, a manatee protection zone extends throughout the Sebastian River system, where boat speed restrictions are in effect.

The last state system affecting the Lagoon near the study area is the boundary used by the Hutchinson Island Resource Planning and Management Committee (Cassens, 1983). The committee was appointed by Governor Graham to organize a management program to address problems of resource protection in the face of rapid population growth. Limits of their study area included Atlantic nearshore waters and all of the Indian River Lagoon east of U.S. 1 in Indian River County, except that the boundary ran to the north bank of the Sebastian River (Figure 12).

The St. Johns River Water Management District recognizes an arc 1000 m from the mouth of the Sebastian River as an interim limit to the depression of salinity below 20 parts per thousand (ppt) during clam spawning seasons of spring and fall (J. Steward, SJRWMD, personal communication). The interim goal, illustrated in Figure 13, is based on the transfer of findings from a study performed near the mouth of Turkey Creek (Steward and Higman, 1989). The arc crosses the Intracoastal Waterway but lies entirely within the shellfish lease limit area shown in Figure 10).

3. Local

The City of Sebastian includes a reach along the eastern shore of the South Prong of Sebastian River, between river miles 5.0 and 7.0 (not illustrated).

II.B. Lagoon Science

The present study was directed to concentrate on the characteristics of a desirable and ecologically acceptable salinity regime for the waters of the Sebastian River, and waters of the Indian River Lagoon within a radius of 2.5 miles from the mouth of the River (Figure 14). Such an area includes the Sebastian Inlet and a small area of shellfish leases in Brevard County, but no shellfish areas in Indian River County (compare Figure 10).

II.C. Natural Features

Bathymetry of the Indian River Lagoon and Sebastian River is imprecisely known. Bottom features of the Sebastian Inlet area are well mapped but the only existing Lagoon bathymetry is that available from NOS Nautical Chart 11472 (26th Edition). Bathymetry of the Lagoon north of the River is part of a physical modeling effort focusing on Turkey Creek (G. Zarillo, Florida Institute of Technology, personal communication) but the present study area is excluded. The bathymetry of the Sebastian River is completely unknown although the District has contracted for a bathymetric survey (F. Morris, SJRWMD, personal communication). Data from the NOS chart (not corrected for features of the flood tidal delta inside Sebastian Inlet) are illustrated in Figure 15. Waters deeper than 6 feet follow an irregular area near the center of the Lagoon. Depths of 4 feet parallel the shore with two eastward projections and depths of 2 feet parallel the western shore except for the River mouth. The Intracoastal Waterway lies west of the deepest natural waters. Numerous islands and subtidal shoals parallel the Intracoastal Waterway.

Submerged aquatic vegetation occurs in the Indian River Lagoon near the Sebastian River. Three examples of SAV maps are illustrated. Figure 16 depicts SAV cover based on 1974-1975 imagery (Downs, 1983). A broad area of seagrasses was mapped north of the River and another large area of potential SAV was indicated south of the River. Carroll (1983) mapped a considerably smaller area of seagrass growth, especially to the north of the River (Figure 17). Carroll's map was based on 1982 imagery and 100 percent ground-truthing, and depicted SAV associated with spoil islands and shoals. White (1986) used 1986 imagery to depict SAV in the area (Figure 18): the

1986 work agrees with Carroll's in 1982 by reporting continuous shoreline beds south of the River, and small fringing beds around islands and shoals.

SAV data from Carroll (1983) were investigated to determine what relationship, if any, could be made between SAV cover and distance from the mouth of the Sebastian River. Figure 19 depicts raw SAV cover in relation to distance from the River; SAV cover is fairly constant until the large shoals along the eastern shoreline of the Lagoon are encountered. Because the tiers varied in absolute area and the "catch" of SAV could therefore be affected, SAV area was normalized by the amount of subtidal area in each tier (Figure 20). Normalized area rises and falls before reflecting the eastern shore SAV. The decline in relative SAV cover at 2.0 km corresponds to the deeper waters of the Lagoon (Figure 15). Local SAV reaches a maximum at 1.0 km (1000 meters) from the River. Approximately 15.0 hectares of SAV existed within 1000 m of the River in 1982.

III. Local Systems within the Sebastian River

These systems occur west of U.S. Highway 1.

III.A. Governmental Units

No regulatory boundaries were found within the Sebastian River except for the Brevard - Indian River County line, described earlier.

III.B. River Science

Three District-sponsored data collection programs are underway in the River. One, a contracted bathymetric survey, covers the waters downstream of S 157, entrances to the North and South Prongs, and the confluence of all three tributaries east to U.S. Highway 1. Another study is a collaboration of the District and U.S. Geological Survey, and involves stage/discharge, water level, current, salinity and temperature measurements. Stations fall within the area of the bathymetry survey but one additional station is situated in the Lagoon east of U.S. Highway 1 (F. Morris, SJRWMD, personal communication). Finally, the District has collected water quality data at a few stations in the same area, with increased effort during periods of canal discharge. The sampling was performed by Indian River County, for the District, during the summer of 1992.

Water quality is also being monitored by volunteers coordinated by the Marine Resources Council, under a grant from the Florida Department of Environmental Regulation and Indian River Lagoon National Estuary Program. Nine stations are sampled weekly, at the surface (Figure 21). Parameters include salinity, dissolved oxygen, temperature, pH and Secchi depth (B. Frease, MRC, personal communication).

Two biological studies have segmented the "North" Prong, in both cases referring to the S 157 approach. It would be more precise to refer to the approach to S 157 as the "West Prong"[1] and retain "North Prong" as the name of the tributary flowing south from Brevard County. In correspondence to the U.S. Army Corps of Engineers, Gilmore (1981) described study reaches and micro-habitats for fishes in the West and North Prongs (Figure 22). Gilmore reported on the presence of oligohaline environments and fauna and an arteminimum (estuarine reach of low species richness) east of S 157. Heyman (1990) reported on manatee use of 10 individual segments in the West and North Prongs of the River (Figure 23), and described patterns and trends in manatee abundance. The downstream limit of both biological studies was immediately east of the mouth of the North Prong.

III.C. Natural Features

An interesting transition between soil types occurs in the North and South Prongs of the River. In Brevard County, first edition soil maps depict a river corridor of Swamp soils extending downstream to a point where the soils become Tidal Swamp (Soil Conservation Service, 1974). Swamp soil is nearly level and poorly drained, with a dense cover of wetland hardwoods, cypress, vines and shrubs. It occurs in poorly defined natural drainage-ways and is flooded with fresh water most of the time. Tidal swamp soil is similar but dominated by mangroves and other tidal vegetation. In the South Prong, soil nomenclature is different but their ecological properties are analogous to those in the North Prong. An upstream Riviera fine sand is nearly level and poorly drained. Natural flora include blue maidencane, cypress trees, red maple, sand cordgrass, and arrowhead. Downstream of

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1/ Historical literature (Henshall, 1884) and soils maps support this interpretation.

Riviera sand, Floridana sand parallels the river corridor. Its flora resembles that of Riviera sand without cypress or red maple.

The transitions noted in the Sebastian River are similar to those seen in rivers on the Florida west coast, where salinity measurements have shown that the transitions correspond to very low (<5.0 ppt) salinities (Estevez et al., 1991b). Using the west coast data as a guide, the Sebastian River soils may indicate the long-term location of the saltwater-fresh water interface. These locations are depicted in Figure 24. In the South Prong the transition occurs at river kilometer 11.1. This position corresponds well with mean surface salinity measured by the Marine Resources Council volunteer program (Figure 25), where the interpolated mean salinity at river kilometer 11.1 is approximately 1.0 ppt. As shown by Figure 26, the variance in surface salinity at this location is approximately 1.0 ppt, implying a range of up to 2.0 or 3.0 ppt.

Salinity characteristics of the South Prong correspond well with the stream's geometry (Figure 27). Surface area of the River was measured on aerial photographs having a scale of 1" = 200 ft. Area was measured for separate 250 m intervals along the thalweg of the stream. In the first three kilometers from U.S. Highway 1, area is large and variable. Some of the variation is attributable to irregular segment shapes but the River naturally varies at the confluence of its tributaries. In the South Prong, area declines rapidly as the stream narrows. Upstream of river kilometer 8.0, river area becomes constant and varies little. This geometry is typical of tidal streams, and the regular, narrow reach of other rivers is where transitions of fresh to salt water have been documented.

The transitions expected in actual plant communities along the gradients described above cannot be documented with existing surveys. For example, District GIS maps of land use and vegetation depict no mangroves in the South Prong of the River (not illustrated). This situation is probably due to the scale, data sources, and classification system employed in the mapping (Florida Land Use and Cover Classification System). Proliferation of brazilian pepper (<u>Schinus</u> <u>terebinthifolius</u>) throughout the river corridor may have obscured photointerpretation, because the dominant plant community mapped in the South Prong is non-forested mixed scrub and shrub. Upstream of Fellsmere Road, the dominant corridor plant community is mapped as fresh water marsh.

DISCUSSION

The geographic boundary most commonly encountered in this review was the line separating Brevard County and Indian River County. The line runs east parallel to Canal 54 to the South Prong of the Sebastian River, north more-or-less along the center of the South Prong and confluence to U.S. Highway 1 and the river mouth, then across the Indian River Lagoon to Sebastian Inlet. At least 14 systems use the line to divide regulatory, management, or other programs.

Despite its widespread use, this line is not helpful in the present task of defining a desirable and ecologically acceptable salinity regime for the study area because it divides the River and Lagoon artificially. Rivers are used to divide at least 42 counties and numerous municipalities in Florida. The impact of this practice on resource management is not known but may be postulated as unfavorable because it does not promote the ability of local governments to manage streams and their watersheds on a hydrological or ecosystem basis. Although the Florida Comprehensive Planning and Land Development Regulation Act of 1985 directs local government comprehensive plans to agree where governments share common bodies of water, there is little evidence that such coordination has occurred in Florida and no evidence of it regarding the Sebastian River. On the other hand, the voluntary Watershed Action Committee for the Sebastian River holds considerable promise for integrated basin and stream management (D. Barile, Marine Resources Council, personal communication).

Another existing boundary that is in common use and of more potential value in this project is the Intracoastal Waterway. It is part of the present boundary of the Pelican Island National Wildlife Refuge and forms the divide between Class II and Class III waters of the State. It also divides waters of the Indian River Lagoon into areas of different shellfish sanitation. Spoils associated with the Waterway support the last seagrasses one encounters in crossing the Lagoon from the Sebastian River, until grass beds in shallows and near the Inlet are met. The Intracoastal Waterway is 1.22 km from the mouth of the Sebastian River, as measured along the county line.

Proposed Segmentation System

The objective of later project tasks will be to recommend desirable and ecologically acceptable salinity characteristics for specific areas in the Sebastian River and adjacent waters of the Indian River Lagoon. The ideal form of the recommendations would contain guidelines for mean salinity, salinity ranges, rates of change, vertical differences, etc. for each segment within the study area.

Existing governmental, scientific, and natural boundaries have been considered in the design of a segmentation system. Additional considerations include the segments' usefulness in compiling and analyzing existing salinity data and ecological information; correspondence to ongoing data collection programs; and application of the recommended salinity regime in District modeling and decision-making. Based on these considerations, the study area is provisionally segmented as follows (see Figure 28):

Sebastian Inlet: Mid-channel of the Inlet at A1A bridge. This is a *site* rather than a segment, useful because of its accessible proximity to the Atlantic Ocean.

"Inlet" Segment: Indian River Lagoon west of Sebastian Inlet and east of the Intracoastal Waterway, extending 2.0 km north and south of the Brevard/Indian River County line. It is the largest proposed segment and encompasses the flood-tidal delta, extensive seagrass and intertidal wetland areas, and a small area of active shellfishing.

Intracoastal Waterway: Mid-channel at the intersection of the Intracoastal Waterway (ICW) and the Brevard/Indian River County line. Also a *site* rather than a segment, this station is a common sampling and measurement location. In the field, its location may be set near an ICW daymark, "Green 61".

"River Mouth" Segment: Indian River Lagoon west of the Intracoastal Waterway to the mainland shore and U.S. 1 bridge, between ICW daymarks "R58" and "R62". These daymarks are approximately as far north and south of the county line as the ICW is east of U.S. 1.

U.S. 1: Mid-channel of the River at U.S. 1 bridge. This is a *site* rather than a segment.

"River" Segment: Sebastian River west of U.S. 1 bridge to mouths of North and South Prongs. This segment is also referred to as the "confluent" river segment.

"Lower South Prong" Segment: South Prong from its entry to the River Segment, upstream to a point near 27°46'50" N. latitude. The point corresponds to the location of a transition in shoreline soil types.

"Upper South Prong" Segment: South Prong upstream of 27°46'50" N. latitude.

"Lower North Prong" Segment: Canal 54 upstream of the River Segment to and including the North Prong from its confluence with C-54, upstream to a point near 27°50'45" N. latitude. The point corresponds to the location of a transition in shoreline soil types.

"Upper North Prong" Segment: North Prong upstream of 27°50'45" N. latitude.

"Canal 54" Segment: Canal 54 west of the mouth of the North Prong Segment, to and including the outlet of Fellsmere Canal.

"Structure 157" Segment: Canal 54 west of Canal 54 Segment to S-157.

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Table 1. Summary of segmentation systems, natural features, and other geographic boundary systems reviewed in this report.

1. Brevard/Indian River County Line
2. Malabar/Vero Beach Aquatic Preserve
3. Outstanding Florida Waters Designation
4. Sebastian Inlet Tax District
5. SWIM Segments and Sub-Basin Drainage Areas
6. Lagoonal Tidal Characteristics
7. Pelican Island National Wildlife Refuge
8. Class II and III Waters of the State
9. State Shellfish Sanitation Classification
10. State Shellfish and Aquaculture Leases
11. Manatee Protection Area
12. Hutchinson Island Resource Planning and Management Committee
13. Interim District Salinity Target for Turkey Creek and Sebastian River
14. Bathymetry of the Indian River Lagoon
15. Seagrass of the Indian River Lagoon
16. Municipal Jurisdictions: City of Sebastian
17. Sebastian River Bathymetric Survey -- Scope of Work
18. Sebastian River Circulation and Salinity Model -- Scope of Work
19. District Water Quality Monitoring Program
20. Manatee Utilization of the North Prong
21. Oligohaline Fish Utilization of the North Prong and C 54.
22. Soil Types in the North and South Prongs
23. Salinity Profile of the South Prong
24. Geometry of the Sebastian River -- Length
25. Geometry of the Sebastian River -- Surface Area
26. Wetland Plant Communities of the South Prong

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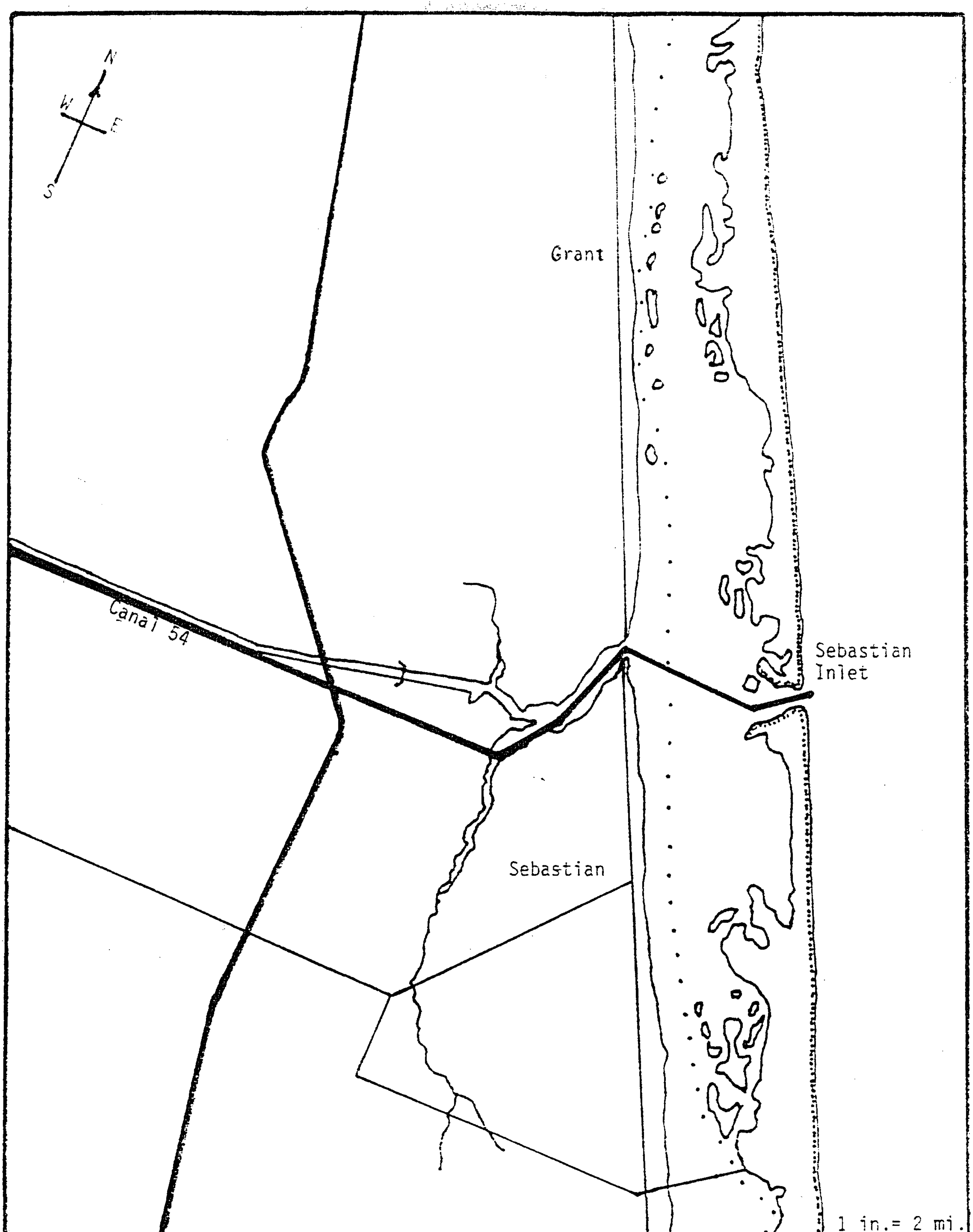

Figure 1. Brevard -- Indian River County Line.

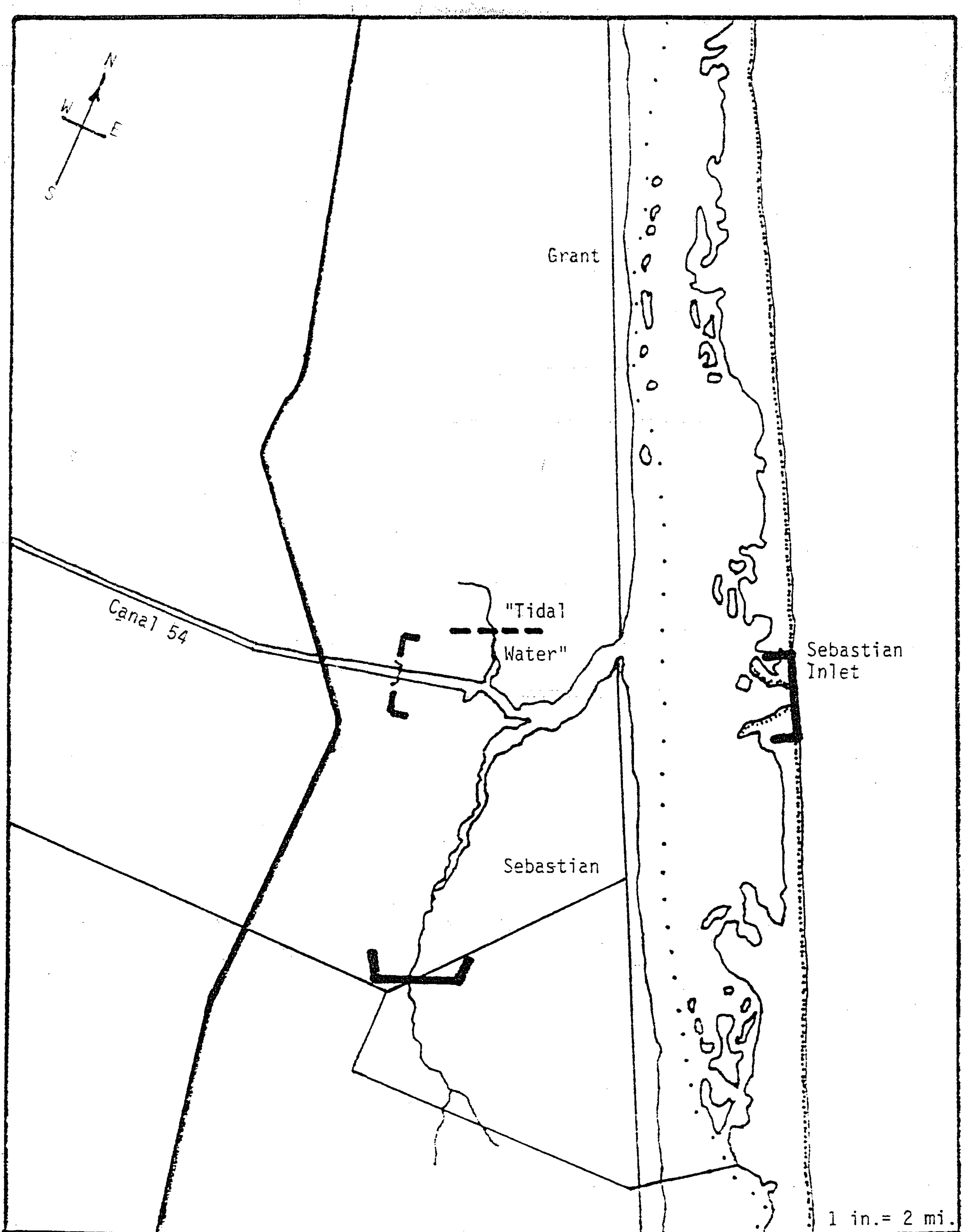

Figure 2 . Aquatic Preserve Boundaries.

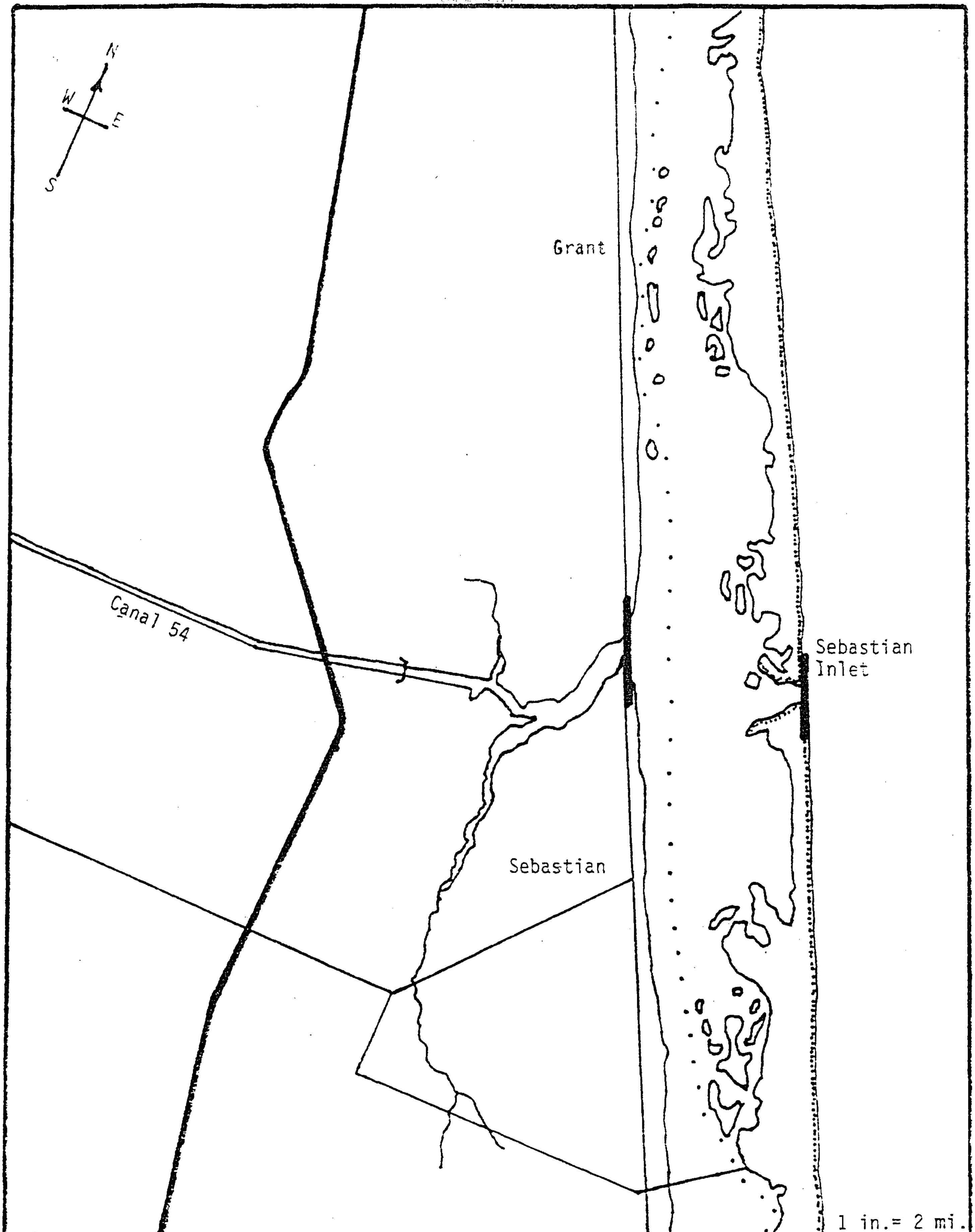

Figure 3. Outstanding Florida Water Boundaries.

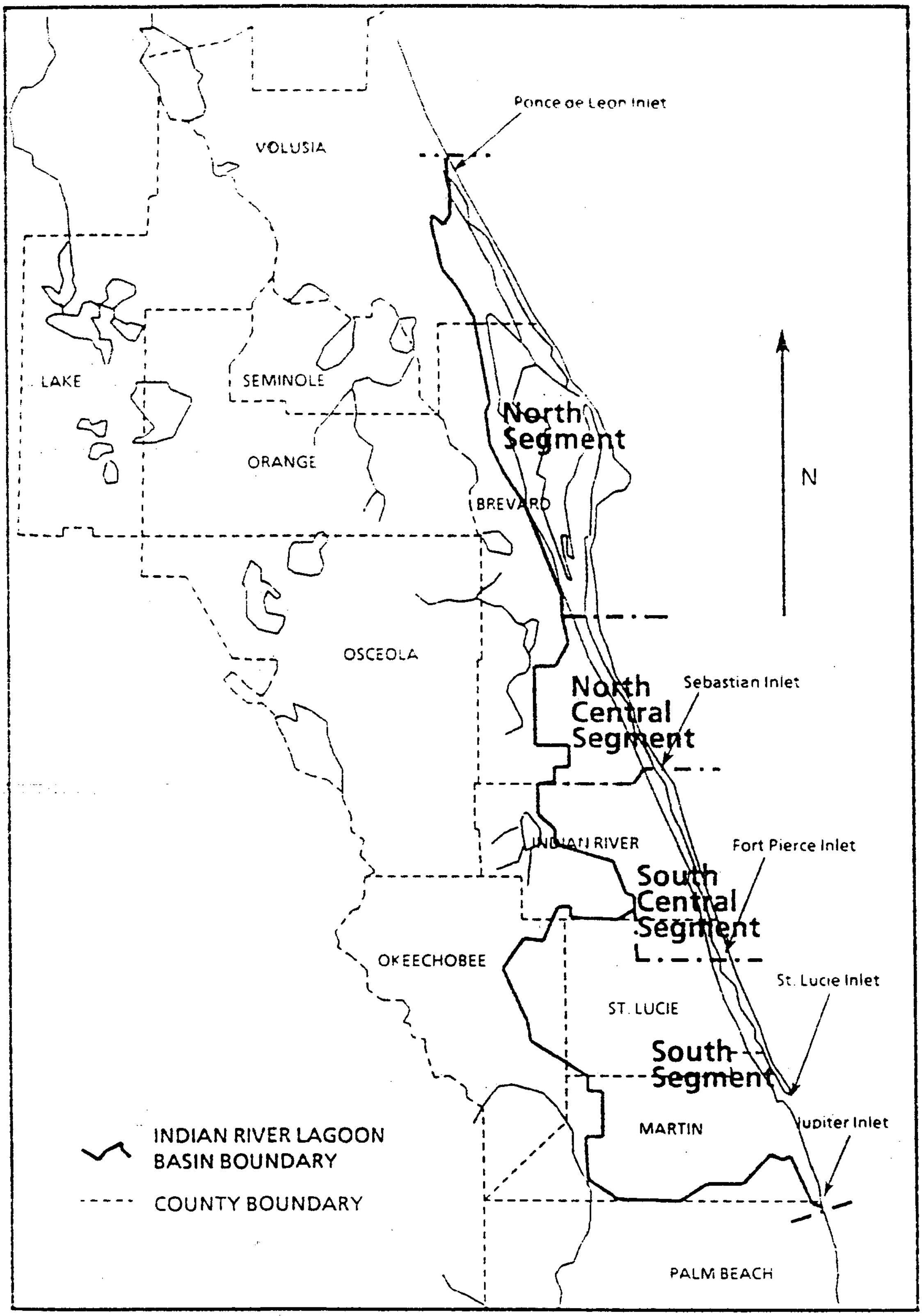

Figure 4. Major Geographic Segments of the Indian River Lagoon Basin

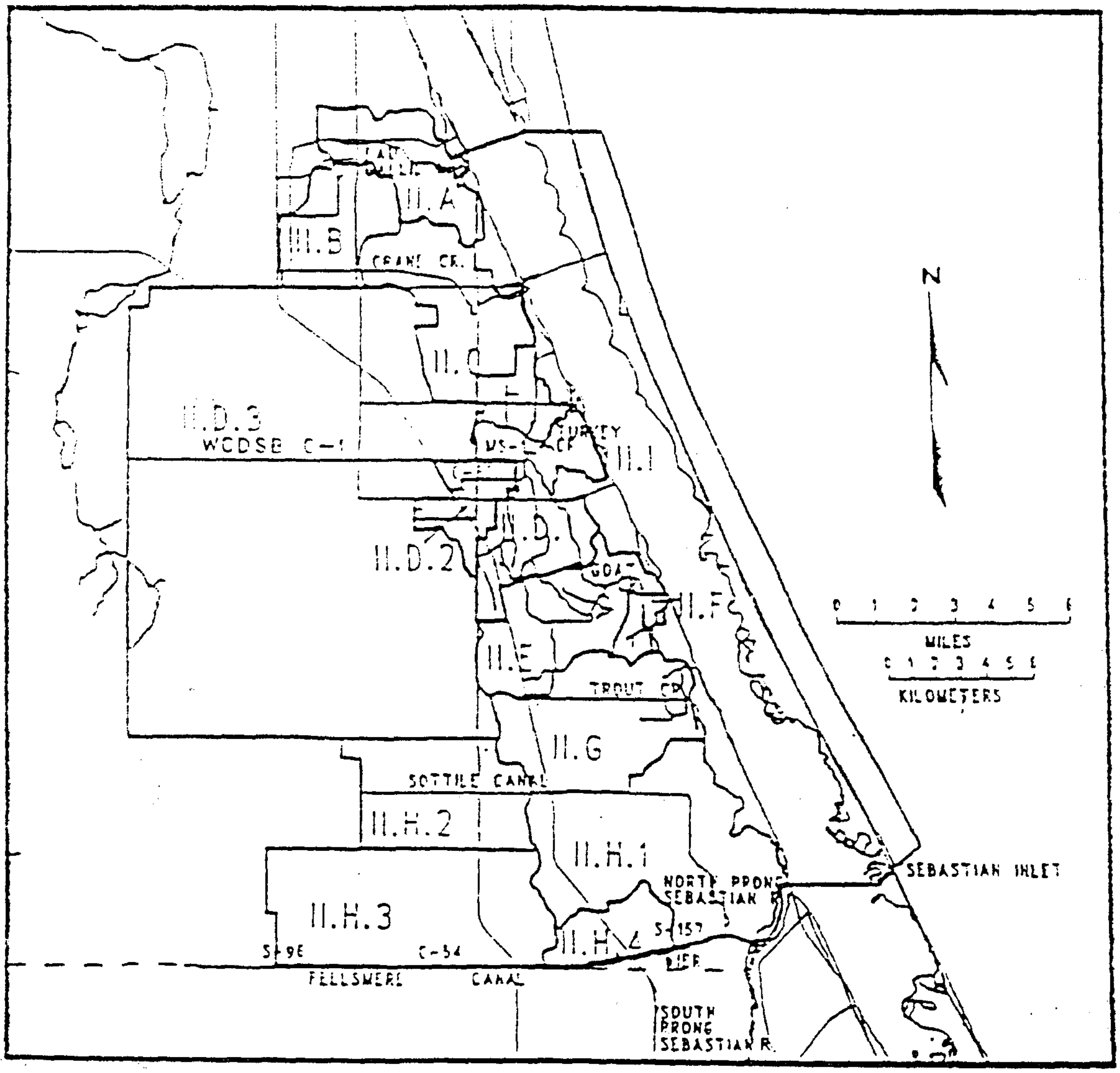

Figure 5. Sub-basin and Drainage Area Boundaries Within the North Central Segment of the Indian River Lagoon

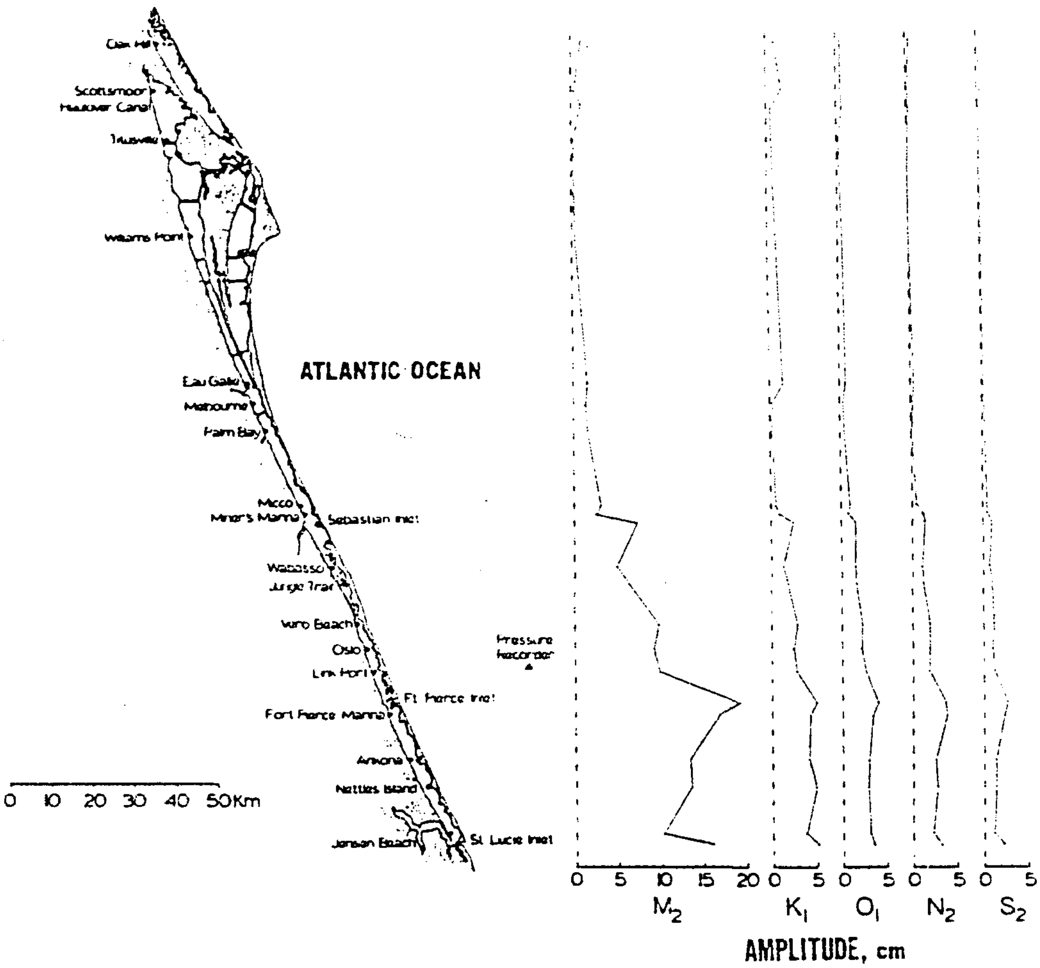

Figure 6. Tidal Constituents of the Indian River Lagoon.
Adapted from Smith (1987).

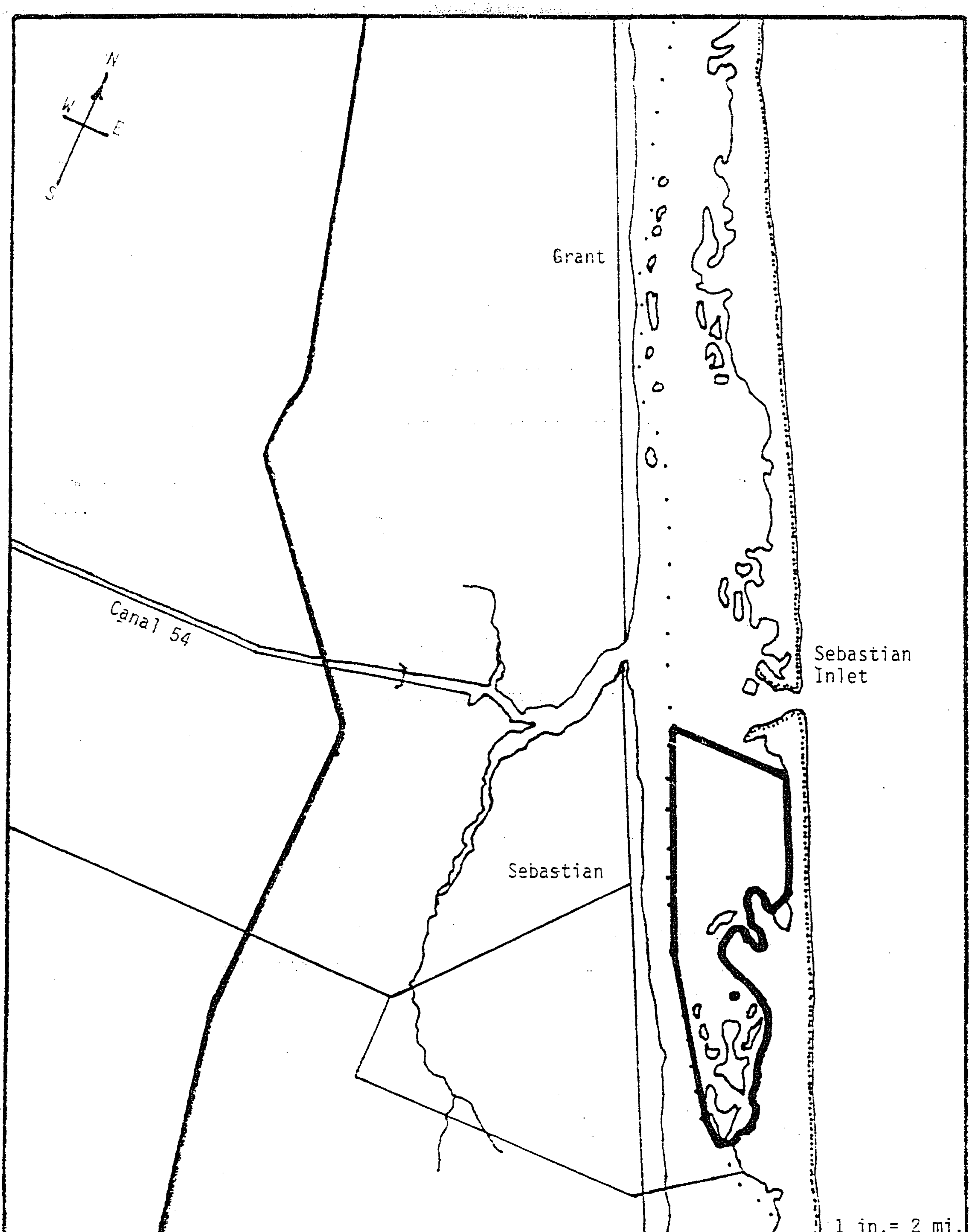

Figure 7. Pelican Island National Wildlife Refuge Boundaries.

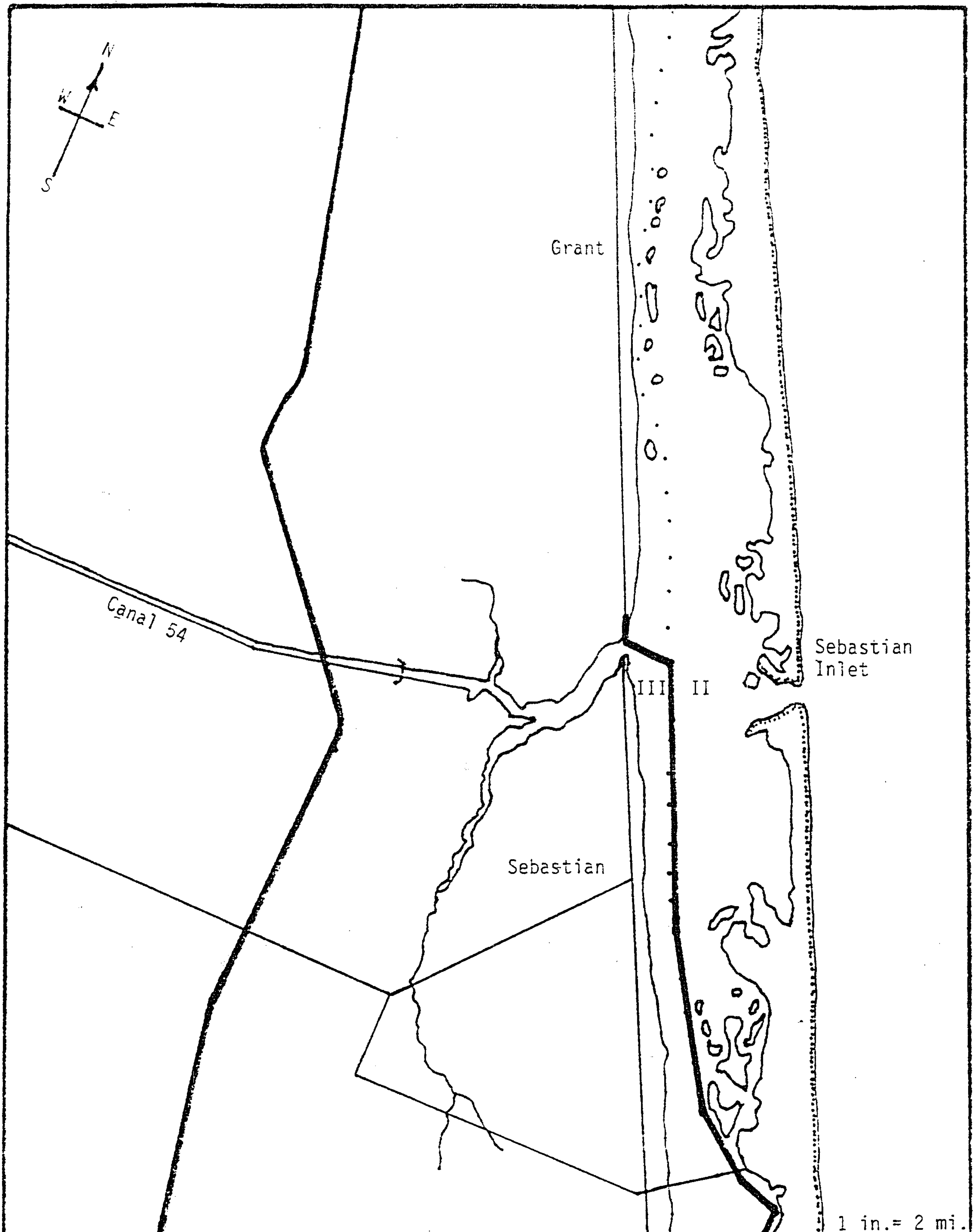

Figure 8.. Class II and Class III Waters.

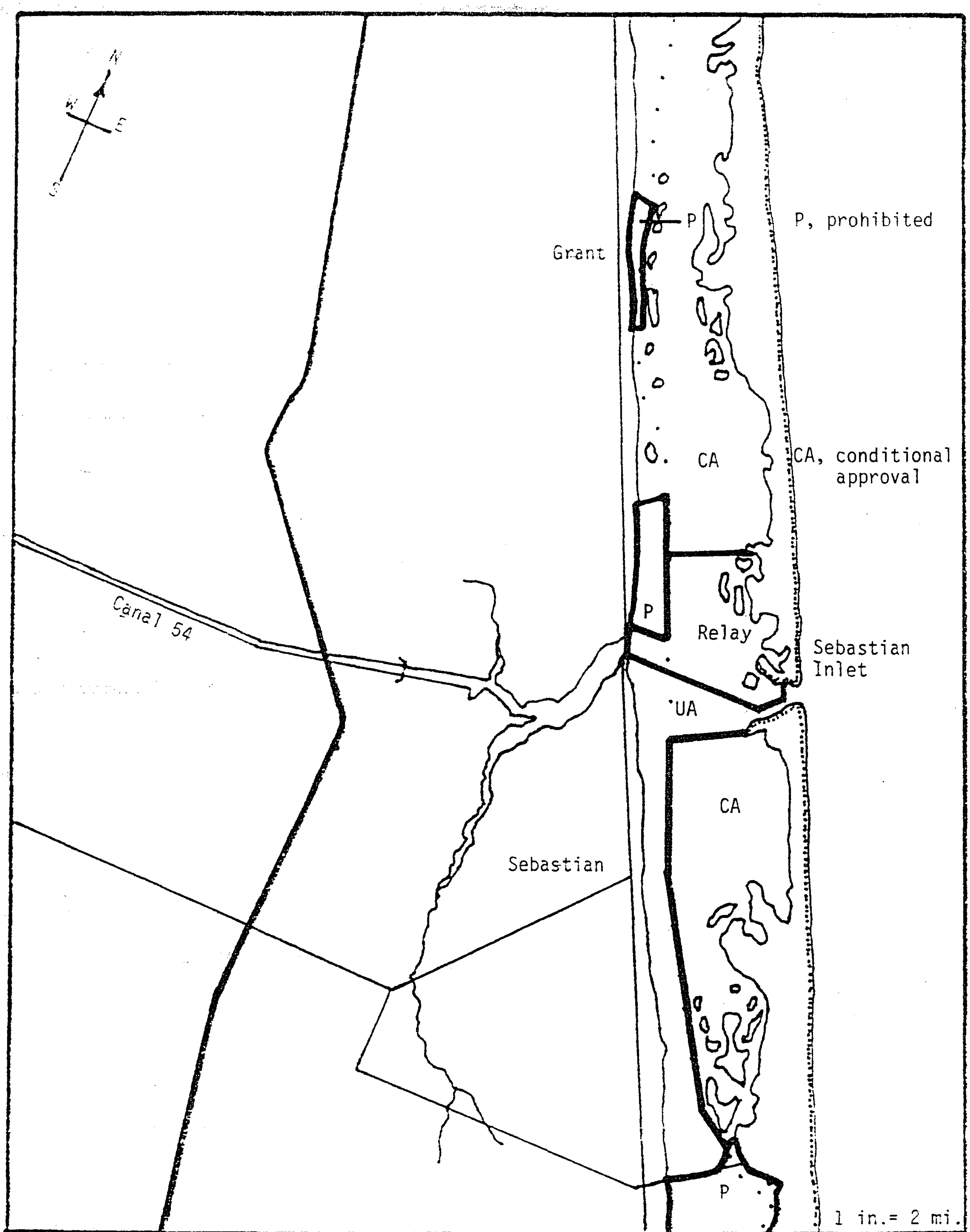

Figure 9. Shellfish Sanitation System. UA, unapproved.

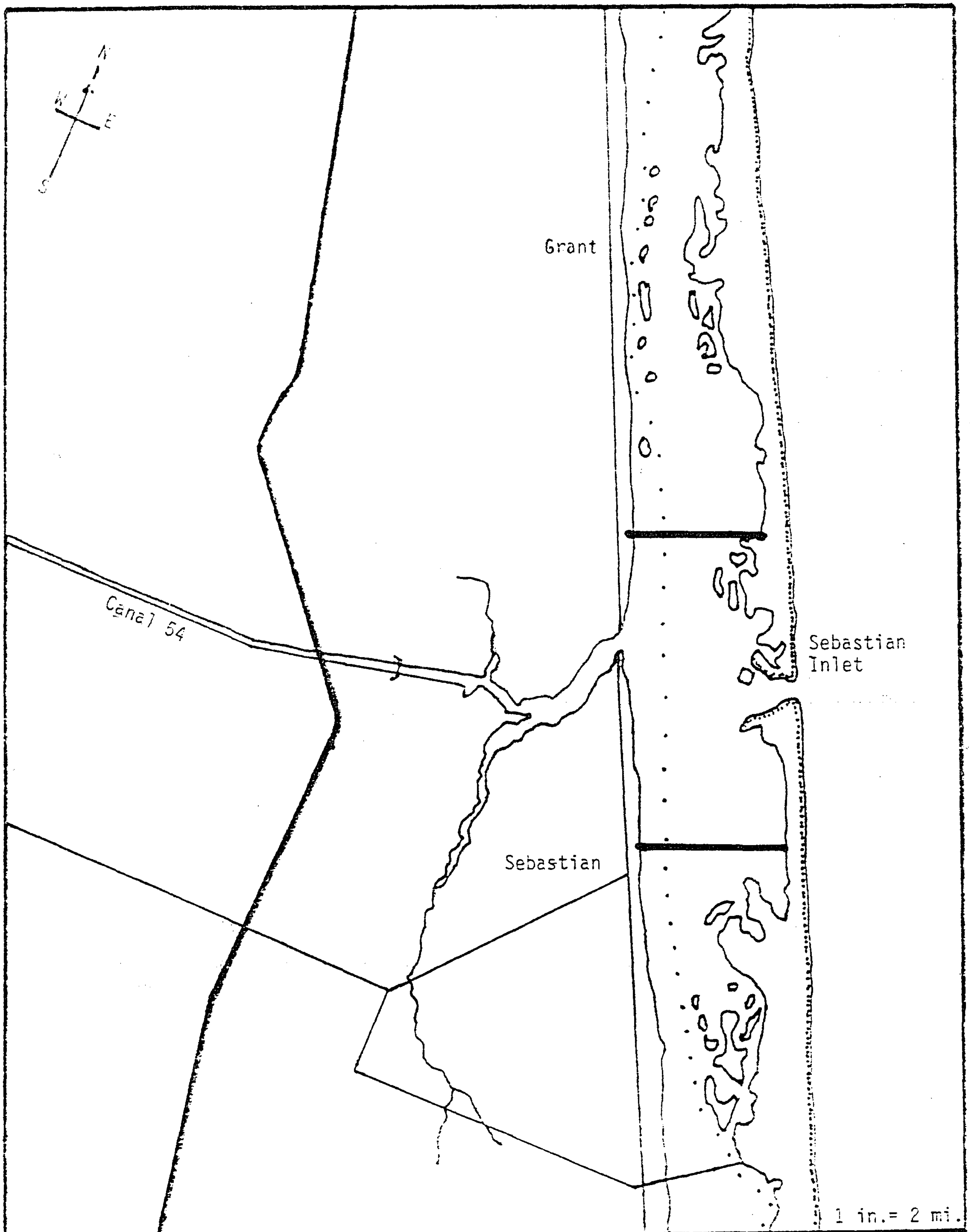

Figure 10. Shellfish Lease Areas. None occurs between lines.

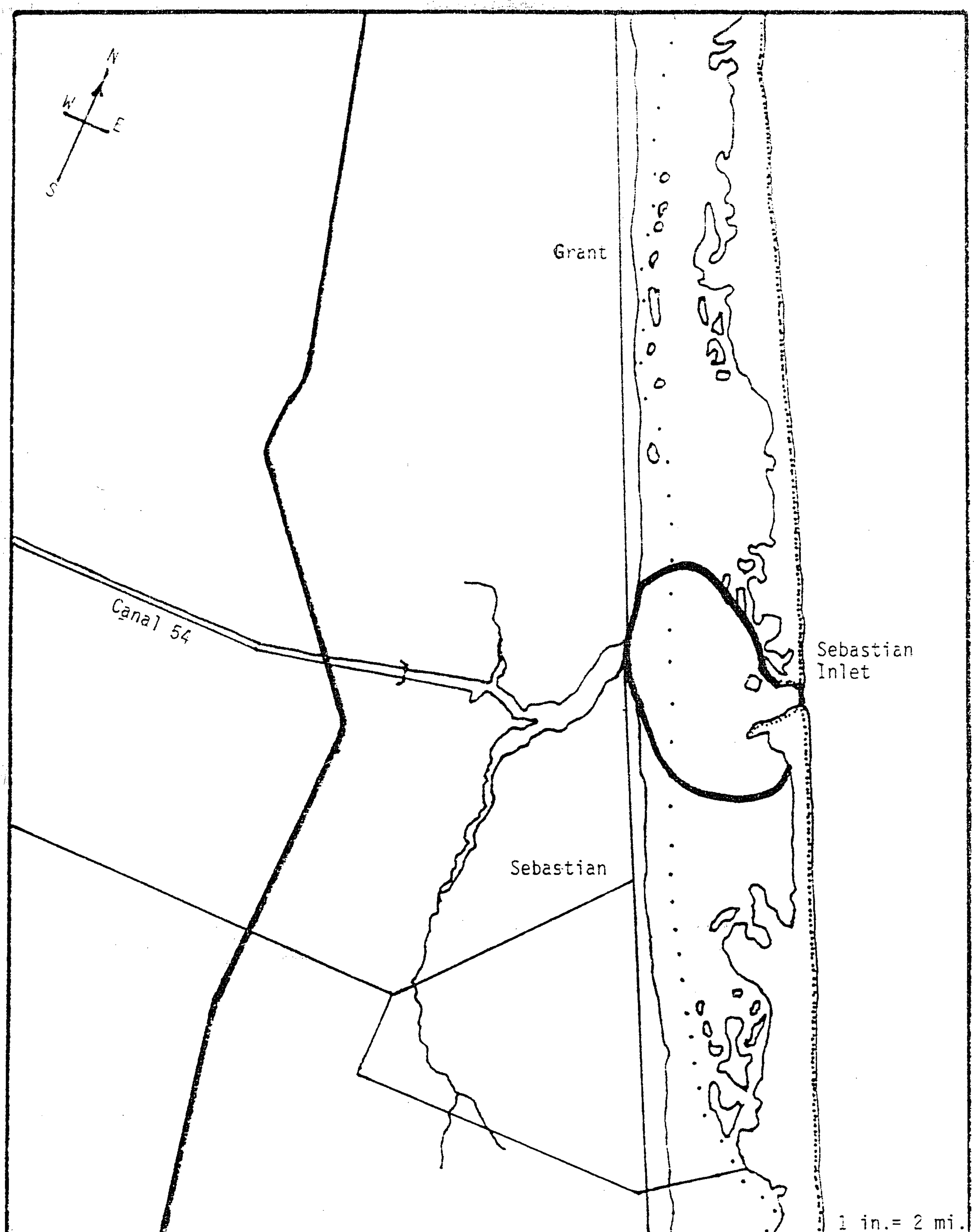

Figure 11. Manatee Over-wintering Area.

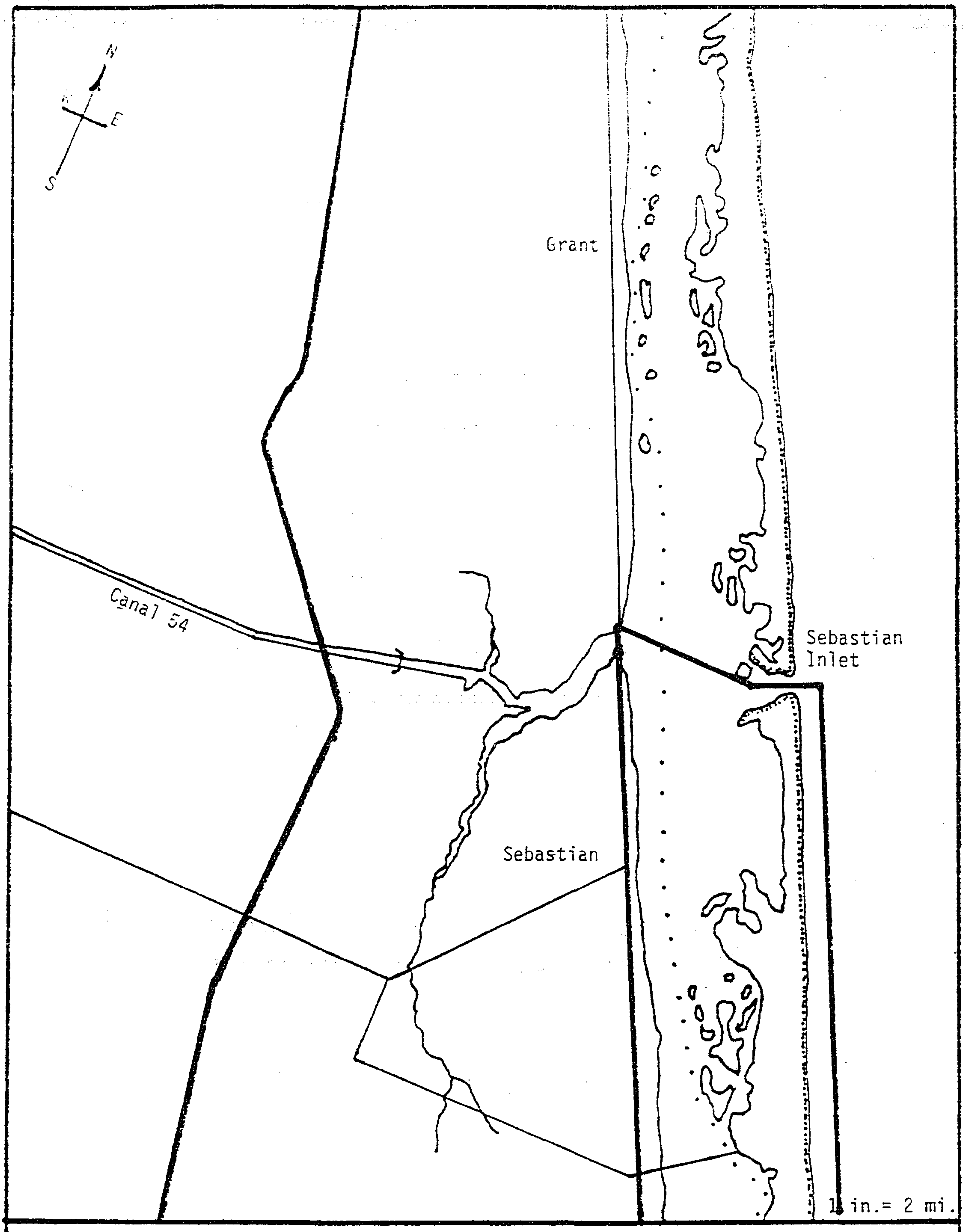

Figure 12. Hutchinson Island Resource Management and Planning Study Area.

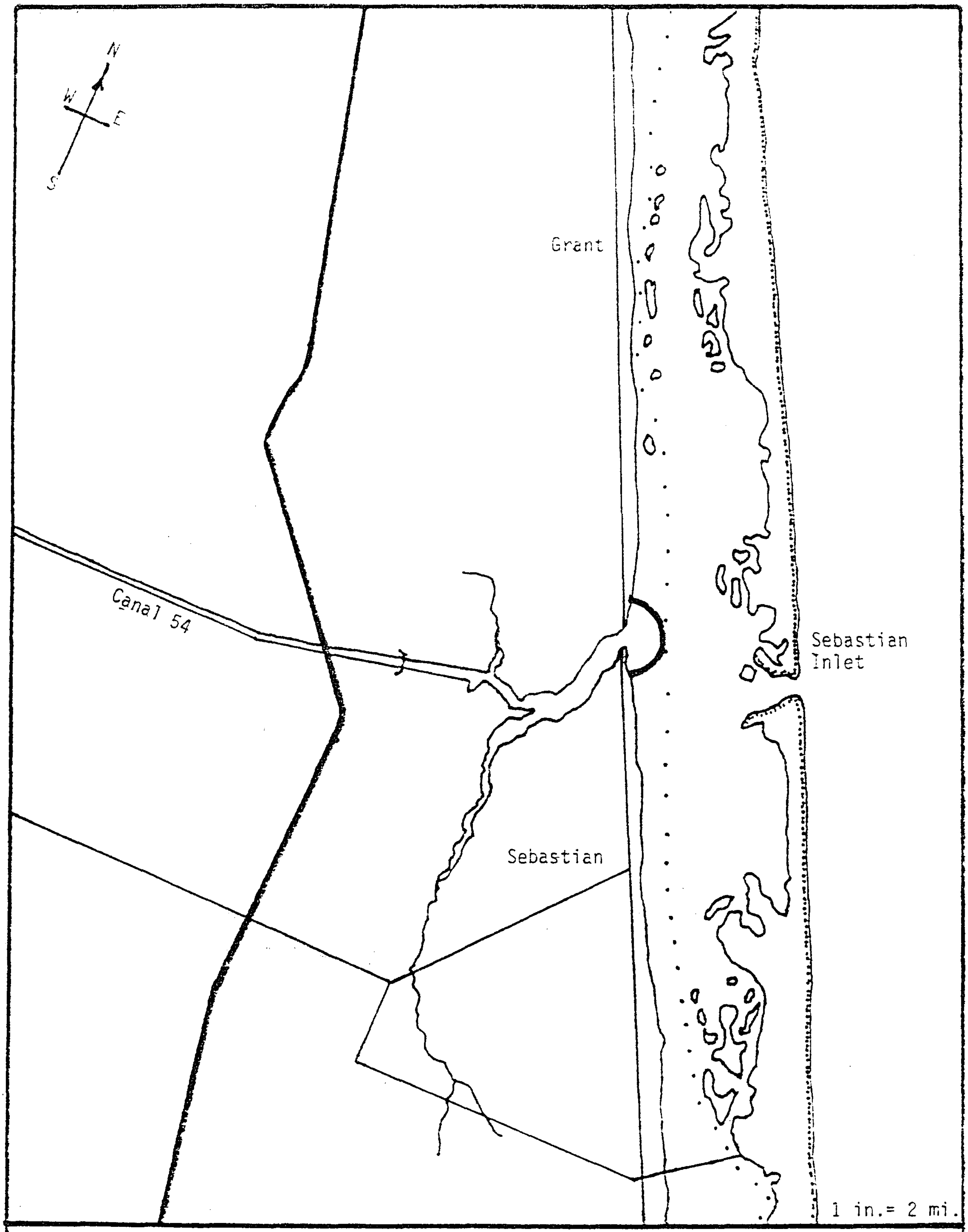

Figure 13. Interim SJRWMD Salinity Management Boundary.

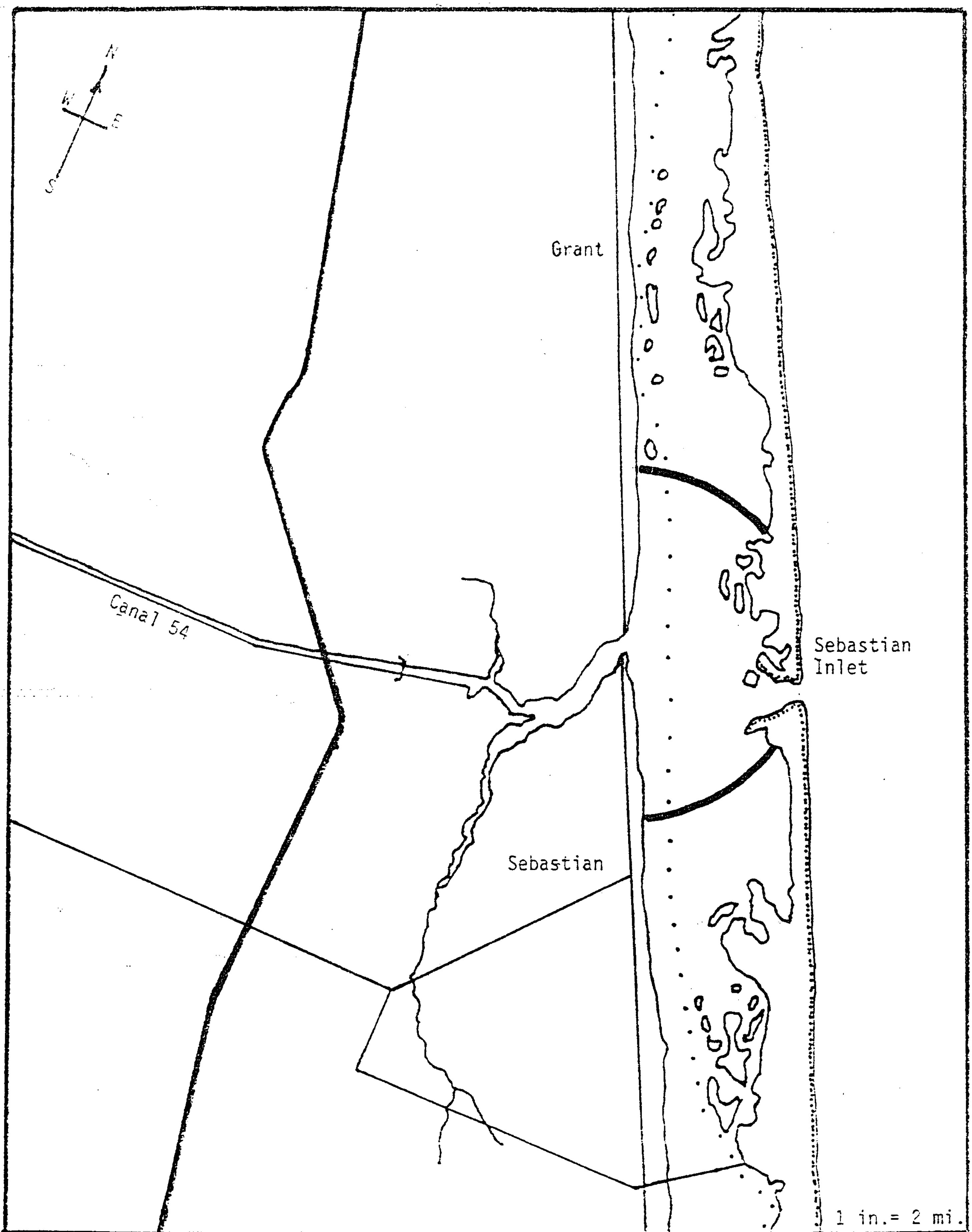

Figure 14. Project Study Area.

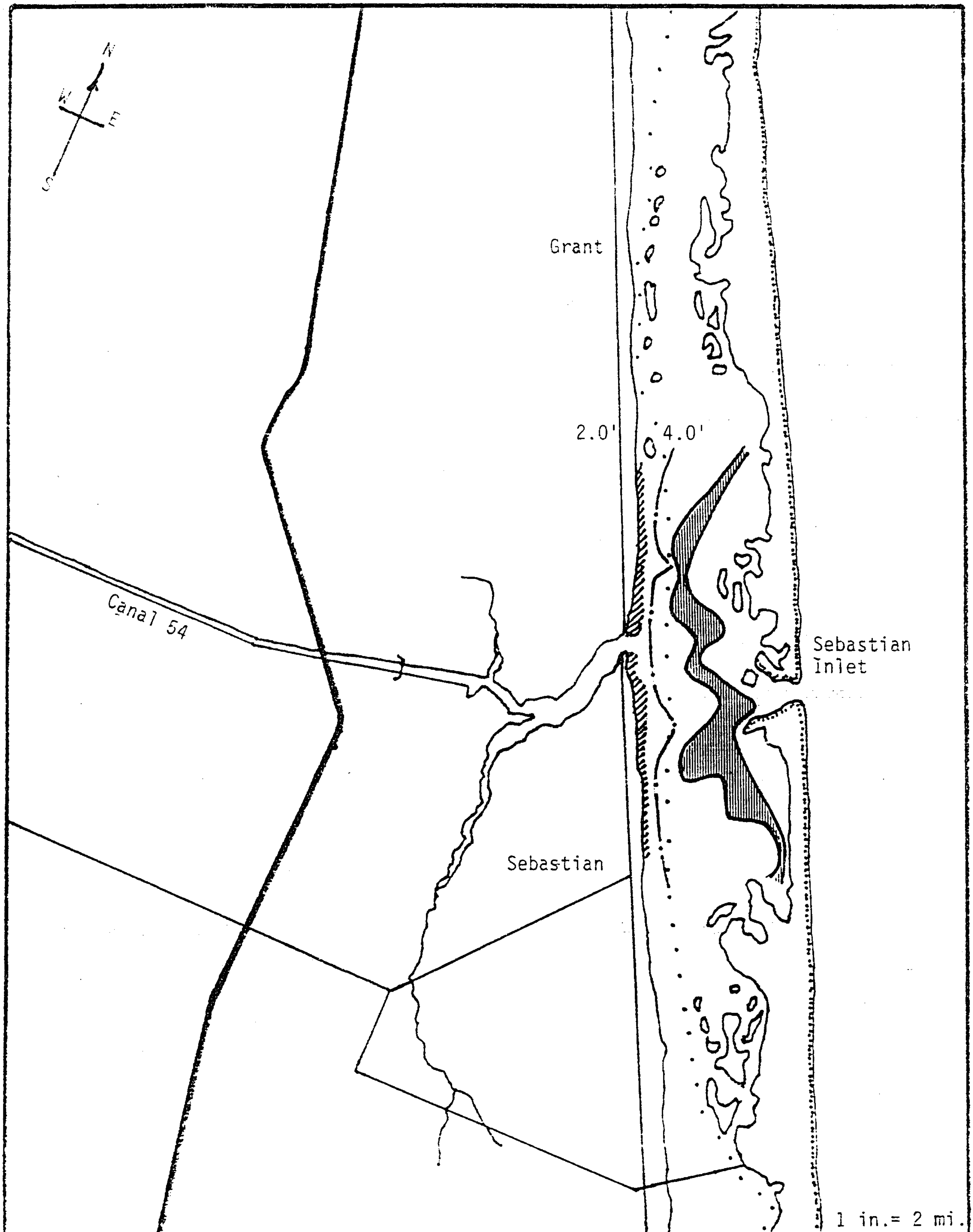

Figure 15. Bathymetry. Central Shaded Area, 6.0 ft. See text on page 8.

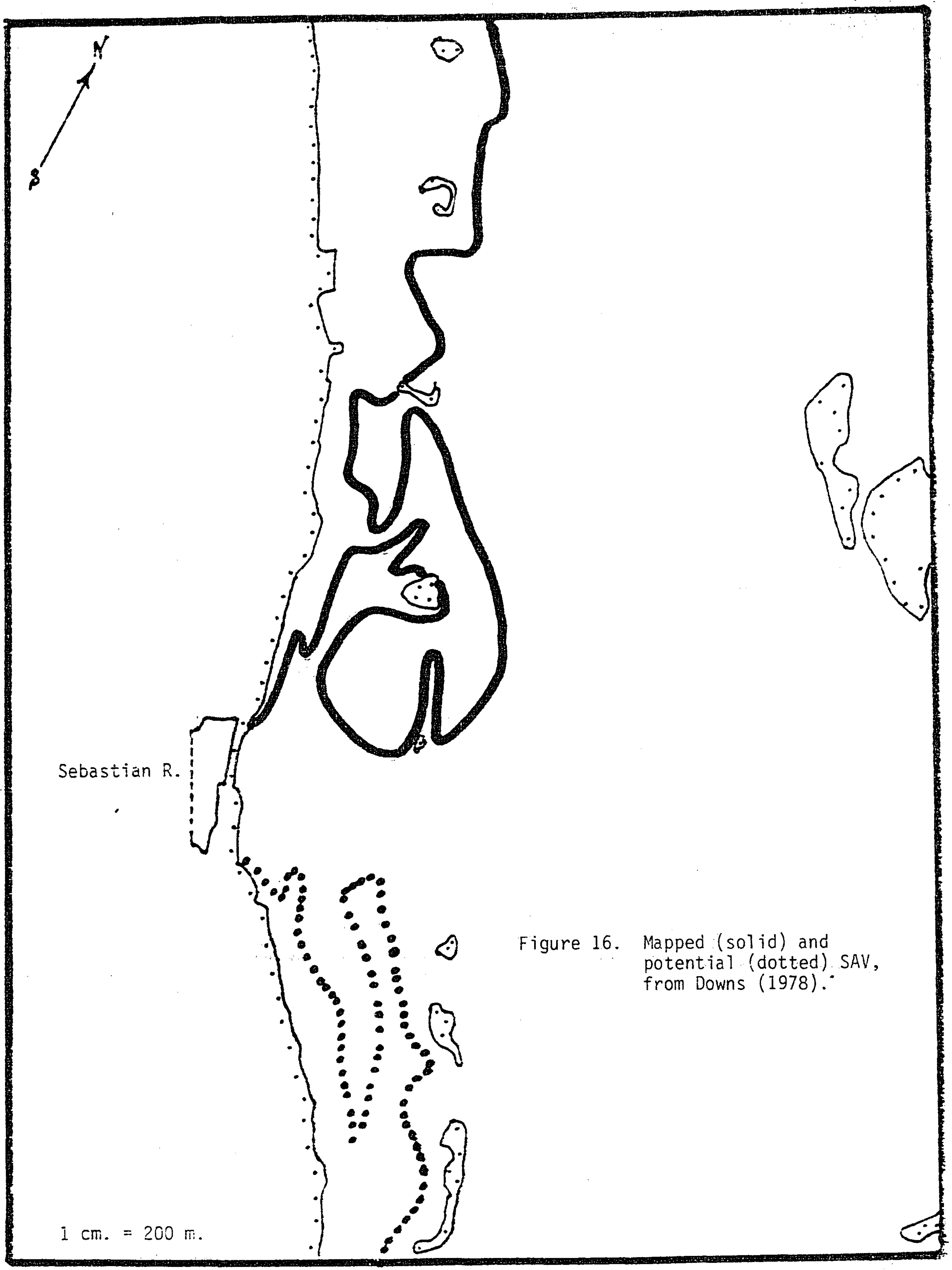

Figure 16. Mapped (solid) and potential (dotted) SAV, from Downs (1978).

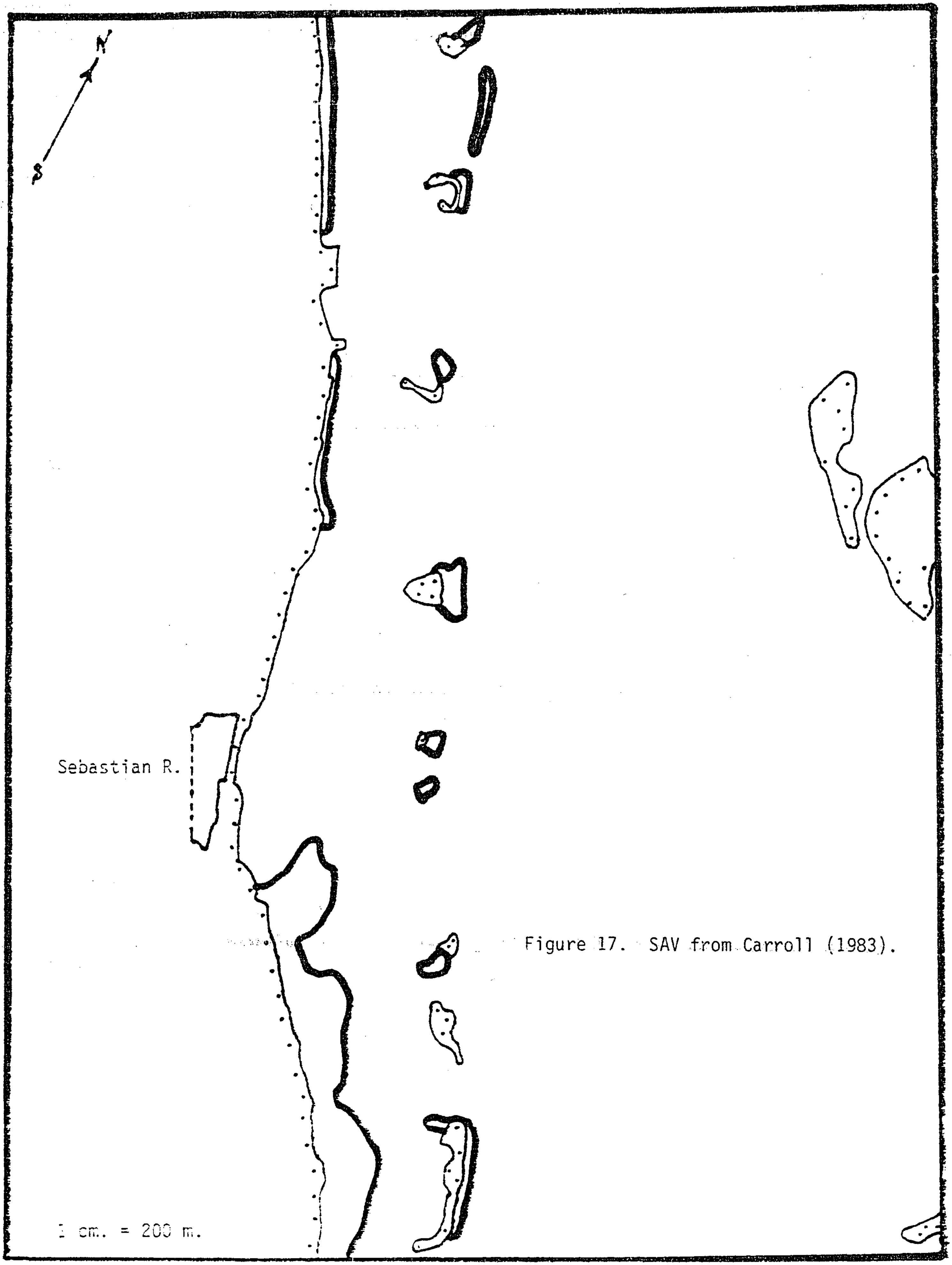

Figure 17. SAV from Carroll (1983).

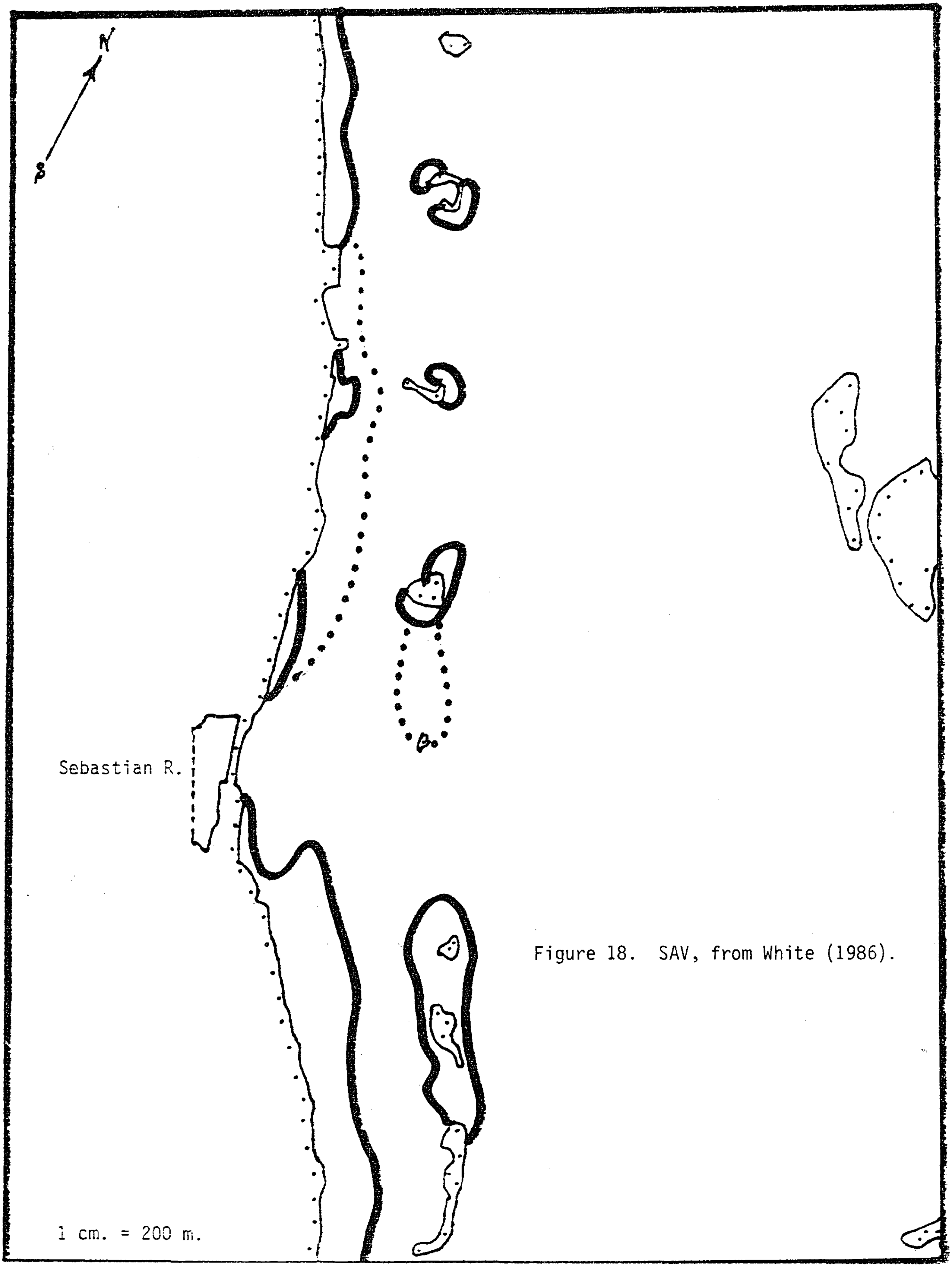

Figure 18. SAV, from White (1986).

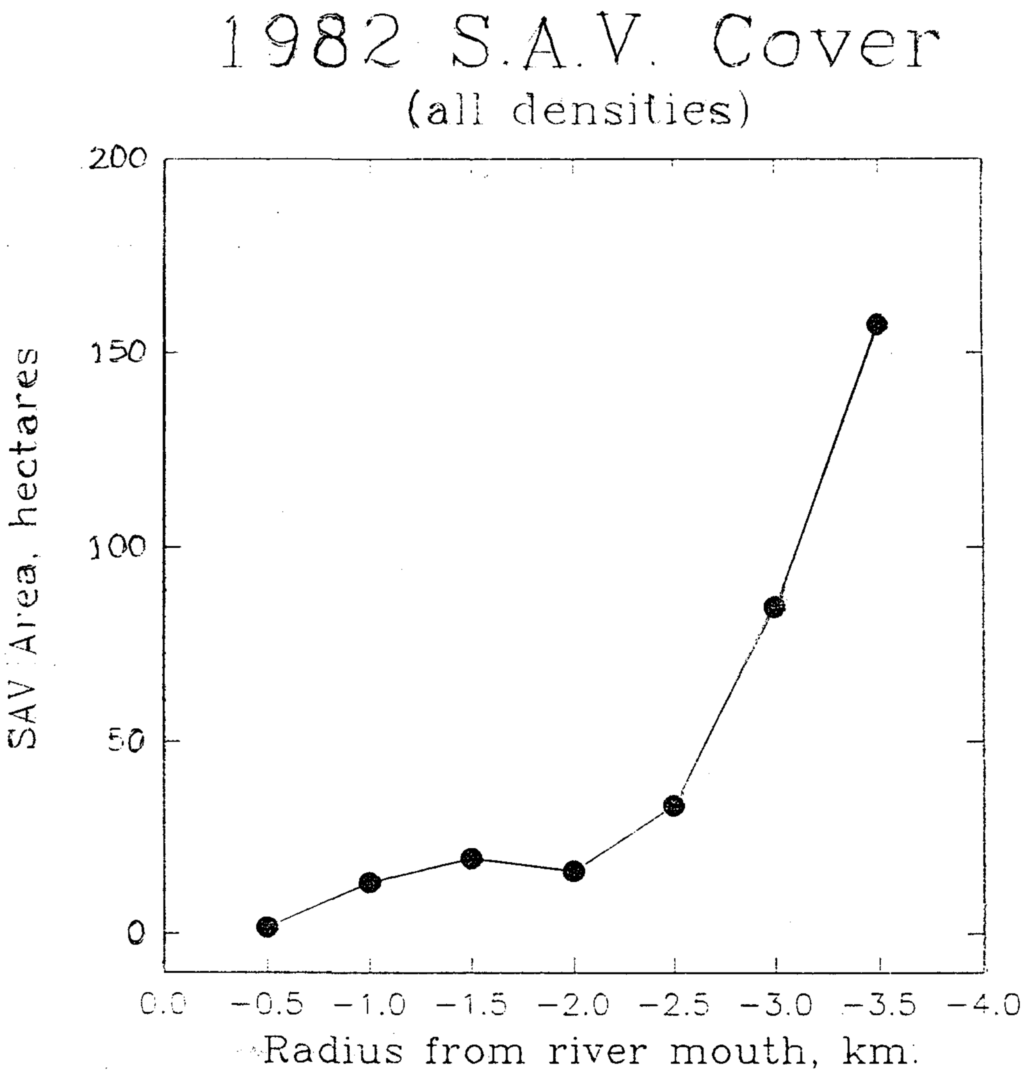

Figure 19. Raw Area of SAV near Sebastian River, from Carroll (1983).

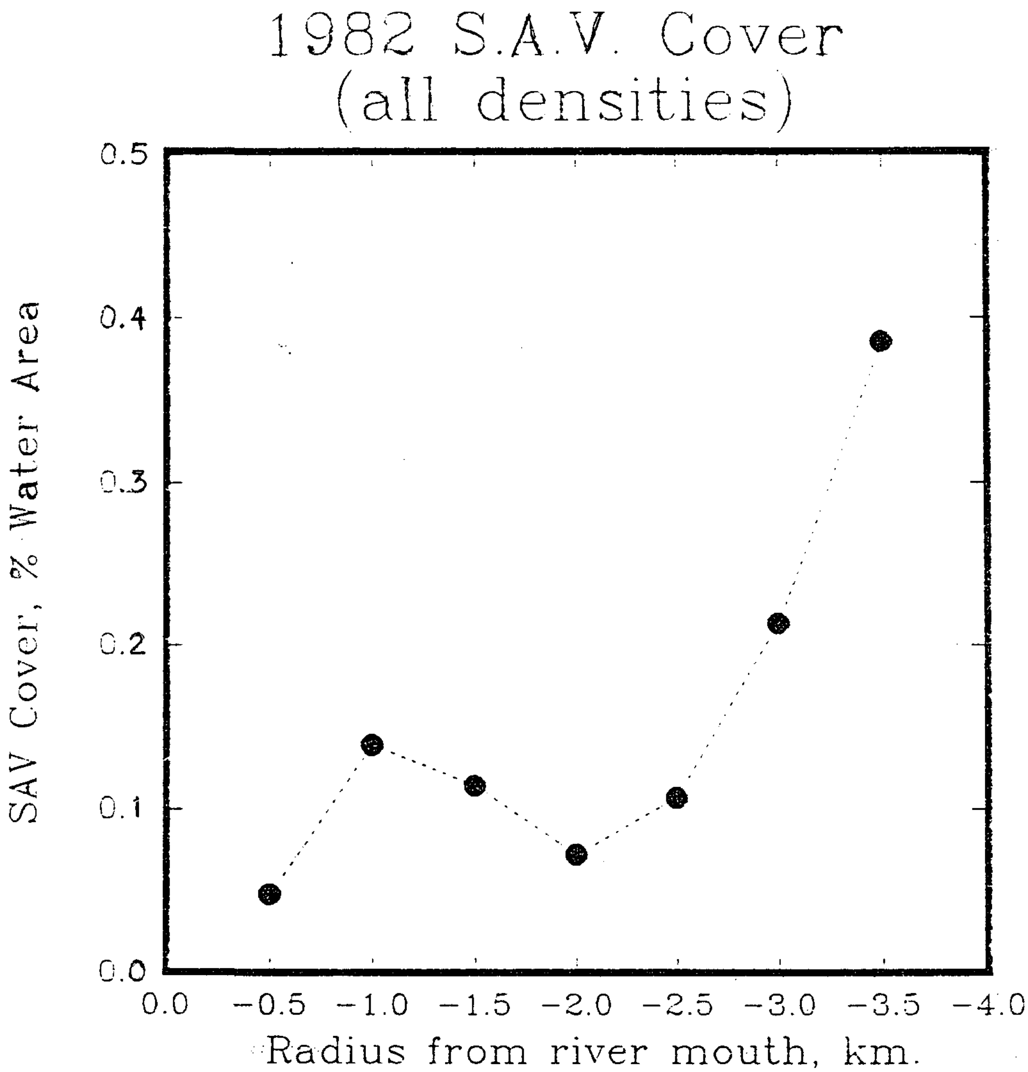

Figure 20. Normalized Area of SAV near Sebastian River, from Carroll (1983).

VOLUNTEER WATER QUALITY MONITORING SITES IN THE SEBASTIAN RIVER

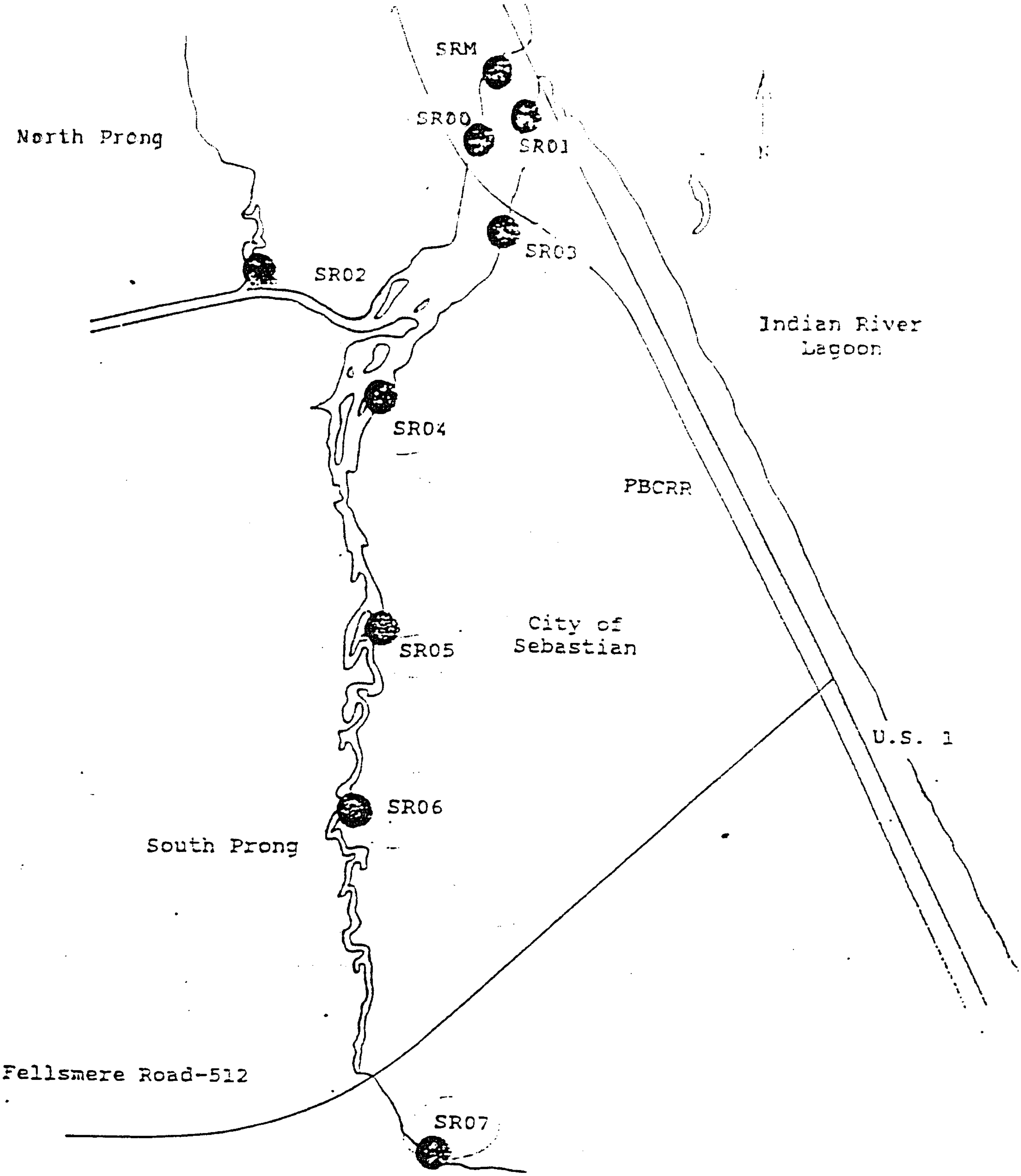

Figure 21.

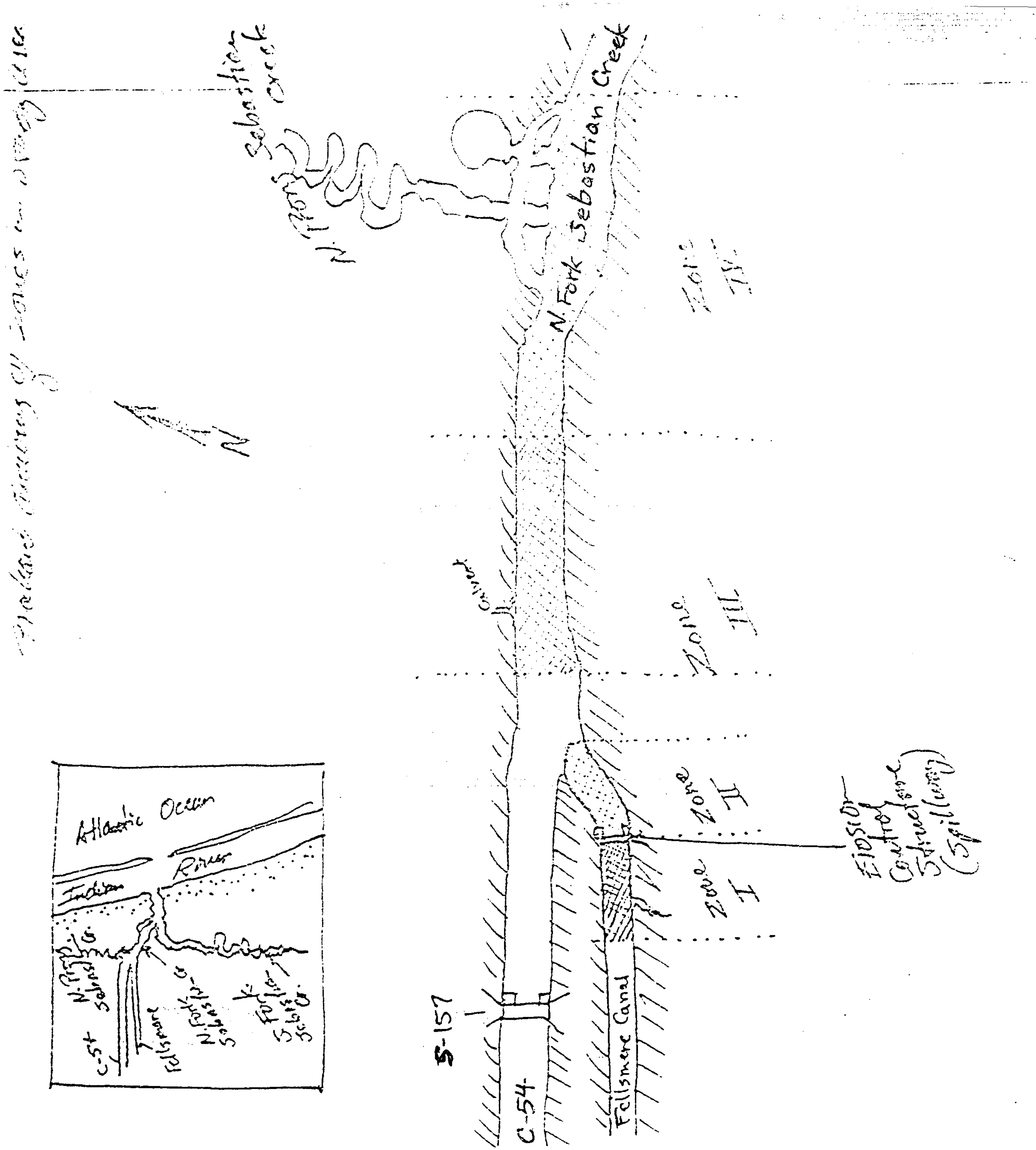

Figure 22. Oligohaline Boundaries in C54 and North Prong (Gilmore, 1981).

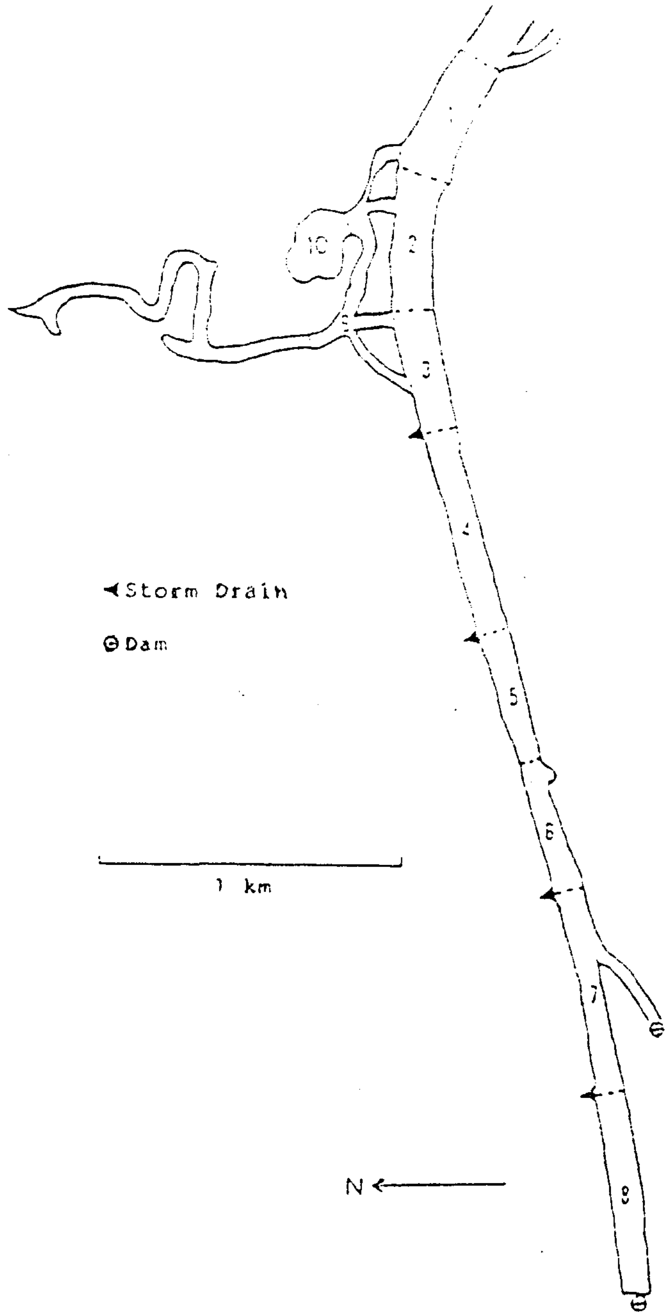

Figure 23. The North Canal of the Sebastian River subdivided into block quadrats. (Heyman, 1990)

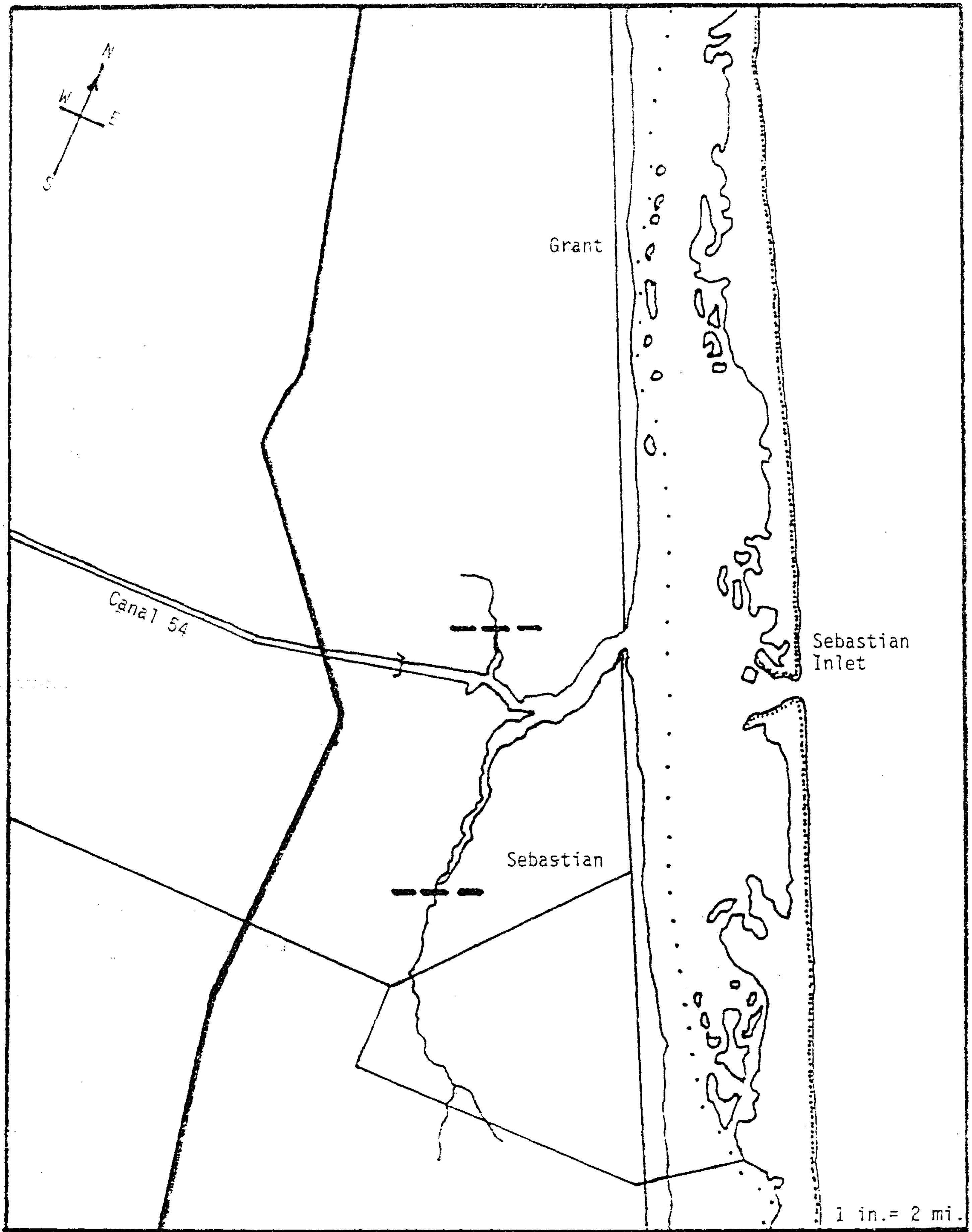

Figure 24. Tidal Soil Transitions in North and South Prongs.

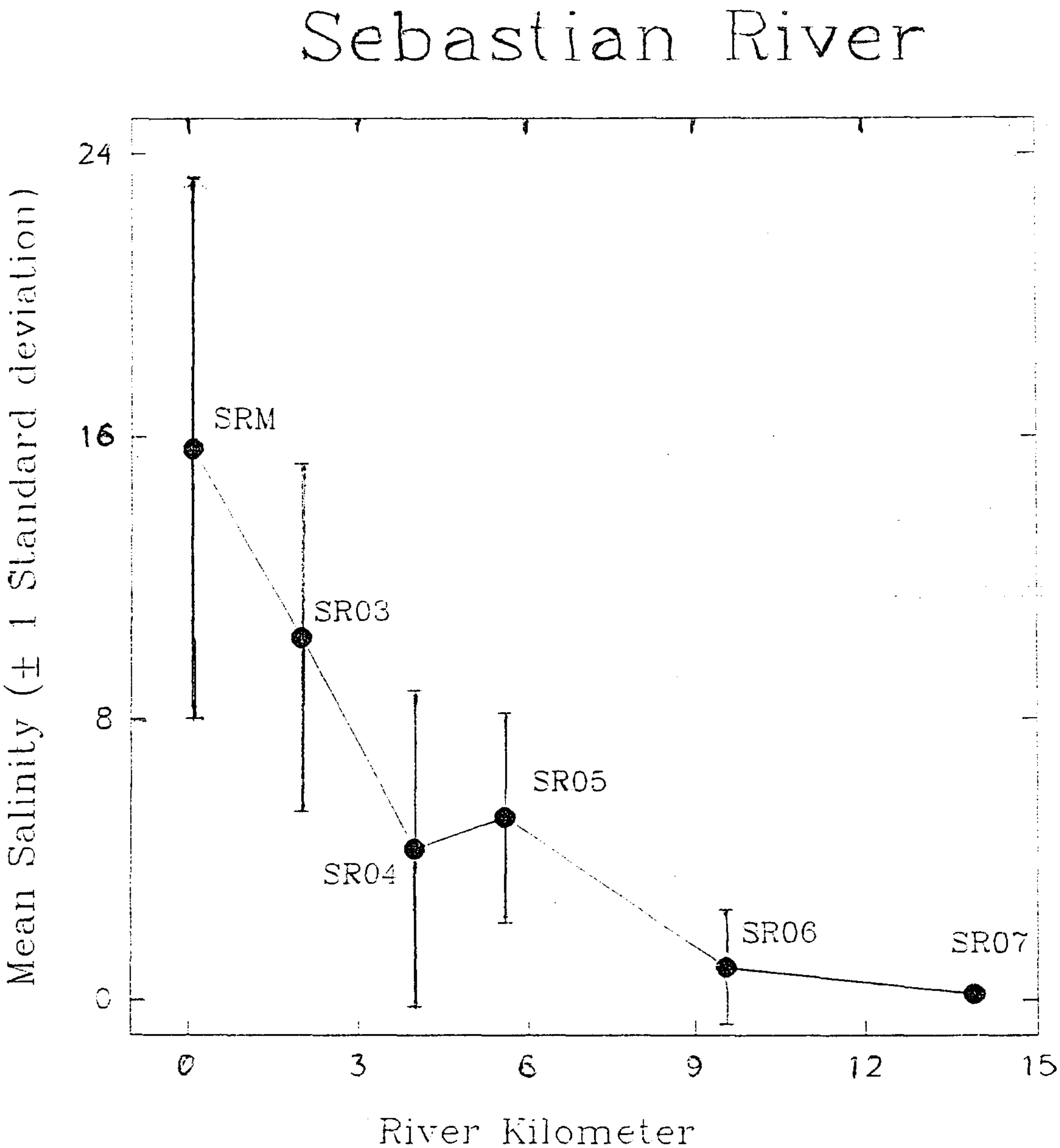

Figure 25. Mean Surface Salinity of the South Prong, courtesy B. Frease, Marine Resources Council.

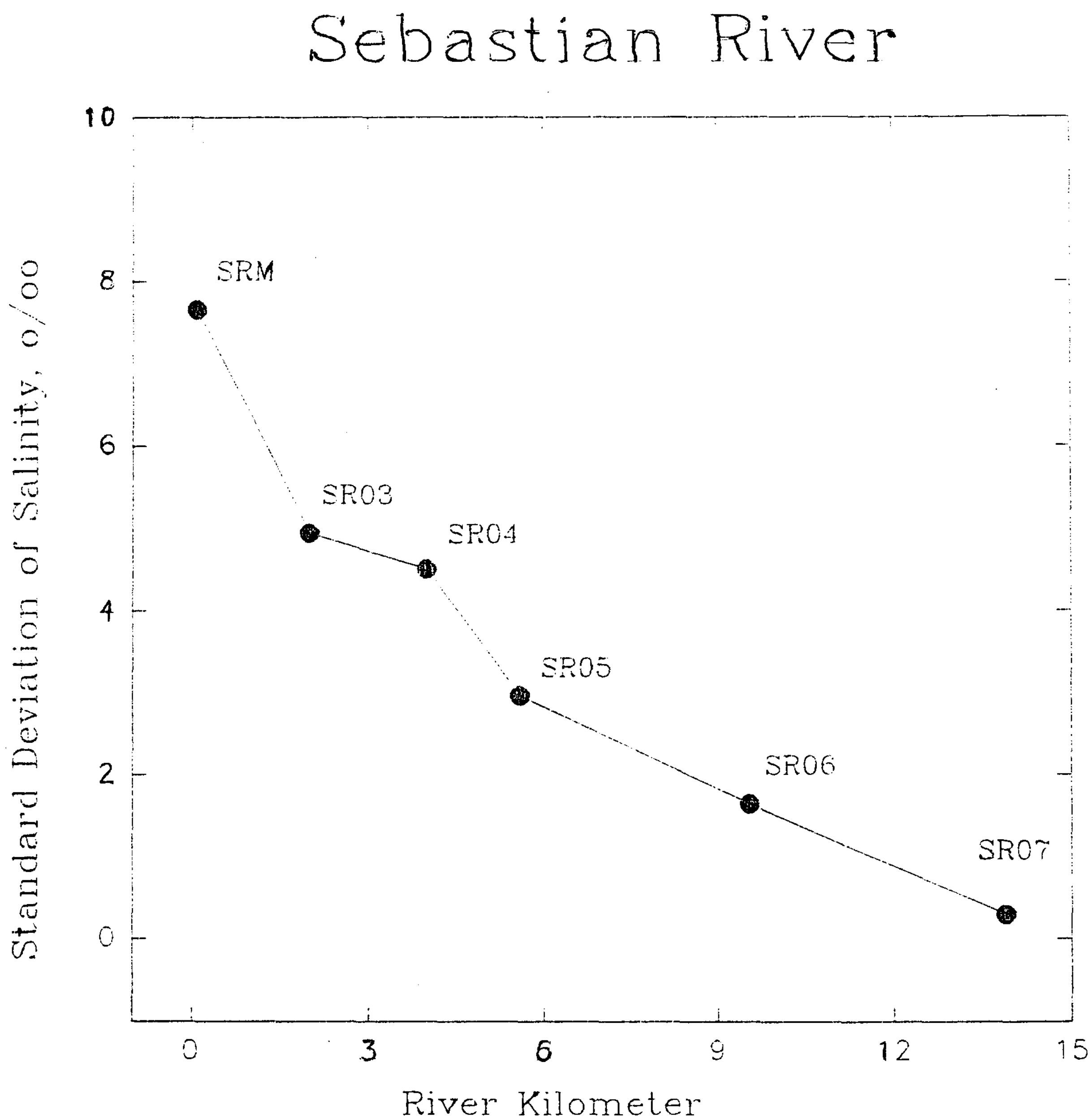

Figure 26. Variance in Mean Surface Salinity, South Prong, courtesy B. Frease, Marine Resources Council.

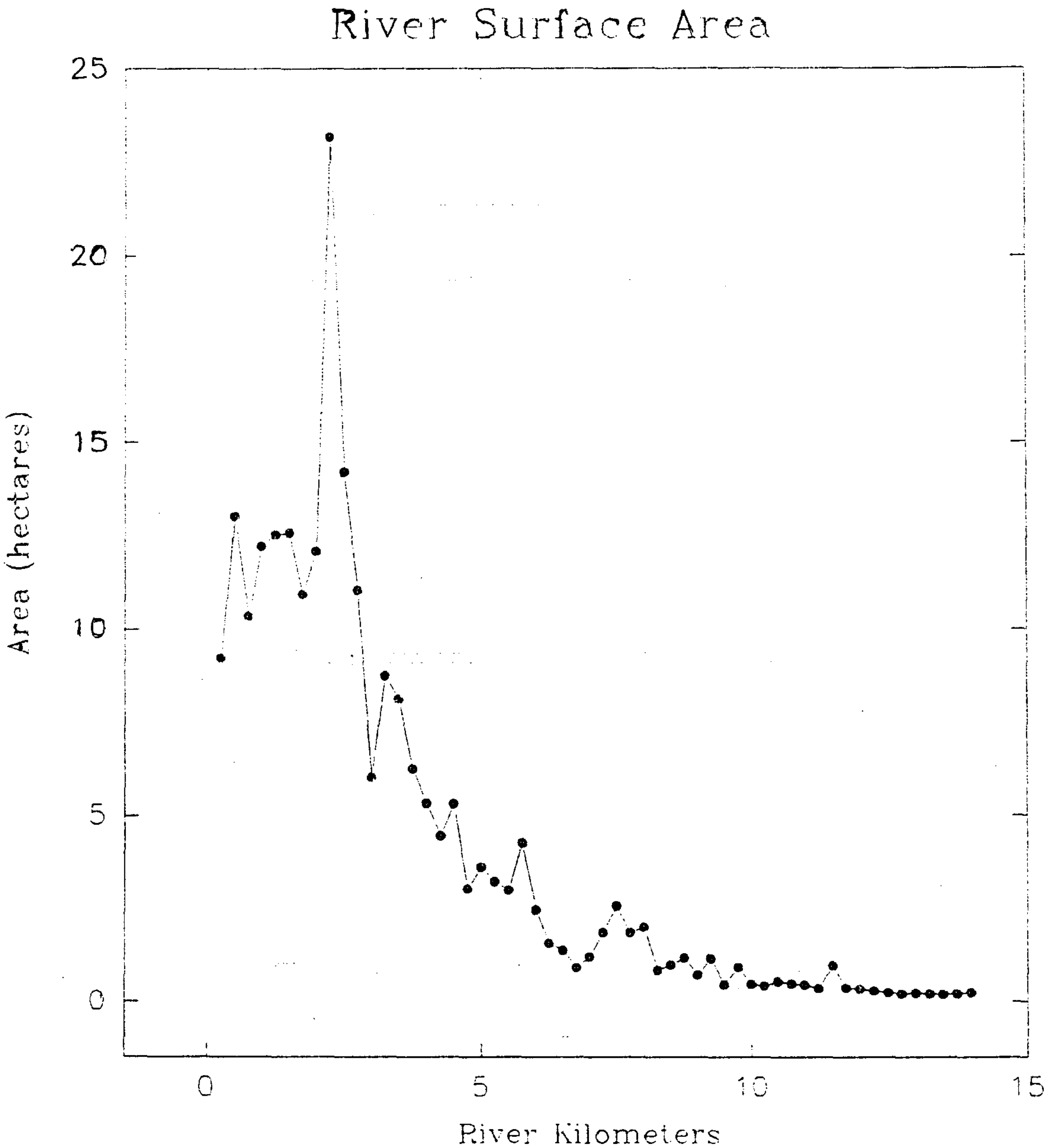

Figure 27. Surface Area of the South Prong. Data compiled for 250 m segments from aerial photographs.

PART III and PART IV

SEBASTIAN RIVER SALINITY REGIME

Parts III and IV: Recommended Targets

(Contract 92W-177)

submitted June 1993 to:

St. Johns River Water Management District

by the:

Mote Marine Laboratory
1600 Thompson Parkway
Sarasota, Florida 34236

Ernest D. Estevez, Ph.D.
and
Michael J. Marshall, Ph.D.
Principal Investigators

Mote Marine Laboratory Technical Report Number 308

EXECUTIVE SUMMARY

This is the third and final report of a project concerning desirable salinity conditions in the Sebastian River and adjacent Indian River Lagoon. A perception exists among resource managers that the present salinity regime of the Sebastian River system is undesirable. The St. Johns River Water Management District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the Sebastian River and adjacent waters of the Indian River Lagoon. The District can then calculate discharges needed to produce the desired salinity regime, or conclude that optimal discharges are beyond its control.

The values of studying salinity and making it a management priority in estuaries are four-fold. First, salinity has intrinsic significance as an important regulatory factor. Second, changes in the salinity regime of an estuary tend to be relatively easy to handle from a computational and practical point of view. Third, eliminating salinity as a problem clears the way for studies of, and corrective actions for, more insidious factors. Fourth, the strong covariance of salinity and other factors that tend to be management problems in estuaries makes salinity a useful tool in their analysis.

Freshwater inflow and salinity are integral aspects of estuaries. Major, largely unnoticed changes in these factors have been underway for decades. In Florida, as elsewhere in the world, these changes are likely to accelerate. Implications for estuarine productivity and management are critical. Existing data are seriously incomplete. At the present time, no comprehensive literature reviews exist of ecological impacts in estuaries resulting from altered freshwater inflow or salinity. Part of the reason for this situation is that inflows can be altered in many direct and indirect ways. Such alterations include increases or decreases in the quantity of inflow, changes in the short-to-long period temporal variations of inflow, inflow location, etc. Another reason is that truly comprehensive ecological studies of estuaries are few and have tended to be made in relatively pristine, rather than altered, estuaries. Scientists and policy analysts agree that a coherent and transferable science is needed to determine the freshwater inflow and salinity requirements of estuaries. This report presents the results of one attempt to systematically determine a restorative and protective salinity regime for the Sebastian River and adjacent Indian River Lagoon.

Not counting basin alterations and augmented river flows, the salinity trend of the Indian River Lagoon during the past few centuries and especially the 20th Century has been one of increase. Sea level rise, island breaching, and inlet stabilization have been working to increase the connection between the Lagoon and Atlantic Ocean. The increased connection has altered water levels and circulation, sedimentation, salinity, and the numbers and kinds of plants and animals inhabiting the Lagoon. During this period, the major source of natural variation was probably related to the incidence and severity of tropical storms and hurricanes.

Large changes have occurred to inflows of both fresh and salt water to the River and Lagoon near Sebastian. Discharge of the Sebastian River has been increasing for decades because (1) gaps in the coastal ridge were closed, (2) wetlands in the basin were diked and filled, (3) drainage canals and laterals were dug, (4) the deepest canals increased drainage of the non-artesian aquifer, (5) deep wells pumping the Floridan aquifer added groundwater to surface waters, especially as agricultural runoff, and (6) urbanization has increased stormwater runoff. During the same period, Sebastian Inlet has been open and stabilized. Thus, the Sebastian area has become a mixing zone for higher freshwater inflows and higher salt water inflows than occurred historically.

*****

The first component of this project was an analysis of existing goals for the study area, emphasizing those that directly or indirectly related to the question of salinity. The first report assessed existing laws, policies and objectives at federal to local government levels for insight to official expectations for the Sebastian River or Indian River Lagoon, and found:

1. There is an overall intent to reduce fresh water inflows to the River and Lagoon. A reduction of inflow will result in higher salinities in both the River and Lagoon.

2. At the same time, there is a perceived need to provide base flows for certain oligohaline species and their habitats. A base flow will result in the establishment of permanent, tidal fresh water and low salinity areas.

3. Inflows and salinities should vary according to seasonal or daily or other cyclic patterns. At the same time, the rate of change of inflows, and consequently of salinity variations, should be moderated. Given the concern for acute changes, guidelines for rates and ranges of salinity variation are as important as average salinity conditions.

4. The peaks of inflow should coincide with the natural wet season runoff of the basin, meaning that low salinities caused by regulated inflows should coincide with low salinities caused by natural runoff. Natural seasonality of salinity variation is sought.

5. The area and duration of low salinities caused by natural runoff should not be made significantly larger or longer because of regulated inflows, in order to protect seagrasses, shellfish, and other estuarine biota in the Lagoon.

6. Additional constraints to salinity are believed needed in the Lagoon near the mouth of the River in order to restore and enhance seagrasses, and may be needed within 2.5 miles of the River mouth to protect hard clams or oysters.

7. A minimum of 20 parts per thousand is presently in use as an interim salinity standard during hard clam spawning seasons of spring and fall.

It is noteworthy that these findings already exist in official program and policy documents affecting the study area. Findings are instructive insofar as the appropriate direction for future salinity alterations is suggested, but they are incomplete. In order to add detail to these findings, additional research was undertaken.

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The second component addressed the geographical segmentation of the study area. Pertinent reports and data were used to divide the study area into discrete geographical units called segments (Figure I). The Indian River Lagoon near Sebastian, and the Sebastian River, were subdivided according to physical, chemical and biological boundaries and other natural transitional zones. Management boundaries (shellfish areas, aquatic preserves, etc.) were also used to define segments. Segments formed the basis for additional analyses and the formulation of recommended salinity conditions, called targets. The second project report defines the boundaries of each segment.

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This third and final report recommends salinity targets based on community and habitat requirements (Task 3 of the project) and individual species of ecological or economic concern (Task 4). Potential salinity targets were compiled through literature reviews, analysis of salinity data, and interviews. Summary reports were prepared for (1) freshwater inflow and estuarine productivity, (2) an overview of small coastal rivers of peninsular Florida, (3) case studies of altered inflow and salinity, (4) environmental setting, early conditions, and changes in the study area, (5) salinity, (6) seagrasses, (7) hard clams, (8) oysters, (9) fish, (10) species at risk, and (11), recapitulation of past task findings. In each review, the findings, salinity targets, and recommendations potentially pertinent to a salinity regime for the Sebastian River were identified. A total of 56 potential guidelines was compiled from these sources. The potentially useful findings were then compiled and evaluated in a synthesis. Final salinity recommendations (targets) were inferred from the list of potentially useful findings, plus additional considerations.

Salinity targets were organized around a spatial or landscape framework. A geographic or landscape approach to formulating salinity recommendations is possible because of the availability of spatially-referenced information. Sufficient information exists to support general salinity characteristics from marine to oligohaline waters, including intermediate mixing (estuarine) waters. Sufficient information also exists to specify the nature of salinity where the Sebastian River enters the Indian River Lagoon. Information regarding temporal variation was added to this spatial framework to address particular habitat or species requirements.

Separate targets are identified for each of 12 geographic segments or specific locations (Table I). Values are given for means, standard deviations (S.D.), coefficients of variation (C.V.), minima, maxima, and ranges of salinity recommended for each area. In general, these salinity targets resemble the existing salinity structure of the system, but there are several important differences:

1. Salinity targets at Segment S-157 are substantially lowered, from a present-day mean of 10.4 ppt to less than 1 ppt. The new S.D. is less than 2 ppt compared to 9.1 ppt. Minimum salinity is reduced greatly, from 29 ppt to 3 ppt.

2. The maximum recommended salinity target in Segment C-54 (15 ppt) is reduced by almost half from the Segment's existing maximum salinity (29 ppt).

3. The C.V. of salinity in the South Prong is increased from 87% to 133%.

4. Maximum recommended salinity is decreased in the North Prong, from 30 ppt to 20 ppt.

5. Seeming contradictions are proposed for the River Segment: (A) salinity range is contracted by raising minimum and lowering maximum salinity targets, while (B) mean salinity targets are unchanged but (C) S.D. is doubled and C.V. is increased by 50 percent.

6. Minimum salinity targets in the River Mouth and Inlet Segments are increased from 0 to 10 ppt and from 9 ppt to 28 ppt, respectively.

This set of recommended values address surface waters only because surface data are more numerous than data at depth. Once the relationship of bottom salinity to surface salinity is evaluated analytically for the study area, separate recommendations may be sought. For now, these recommended targets for surface salinity imply a given salinity structure near the bottom, and no specific problems resulting therefrom are known. Where possible, specific targets for bottom salinity in particular segments are presented below.

Weekly or bi-weekly sampling is recommended as a reasonable interval between sampling events employing grab samples. Continuous recording instruments should be deployed at stations in the River and River Mouth Segments. Because the duration targets pertain to neighboring segments, it may be possible to employ just one such instrument in the vicinity of the U.S. 1 bridge. Because the critical targets reflect summer and/or high discharge periods, instrument use could be restricted to times and conditions when duration limits were most likely to be exceeded.

Taken as a whole, the recommended target salinities should have the following effects. First, salinity gradients across the landscape will be stabilized, with a stronger longitudinal signal from the ocean to freshwaters. Second, the low salinity reaches of the landscape will be insulated more from incursions of high-salinity water, in the past as high as 29 ppt. Third, lagoonal landscapes will be protected from excursions of low-salinity waters, at least insofar as the Sebastian River are their source. Fourth, and perhaps of greatest potential benefit, the largest range and variation in salinity within the landscape will be moved out of the Indian River Lagoon and into the confluent reach of the Sebastian River.

This last action has two benefits. Waters of highly variable salinity will be sheltered from the dispersive effects of winds. Also, highly variable salinity will be "registered" to a reach of river naturally associated with such conditions.

Ecological consequences of these targets are mostly beneficial. In the Lagoon, mean salinity requirements of hard clams and seagrasses would be met all of the time in the Inlet Segment, and much of the time in the River Mouth Segment. Extreme salinity stress would be reduced greatly. All other things being equal, the seagrass, Halodule, and the hard clam, Mercenaria, should successfully persist in close proximity to the River mouth. The chances of this happening are improved by additional targets defined for particular species of value (Table II).

If clams are the focus for salinity management in the Indian River Lagoon, then oyster areas may be restricted to the Sebastian River. Oysters in the River would not be safe to eat but they could serve to demonstrate the attainment of target salinity regimes. Oysters also accumulate a wide array of pollutants and are useful as indicator species. More importantly, oyster reefs are an important habitat for a wide variety of associated organisms. Small crabs, fish, shrimp, sponges, other mollusks, and numerous polychaete species are all typical inhabitants of healthy oyster reef communities. An increase of oyster habitat in the tidal reaches of the Sebastian River would increase the River's overall levels of biodiversity and productivity.

Recommended salinities should not have adverse effects on three fish species of economic interest, the red drum, snook, and spotted seatrout. The salinity requirements of these species are not completely known, but recommended salinities fall within the envelope of known, protective salinities. By the same token, recommended salinities will preserve tidal freshwater and low salinity environments required by several fish species officially listed as threatened. Recommendations for flowing fresh waters also will perpetuate habitat requirements of the West Indian manatee.

We found very little useful information concerning the maximum rates of salinity change tolerable by estuarine or marine organisms. The only finding, for hard clams, results in the fastest possible rate of salinity change that is measurable. Without better data on real-time rates of salinity change near Sebastian, an additional precaution is recommended, to make the limits contingent upon a comparison to "background" rates of change. A definition of background is offered but it does little to change our view that this target should be advisory rather than certain.

In the event that all salinity targets cannot simultaneously be met, the following priorities are suggested. Minimum targets are more important than maximum targets. In upstream waters, maintenance of low mean salinities is more important than the maintenance of salinity variation. In marine waters, low variation is probably more important than the mean salinities they accompany. Achieving targets for the River and River Mouth Segments, and letting salinity vary as needed in other segments, will do significant good. And as long as problems of low salinity stress remain a problem, bias in sampling programs toward low tide conditions is justified.

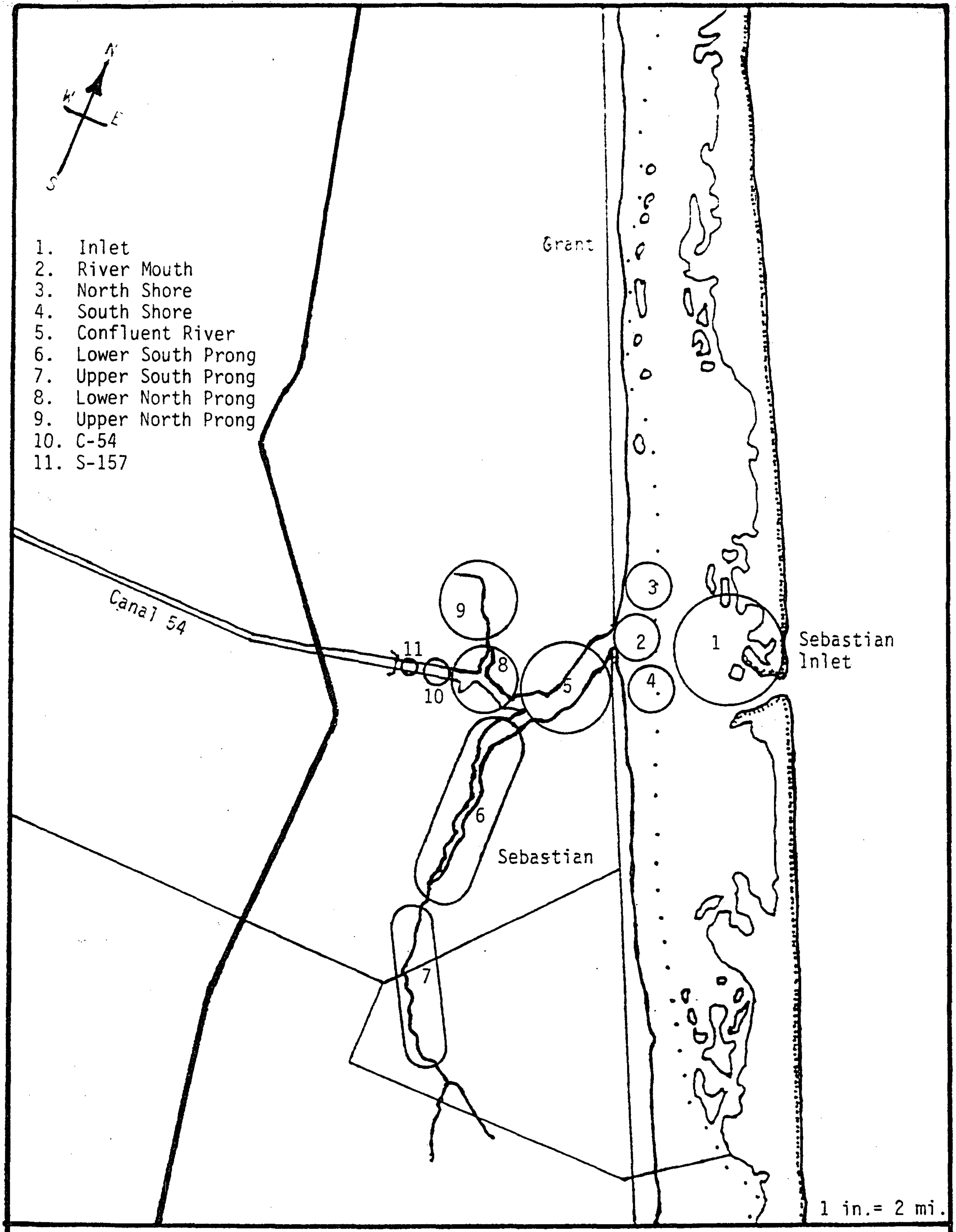

Figure I. Salinity Segments. See Table 1 in Section 14 for definitions.

Table I. Surface Salinity Targets by Segment or Site (parts per thousand). Segment names are in quotes and the names of geographic points are in parentheses.

"Segment"(Site)	Mean	Standard Deviation	C.V.[1], %	Minimum	Maximum	Range
(Sebastian Inlet)	33	5	15	28	--	--
"Inlet"	30	5	17	28	--	--
(ICW[2])	25	5	20	20	--	--
"River Mouth"	20	10	50	10	--	--
"River"	15	15	100	5	30	25
"Lower Prongs[3]"	6	8	133	0	20	20
"C-54"	5	8	160	0	15	15
"Upper Prongs[3]"	1	2	200	0	4	4
"S-157"	0.5	<2.0	--	0	3	3

[1]/Coefficient of variation
[2]/At county line
[3]/North and South Prongs

Table II. Additional salinity (S.) targets, in parts per thousand (ppt.).

Target	Resource	Affected Segments	Reference[1]
Mean bottom S = 25.0 ppt $\pm$ 10 ppt or less	*Halodule* (seagrass)	River Mouth	[25]
0 ppt duration at bottom < 24 hr.	*Syringodium* (seagrass)	River Mouth	[26]
Annual mean bottom S > 20 ppt.	*Mercenaria* (hard clam)	River Mouth	[27]
Minimum bottom S $\geq$ 10 ppt.	*Mercenaria*	River Mouth	[28]
Summer mean bottom S > 20 ppt $\pm$ 5 ppt or less	*Mercenaria*	River Mouth	[29]
Duration of summer mean bottom S < 15 ppt $\leq$ 7 days	*Mercenaria*	River Mouth	[29]
Non-summer mean bottom S $\geq$ 25 ppt $\pm$ 5 ppt or less	*Mercenaria*	River Mouth	[30,31]
Duration of S < 6 ppt < 14 days	*Crassostrea* (oyster)	River	[34]
Duration of S < 2 ppt < 7 days	*Crassostrea*	River	[34]
Provide flowing/ falling freshwater	Listed fish species and manatees	S-157; Lower N. Prong	[39]

[1]/ See list of findings and recommendations in Section 13.

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PREFACE

This is the third and final report of a project concerning desireable salinity conditions in the Sebastian River and adjacent Indian River Lagoon. A perception exists that the present salinity regime of the Sebastian River system is undesirable. Based on studies in nearby estuaries (Haunert and Startzman, 1985) discharges from C-54 are implicated as a component of the problem. The District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the Sebastian River and adjacent waters of the Indian River Lagoon. The District can then calculate discharges needed to produce the desired salinity regime, or conclude that optimal discharges are beyond its control.

The first component of this project was an analysis of existing goals for the study area, emphasizing those that directly or indirectly related to the question of salinity. Goal statements were sought from federal and state laws, agency rules, resource management plans, local government comprehensive plans, and other sources. The second component addressed the geographical segmentation of the study area. This third and final component recommends salinity guidelines for the river and adjacent lagoon.

This project is one of several activities concerning resource planning and management in the Sebastian River and lagoon region. The St. Johns River Water Management District has undertaken three related modeling projects. The first is a basin runoff modeling project to determine the quantity of water entering the Sebastian River from various sources. Results of this effort will be used as input to a circulation and salinity model of the River. Modeling efforts will be coordinated with a model of the Indian River Lagoon from the Sebastian River north to, and including, Turkey Creek.

The final results of this project will be used in concert with the three modeling efforts described above to estimate the attainability of improvements to fresh water discharge and overall ecological conditions in and near the Sebastian River.

On Salinity Optimization

To say that the salinity of a tidal waterway should be this or that is to presume a great deal. It is worth discussing the nature of these presumptions in order to know the meaning and limitations of a recommended salinity regime.

An important point is the difference between salinity as an independent factor, and salinity as a factor that is highly correlated with other independent factors. Salinity is intrinsically significant as an environmental factor. The anatomy, physiology, and behavior of most estuarine species display adaptations to the osmotic strength of ambient waters. The range and limits of such adaptations have been shown in laboratory and mesocosm experiments where only salinity was varied. The geographic distribution and abundance, growth, reproduction, and dispersal of estuarine plants and animals can be interpreted with meaning in the light of ambient salinities.

Having said that, it is necessary to point out that salinity in the real world rarely if ever varies without the simultaneous variation of many other physical, chemical, and biological conditions. Salinity gradients are also gradients for many of these other factors. As a consequence of inseparable co-variation in salinity and other factors, salinity has come to be used as a reference or proxy record of estuarine structure. However, it is also possible for gradients in these factors to occur in a given area where salinity happens to be uniform and stable.

Recommendations for a salinity regime are going to be most meaningful and effective where there is reason to believe that estuarine problems are primarily the consequence of disruptive salinities *per se*. An example of such a situation may be the case of marine predators invading oyster reefs, where normally lower salinity makes oyster areas unfavorable physiological environments for the predator species.

Salinity recommendations will be less successful in estuaries where the true cause of ecological problems is some other factor, such as eutrophication. Changes in freshwater inflow may reduce nutrient loads to the extent that the volume of nutrient-laden water is reduced, but it is also possible that the concentration of nutrients is such that salinity recommendations can be implemented with little or no improvement to eutrophication.

Some physical factors that co-vary with freshwater inflow (and therefore, salinity) include water velocity, temperature, sediment transport and deposition, and density stratification. Chemical factors include nutrient concentration, the concentration of light attenuating factors (and hence, transparency) and dissolved gases, and a range of chemical contaminants of anthropogenous origin. As stated earlier, a number of biological features also vary with salinity.

If the velocity, sedimentation, nutrient load, or other such salinity co-variant is known to cause a given estuarine problem it is better to measure and manage that factor directly, rather than to do so indirectly by using salinity as its proxy. This is not to say that salinity should be ignored --as it often is-- because the interaction of salinity with other environmental factors has been well-documented.

The extent to which we mistakenly attribute estaurine problems to salinity is unknown. The problems with the greatest likelihood of being caused by salinity are those that can be traced to alterations in the mean and range of salinity, the location of given salinities within an estuary, and such temporal parameters as seasonality, rates of salinity changes, and the frequency with which certain salinities occur. Each of these aspects can be tied directly to their counterparts regarding freshwater inflow, and (more or less) to circulation.

The values of studying salinity and making it a management priority in estuaries are therefore four-fold. First, salinity has intrinsic significance as an important regulatory factor. Second, changes in the salinity regime of an estuary tend to be relatively easy to handle from a computational and practical point of view. Third, eliminating salinity as a problem clears the way for studies and corrective actions for more insidious factors. And fourth, the strong covariance of salinity and other factors that tend to be management problems in estuaries makes salinity a useful tool in their analysis.

There are no known cases in which an estuary has been managed on the basis of salinity, only to find that some other factor was mistakenly unmanaged. By the same token, there probably have been many cases where an estuary failed to improve even after the extensive management of a factor, because salinity was not considered. As we move into the management of freshwater inflow, and salinity, we must be careful to recognize the difference.

Acknowledgements

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1. Introduction

Salinity variations in space and time are integral aspects of estuaries. The relationships between salinity and the distribution, abundance, and condition of estuarine plants and animals have long been recognized, and these are among the elementary lessons of estuarine ecology (Snedaker and DeSylva, 1977). Estuarine ecology has progressed significantly beyond the direct effects of salinity. Major themes of modern estuarine ecology have involved energy and matter fluxes, keystone species effects, symbioses, the fate and effect of pollutants, and much more.

These advances in estuarine ecology have been made against the backdrop of seasonal and annual salinity changes that were generally accepted as part of an estuary's unique character. But despite such attention, a process of considerable significance to estuaries has been underway that traditional ecological research has largely ignored. That process has been the insidious alteration of basic estuarine structure and function, through modifications of freshwater inflow and resultant salinity.

Natural patterns of freshwater flow to estuaries have undergone significant changes. Chief among these have been changes to the total amount, timing, and locations of inflow caused by flood control structures, instream and off-stream dams and reservoirs, navigation structures, diversions for consumptive use, and augmentation of flows by point and nonpoint source discharges. These inflow changes result in changes in the downstream delivery of sediment and nutrients, the salinity of tidal rivers and estuaries, and ultimately, in changes in estuarine productivity and usefulness (Halim, 1990).

Other forces have operated simultaneously to alter estuarine salinity regimes. Inlet management practices, navigation channels, spoil disposal, and other changes to boundary conditions and system geometry during the past century add to the list of salinity changes of anthropogenic origin. Notwithstanding natural processes such as climatic or sea level change, the combined effects of inflow and salinity alterations have virtually destroyed estuaries around the world (Mahmud, 1985). Despite this trend, the problems of physical habitat loss and chemical contamination have received much more scientific and regulatory attention than have inflow and salinity changes.

Consequently, profound changes to inflow, salinity, and productivity have been developing during the same, mostly post-war, period in which so much progress has been made in the basic discipline of estuarine ecology.

Today, many estuaries in Florida and the United States exhibit large, if not significant, changes in their natural inflow and salinity patterns. The same is probably true for estuaries around the world. On average, one new large dam is commissioned every day somewhere in the world. By the year 2000, more than 60% of total stream flow in the world will be regulated (Gore and Petts, 1989). With its recent settlement history and cosmopolitan population, Florida is a microcosm of inflow and salinity pressures facing estuaries in general. The Everglades already experience greatly reduced inflows. Interstate pressures for potable water from the Chatahoochee/Flint/Apalachicola Rivers have sounded alarms in Florida for the sustained productivity of Apalachicola Bay. Flood control projects on the state's eastern seaboard pulse huge quantities of water through small, usually stenohaline tidal areas. Most of Tampa Bay's tributaries are impounded (Estevez, Dixon and Flannery, 1991a) and plans exist to divert water from almost every coastal stream, including first magnitude spring runs.

The characteristic of Florida estuaries that most typifies estuaries elsewhere in the United States and world is the lack of comprehensive inflow and salinity data. Inflows are poorly known throughout Florida, especially the southern peninsula (Slade, 1991). Even well-gaged streams are gaged well above the reach of tides; given the state's low relief this practice results in most of a river's basin not being gaged. Furthermore, the impoundment effects of instream reservoirs and diversions of water for consumptive use are not always considered. The flows of some major streams are basically unknown.

The problem is even worse when salinity is considered. Where are the tidal fresh and oligohaline reaches of coastal rivers? How does salinity in tidal rivers vary with inflow, tides, seasons, or years? In which estuaries does vertical stratification always occur; in which is it present only during peak flows; where is it a symptom of mismanagement? What are the long term salinity trends of estuary X, and do these trends explain changes in its valued resources, such as fisheries? How do trends in nearby or distant estuaries compare?

Florida's large estuaries tend to have large amounts of salinity data. Tampa Bay, for example, has been measured monthly at 66 stations for 20 years. It is probably one of the state's best salinity data-bases, but little is known about freshwater inflows to the Bay. Not all large systems are monitored as well. Charlotte Harbor, for example, has been studied intensively for one or a few years, or salinity in one reach of the system has been monitored for a long period, but data comparable to Tampa Bay's do not exist. Salinity data of any kind for Florida's "Big Bend" coastline are very scarce. Data density does not necessarily follow resource abundance. For example, the Braden River in Manatee County has more intertidal wetland per unit of river area than any tributary to Tampa Bay (Estevez, Edwards and Hayward, 1991b). Yet, its salinity characteristics are essentially unknown.

Regulatory deficiencies parallel scientific ones. A recent analysis of legal and policy options to minimize adverse effects of surface water management practices on Florida's saltwater fisheries (Wade and Tucker, 1991) found that the importance of freshwater inflow to estuaries and estuarine fisheries was generally appreciated, but that existing laws, rules, and management programs had serious deficiencies. The analysis found support among agency staff for basic and applied research and increased consideration of estuarine needs in water-use permitting. The authors recommended that a statewide status and trends assessment should be implemented as part of a larger program to protect estuarine fisheries. Such a program would greatly enhance the ability of water management districts and fishery managers to address the present and growing threat of altered inflows and salinity, and also make basic contributions to the solution of a problem of international scope.

To recapitulate, freshwater inflow and salinity are integral aspects of estuaries. Major, largely unnoticed changes in these factors have been underway for decades. In Florida, as elsewhere in the world, these changes are likely to accelerate. Implications for estuarine productivity and management are critical. Existing data are seriously incomplete. Scientists and policy analysts agree that a coherent and transferable science is needed to determine the freshwater inflow and salinity requirements of estuaries. This report presents the results of one attempt to systematically determine a restorative and protective salinity regime for the Sebastian River and adjacent Indian River Lagoon.

Organization of the Report

This report comprises a series of essays ranging from the general to specific issues involved in recommending a salinity regime for the study area. Each essay is separately numbered and contains its own list of citations, tables, and figures. Readers interested in a summary of findings from each essay may turn to Section 13. Recommended salinity targets are described in Section 14.

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2. Freshwater Inflow and Estuarine Productivity

Estuaries depend upon freshwater inflow by definition, so it is logical to postulate that variations in freshwater inflow should affect estuarine characteristics, including ecological processes. Numerous studies have documented this postulate to be true. The physical energy of inflows structures estuarine environments. Inflows control the delivery of nutrients and sediment to estuaries. Freshwater establishes weak to strong gradients in salinity, temperature, and other physical and chemical attributes across the lengths of estuaries. Such inflow effects also act to control biological processes, and the link between freshwater inflow and productivity is established thereby.

The role of freshwater in estuaries has been reviewed by Gunter et al. (1973), Hopkins (1973), Snedaker and DeSylva (1977), Cross and Williams (1981), and Stickney (1984), to cite some of the more comprehensive English-language treatments available. Generally speaking, the types of studies relating freshwater inflows to estuarine productivity do so either using river discharge or salinity as independent variables, or use intermediate variables with strong correlations to discharge or salinity. Most intermediate variables are conservative but, depending on the nature of a particular estuary, they may also include non-conservative variables.

Although salinity effects have been studied for years at levels of biological organization ranging from the molecular to the ecosystem, and definite effects of salinity have been documented in countless specific instances, it has been difficult to demonstrate that inflows or salinity regimes exert a direct, controlling effect on the abundance or harvest of higher-order secondary producers. Significant progress has been made in recent years, however, because of improved data sets, and two valuable insights.

Taken directly, stock assessments or effort-adjusted landings of a given species have not shown strong correlations with inflow or salinity. On the other hand, population sizes of sea and shore birds, total yield of shrimps, and catch-adjusted landings of certain finfish have been correlated significantly with the area of wetland in an estuary. Depending on the estuary and species, similar relationships exist between the area of open water in an estuary, and fishery yields. Deegan et al. (1986) showed, in a comparison of data from a large number of Gulf of Mexico estuaries, that fishery landings could also be correlated significantly (r=0.98) with fresh water inflow, *once the landings data were normalized by the amount of estuarine area available in each system.* One insight to the role of inflow and salinity in fishery regulation, therefore, is that estuarine area, including wetlands, plays an important collateral role that can be accounted for in order to reveal the singular effects of inflow and salinity.

Between-year changes in inflow and salinity within a given estuary have been difficult to relate to fishery data. In light of the prior discussion, such a relationship should be obvious because the area and wetland cover of the estuary is constant between years. Nevertheless, significant correlations between inflows and yields have been elusive. Recent study of long-term data, however, has been more successful because of two improvements. First, inflows have been decomposed and independently analyzed for dry seasons and wet seasons, in addition to total annual inflow. Similar analyses can be done for times of the year critical to the life history of a particular species. Second, fishery yields are now being "lagged" according to the developmental rates of individual species. Relationships between particular inflow characteristics and lagged yield can then be evaluated, as Wilbur (1992) has demonstrated for oyster landings in Apalachicola Bay. The second insight, then, is that significant relationships between inflows and fishery yields can be uncovered by better matching of independent and dependent variables.

Another line of evidence linking inflows and salinity to estuarine productivity is found in the effect of unusual events, such as hurricanes and droughts, and human impacts. Storms add and droughts subtract from the normal amounts of inflow to an estuary. Public works projects may affect the amount, timing, or location of inflows, which in turn affect estuarine salinities and productivity. Each of these topics is reviewed in more detail elsewhere in this report. All may be summarized by the view of Rozengurt (1992) that inflow alterations that exceed the natural variation of a system will damage it. Rozengurt (1992) opines that the coefficient of variation of inflow corresponds to the natural limit of tolerable inflow alteration, but this value is not universally accepted.

While insights of recent studies offer promise for understanding how inflows, salinity, and habitat are to be viewed in relation to secondary productivity, no proven models of system function exist to assist resource managers who must decide how much water an estuary needs. One model developed by Browder and Moore (1981) looks promising, at least for Florida's estuaries. They postulate that fishery production is a direct function of the overlap between a species' structural habitat needs and its "dynamic habitat" needs. Using salinity as the principal component of dynamic habitat, the model reduces to the overlap of wetlands and favorable salinities, at key life-stage moments. Browder and Wang (1988) applied the model to Faka Hatchee Bay and Edwards (1991) refined the model for habitat specialization in the Manatee River, but the model has not yet been tested formally. If proven, the model could become a useful analytical tool for resource and water managers working in estuaries, comparable to methods for determining the instream flow requirements of freshwater systems.

Critique

The fact that inflows become important once fishery yields are normalized for habitat area underscores and reinforces our understanding that habitat is a critical factor. It also supports the idea of Browder and Moore (1981) that the interaction between stationary and dynamic habitat determines fishery production. When the Browder and Moore model is eventually tested, it can take advantage of filtered inflow and salinity data and lagged landings.

The existence of between-estuary and within-estuary relationships does not mean that more freshwater is necessarily related to greater productivity, or that it is necessary at all. West Texas lagoons are hypersaline but support productive fisheries. Estuaries that are deluged by storms or public works projects tend to be less productive in subsequent years, rather than more productive. Rozengurt's concept of stressful extremes is probably correct, at least for estuaries with natural salinity variation due to inflow variation, and the concept can be explicitly analyzed using the Browder and Moore hypothesis.

What is known or hypothesized for estuaries in general signify for the Sebastian River and Indian River Lagoon that:

1. To the extent that the River is managed as an estuary, salinities of an estuarine nature are appropriate.

2. The amount, timing and location of inflows are important because of the salinity responses that result.

3. The River's wetland systems are important, in conjunction with salinities, for the production of desirable species, and it is fortunate that much of the River's natural wetlands are intact.

4. There probably are limits to inflow/salinity alterations in the River that are injurious. Rozengurt's postulate that the limit is approximated by an estuary's coefficient of hydrological variation may provide insight, and would work for high flows as well as low flows, but is presently unknown.

5. The River is part of a larger ecosystem, the Indian River Lagoon, and these findings may be expected to apply in the Lagoon as well.

6. Quantitative studies suggested by these findings include fine-grain mapping of wetlands in the River and Lagoon near the River; the behavior of salinity under a range of discharge conditions relative to wetlands; and catch-normalized yield data for species of interest.

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3. An Overview of Small Coastal Rivers in Peninsular Florida

Although the original conditions of the Sebastian River and the Indian River Lagoon are poorly documented, goals and policies reviewed in the Task 1 Report of this project (Estevez, 1992) suggest a reasonably meaningful image or vision of the modern river area. There is a general expectation that the River and Lagoon will remain similar to their present states but also should be better managed, to eliminate their problems and preserve their qualities. For example, there are no official proponents for the complete elimination of augmented inflows to the River or closure of Sebastian Inlet.

The consequence of this thinking is useful because it prescribes a "model" against which the direction and effectiveness of management can be judged. The model is that of a small, variably flowing river that enters a stable, usually high-salinity Lagoon. Such a model is considerably different than, say, the tidal backwaters of a mesohaline bay, in which relatively little freshwater inflow enters the system through the backwaters.

Where in Florida are there naturally small rivers with non-zero or even significant base flows, discharging directly into protected marine waters? On the east coast, one possible example is the Loxahatchee River in Martin and Palm Beach Counties. On the Gulf shore, rivers of the "Springs Coast" (Wolfe, 1990) may also be useful analogs. Characteristics of these rivers are described below in order to look for information useful to the development of salinity recommendations in the present study area.

Loxahatchee River

This is an interesting river to compare to the Sebastian River because it occurs on the east coast of Florida, is approximately the same size, and management is trying to accomplish the same "model" as described above. The Loxahatchee is branched and has three forks. One of the forks was greatly modified as the outlet of an inland canal system. The canal's discharge-control structure occurs in tidal waters, and manatees frequent the local area of the structure (Mote Marine Laboratory, 1991).

The river empties into the Atlantic Ocean through an inlet that must be kept open through maintenance dredging. The proximity of the inlet creates a strong salinity gradient along the length of the longest river fork. Salinity near zero occurs upriver and salinity near the river mouth is usually greater than 30 parts per thousand. The highest turbidity and variation in salinity occur within the area of confluence of the three river forks. Mangroves dominate the intertidal vegetation in the lower and middle reaches of the North and Northwest Forks, but sparse grassy marshes are more common on the Southwest Fork (where the canal empties).

Oligohaline marshes occur upstream of the mangrove areas, and these grade into cypress forests farther upstream in the Northwest Fork. Seagrasses are luxuriant near the river mouth, but species diversity declines rapidly up the river. The upstream-most seagrass is Halodule wrightii, and its cover varies greatly between survey periods (Mote Marine Laboratory, 1990a).

The main management problems facing the Sebastian River have concerned regulation of freshwater inflows. In the past, sudden and large discharges of freshwater to the River have caused sedimentation, discoloration, sags of dissolved oxygen, and salinity shocks in the receiving waters. The largest discharges affected all of the Intracoastal Waterway and the Atlantic Ocean near Jupiter Inlet. Canal discharges also reduced natural flow of the Northwest Fork. Large areas of cypress forest in the Northwest Fork have died because of salinity impacts (McPherson et al., 1982). The canal discharges are better managed, and the Northwest Fork receives more water than it did, but it does not receive the inflows it probably should to completely retard salt water intrusion (Russell and McPherson, 1984). The present problem concerns how best to provide even more water to the River's Northwest Fork. Coliform contamination has also been a problem in public bathing areas along the river.

Details of the salinity structure in the Northwest Fork of the River were available from a monthly monitoring program conducted by the South Florida Water Management District (Mote Marine Laboratory, 1990b). During the monitoring period (3 years) mean discharge of the Northwest Fork was 50 cfs and mean discharge of structure S-46 (on the Southwest Fork) was 43 cfs. Median flows were 56 cfs for the Northwest Fork and zero cfs for S-46.

There was no flow for 23% of the days in the northwest Fork and for 53% of the time at S-46.

Some biological attributes of the Loxahatchee River are known, at least at the habitat and community levels. Oyster size varies consistently with river mile, reaching a maximum height in the middle reach of the tidal river (Figure 1). As mentioned above, seagrasses (Thalassia, Syringodium, Halophila, and Halodule) occur near the mouth of the river although none but Halodule extends farther upstream (Mote Marine Laboratory, 1990a). Oyster and seagrass distributions are plotted against mean salinity and salinity variation in Figure 2. These data illustrate a strong salinity control on oyster distribution and size, and a weaker correspondence of salinity with upriver limits of seagrass distribution.

West Coast Rivers

Spring runs and small rivers on the Florida west coast share some physical similarities with the Sebastian (Estevez et al., 1991a). Rivers with a tidal length approximately that of the South Prong of the Sebastian River include the Econfina, Steinhatchee, Anclote, and Little Manatee (Table 1). Rivers with mean discharges similar to the combined discharges of the Sebastian River tributaries include the Econfina, Steinhatchee, Waccasassa, Weeki Wachee, and Myakka. Rivers prone to pulses of regulated discharge include the Hillsborough, Manatee and Caloosahatchee.

The Econfina River is more like the Sebastian River than any other west coast river in terms of tidal length and mean discharge. Unfortunately, it is also similar to the Sebastian in that it is not a data-rich river (R. Mattson, Suwannee River Water Management District, personal communication). Some useful information can be compiled from the other west-coast rivers, however, in terms of ecosystem structure in relation to salinity.

In a comparison of data from several small west-coast rivers, Estevez et al. (1991b) determined that a regular pattern occurs among soils affected by tides. Soils of alluvial origin are sequentially replaced along river banks by tidal soils (Figure 3). Alluvial soils tend to be well drained and low in organic content compared to tidal soils, and alluvial soils tend to support forested bottomland hardwoods whereas tidal soils support oligohaline to estuarine marshes.

The point of transition from alluvial to tidal soils corresponds to mean surface salinities of 1.4 ppt in two pristine rivers and mean salinities were higher at soil transitions in rivers affected by impoundments (Table 2). Standard deviations about salinity means also are lower in pristine rivers than in regulated rivers. These results have since been observed in the Loxahatchee River. In the Sebastian River's South and North Prongs, the same transition from alluvial to tidal soils occurs (Estevez, 1993), and a transition is suggested in remnant soils of the West Prong. In the South Prong, volunteer monitoring data coordinated by the Marine Resources Council indicates that salinities of 1 to 2 ppt occur in the vicinity of mapped soil transitions (Estevez, 1993).

Shoreline vegetation corresponds to soils in these and other small west-coast rivers. Tidal soils near river mouths are inhabited by mangroves, or salt marsh (primarily Juncus roemerianus) where cold excludes mangroves. Tidal soils upstream of river mouths tend to support uniform Juncus marshes, and these river reaches have salinities ranging from 5 to 20 ppt. The most upstream tidal soils support a mixture of marsh species with moderate to high tolerance to periodic exposures to salt water. In larger rivers (the Suwannee, for example) a reach of salt-intolerant (obligate freshwater) marsh species may occur before the river enters floodplain forest, but this habitat is either absent or highly compressed in the small rivers[2].

The river-mile dispersion of tidal marsh plants was investigated in relation to different salinity characteristics in several west coast rivers (Hussey, 1985). The most meaningful "fit" was found between the downstream limit of a species, and maximum surface salinity (Figure 4). Mean or minimum salinities were not related as well to a species' extreme or central ranges along rivers. These findings suggest that low flow (high salinity) periods regulate plant community structure by differentially regulating the

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[2]/ Spring runs are an exception among small rivers. The large amount and constancy of discharge may allow for larger areas of tidal soils to support freshwater species.

downstream extent of individual species, along with intervals of high flow (the "low-salinity gap" process described by Zedler and Beare, 1986) that replenish or extend downstream ranges of individual species.

In the Sebastian system, mangroves occur in the confluent river area but none are mapped in any Prong (SJRWMD, 1992). Wetlands are present in the North and South Prongs but these are mapped as freshwater marsh, non-forested scrub/shrub, or river/lake swamp. The absence of mangroves from the South Prong and the erratic dispersion of freshwater marsh suggest a need for additional ground-truthing of the map.

Oyster reefs are abundant near small west coast rivers. Condition indices for oysters studied at four central Florida rivers (Sprinkel, 1985a) and the Myakka River (Sprinkel, 1985b) indicated that oyster survival and growth were greatest just inside river mouths and in areas of open water directly affected by river discharge. Dixon (1986) mapped the location of isohalines in the same west coast rivers where oysters were studied (Figure 5). In general, the best oyster reefs occurred between an upriver point defined as the maximum penetration of the 15.0 ppt isohaline, and a seaward point defined as the mean position of 15.0 ppt minus one standard deviation.

West coast rivers are not very informative with respect to seagrass distribution. None occur within the Waccasassa, Withlacoochee[3], Alafia, or Peace, and only *Ruppia* or small areas of *Halodule* occur in the Pithlachascotee, Anclote, Manatee, Braden, and Myakka Rivers. Seagrasses are, however, abundant in the highly transparent spring runs of west central Florida.

Critique

A few characteristics of rivers similar to the Sebastian system are informative for the purpose of recommending a salinity regime, given that each is unique and direct transfers of their specific features to the Sebastian are not proposed.

The Loxahatchee River has a number of interesting similarities to the Sebastian River, more so than the west coast rivers. Factors preventing it

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[3]/ Although *Vallisneria* is present in tidal freshwater.

from being a more perfect model are the lack of ecological data when S-46 was discharging large volumes of water, and the fact that the river presently faces a shortfall of flow. With these factors in mind, some features of the Loxahatchee River seem reasonable to consider as they may be adapted and applied in the Sebastian River.

The first of these, salinity structure, suggests that it is possible for maximum salinity variance to occur within the River, or in the Lagoon near the river mouth. Salinity variance is emerging as a feature as important as mean salinity in structuring the chemistry and biology of estuaries (See for example, Montague et al., 1989).

The second feature, wetland habitat distribution, is also suggestive. Soils and wetlands follow regular patterns in the reference rivers, and, despite problems with existing wetland maps in the study area, the same patterns appear to occur in the Sebastian River. If anything, increased freshwater discharges have extended the range of freshwater plant communities downriver, perhaps into areas where cold stress has suppressed mangroves.

Were it not for the large base flows of the Sebastian system, it is not unreasonable to think of oysters or seagrasses occurring within the river confluence. The confluence area is shallow and is bordered by firm, gradually sloped bottoms where oysters could grow if salinities were on the order of 15 to 20 ppt, with intermittent periods of lower salinity. Wide salinity variation and the [postulated] unavailability of light are probably responsible for the reported absence of <u>Halodule</u> or <u>Ruppia</u> from this area. Their distribution in the Loxahatchee River suggests that either oysters or seagrasses, but not both, might persist in the relatively confined area of the Sebastian River confluence, with appropriate inflow and salinity management. It is also possible that a seagrass, <u>Halodule</u> for example, might grow in the confluence area and oysters would populate upstream reaches. This latter scenario implies higher salinity in at least the South Prong, with a corresponding compression of low salinity areas farther upstream.

An overview of small coastal rivers in peninsular Florida suggests that:

1. Tidal freshwater areas tend to be confined within relatively short river reaches, and occur in the vicinity of transitions in soil types. Mean salinity at such points tend to be low (1 - 2 ppt) with standard deviations between 2 and 4 ppt.

2. Seagrasses are not extensive or abundant within small tidal rivers (other than spring runs), and where they occur, <u>Ruppia</u> and/or <u>Halodule</u> are the principal species. It is possible that one of these species would grow in the Sebastian River's confluence area given suitable salinities. The salinity conditions associated with these species are described in another section of this report.

3. Oyster reefs are commonly encountered in and near tidal rivers and their condition along a salinity gradient is often best in the vicinity of river mouths. Salinities favorable to oysters are reported in another section of this report but mean values tend to fall between 15 and 25 ppt, and oysters tolerate and may benefit[4] from day-to-week long periods of fresher water.

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[4]/ By disease and/or predator exclusion.

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Table 1. West-Coast Rivers of Peninsular Florida

Name	Latitude N (deg.-min.)	Tide Range[A] (m)	Length (km)	Drainage Area (km^2)	Discharge (m^3/s)	Tidal Length[E] (km)	Spring Flow	Regulated Flow	References
Aucilla	30°06'	1.01	110.6	2,279	17.0	8.0[F]	yes	no	1,2,3,5,8
Econfina	30°02'	1.01	57.9	1,140	4.1	14.6[F]	no	no	1,2,3,6,7,8
Fenholloway	29°58'	1.04	54.7	855	1.6[B]	unknown	yes	no	1,2,3,6,8
Steinhatchee	29°41'	1.04	45.9	1,528	9.4	14.5[F]	yes	no	1,2,3,6,8
Suwannee	29°19'	1.04	394.2	25,641	301.0	43.0[F]	yes	no	1,2,3,5
Waccasassa	29°11'	1.07	61.6	1,373	8.6	9.1	yes	no	1,2,3,4
Withlacoochee	28°59'	1.07	252.6	5,180	51.2	15.0[F]	yes	yes	1,2,3,4,5
Crystal	28°54'	1.07	11.0	coastal	27.6	10.0[G]	yes	no	1,2,3,4
Homosassa	28°47'	1.04	12.9	coastal	11.0	10.0[G]	yes	no	1,2,3,4
Chassahowitzka	28°42'	1.04	7.9	coastal	4.0	6.0[H]	yes	no	1,2,3,4
Weeki Wachee	28°32'	1.04	11.6	coastal	5.0	3.1	yes	no	1,2,3,4
Pithlachascotee	28°16'	1.04	66.0	191	0.9	10.3	no	no	1,2,3,4
Anclote	28°10'	.82	44.2	113	2.0	17.7	no	no[I]	1,2,3,4
Hillsborough	27°57'	.85	88.5	690	17.9	16.0[C]	yes	yes	1,2,3,4
Alafia	27°52'	.85	38.6	420	10.5	16.7	yes	no	1,2,3,4
Little Manatee	27°44'	.70	62.8	220	4.9	18.0	no	no[J]	1,2,3,4
Manatee	27°32'	.70	57.1	280	4.5	35.4	no	yes	1,2,3,4
Braden	27°30'	.70	32.5	89	1.9[C]	9.6	no	yes	1,2,3,4
Myakka	26°56'	.58	87.0	540	7.1	>34.0	yes	no	1,2,3,4
Peace	26°54'	.58	168.9	2,300	33.0	42.0[F]	no	no[J]	1,2,3,5
Caloosahatchee	26°32'	.30	120.5	indefinite	locks[D]	41.0[F]	no	yes[D]	1,2,3,5

Notes: (A) Spring tide; (B) 3.7 m^3/s after industrial discharge; (C) estimated; (D) regulated for navigation and flood control; (E) 0.5 parts per thousand [ppt] salinity unless noted otherwise; (F) based on stage variation; (G) 2.0 ppt; (H) 3.0 ppt; (I) Lake Tarpon outlet is regulated; (J) off-stream storage.

References: (1) Fernald and Patton, 1984; (2) National Ocean Service, 1992; (3) Florida Board of Conservation, 1966; (4) Estevez et al., 1991; (5) McPherson and Hammett, 1991; (6) Meadows et al., 1992; (7) Marvin Franklin, U.S. Geological Survey, personal communication; (8) Rob Mattson, Suwannee River Water Management District, personal communication.

Table 2. Salinity data in parts per thousand (ppt) for selected west coastal rivers, near transitions between alluvial and tidal soil types (Estevez *et al*., 1991b).

RIVER	(N)	MEAN	SD	MAXIMUM	SOURCE
A. High tide surface salinity, near soil transitions:					
Anclote	26	2.13	3.24	10.94	SWFWMD
Alafia	26	2.22	nd	12.14	SWFWMD
Little Manatee	36	1.41	2.05	8.18	SWFWMD
Manatee	57*	4.77	4.83	nd	(1)
Myakka	16	1.42	3.38	11.10	(2)
B. High tide bottom salinity, near soil transitions:					
Anclote	26	2.82	4.34	13.19	SWFWMD
Alafia	26	6.75	nd	18.55	SWFWMD
Little Manatee	36	1.59	2.28	8.18	SWFWMD
Manatee	57*	5.97	5.33	nd	(1)
Myakka	16	1.56	3.48	11.10	(2)

*mixed tides
nd - not determined
(1) CDM and Manatee County Utilities Department, 1984.
(2) S. Lowrey, Sarasota County Ecological Monitoring Division.

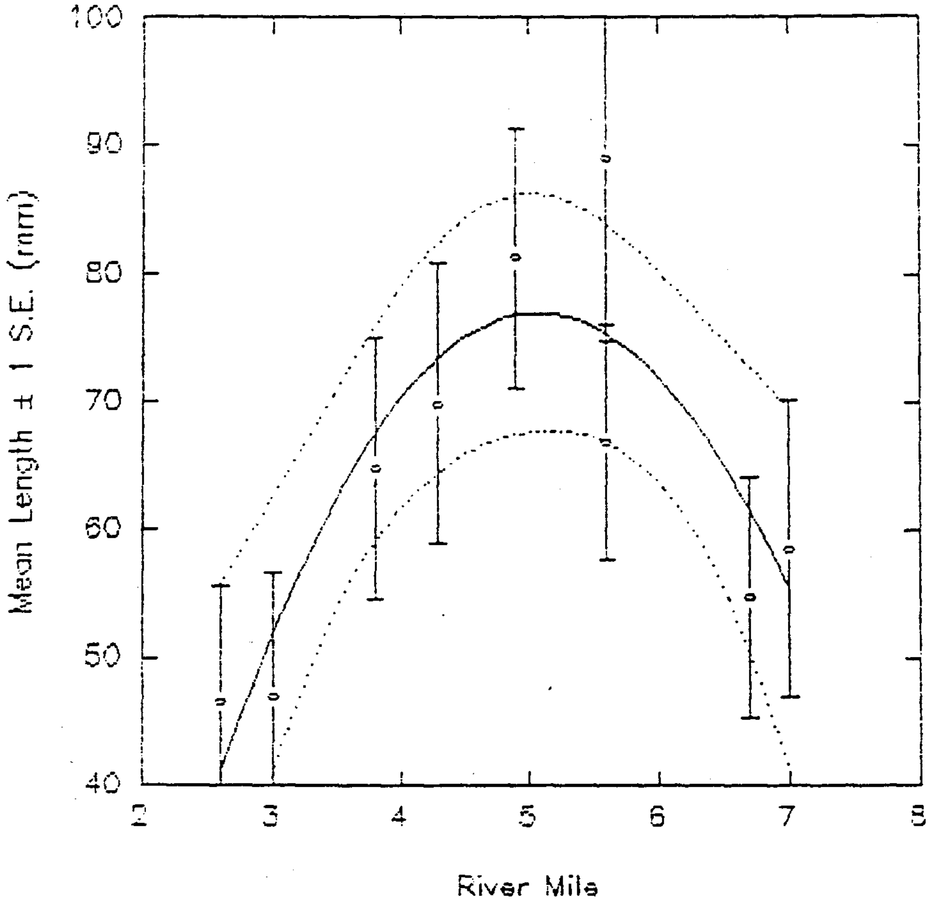

Figure 1 Mean lengths and ranges of largest living oysters at reef stations along the Northwest Fork. Solid line is 2nd order polynomial fit and dashed lines bracket the 95% confidence interval.

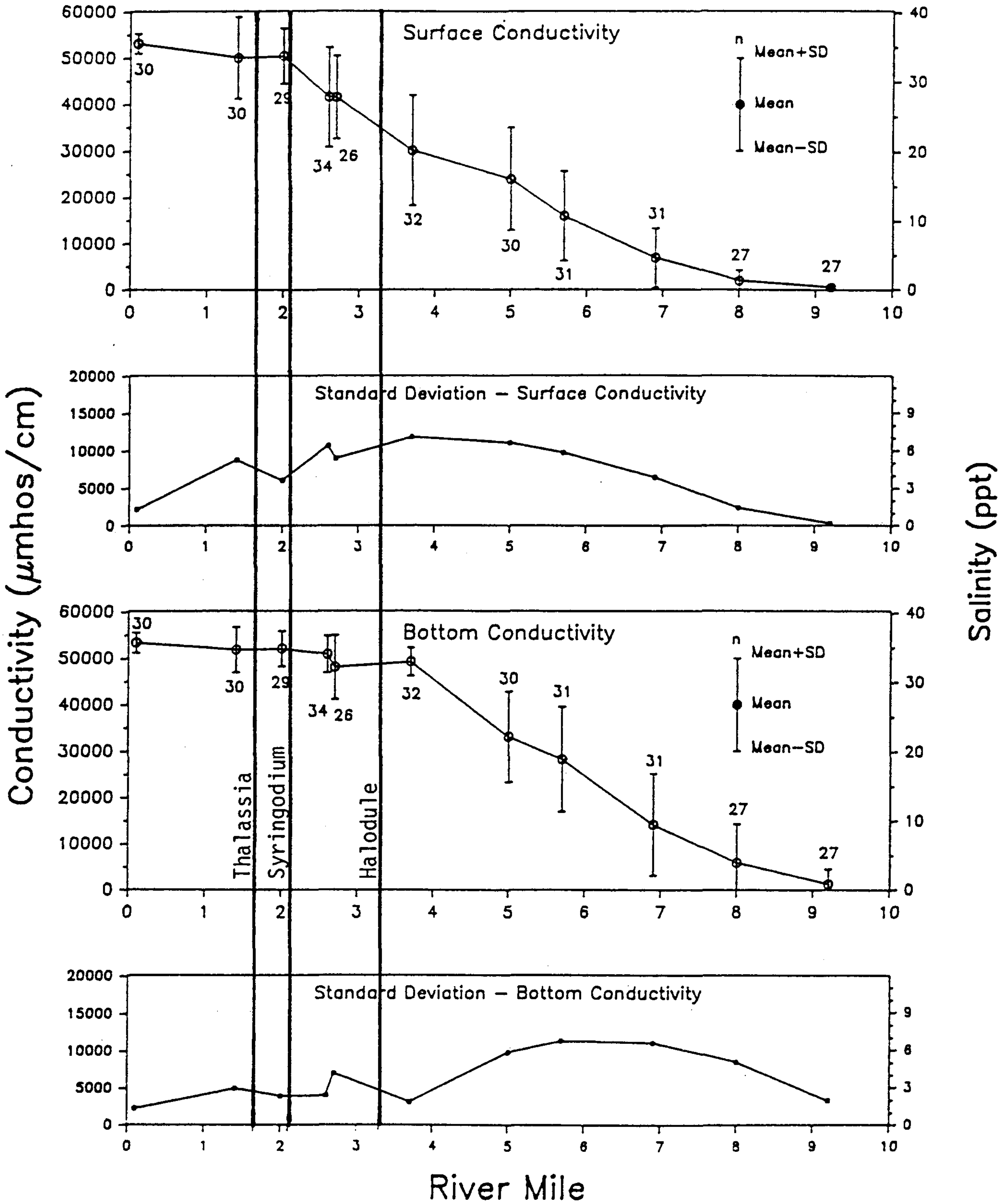

Figure 2. Upstream limits of seagrasses in the Loxahatchee River, compared to means and standard deviations of surface and bottom conductivities (sampled during high tides, 1985 - 1988).

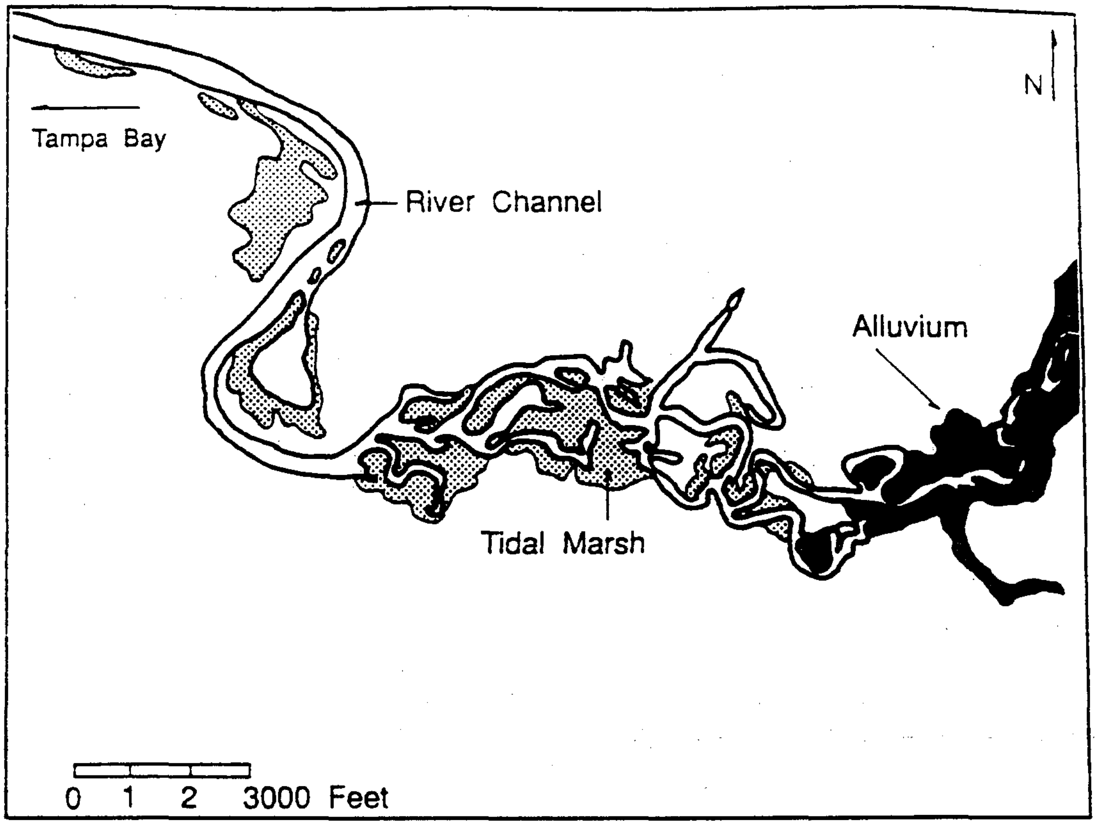

Figure 3 Transition from alluvial soils (dark areas) to tidal marsh soils (shaded areas) along the banks of the Little Manatee River in Hillsborough County, Florida (adapted from SCS 1958).

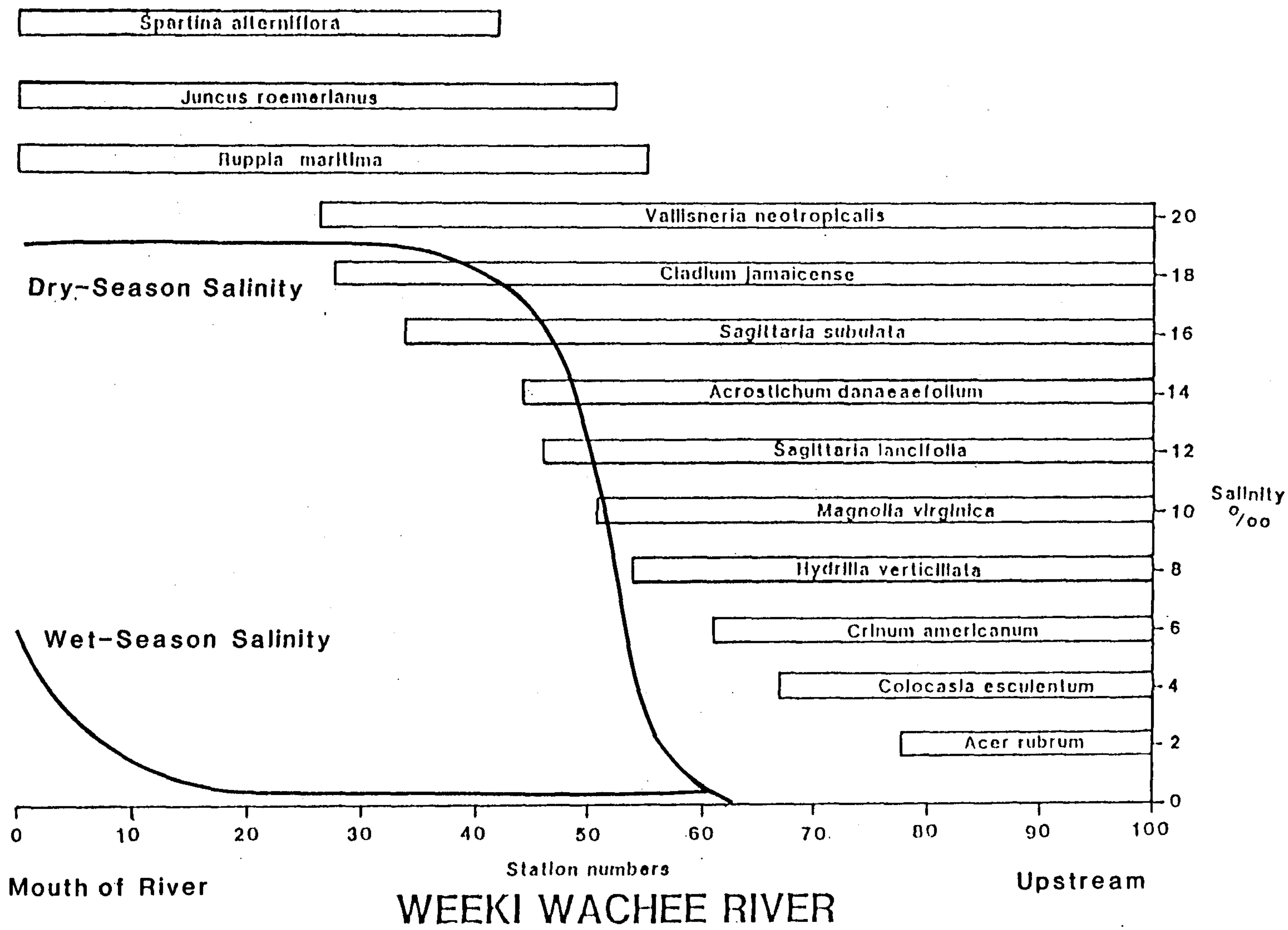

Figure 4. Relation of wetland species distribution to salinity.

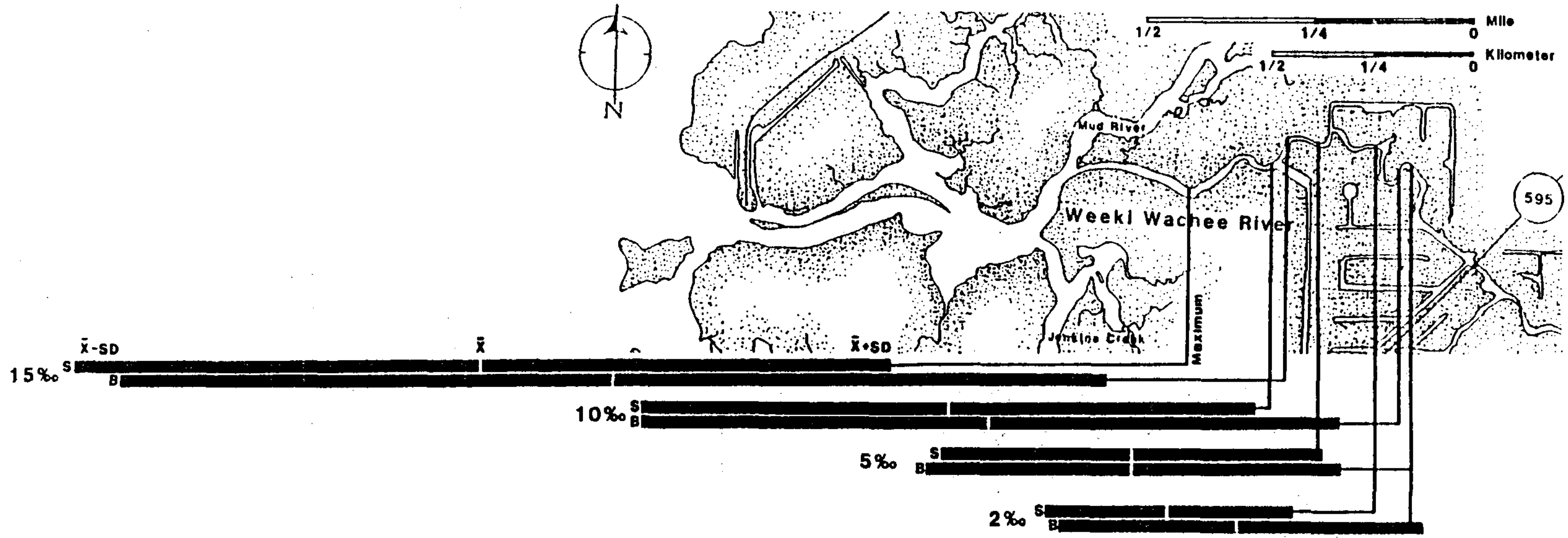

Figure 5 Weeki Wachee River: surface and bottom, high-tide isohaline positions; mean, standard deviation, and maxima of penetration during 1984–1985 (Dixon 1986).

4. Case Studies of Altered Inflow and Salinity

At the present time, no comprehensive literature reviews exist of ecological impacts in estuaries resulting from altered freshwater inflow or salinity. Part of the reason for this situation is the diversity that exists in the ways that inflows can be altered. Such alterations include increases or decreases in the quantity of inflow, changes in the short-to-long period temporal variations of inflow, inflow location, etc. Another reason is that truly comprehensive ecological studies of estuaries are few and have tended to be made in relatively pristine, rather than altered, estuaries.

On the other hand, a number of case studies are available for specific types of inflow/salinity alteration, estuaries, and ecological components. Existing reviews have been organized phylogentically (Gunter et al., 1973) or by estuary (Halim, 1990; Mahmud, 1985) but the latter addressed inflow reduction rather than augmentation. Highlights of estuarine studies involving the impacts of increased and/or erratic inflows are reviewed below, with examples drawn mostly from studies relevant to the Sebastian River and Indian River Lagoon situation (e.g., relatively small estuaries and Florida examples).

Storms, Managed Discharges and Freshets

A number of incidental reports provide insight to the nature of ecological impacts caused by natural or man-made releases of freshwater to estuaries. In the Gernika estuary (northern Spain), salinity fluctuates greatly due to the runoff of heavy rains. Chlorophyll *a* levels were highest in the upper estuary until discharges increased. Discharge rather than phytoplankton growth dynamics controlled chlorophyll levels. Zooplankton in the estuary was essentially marine. When large discharges occurred, the zooplankton did not become a freshwater or estuarine community; it simply disappeared. When discharges subsided, the marine zooplankton community was re-established (Madariaga et al., 1992). Large discharges of freshwater may kill marine zooplankton by entraining it into upper estuarine reaches. In a Norwegian fjord, Kaartvedt and Aksnes (1992) found that releases of freshwater from a hydroelectric plant generated an inward countercurrent that moved zooplankton into freshwater, where the plankters were killed by osmotic stress. Although not specifically studied in Florida systems, the same effects of freshwater on phytoplankton and zooplankton are plausible, especially in riverine systems. The plankton of larger Florida estuaries probably respond more like the plankton of Lakes Pontchartrain and Borgne in the northern Gulf of Mexico. There, freshwater pulses promote estuarine plankton communities by augmenting the oligohaline species and displacing marine forms, which return with higher salinities (Hawes and Perry, 1978). The same heavy discharges displaced commercial bottomfish (mostly Atlantic croaker, *Micropogonias undulatus*) offshore, resulting in temporary declines in inshore fishery landings (Russell, 1977). Blue crabs evacuate areas of Apalachicola Bay flushed by stormwater runoff, although their avoidance behavior is tied more to low pH than to low salinity (Laughlin et al., 1978). Oysters in Apalachicola Bay were damaged seriously by Hurricane Elena in 1985. Damage was caused in part by high rainfall and runoff, but also by physical disruption of reefs by strong waves and currents. Productivity of the Bay's oyster fishery was significantly reduced by the combined storm effects (Berrigan, 1988).

Alewife Cove

In Alewife Cove (Connecticut) the loss of freshwater wetlands within the watershed and tidal wetlands within the estuary eliminated that estuary's natural buffer against erratic freshwater runoff. Runoff quantities were increased and the hydrograph of runoff was compressed (pulsed) over historic conditions. Salinity was greatly affected because the estuary's mixing zone was caused to oscillate over more than 50% of the estuary's surface area. As a result, the mixing zone delivered and deposited flocculent silt-clay sized sediment over a larger area of the benthos. Surface and groundwater inflows to the estuary caused harsh salinity gradients and low pH values within benthic sediments. These salinity and pH gradients retarded infaunal community development, with selection for opportunistic species such as the polychaete, *Capitella capitata*. Detritivores (amphipods) and filter-feeders (mollusks) were eliminated from benthic communities. Organic sediment accumulated because benthic invertebrates were not present to process incoming loads, and the new accumulations worsened benthic conditions. This negative feedback resulted in large areas of the estuary having a benthic community structure typical of a polluted environment (Welsh et al., 1978).

Fahka Union Bay

In southwestern Florida, channelization of uplands and inland wetlands resulted in the delivery of large quantities of freshwater, often in massive pulses, to Fahka Union Bay. Neighboring Fahkahatchee Bay, being unaffected by the canal discharge under most conditions, has been compared to Fahka Union Bay for insight to the effects of the canal. Salinity is always lower in Fahka Union Bay and stratification is more pronounced and persistent. Total nutrient loads to Fahka Union also are greater. Fahkahatchee Bay bottoms are dominated by seagrasses whereas seagrass cover in Fahka Union Bay has declined while benthic macroalgae and filamentous green algae has proliferated. The biomass of benthic fauna in mud, sand and shell substrata within Fahka Union Bay was significantly lower than in Fahkahatchee Bay. Conversely, the number and density of pink shrimp, grass shrimp, and blue crabs were higher in Fahkahatchee Bay. Higher salinity variability also affected the composition of fish communities and the abundance of juvenile fishes (Carter et al., 1973; Drew and Schomer, 1984; Browder et al., 1986). Browder et al. (1986) related depressed abundances of fish species in Fahka Union Bay (Figure 1) to its lower salinity and higher salinity variation (Figure 2). Mean salinities were close to 15 ppt, 5 to 10 ppt lower than in adjoining bays. Salinity variance was 100% to 150% greater in Fahka Union Bay than neighboring bays, and salinity ranges also were greatest there (spanning near-zero to 36 ppt).

Etang de Berre

The Etang de Berre near Marseilles, France was a high salinity lagoonal basin connected to the Mediterranean Sea. Typical salinities ranged from 31 to 34 ppt. It originally contained extensive beds of the seagrass, Zostera, and the mussel, Mytilus. Since 1966 a canal from the Durance River and hydropower plant has pulsed large quantities of water (to 125 cubic meters per second) to the Lagoon, on a highly erratic schedule. By 1970 the system had changed significantly. Vast seagrass areas had disappeared and mussel beds contracted to areas farthest from the canal. Mussel beds and sandy bottoms became dominated by the polychaete, *Capitella capitata*. Instead of acquiring a brackish water fauna, the lagoon instead developed a marine seral community indicative of significant stress. Because the system was relatively unpolluted, salinity variation was identified as the primary stressor (Bellan, 1972). Benthic communities in deeper waters disappeared altogether during later years, except near the lagoon's connection to the sea. In shallower waters, a euryhaline benthic community eventually developed but the largest of canal discharges caused it to decline for long periods of time during the past two decades. Freshwater pulses caused a large number of the significant declines in mollusc species diversity and abundance, sampled on a monthly basis over several years. Today, the lagoon is "an estuarine environment in which there is no real transition between brackish and marine communities. Rather, euryhaline, opportunistic species dominated throughout. This is a typical condition for estuarine environments experiencing highly variable salinity fluctuations" (Stora and Arnoux, 1983).

St. Lucie River

A canal connecting Lake Okeechobee to the Indian River Lagoon, constructed between 1916 and 1924, has a peak discharge of about 9,000 cfs. In the 1950s, biological sampling found that most fish species utilizing the St. Lucie River and estuary were marine, and freshwater species were numerically rare. Most (89%) of the catch was made of five species -- striped mullet, menhaden, croaker, saltwater silverside, and bay anchovy -- all are forage fish. Most marine species persisted in the estuary, even during high inflows, because a salt wedge underlies the system in all but extreme flows. High flows did exclude pompano and snappers from the area. Blue crab and brown shrimp were common but never abundant. The study concluded that high discharges were not damaging fish resources, and that moderate flows actually benefitted the area by promoting forage species reproduction and growth (Gunter and Hall, 1963).

Haunert and Startzman (1980) performed baseline biological sampling in the St. Lucie estuary prior to a controlled release of 1000 cfs. Marine species community structure was similar to that reported by Gunter and Hall

(1963) but freshwater species were absent because the canal was closed. No significant differences in the distribution of individual species were found after the Canal was opened for the 3-week, 1000-cfs discharge. The number of species per station and dominance patterns in fish communities also did not change. Mean species diversity among benthic macroinvertebrates collected before and after the discharge did not change significantly, either. On the other hand, many dominant species were opportunistic pollution indicators. A variety of changes in benthic community structure were observed.

Haunert and Startzman (1985) repeated the experiment of 1978, using a 3-week discharge of 2,500 cfs. Effects of this discharge level were much different than the 1,000-cfs discharge. Much of the inner and middle estuary became oligohaline, and a highly compressed and stable salt wedge formed at its seaward edge. Benthic infaunal abundance declined by 44%, although this decline occurred in an opportunistic benthic community. Freshwater fish expanded their range downstream and euryhaline larvae of marine species were entrained upstream. Forage species distribution expanded across the low salinity reach of the estuary. The 2,500-cfs discharge would have threatened oyster reefs in the inner and middle estuary if it had persisted another 10 days. Discharges of 2,500 cfs were also found to have significant effects on the [recreational] catch rates for nine important species in the estuary and seven important species in the inlet, although some catches were increased while others were decreased. The mobility and feeding habits of individual species confounded the results (Van Os et al., 1981).

Caloosahatchee River

Beginning in 1884, canals have been built and enlarged to drain Lake Okeechobee to the Gulf of Mexico along the Caloosahatchee River. Between 1957 and 1960 Gunter and Hall (1965) assessed ecological conditions in the tidal Caloosahatchee River and estuary, during a period when discharges of the canal varied from 960 to 12,600 cfs. They found that fish species richness and abundance was greater in the river than in the estuary and the opposite pattern was true for invertebrates. Large discharge events caused an expansion in the distribution of freshwater species throughout the river and low discharges allowed marine species to expand upriver. The dominant fish species taken in the survey were silversides, striped mullet, bay anchovy, mosquitofish, spot, sea catfish, silver mojarra, and sardines. A comparison was made between the species taken over 100 times in the Caloosahatchee and St. Lucie Rivers (15 and 13 species, respectively) and 8 were on both lists. Gunter and Hall (1965) concluded that a wide range of economic impacts to local fisheries were due more to the temporary movements of fishes than to long-term ecological impacts.

Lake Worth

Lake Worth, in southeast Florida, is a long and narrow lagoon with a northern connection, Lake Worth Inlet, and southern connection (South Lake Worth Inlet) to the Atlantic Ocean. The West Palm Beach Canal is its main source of fresh water. The Canal has a maximum discharge capacity of 1,000 cfs. Van de Kreeke et al. (1976) evaluated the hydrology and biology of the Lake to determine the effects of large freshwater discharges from the Canal. No data were available for pre-canal or no-discharge conditions, and the effects of a specific discharge event were not investigated, so the study was basically an analysis of biota along a strong salinity gradient. A rapid decline in algal species diversity was observed at salinities below 30 ppt. Faunal changes were evaluated by exclusion analysis (Figure 3), revealing significant discontinuities at 20 and 30 ppt. Greatest faunal species richness was found near the inlets (30-36 ppt) but the majority of individuals tolerated a relatively wider salinity range (substrate limitations affected the influence of salinity on abundance data). Fishes were more abundant than invertebrates in low salinities, "probably because their mobility allows them to enter under favorable conditions and leave if conditions change or food becomes scarce" (page 15). Based on results of the biological data, Van de Kreeke et al. (1976) concluded that maintaining salinities of 30 ppt or higher in the interior of the lagoon would improve species richness by increasing marine species, and allowing euryhaline taxa to continue to exist. Complete utilization of the central lagoon area was considered unlikely because of unsuitable substrate conditions. Such a salinity goal would require reductions in discharges of the West Palm Beach Canal to approximately 100 cfs.

Emergent Wetland Responses

Estuarine case studies of increased discharge effects on tidal wetlands are not as numerous or complete as the studies cited above but some findings are instructive. In fact, most of the available studies concern the effect of increased salinity rather than decreased salinity (see Hoese, 1967; Smalley and Thien, 1976; and Bradley et al., 1990 for pertinent citations). Salinity alone is not generally considered to be a major factor responsible for species distribution among salt marsh plant species (Latham et al., 1991). Elevated salinity has not been found to pose great problems for salt marsh vegetation although hypersaline conditions are known to reduce species diversity and productivity. Flowing water and water level (stage) are regarded to be more important than salinity as regulators of salt marsh productivity.

Erratic inflows and salinities or increased flows and reduced salinities have the effect of mixing or extending the ranges of freshwater or oligohaline plant species down-estuary. In the arid Tijuana estuary (California), floods and channel blockage caused large swings in salinity. *Spartina* and succulent species such as *Suaeda* and *Salicornia* alternated in dominance as salinity changed, but cattail (*Typha*) persisted after becoming established during periods of low salinity (Zedler and Beare, 1986). The effect of flooding on normally hypersaline marsh was an increase in productivity without major changes in species composition (Zedler, 1983), which tends to be the same effect of reduced salinity on mangrove forests (Odum et al., 1982).

Critique

Among studies of new or increased inflows to estuaries, data tend to be most abundant for physical and chemical changes and effects on adult fishes. Moderate amounts of data exist for phytoplankton, salt marshes, and benthic effects, but much less data are available for seagrasses, zooplankton, or ichthyoplankton.

Phytoplankton in marine systems are displaced by inflows of freshwater but not replaced, whereas the phytoplankton of estuarine systems may be displaced or even enhanced with additions of freshwater forms. Estuarine phytoplankton community structure shifts according to prevailing salinity.

Zooplankton appear to follow a similar pattern. Marine species may be killed by osmotic shock caused by reverse-flow and entrainment in low salinity areas, but much is left to learn about their response. Overall trophic impacts in the water column seem proportional to the duration and spatial extent of lowered salinity, which may be part of the basis for lagged responses to inflow displayed in landings of fishes or invertebrates.

Sessile invertebrates such as oysters or clams are affected more than mobile benthic species. Persistence of fresh water in the St. Lucie estuary for 30 days was anticipated to cause the demise of entire reef systems, although osmotic stress of shorter period can affect individual oysters or clams (see Sections 8 and 9). Crustaceans and echinoderms are able to evacuate areas of low salinity that develop naturally with seasonal increases in freshwater inflow, even though such movements can affect catch-rates of targeted species in affected areas. Fishes, at least late juvenile and adult stages, do not appear to be affected greatly by natural or man-made salinity reductions because of their high mobility.

A common phenomenon related to increased inflows is the wider geographic and salinity ranges of oligohaline areas. This may be accompanied by sharp compression of salinity gradients. Areas affected by oscillating salinity lose seagrasses and large bivalves, and benthic community structure shifts toward higher dominance by opportunistic species. In severe cases of community set-back, organic material accumulates faster than it can be reduced by chemical or biological processes. Changes in the abundance and biomass of benthic communities has indirect effects on fish communities by altering feeding guilds or total fish abundance, as shown in Fahka Union Bay. Lagged effects in benthic food supply is probably another reason for the delayed response of fish landings to inflow alterations.

There is a striking qualitative difference in the findings of studies in estuaries newly affected by large inflows, and the findings of studies in estuaries where large and variable inflows have existed for some time. In the Etang de Berre, for example, the onset of large inflows precipitated the widespread loss of seagrasses and mussels, and simplification of benthic communities. In the St. Lucie River, however, large inflow variations had more subtle effects on the distribution and abundance of species that persisted during experimental discharges. Similar results were observed in the Caloosahatchee River. These canals were constructed 70 to 110 years ago. It is reasonable to conclude that significant, system-level changes like those seen in the Etang de Berre probably occurred in the St. Lucie and Caloosahatchee systems shortly after their canals were constructed. Today, inflow variations affect the distribution and abundance of a eurytopic community of tolerant species. The intolerant species are gone.

The same kinds of changes have probably occurred in the Sebastian River. Inflows have been increasing continuously in the river for 80 years. At some point, combined inflows and salinity oscillations led to system-level impacts such as seagrass loss and permanent alteration of benthic infaunal communities. A return to pre-development ecological conditions implies that significant changes to the existing salinity regime of the area are needed.

A review of case studies of estuaries and other ecosystems affected by large freshwater inflows recommends these conclusions concerning salinity:

1. Oligohaline waters are natural and ecologically important components of estuaries but their enlargement by erratic inflows retards estuarine and marine communities in undesirable ways.
2. Oligohaline waters and areas of maximum salinity variation should be registered to the geomorphic and physical regions of estuaries where they naturally occurred, and prevented from expanding into middle or lower estuarine areas.
3. The greatest salinity impacts in estuaries seem to occur in years following the enhancement of inflows. Significant ecological differences become more difficult to identify as the system later develops eurytopic characteristics. Salinity regimes may therefore be refined to minimize variations among tolerant species, or greatly revised to restore conditions conducive to the needs of stenotopic species.
4. Given the desire to enhance seagrasses and protect hard clams in the Sebastian River and estuary area, the extent of salinity changes that will be required will be greater than needed simply to maintain the status quo.

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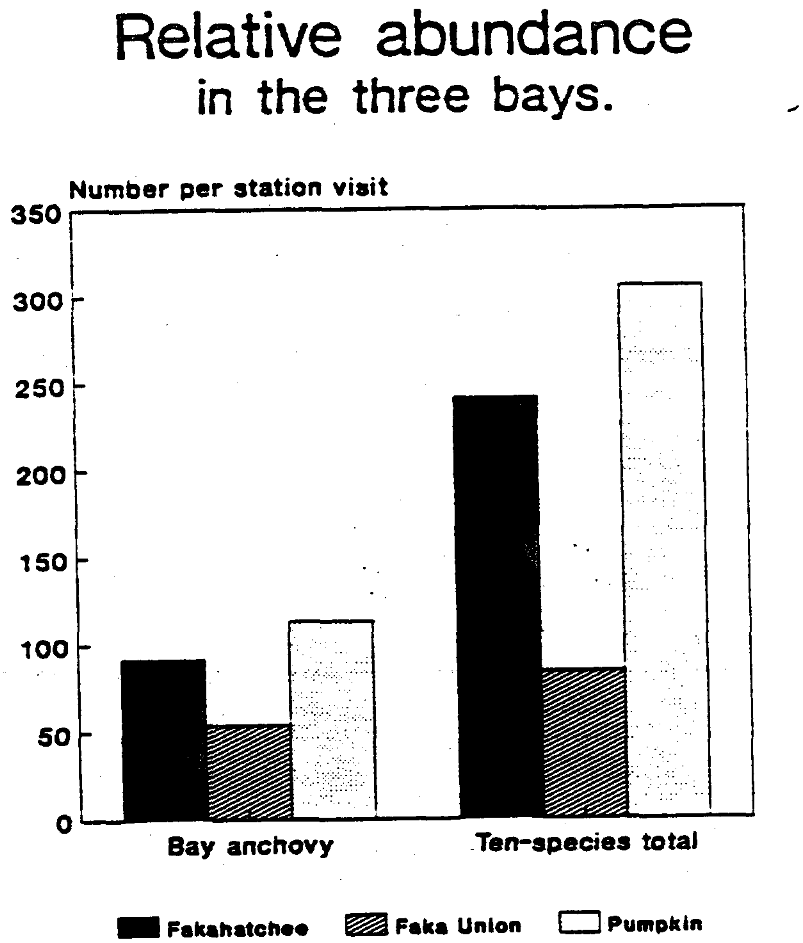

Figure 1 Relative abundance of the bay anchovy and 10 dominant taxa, including bay anchovy, in Fakahatchee, Faka Union, and Pumpkin bays from October, 1982, through June, 1984.

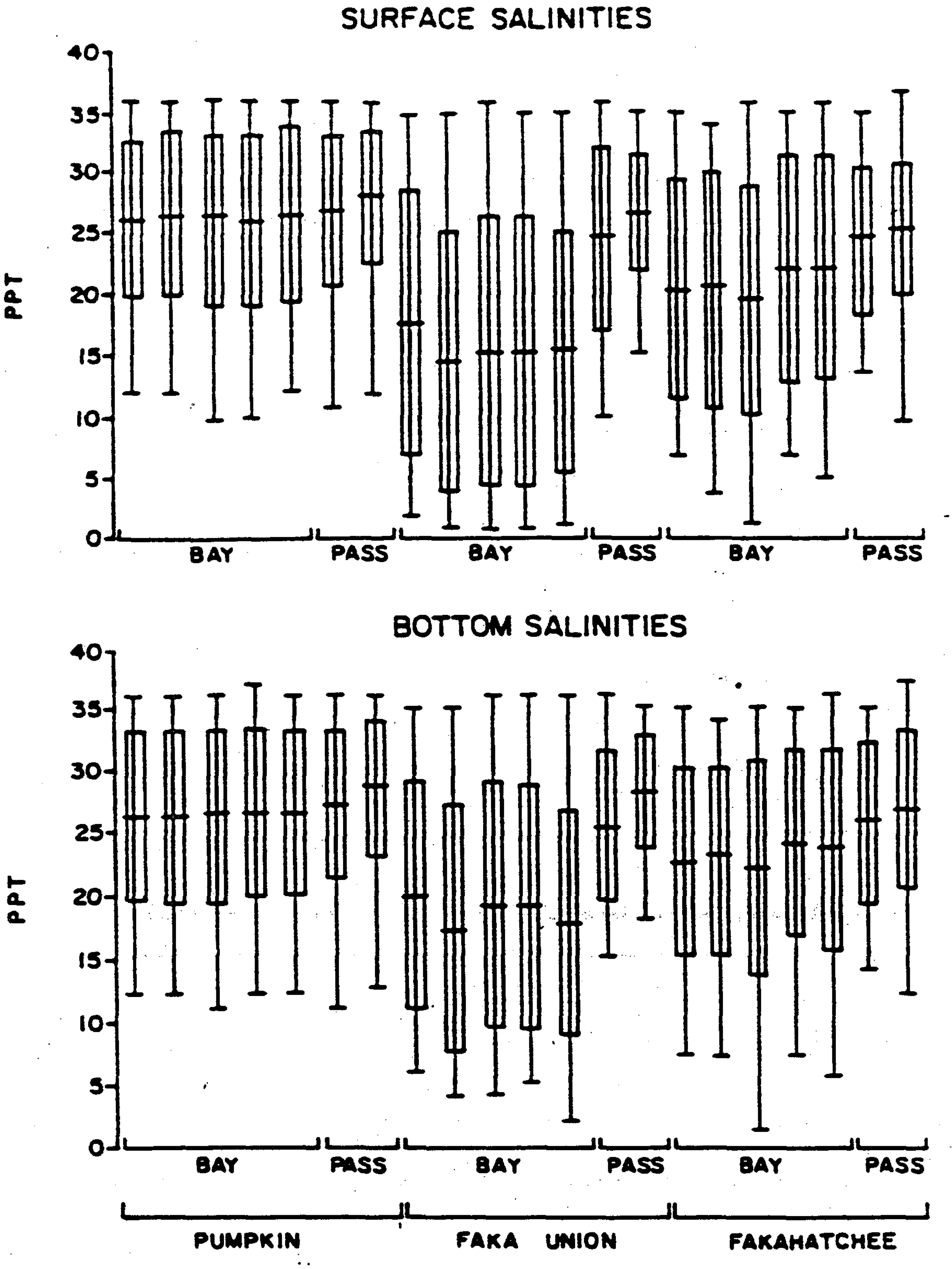

Figure 2 . Mean, standard deviation, and range of salinities in parts per thousand at each sampling station from spot measurements each month from July, 1982, through June, 1984 (Browder et al 1986).

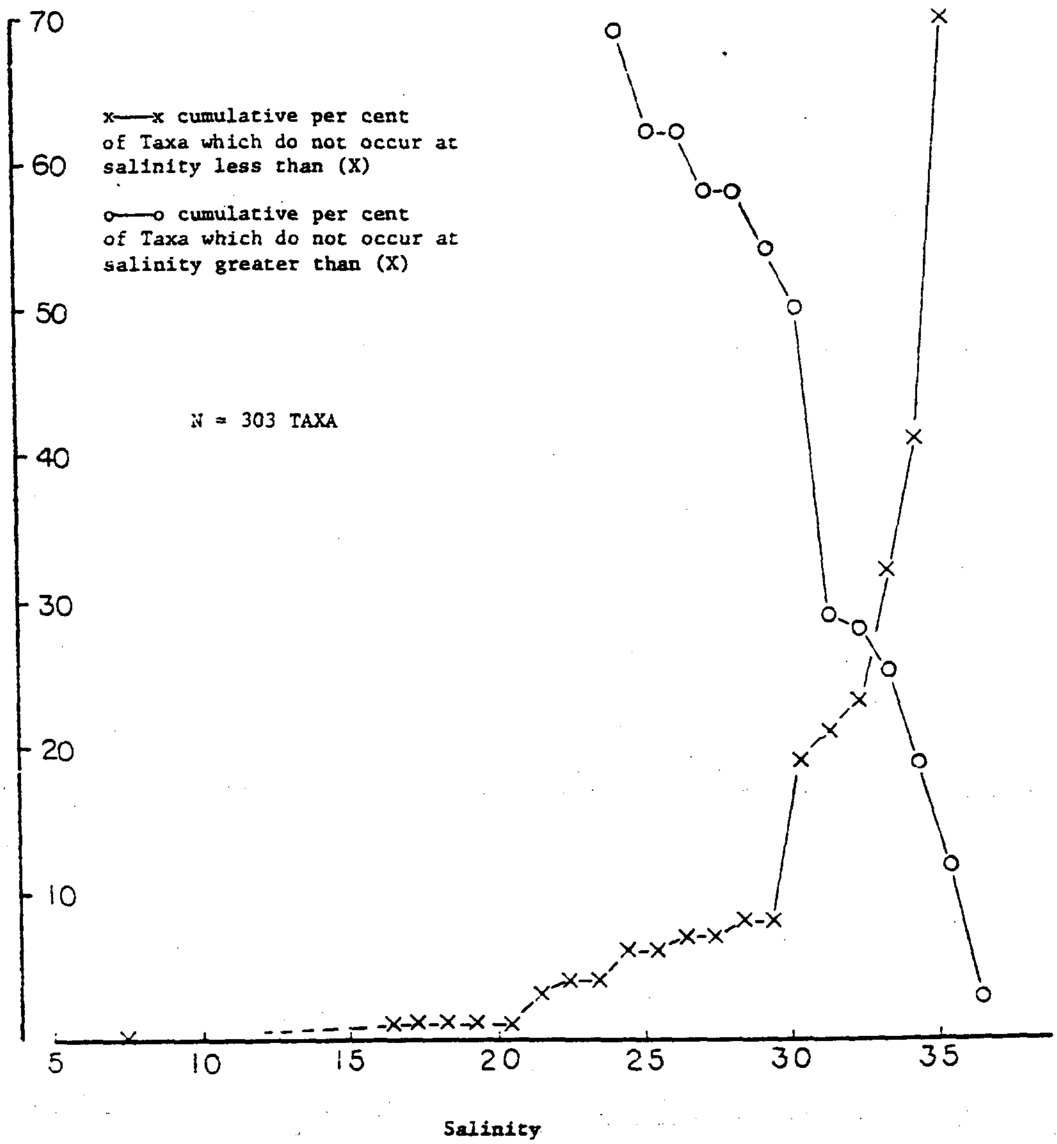

Figure 3. Exclusion curves for Lake Worth fauna.

5. Environmental Setting, Early Conditions, and Change

Much is known about the physical, chemical, and biological characteristics of the land and waters of the Indian River watershed and lagoon, in the vicinity of the study area (Montgomery and Smith, 1982; Steward and VanArman, 1987; Morris, 1989; Smith and Turner, 1990). This information is not reviewed comprehensively here; an assumption is made that users of this report already are familiar with many of these basic data. Rather, the literature is evaluated to address some questions that are directly or indirectly related to the objective of recommending a salinity regime for the Sebastian River and Indian River Lagoon. The questions are:

1. What is the geographic and hydrological setting of the study area?
2. How much of the area's natural or presettlement condition can be described?
3. What have been the major changes to the area and how have these changes probably changed natural conditions?

Answers to these questions are useful because they identify some of the natural constraints to a proposed salinity regime, and also the direction such proposals should take to be restorative or protective. If the pre-settlement salinity regime of the area was perfectly known, which it is not, a strong case could be made that the original regime should be the recommended one. Several permanent changes to the system have been made, however, that must be reckoned with in recommending a new salinity regime.

The following descriptions are based largely on references cited above, and a draft monograph in preparation for the Florida Sea Grant College Program by a number of Lagoon scientists (Barile, in preparation). The cooperation of the Marine Resources Council in providing the draft is appreciated; additional references are cited as needed.

Environmental Setting

The topography of the study area may be viewed as a set of long, relict and modern dune systems trending parallel to the coastline. The eastern-most system is made of modern barrier islands, and is probably younger than 5,000 years. A mainland system of relict dunes, the Atlantic Coastal Ridge, follows the shoreline of the Indian River Lagoon, a shallow tidal basin lying in the Silver Bluff Terrace west of the barrier islands. A third dune system, the Ten Mile Ridge, occurs further inland and comprises the divide between the St. Johns River basin and the coastal watershed. The Ten Mile Ridge system is the highest and the most continuous of the three, although discontinuities occur near the Indian River/Brevard County line.

The Sebastian River system represents three independent drainages within the Pamlico Terrace that lies between the relict mainland dune lines. The three meet in an area of confluence that connects to the Indian River Lagoon at a breach in the Atlantic Coastal Ridge. Three prongs drain inter-dune lands to the north, south, and west of the river mouth area. Sea level rise has drowned the floodplain of the confluence area and given it a shallow, level bottom, but the combined discharges of the three prongs maintains a natural thalweg to the Lagoon.

The Indian River Lagoon is a shallow basin that formed as the rise of sea level slowed and the barrier island system stabilized and grew where it occurs today. The Lagoon is maximally 4 km wide and 2 m deep. Its mainland shore is comprised of mostly unvegetated, eroding deposits of relict dune sediment. Its seaward shore is a young mangrove forest growing on overwash fans punctuated by former inlet channels. Seagrasses cover large areas of the Lagoon floor.

Major features of the area's hydrology are determined by the local drainage and ponding of rain water in the basin between the relict dune systems on the mainland. Ponded areas led to the formation of hydric soils and isolated wetland systems. Other basin soils with higher infiltration led to the formation of a surficial aquifer. Direct runoff and bank seepage from the water table created the North, West and South Prongs of the Sebastian River. A highly-mineralized Floridan Aquifer underlies the surficial aquifer, although a lens of less-mineralized ground water occurs in the Sebastian area.

Climatological patterns in the area are relatively well documented. Long-term (1912-1985) mean monthly rainfall at Fellsmere totals 53.94 inches per year. The coefficient of variation calculated using monthly mean data is 50.6%. A composite dry year (monthly minima) for the same period of record equals 27.94 inches; the coefficient of variation for the composite dry year is 153.2%. A composite wet year (monthly maxima) has 78.83 inches of rain annually, and a coefficient of variation of 38.7%. The wettest months are June through September, and the driest are November and December. Natural runoff and stream flow rates for the Sebastian River system are unknown.

Natural Features

The original land cover of the Sebastian River watershed was primarily southern Florida Flatwoods. The Pamlico Terrace was a wide, low, nearly level land covered by pine flatwoods, areas of oak scrub, and numerous small, medium and large swamps. Flatland swamps were wet prairie, and swamps near organized drainage-ways were hardwood forests. Groundwater was near the soil surface, and soils were affected by the water table, making many swamps perennially wet. Much of the land was overflowed during the wet season and stayed wet for weeks at a time (USDA, 1969).

Sea level was approximately a meter lower than its present stand, prior to European settlement. The three prongs of the Sebastian River were then the headwater streams of a longer river that flowed somehow to the Ocean. The river may have had other tributaries that paralleled the coast and drained tidal ponds in what now is the Indian River Lagoon. Most treatments describe the Lagoon as upland during lower stands of sea level. In such a scenario the uplands would have been similar to the natural cover of the Silver Bluff Terrace. The Sebastian River may have been an open-water, flowing stream all the way to tidal water, where salt marsh grew in various mixtures with tidal freshwater marshes.

The rise and stabilization of sea level during the past few thousand years created the Indian River Lagoon. It is not clear where the energy came from to down-cut the Silver Bluff Terrace, and it is possible that the long-axis of the Lagoon was deeper than it is today. Parts of the Lagoon were perhaps similar to the forested sloughs originally associated with the

Loxahatchee and Lake Worth areas (Bader and Parkinson, 1990). Early circulation of open waters in the lagoon-like pond was probably internal, the result of wind-driven water movement; tidal motions within the early lagoon were absent.

Tropical storms and hurricanes over-washed the barrier islands, filling the Lagoon with sediment and punctuating the islands with ephemeral inlets. As sea level rose, the Sebastian River flood plain slowly drowned. Salt water added to the Lagoon and periods of tidal action compressed freshwater plants and animals further upriver. The flow of the River declined as its effective catchment area was reduced by sea level rise, further contracting freshwater environments.

By the nineteenth century, but prior to significant man-made alterations, the Lagoon was probably more estuarine than it had been but also less marine than it would become. Oysters grew in some areas along the Lagoon and probably grew near the entrance to the Sebastian River, but the River was naturally deep enough for boats of moderate draught to enter. Lagoon circulation and water level were still dominated by wind, and tidal components occurred only near and during open inlets. Seagrasses coverage may have been at its historic maximum development, and faunal diversity was at its peak.

The widest swings in Lagoon salinity during this period resulted from tropical storms and hurricanes which added both fresh and salt water to the system in pulses. Between 1871 and 1985 (114 years), a total of 51 tropical storms and hurricanes occurred in the central portion of the Indian River Lagoon. The frequency of years with and without storms is given in Table 1. In most cases (20), a year with one or more storms was preceded and followed by years without storms. In only one period did large storms occur during each of 5 consecutive years. About half of the time, three or more consecutive years of calm elapsed without a tropical storm or hurricane. Large pulses of fresh or salt water into the Lagoon did not occur every year.

<u>Major Changes</u>

From the standpoint of River and Lagoon salinity, large changes have occurred to the inflows of both fresh and salt water. Part of the Sebastian

River's watershed drained eastward to the Lagoon, through gaps in the coastal ridge before drainage improvements; closure of these gaps resulted in more River flow. Wetlands in the basin and along the Sebastian River were diked to reduce flooding, with the consequence of increasing River flow. Canals and laterals were dug to drain areas east of the dikes, and the water thus diverted increased River flows. The deepest canals increased drainage of the non-artesian aquifer, adding more flow to the River. Deep wells penetrating into the artesian and Floridan aquifers added to surface waters finding their way to the River. Some of the artesian wells were used to drain lowlands near the Sebastian River; known locally as siphon wells, this drainage effect added still more water to the River (Bermes, 1958). Stormwater from impervious areas of development in Fellsmere and Sebastian also makes abrupt inputs of water to the River.

Water quality, specifically the hardness, conductivity, and salinity of water in the Sebastian River, has probably been affected by the surface discharge of highly mineralized groundwater used for irrigation. According to Schiner et al. (1988), "Specific conductance of canal water is generally highest in the dry season (November to June) because flow in the [South] canal consists largely of irrigation water from the Floridan Aquifer system." Most of the groundwater is used to irrigate citrus. Schiner et al. (1988) note that urbanization of cropland decreases use of water from the Floridan Aquifer, but that new groves are also being started. Little is known of the ecological effect of salinization in tidal freshwater environments, but it is clear that agricultural runoff is increasing base flows and conductivity of Florida streams (Flannery et al., 1991).

Hydrological alterations to the Sebastian River increased further when the West Prong became the tidal terminus of Canal 54, a waterway connecting the St. Johns basin to the coastal basin. Canal 54 was built by the Army Corps of Engineers in 1969 to provide flood relief in the upper St. Johns River basin. The east-west canal has water control structures at each end; the eastern structure, S-157, has a maximum discharge capacity of 6,500 cubic feet per second (cfs). Additional waters from the Fellsmere Main Canal (south of C-54) and the Sottile Canal (north of C-54) find their way to the Sebastian River.

Table 2 summarizes interbasin flow diversions to the Sebastian River. Base flow (dry season average daily mean flow) is at least 152 cfs. Average daily mean flow is at least 213 cfs. Wet season (average daily mean) flows to the Sebastian River are at least 280 cfs and the combined, historic daily mean high flow of these canals is at least 5,612 cfs. Details of flows in C-54, the Fellsmere Main Canal, and the Sottile Canal are available in Clapp and Wilkening (1984), who observed that there were long periods of little or no diversion through C-54 but diversion flows in the Fellsmere Main were more consistent.

During the past century of alterations described above, similar changes were being made to the coastal basin north and south of the Sebastian River. The flows of five freshwater sources north, and four south of the Sebastian River were either greatly increased or created where there had been no inflow. Thus were the amount, duration, location, and rates of change in freshwater inflow to the Lagoon changed, at regional scale around the Sebastian River, and all of the freshwater entering the central Lagoon now moves toward Sebastian Inlet.

Sebastian Inlet is located in the central reach of the Indian River Lagoon. One inlet distantly north (Ponce De Leon Inlet) is open to the Ocean and two inlets to the south (Fort Pierce and Jupiter) are oceanic connections. The narrowest portion of the Lagoon is immediately south of Sebastian Inlet, restricting the influence of Fort Pierce Inlet. For all practical purposes, the central lagoon area is dominated by Sebastian Inlet.

Sebastian Inlet is a man-made feature. Prior to creation of the Inlet in 1886 the barrier island was breached by storms in several places but these openings were short-lived. Between 1886 and 1918 attempts to open or keep open the Sebastian Inlet were modest, and often failed. Salinity in the Lagoon near Sebastian probably ranged greatly during this period. From 1924 to 1942 the Inlet was kept open but its channel was unstable and the Inlet again closed in 1943. Since 1948 the Inlet has remained open and the channel has been stabilized by the use of maintenance dredging, jetties, and sand traps. Jetties were expanded in 1970 (Mehta et al., 1976).

The opening and stability of the Inlet had profound effects on the Indian River Lagoon. It added tidal motion (ebb/flood action), ocean water, and long period flushing to an area that did not have these properties before. The effects were local, not lagoon-wide, but they represented a significant change in historic conditions by maintaining a continuous oceanic connection. Full-strength oceanic water could cross the Lagoon and enter the Sebastian River on a single tidal cycle. Salinity in the Lagoon near the River rose to near oceanic levels, and denser water settled into deeper Lagoon areas during periods of calm weather. Water levels rose and fell with tidal periodicity and seasonal to inter-annual variations in oceanic sea level became manifest in the central Lagoon area and in the Sebastian River (Figure 1).

The Inlet also changed sedimentation in the Lagoon. Prior to its opening the main force for sedimentation was the overwash of barrier islands by tropical storms, resulting in broad, back-bay fans of sediment. When the Inlet was opened, new forces focused through the channel built a flood-shoal delta in the Lagoon as oceanic sediment was trapped by quiescent Lagoon water.

During the same period of recent development, construction of an Intracoastal Waterway altered circulation and sedimentation patterns near the mouth of the Sebastian River. First built in 1912, the Miami to Jacksonville channel was deepened during World War II and again in the 1960s. The Intracoastal Waterway created a route for upwind bottom flows of tidal waters, increasing mixing forces in the Lagoon. Sediments displaced by spoiling of dredged materials formed islands and subtidal shoals that altered local circulation, and provided a source for the protracted introduction of fine sediments into the water column. Deeper areas of the Waterway near Sebastian contain fine, organically-enriched sediments of terrestrial origin since the 1960s ("muck"), although such sediment is not as abundant as it is elsewhere in the Lagoon (Trefry et al., 1987).

The juxtaposition of these two coastal landforms, Sebastian Inlet and Sebastian River, has resulted in a locally dynamic area within a larger and more stable environment of the Indian River Lagoon. Augmented river discharges into Lagoon water of nearly oceanic salinity create salinity gradients and stratification not "naturally" present in this reach of the Lagoon, and stratification may be of sufficient strength to possibly induce two-layered circulation. The potential for layered circulation is further enhanced by the proximity of the Intracoastal Waterway. Because the Inlet and augmented River flows increase flushing in the Sebastian area, water quality could be improved over past conditions, although these gains may be offset by increased loads of nutrients or contaminants from the River. Whether salinity in the Lagoon is higher or lower than it used to be cannot be stated with certainty, but it probably is higher. Variability and the rate of change in salinity in the tidal River and nearby Indian River Lagoon are almost certainly greater than in pre-settlement times.

These and other changes in the watershed, River and Lagoon have been paralleled by changes in living resources. Urbanization and agricultural expansion caused a 63% loss in freshwater lowlands between the 1940s and 1980s. The area of tidal wetlands near Sebastian decreased by 54% as impoundments and spoil increased by 782%. Seagrasses near Sebastian declined 34% by 1970 and 42% by 1986. The extent to which salinity change was responsible for these trends in living resources, or the causal links between the two, are unknown.

Critique

Not counting basin alterations and augmented river flows, the salinity trend of the Indian River Lagoon during the past few centuries and especially the 20th Century has been one of increase. Sea level rise, island breaching, and inlet stabilization have been working to increase the connection between the Lagoon and Atlantic Ocean. The increased connection has altered water levels and circulation, sedimentation, salinity, and the numbers and kinds of plants and animals inhabiting the Lagoon. During this period, the major source of natural variation was probably related to the incidence and severity of tropical storms and hurricanes.

In this context the widening and deepening of inlets may be viewed as consistent with natural trends. Inlets accelerated the rate by which oceanic influences dominated the Lagoon. Their effect has been to increase salinity, water levels, circulation, and flushing. The inlets have boosted species diversity with additional resident and transient marine species.

Without the influence of man, freshwater inflows would have remained the same. Although an increase in rainfall and runoff might be expected during warmer climate periods, there is no local evidence for trends in increasing rainfall in the area. The augmentation of flows by deep wells and inter-basin transfers has increased base, mean, and peak flows of the Sebastian River system, and stabilized riverine environments. On the other hand, increased flows are significant departures from "natural" conditions insofar as the Lagoon are concerned, and have de-stabilized the marine environment. When coupled with natural and cultural forces raising salinity in the Lagoon, the combination of increased River flows and Inlet effects has created a strong salinity gradient over a relatively short distance, and a local area capable of rapid, large oscillations in salinity.

On a larger scale, circulation and salinity have been changed throughout the Central Lagoon because of greatly augmented inflows. Discharges of three canals to the Narrows south of Sebastian, and discharges of Turkey Creek to the north, create cells of low-salinity water that elevate Lagoon water levels, drive circulation, and alter Lagoon chemistry. Winds, bottom topography, and tidal action move and mix these cells in complex fashion toward Sebastian Inlet. As cells modify salinity to the north and south of Sebastian, the effects of Sebastian River discharge may be dampened or amplified in non-linear and/or long period forms (G. Zarillo, Florida Institute of Technology, personal communication).

Within the limitations of available information, a review of historic data suggests the following conclusions relative to salinity:

1. Flows of the pre-settlement River probably were much lower than today, perhaps by an order of magnitude. Wetland storage of surface water in the basin was extensive, resulting in large, highly pulsed discharges only when very heavy rains fell during the wettest months. Otherwise, river flows were low and probably exhibited significant time lags relative to rainfall.
2. Consequently, salinity variation under natural hydrological conditions was probably greater in the Sebastian River than it was in the Central Lagoon. Also, low salinities lagged all but extreme rainfall and runoff events and the rate of salinity change was lower than it is today.
3. A natural trend was developing of increasing oceanic influence in the Lagoon, meaning higher mean salinities and tidal to interannual variations in water level, circulation, and salinity. Increasing

oceanic influence prior to flow augmentation also meant that tidal freshwater reaches of the Sebastian River were migrating up-river.

4. The frequency of tropical storms and hurricanes is useful as a guide to how often the Lagoon would be experiencing extreme salinity variations in the absence of human influences. On average, about half of the available storm record contains periods of three or more years between major storms, suggesting that large salinity swings within the central Lagoon did not occur every year and that several consecutive years of stable salinity were possible.

5. Inlet management has worked in the same direction as natural forces affecting the Lagoon, whereas River flow augmentation has worked against the trend. Salinity conditions within the Indian River Lagoon, attributable to the influence of the Sebastian River, are consequently undesireable from an ecological point of view. Such conditions include lower mean salinity and higher salinity variation.

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Table 1. Tropical storms and hurricanes, 1871-1985 (114 years) near Sebastian.

Number of Consecutive Years	Frequency, With Storms	Frequency, Without Storms
1	20	14
2	7	5
3	2	6
4	0	2
5	1	1
6	0	2
7	0	1
8	0	0

Multiple storms occurred in ten years.

Table 2. Interbasin diversion flows in the Sebastian River, from Clapp and Wilkening, 1984.

Feature	Sottile	C-54 at S-157	Fellsmere Main
Historic Daily Mean Low Flow (cfs)	---	15	23
Dry Season Avg. Daily Mean Flow (cfs)	---	50	102
Avg. Daily Mean Flow (cfs)	30*	70	133
Wet Season Avg. Daily Mean Flow (cfs)	---	103	177
Historic Daily Mean High Flow (cfs)	---	3582	2030

* Average of miscellaneous discharge measurements.

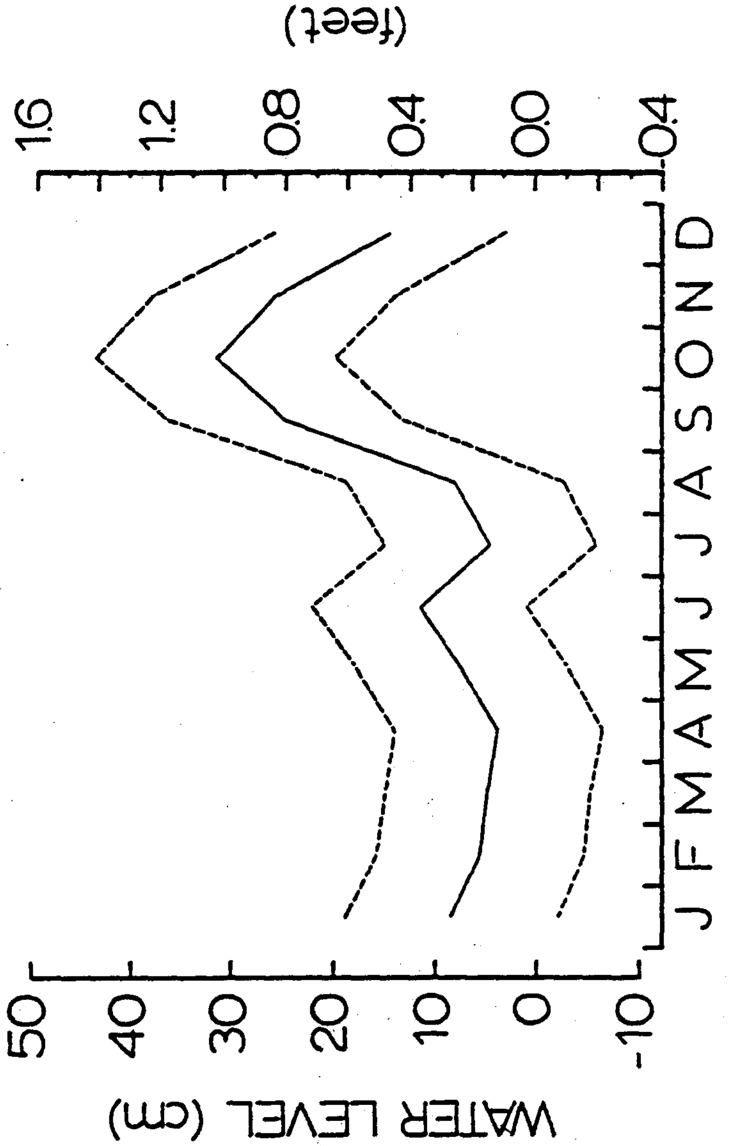

Figure 1 Multi-annual mean monthly levels (solid line) and mean high and low tide levels (broken lines) for Indian River lagoon, measured at latitude 27°35'N, 1959-1980 (After Smith [1986], used with permission).

6. Salinity

Although the salinity structure of the Central Indian Lagoon is not presently understood in an analytical sense, much of the necessary bathymetry, freshwater inflow, stage, circulation and salinity measurements needed to do so are presently being made. In addition, much descriptive information is available. This section reviews selected salinity characterizations available for the study area and provides a statistical summary of salinity data for specific segments within the study area.

The Central Indian River Lagoon is a narrow and shallow body of water connected to the Atlantic Ocean by Sebastian Inlet. Tides outside of Sebastian Inlet have a 2.5 ft Spring range but tidal ranges within the Lagoon may be considerably less. The oceanic connection creates tidal and longer-period cycles of exchange within the Lagoon. Freshwater inflow from surface runoff and groundwater flux change water levels and the density of water, adding to the forces of mixing and circulation. Because it is shallow and wide, the levels and circulation of water in the central Lagoon are also significantly affected by wind.

Organized drainage systems such as the Sebastian River provide large quantities of freshwater to the Lagoon at irregular shoreline points. Depending on the quantity and duration of their discharges, these rivers and canals exert small to large areal effects on Lagoon salinity. Large cells of well-mixed, low salinity water may move along or across the Lagoon, or strong vertical stratification can exist over small to large areas of the Lagoon. Tributaries also have an internal salinity structure that integrates discharge rates, channel geometry, and tidal action.

Previous Studies

A variety of data collection programs and published reports are available to illustrate particular features of salinity in the study area. These data are reviewed below for the sake of characterization, and with the precaution that their use beyond such a purpose is constrained by several considerations: the great majority of the data is unpublished; the studies vary widely over time and tide; spatial coverage of segments within the study area is uneven; surface data are more common than bottom data or vertical profiles; sampling and measurement methods, including precision and accuracy, also vary; and finally, conditions may be biased toward storm events and other periods of interest not representative of long-tern conditions.

Profiles along the length of the Lagoon depict the Sebastian Inlet reach as higher in salinity during normal wet and dry seasons than reaches north or south of the Inlet. Figure 1 illustrates seasonal conductivity patterns from Round Island, south of Vero Beach, north to Turkey Creek. Alexander and Hulbert (1984) observed that conductivity north of the Inlet was greater than conductivity to the south, during wet and dry seasons. In the reach north of Sebastian Inlet, salinity in 1985 declined from about 30 ppt to below 20 ppt at Turkey Creek, prior to a major storm (Steward, 1986). The storm depressed salinities to below 20 ppt throughout the reach, with minimum values below 10 ppt near Sebastian Inlet (Figure 2). Davis (1985) depicts conductivity south of Sebastian Inlet (Figure 3), showing a 20% drop in minimum values near Vero and highest conductivities at Ft. Pierce. Figure 3 also illustrates variation in salinity across the Indian River Lagoon, which was negligible for the time of sampling.

Temporal variation of salinity at a place within the Lagoon is significant. DaCosta (1986) depicted monthly salinity trends over an 8-year period near Grant (Figure 4). Salinity varied overall between 15 ppt and 34 ppt at Grant. In addition to monthly variation (as much as 13 ppt), longer-period variations are also evident: long-period salinity oscillations appear to be a significant feature of the central Indian River Lagoon (G. Zarillo, Florida Institute of Technology, personal communication). Glatzel and DaCosta (in preparation) find that mean salinity and mean monthly rainfall are closely related for the Grant station (Figure 5).

Other data depict the relationship of runoff (discharge) to Lagoon salinity. Glatzel and DaCosta (in preparation) depict the depression of surface salinity in the Lagoon near Sebastian, as the mean discharge of C-54 during 5 prior days increases (Figure 6). Canal 54 discharges below 100 cfs are associated with surface and bottom salinity values greater than 20 ppt, whereas discharges greater than 500 cfs are associated with surface salinities less than 20 ppt. Bottom salinities are less-affected, causing vertical stratification on the order of 12 to 28 ppt. The dispersion of stratified Lagoon waters in the vicinity of Sebastian River is spatially depicted by Steward (1986). In October 1985 the Sebastian River was fresh to its mouth (Figure 7). Most (73%) of the Lagoon profiles had surface salinities below 20 ppt and bottom salinities above 20 ppt.

Unpublished District data near Sebastian in July 1991 illustrate the complex effects of discharge and depth on salinity structure. Figure 8 depicts temporal changes in vertical salinity values at a Lagoon station 1,500 m northeast of the River's mouth. Almost all values are greater than 20 ppt and vertical differences are less than 10 ppt. At U.S. 1 (Figure 9), bottom (1.5 m) salinities are virtually the same as the offshore Lagoon station whereas all but one surface value are below 10 ppt. Vertical differences in salinity at the River's mouth were greater than 20 ppt. The South Prong had bottom salinities about 20 ppt (Figure 10) but vertical differences were comparable to the River mouth station because surface salinities were at or near zero ppt. On the other hand, surface and bottom salinities at the mouth of the North Prong (Figure 11) bear a strong similarity to the River mouth. Apparently, the regulation of salinity in the North Prong (Figure 12) as far west as S-157 (Figure 13) is such that bottom salinities may be maintained at high values, despite the local effect of inflows at the Fellsmere Weir (Figure 14). Bathymetry of C-54 appears to play an important role in regulating bottom salinity in C-54. The Canal is 4 m deep downstream of S-157, and may entrap denser Lagoon waters during periods of low flow. An upstream bottom current caused by freshwater discharge is also possible in the North Prong/C-54 waterway.

The multiple roles of discharge, tides and *wind* on the dispersion of low salinity waters into the Lagoon were investigated by St. Johns River Water Management District (1990). Intensive spatial sampling in July and August 1990 mapped the excursion of River water over a ranges of discharge rates and results were depicted for 4 salinity ranges. Figure 15 illustrates calm wind conditions. Surface waters throughout the River were below 20 ppt, and some of this water extended into the Lagoon as far east as the Intracoastal Waterway. A transitional area (26 - 29 ppt) meandered toward the Inlet. This calm wind survey is similar to results observed under north and most south winds, with an interesting exception shown in

Figure 16. The calm wind survey was also similar to conditions observed under east and west winds.

The largest variation in dispersion patterns occurred when winds were aligned on a northeast/southwest axis. These conditions are illustrated in Figures 17 and 18. Southwest wind expanded the <20 ppt zone to the north, east and west, and extended the 26 - 29 ppt zone nearly across the Lagoon. Transitional salinities behaved the same under northeast winds (Figure 18) but the lower salinity water (<20 ppt) was compressed along the western shore of the Lagoon and elongated greatly. Because northeast/southwest winds are frequent, these latter figures provide useful insight to the potential reach of low salinity waters discharged by the Sebastian River.

Despite considerable variability in the fate of River water once in the Lagoon, plume behavior under differing conditions of discharge and wind has an interesting point in common, as illustrated in Figure 19 from St. Johns River Water Management District (1990). All permutations of discharge and wind shared the same pattern in salinities between the River and Lagoon, namely an abrupt and large increase in surface salinity at Station S03A (U.S. 1). In some cases River salinities were higher or Lagoon salinities were lower, but all tide and discharge conditions are accompanied by a sharp rise in surface salinity, similar to Figure 19, once out of the River. A characteristic of strongly positive estuaries, this property signifies that a large amount of mixing occurs in the Lagoon rather than in the River. Whether the same pattern exists in bottom salinity cannot be determined with data at hand.

A New Analysis

In this section we report on the outcome of an analysis of surface salinity data by segment. Data were compiled from a number of published and unpublished reports (see underlined references) and also from data reports requested from the District (Figure 20). Several thousand data were available over a 20-year period but we chose to work with surface salinity only, because bottom data were not as complete. Data with unspecified sampling depths were also disqualified, leaving a data-base of approximately 1,700 measurements.

Data were assigned to segments created for the purpose of this analysis (Figure 21). Lagoon waters were divided into three western segments (North Shore, South Shore, and River Mouth) and one large eastern segment (inlet), with the Intracoastal Waterway as their common boundary. A River segment extends west from U.S. 1 to the entrances to the North and South Prongs. The South Prong is divided into Lower and Upper reaches using the soil transition described previously as the boundary; the Lower North Prong also includes the eastern terminus of C-54. A C-54 segment covers the Canal west of the North Prong and includes the Fellsmere Canal. A final segment, S-157, covers the Canal downstream of the structure, to a point upstream of the Fellsmere Canal entrance. Data available in each section were randomly sub-sampled in an attempt to correct for the bimodal distribution generated by Canal operations. A sample size of 100 was used for main-stem segments and a sample of 50 was used for terminal and flanking segments. There were insufficient data to describe the Upper North Prong segment.

Results appear in Table 1 and Figures 22 through 25. Figures 22 and 23 run from the Inlet to the Upper South Prong and Figures 24 and 25 run from the Inlet to S-157. Mean salinity decreases monotonically into the South Prong. Mean surface salinity grades from 28.5 ppt near the Inlet to 20.9 ppt in the River Mouth segment (still in the Lagoon), then to 13.4 in the confluent River segment. Mean surface salinity in the Lower South Prong is 5.8 ppt and the mean surface salinity of the Upper South Prong is 1.0 ppt. Along this transect, salinity range and variance are greatest in the River Mouth segment and decrease seaward and landward, to a standard deviation of 1.8 ppt in the Upper South Prong. At the same time, the coefficient of variation increases steadily from the Inlet segment to the Upper South Prong segment (Figure 23).

Mean salinity from the Inlet to S-157 follows a similar pattern until the two western segments (C-54 and S-157) are encountered. There, mean surface salinity increases (Figure 24) and the coefficient of variation decreases (Figure 25). Standard deviations are more or less uniform throughout the transect, meaning that variation in surface salinity is pattern-less from S-157 into the Indian River Lagoon.

Critique

It is evident from transects along the Lagoon that Sebastian Inlet has a significant, positive effect on salinity. On the one hand, the inlet's effect on Lagoon salinity is retarded by the freshwater inflows of the Sebastian River. On the other hand, proximity of the Inlet to the River has a strong ameliorating effect on the latter's impact, and some measure of the area's interesting biology is no doubt the result of their juxtaposition. On balance, the same biology would probably result even under much-reduced rates of freshwater inflow (Van de Kreeke et al., 1976).

Despite low differences in salinity from east-to-west across the Lagoon (Davis, 1985), longitudinal salinity gradients are the rule rather than the exception between Sebastian River and Inlet. How much of the decrease in salinity observed near the Inlet is attributable to the River, as opposed to long-period changes in coastal and Lagoon waters, is unknown. A storm analysis illustrated the long-distance effect of freshwater entering the Lagoon north of the Inlet, as well as the effect of Sebastian River (Steward, 1986). It is clear from salinity maps made under specific conditions of tide, discharge and wind that River water has a pronounced effect on Lagoon waters west of the Intracoastal Waterway, and the singular effect of wind on the movement of River water is impressive.

Mean monthly salinity near Grant is highest from May to July and lowest from November to February, lagging rainfall. Salinity oscillations of longer period impose cycles of change with lower amplitude than seen in monthly records, but these can make the difference between years with minimum monthly salinities above or below 20 ppt at Grant (Figure 4). It is against this larger and undocumented pattern of change that a recommended salinity regime near Sebastian is sought, and is of neccesity ignored here because data are lacking.

Other limitations should be acknowledged. Salinity data are too few as continuous and/or synoptic surveys, especially insofar as tidal and daily variations are concerned. Many data were disqualified in our analysis because collection depths were unspecified, and bottom data were relatively few among those where depths were known. Spatial coverage is also uneven.

Despite these shortcomings, some insights were achieved that are useful in structuring this analysis. One is that mean surface salinities may be too low and standard deviations may be too high in the River Mouth segment. The River Mouth segment appears to be the site of greatest mixing, meaning that wide salinity variations occur there and probably east into the nominal Inlet segment where the variations may cause ecological injury to benthic communities. In other respects, the transect entering the South Prong has salinity characteristics resembling the Loxahatchee River and small west coast streams.

By comparison, the transect to S-157 poses a different and confounding picture. Mean surface salinities actually increase toward the west, from the confluent River segment. Standard deviations and ranges are more like the River and Mouth segments than they are like the South Prong segments. Artifactual reasons for these results may include errors in data entry, although review of their context (dates, vertical relationship, etc.) suggest this to be a small problem. Bias may have resulted in the disqualification of data because depth data were lacking, but there appear to have been several well-documented instances of high-salinity water upstream of the Fellsmere entry to C-54. As mentioned previously, deep canal waters may trap dense Lagoon waters during low-flow conditions, or positive discharge may induce reverse bottom flow. Without data on ionic composition of the water, groundwater influx may also be a possibility. Without a better data-base, especially for tidal and bottom data, it is difficult to state how these conditions may affect habitat quality. The upstream tidal reaches of C-54 are apparently used by a variety of fish species, including rare or threatened species. Their persistence in this area would not likely be endangered if mean salinities were lowered, because of the close proximity of brackish waters. In fact, stability of oligohaline habitat could be improved. Browder and Wang (1988) have shown that the relationship of discharge to salinity is non-linear, so that discharges may be reduced greatly before salinity is affected. By this method, the physical stability (absence of catastrophic flows) of the segment could be enhanced.

Dispersion maps of low-salinity water in the Lagoon suggest two additional processes to consider. River effluent follows a regular path under most wind conditions: a tongue of water moves east toward the Inlet in a manner that reflects control by bottom topography. In the absence of influential winds, spoil banks associated with the Intracoastal Waterway may confine low to moderate discharges to open water along a common route. Large discharges may overwhelm such control and course through flanking channels of less relief, across shallow areas and between neigboring spoils. Winds from the southwest may promote this process even when discharges are not great. Northeast winds redirect the River's plume and channel it down-shore behind ICW spoils. With or without reductions in regulated flow, opportunities may exist to improve mixing or the path of the River plume once it enters the Lagoon, if circulation or modelling studies agree.

The "Station S03 Effect" depicted in Figure 18 is an unambiguous salinity feature of the River/Lagoon area. Freshwater is moving at the surface downstream to the U.S. 1 bridge with little mixing. The south bridge approach intrudes into the River and narrows the River mouth, having the apparent effect of jetting surface freshwater into the Lagoon. Whether jetting occurs with normal ebbing tides or only at high discharge is not clear, and winds play a controlling role. Salt water from the Lagoon unquestionably enters the River here, at least during low discharge periods, but there is less mixing in the confluent River segment than in the River Mouth segment.

Stratification is commonplace in the River and Lagoon near the River, but was probably not part of the area's pre-settlement salinity regime. Too little is known of its causes and behavior in the study area to describe analytically, but a fundamental question is whether or not stratification ought to be continued. From a physical stand-point, stratification retards mixing, so to the extent that we recommend greater mixing, especially in the confluent River segment, stratification should be reduced. From a biological point of view, the presence of dense salt water along the bottom of a river provides a transport mechanism and osmotic refuge for planktonic and mobile species (Haunert and Startzman, 1980 and 1985), so there is merit for the presence of density-stratified water *in the Sebastian River*. If salinity structure is based on other features, stratification will or will not occur as a consequence of flows. Given the paucity of explanatory information about the process in this area, and the existence of better salinity features to recommend changing, this question should be deferred until the results of other studies are available.

There are few lessons in the existing chemical data regarding existing or desirable rates of salinity change, other than can be taken from segment-wise variability. This question will be revisited in the section on Synthesis, after biological considerations.

A review of past salinity studies and an analysis of historical salinity data in the Sebastian River and adjacent Indian River Lagoon suggest that:

1. The Lagoon near Sebastian Inlet has the highest salinities of the South Central Region. The Inlet exerts a significant effect on salinity structure to the north and south, but this effect is interfered with, at least locally, by discharges of the Sebastian River. In terms of Lagoon-wide conditions, River influence should be reduced.
2. The River Mouth area is presently the site of maximum salinity variance. Tides and wind are able to move low-salinity water over large areas of the Lagoon before significant mixing occurs. Greatest mixing could be moved into the neighboring River segment. Doing so would reduce the effect of wind and give the River Mouth segment a salinity structure more like those of the North and South Shore segments, which in turn resemble the Inlet segment.
3. Salinity structure of the Lower North Prong, C-54 and S-157 segments differs greatly from that of the South Prong. Terminal salinities are higher, not lower, than salinities in intermediate reaches of this system, and variation is irregular. Within limits set by bottom topography or other factors, the salinity structure of waters leading to S-157 should be consistent with the salinity structure of the South Prong.
4. Better data are needed. Salinity of the North Prong should be described. Tidal-to-monthly patterns of surface and bottom salinity should be determined from the Inlet through tidal freshwater reaches. Lagoon circulation near the River mouth needs to be understood, especially the regulation of River plume behavior and stratification.
5. Physical options for altering salinity should be considered in addition to flow regulation. These options could include sills in the

Lagoon to steer River plumes, alterations to bridge approaches, and channels into upper River reaches.

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(Sources of data are underlined)

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Table 1. Surface salinity characteristics of Sebastian River and Indian River Lagoon segments, in parts per thousand (ppt).

Segment	N	Mean, ppt	S.D., ppt	C.V., %	Range, ppt
Inlet	100	28.5	5.4	19.1	9.0 - 35.8
N. Shore	50	22.3	7.5	33.6	3.0 - 38.0
Mouth	100	20.9	9.7	46.7	0.0 - 36.0
S. Shore	50	23.4	7.7	32.6	4.0 - 38.0
River	100	13.4	8.7	64.6	0.0 - 32.7
Lower S. Prong	100	5.8	5.0	86.6	0.0 - 22.4
Upper S. Prong	50	1.0	1.8	188.4	0.0 - 9.9
C-54	100	5.7	9.0	157.0	0.0 - 29.1
S-157	50	10.4	9.1	87.8	0.0 - 29.0
Lower N. Prong	100	6.1	7.8	128.2	0.0 - 29.7

S.D., standard deviation; C.V., coefficient of variation

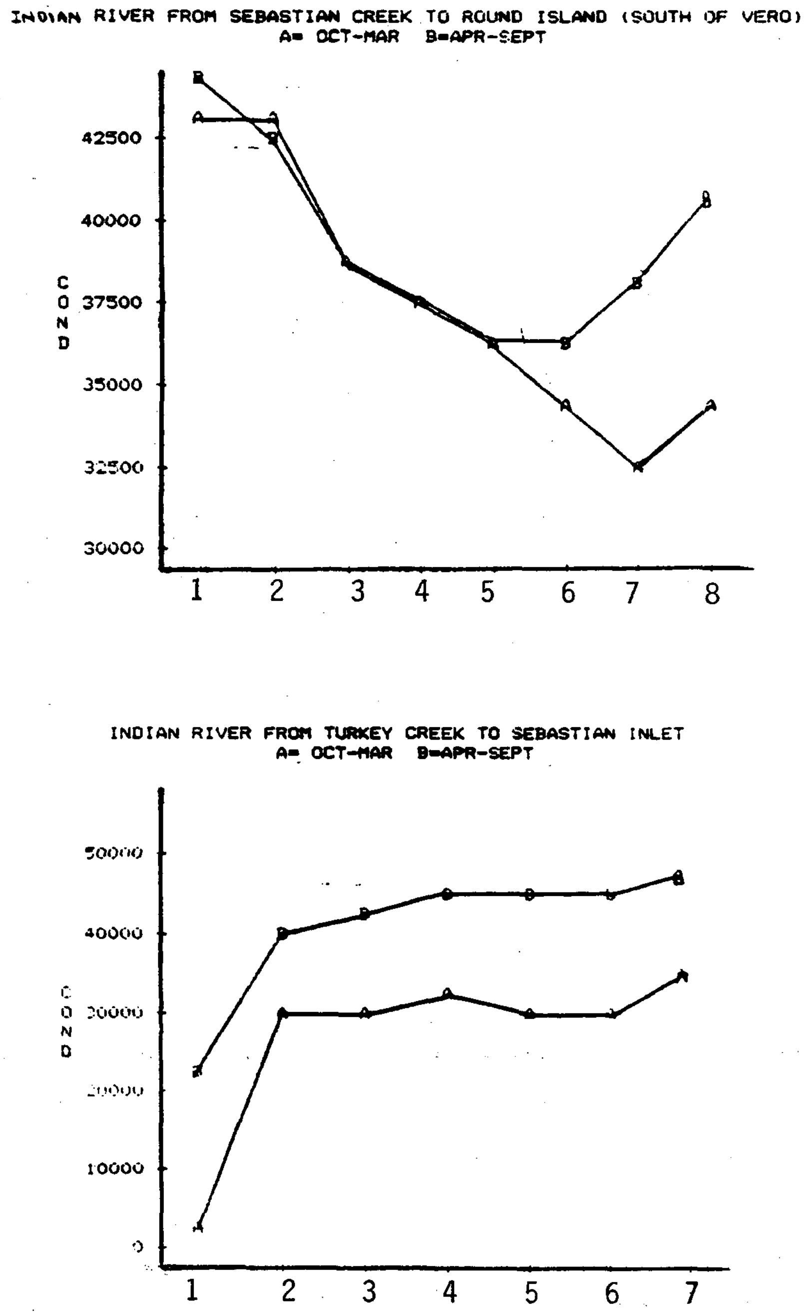


Figure 1. Conductivity of the Lagoon north and south of Sebastian Inlet.

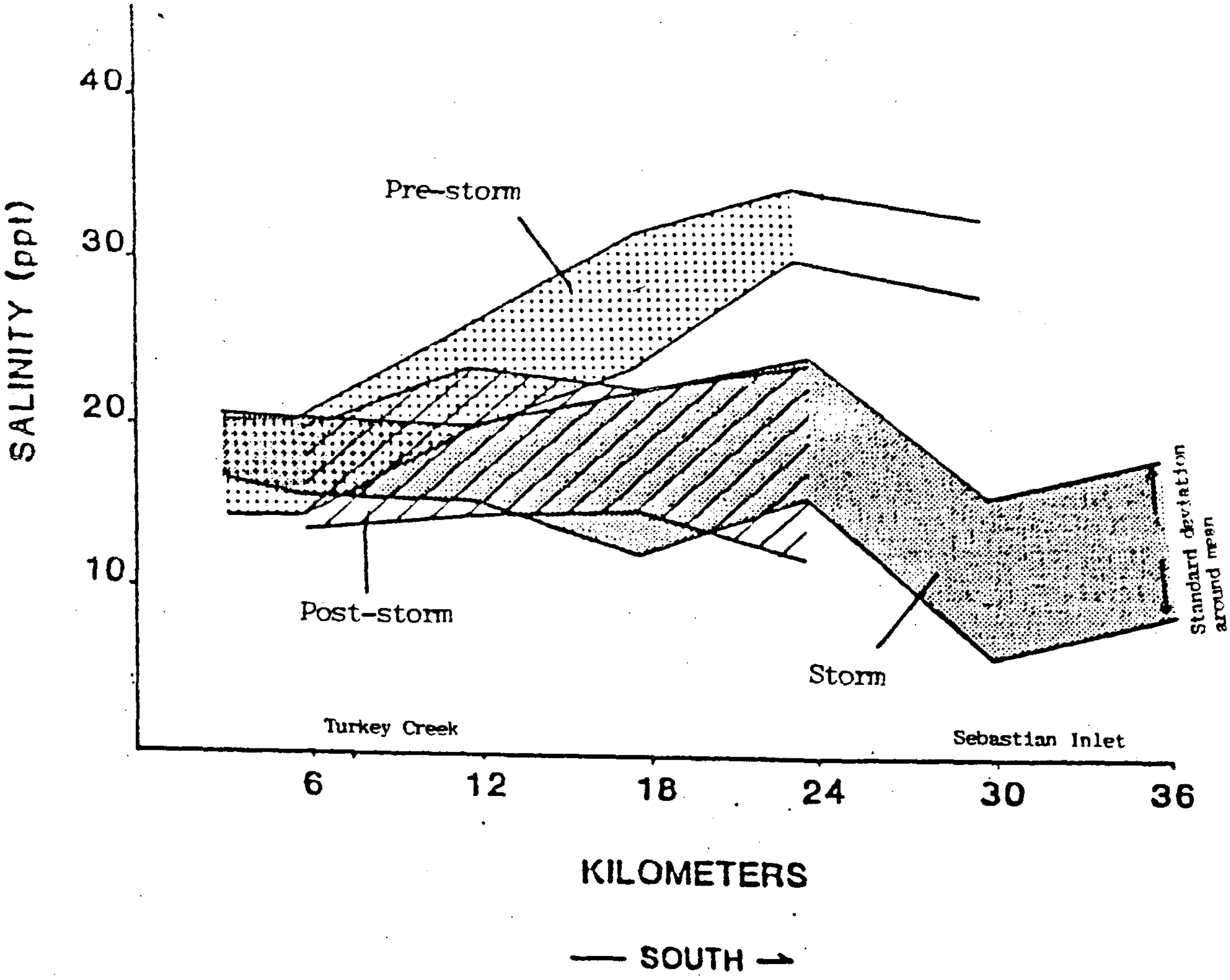
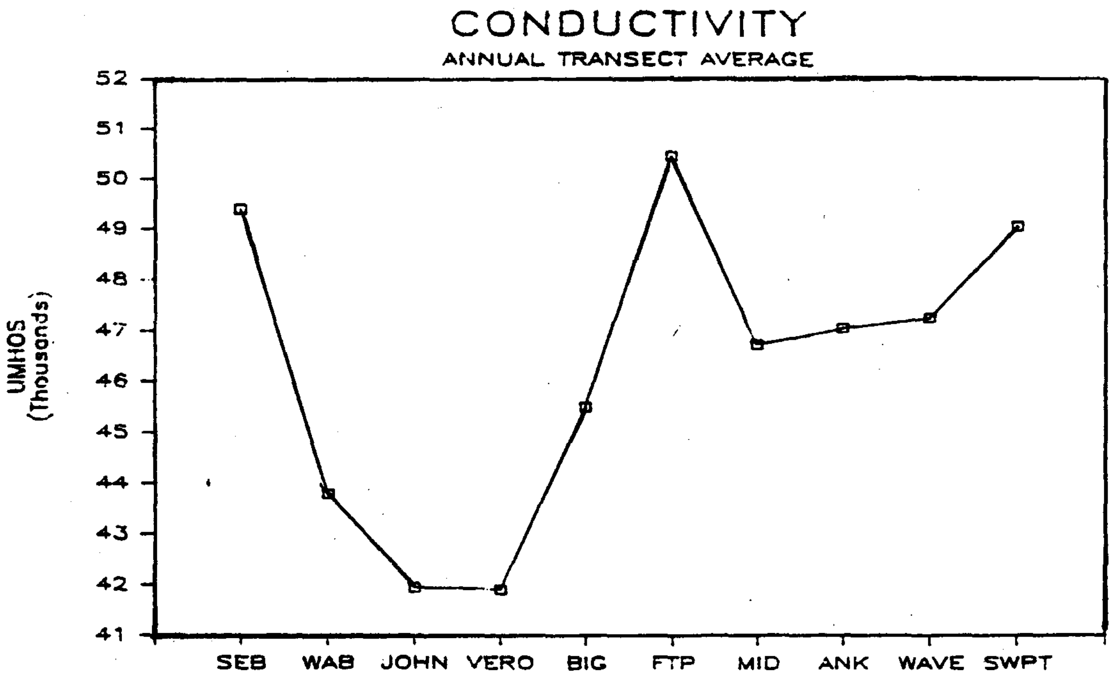


Figure 2

Spatial Salinity Gradient Indian River Lagoon, Turkey Creek to Sebastian Inlet Brevard County, Florida, for September - October 1985 Storm



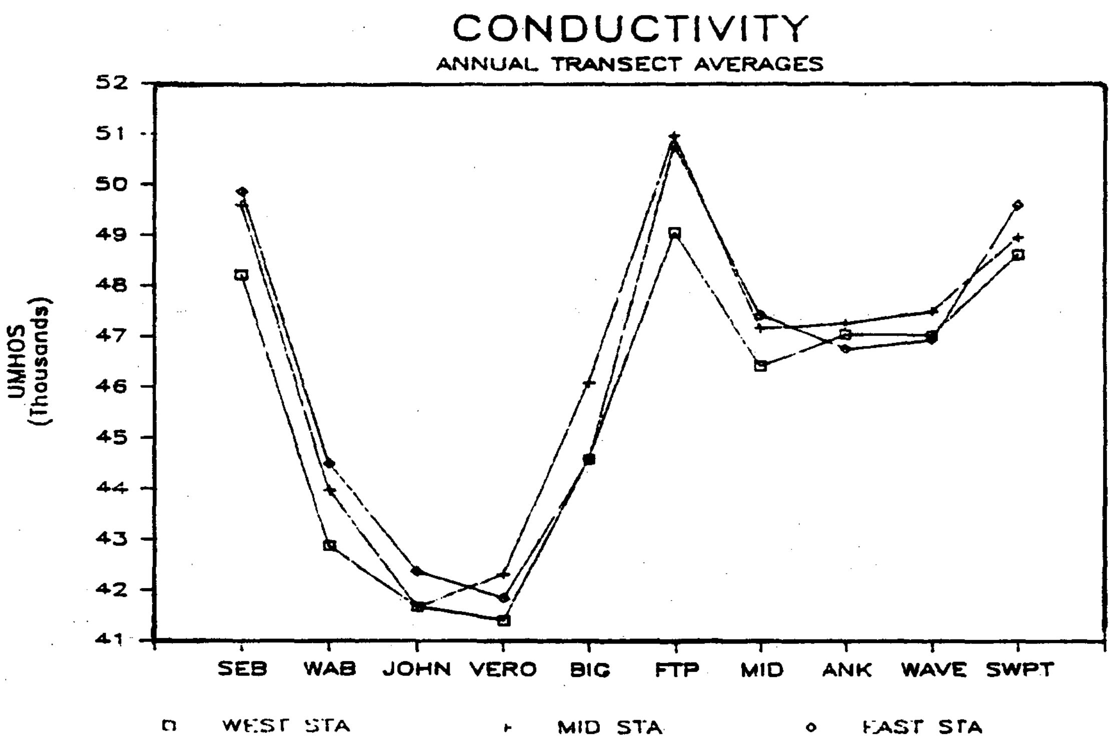


Figure 3
INDIAN RIVER WATER QUALITY SURVEY

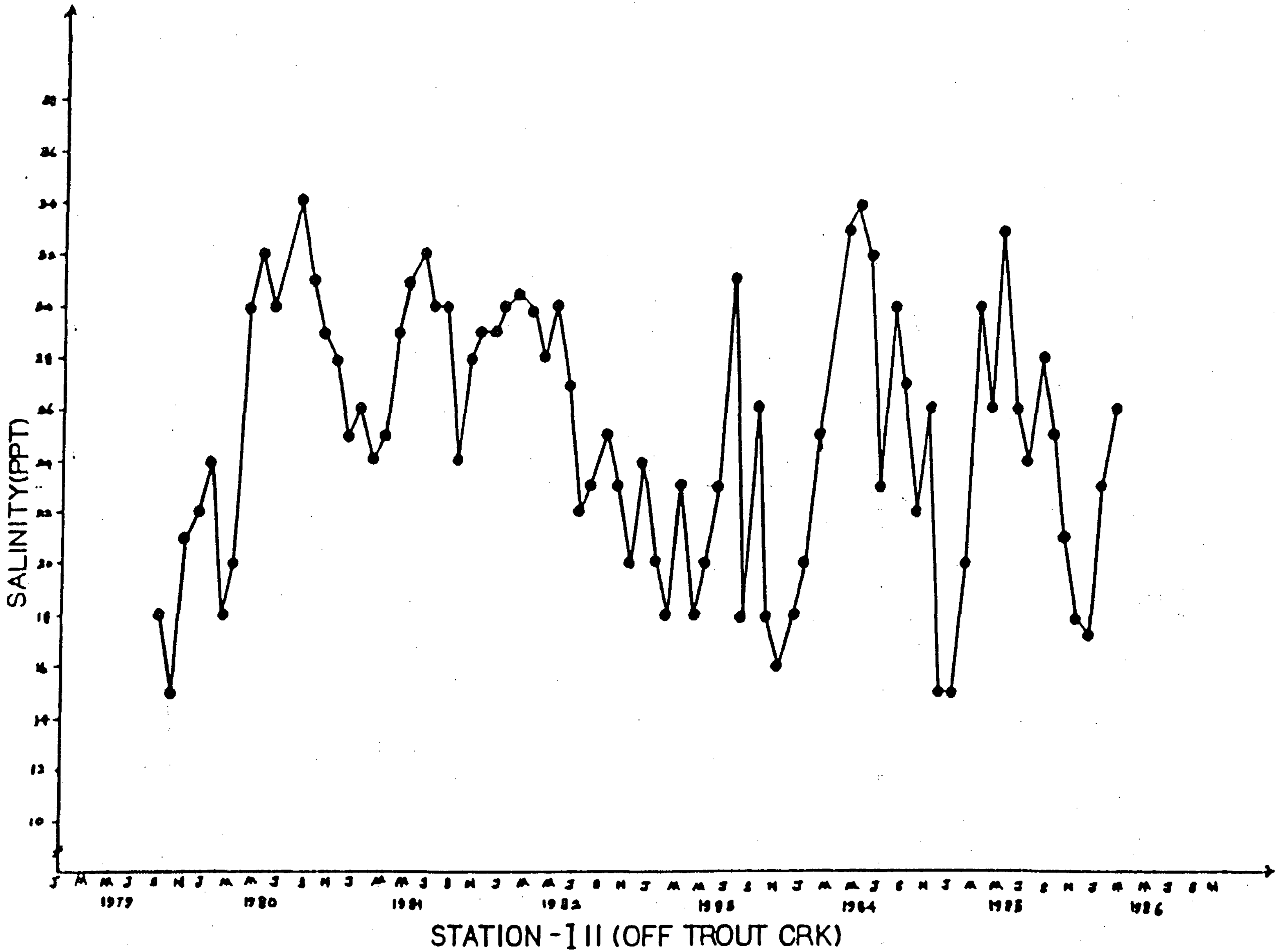


Figure 4

Seasonal Salinity Trends in the Grant Area

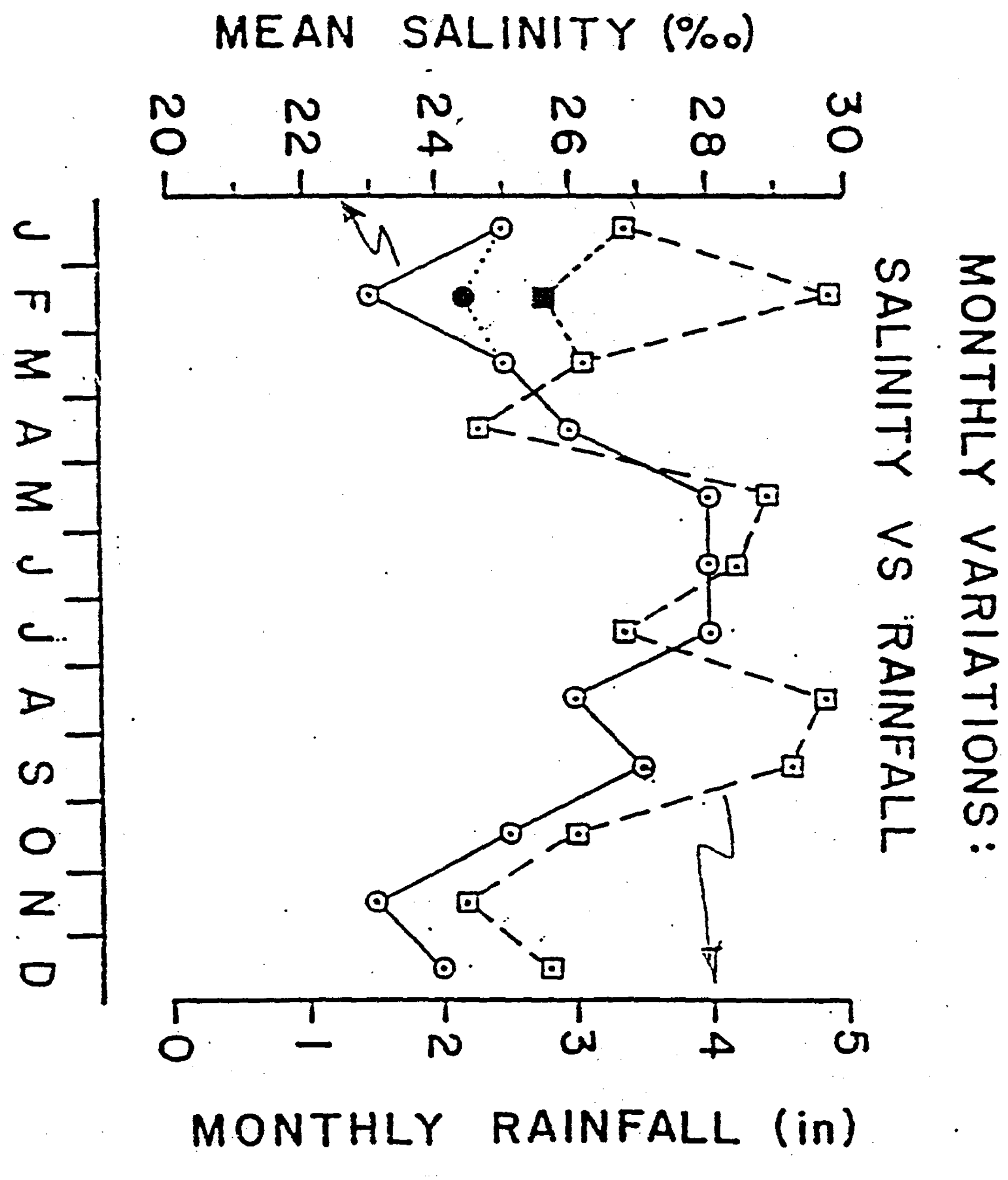


Figure 5 Mean Salinity (1980-84) and Mean Monthly Rainfall for a station in the middle portion of Segment II (see Figure A1). Rainfall based on Melbourne station.

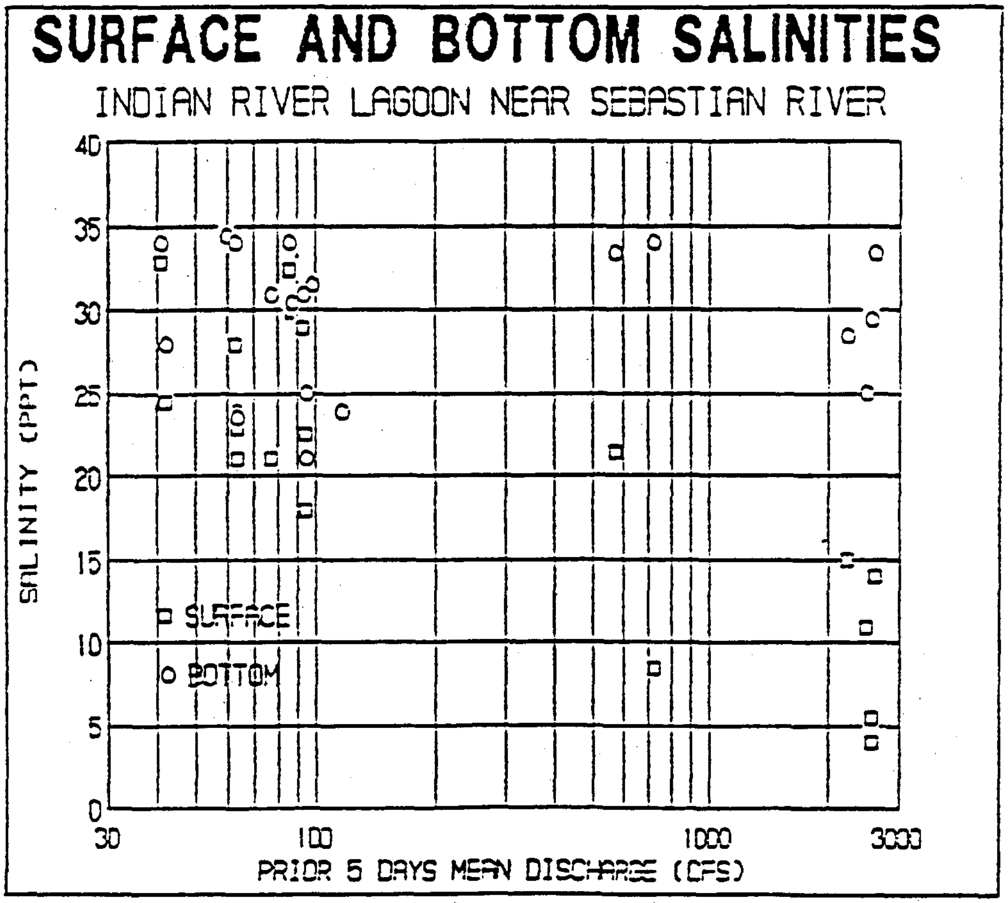


Figure 6 Effect of High Flow Rates on Surface and Bottom Salinity, Indian River lagoon near Sebastian River. See Figure A1 for station location.

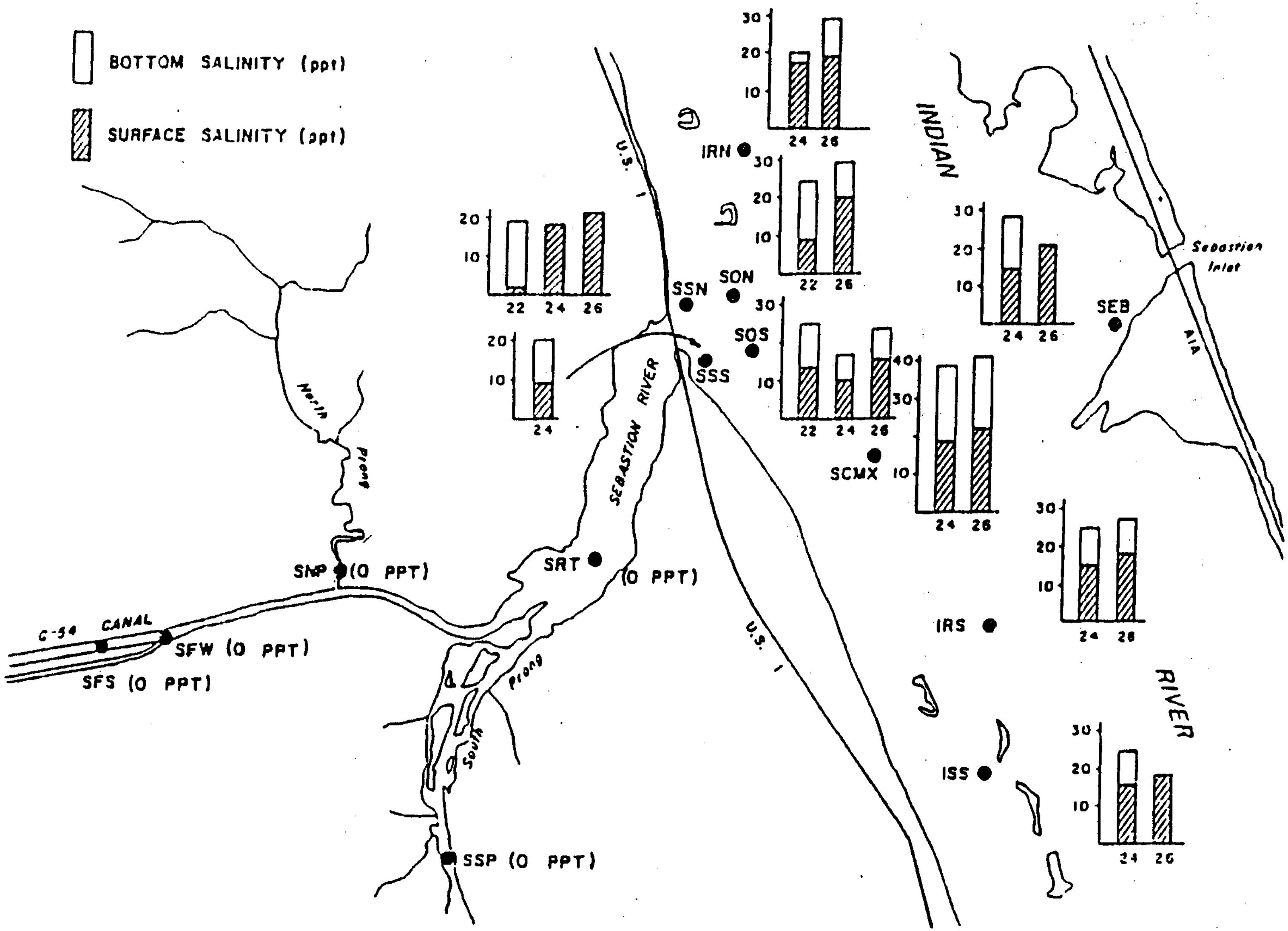
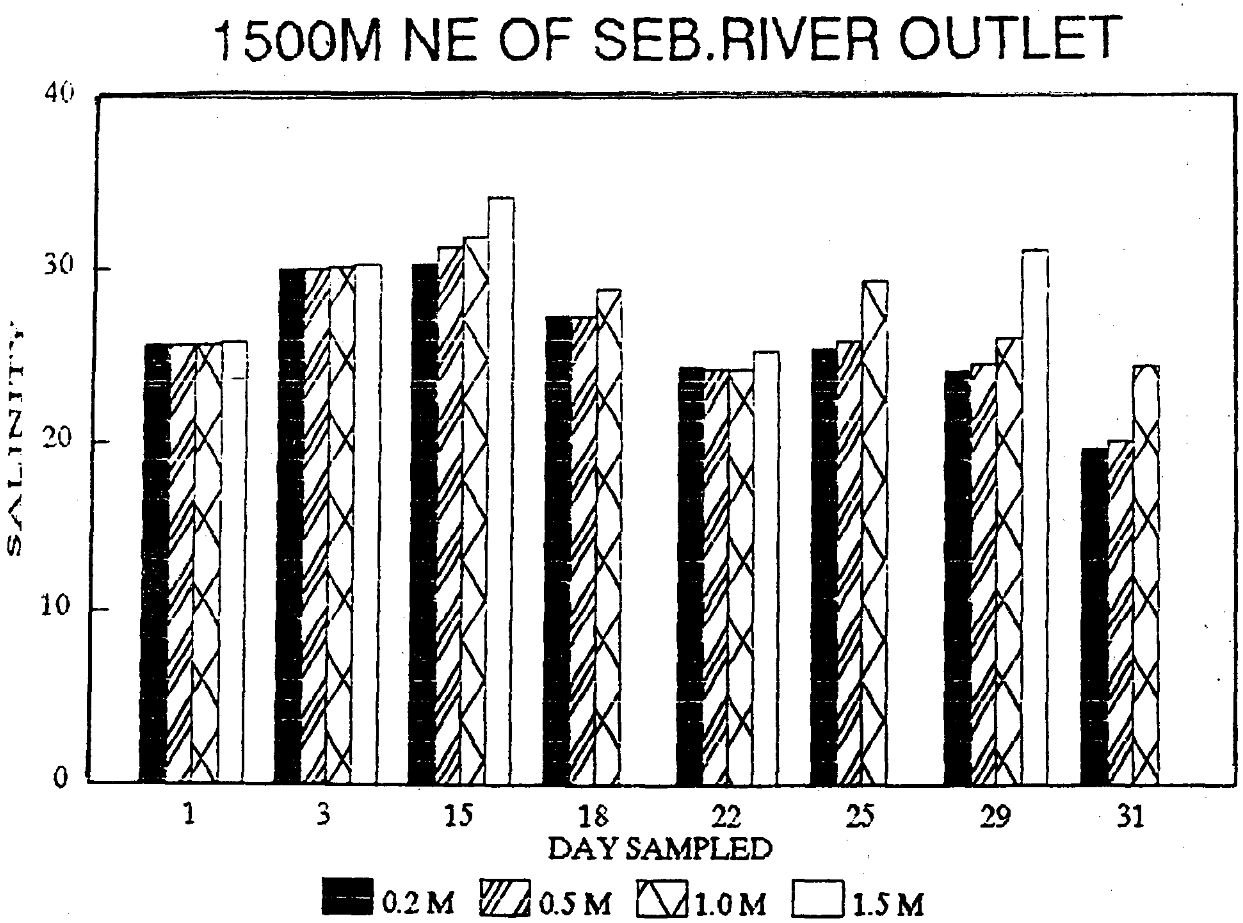


Figure 7

Bottom and Surface Salinity
Sebastian River and Indian River Lagoon

Oct. 22 - 26, 1985
Brevard County, Florida

Figure 8.



JULY 1991

Figure 9.

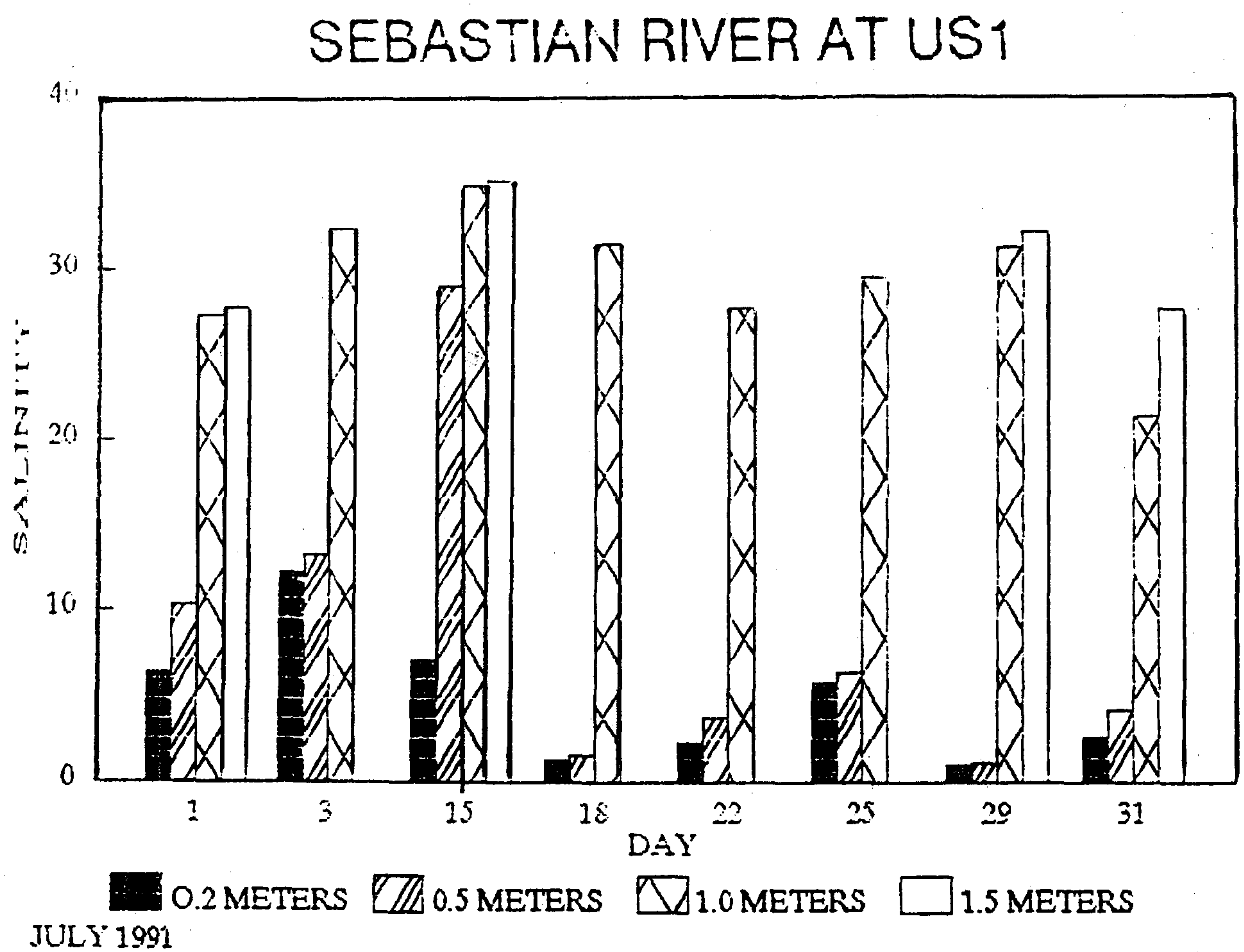
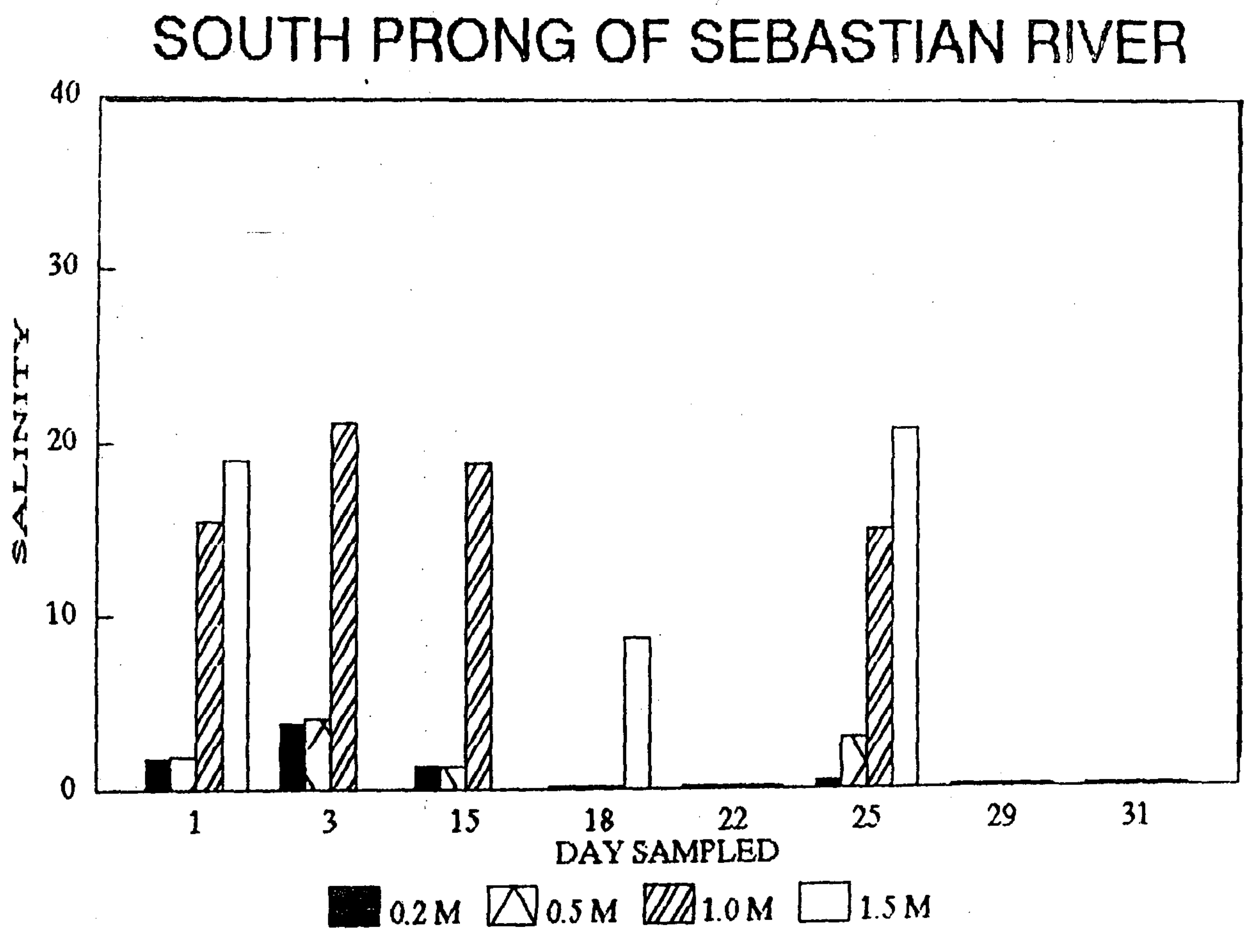

SEBASTIAN RIVER AT US1
40
30
20
10
0
SALINITY
1
3
15
18
22
25
29
31
DAY
0.2 METERS
0.5 METERS
1.0 METERS
1.5 METERS
JULY 1991

Figure 10.



JULY 1991

Figure 11.

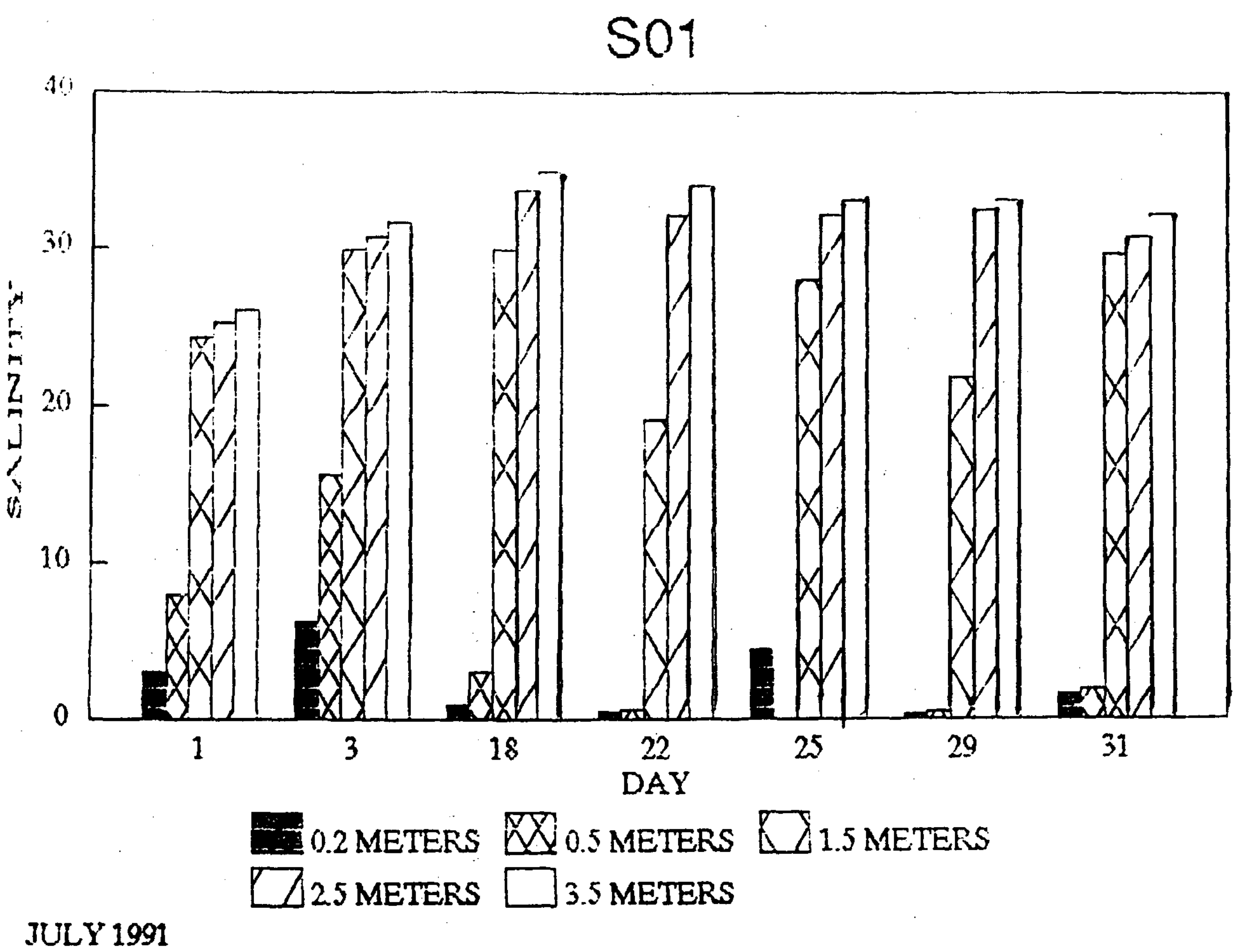
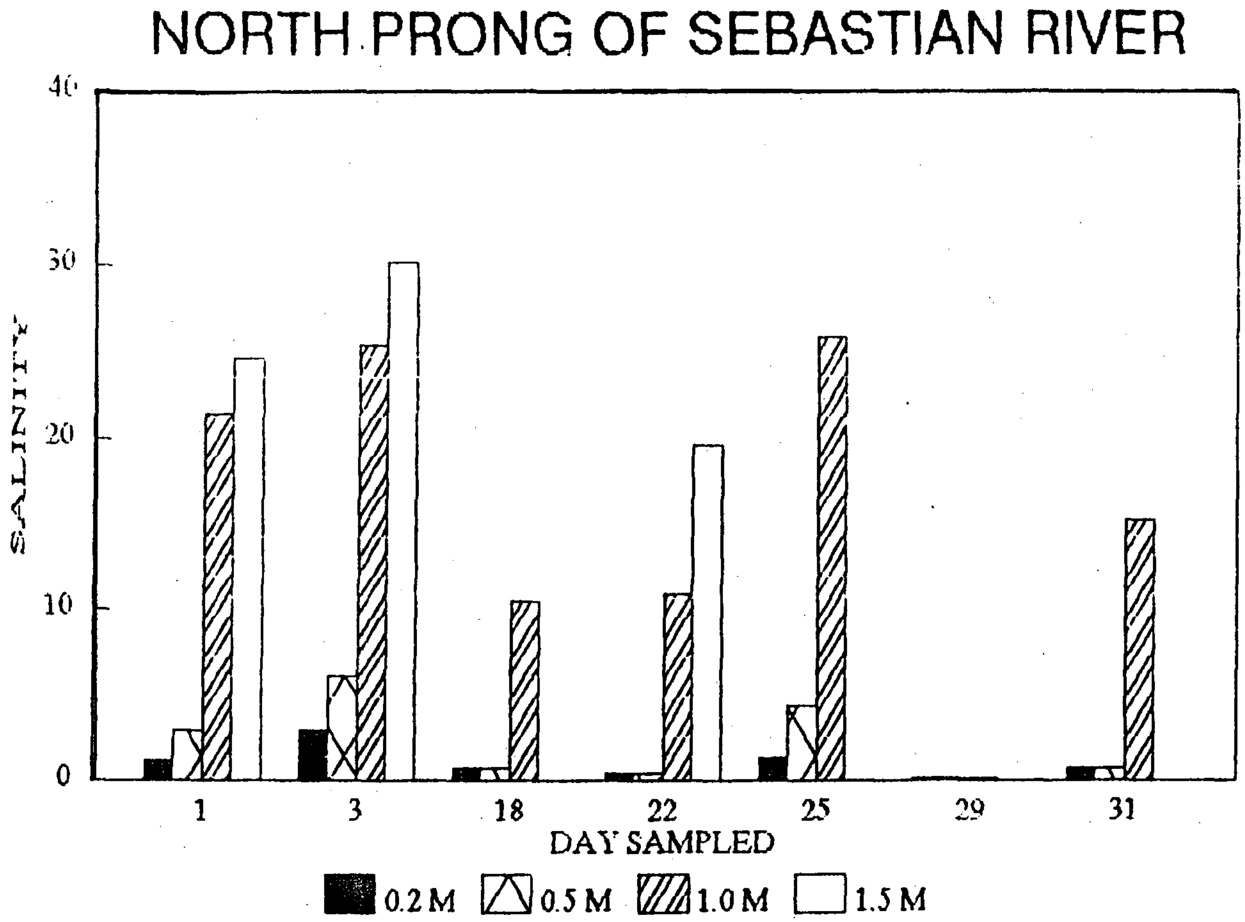

S01
40
30
20
10
0
SALINITY
1
3
18
22
25
29
31
DAY
0.2 METERS
0.5 METERS
1.5 METERS
2.5 METERS
3.5 METERS
JULY 1991

Figure 12.



JULY 1991

Figure 13.

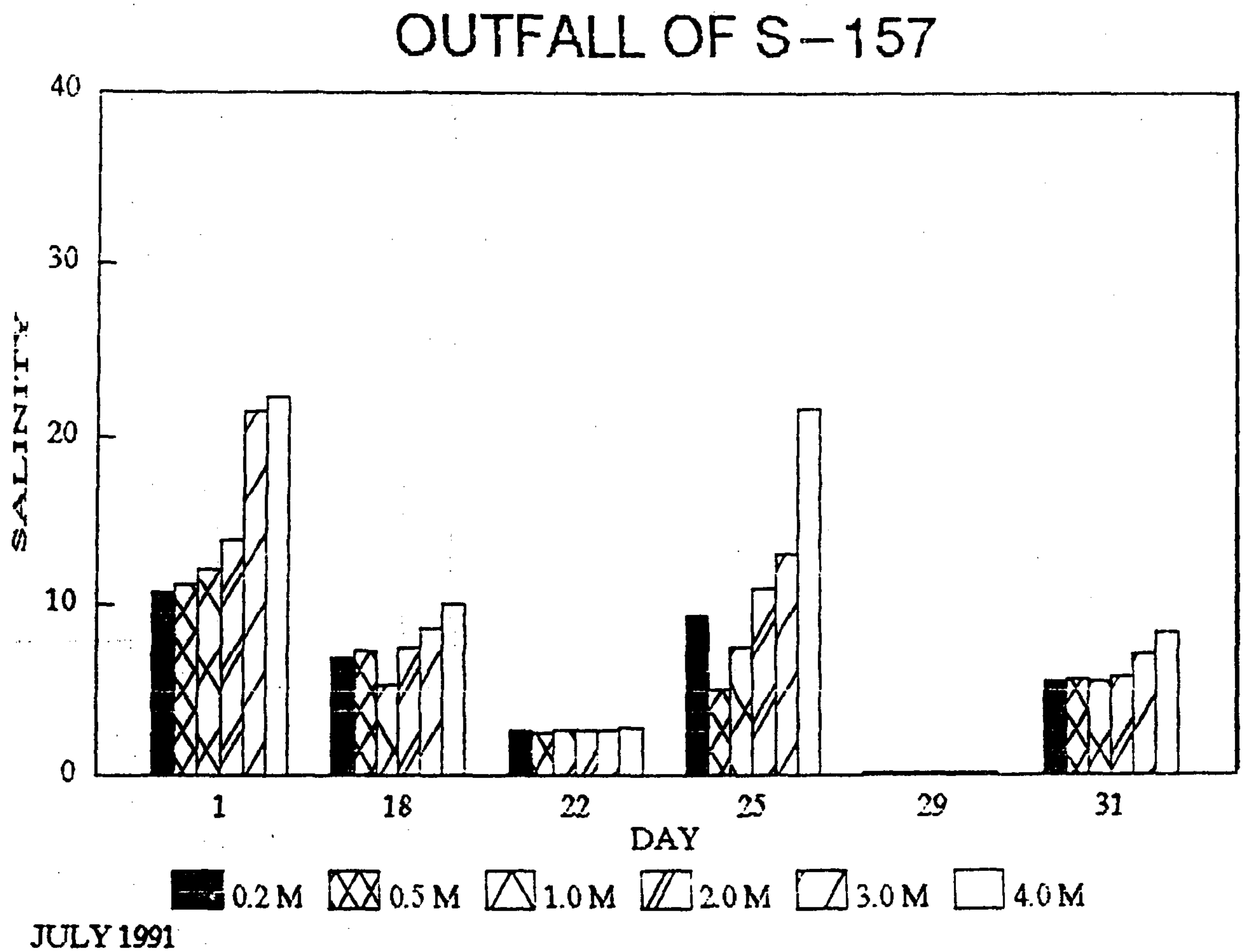
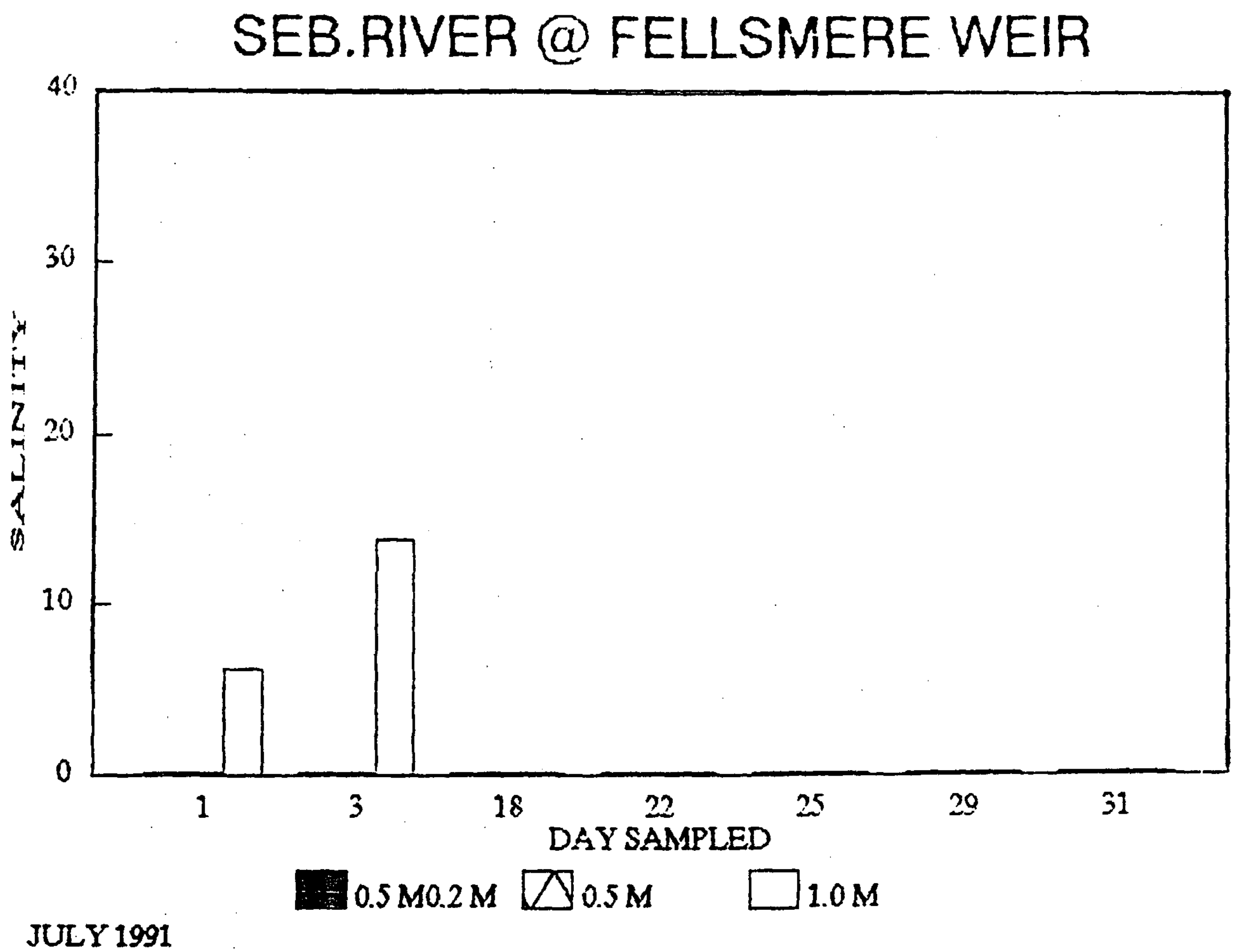
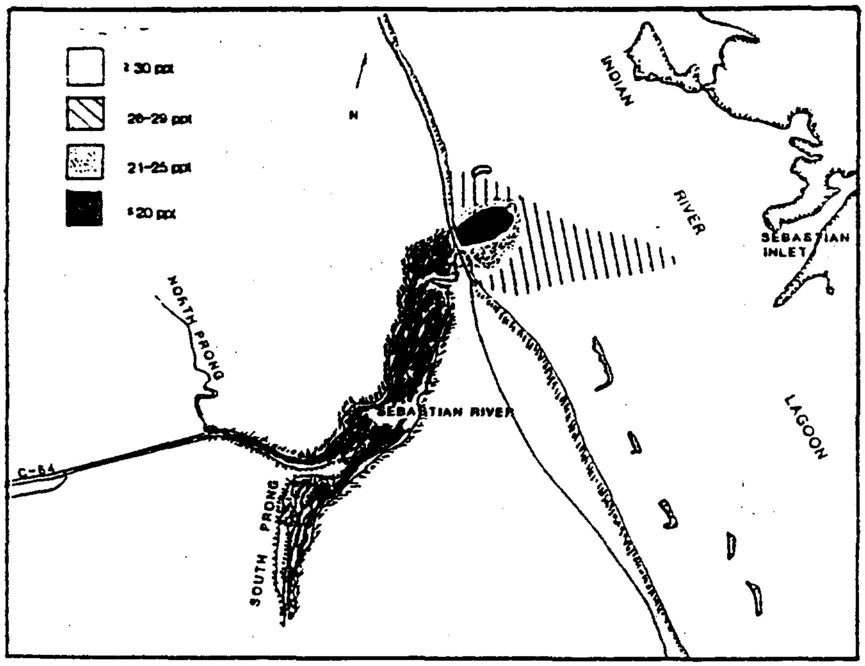

OUTFALL OF S-157
SALINITY
40
30
20
10
0
1
18
22
25
29
31
DAY
0.2 M
0.5 M
1.0 M
2.0 M
3.0 M
4.0 M
JULY 1991

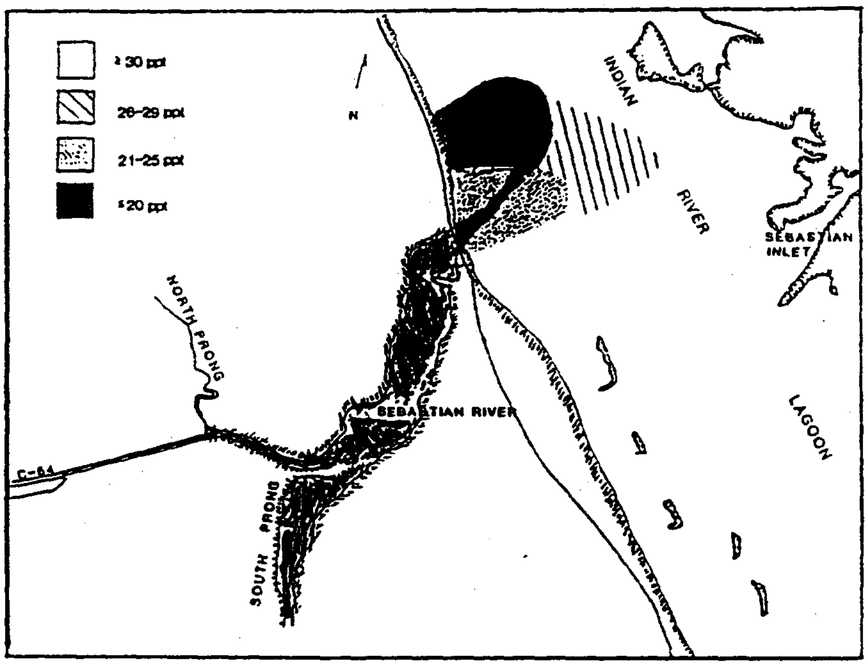
Figure 14.


SEB.RIVER @ FELLSMERE WEIR
40
30
20
10
0
SALINITY
1
3
18
22
25
29
31
DAY SAMPLED
0.5 M0.2 M
0.5 M
1.0 M
JULY 1991



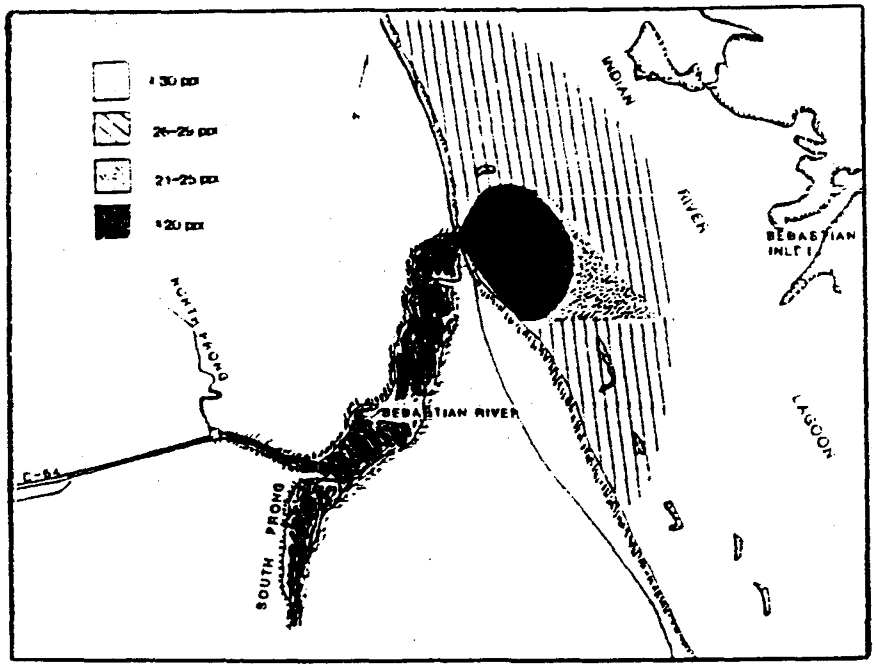
a. Surface Salinities (0.2 m); August 22, 1990; Calm Winds
Tides: 0847 H, 1504 L

Figure 15.



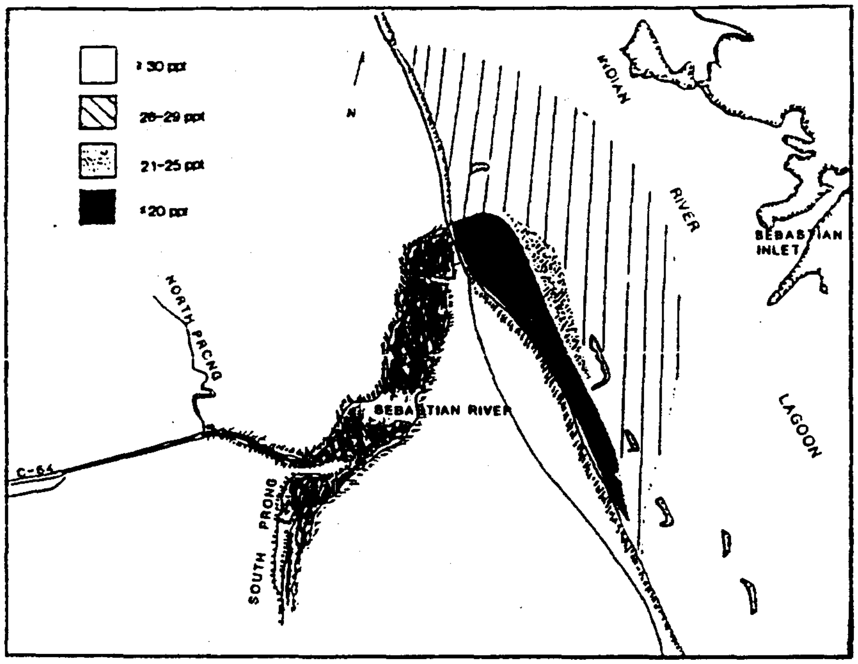
b. Surface Salinities (0.2 m); August 21, 1990; S Winds
Tides: 0803 H, 1422 L

Figure 16.



Surface Salinities (0.2 m); August 16, 1990; SW Winds
Tides: 0958 L, 1622 H

Figure 17.



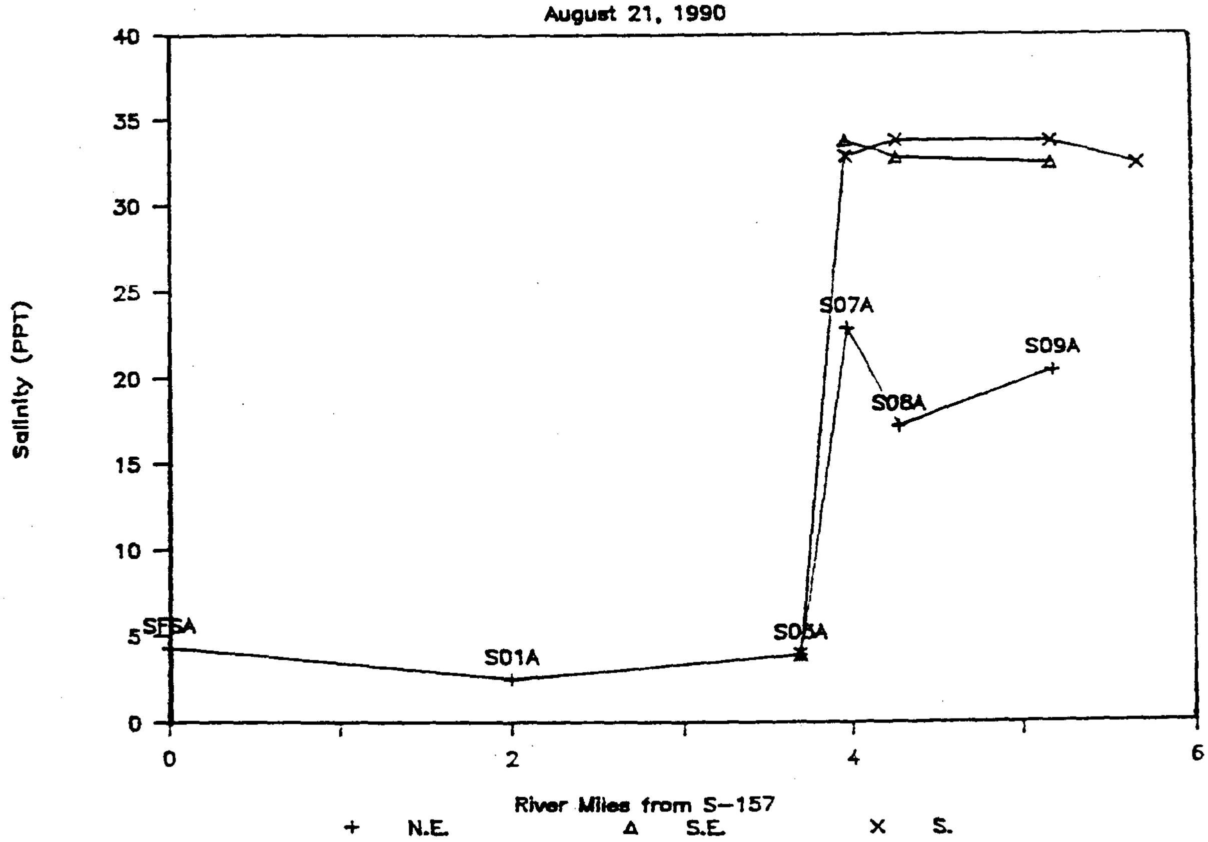
a. Surface Salinities (0.2 m); August 28, 1990; NE Winds
Tides: 0703 L, 1331 H

Figure 18.

Figure 19.

Sebastian and IRL Salinities at 0.2 m

August 21, 1990



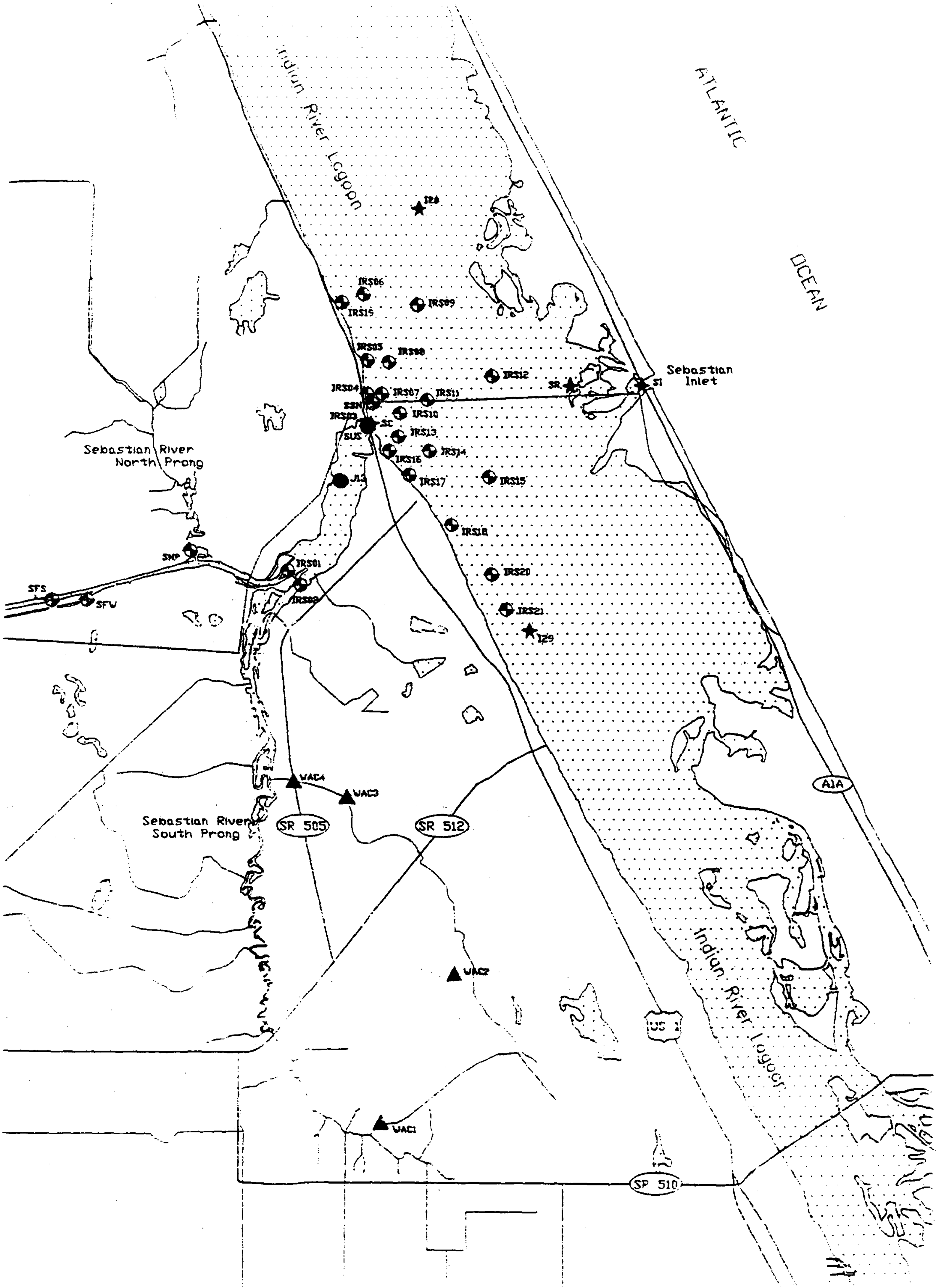


Figure 20. Sampling stations queried for salinity data.

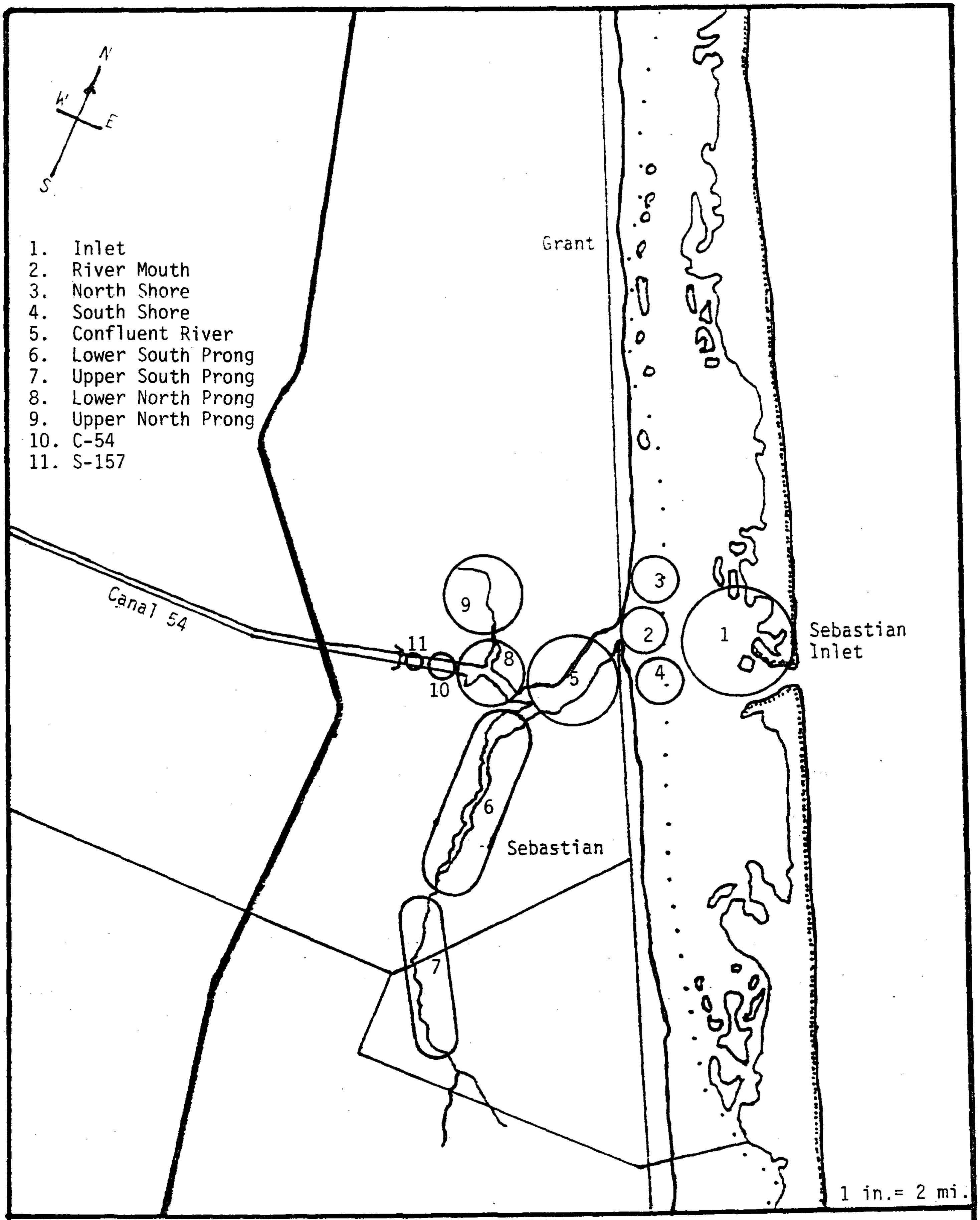


Figure 21. Salinity Segments. See Table 1 in Section 14 for definitions.

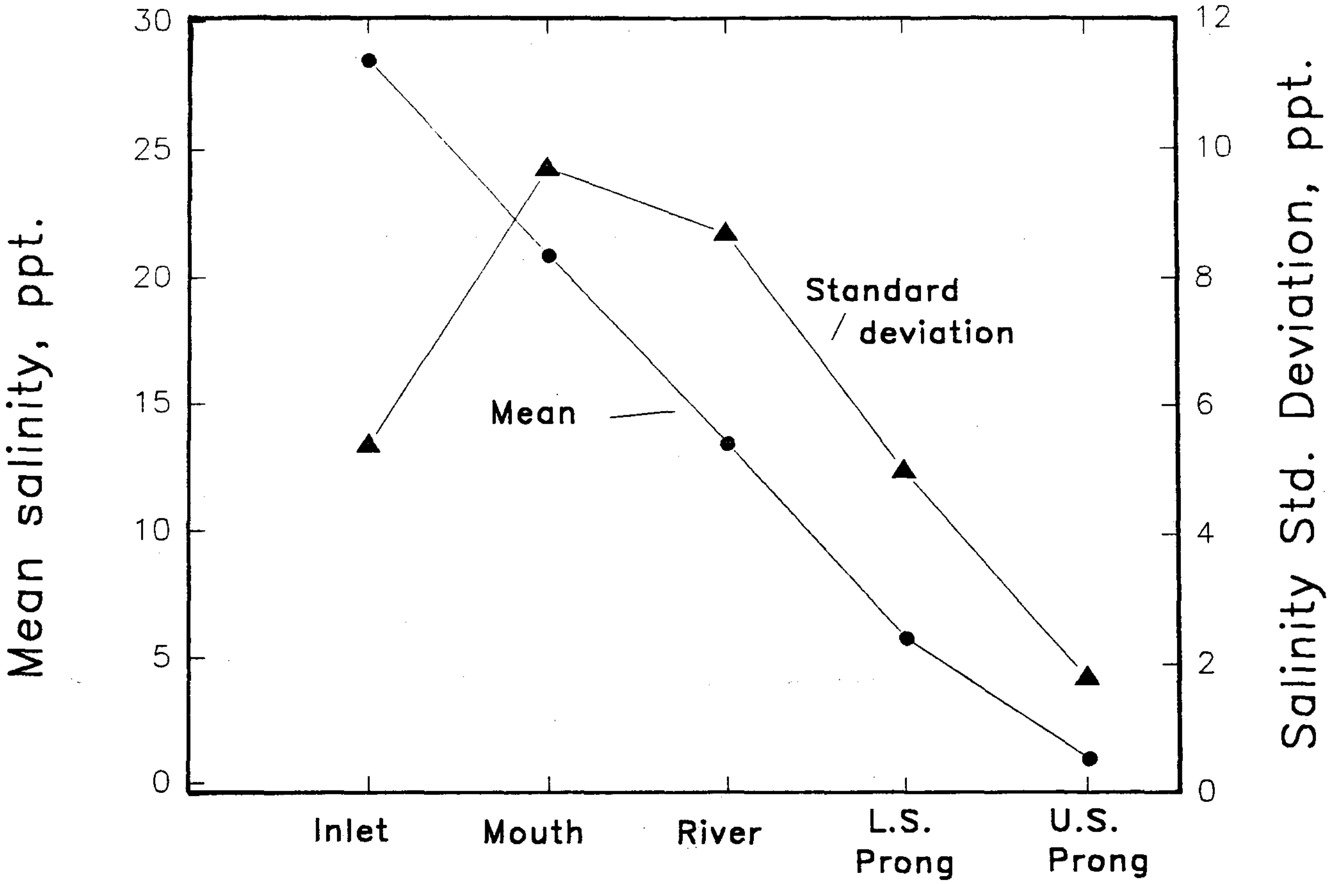

Mean salinity, ppt.
Salinity Std. Deviation, ppt.
30
25
20
15
10
5
0
12
10
8
6
4
2
0
Standard
deviation
Mean
Inlet
Mouth
River
L.S.
Prong
U.S.
Prong

Figure 22.

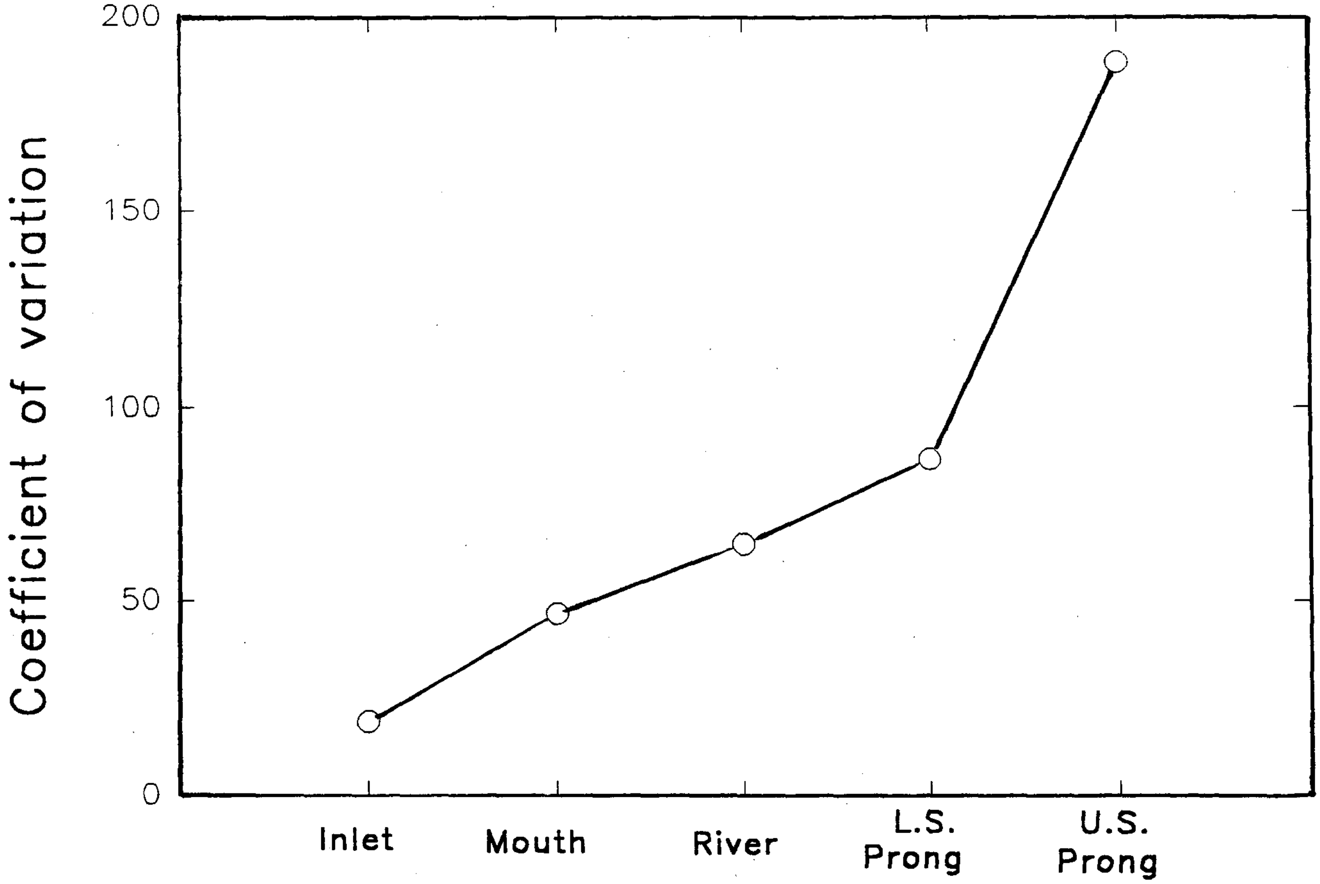
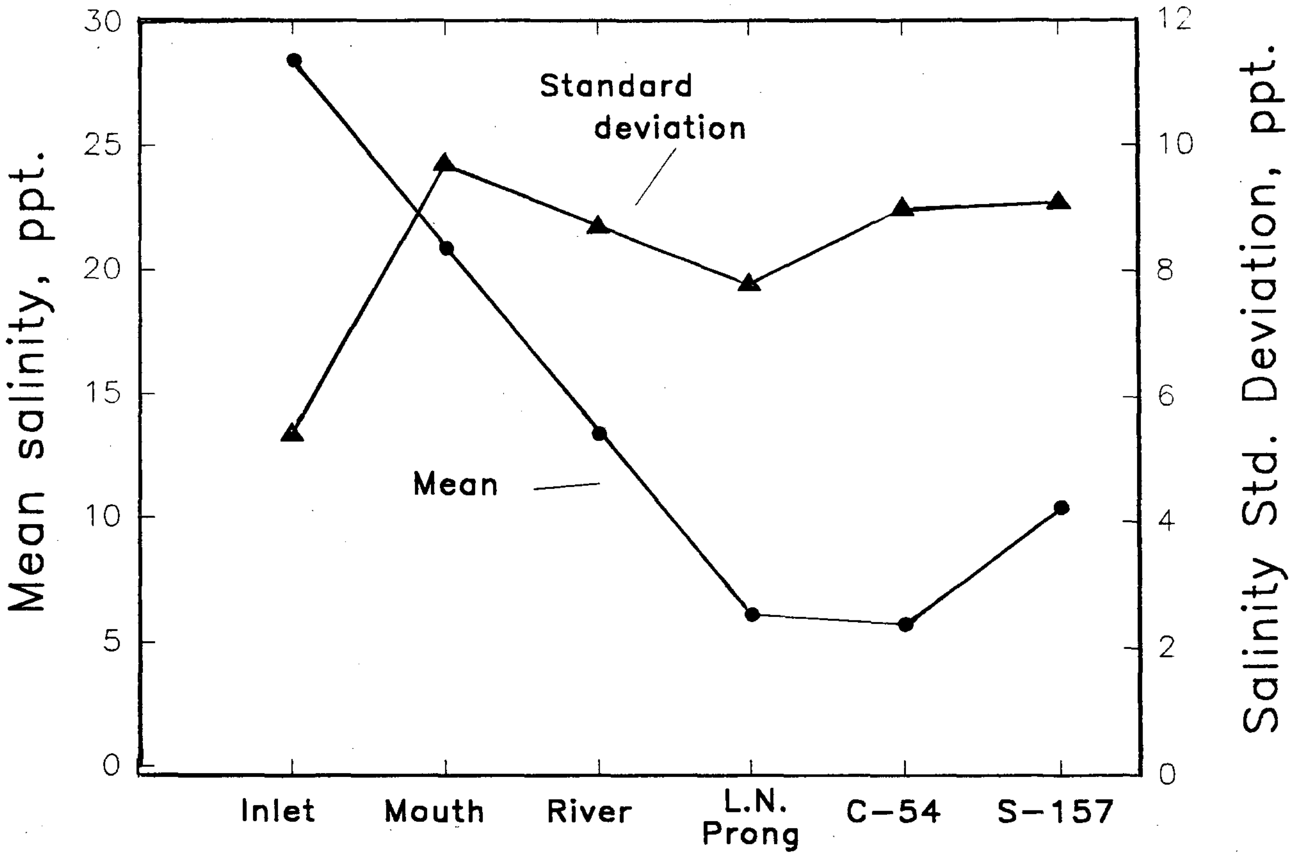
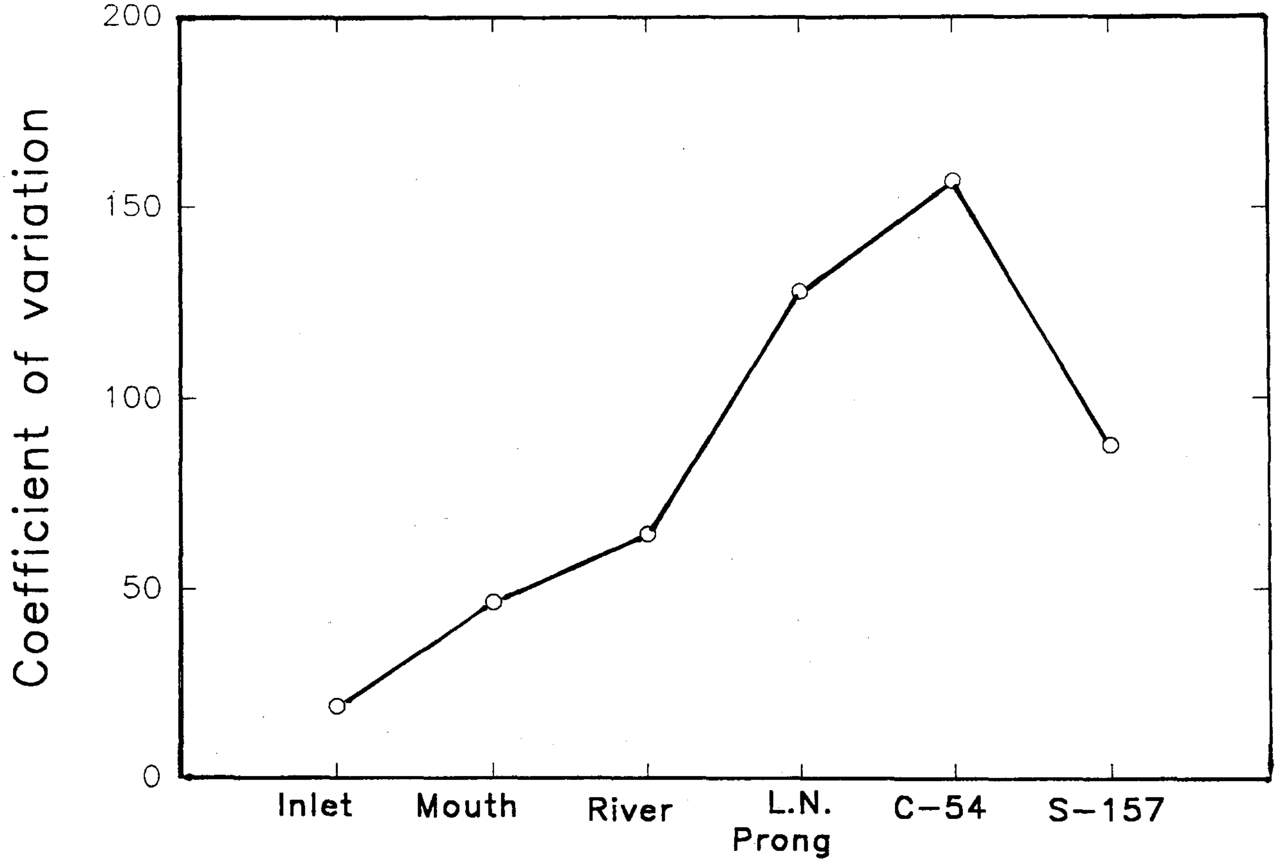

200
150
100
50
0
Coefficient of variation
Inlet
Mouth
River
L.S. Prong
U.S. Prong

Figure 23.



Mean salinity, ppt.
Salinity Std. Deviation, ppt.
30
25
20
15
10
5
0
12
10
8
6
4
2
0
Standard deviation
Mean
Inlet
Mouth
River
L.N. Prong
C-54
S-157

Figure 24.



Coefficient of variation
200
150
100
50
0
Inlet
Mouth
River
L.N.
Prong
C-54
S-157

Figure 25.

7. Seagrasses

Seagrass beds have a variety of functions within estuarine habitats (Wood et al., 1969). They are important as a structural habitat for juveniles and adults of many animal species. Seagrasses anchor sediments and slow water currents to the point at which part of the water column sediment load settles to the bottom (Ward et al., 1984). Nutrients carried by these sediments are utilized directly by the seagrass plants and indirectly by the grazers and detritus feeders within the seagrass beds. Reductions in seagrass bed coverage usually result in drastic shifts in community composition. Major seagrass losses typically change the nature of or cause large decreases in the productivity of fisheries within the affected areas (Livingston, 1987).

Seagrasses found in the Indian River Lagoon include _Halodule wrightii_, _Thalassia testudinum_, _Syringodium filiforme_, _Halophila decipiens_, _Halophila johnsonii_, _Halophila decipiens_ and _Ruppia maritima_ (Thompson, 1976; Heffernan and Gibson, 1983). _Halophila decipiens_ has not been reported north of the Ft. Pierce Inlet and _Thalassia testudinum_ and _Halophila johnsonii_ are not found north of the immediate vicinity of the Sebastian Inlet (Virnstein, 1988). _Halodule wrightii_ and _Syringodium filiforme_ are the dominant seagrasses in the vicinity of the Sebastian River study area (Thompson, 1976; Downs, 1978; Carroll, 1983; White, 1986). Seagrasses followed a typical zonation pattern with _Halodule_ most abundant in very shallow water to about 2 m depth. _Syringodium_ was found mixed with _Halodule_ from below 1 m to 2 m and then in pure stands below 2 m (Carroll, 1983). Carroll reported that 13% of the Lagoon bottom within 3 nautical miles north and south of the Sebastian River mouth was vegetated by seagrass at the time of the USFWS surveys in 1982. The most densely (700-2,500 shoots/m^2) vegetated areas, in the vicinity of the mouth of the Sebastian River, were located on spoil islands and on the eastern shore of the Indian River adjacent to the Sebastian Inlet. Seagrass beds closest to the Sebastian River mouth were very sparsely vegetated (100-700 shoots/m^2).

A recent study in northeastern Florida Bay (Montague et al., 1989) demonstrated that seagrasses and benthic fauna were much less abundant where bottom salinities were highly variable (Figure 1). Montague et al. (1989) stated that:

> "Submerged vegetation found in small quantity at the upstream stations...are known to thrive elsewhere at salinities comparable to the mean salinities found at those stations. Frequent, large, and sudden variations in salinity at a station...might reset succession, preventing good development of any one benthic community."

In a rule-based ecological model of an estuarine lake, Starfield et al. (1989) concluded that the abundance of underwater plant biomass was sensitive to the rate of change of salinity rather than the salinity level *per se*, but these model outputs have not yet been confirmed. Montague et al. (1989) pointed out that the basic research necessary to understand the effect of salinity variation on seagrasses has not yet been done. A recent proposal to Florida Sea Grant (M.D. Hanisak, Harbor Branch Oceanographic Foundation, 1991, unpublished document) states that the responses of two important seagrasses (Halodule wrightii and Syringodium filiforme) to environmental stresses, including salinity, have not been adequately documented. The proposed approach to test salinity tolerances of Halodule and Syringodium under various nutrient and light regimes, in a 3 X 3 X 3 factorial experiment, will produce much needed information. It will not answer the questions of how frequently and how long these species can be exposed to lowered salinities and still recover. Fears (1992) tested the effects of salinity shocks of various intensities and durations on the growth rate and survival of Thalassia, Halodule, and Syringodium. His experimental design did not mimic situations where drastic salinity changes occur on tidal, daily, weekly, or longer temporal cycles. Extreme variation in salinities adjacent to the Sebastian River mouth (Figure 2) may be the major cause of the gradient of seagrass bed densities that existed from the eastern to the western shores of the Indian River Lagoon in 1982 (Carroll, 1983). Data from Montague et al. (1989) on the effects of salinity variation on seagrass growth in Florida Bay suggest that the pattern seen in the area of the Sebastian River can be explained by the same factor.

Halodule wrightii

Halodule wrightii is the most abundant seagrass in the Indian River Lagoon; it covered an estimated 3,163 acres in 1976 (Thompson, 1976). Near the confluence of the Sebastian and Indian Rivers Halodule covered 76% of the bottom within seagrass beds. A later study (Carroll, 1983) showed increased seagrass coverage on shoals between the Sebastian River mouth and the Sebastian Inlet. Carroll stated that the tidal waters coming through the Sebastian Inlet appear to have a greater influence over this area than does the fresh water from the Sebastian River. No other changes were noted in the size and distribution of seagrasses within this study area. Carroll reported that 13% of the bottom was covered by seagrass within a 3-mile (=4.82 km) radius of the Sebastian River mouth. Figure 3 shows a decrease in seagrass cover, within concentric bands of 0.5 km width, as distance to the River's mouth decreases. The decrease could be due to the effect of discharges of freshwater or to bottom types and depths that will not support seagrass growth.

Highly colored runoff may have a strong effect on seagrass penetration into the Sebastian River (C. White, personal communication). Algal blooms associated with large discharges of freshwater from the Sebastian River into the Indian River Lagoon (J. Steward, St. Johns River Water Management District, unpublished memo, August 31, 1990) may cause shading problems for seagrasses. Seagrasses have penetrated the *Loxahatchee River* estuary to a point where bottom salinities on high tides averaged just above 30 parts per thousand and where standard deviations about salinity means equal 6 ppt (Mote Marine Laboratory, 1990). Salinities in the Sebastian River mouth (west of the U.S. 1 bridge) have a much lower average (15.7 ppt) and fluctuate more broadly (S.D. = 7.6 ppt) (Figure 2). The highest salinity recorded during a monthly monitoring program begun in June 1991 was 31.0 ppt in May 1992; the lowest salinity recorded was 3.7 ppt in November 1991 (R. Frease, Marine Resources Council, unpublished data). The ranges and standard deviation about the salinity mean at the River mouth demonstrated a very unstable salinity regime.

Phillips (1960) reported observations of Halodule in the St. Lucie River until freshwater releases from Lake Okeechobee killed the grass. Normal salinity ranges in this area were reported as 17 - 24 ppt. Florida

Bay stands of _Halodule_ were reported in areas where salinities ranged from 12 - 33 ppt.

Experimental information currently available about the salinity tolerance limits of this plant suggests that it is the most euryhaline species of seagrass in the Indian River Lagoon (Fears, 1993). Fears states that despite the euryhalinity of this species, it is not indestructible. In an early study (McMahan, 1968) pots of _Halodule_ maintained vigorous growth in salinities from 23 to 37 ppt, for 5 weeks, and it survived in salinities up to 60 ppt. In a separate experiment an attempt was made to grow _Halodule_ at salinities ranging from 0 to 87 ppt. It survived for 6 weeks in salinities ranging from 3.5 to 52.5 ppt. After 2 weeks at salinities under 9 ppt _Halodule_ began to show adverse effects. Fears (1993) demonstrated that _Halodule_ could tolerate short term, to 24 hrs duration, salinity shocks in fresh water. He warned that longer duration exposures or repeated shocks could kill this seagrass. Field data on _Halodule_ distribution near river mouths and on tidally exposed sandbars also suggest that it can tolerate wide salinity fluctuations.

No information is available on the reproduction and germination of this seagrass under artificially manipulated salinity regimes. _Halodule_ flowers have been reported to occur in various areas at temperatures between 22 °C and 26 °C and in salinities ranging from 26.0 ppt to 36.0 ppt (Moffler and Durako, 1987).

Syringodium filiforme

Phillips (1960) summarized observations related to salinity effects on the distribution of _S. filiforme_. His summary suggested that _Halodule_ is more tolerant of low salinities. Phillips reported dense beds of _Syringodium_ in the Indian River Lagoon in salinities of 22 - 35 ppt. He suggests that an optimum salinity level to support _Syringodium_ should exceed 20 - 25 ppt.

Fears' (1993) results showed that _Syringodium_ growth rates were not noticeably affected by salinity shocks (= submergence in water of low or zero salinity) until they were placed in freshwater for 24 hrs. Less harsh treatment did not result in noticeable growth rate decreases for this species.

Syringodium is rarely seen in flower in Florida waters (Phillips, 1960) and therefore no information exists on the effects of salinity on the processes of reproduction and seed germination.

Thalassia testudinum

A dominant species throughout its range, Thalassia nonetheless constitutes a relatively minor element of the Lagoon's seagrass cover. The paucity of Thalassia may be explained by the Lagoon's recent geological history, especially the periodic closing of inlets and associated intervals of low salinity or freshwater. Thalassia is intolerant of low salinity (Fears, 1993), and is the slowest spreading and the poorest colonizer of Lagoon seagrass species. These characteristics give Thalassia a low recovery rate during favorable salinity periods. The areal extent of Thalassia indicates that modern Thalassia beds are not more than a few centuries old (Virnstein, 1988).

Critique

Limiting salinities for common seagrasses are not presently known in any dynamical sense, which is rather remarkable given the considerable importance of seagrasses and concern for their management. It is a mystery that anyone expects to understand or manage the effects on estuarine seagrasses of nutrients, light stress, or contaminants without first understanding the basic effect of salinity [but see Dennison et al. (1993) for an enlightened attempt].

Seagrasses seem to disappear soon after the introduction of large freshwater inflows (Bellan, 1972), or species diversity among seagrasses is reduced. Thereafter, salinity or other impacts become more difficult to observe because affected living resources left in the area tend to be eurytopic. Since seagrasses are sensitive to salinity fluctuation and because they are easy to survey (from the air or sea surface) they would be an excellent index of the effect of any salinity regime. Many of the estuarine animals, including numerous commercially and recreationally important species, and plants within the Indian River Lagoon are seagrass dependent (Gilmore, 1988; Virnstein et al., 1983; Virnstein, 1988). Seagrass loss from any area will have tremendous impacts on the overall productivity of that area that may extend to fisheries in adjacent waters (Virnstein, 1988). The alternative state, bare sand or mud bottoms, typically support a much less abundant fauna (Stauffer, 1937) that is less heavily preyed upon (Virnstein et al., 1983) because the large predators (e.g., commercially and recreationally important species) are also gone.

In a static sense, some relevant distributional and limiting salinity data are available for seagrasses near Sebastian River. Halodule closest to the River mouth is sparse, compared to Halodule on spoil islands aligned with the Intracoastal Waterway. Mean salinity is lower and salinity variance is greater near the River mouth than at the Intracoastal Waterway, suggesting that the River has a depressing effect on Halodule growth potential. This interpretation is consistent with reports that (a) Halodule tolerates exposures to freshwater for at least 24 hours, (b) it can survive for at least 6 weeks at 3.5 ppt, (c) it exhibits vigorous growth at 23.0 ppt, and (d) has been seen to flower in salinities as low as 26 ppt. Syringodium, on the other hand, occurs near the Inlet but not near the River. It is damaged by freshwater exposures of 24 hours. It is found in salinities of 22 to 35 ppt across its range. In the Loxahatchee River, its upstream-most limit occurs at a mean bottom salinity of 35 ppt and a standard deviation of 2 ppt (based on monthly samples). A minimum salinity range of 20 to 25 ppt was previously recommended for Syringodium.

Conclusions based on a review of literature concerning the effects of salinity on seagrasses are that:

1. Seagrasses occurred along the western shore of the Indian River Lagoon, but are fewer in kind and less abundant now. The pattern of mean salinity and salinity variation near the River mouth is consistent with conditions associated with seagrass loss, but other factors related to River discharge or dredging may be involved.
2. To restore Halodule near the mouth of the Sebastian River, mean bottom salinity should be maintained near 25 ppt, with a standard deviation about the mean less than 10 ppt.
3. To enhance the potential for Syringodium recovery, the duration of bottom salinities of zero ppt should be kept to less than 24 hours.

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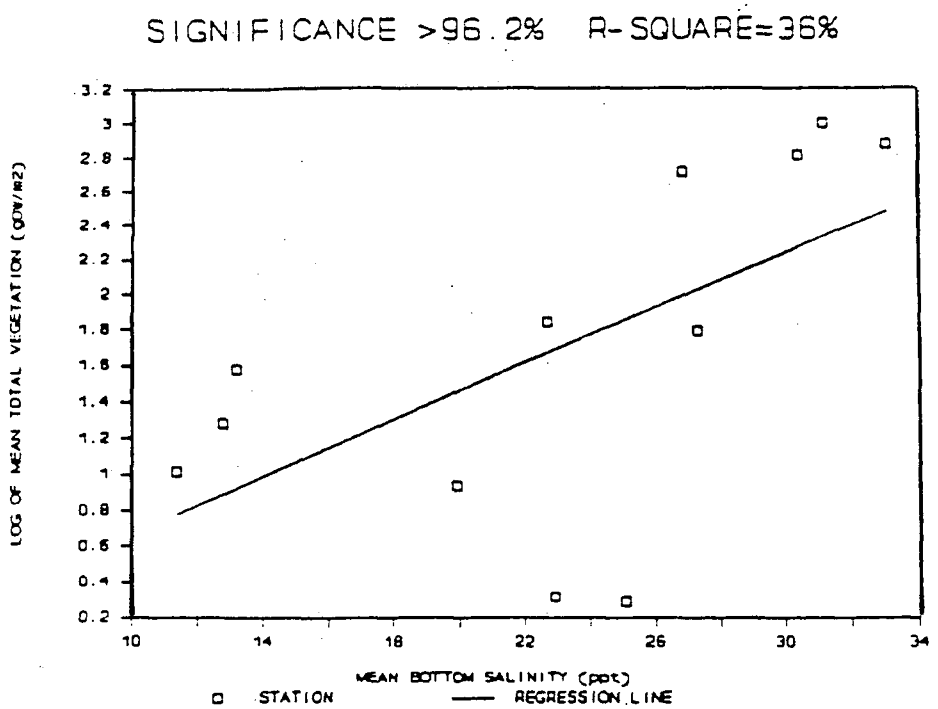
a)



b)

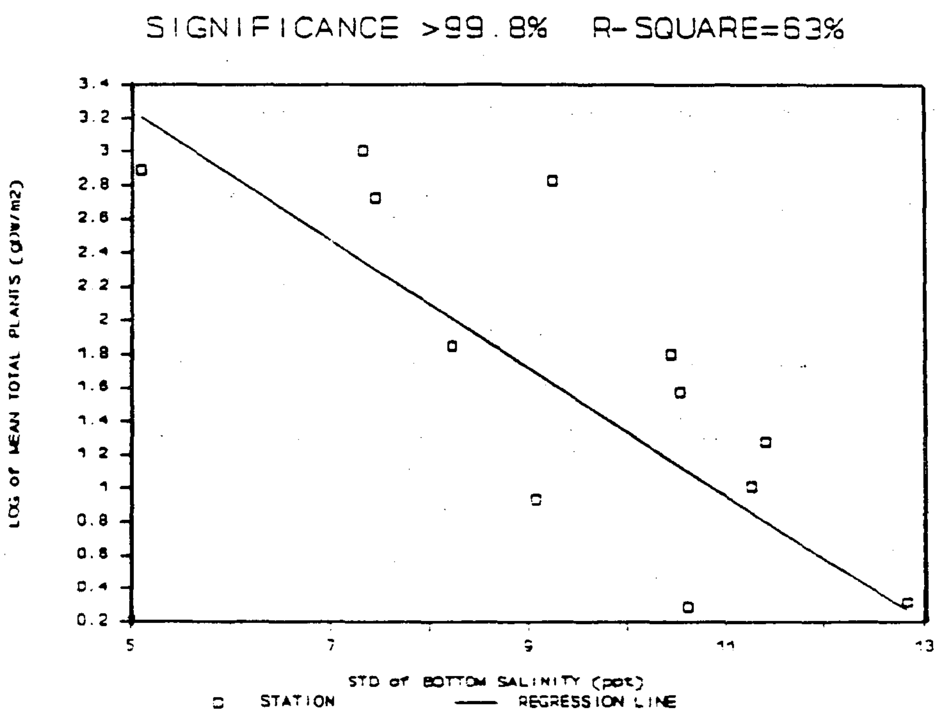


Figure 1. a) log (base 10) of mean total plants vs mean bottom salinity; b) --- vs standard deviation of bottom salinity.

Figure 2.

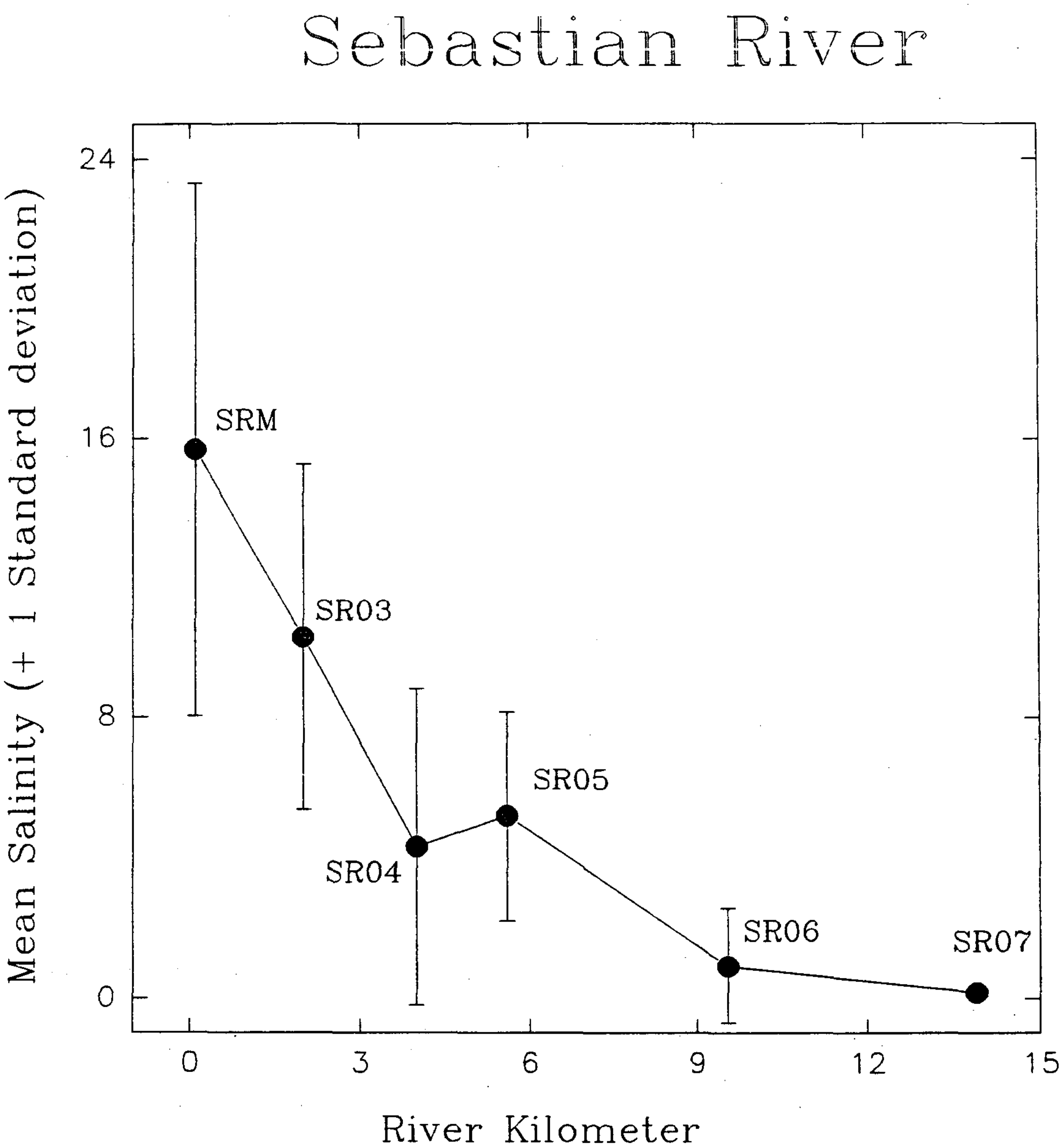
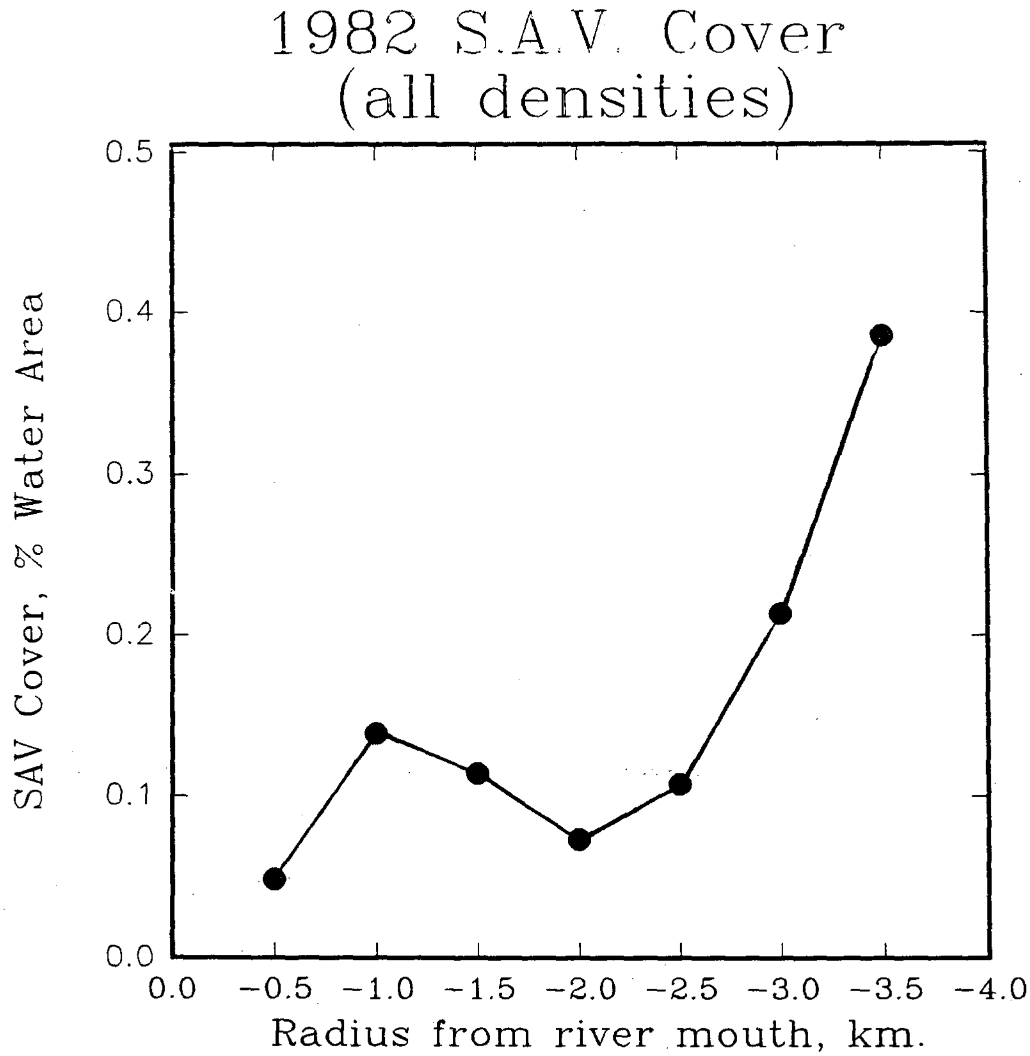

Sebastian River
Mean Salinity (+ 1 Standard deviation)
24
16
8
0
SRM
SR03
SR04
SR05
SR06
SR07
0
3
6
9
12
15
River Kilometer

Figure 3.


1982 S.A.V. Cover
(all densities)
SAV Cover, % Water Area
0.0
0.1
0.2
0.3
0.4
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
Radius from river mouth, km.

8. Hard Clams

A fishery for the hard clam, Mercenaria mercenaria, is well established within the Indian River Lagoon (Cato, 1991). In the past, many hard clams have been collected in polluted, shellfish-restricted areas and depurated in tanks supplied with artificially purified water, or transferred (= "relayed") to less polluted sections of the Indian River Lagoon (Busby, 1986). Very few clams are harvested and sold without depuration. Presently, many operations use hatchery-raised stock for grow out. Natural clam beds immediately adjacent to the Sebastian River and for several miles to the north are sparsely populated (Arnold, 1986).

Clam losses of 75% during 1985 in the Indian River Lagoon adjacent to the mouth of the Sebastian River have been attributed to low salinities created by the release of large volumes of freshwater through flood control structures (Busby, 1986; Barile, 1986). Other losses have occurred since that date (E. Mangano, Sea Farms, personal communication; C. Sembler and B. Alles, Sembler and Sembler, Inc., personal communication). Indian River Lagoon clammers understand that natural variation in salinities, especially after storm events, occasionally caused hard clams to disappear from the Indian River Lagoon before the construction of water management systems. They believe that the current operating procedure adopted by local water managers has, in terms of freshwater effects on hard clams, created many artificial "storm" events.

Occasional large discharges of freshwater from the Sebastian River and other Indian River Lagoon tributaries may actually enhance hard clam production (D. Vaughn, Harbor Branch Oceanographic Institution, personal communication; Ryther, 1986). Only large "chowder" clams survived the 1982 discharge but virtually all clam predators were removed from the Indian River Lagoon by this event. When the naturally-occurring adult clams reproduced a very high percentage of their larvae survived to restock the lagoon. This approach to hard clam management would possibly benefit those clam producers depending on natural clam stocks but it would be very hard on many other living marine resources.

Adult hard clams survive short spells of lowered salinities by closing their valves, and stop pumping at salinities below 15 ppt (Eversole, 1987). Survival times under adverse environmental conditions are age/size dependent. Ambient temperatures and dissolved oxygen levels alter salinity tolerances and survival times. Larval and juvenile clams are more susceptible to low salinities because they lack the protection of the heavy, thick shells of older clams (Wells, 1957). Fishermen in the Indian River lagoon (loc. cit.) have noted that small clams can tolerate low salinity for 2 to 3 hours while adults may be able to withstand low salinity for several days. Hard clams already stressed by other environmental factors may be more susceptible to salinity stress (Wells, 1957). High temperatures, for example, increase respiratory demands and decrease the length of valve closure periods (Barnes, 1987). Elevated summertime water temperatures and high biological oxygen demands, created by excess nutrient supplies, reduce dissolved oxygen availability (Windsor, 1985) below the metabolic needs of clams stressed by low salinities. Even normal summertime salinity decreases can therefore be damaging to a hard clam fishery dependent on stable conditions.

Sudden increases in salinity, exceeding 8 parts per thousand (ppt) are also lethal to hard clams (M. Castagna, Virginia Institute of Marine Science, personal communication). In fact, hard clams can tolerate a larger decrease -- drops of up to 15 ppt -- if the lowest salinities remain above seasonally changing and geographically variable lethal salinity limits.

Distributional patterns of Mercenaria mercenaria in several areas suggest that salinity has a strong influence either on recruitment or on subsequent post-recruitment survival and growth (Wells, 1957; Walker and Tenore, 1984; Craig et al., 1988). Physiological changes occur within clam tissues when exposed to low salinities. Clam tissues leak amino acids at salinities that truly euryhaline species, such as Mytilus and many others, can tolerate without amino acid losses (Rice and Stephens, 1988). Amino acid loss continued after a 5-day acclimation period, at 17.0 ppt, for adult Mercenaria. Net losses of amino acids can be used as an index of a species' ability to tolerate salinity fluctuations. Adult Mercenaria can tolerate long exposures to lowered salinities by tightly closing their thick valves (Wells, 1957), but the duration of the maximal period of closure is a function of temperature.

Patterns of shell growth in adult hard clams have been studied in 10 southeastern estuaries, including two sites in the Indian River Lagoon (Jones, et al. 1990). Florida clams have higher growth rates and shorter life spans than northern clams. Shells exhibit a bimodal growth pattern with peak rates of new shell deposition in the spring and late fall of the year. Shell growth is lowest in summer when temperatures are highest and salinities are lowest. Salinity data for three sites are available. At no time were monthly salinities below 10 ppt. In 3 months (8% of 36 station-months), salinities were lower than 15 ppt. Salinities were between 15 and 20 ppt during 33% of visits and salinities were greater than 20 ppt on more than half (56%) of the visits.

Salinity requirements of embryonic, larval, and juvenile clams change throughout development and early growth (Mulholland, 1984). Temperature has a complicating effect on the interpretation of salinity requirements of Mercenaria mercenaria and M. campechiensis. Female clams in spawning state were found to be almost continuously present in the Indian River near Melbourne (Hesselman et al., 1989). Bimodal peaks of clam spawning activity occurred from September through December and from March through June. Spawning activity in this area occurs over a broad range of salinity (Figure 1) and temperature (Figure 2). No spawning was observed below 15 ppt, and populations with the highest spawning incidence (>50%) were observed at an average salinity of about 20.5 ppt. Large numbers of spent individuals were found during August and September.

A strong biphasic period of spring (March - June) and fall (August - October) ripening and spawning of female littleneck hard clams in Wassaw Sound, Georgia, was reported by Pline (1964). There was a strong correlation between recruitment failure and depressed winter salinity (< 30 ppt) in winter. Hard clams postponed high experimental mortality in 10.0 ppt salinity by remaining tightly closed for 4 to 5 weeks, but eventually succumbed. Salinity of productive hard clam beds in Wassaw Sound is shown in Figure 3. Salinity was usually greater than 20 ppt and fell to 15 ppt in only one month.

Studies of the salinity requirements of larval and juvenile clams are summarized in Table 1. In most cases the minimum tolerable salinity was 20 ppt or greater. Given that low-latitude clam populations encounter higher water temperatures, published salinity requirements of larval clams suggest that it would be advisable to avoid salinity decreases to levels below 20 ppt at least during the two periods of most intense spawning seen in the Indian River Lagoon, and preferably throughout the year. Clam larval losses during the rest of the year could have a major impact on natural lagoon populations.

Mojica (1991), in a study of environmental impacts of cultured hard clam growout 2 km north of Grant, recorded monthly salinity patterns for a 10 month period. Salinity averaged about 26 ppt and minimum salinity did not fall below 20 ppt (Figure 4). Clam farm operations were unaffected by salinity between 20 and 25 ppt, and natural specimens of Mercenaria were collected alive in benthic faunal samples at the Farm and nearby control sites.

Wells (1957) noted that few hard clams were found in parts of Chincoteague Bay where salinities often reached levels ranging from 13 to 21 ppt. The western and northern margins of the bay are affected by fresh water from creeks and rivers. Wells stated that productive clam beds in Chincoteague Bay are located near inlets in relatively saline waters. Further south in Georgia's Wassaw Sound, dense clam beds (with finds of >15/15 min effort) are mostly located in the shallow waters of the Sound within 6 km of coastal inlets. Clam beds near the Sebastian Inlet were found to be less sparsely populated than beds in areas just to the north (Arnold, 1986). The difference in distributional patterns between the Sebastian Inlet and the inlets mentioned above could possibly be explained by the presence of a different set of predators in the Indian River's "high salinity" areas or by long-period oscillations in salinity, water quality, or food supply.

Adult clams can, under certain conditions, tolerate low salinities for extended periods. Burrell (1977) found that oysters, although tolerant of lower salinities than clams, suffered much higher mortality during floodwater discharges from the Santee River system in South Carolina. Salinities remained below 10 ppt for 2 to 3-week periods. Oysters suffered mortalities ranging from 32% to 66% in various areas while clam mortality was less than 5%. Clam and oyster internal liquors remained at higher salinities than did their ambient environment. Hard clams can withstand direct exposures to fresh water for up to 114 hours (Pearse, 1936). Despite these extreme exposures, Eversole (1987) describes the hard clam as only moderately euryhaline and concludes, in reviewing the literature on clam responses to salinity, that optimum salinities for egg development, larval growth and survival, and adult growth are in the 24 to 28 ppt range.

Critique

The data needed to precisely define an acceptable and accurate salinity regime for clams in the Indian River Lagoon, within the range of Sebastian Creek freshwater outflows, need to be determined by research done in the area. Modern, *in situ* monitoring equipment now make it possible to follow salinity and temperature fluctuations in great detail. Such data sets, in conjunction with clam population data, would make it much easier to draw conclusions about the salinity tolerance limits of hard clams. The entire size spectrum of clams in the Indian River lagoon needs to be considered in such studies, and seasonal differences in salinity effects need to be observed.

The historical record that can be read from changes in abundances of hard clams and oysters in shell middens near the Sebastian River probably shows the effect of natural fluctuations in salinity regimes within the Indian River Lagoon (Busby, 1986). Elevated salinities are beneficial to clam populations while fluctuating salinities benefit oyster populations. Changes in salinities that could affect clam and oyster populations in historical times were probably due to drought/flood cycles and to changes in inlet locations. Recent records of shellfish bed types and locations, as seen in aerial photographs, observations by local fishermen, or positions of modern shell beds, could be used as a key to understanding salinity change in the Sebastian River area.

Some useful literature exists concerning the salinity tolerances of hard clams (Table 1). The field-data sets which include clam densities reported salinity as a variable measured only occasionally. Additionally, most studies were located well north of the area of our interest. Temperature tolerances, reproductive and spawning cycles, growth rates, and salinity tolerances vary between clam populations. Despite these limitations, some insights can be developed from the laboratory and field studies described above.

Salinity below 15 ppt may be considered "low;" such salinities affect clam physiology, behavior, reproduction, and survival. Small clams may survive low salinities for hours while large clams may survive for days, or even weeks, but they do so under stressful conditions.

A bottom salinity of 20 ppt is recommended as the lowest average salinity genuinely suitable for hard clams in the Indian River Lagoon near Sebastian. This value emerges from divergent studies of shell growth, spawning, larval growth, and field studies. In the spring and fall, when shell growth and spawning are normally at peak levels, salinities of 25 ppt or greater would be protective. With these as reference-points, salinity characteristics that may be recommended to maintain and enhance hard clam populations in the Lagoon[5] are that:

1. For a year as a whole, mean bottom salinity should be maintained at levels above 20 ppt.
2. The lower limit of bottom salinity should be 10 ppt and the upper limit can equal oceanic values.
3. In summer, mean bottom salinities should exceed 20 ppt and be associated with standard deviations not greater than 5 ppt. Excursions of summer-time salinity below 15 ppt should not persist for more than 1 week (7 days).
4. During other times of the year, mean bottom salinities should be equal to or exceed 25 ppt and be associated with standard deviations not greater than 5 ppt.
5. From September to December and from March to June[6], minimum bottom salinities should be greater than 25 ppt.
6. Successive high tide, bottom salinities should not increase by more than 5 ppt, and successive low tide, bottom salinities should

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[5]/ Salinity segments "Inlet," "North Shore," and "South Shore."

[6]/ Or when local data indicate onset of peak spawning.

not decrease by more than 10 ppt, beyond background rates[7] as a result of surface water management operations.

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7/ Defined as the rates of salinity change that would occur between reference tides in the absence of surface water management structures and operations.

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Table C-1. Salinity tolerance studies of embryonic, larval, juvenile, and adult *Mercenaria mercenaria* and *M. campechiensis*.

Species	Life History Stage	Source of clams	Salinity Range Tolerated	Citation
M. mercenaria	egg to veliger	Long Island	20.0-32.5	Stanley and DeWitt, 1983
M. mercenaria	egg development		26.5-27.5	Davis, 1958
M. mercenaria	larval growth		>20.0	Davis, 1958
M. mercenaria	larval growth		>22.5	
M. mercenaria	adult growth	Narragansett Bay	21.4-32.0†	Pratt and Campbell, 1956
M. mercenaria				
M. mercenaria	adult growth	Redfish and Christmas Bays, Texas	>18	Craig et al., 1988

† Range of salinities measured over healthy clam beds in Narragansett Bay... salinities within this range were not correlated with clam growth rates. Few clams are found in or near the Wilmington or Bull Rivers.

Figure 1.

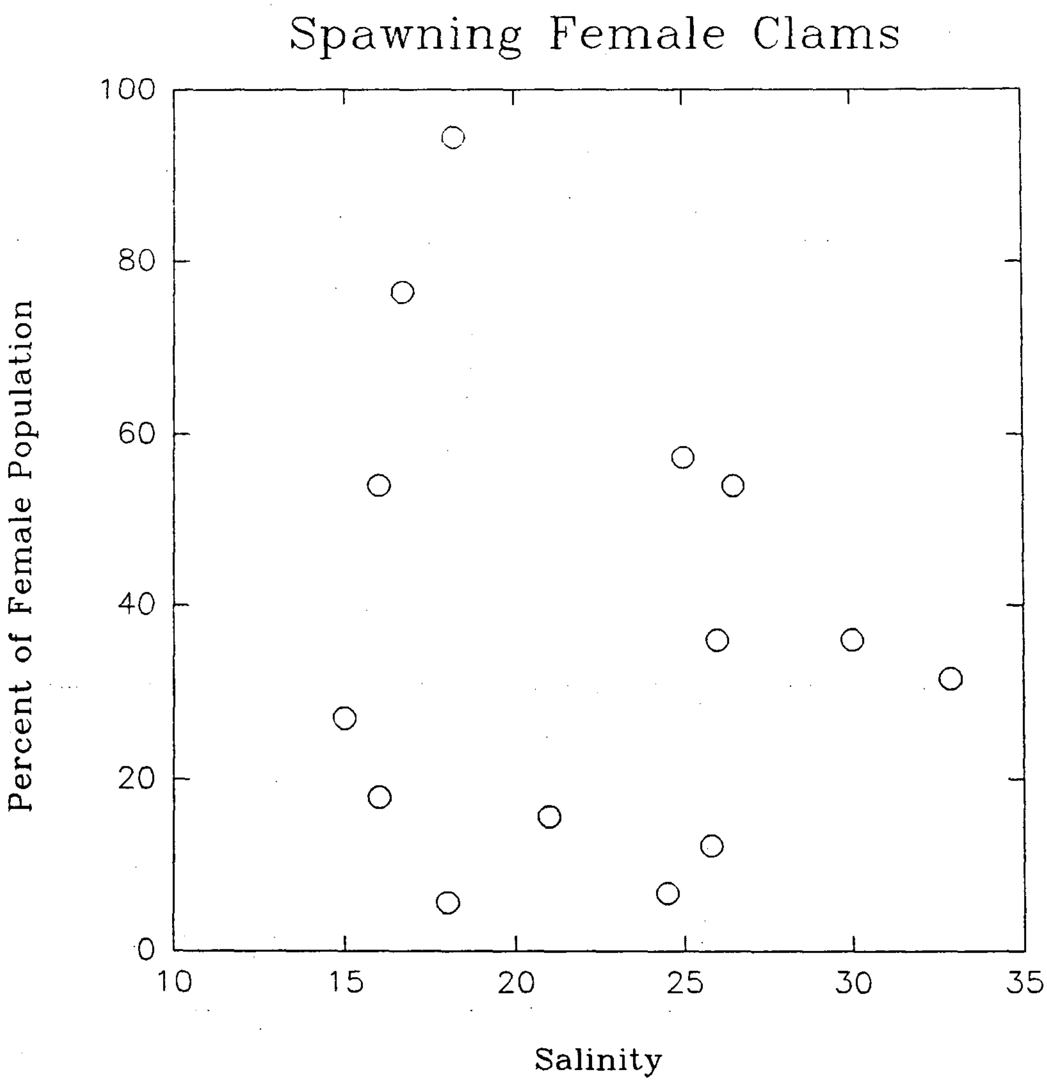
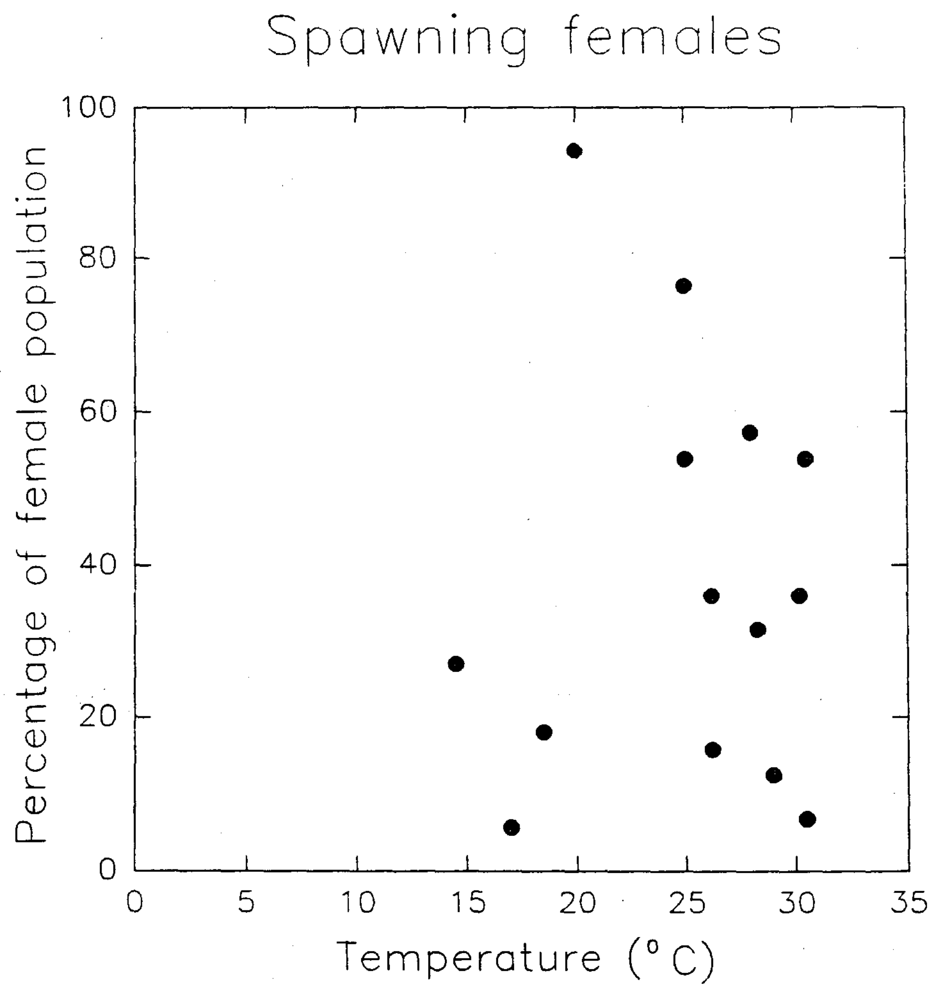

Spawning Female Clams
Percent of Female Population
100
80
60
40
20
0
10
15
20
25
30
35
Salinity

Figure 2.


Spawning females
Percentage of female population
Temperature (°C)
0
20
40
60
80
100
0
5
10
15
20
25
30
35

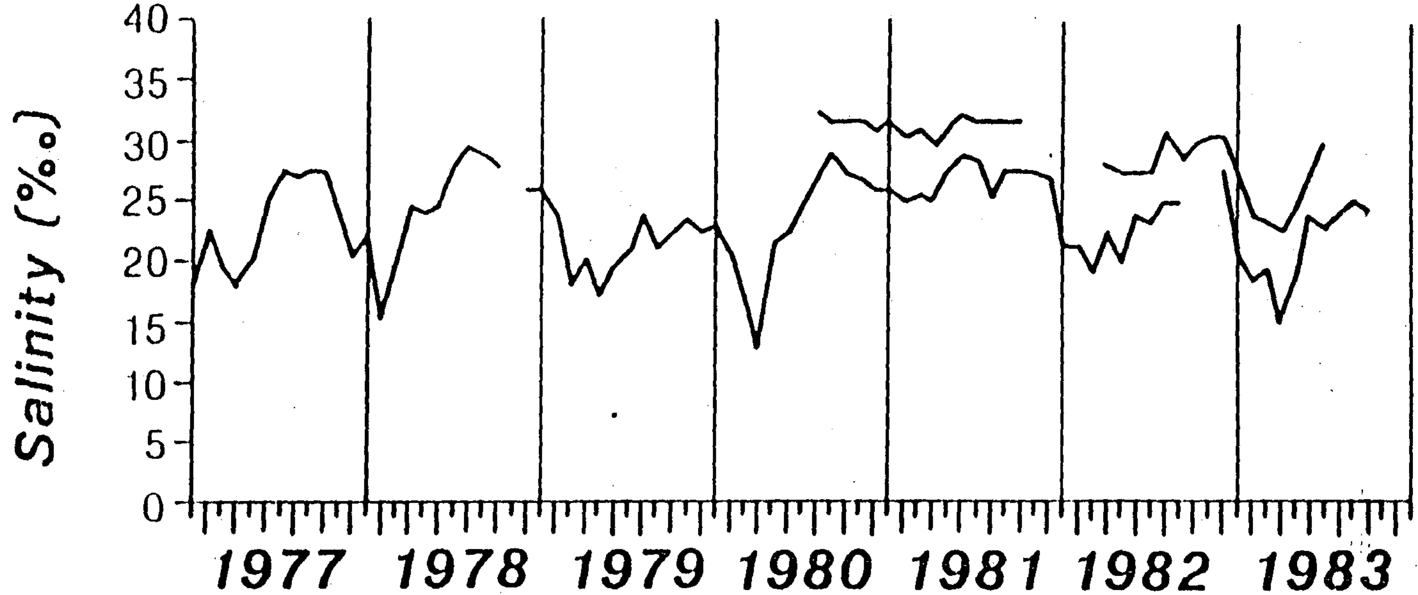


Figure 3. Average monthly water salinities of Skidaway River at Skidaway Institute near Wassaw Sound (lower line, 1977-83), and of Dead Man Hammock tidal creek, Wassaw Sound (upper line, 1980-83).

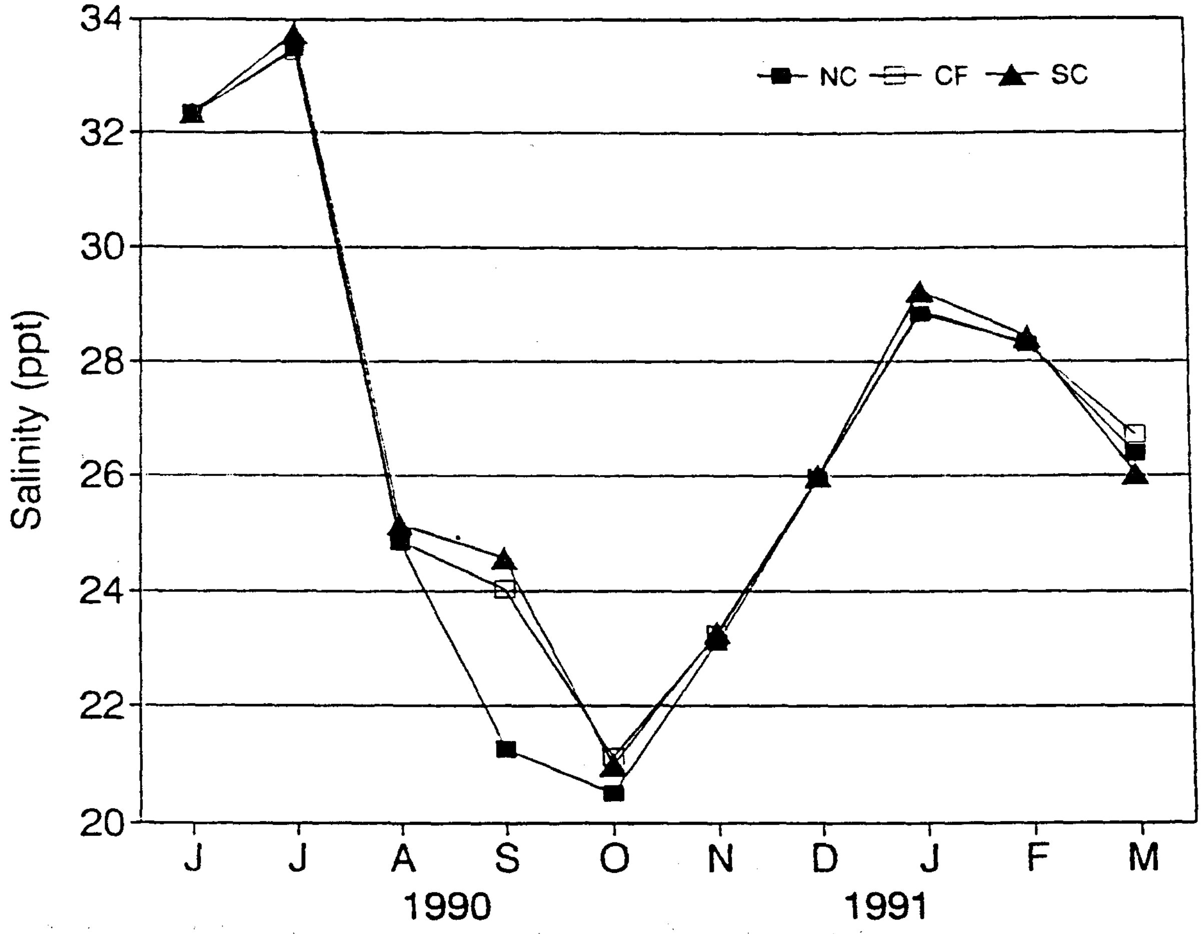


Fig. 4 Comparison of mean monthly salinity among sites (NC=North Control, CF=Clam Farm, SC=South Control; n=10 readings/site/date).

9. Oysters

Oysters were once abundant in sufficient quantities to form significant shell formations in the geologic strata underlying the Indian River Lagoon near Vero Beach (Trefry, in preparation), but such formations are not present near Sebastian. Historically, oysters were present in abundance within certain sections of the Indian River Lagoon. However, Carroll (1983) reported only small patches of oysters scattered in the nearshore area along the western shore of the Indian River Lagoon, both north and south of the mouth of the Sebastian River. Based on the scarcity of published reports on oysters (Virnstein, 1987), oyster reefs are not extensive in the Lagoon today.

Oysters are immobile, after a larval stage, and are therefore subject to the permanent effects of salinity changes due to alterations of riverine inflow, ocean influence, or circulation. Low riverine flows of short duration result in high salinities in Apalachicola Bay and result in increased predation on newly settled spat; population sizes of adult, harvestable oysters are reduced 2 and 3 years later (Wilber, 1992). Wilber found little evidence that high flows of short duration (≤ 30 days) adversely affected oyster harvests for the same or subsequent years. Her analyses were based on river flow data (kept by the Northwest Florida Water Management District) and oyster harvest data from 1960 to 1981.

Oysters can avoid predation by tolerating salinity fluctuations that their natural predators cannot tolerate (Gunter, 1955). Low salinities kill oyster drills and starfish (Sellers and Stanley, 1984). Maintenance of salinities within ranges above the lower tolerance limits of oyster predators usually results in major declines in oyster abundance (Allen and Turner, 1989). Ortega and Sutherland (1992) found adequate spat settlement in both low salinity (< 15 ppt) and high salinity (> 20 ppt) reaches of Pamlico and Core Sounds, North Carolina. Algal turfs and poor sediment inhibited growth in low salinity areas and competition by fouling organisms retarded success in high salinity areas.

Salinity requirements of _Crassostrea virginica_ are reviewed in Sellers and Stanley (1984). Adult oysters tolerate a salinity range of 5 to 30 ppt. They do best within a salinity range of 10 to 28 ppt (Loosanoff

1965a). Salinities below 7.5 ppt inhibit spawning. Maximum larval growth and survival occur above salinities of 12.5 ppt and maximum spat growth occurs between 15 and 20 ppt.

Oysters can tolerate salinities as low as 6.0 ppt for 14 days, and 3.0 ppt for up to 30 days (Loosanoff 1965b). When flood conditions persist for 30 days or more, oyster mortalities typically reach 100% (Allen and Turner, 1989). Sellers and Stanley (1984) reported major oyster mortalities in several areas that were affected by major floods when salinities remained below 2 ppt for extended periods.

On Louisiana's state seed grounds Chatry et al. (1983) found that salinity in the setting year is the prime determining factor for the production of seed oysters. Both high and low salinities resulted in poor seed production. Low salinities resulted in insufficient setting while the negative effects of high salinities were believed due to the effects of predation on oyster spat. The maintenance of optimum setting salinities was most critical from May through September. To optimize Louisiana spat production, Chatry et al. recommended May salinities between 6 to 8 ppt; salinities should average 13 ppt in June and July and not increase to greater than 15 ppt until late August, and September salinities should not average more than 20 ppt.

In the Loxahatchee River, Mote Marine Laboratory (1990) determined that the mean size of the largest oysters among 15 oyster clumps per station was greatest where surface salinity was approximately 15 ppt and the standard deviation about the mean was at its greatest in the River, about 7 ppt (Figure 1). On the Florida west coast, Dawson (1955) found that oyster production near Crystal River was high along a marsh-dominated coast with salinity averaging between 10 and 20 ppt (Figure 2). Salinity ranged from 0 to 28 ppt across all stations.

Critique

Salinity fluctuations within the natural Indian River Lagoon apparently favored clams during certain periods and oysters during others (Busby, 1986). Very few oyster fishermen currently operate in the Sebastian River area of the Indian River Lagoon. Oyster bars used to extend well into the mouth of the Sebastian River. Some large oysters can still be found on the pilings of the railroad bridge near the mouth of the Sebastian River (B. Alles and C. Sembler, Sembler and Sembler, Inc., personal communication). Local fishermen believe that recent salinity fluctuations caused by freshwater discharges have exceeded even the broad salinity tolerances of the truly euryhaline C. virginica. Other water quality factors are also believed to contribute to the decimation of oyster populations in the Sebastian River vicinity. High levels of nutrients, biological oxygen demand, and color in water coming out of agricultural areas and other basins drained by the various canals may lower dissolved oxygen (D.O.) levels. Low D.O., in turn, has the potential to impact larval, juvenile, and adult oysters. Low D.O. and salinity stress may act synergistically to kill all but the most hardy adults.

If salinities are managed for clams in the Indian River Lagoon, then oyster areas may be restricted to the Sebastian River. Oysters in the River would not be safe to eat but they could serve to demonstrate the attainment of target salinity regimes. Oysters also accumulate a wide array of pollutants and are useful as indicator species. More importantly, oyster reefs are an important habitat for a wide variety of associated organisms. Small crabs, fish, shrimp, sponges, other mollusks, and numerous polychaete species are all typical inhabitants of healthy oyster reef communities (Bahr and Lanier, 1981). An increase of oyster habitat in the tidal reaches of the Sebastian River would increase the River's overall levels of biodiversity and productivity.

Based on a review of oyster salinity requirements we find that:

1. Salinities in areas where oyster bars are desired can be allowed to fluctuate broadly between 10 to 28 ppt, and these areas should possess strong longitudinal salinity gradients and mixing.
2. Lower salinities can be briefly tolerated by adult oysters. Salinities less than 6 ppt should not be allowed to persist longer than 2 weeks, nor should salinities lower than 2 ppt be allowed for longer than a week.
3. To protect recruitment, salinity during local spawning seasons should be above 10 ppt. Optimal larval and spat growth and survival can be obtained in salinities between 12.5 and 20 ppt.

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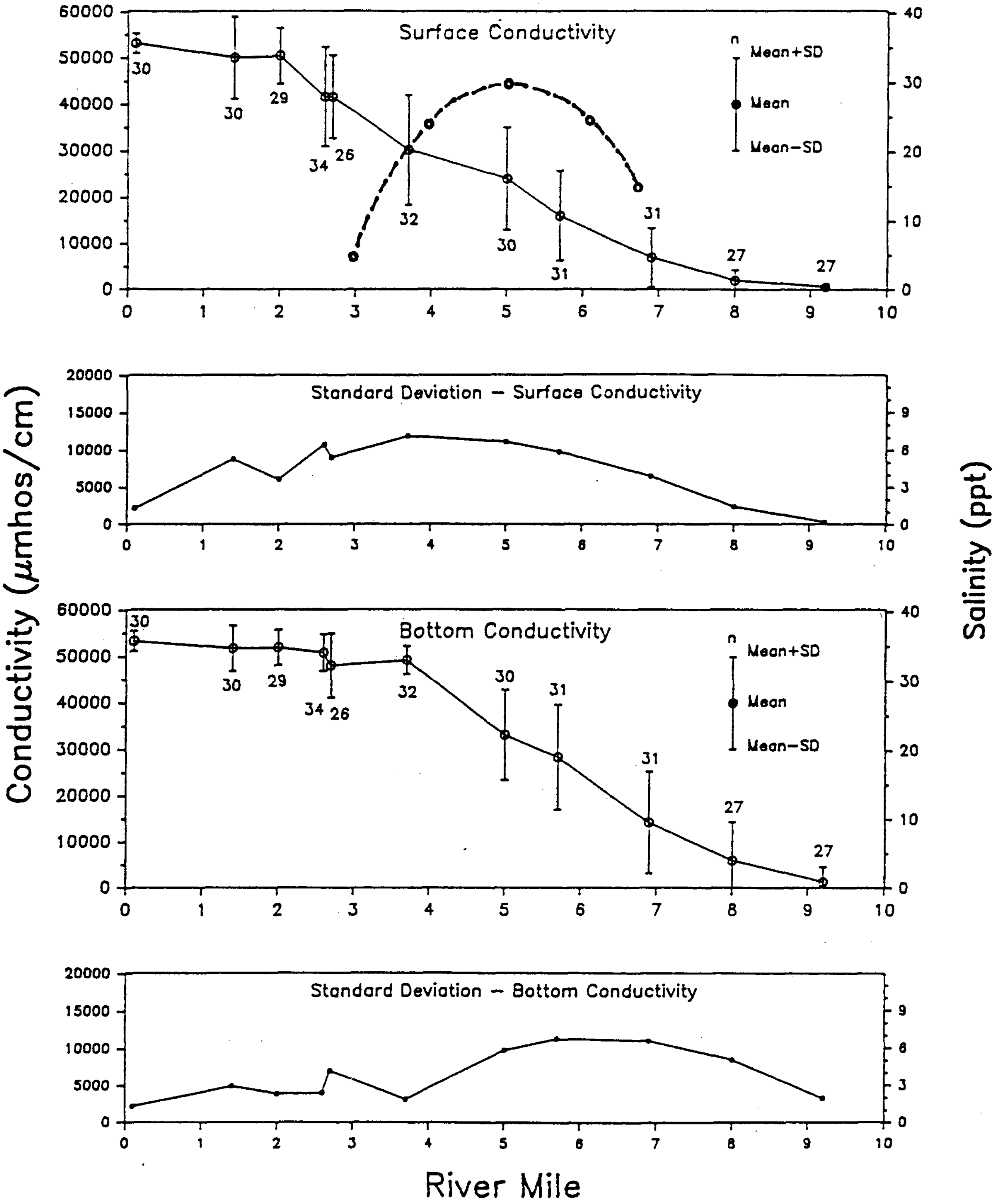

Figure 1. Second-order polynomial fit of oyster size (curved, dashed line at top of figure) in relation to mean surface conductivity of the Loxahatchee River. Sampled during high tides, 1985 - 1988.

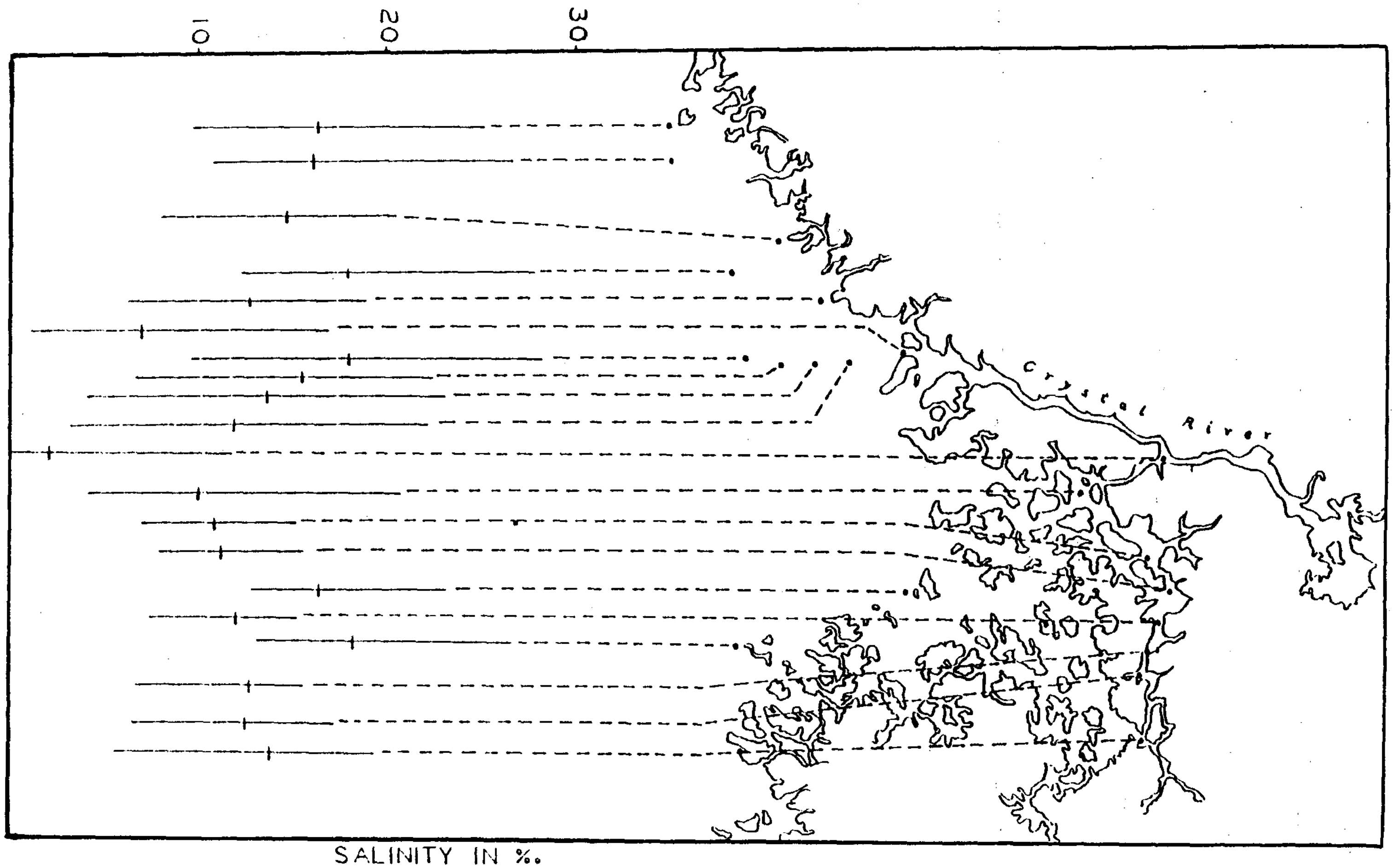

Figure 2 Haligraph showing surface salinity means and ranges at all stations, September 1951 through August 1952. Perpendicular solid line shows salinity range and cross-bar indicates the mean. Stations are, from left to right, Drum Island, Demory Gap, Negro Island, Tin Pan Gap, Black Point, Shell Island, Marker #5, Marker #10, Marker #12, Marker #16, Salt River Branch, Big Coon Gap, Lewis Creek, N. Dixie Bay, Mullet Key, S. Dixie Bay, Mangrove Point, N. Narrows, Mid Narrows and S. Narrows.

10. Fish

Fish populations may be affected greatly by rapid salinity shifts. Spotted seatrout (Cynoscion nebulosus), snook (Centropomus undecimalis), and red drum (Sciaenops ocellatus) are common residents of the Sebastian and Indian Rivers (Evermann and Bean, 1898; USFWS, 1958; Gilmore, 1988). They are variably affected by low salinities, and a single salinity regime may not be suitable for all three species. Additionally, these three fish are dependent on a rich and diverse invertebrate and fish-based food chain. Altered salinities can be predicted to have different effects on each of the prey species of the three carnivores mentioned above. A study of salinity change effects on fish and invertebrate populations in the St. Lucie estuary (Haunert and Startzman, 1980), while informative, was concerned with short-term changes in fish and invertebrate populations. They did not consider the long-term biotic changes in this estuary that resulted from the permanent alteration of stream flow caused by the various water control structures upstream from the St. Lucie Estuary. Their study basically reported that animal communities which had already been affected by a long history of stream flow alterations were not significantly affected by a single test discharge.

Adults of the three species considered below are mobile, and they have wide salinity tolerance ranges (Haunert and Startzman, 1980; Banks et al., 1991). Their larvae and juveniles are poor to weak swimmers and have more narrow salinity tolerance ranges. Adult snook, for example, spawn in inlets and spend much time in the vicinity of dams feeding on freshwater prey species that are stunned or killed by their passage over dams (Marshall, 1958; Seaman and Collins, 1983). Much of the following discussion centers on the salinity requirements of the larval and juvenile stages of these three fishes.

Spotted Seatrout (Cynoscion nebulosus)

Spotted seatrout supported an active fishery in the Indian River for many years (Everman and Bean, 1898). Few trout fishermen still fish in the Indian River near Sebastian (C. Sembler, Sembler and Sembler, Inc., personal communication). They either fish for other species or have retired. The apparent decline in this fishery may be related to losses of seagrass beds on which juvenile and adult seatrout are fully dependent. The seatrout may also be directly affected by altered salinity regimes produced by current water management practices.

A recent study (Banks et al, 1991) demonstrated that salinity tolerances of spotted seatrout are age-linked. Upper and lower tolerances changed during early growth. The results of this study were complicated by the fact that seatrout embryos -- acclimated to altered salinities -- produced larvae that were more tolerant of extreme salinities. The narrowest range of salinity tolerance, 6.4 to 42.5 ppt, occurred on day 3 after hatching. Feeding begins on day 3 after hatching; the change from dependency on yolk to exogenous foods and the immature state of the osmoregulatory system undoubtedly account for the higher sensitivity to salinity change. Figure 1 summarizes the salinity requirements of larval spotted seatrout spawned in full strength seawater and reared under optimum temperature conditions. Salinity ranges for successful reproduction and larval survival of spotted seatrout were approximately 20 - 45 ppt and 10 - 40 ppt, respectively (Holt and Banks, 1989).

Seatrout spawn in deep channels adjacent to seagrass beds or in tidal portions of estuaries (Lorio and Perret, 1978). The Intracoastal Waterway in the vicinity of the Sebastian River would fully fit this description of optimum spawning grounds. Florida's spotted seatrout spawn from April through September with peaks in late May or early June (Lorio and Perret, 1978). Salinity reductions, to levels below the tolerance limits of seatrout larvae (below 10 ppt), during this time could cause tremendous mortalities to occur among populations of recently hatched seatrout larvae.

Sudden, massive salinity reductions have been observed to cause either mass migrations from or mortalities of adult seatrout in Florida estuaries (Tabb, 1966). Adult seatrout are a truly euryhaline species, but they apparently cannot tolerate sudden salinity changes of the type that may occur during hurricanes or tropical storms.

Juvenile seatrout feed on larval shrimp, copepods, small fish, and crabs. Larger fish switch to larger prey including croaker, spot, mullet, and penaeid shrimp. The proportions of these prey change during the year as their abundances change within seatrout feeding grounds (Gunter, 1945).

Seagrass beds are optimum feeding grounds for seatrout because of their highly abundant and diverse assemblages of animals (Virnstein, 1983; Gilmore, 1988). The salinity requirements of these organisms, which may be more or less salinity tolerant than are seatrout, must also be considered when addressing the question of an acceptable salinity regime for seatrout within the vicinity of the Sebastian River.

Pink shrimp require changing salinities but in a particular pattern during larval, juvenile, and adult life (Browder, 1985). Caridean shrimp can be expected to have a wide range of salinity tolerances that are also affected by life stage (Anderson, 1985). Blue crabs also have highly variable salinity requirements throughout larval, juvenile, and adult stages (Perry and McIlwain, 1986). The many other species characteristic of seagrass beds can be expected to have a very wide array of salinity requirements. Because prey species should all be capable of living and successfully reproducing in the salinity regimes that most favor seagrasses, recommended salinities for seagrasses (Section 7) should be consulted.

Snook (Centropomus undecimalis)

Within the Indian River Lagoon, snook utilize a series of habitat types that are dependent upon the growth stage of this species (Gilmore et al., 1983). Juvenile snook, ranging from 11-156 mm SL (mean = 27.5 mm) reside for 10 to 70 days within the freshwater tributaries of the Indian River Lagoon. Larger juveniles, from 10-174 mm SL (mean = 67 mm) are found in marsh habitats where they remain from 60 to 90 days. Freshwater and marsh recruitment peak in summer and fall (Gilmore et al, 1983). Juvenile snook move from marshes to seagrass meadows after reaching lengths from 100 to 150 mm SL at ages of 4 months or more. Seagrass meadows above a minimal density are more heavily utilized by juvenile snook than are low density seagrass beds. Seagrass beds offer protective shelter for snook, and the beds are inhabited by a wide array of prey species that are consumed by snook. The average size of juvenile snook within Indian River Lagoon grass beds averages 240 mm SL. Seagrass-resident snook reach ages of 220-285 days old before they leave grass beds as maturation begins.

Snook diets change during juvenile growth and adult maturation. In freshwater, juveniles prey upon microcrustacea, palaemonid shrimp, and neonatal mosquitofish, Gambusia affinis (Gilbert et al, 1983). Saltmarsh juveniles prey upon sheepshead minnows (Cyprinodon variegatus), mosquito fish, palaemonid shrimp, and microcrustacea (mysids, copepoda, etc.). In seagrass beds, larger juveniles prey upon a variety of fish and penaeid shrimp (Gilbert et al., 1983). Adult snook switch diets as they move from areas of higher to lower salinity (Marshall, 1958).

Snook survive in freshwater but they cannot reproduce because their spermatozoa require activation by saltwater (Seaman and Collins, 1983). Massive releases of freshwater into the Sebastian River probably do not compromise the osmoregulatory abilities of the common snook, but increased flows may wash weakly swimming juveniles and their prey from the preferred low-salinity habitats. Salinity reductions within saltmarshes and seagrass beds may cause drastic shifts in the abundance and composition of prey communities. Additionally, nursery and juvenile habitat destruction caused by the death of seagrasses and algae may ensue after salinity reductions occur.

Red Drum (Sciaenops ocellatus)

Red drum are tolerant of a wide range of salinities (reviewed by Reagan, 1985). Adults have been collected from areas of virtual freshwater (0.3 ppt in Louisiana) and from areas with salinities exceeding that of full strength seawater (40 - 50 ppt in Texas). Small fish are more common at low salinities, and large fish seem to prefer higher salinities (Yokel, 1966). Perret et al. (1980) summarized numerous studies from widely scattered areas to report that juvenile red drum have been captured at salinities ranging from 0 ppt to 30 ppt. Highest catches of small red drum in Mississippi occurred when salinities ranged from 20 to 25 ppt.

Red drum larvae have salinity tolerances (15 - 35 ppt., Figure 1) that were somewhat narrower than the salinity range tolerated by larval spotted seatrout (Holt and Banks, 1989). These authors found that salinities above and below these ranges significantly impaired all phases of reproduction and larval development in red drum.

Adult red drum are likely to swim away from areas with salinities above or below their preference range. Juveniles may be able to tolerate extremely low salinities, but their rates of acclimation to freshwater are not known. A sudden salinity shock could have a large negative impact on red drum juveniles within the Indian River Lagoon. The preferred prey of red drum undoubtedly have a wide array of salinity tolerances and preferences.

Critique

Salinity tolerance experiments, of a design meaningful to the establishment of an acceptable salinity regime for the Sebastian River, have not been done with the three fishes reviewed in this section. The prey of these carnivorous fish must also be considered before adopting any given salinity regime for the Sebastian River. All classic field studies on catches and salinities are based on non-continuous salinity monitoring. It is impossible to describe the time course of salinity changes that are faced by these three estuarine fish species and their prey in any area. Catch data must be based on frequent collections and, to be meaningful for our purposes, must be correlated with continuously collected salinity, temperature, and dissolved oxygen records. This type of research was virtually impossible until the advent of relatively low-cost remote monitoring units. Now that this equipment is available, much new research should be funded to produce the kind of data that is needed to fully understand the impacts of managed salinity regimes.

The salinities required by the three fishes are dependent upon their respective life stages. Populations of the three fish considered herein would benefit if salinities could be regulated to mimic their developmentally and seasonally changing needs.

Based on a review of seatrout, snook, and red drum salinity requirements we find that:

1. Salinities must be held at seasonally appropriate levels within nursery grounds and spawning areas for each of these three species. When red drum and seatrout larvae are present the red drum larval tolerance range of 15 -35 ppt should not be exceeded.
2. Juvenile snook must have access to freshwater nursery areas such as those which exist in the upper reaches of the Sebastian River. Salt-water should not be allowed to encroach on these areas due to its lethal effects on many of the prey species consumed by juvenile

snook. Existing flood control structures may block juvenile snook from a large part of their favored nursery habitat.

3. Any salinity regime must also consider the changes in salinities that occur during the life cycles of the prey species eaten by seatrout, snook, and red drum. These requirements are poorly known but should, in general, follow the salinity requirements of the seagrasses common in the area. In upstream nursery habitats, vegetation patterns could be used a simple index of the impacts of water management options.

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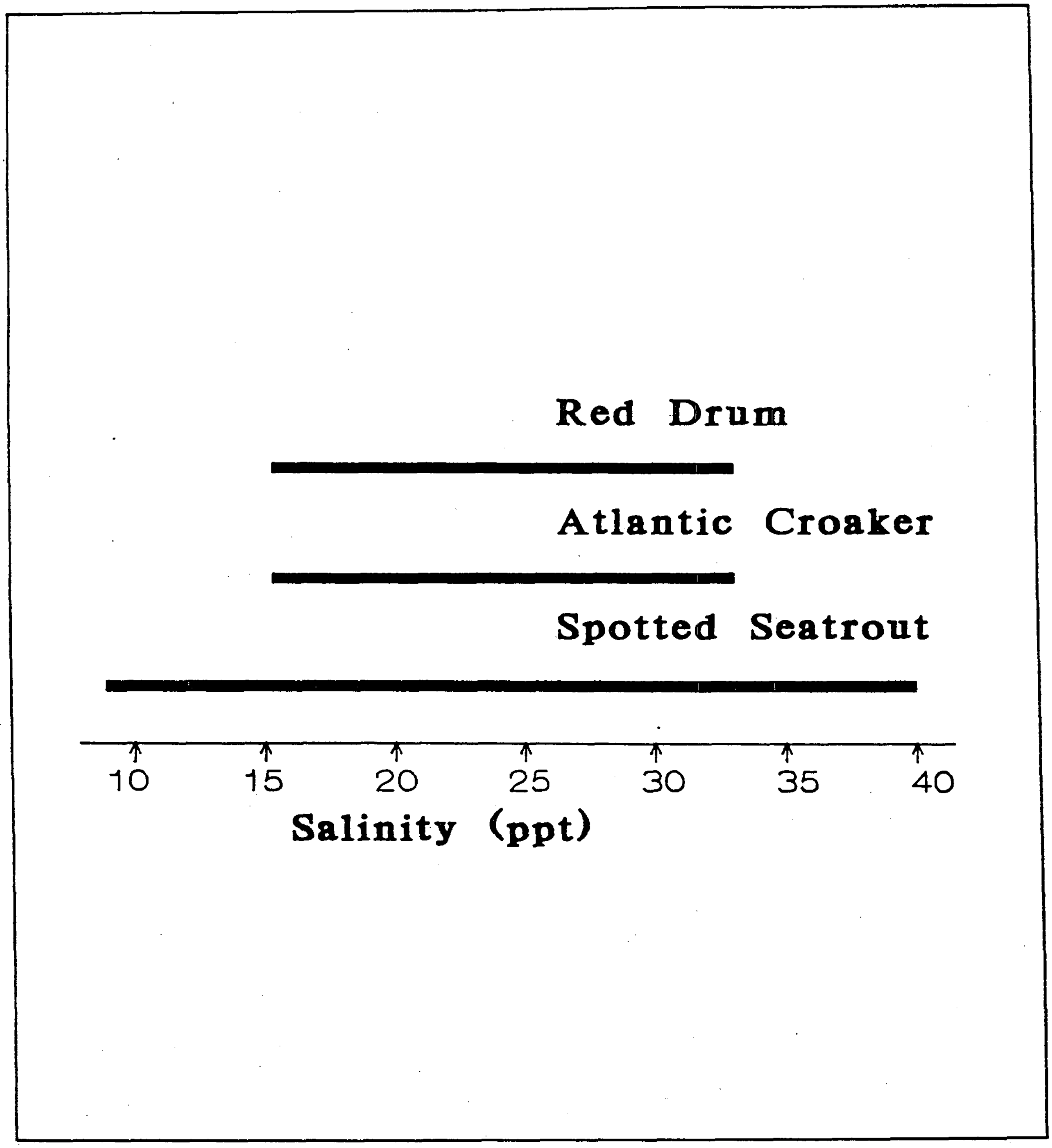

Figure 1. Salinity limits for no salinity related mortality during the pelagic larval stage of three species of sciaenids spawned in near full strength sea water and reared under optimum temperature conditions.

11. Species at Risk

Species at risk refers to species listed by federal or state agencies as endangered, threatened, rare, or of special concern. Data for the following reports were taken from Gilmore and Hastings (1983), Heyman (1990), Muller (1990), and Gilbert (1992). Unpublished data from J.D. Carroll, Jr. (U.S. Fish and Wildlife Service, Vero Beach) are also reported.

Muller (1990) notes 31 listed species from Brevard County and 34 species from Indian River County, with riverine or estuarine affinities. Three-fourths of the listed species are birds in each county, and 10 in each county are listed as rare; the others are listed as common. Based on the availability of data and the nature of their distribution and ecology near Sebastian, this analysis focuses on selected species of fish and the West Indian manatee.

Fish

Four species of fish are listed as threatened by Gilbert (1992) and all occur within the Sebastian River. They include the opossum pipefish (*Microphis brachyurus lineatus*), bigmouth sleeper (*Gobiomorus dormitor*), river goby (*Awaous tajasica*), and slashcheek goby (*Gobionellus pseudofasciatus*).

The opossum pipefish is a cosmopolitan anadromous species of the tropics and subtropics, and occurs in canals and rivers discharging to the Atlantic coast of Florida, including the Sebastian River. Found in a wide range of salinities (to 37 ppt), most captures have been in fresh water. It grows and reproduces in freshwater marsh environments. The species is present year-round, but larger fish and brooders were more abundant in low salinity during summer months; smaller animals were taken at higher salinities in winter (Gilmore, 1977). The species was designated as rare by FCREPA[8] in 1978 and is now listed by that group as threatened.

The bigmouth sleeper has a Caribbean distribution and a southeast Florida distribution similar to the opossum pipefish. It has been collected in the Sebastian River, where there is also evidence for spawning. The

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8/ Florida Committee on Rare and Endangered Plants and Animals.

species is eurytopic for salinity (0 to 13 ppt) and habitat but is typically found in flowing fresh water. It also occurs in sluggish water near vegetated banks. It has been collected throughout the year with peak abundance from January through July. Abundance declines in wet seasons.

The river goby inhabits shaded sand bottoms of flowing, oxygenated streams where salinities fall below about 4 ppt. Larval stages may occur in brackish water, but the species is otherwise a freshwater inhabitant and is most abundant in the spring. Unlike the opossum pipefish and bigmouth sleeper, upstream movement of the river goby is adversely affected by dams and salinity barriers. Like the opossum pipefish, FCREPA has elevated its designation from rare to threatened. The slashcheek goby also occurs year-round in flowing freshwater below structures, over unshaded sand bottoms. It is most common in the spring dry season. This goby has a salinity range of 0 to 13 ppt, and it aggregates in upstream areas during the spring of the year. Figure 1 illustrates changes in the seasonal dispersion of slashcheek gobies in the Sebastian River.

The relationships of these listed species, and species of economic value, to the low salinity areas of the Sebastian River system were discussed in detail by Gilmore (1981):

> "Our data indicate that the present freshwater flow conditions in the North Fork (not North Prong) of Sebastian Creek, Fellsmere Canal - C-54 canal region, are sufficient to produce a productive nursery area for commercial and sport fisheries and rare fish species that appear to be limited to the Sebastian Creek drainage and adjacent freshwaters in Indian River County.
>
> The freshwater flow through the North Fork of Sebastian Creek is much lower than that flowing through the South Fork. Because of this differential flow a further reduction of flow in the North Fork may reduce its estuarine character to the point that it is not a viable habitat for many of the species we have collected there. However, I have no information on predicted flow rates and present flow rates and what may be the reduced flow rate effects on the fish fauna of the Sebastian Creek estuary. It is, therefore, difficult for me to predict the changes that may take place. We do have considerable data on the fish fauna in the North Fork of Sebastian Creek and the Fellsmere Canal. We have collected fishes at these locations on a monthly schedule from 1978 to December 1980.
>
> Our data is still being analyzed but several preliminary results can be presented. We have collected 73 fish species in Fellsmere Canal and the adjacent portion of the North Fork of the Sebastian Creek. Thirty-one of these fishes occur in local sport and commercial fisheries. I have observed a gradient of both species and

numbers of individuals relative to the Fellsmere spillway (Erosion Control Structure on map Enclosure 2 of your 4 February, 1981, correspondence). More species and individuals per species occur in the vicinity of the spillway than downstream. There is a gradient of species and individuals which roughly follows the salinity gradient with fewer species under brackish conditions (5-13 ppt) than under freshwater to very low salinity conditions (0-4 ppt). The Fellsmere Canal spillway creates a discrete ecotone between freshwater and brackish water habitats and therefore acts as a speciose transition zone between representative faunas. A similar ecotone and rich ichthyofauna occurs [sic] at the mouth of the Sebastian Creek where it enters the Indian River lagoon where a marine faunal element is encountered.

The Fellsmere Canal spillway also acts as a barrier to the upstream migration of many euryhaline species (i.e., snook, *Centropomus undecimalis*, and mullet *Mugil* spp.) which tend to concentrate below it. Our studies show that post larval snook (15 to 25 mm in standard length) migrate to freshwater tributaries such as Sebastian Creek after hatching in the Atlantic Ocean. Sebastian Creek is a critical nursery area for juvenile snook in their early periods of development. Their upstream migration appears to be oriented along the salinity gradient with most individuals being captured under the Fellsmere Canal spillway.

The first continental record for the slash-cheek goby, *Gobionellus pseudofasciatus* was made from specimens collected in the Sebastian Creek at the Fellsmere Canal. Our research indicates that the largest concentration of this rare species in North American waters occurs in the Sebastian Creek and the Fellsmere Canal. This is also true for the rare species the opossum pipefish, *Oostethus brachyurus*, and the bigmouth sleeper, *Gobiomorus dormitor* (the former species is listed as rare in Florida waters by the Florida Game and Freshwater Fish Commission, FGFFC). Another species considered rare in Florida waters (listed by FGFFC), which has also been collected below the Fellsmere Canal spillway, is the river goby, *Awaos taiasica* [sic].

It is therefore apparent from our work that the Sebastian Creek drainage not only supports many species of sport and commercial fishery value but a number of rare species unique to this portion of Florida and North America.

Our data indicates that the release of freshwater during 1979 created an ephemeral problem for fishes in the drainage. Both freshwater and estuarine species were displaced downstream. However, these releases occurred during periods of natural seasonal peaks in freshwater flow and had no evident long lasting effects on the spot release readjustment of the faunas. From these observations I would tend to believe that removal of freshwater from the Sebastian drainage would be more damaging than major releases of freshwater into the drainage during natural seasonal periods of heavy rainfall.

The gobiid fauna of Sebastian Creek is particularly rich. Besides the nine species listed in the enclosure, *Bathygobius soporator* occurs in the lower reaches of the stream, east of Zone IV. I know of no other stream in the United States where ten species of gobies could be found. These fishes, although basically a marine group, are very much like freshwater darters (percids, *e.g.*, snail darter, *Percina tanasi*) in that they are small (usually <75 mm SL) benthic fishes with limited mobility. Therefore, like benthic invertebrate communities, microhabitats and water character are critical parameters. These parameters are currently adequate in Sebastian Creek or these species would not be there today."

Manatees

The West Indian manatee is one of the most endangered of American marine mammals and is protected by federal and state law. It is present in relatively high numbers in Brevard County (Hartman, 1979), and consistently inhabits the Sebastian River. Several manatee mortalities are reported for the Sebastian River system (Figure 2).

Heyman (1990) estimated manatee use of the North Canal from November 1989 to June 1990. Manatee numbers were negatively correlated with water temperature. Salinity at the upstream (west) end of the study area ranged from 2 to 17 ppt. At the east end of C-54 salinity varied between 11 to 16 ppt and at the confluence of the North and South Prongs the mean salinity was 23.0 ppt. Salinity did not appear to play as significant a role in manatee distribution as did the presence of freshwater near the control structure. Salinity was indirectly important insofar as manatee distribution was also affected by the availability of natant vegetation (alligator weed and water hyacinths). Feeding was not, however, a predominant activity because suitable vegetation was not abundant. Heyman (1990) opined that manatees entered the Indian River Lagoon to feed on seagrasses. Manatees are present in the Sebastian River in summer as well, but their abundance in winter suggests that the river is also used as a resting stop during coastal migrations.

Critique

Fish species at risk that inhabit the Sebastian River system share interesting functional similarities, and some of these are also shared with manatees. These species utilize tidal and non-tidal, flowing fresh waters that may be occasionally affected by low salinity. Water temperature is a significant controller of their distribution and reproduction. All of these species make brief to long excursions into estuarine waters. The composition and abundance of floating and shoreline vegetation (marshes of Polygonum or Panicum) are important as cover or food. Most are affected to some extent by the presence of instream structures, and this applies to other, unlisted but important fish species, as well. "Of 73 species found in the North Fork of Sebastian Creek, 44 (60%) do not occur above the spillway" (Gilmore et al., 1981).

These shared habitat requirements underscore the role of tidal freshwater reaches of the Sebastian River system, and lead to the conclusions that:

1. Permanent reaches of tidal freshwater are desireable.
2. Their locations should correspond to known sites of listed species abundance and the presence of appropriate shoreline plant habitats.
3. Flowing/falling water conditions created by control structures should be perpetuated, although the feasibility of bypasses should be considered, to promote the movement of fishes beyond structures.
4. The areal extent of tidal freshwaters should be largest during summer and fall and smallest during winter and spring. Largest excursions of freshwater should coincide with naturally wettest periods.
5. Contractions of tidal freshwater reaches made for the purpose of acheiving other salinity recommendations should not extend farther upstream than the natural transition of historically present wetland soils and plant communities.
6. To benefit manatees, salinities of the Indian River Lagoon near the mouth of the Sebastian River should be conducive for seagrass growth.

A final conclusion may be transferable from a study of freshwater fish community structure in the West and Deerfield Rivers, two fifth-order tributaries of the Connecticut River (Bain et al., 1988). The West River is a natural stream and the Deerfield has artificial short-term fluctuations caused by hydroelectric plants. A guild of small species using shallow flowing waters and concentrated along stream margins (>90% of the fish in the unregulated West River) was significantly affected by erratic flow regimes in the Deerfield River. Pulsed flows retarded access to and persistence of this guild in shoreline vegetation. Although this study was performed in a freshwater environment, similarities of the affected guild to fish species at risk in the Sebastian River suggest that:

7. Rapid fluctuations of water levels in upper reaches of the North and South Prongs may adversely affect species with special affinity to shoreline habitats, and should be moderated to prevent loss of structural habitat.

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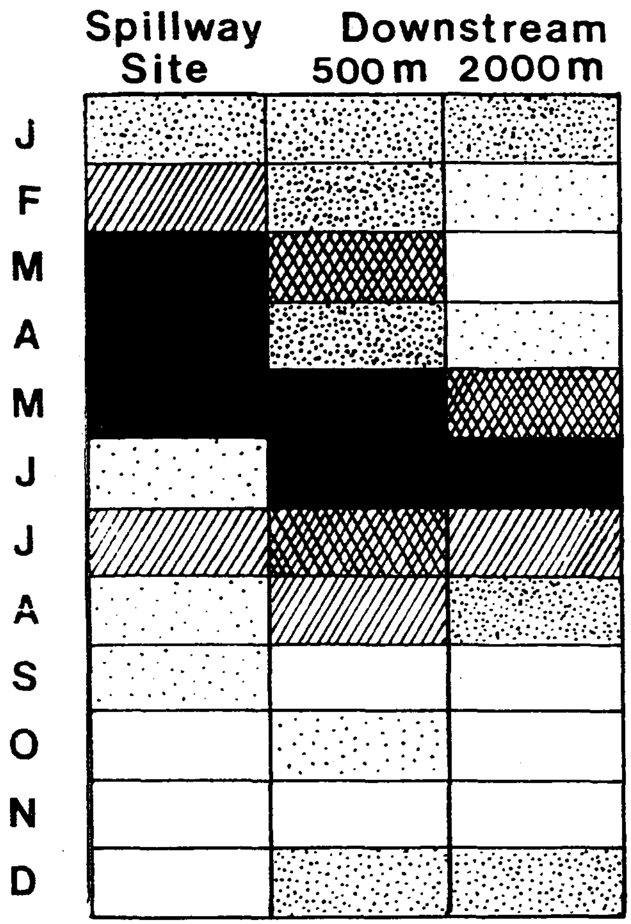
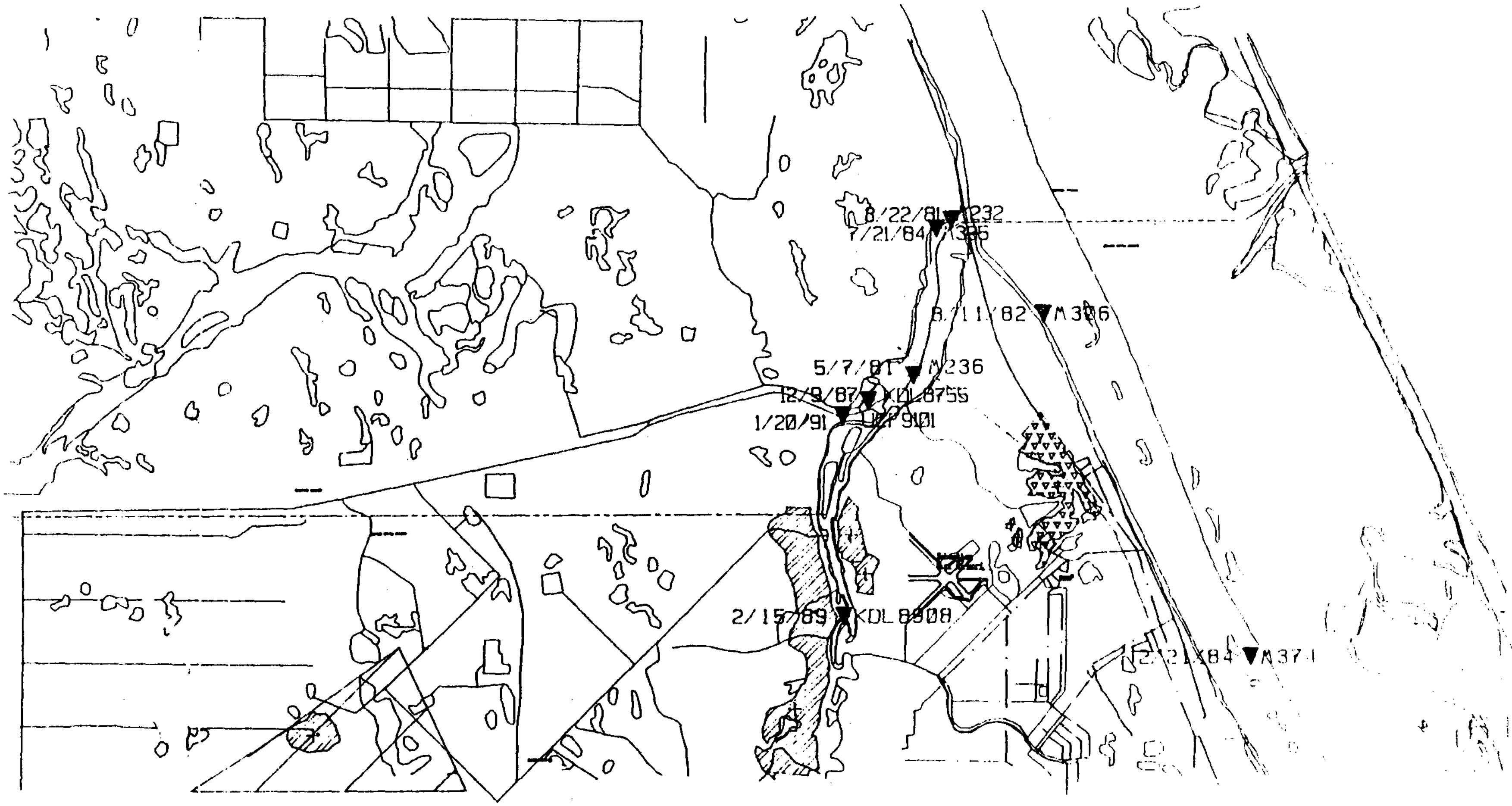


FIG. 1 Spatial and temporal distribution of *G. pseudofasciatus* in the north fork of Sebastian Creek and the Fellsmere Canal, 1979-1980. = 1-4 individuals, = 5-10, = 11-15, = 16-19, = 20+.



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Roads

FEC RR

County line

▼ West Indian manatee

Scrub - Type 2

Scrub - Type 3

Fl. panther "May Affect"
(Potentially suitable habitat)

⊗ Wood stork

Figure 2.

C-54 AREA, N. INDIAN RIVER COUNTY

USFWS NOV92

12. Recapitulation of Study Findings

This section provides excerpts from two earlier project reports, the Task 1 and Task 2 Reports, in order that pertinent guidelines used in this third report can be cited independently. Readers interested in details or context of the following remarks are referred to Estevez (1992) and Estevez (1993).

Task 1 Report: Review of Goals and Objectives

This report assessed existing laws, policies and objectives at federal to local government levels for insight to official expectations for the Sebastian River or Indian River Lagoon, and found:

1. There is an overall intent to reduce fresh water inflows to the River and Lagoon. A reduction of inflow will result in higher salinities in both the River and Lagoon.

2. At the same time, there is a perceived need to provide base flows for certain oligohaline species and their habitats. A base flow will result in the establishment of permanent, tidal fresh water and low salinity areas.

3. Inflows and salinities should vary according to seasonal or daily or other cyclic patterns. At the same time, the rate of change of inflows, and consequently of salinity variations, should be moderated. Given the concern for acute changes, guidelines for rates and ranges of salinity variation are as important as average salinity conditions.

4. The peaks of inflow should coincide with the natural wet season runoff of the basin, meaning that low salinities caused by regulated inflows should coincide with low salinities caused by natural runoff. Natural seasonality of salinity variation is sought.

5. The area and duration of low salinities caused by natural runoff should not be made significantly larger or longer because of regulated inflows, in order to protect seagrasses, shellfish, and other estuarine biota in the Lagoon.

6. Additional constraints to salinity are believed needed in the Lagoon near the mouth of the River in order to restore and enhance seagrasses, and may be needed within 2.5 miles of the River mouth to protect hard clams or oysters.

7. A minimum of 20 parts per thousand is presently in use as an interim salinity standard during hard clam spawning seasons of spring and fall.

Details and Other Ideas from Task 1

Although not incorporated directly into the findings of the Task 1 Report, these specific references to salinity are presented in support of this Final Report's recommended salinity regime.

1. CHAPTER 17-302 F.A.C. (Surface Water Quality) governs the amount of change in specific parameters allowed by discharges. Among the guidance it provides is:

- "In predominantly marine waters the chloride content shall not be increased more than ten percent (10%) above normal background chloride content, and that normal daily and seasonal fluctuations in chloride levels shall be maintained;"

- "Specific conductance shall not be increased more than 50% above background or to 1,275 micromhos per centimeter, whichever is greater, in predominantly fresh waters;" and

- For Classes I, II and III waters, biological integrity cannot be reduced to less than 75% of background. ("Biological integrity" is defined in the rule as the Shannon-Weaver diversity index and "background" is defined as condition of a water body in the absence of an activity or pollutant.)

2. CHAPTER 17-4 F.A.C. (Permits), on the subject of discharges and mixing zones of pollutants, allows for mixing zones but states that "no mixing zone...shall be allowed to significantly impair any of the designated uses of the receiving body of water." Some of the considerations for mixing zones include:

1. Condition of the receiving body of water including present and future flow conditions and present and future sources of pollutants;

2. The nature, volume and frequency of the proposed discharge including any possible synergistic effects with other pollutants or substances which may be present in the receiving body of water;

3. A mixing zone shall not include a nursery area of indigenous aquatic life or any area approved by the Department of Natural Resources for shellfish harvesting;

4. In lakes, estuaries, bays, lagoons, bayous, sounds and coastal waters, the area of a mixing zone shall not exceed 125,600 square meters, and all mixing zones shall not exceed 10 percent of an estuary's area;

5. The maximum concentration of wastes in the mixing zone shall not exceed the amount lethal to 50 percent of the test organisms in 96 hours (96 hr LC_{50}) for a species significant to the indigenous aquatic community.

Although largely a procedural rule, it does provide some guidance useful to the present Sebastian River case, although it should be noted that board-approved works of a water management district are probably exempted from the permit requirements of this rule. Furthermore, the rule does not appear to speak to the discharge of fresh water <u>per se</u>. Nevertheless, the rule provides insight to limits the state seeks in permitting new sources of pollutants to surface waters, and these features may be instructive for the Sebastian River study.

Considering fresh water as a pollutant, for example, the rule requires that the nature, volume and frequency of the proposed [fresh water] discharge including any possible synergistic effects with [fresh water already] present in the receiving body of water be considered. Likewise, a mixing zone [of fresh water] shall not include a nursery area of indigenous aquatic life or any area approved by the Department of Natural Resources for shellfish harvesting.

The rule states that in estuaries [and] lagoons the area of a mixing zone shall not exceed 125,600 square meters, and all mixing zones shall not exceed 10 percent of an estuary's area. It is presently not known whether 10 percent of the Indian River Lagoon's total surface area is affected by the "mixing zones" of canals. On the other hand, 125,600 square meters as a maximum mixing zone is equal to about 31 acres, or an area of the Lagoon enclosed by a radius of 935 feet from the mouth of the Sebastian River.

3. SEBASTIAN RIVER SALINITY REGIME -- RFP AND RELATED GUIDANCE prepared by the St. Johns River Water Management District states "The District desires to regulate structurally controlled freshwater inflows in an environmentally sensitive manner" because "there may be times when too much or too little water is released..."

The District states "the objective of this project is to determine an environmentally desirable and acceptable salinity regime..." from which "the amount of freshwater required to maintain acceptable salinities...can be calculated." In guidelines for establishing a salinity regime for the study area the District states "the guidelines are intended to achieve a complementary blend of, or an equitable balance between, ecological concerns and fishery industry concerns." The District advises that an environmentally desirable salinity regime would minimally support:

1. Macrophyte based primary productivity (meaning that seagrass contributions should be greater than that of phytoplankton);

2. A variety of native macrophyte communities over a full salinity range (meaning that emergent wetlands should grade from tidal freshwater to marine species);

3. Significant macrophytic habitats of species at risk and economically important species (meaning that seagrasses and wetlands should be in sufficient abundance and salinity position to support

species of invertebrates, fishes or mammals that are listed by state or federal agencies, or constitute the basis of locally important recreational or commercial fisheries);

4. Species at risk and species of recreational or commercial economic importance (as above);

5. Hard clams within 2.5 miles of the Sebastian River, and blue crabs (meaning that hard clam harvest and culture should be possible under existing environmental and regulatory constraints, in the part of the Indian River Lagoon potentially affected by the Sebastian River).

4. A PRELIMINARY ASSESSMENT OF THE EFFECTS ON SALINITY OF THE INDIAN RIVER LAGOON FROM WCDSB CANAL 1 DISCHARGES (St. Johns River Water Management District, 1989) concerned possibility of adverse estuarine impacts caused by discharges of Canal 1 through Turkey Creek to the Indian River Lagoon. District staff produced an analysis of flow and salinity relationships based upon historic data and measurements made during three periods in 1989.

The report notes that clam harvesting and mariculture depend on good water quality, including salinity, and states, "Proper salinity ranges in the lagoon must be maintained to ensure viable clam populations and survival of their progeny."

The report concludes, "Discharges from Canal 1 that exceed 1000 cfs can decrease the salinity of the Indian River Lagoon below 20 ppt, the incipient standard adopted by SJRWMD staff. *It is desirable to maintain salinities at or above 20 ppt during the hard clam spawning seasons of spring and fall.* A maximum threshold of approximately 1000 cfs for Canal 1 appears necessary to meet the 20 ppt standard." (Emphasis added.) The report defines the spring as March-May and the fall as September-November. The 20 ppt salinity is meant to apply in Lagoon waters 1000 meters from the mouth of Turkey Creek.

This analysis and canal operation schedule apply to Turkey Creek, not the Sebastian River. However, Joel Steward (SJRWMD, memorandum of November 30, 1992) writes, "This same 20 ppt standard has also been applied to the Sebastian R./IRL area and the regulation of C-54 discharges since the summer/fall of 1990." The standard presumably applies in spring and fall, at a 1000 m distance from the mouth of the Sebastian River. The statement that, "Proper salinity ranges in the lagoon must be maintained to ensure viable clam populations and survival of their progeny" has two implications. The first is that Lagoon salinity ranges can be maintained. The second is that viable [hard] clam populations are a desired end-point or outcome of inflow and salinity management, as opposed to oysters, for example.

<u>Task 2 Report: Segmentation</u>

The second project report examined regulatory, geographic, natural and scientific information to identify reaches of the Sebastian River and Indian River Lagoon for which salinity recommendations should be sought.

The most significant of the existing segmentation systems is the line between Brevard and Indian River Counties. The county line has been used to define a number of federal, state, regional and local regulatory and resource management programs. Despite its widespread use, this line is not helpful in the present task of defining a desirable and ecologically acceptable salinity regime for the study area because it divides the River and Lagoon artificially. Four systems pertain in some way to shellfish, and the Intracoastal Waterway is an integral part of these and other systems. Based on these considerations, the study area is provisionally segmented as follows:

1. Upstream Reaches of the North and South Prongs

2. Tidal Waters Upstream of U.S. Highway 1
   Depending on studies in progress, it may be possible to divide this area further; such division may make it possible to recommend salinity characteristics for the wide and shallow waters of the River east of the main tributaries. Additional recommendations may be possible for the tidal streams, as well.

3. Lagoon Waters Between U.S. Highway 1 and the Intracoastal Waterway

4. Remaining Lagoon Waters to the Limit of the Study Area
   This segment also may be subdivided as a result of additional study.

Details and Other Ideas from Task 2

The Intracoastal Waterway also serves as part of the divide between Class II and Class III waters of the State. Class II waters allow for shellfish propagation and harvest, whereas Class III waters do not. Class III waters include the Sebastian River, the Indian River Lagoon off the mouth of the River in Indian River County, and all of the Lagoon west of the Intracoastal Waterway. The Intracoastal Waterway therefore represents the boundary between shellfish propagation and harvest, and general fish and wildlife management.

Another segmentation system involving shellfish affects the study area. As part of Florida's shellfish sanitation program, waters of the state are classified according to their ability to support safe harvests. The mainland shore immediately north of the mouth of the Sebastian River, and in the vicinity of Grant, is closed to harvesting. The waters of Indian River County outside of the Refuge are unapproved, meaning that harvests are not allowed by default. Refuge waters are open to harvest based on conditional state approval. An area of the Lagoon in Brevard County, north of the Inlet, is designated as a relay area and the Lagoon north of that is conditionally approved. The county line and Intracoastal Waterway are utilized in this segmentation system. Changes to the system have been proposed but have not been adopted (B. Browning, Florida Department of Natural Resources, personal communication).

Another form of governmental segmentation related to shellfish concerns the award of leases for shellfish operations. These include shellfish leases and aquaculture leases. These leases tend to honor the shellfish sanitation classification system described above, but shellfish leases may be much older than the current shellfish classification system in use. The location of 47 leases and two proposed shellfish leases in the vicinity of the study area was determined from records of the Florida Department of Natural Resources (D.C. Heil, Bureau of Marine Resource Regulation and Development, personal communication). Locations of all leases were mapped and the area in which no recorded or proposed shellfish leases were identified. Comparable data on aquaculture leases were requested from FDNR on October 7, 1992 but no information has been received as of this writing.

As mentioned above, The St. Johns River Water Management District recognizes an arc 1000 meters from the mouth of the Sebastian River as an interim limit to the depression of salinity below 20 parts per thousand (ppt) during clam spawning seasons of spring and fall (J. Steward, SJRWMD, personal communication). The interim goal is based on the transfer of findings from a study performed near the mouth of Turkey Creek. The arc crosses the Intracoastal Waterway but lies entirely within the shellfish lease limit area.

References

Estevez, E.D., 1992. Sebastian River salinity regime: Review of goals, policies and objectives. Contract 92W-177 report to SJRWMD. Mote Marine Laboratory Technical Report No. 275.

Estevez, E.D., 1993. Sebastian River salinity regime: Segmentation. Contract 92W-177 report to SJRWMD. Mote Marine Laboratory Technical Report No. 286.

13. Summary of Potential Recommendations

Guidelines for the development of salinity recommendations affecting the Sebastian River and adjacent Indian River Lagoon have been drawn from existing literature regarding the area, key living resources found in the area, and analyses of unpublished data. In addition, we have drawn from studies in other areas, and from case studies involving estuary-level and event-based assessments. The purpose behind this approach has been to identify as many potential recommendations as possible, from which a single set of salinity targets may be inferred.

A total of 56 potential recommendations was identified. Many are qualitative and some are quantitative. More items are redundant than singular, and we do not find any that are clearly contradictory. The body of guidelines is listed below and each is numbered sequentially through chapters for subsequent reference, where their numbers appear in [brackets] in tables at the end of this section and in Section 14. Section 14 presents the inference methods and results.

2. Freshwater Inflow and Estuarine Productivity

1. To the extent that the River is managed as an estuary, salinities of an estuarine nature are appropriate.
2. The amount, timing, and location of inflows are important because of the salinity responses that result.
3. The River's wetland systems are important, in conjunction with salinities, for the production of desirable species, and it is fortunate that much of the River's natural wetlands are intact.
4. There probably are limits to inflow/salinity alterations in the River that are injurious. Rozengurt's postulate that the limit is approximated by an estuary's coefficient of hydrological variation may provide insight, and would work for high flows as well as low flows, but is presently unknown.
5. The River is part of a larger ecosystem, the Indian River Lagoon, and these findings may be expected to apply in the Lagoon as well.
6. Quantitative studies suggested by these findings include fine-grain mapping of wetlands in the River and Lagoon near the River; the behavior of salinity under a range of discharge conditions, relative to wetlands; and catch-normalized yield data for species of interest.

3. An Overview of Small Coastal Rivers in Peninsular Florida

7. Tidal freshwater areas tend to be relatively short river reaches, and occur in the vicinity of transitions in soil types. Mean salinity at such points tend to be low (1 - 2 ppt) with standard deviations between 2 and 4 ppt.

8. Seagrasses are not extensive or abundant within small tidal rivers (other than spring runs) and where they occur, *Ruppia* and/or *Halodule* are the principal species. It is possible that one of these species would grow in the river confluence area with suitable salinities. The salinity conditions associated with these species are described in another section of this report.

9. Oyster reefs are commonly encountered in and near tidal rivers and their condition along a salinity gradient is often best in the vicinity of river mouths. Salinities favorable to oysters are reported in another section of this report but mean values tend to fall between 15 and 25 ppt, and oysters tolerate and may benefit[9] from day-to-week long periods of fresher water.

4. Case Studies of Altered Inflow and Salinity

10. Oligohaline waters are natural and ecologically important components of estuaries but their enlargement by erratic inflows retards estuarine and marine communities in undesirable ways.

11. Oligohaline waters and areas of maximum salinity variation should be registered to the geomorphic and physical regions of estuaries where they naturally occurred, and prevented from expanding into middle or lower estuarine areas.

12. The greatest salinity impacts in estuaries seem to occur in years immediately following the enhancement of inflows. Significant ecological differences become more difficult to identify as the system later develops eurytopic characteristics. Salinity regimes may therefore either be refined to minimize variations among tolerant species, or greatly revised to restore conditions conducive to the needs of stenotopic species.

13. Given the desire to enhance seagrasses and protect hard clams in the Sebastian River and estuary area, the extent of salinity changes that will be required will be greater than needed simply to maintain the status quo.

5. Environmental Setting, Early Conditions, and Change

14. Flows of the pre-settlement River probably were much lower than today, perhaps by an order of magnitude. Wetland storage of surface water in the basin was extensive, resulting in large, highly pulsed discharges only when very heavy rains fell during the wettest months. Otherwise, river flows were low and probably exhibited significant time lags relative to rainfall.

9/ By disease and predator exclusion.

15. Consequently, salinity variation under natural hydrological conditions was probably greater within the Sebastian River than it was in the Central Lagoon. Also, low salinities lagged all but extreme rainfall and runoff events, and the rate of salinity change was lower than it is today.

16. A natural trend was developing of increasing oceanic influence in the Lagoon, meaning higher mean salinities and tidal to inter-annual variations in water level, circulation, and salinity. Increasing oceanic influence prior to flow augmentation also meant that tidal freshwater reaches of the Sebastian River were being compressed inland.

17. The frequency of tropical storms and hurricanes is useful as a guide to how often the Lagoon would be experiencing extreme salinity variations in the absence of human influences. On average, about half of the available storm record contains periods of three or more years between major storms, suggesting that large salinity swings within the Central Lagoon did not occur every year and that several consecutive years of stable salinity were possible.

18. Inlet management has worked in the same direction as natural forces affecting the Lagoon, whereas River flow augmentation has worked against the trend. Salinity conditions within the Indian River Lagoon, attributable to the influence of the Sebastian River, are consequently undesirable from an ecological point of view. Such conditions include lower mean salinity and higher salinity variation.

6. Salinity

19. The Lagoon near Sebastian Inlet has the highest salinities of the South Central Region. The Inlet exerts a significant effect on salinity structure to the north and south, but this effect is interfered with, at least locally, by discharges of the Sebastian River. In terms of Lagoon-wide conditions, River influence should be reduced.

20. The River Mouth area is presently the site of maximum salinity variance. Tides and wind are able to move low-salinity water over large areas of the Lagoon before significant mixing occurs. Greatest mixing could be moved into the neighboring River segment. This shift will reduce the effect of wind and give the River Mouth segment a salinity structure more like those of the North and South Shore segments, which in turn resemble the Inlet segment.

21. Salinity structure of the Lower North Prong, C-54 and S-157 segments differs greatly from that of the South Prong. End-point salinities are higher, not lower, than salinities in intermediate reaches of this system, and variation is irregular. Within limits set by bathymetry or other factors, the salinity structure of waters leading to S-157 should be consistent with the salinity structure of the South Prong.

22. Better data are needed. Salinity of the North Prong should be described. Tidal-to-monthly patterns of surface and bottom salinity should be determined from the Inlet through tidal freshwater reaches. Lagoon circulation near the River mouth needs to be understood, especially the regulation of River plume behavior and stratification.

23. Physical options for altering salinity should be considered in addition to flow regulation. These options could include sills in the

Lagoon to steer River plumes, alterations to bridge approaches, and channels into upper River reaches.

7. Seagrasses

24. Seagrasses occurred along the western shore of the Indian River Lagoon, but are fewer in kind and less abundant now. The pattern of mean salinity and salinity variation near the River mouth is consistent with conditions associated with seagrass loss, but other factors related to River discharge or dredging may be involved.

25. To restore *Halodule* near the mouth of the Sebastian River, mean bottom salinity should be maintained near 25 ppt, with a standard deviation about the mean less than 10 ppt.

26. To enhance the potential for *Syringodium* recovery, the duration of bottom salinities of 0 ppt should be kept to less than 24 hours.

8. Hard Clams

27. For the year as a whole, mean bottom salinity should be maintained at levels above 20 ppt.

28. The lower limit of bottom salinity should be 10 ppt and the upper limit can equal oceanic values.

29. In summer, mean bottom salinities should exceed 20 ppt and be associated with standard deviations not greater than 5 ppt. Excursions of summer-time salinity below 15 ppt should not persist for more than 1 week (7 days).

30. During other times of the year, mean bottom salinities should be equal to or exceed 25 ppt and be associated with standard deviations not greater than 5 ppt.

31. From September to December and from March to June[10], minimum bottom salinities should be greater than 25 ppt.

32. Successive high tide, bottom salinities should not increase by more than 5 ppt, and successive low tide, bottom salinities should not decrease by more than 10 ppt, beyond background rates[11] as a result of surface water management operations.

9. Oysters

33. Salinities in areas where oyster bars are desired can be allowed to fluctuate broadly between 10 to 28 ppt, and these areas should possess strong longitudinal salinity gradients and mixing.

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[10]/ Or when local data indicate onset of peak spawning.

[11]/ Defined as the rates of salinity change that would occur between reference tides in the absence of surface water management structures and operations.

34. Lower salinities can be briefly tolerated by adult oysters. Salinities less than 6 ppt should not be allowed to persist longer than 2 weeks, nor should salinities lower than 2 ppt be allowed for longer than 1 week.

35. To protect recruitment, salinity during local spawning seasons should be above 10 ppt. Optimal larval and spat growth and survival can be obtained in salinities between 12.5 and 20 ppt.

10. Fish

34. Salinities must be held at seasonally appropriate levels within nursery grounds and spawning areas for snook, red drum, and spotted seatrout. When red drum and seatrout larvae are present the red drum larval tolerance range of 15 to 35 ppt should not be exceeded.

35. Juvenile snook must have access to freshwater nursery areas such as those which exist in the upper reaches of the Sebastian River. Salt-water should not be allowed to encroach on these areas due to its lethal effects on many of the prey species consumed by juvenile snook. Existing flood control structures may block juvenile snook from a large part of their favored nurserry habitat.

36. Any salinity regime must also consider the changes in salinities that occur during the life cycles of the prey species eaten by seatrout, snook, and red drum. These requirements are poorly known but should, in general, follow the salinity requirements of the seagrasses common in the area. In upstream nursery habitats, vegetation patterns could be used as a simple index of the impacts of water management options.

11. Species at Risk

37. Permanent reaches of tidal freshwater are desireable.

38. Their locations should correspond to known sites of listed species abundance and the presence of appropriate shoreline plant habitats.

39. Flowing/falling water conditions created by control structures should be perpetuated, although the feasibility of bypasses should be considered, to promote the movement of fishes beyond structures.

40. The areal extent of tidal freshwaters should be largest during summer and fall and smallest during winter and spring. Largest excursions of freshwater should coincide with naturally wettest periods.

41. Inland compression of tidal freshwater reaches made for the purpose of achieving other salinity recommendations should not extend farther upstream than the natural transition of historically present wetland soils and plant communities.

42. To benefit manatees, salinities of the Indian River Lagoon near the mouth of the Sebastian River should be conducive for seagrass growth.

43. Rapid fluctuations of water levels in upper reaches of the North and South Prongs may adversely affect species with special affinity to shoreline habitats, and should be moderated to prevent loss of structural habitat.

12. Recapitulation of Task 1 and 2 Findings

44. There is an overall intent to reduce fresh water inflows to the River and Lagoon. A reduction of inflow will result in higher salinities in both the River and Lagoon.

45. At the same time, there is a perceived need to provide base flows for certain oligohaline species and their habitats. A base flow will result in the establishment of permanent, tidal fresh water and low salinity areas.

46. Inflows and salinities should vary according to seasonal or daily or other cyclic patterns. At the same time, the rate of change of inflows, and consequently of salinity variations, should be moderated. Given the concern for acute changes, guidelines for rates and ranges of salinity variation are as important as average salinity conditions.

47. The peaks of inflow should coincide with the natural wet season runoff of the basin, meaning that low salinities caused by regulated inflows should coincide with low salinities caused by natural runoff. Natural seasonality of salinity variation is sought.

48. The area and duration of low salinities caused by natural runoff should not be made significantly larger or longer because of regulated inflows, in order to protect seagrasses, shellfish, and other estuarine biota in the Lagoon.

49. Additional constraints to salinity are believed needed in the Lagoon near the mouth of the River in order to restore and enhance seagrasses, and may be needed within 2.5 miles of the River mouth to protect hard clams or oysters.

50. A minimum of 20.0 ppt is presently in use as an interim salinity standard during hard clam spawning seasons of spring and fall.

51. In predominantly marine waters the chloride content shall not be increased more than ten percent (10%) above normal background chloride content, and normal daily and seasonal fluctuations in chloride levels shall be maintained.

52. Specific conductance shall not be increased more than 50% above background or to 1,275 micromhos per centimeter, whichever is greater, in predominantly fresh waters.

53. For Classes I, II and III waters, biological integrity cannot be reduced to less than 75% of background. ("Biological integrity" is defined as the Shannon-Weaver diversity index and "background" is defined as condition of a water body in the absence of an activity or pollutant.)

54. A mixing zone shall not include a nursery area of indigenous aquatic life or any area approved by the Department of Natural Resources for shellfish harvesting.

55. In lakes, estuaries, bays, lagoons, bayous, sounds and coastal waters, the area of a mixing zone shall not exceed 125,600 square meters, and all mixing zones shall not exceed 10 percent of an estuary's area. The 125,600 square meter, maximum mixing zone is equal to about 31 acres, or an area of the Lagoon enclosed by a radius of 935 feet from the mouth of the Sebastian River.

56. A recommended regime should support hard clams within 2.5 miles of the Sebastian River, and blue crabs (meaning that hard clam harvest and culture should be possible under existing environmental and regulatory

constraints, in the part of the Indian River Lagoon potentially affected by the Sebastian River).

Assessment

The distribution of findings and recommendations listed above are grouped by general attribute in Table 1, by geographic segment in Table 2, and by category of living resource in Table 3. There are approximately twice as many items assignable to spatial features than to either temporal features or limiting conditions, and this outcome therefore commends a spatial or landscape approach to developing a salinity regime. Within this approach, first reference should be made to geomorphic and geographic factors, followed by reference to the relationship of the entire Sebastian River to the Indian River Lagoon. Then, temporal data should be added where possible. Many ideas exist for waters within the Sebastian River itself (Table 2), which was an unexpected outcome of the review. On balance, many of these ideas are qualitative in nature or are redundant. Within the Indian River Lagoon, most ideas and guidelines affect the area of the River's mouth, specifically the waters east of U.S. 1 and west of the Intracoastal Waterway. This emphasis is also reflected in the distribution of ideas according to living resources (Table 3); most ideas pertain to benthic fauna and seagrasses of the estuarine and lagoonal environments. Species-wise distribution of findings and recommendations is fairly equitable and meaningful.

Conclusion

A large number of findings and recommendations derived from independent reviews of topics relevant to a salinity regime have been compiled and grouped by type. A total of 56 possible recommendations is considered. Coverage according to three systems of classification is adequate. Many items are qualitative but support the intent and outcome of more specific items. In this way, redundancy and a lack of contradictions helps to demonstrate the reasonableness of recommendations they support.

A geographic or landscape approach to formulating salinity recommendations is possible because of the availability of spatially-referenced information. Sufficient information exists to support general salinity characteristics from marine to oligohaline waters, including intermediate mixing or estuarine waters. Sufficient information exists to specify the nature of salinity where the Sebastian River enters the Indian River Lagoon. Information regarding temporal variation can be added to this spatial framework to address particular habitat or species requirements.

Table 1. Distribution of Recommendations by General Attribute. (Reference numbers refer to numbered guidelines listed in Section 13.)

Attribute	[Reference]
1. Spatial	
A. System-Wide	18, 19, 23, 55
B. Indian R. Lagoon	34, 46, 50, 51, 52, 56, 57
C. Sebastian River	1, 10, 41
D. Specific Segments	20, 21, 47
E. Geomorphic Zones	3, 7, 8, 9, 11, 35, 39, 40, 43, 44
F. Surface/Bottom	27, 28, 29, 30, 31, 32
2. Temporal	
A. Interannual-annual	27, 28
B. Seasonal	14, 29, 34, 42, 48
C. Monthly-Tidal	30, 49
D. Instantaneous	45
E. Rate of Change	15, 32, 53, 54
3. Limiting Conditions	
A. Upper Salinity	16, 28
B. Lower Salinity	17, 26, 28, 30, 34
C. Mean, ± S.D.	4, 7, 12, 13, 24, 25, 34, 52
D. Ranges	9, 12, 33, 35
4. Monitoring	6, 22

Table 2. Distribution of Recommendations by Segment. (Reference numbers refer to numbered guidelines listed in Section 13.)

Attribute	[Reference]
1. Indian River Lagoon	-
A. >2 km from River	17, 46
B. <2 km from River	-
1. East of ICW	16, 18, 19, 26, 27-32, 34, 50, 58
2. West of ICW	-
a. River mouth	12, 18, 20, 23, 24, 25, 26, 27-32, 44, 51, 52, 56, 57
b. North/South Shores	12, 26, 27-32, 44, 53
2. Sebastian River	
A. Confluence Area (River)	8, 9, 20, 23, 33, 34, 35
B. Lower South Prong	16, 42
C. Upper South Prong	7, 10, 11, 39, 30, 43, 47, 54
D. Lower North Prong	16, 21, 22, 42, 45
E. Upper North Prong	7, 10, 11, 22, 39, 40, 43, 47, 54
F. C-54	10, 11, 21, 35, 41
G. S-157	10, 11, 21, 35, 41

Table 3. Distribution of Recommendations by Habitats and Species. (Reference numbers refer to numbered guidelines listed in Section 13.)

Attribute	[Reference]
1. Habitat	
A. Oligohaline	
1. Water	7, 10, 11, 21, 35, 42, 47, 54
2. Wetland	2, 39, 40, 43
B. Estuarine	
1. Water	1, 4, 10, 11, 12, 15, 51, 56
2. Wetland	2, 43
3. Benthic/SAV	8, 9, 20, 23, 27-31, 33, 34, 35, 44, 52, 57
C. Lagoonal	
1. Water	16, 17, 18, 19, 46, 50, 51, 53
2. Benthic/SAV	13, 24, 25, 26, 28-32, 50, 58
2. Species	
A. Seagrass	24, 25, 26, 55
B. Clams	27, 28, 29, 30, 31, 32, 55
C. Oysters	33, 34, 35, 55
D. Fish	34-37, 38, 39, 40, 41, 45, 47, 55
E. Manatees	41, 44

14. Salinity Recommendations

The St. Johns River Water Management District desires to learn the nature of an "environmentally desirable and acceptable salinity regime" for the Sebastian River and adjacent waters of the Indian River Lagoon. A perception existed at the time the project was initiated that the discharge of freshwater from combined tributaries of the Sebastian River was causing adverse environmental impacts to estuarine and marine systems. During this project we have examined goals for the region and data concerning the salinity and biology of the River and Lagoon. On the basis of this review we conclude that perceived problems have valid grounds, and that an effort should be made to protect and restore living resources in the area through the implementation of a salinity structure that differs from the existing one.

In developing recommended salinity targets we have considered a variety of methods that could be used. These included the comparison of existing salinity regimes in a system to:

-Historic (pre-settlement) salinity regimes;

-The salinity regime of a comparable but unregulated system;

-Known salinity requirements of specific communities, habitats, species, life stages or other biological attributes, and/or salinity regimes associated with beneficial social uses, and,

-*A priori* salinity conditions based on general ecological theory and knowledge of estuarine structure and function.

The historic or pre-settlement salinity regime of the River and Lagoon is unknown. We have attempted to describe the possible salinity regime of the River and Lagoon and how these systems evolved before and after settlement. The salinity regimes of comparable but unregulated systems on the Florida west coast, and the regulated Loxahatchee River on the east coast, have also been investigated, as have case studies of estuaries affected by large inflows of freshwater. Known salinity requirements of specific communities, habitats, species, and life stages were compared with existing salinity data, as was a long list of legal, management, economic, and other social uses. Finally, *a priori* salinity conditions, based on general ecological theory and knowledge of estuarine structure and function, were considered.

None of these approaches was found wholly satisfactory, but each provided some measure of insight to salinity optimization. We learned that bathymetric and circulation data are unavailable for the River and Lagoon, and that historical salinity data portray an incomplete picture of short and long-term trends, or spatial and vertical variation. We learned that the two systems most comparable to the Sebastian are imperfect models: the St. Lucie system, which receives excess flows, has been altered for nearly a century, whereas the Loxahatchee system receives too little inflow. And we learned that published literature on salinity requirements of valued habitats and species fell short of providing certain kinds of desired guidance, or was virtually moot, as in the case of seagrasses.

Landscape Approach

Ecological features of the Indian River Lagoon and tidal coastlines generally are created through the action of geological, hydrological, chemical, and biological forces. The distribution, composition, abundance and condition of living resources along these coasts acquire common features and regionally unique features (Odum et al., 1975). Soils, wetlands, seagrass beds, oyster reefs, and other structural ecosystem features develop in analogous ways across estuaries within specific climatic zones. The relationship of these features to freshwater inflow, tidal amplitude, salinity and other dynamical features also follow regular patterns. Productivity of individual species is regulated by the overlap of structural and dynamic habitat (Browder and Moore, 1981).

It follows from the regularity of these patterns and processes that salinity recommendations registered to major landscape features of the study area form an environmentally acceptable point of beginning. Major landscape features of the Sebastian River include its headwater reaches, where stream bed elevations fall from an average elevation of about 25 feet to sea level; tidal freshwater reaches; and tidal reaches with varying levels of salinity. Tidal reaches have shorelines and islands bordered by freshwater, brackish, or salt marshes and mangrove forests. The area and volume of tidal reaches increases logarithmically toward the River's mouth. Major landscape features of the Indian River Lagoon include its barrier islands and back-bay wetlands; Sebastian Inlet and its flood-tidal delta and associated seagrass systems; long expanses of shallow water over sandy sediments, some with seagrasses and clam beds and some without; and the Intracoastal Waterway and its associated spoil islands and shoals.

These landscape elements have been separated into geographic areas or segments (Table 1). The dominant landscape features of the Inlet Segment are barrier islands, the Inlet, flood-tidal delta, and seagrass beds. The River Mouth Segment is dominated by spoil shoals, shallow unvegetated bottoms with muddy inclusions, sparse seagrass, and developed shorelines. Dominant features of the River Segment are broad, level mud-flats, mildly developed shorelines with intermittent marshes, and shallow open waters. The Lower South Prong Segment is dominated by natural and developed uplands, islands of marsh, mangrove, and upland vegetation, and darkly colored water. Dominant landscape elements of the Upper South Prong and Lower North Prong are meandering channels through brackish and fresh marshes, and uplands with sparse to no development. Canal banks also comprise part of the Lower North Prong's landscape, and canal banks are the dominant feature of the Canal 54 and Structure 157 Segments. Deep water is another characteristic of the canal segments.

Salinity in the Landscape

Salinity ranges from freshwater to fully marine conditions across the landscape of the study area. It is clear from our review of management goals and objectives, existing salinity data, and the ecology of aquatic and marine organisms inhabiting this area that these salinity end-points are to be perpetuated. Therefore, our recommendations speak to the salinity structure of intervening waters (Table 2). Values are given for means, standard deviations (S.D.), coefficients of variation (C.V.), minima, maxima, and ranges of salinity recommended for each segment and two specific locations. A discussion of rate limitations is also provided.

In general, these salinity targets resemble the existing salinity structure of the system (Table 3), but there are several important differences:

1. Salinity targets at the landscape end-point of Segment S-157 are substantially lowered, from a mean of 10.4 ppt to less than 1 ppt. The new S.D. is less than 2 ppt compared to 9.1 ppt. Minimum salinity is reduced greatly, from 29 ppt to 3 ppt.
2. In similar fashion, the maximum salinity target in Segment C-54 is reduced by almost half from existing salinity, from 29 to 15 ppt.
3. The C.V. of Lower Prong Segments is increased in the South Prong and maximum salinity is decreased in the North Prong, from 30 to 20 ppt.
4. Seeming contradictions are proposed for the River Segment.
   -- Salinity range is contracted by raising minimum and lowering maximum salinity targets, while
   -- Mean salinity targets are unchanged but
   -- S.D. is doubled and C.V. is increased by 50 percent.
5. Minimum salinity targets in the Mouth and Inlet Segments are increased from 0 and 9 ppt to 10 and 28 ppt, respectively.

Before discussing the implications of these recommendations, it is necessary to recognize that this set of values address surface waters only. As stated in Section 6, surface data are more numerous than data at depth. Section 6 also discussed the issue of stratification, finding merits and demerits but deferring a recommendation until better data become available. Once the relationship of bottom salinity to surface salinity is evaluated analytically for waters throughout this landscape, separate recommendations may be sought. For now, we understand that these recommended targets for surface salinity imply a given salinity structure near the bottom, and see no specific problems resulting therefrom. Where possible, specific targets for bottom salinity in particular segments are presented below.

The use of means, S.D., C.V. and ranges also raises a valid question or criticism having to do with time steps. Over what period(s) of time are these targets meant to apply? The answer is, over periods of a year or longer. Minima are meant here as absolute minima. We appreciate that minima are likely to be violated in the real world but recommend that these events be at the very tails of salinity duration curves. The tougher question to answer about time steps is, "With what frequency of measurement are the target statistics meant to be computed?" We must digress to answer it.

Because sampling effort depends on station number as well as sampling frequency, we begin by noting that the target statistics are meant to represent data from a number of stations in each segment. Targets for specific sites are self-explanatory. In other words, we recommend sampling and measurement from stations at several sites in each segment. Such was the origin of data in Table 3. Recommended targets, then, account for variation internal to segments.

Occupation of many stations precludes continuous measurement systems, although these can still be used at single sites for which target values are recommended. By the same token, tidal sampling periods (every high and low tide through time) are impractical, and ill-advised given the influence of winds on water levels. Daily sampling of multiple stations is equally hard to justify on practical grounds, unless special circumstances exist. At least one clam farm in the vicinity of Grant makes daily salinity readings, for example. Such sources of data should not be declined, but are difficult to rely upon as sources to monitor target success. Because available data show considerable variation over monthly sampling intervals, monthly sampling is unreliable for affirming that minimum or maximum targets have been met.

Weekly or bi-weekly sampling is therefore recommended as a reasonable interval between sampling events. Some independent justification for this idea may be found in Frederico (1983), who examined the effect of sampling frequency on the calculation of nutrient and chloride loads from three south Florida canal systems (S-49, S-97 and S-99). Sampling frequencies from 1 to 60 days were reconstructed from daily data (Figure 1). Differences from daily starting values were conservative in most cases but began to decay after 10 to 15 days. In the absence of other data, then, weekly or bi-weekly sampling seems a reasonable compromise for the initial monitoring of salinity target success. Different sampling schedules are recommended for other salinity targets described below.

Implications

Taken as a whole, the recommended target salinities should have the following effects. First, salinity gradients across the landscape will be stabilized, with a clearer longitudinal signal from the ocean to freshwaters. Second, the low salinity reaches of the landscape will be insulated more from incursions of high-salinity water, in the past as high as 29 ppt. Third, lagoonal landscapes will be protected from excursions of low-salinity water, at least insofar as the Sebastian River is its source. Fourth, and perhaps of greatest potential benefit, the largest range and variation in salinity within the landscape will be moved out of the Indian River Lagoon and into the confluent reach of the Sebastian River. This last action has two benefits. It shelters waters of highly variable salinity from the dispersive effects of winds. It also "registers" highly variable salinity to a reach of the River commonly associated with such conditions.

The ecological consequences of these targets are mostly beneficial. In the Lagoon, mean salinity requirements of hard clams and seagrasses would be met all of the time in the Inlet Segment, and much of the time in the River Mouth Segment. Extreme salinity stress would be reduced greatly. All other things being equal, Halodule and Mercenaria should successfully persist in close proximity to the River mouth. The chances of this happening are improved by additional targets to be defined below. On the other hand, the area of the western Lagoon fished by commercial crabbers could be compressed somewhat. This possibility could, however, be offset by the absence of freshwater flushes into Lagoon areas fished by crabbers, as well as the increased area of crab habitat created inside the River.

Salinity conditions suitable for oysters are similar to, but not precisely the same as proposed for the River Segment west of U.S. 1. Ideal oyster salinities range from 10 to 28 ppt and do not stay below 6 ppt for extended periods. Expansion of oysters may be inhibited by adverse substrate or water quality conditions, but target salinities would allow for gametogenesis, spawning, settling, and growth. As discussed in Section 9, the consumption of oysters from this segment would be prohibited, but oyster reefs would provide valuable habitat. To the extent that proposed salinity targets confine the River's turbidity maximum within this segment, oysters in the River and seagrasses in the Lagoon would benefit.

Lower Prong Segments, particularly the South Prong, could see some retreat in the downstream distribution of some marsh plant species (such as the leather fern, Acrostichum, or swamp lily, Crinum americanum). Otherwise, periods of cold weather will largely control plant species dominance in tidal wetlands there. Brackish and freshwater marsh species should increase in cover in the C-54 part of the Lower North Prong Segment because very high salinities presently occur at the surface. The establishment of permanent, tidal freshwater conditions below S-157 will anchor the salinity gradient leading to Sebastian Inlet. Freshwater conditions at S-157 should benefit manatees, and a variety of interesting fish species at risk. Rare and threatened fish species would be affected beneficially by the perpetuation of freshwater and low-salinity waters in close ecological proximity to waters of higher salinity.

Additional Salinity Standards

A number of additional constraints on salinity can be placed on the landscape-level targets described above (Table 4). Most involve bottom salinity, Lagoon biota, hard clams, and the River Mouth Segment. Most are also supportive of or consistent with targets listed in Table 2. One of the additions, the second oyster target, calls for the duration of salinities below 2 ppt to last no longer than 7 days. Because bottom salinity is usually greater than surface salinity, and the minimum surface salinity recommended for the River Segment is 5 ppt, the second oyster target may be unnecessary.

Targets addressing the duration of limiting conditions cannot be assessed by spatially intensive but temporally practical sampling and measurement described earlier. In these cases, continuous recording instruments should be deployed at stations in the designated segments found to be representative of potentially critical conditions. Because the duration targets pertain to neighboring segments, it may be possible to employ just one such instrument in the vicinity of the U.S. 1 bridge. Because the critical targets reflect summer and/or high discharge periods, instrument use could be restricted to times and conditions when duration limits were most likely to be exceeded.

Rate Limits

We found very little useful information concerning the maximum rates of salinity change tolerable by estuarine or marine organisms. The only finding, for hard clams,

> [32]: Successive high tide, bottom salinities should not increase by more than 5 ppt, and successive low tide, bottom salinities should not decrease by more than 10 ppt, beyond background rates[12] as a result of surface water management operations,

requires explanation. Based on personal communications with scientists and fishermen in the clam industry, we trimmed the amplitude of tolerable "sudden" salinity increases and decreases and have expressed them in terms of successive tides. This modification results in the fastest possible rate of salinity change that is measurable. Without better data on real-time rates of salinity change near Sebastian, we felt obligated to take the additional precaution of making the limits contingent upon a comparison to "background" rates of change. A definition of background is offered but it does little to change our view that this target should be advisory rather than certain.

Discussion

Issues of freshwater inflow and salinity alterations remain on the forefront of estuarine management (Gulf of Mexico Committee, in preparation). Methods of inflow and salinity optimization are needed around the world, but progress has been slow. In the United States, a number of projects have been conducted to solve a salinity-related problem, but only

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[12]/ Defined as the rates of salinity change that would occur between reference tides in the absence of surface water management structures and operations.

two salinity *optimization* projects have thus far progressed past the study phase into implementation, and these were concerned with inflow augmentation and salinity reduction (Van Beek et al., 1982; Moulton, 1991). Much basic research is needed before estuarine inflow and salinity optimization reach levels of sophistication available for freshwater streams.

In this project, published literature and raw field data have been used to construct a framework of salinity targets on which refinements may be added. As local data on the specific salinity requirements and tolerance limits of key species become available, ideally by life stage, adjustments to the salinity targets can be made. Monitoring of dependent living resources in the study area would be a considerable assistance in this effort. Halodule and natural clam beds should be censused regularly in the Inlet and River Mouth Segments. Oyster recruitment should be monitored in the River Segment, perhaps in conjunction with cultching experiments. And seasonal surveys of shoreline vegetation would provide much useful insight into long-period salinity trends in the River.

Many programs of sampling and measurement are recommended by the findings of this project but none seem so immediately important as ongoing bathymetry, hydrological, and circulation studies, for these will provide the analytical tools needed to determine the feasibility of recommended salinity targets. The targets are ecologically protective but they may not be physically or chemically practical. To reduce that possibility we have employed a landscape approach, targets defined in terms of ranges and variation, and a minimum of species-specific criteria. All of the recommended targets are internally consistent. Most of the special targets were recommended for only one segment, to further reduce the chance of defining impossible conditions. Time will tell.

In the event that all salinity targets cannot simultaneously be met, the following priorities are suggested. Minimum targets are more important than maximum targets. In upstream waters, low mean salinities are more important than their variation. In marine waters, low variation is probably more important than the mean salinities they accompany. Achieving targets for the River and River Mouth Segments, and letting salinity vary as needed in other segments, will do significant good. And as long as problems of low salinity stress remain a problem, bias in sampling programs toward low tide conditions can be justified.

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Table 1. Segment definitions. Locations of specific sites mentioned in this report are also defined.

Sebastian Inlet: Mid-channel of the Inlet at A1A bridge.

"Inlet" Segment: Indian River Lagoon west of Sebastian Inlet and east of the Intracoastal Waterway, extending 2.0 km north and south of the Brevard/Indian River County line.

Intracoastal Waterway: Mid-channel at the intersection of the Intracoastal Waterway and the Brevard/Indian River County line.

"River Mouth" Segment: Indian River Lagoon west of the Intracoastal Waterway to the mainland shore and U.S. 1 bridge, between ICW daymarks "R58" and "R62."

U.S. 1: Mid-channel of the River at U.S. 1 bridge.

"River" Segment: Sebastian River west of U.S. 1 bridge to mouths of North and South Prongs.

"Lower South Prong" Segment: South Prong from its entry to the River Segment, upstream to a point near 27°46'50" N. latitude.

"Upper South Prong" Segment: South Prong upstream of 27°46'50" N. latitude.

"Lower North Prong" Segment: Canal 54 upstream of the River Segment to and including the North Prong from its confluence with C-54, upstream to a point near 27°50'45" N. latitude.

"Upper North Prong" Segment: North Prong upstream of 27°50'45" N. latitude.

"Canal 54" Segment: Canal 54 west of the mouth of the North Prong Segment, to and including the outlet of Fellsmere Canal.

"Structure 157" Segment: Canal 54 west of the outlet of the Fellsmere Canal.

Table 2. Surface Salinity Targets by Segment or Site (parts per thousand). Segment names are in quotes and the names of geographic points are in parentheses.

"Segment"(Site)	Mean	Standard Deviation	C.V.[1], %	Minimum	Maximum	Range
(Sebastian Inlet)	33	5	15	28	--	--
"Inlet"	30	5	17	28	--	--
(ICW[2])	25	5	20	20	--	--
"River Mouth"	20	10	50	10	--	--
"River"	15	15	100	5	30	25
"Lower Prongs[3]"	6	8	133	0	20	20
"C-54"	5	8	160	0	15	15
"Upper Prongs[3]"	1	2	200	0	4	4
"S-157"	0.5	<2.0	--	0	3	3

[1]/Coefficient of variation
[2]/At county line
[3]/North and South Prongs

Table 3. Surface salinity characteristics of Sebastian River and Indian River Lagoon segments, in parts per thousand (ppt). Refer to Section 6 for sources.

Segment	N	Mean, ppt	S.D., ppt	C.V., %	Range, ppt
Inlet	100	28.5	5.4	19.1	9.0 - 35.8
N. Shore	50	22.3	7.5	33.6	3.0 - 38.0
Mouth	100	20.9	9.7	46.7	0.0 - 36.0
S. Shore	50	23.4	7.7	32.6	4.0 - 38.0
River	100	13.4	8.7	64.6	0.0 - 32.7
Lower S. Prong	100	5.8	5.0	86.6	0.0 - 22.4
Upper S. Prong	50	1.0	1.8	188.4	0.0 - 9.9
C-54	100	5.7	9.0	157.0	0.0 - 29.1
S-157	50	10.4	9.1	87.8	0.0 - 29.0
Lower N. Prong	100	6.1	7.8	128.2	0.0 - 29.7

S.D., standard deviation; C.V., coefficient of variation

Table 4. Additional salinity (S.) targets, in parts per thousand (ppt.).

Target	Resource	Affected Segments	Reference[13]
Mean bottom S = 25 ppt ± 10 ppt or less	*Halodule*	River Mouth	[25]
0 ppt duration at bottom < 24 hr.	*Syringodium*	River Mouth	[26]
Annual mean bottom S > 20 ppt.	*Mercenaria*	River Mouth	[27]
Minimum bottom S ≥ 10 ppt.	*Mercenaria*	River Mouth	[28]
Summer mean bottom S > 20 ppt ± 5 ppt or less	*Mercenaria*	River Mouth	[29]
Duration of summer mean bottom S < 15 ppt ≤ 7 days	*Mercenaria*	River Mouth	[29]
Non-summer mean bottom S ≥ 25 ppt ± 5 ppt or less	*Mercenaria*	River Mouth	[30,31]
Duration of S < 6 ppt < 14 days	*Crassostrea*	River	[34]
Duration of S < 2 ppt < 7 days	*Crassostrea*	River	[34]
Provide flowing/ falling freshwater	Listed fish species and manatees	S-157; Lower N. Prong	[39]

[13]/ See list of findings and recommendations in Section 13.

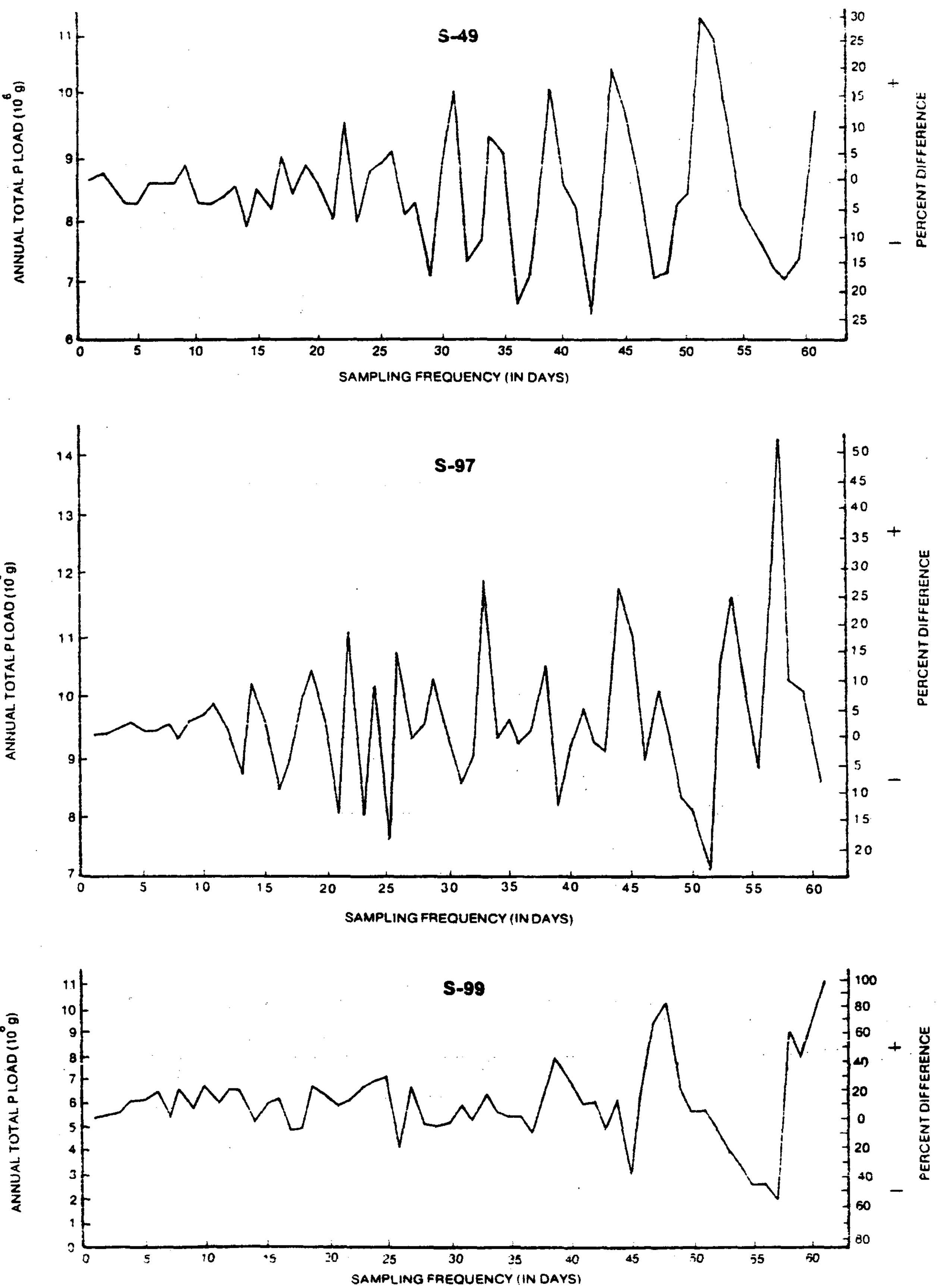

Figure 1. EFFECT OF SAMPLING FREQUENCY ON ANNUAL TOTAL P LOADS