PD-AAU-664
47982

FINAL REPORT

To the Office of Science Advisor
to the Administration

U.S. Agency for International Development
Washington, D.C.

U.S.A.I.D. Program Title
Seagrass Restoration in Caribbean Nearshore Areas

Grant No: DAN-5542-G-SS-2101-00

Submitted by

Department of Biological Sciences
Florida International University

Co-Sponsored by

Natural Resources Conservation Department
Government of Jamaica

October 17, 1984

Principal Investigator

A. Thorhaug, Ph.D.
Department of Biological Sciences
Florida International University

Co-Principal Investigators

Beverly Miller, Principal Director
Natural Resources Conservation Department

Barry Jupp, Ph.D.
Consultant to FIU
Department of Botany
University of the West Indies

TABLE OF CONTENTS

Executive Summary 1

Acknowledgements 4

General Recommendations 5

Policy Recommendations 6

Draft Policy for Zero-Loss 7

Specific Recommendations 8

Objectives and Goals Met 11

Awareness of Rehabilitation 12

Training 14

Socio-economic Benefits 14

Scientific Results 15

Discussion and Conclusions 63

Literature Cited 64

Appendices 65

Executive Summary

Seagrasses are one of the most important habitat organisms in tropical coastal and estuarine areas throughout the developing world. They serve as a habitat for fisheries nurseries, food source as a major primary producer in the tropical ecosystem, and also as anti-erosion sediment stabilizers. During development these systems are particularly perturbed by shoreline construction, dredging, filling, industrial and urban effluents, and accidental spills. As long-lived species, once perturbed, decades may be required to reconstitute the seagrass beds. In the United States 40% of coastal wetlands were lost before their value was fully realized and as a result of this a "zero-loss" policy of rehabilitating or replacing impacted systems was adopted. Decades of biological research were necessary to develop techniques for wetland conservation.

This project is the first attempt in the world to transfer the technology of seagrass restoration to a developing tropical nation. Eighteen developed sites, including infrastructure, urbanization, and industry were chosed by a team from Jamaica's NRCD as important types of impacts to rehabilitate. At each test site plots of three species of seagrass (a fourth added at high salinity sites) were tested using different planting and/or anchoring techniques. Spring and fall planting success was also examined.

Results showed a variety of responses dependent upon impact type. All three species of seagrasses proved capable of rehabilitating areas impacted by dredge and fill activities, as well as certain areas of urban impact. Industrial impacts differ in

rehabilitative potential. In bauxite sites Thalassia and Halodule could be rehabilitated; in thermal effluents only Halodule could survive; at cement sites none of the species could be rehabilitated. Indirect evidence suggests that rehabilitation in areas of oil spills may be feasible. Urban influences such as riprapping, river mouth construction, dredge and fill for land fill, and urban run-off appear feasible for rehabilitation. Erosional sites possibly can be rehabilitated. Very high energy erosion areas need additional testing of Thalassia and Syringodium sprigs with heavy cement anchors. Medium erosion areas were moderately successfully rehabilitated with Thalassia shoots and cement anchors. The most rapid rehabilitation occurred at a one acre site planted with 6 inch plugs of Halodule at 3 foot centers. Within four months a dense seagrass meadow covered the area and local fishermen were commercially fishing the area.

Other major accomplishments include the employment of local fishermen to help plant. This worked well for collecting material, sorting, plugging, and planting by those fishermen able to SCUBA dive. This activity provided the opportunity to demonstrate the high employment content included in conservation activities. The fish and invertebrates clearly returned rapidly into the planted seagrasses. Nursery functions, as seen from the abundance of egg cases, larvae and juveniles, were noted.

Success in raising environmental awareness about the importance of seagrasses as a national resource was reflected in a number of media articles and the filming of a TV special by the Jamaica Broadcasting System. Several articles of international scope also

appeared in UNEP's bulletin, Siren, and as a part of a National Geographic Special article on Jamaica.[3] Scientific presentations at international meetings resulted, and three additional scientific papers are in preparation. Policy for the Jamaican government to utilize rehabilitation of seagrasses (and mangroves) was jointly drafted by the NRCD and FIU Principals. Recommendations for large scale projects of fisheries renabilitation by seagrass restoration are included.

The economic value of one acre of seagrass has been calculated by UNEP (1981) to be $86,000. If an acre of seagrass can be rehabilitated for $500, this is a sound investment.

Acknowledgements

We wish to thank the following people who have cooperated in various ways to make this program possible: Honorable Minister Dr. Ronald Irvine, Minister of Science, Technology and Environment; NRCD: Paul Caroll, Elizabeth Ross, Barbara Chow, Peter Gayle, Everton Kelly, Elean Thomas, and Lloyd Taper; USAID: Drs. Minners and Asher, Mr. Meehan, James Smith, Henry White, Marea Hatziolis, Daniel Rathburn, William Davis (USIS), Roberta Mathis, Stan Johnson, and Michael Lawson.

FIU: Dr. Thomas Breslin, Catherine Kennedy, Harriot Walsh, Dean Leffland, Dr. Martin Tracey, Fitzgerald Booker, and Mimi Christian (computer programmer).

UWI: Professor George Sidrak.

A special thanks to Fitzgerald Booker (FIU) and Peter Gayle (NRCD) for project management and computer and data analyses, as well as diligent field work over the entire project.

I. General Recommendations from this Project

We recommend:

1. The Jamaican Government initiate a zero-loss policy of coastal habitat for permitting future coastal development to halt the loss of natural resources and sustain those resources remaining for future generations.

2. The Jamaican Government initiate an incentive program for development parties which have destroyed seagrasses, mangroves, and corals in the past to rehabilitate the resources thay have destroyed. Tax and other incentives could provide the basis on which hotels, industries, and other offenders take mitigating action.

3. Jamaican Governmnet adopt a policy to protect seagrasses, especially adjacent to high erosion beach sites and critical fisheries nurseries.

4. Jamaican Government a program for rehabilitation of fisheries nurseries to increase employmnet of fishermen during project and after the nursery increase the productivity of the nearshore environment especially for economically important marine species.
   (a) Rehabilitate industrial lagoons and salinas to an environmentally sustainable level which would lead to increased marine productivity.

   (b) Rehabilitate areas of seagrass decimated by government coastal development such as power plants, airports, highways and causeways, bridges, etc.

   (c) Begin using seagrasses and engineering devices to halt loss of beaches in high erosion situations. Encourage hotels and other beach property owners to use the same model in lieu of filling beaches.

5. USAID use this project as a model for rehabilitating the nearshore environment in other coastal developing nations.

II. Policy Recommendations

1. The technology transfer of the process of seagrass and mangrove rehabilitation has been demonstrated to be feasible in Jamaica. Policy for the rehabilitation of seagrass decimated by development should be adopted to implement the scientific transfer.

2. Policies to conserve seagrasses as a valuable natural resource through their structural and biological importance. Removal of these beds should be fully regulated and measures to protect beds from harmful activities should be instituted. Especially important areas of Jamaica to protect are high erosion seagrass sites, critical fisheries nursery areas, and major coastal estuaries.

3. A combination of policies and regulations from U.S. federal and state levels should be carefully retailored to fit the Jamaican government's needs and its environmental situation. The central issue is a "zero-loss" policy, wherein any wetland lost by development, accident, or other activity must be replaced by the party affecting the loss. Regulations for permitting shoreline and coastal development, accidents, and effluent discharge are needed.

4. Especially important are laws allowing Jamaican courts to fine parties gulity of accidents (such as oil spills) decimating seagrasses and mangroves. The power of government to require polluters to provide costs to rehabilitate the decimated coastal resources will help conserve fisheries and environmental resources for future generations.

5. Sample policies jointly drafted by NRCD and FIU principal personnel are appended.

6. A long term government program to rehabilitate critical fisheries nursery areas by replanting seagrasses utilizing fishermen as the chief labor source is recommended to enhance fisheries and natural resource conservation.

III. Draft Policy for Zero-Loss Wetland Regulation

Mitigation of Jamaican Wetlands

1. It is the policy of Jamaica to preserve wetland functions for future generations. It is the objective of mitigation to alleviate unavoidable loss of wetlands, estuarine, coastal and lagoon ecosystems, but not to justify the destruction of them, in such a manner as to sustain or enhance the total wetland resources.

2. Mitigation shall mean for the purpose of this section:
   a) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;
   b) Compensating for the impact by replacing or providing substitute resources of the same type (e.g., seagrasses for impacted seagrasses, mangroves for mangroves, etc.);
   c) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action;
   d) Avoiding the impact by not taking a certain action;
   e) Minimizing impacts by limiting the degree or magnitude of the action and its implementation.

3. When deciding whether to approve a dredge and fill or effluent elimination project, NRCD may consider proposed mitigation by the applicant. Mitigation may only be considered after a project has been proposed in a manner that minimizes loss of wetland functions to the greatest extent possible.

4. If accidental destruction of wetland habitat occurs, the party responsible for the destruction will rectify the accident by repairing, rehabilitating, or restoring the affected environment on a 2:1 basis, by restoring twice the acreage of wetland accidentally destroyed.

5. NRCD will have the final decision in the above situation, the species to be rehabilitated, density, and time period for planting. An inspection after 12 to 18 months of rehabilitative restoration and repair projects will occur by NRCD to approve the sufficiency of the effort.

IV. Specific Recommendations Based on Scientific Information from this Project

1. Large scale rehabilitation of seagrasses to restore fisheries nursery habitats and conserve natural resources is recommended as soon as financially feasible in the following locations.

   a) Fort Augusta Causeway, West Kingston Harbor.
   Restoration of all the barren areas here would provide jobs for fishermen, increase several fold the limited fishing activity now occurring here, and provide a cost analysis per acre for future projects and regulatory legal activities. *Halodule* plugs are recommended as easy for fishermen to handle. *Thalassia* seeds in the plugs would enhance final fisheries nurseries.

   b) Port Esquivel, Old Harbor.
   A large barren area due to the multiple activities of the aluminum loading site exists. Restoration at this site will require skilled diver/fishermen.

   c) Old Airport area, South Kingston Harbor.
   In the vicinity of new and old airports, shallow areas of dredge and fill are present (Clearly seen from aerial photos). *Thalassia* shoots or *Halodule* plugs are recommended.

   d) Montego Bay.
   In the areas behing the jetties north of downtown, where extensive filling has been done, the area can be restored to its previous seagrass beds with *Thalassia* shoots or *Halodule* plugs. Local diver/fishermen can be utilized with success. Other areas especially the north side of the freeport area, which formerly was an extensive grassbed, needs further experimentation with *Thalassia* shoots and heavy anchors, as does the ocean shore of the freeport area. Extensive river influences during the rainy season and winter storms are unknowns at present for the freeport area.

   e) Kingston Harbor (East end).
   Areas exist of impact of impact denuded of former seagrasses, especially near the bathing beaches. The cement plant vicinity must be excluded at present from potential sites. *Thalassia* shoots and *Halodule* plugs are recommended. Test sites should precede project.

   f) Other dredge and fill sites occur around the island that this limited study could not test. Many of these probably could be restored as easily as the above sites. Port Morant, Port Antonio, other Ocho Rios sites, Savannah del Mar are all probable locations for restoration.

g) In general a small test plot program that utilizes the most successful techniques (Thalassia and Halodule shoots, Halodule plugs) with 50 units lasting through winter storms and the rainy season is recommended at new sites to select the most cost efficient techniques. This is especially necessary at high erosion sites.

2. Beach and sublittoral erosion are important shoreline problems for Jamaica. Seagrass naturally stabilizes sediment, but an upper energy regime erodes even natural beds. To stabilize these conditions after seagrass is removed requires combined engineering and restoration techniques. Medium energy sites can be restored with Thalassia shoots and heavy cement anchors Further experimentation, especially combined with beach sediment stabilizing devices (artifical seaweed, riprap, groins, etc.), would be necessary.

3. An important opportunity to enhance fisheries nurseries through seagrass restoration is available along the Jamaican coastline. It would replace fisheries nurseries now irreversibly dying under roads, causeways, airports, and urban landfill. Saline lagoons and ponds, some created industrially or by roads, others historically used in salt manufacture, and some natural ponds are found along the coast. Our study showed them to be ideal for restoration, except in the case of high salinity. If devices to bring these lagoons and ponds to near oceanic salinities were installed (culverts, cuts in berm, etc.) restoring seagrasses would enhance productivity. The above has been done with success in the United States.

4. Bauxite Plants.
It is possible to correct the combined effects of bauxite loading spills and construction for bauxite loading plants. Thalassia appears from our study to be more resistant to bauxite than other species. Many areas around bauxite loading facilities are now barren. Both to repair present denudation and in case of future accidents, restoration by Thalassia is recommended.

5. Thermal Discharges (Power Plants).
It is possible to restore seagrass beds in areas receiving thermal effluents. Replace Thalassia and Syringodium beds decimated by thermal effluents (esspecially accidental high thermal releases in summer months) by planting Halodule plugs. This strategy is effective in areas sustaining temperatures up to 35^{0}C. Halodule does have fisheries nursery properties and many fish and shellfish have high temperature tolerance and will reinvade if seagrass is present.

6. Oil Spills.
By indirect evidence only, it appears that probably seagrasses can be restored in areas of oil spills after oil is removed. In our chief oil spill site (Alligator Point) such a high energy regime was present that testing appeared more a

function of wave energy than oil. However, frequent small spills and bilging effects were evident throughout work at Fort Augusta, a highly successful restoration site, indicating restoration success. The pipeline spill east of Port Esquivel appeared to decimate seagrasses in the immediate vicinity but an unhealthy fringe of all three seagrasses was found around this. A study for restoring seagrasses directly on oiled sediment is recommended.

7. Cement Plant.
There was no success in attempting to restore seagrasses around the area filled with fine particles from the cement plant. Continual wind-blown particles were entering the area in high quantity and smothering the plants. Theoretically, seagrasses grow well on calcium carbonate sediments.

8. Peat at Negril.
The seagrass did not grow on the flocculent peat material carried out beyond the mouth of the Negril River. This may well indicate that if extensive peat mining were done in the Great Morass, so that peat flocculents settled into the seagrasses, the seagrass areas would not regenerate.

9. River Mouth, Negril.
The constructed area around the river mouth with sandy bottom, tidal flows, and a fairly low pollution load was capable of being restored.

10. A fisheries study of eggs, larvae, juveniles, and adults comparing restored seagrasses to adjacent barren areas is recommended to obtain a cost/benefit analysis of fisheries productivity for justification of future government investment in seagrass restoration versus benefit. Fort Augusta is recommended as a location where a one acre restored site is present.

11. A present large scale project to restore an area using NRCD supervisors and fishermen as labor to get a price estimate per acre, using Jamaican labor costs, is recommended. At present commercial United States prices, seagrasses cost (U.S.) $5,000 to $10,000 per acre. Using fishermen in Jamaica prices should be a small fraction of those U.S. prices. This will be useful information for future permitting and regulating of industry for court judgements and fines, and for grovernment program planning.

12. Mangrove Restoration.
Further expansion of mangrove rehabilitation test sites is recommended. One site was utilized, but high salinities (a 50 year drought) interferred with full information. Mangrove restoration in Puerto Rico and the Virgin Islands has been successful.

13. A workshop using Jamaica as a model for Caribbean coastal rehabilitation is recommended, using the data from this project and including experts from mangrove, coral and marsh

rehabilitation projects, and inviting other Caribbean countries to learn procedures. NSF and UNEP are potential funding sources who have expressed interest.

14. A public education effort to make citizens of Jamaica aware of the value of sustaining important coastal resources for the future is needed.

V. Objectives and Goals Met by Project as Stated in Original Contract.

The purpose of the grant, as stated in the program description, has been met. Jamaica can accelerate re-establishment of seagrass beds destroyed under a variety of conditions.

Specific objectives of the project have been met as stated in the program description.

1) Tropical seagrasses are as feasible to restore as subtropical seagrasses, but time for restoration is accelerated. This is the first time the techniques were attempted in the tropics.

2) Successional stages of seagrass, particularly Halodule, are not necessary for successful Thalassia seed growth (

3) Seagrasses can successfully be rehabilitated into areas where accidental industrial spills, land development impacts, urban run-off, and urban abuse have occurred. Some pollutants can only be rehabilitated with one species of seagrass. Some impacts are more difficult to correct than others (see tables

4) Animal communities in barren impacted areas were seen to be far less in abundance, especially animals of fisheries potential, than in restored areas. In some cases the commercial fishing activities returned within four months after rehabilitation. Eggs and juveniles were noted in all restored areas of blade abundance.

Final Products.

1) This report is the final assessment to USAID and Jamaica. Subtropical seagrass rehabilitation techniques can be extrapolated to the tropics.

2) Included is an analysis of restoring various pollution impacts and a discussion of specific recommendations.

3) Pilot tests at 18 sites have been planted for Spring and Fall. They have been monitored and evaluated.

4) Policy and management sections have been drafted and discussed.

5) Training of NRCD and UWI personnel has been carried out (see training section).

Termination of Project.

Many of the test plots, especially for one species, were successful as to our original criteria. Several sites such as the cement plant, Rocky Point, and Yallah's Pond failed. The failures are discussed.

This report is the act of completion. Papers presented are listed.

VI. Awareness of Seagrass and Rehabilitation in Jamaica and Internationally.

The success of any conservation effort depends on the public understanding. At every stage of this project the public was informed and educated as to the benefits and processes involved.

Events included newspaper articles, journal articles, radio intervies, and a television special (pending Jamaican Broadcasting Company).

News Articles:

Jamaica Daily Gleaner. "U.S. $170,000 Seagrass Project Underway", December 2, 1982, p. 15.

The Star. Newspaper photograph and caption, December 7, 1982.

Jamaica Daily News. "Seagrass Restoration", December 7, 1982.

Jamaica Daily News. "Rehabilitation of Seagrass", March 31, 1983.

Jamaica Daily News. "Pilot Seagrass Project a Success", March 26, 1983.

Other Articles:

UNEP "Siren". "Healing Caribbean Coastlines", December, 1983, pp. 21-24.

USAID "Front Line". SCI, April, 1984, p. 13.

Radio:

Barbados-Trinidad talk show interview of Anitra Thorhaug.

British Broadcasting Company interview of Anitra Thorhaug. Taped at UNEP Caribbean Action Plan.

Television:

"Headline Jamaica's Coastlines" filmed and directed by Pat Lazarus (pending, Jamaican Braodcasting Company).

Scientific Publications and Presentations:

West Indies Island Laboratory: Association of Island Marine Laobratories of the Caribbean Meeting May 16 through 20, 1983, Miami, Florida, U.S.A. "Restoration of Seagrasses in Jamaica: Preliminary summary of Jamaica's management of seagrass restoration."

Internation Conference on the Bioshpere, Miami, Florida, May, 1984. "Management and Rehabilitation of Coastal Resources in the Third World: Jamaican Model for Seagrass Restoration", Beverly Miller, M.C.E. and Anitra Thorhaug, Ph.D.; "Thermal Pollution Effects on an Estuary in a Developing Nation: Impact and Rehabilitation of Seagrass.", Anitra Thorhaug, Ph.D.

Pending

Coastal Wetland Mitigation Policy for Third World Tropics. Beverly Miller and Anitra Thorhaug.

Seagrass Rehabilitation of Pollution in Jamaica. Beverly Miller and Anitra Thorhaug.

Seagrasses of Jamaica. Barry Jupp.

Comparison of Rhizome Growth of Seagrasses in Subtropics Versus Tropics. Anitra Thorhaug.

VII. Training NRCD and UWI Personnel.

The project has transferred the technology of rehabilitating seagrasses to NRCD and UWI personnel. Collecting, planting, and testing, monitoring, evaluation and management skills to perform the tasks necessary have been learned by NRCD staff members. In addition one staff member was brought to Miami to be trained in large scale rehabilitation as a supervisor.

As a result of this project, the Jamaican government has the capability of assisting other members of the international community in this aspect of resource conservation.

VIII. Socio-economic Benefits.

Conservation of natural resources is of long-term economic benefit to the people of Jamaica. In particular the conservation of near-shore resources provides the ability to increase both fishing productivity and recreational areas. In addition, this provides the basis for sound coastal development by retarding beach erosion. This project has demonstrated the potential to increase fishery nursery grounds, thus providing increased near-shore fishing.

The conservation effort provides employment opportunities for the unemployed fishermen and members of the fishing community directly through rehabilitation of seagrasses and mangroves and indirectly through increased fish production.

Jamaica, a small developing country facing severe unemployment will benefit from this component. This form of employment is very positive because members of the fishing community will be working for their own long-term benefits. The reason being, planting seagrass and mangroves will increase fishing.

The tourism industry is at the center of Jamaica's economy. Being an island ecosystem, the coastal areas are of tremendous importance. Planting seagrass has the potential to increase beach stability. Therefore, its implications for recreational development and tourism are obvious. This aspect of coastal zone management is vital in the face of rapid coastal, urban, and industrial development.

IX. Scientific Results.

A. Sites.

The environmental characteristics of the sites are listed in Tables 1, 2 and Figures 1-15. Table 2 shows measured mean environmental parameters. The light transmission from the surface to the bottom differed the most widely of all major parameters between sites. They ranged from 99.64% at Rocky Point Lagoon to 1.20% at Yallah's Pond. The two salt lagoons were not suitable because of high salinities ($160^0/_{00}$ and $62.96^0/_{00}$). Mean temperatures ranged from 28.0^0C to 30.5^0C for all sites except the Power Plant (35.6^0C) and the enclosed lagoon (31.3^0C). Dissolved oxygen ranged from 4.0 to 7.0, but was mostly around 6.0 ppm. Current velocities ranged from 0 to 2.8 cm sec^{-1}.

The pollutant impact experienced at each site is seen in table 1. Many of the sites had dredge and fill impacts. Many were multiply impacted. The sites represented a variety of locations and energy types.

The north coast versus the south coast did not vary in final results as much as energy regime, pollutant impact, light transmission or other site specific characteristics.

Energy regime appeared to be an important variable in determining survival of species. High energy locations favored Thalassia shoots and heavy anchors. In low and medium energy areas survival was higher and all three species grew well depending on impact types.

Sediment varied in particle size from predominantly fine sediment at Yallah's Pond to coarse at Port Esquivel, Hellshire Beach, and the Power Plant. Most sites had either a normal or skewed distribution of sediment particle sizes (figures 16 to 31).

Table 1. Impacts at 19 Test Sites

Site	Industial Waste	Dredge and Fill	Bauxite Spills	Oil Spills	Urban Runoff	River Runoff	Erosion	Peat	Thermal Effluents
Hellshire A and B					X		X		
Fort Augusta	X	X		X	X	X			
Old Airport	X	X		X	X				
Cement Factory	X			X	X				
Rocky Point	X		X	X					
Port Esquivel	X		X	X					
Power Plant									X
Discovery Bay			X	X					
Carlyle Beach	X	X			X		X		
Pelican Jetty		X			X	X			
Fishermens Jetty	X	X		X	X	X			

Table 1. continued: Impacts at 19 Test Sites

Site	Industrial Waste	Dredge and Fill	Bauxite Spills	Oil Spills	Urban Runoff	River Runoff	Erosion	Peat	Thermal Effluent
Seawind		X			X		X		
Negril Point						X		X	
Negril River						X		X	
Rocky Point Mangrove Planting	X		X	X					
Additional Sites Planted in April 1983									
Ocho Rios		X	X	X					
Yallahs Pond									
Alligator Pond				X					
South Port Beach		X			X		X		

Table 2. 18 month mean of measured environmental water parameters per site.

Site	Light Ls. (qua)	Light Lb. (qua)	%trans.	D.O. (ppm.)	Sal. ($^0/_{00}$)	Curr. (cms^{-1})	Temp. (^0C)
Alligator Pond	250.0	20.0	8.00	6.15	35.05	0.0	28.0
Carlyle Beach	263.8	170.0	64.60	6.23	35.75	0.7	28.0
Cement Plant	270.0	240.0	88.90	6.30	35.70	2.0	28.0
Discovery Bay	175.0	98.3	56.19	6.68	34.50	0.3	28.4
Fort Augusta	271.0	226.0	83.39	6.51	35.14	0.5	28.4
Hellshire	282.0	244.0	86.52	6.52	35.53	0.6	28.2
Negril Point	103.0	23.5	22.82	5.67	35.03	0.0	30.3
Negril River	265.0	215.0	81.13	5.50	33.30	2.0	30.5
Old Airport	214.0	158.0	73.83	7.00	35.51	2.2	28.9
Ocho Rios	270.0	242.5	89.81	6.33	35.12	0.0	29.0
Pelican Jetty	276.7	223.3	80.72	6.11	35.43	0.0	28.6
Port Esquivel	273.0	162.0	59.34	6.31	35.53	2.8	28.7
Power Plant	249.0	159.0	63.86	6.03	35.60	2.4	35.6
Rocky Point	276.0	275.0	99.64	7.51	62.96	0.2	31.3
S. Port Beach	257.5	195.0	75.73	6.32	32.90	0.5	29.2
Seawinds Hotel	278.8	251.2	90.13	5.95	35.38	2.0	28.5
Yallah's Pond	83.0	1.0	1.20	4.0	160.20	1.5	28.5

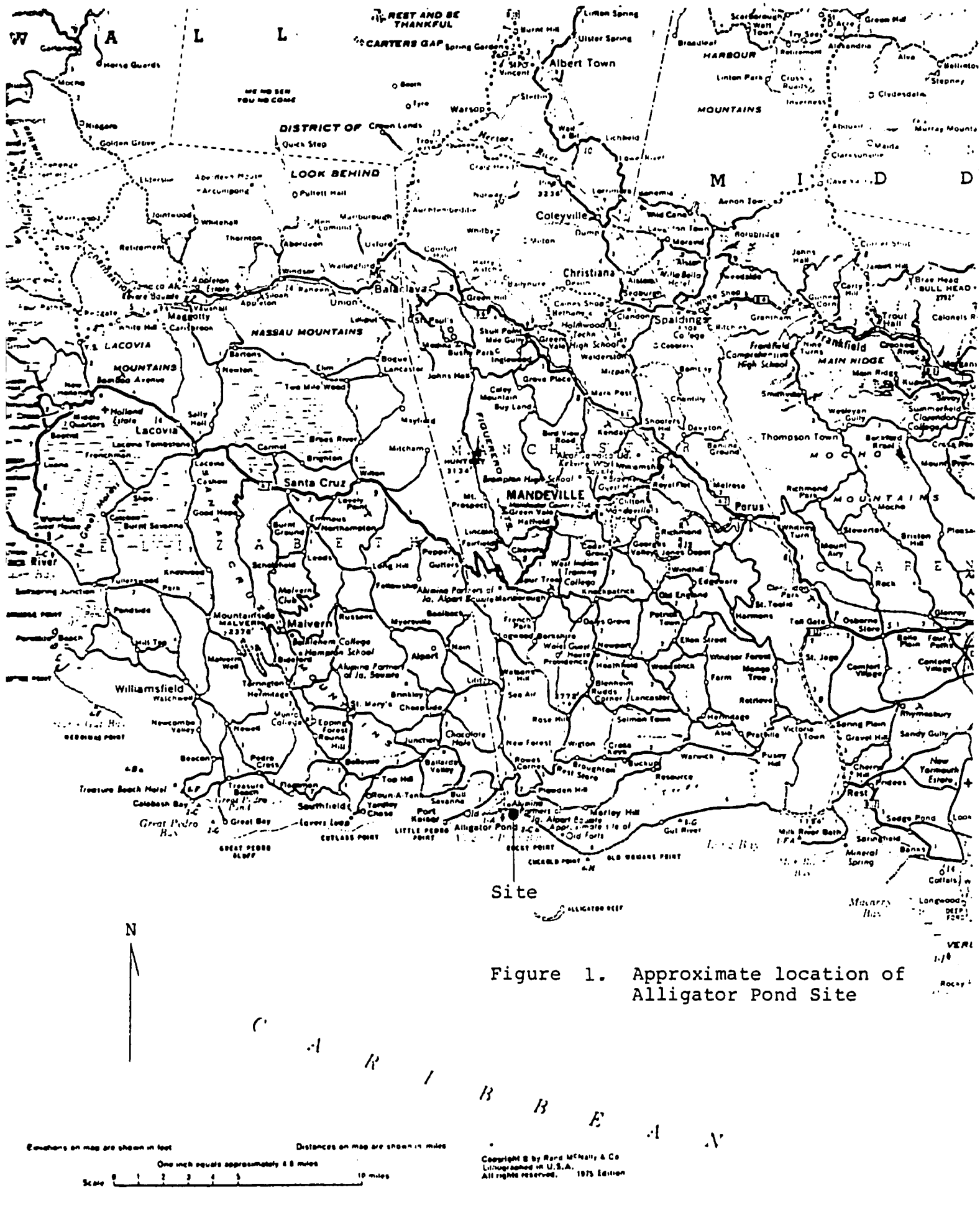


Figure 1. Approximate location of Alligator Pond Site

Copyright © by Rand McNally & Co
Lithographed in U.S.A.
All rights reserved. 1975 Edition

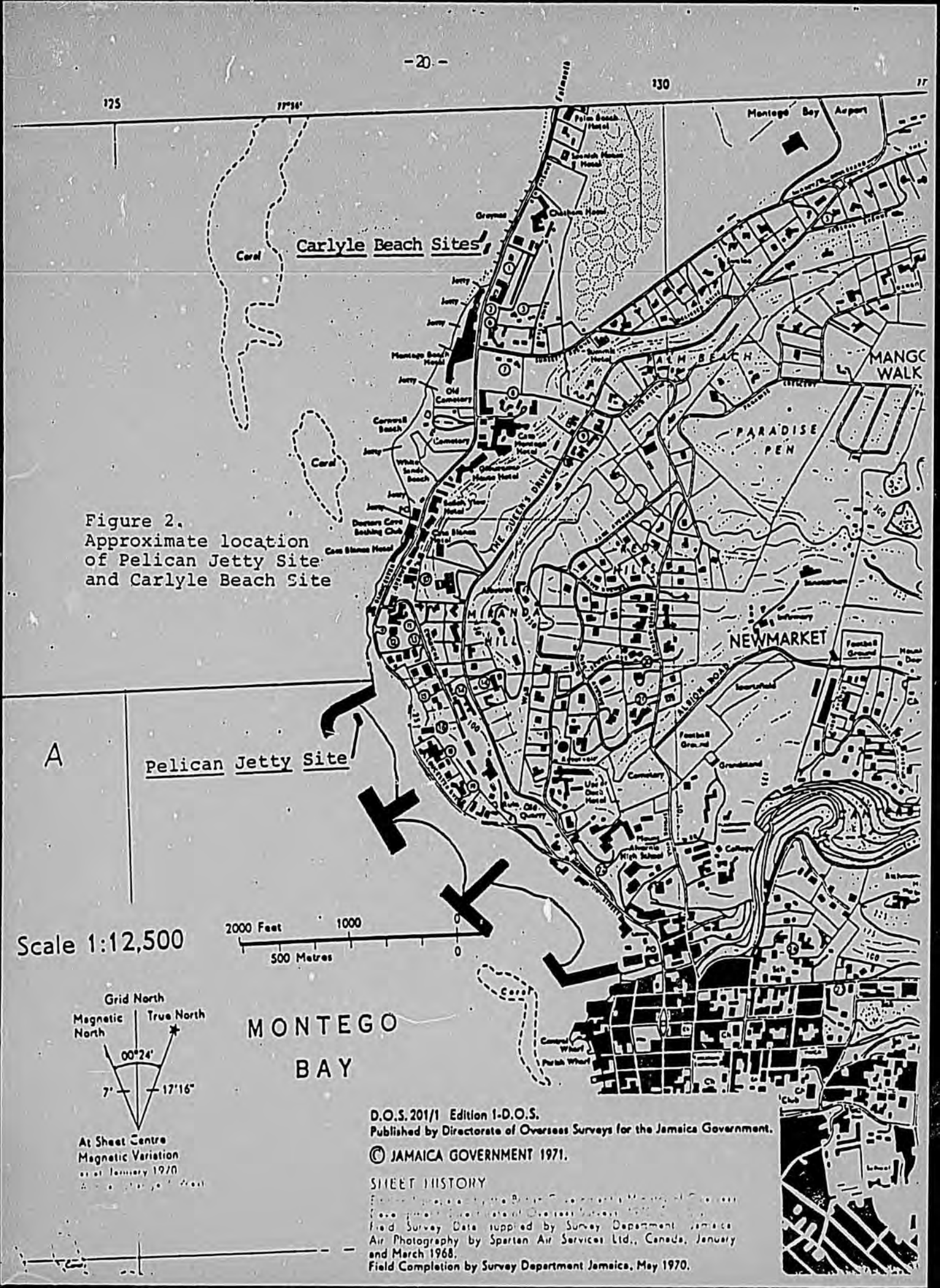


Figure 2.
Approximate location of Pelican Jetty Site and Carlyle Beach Site

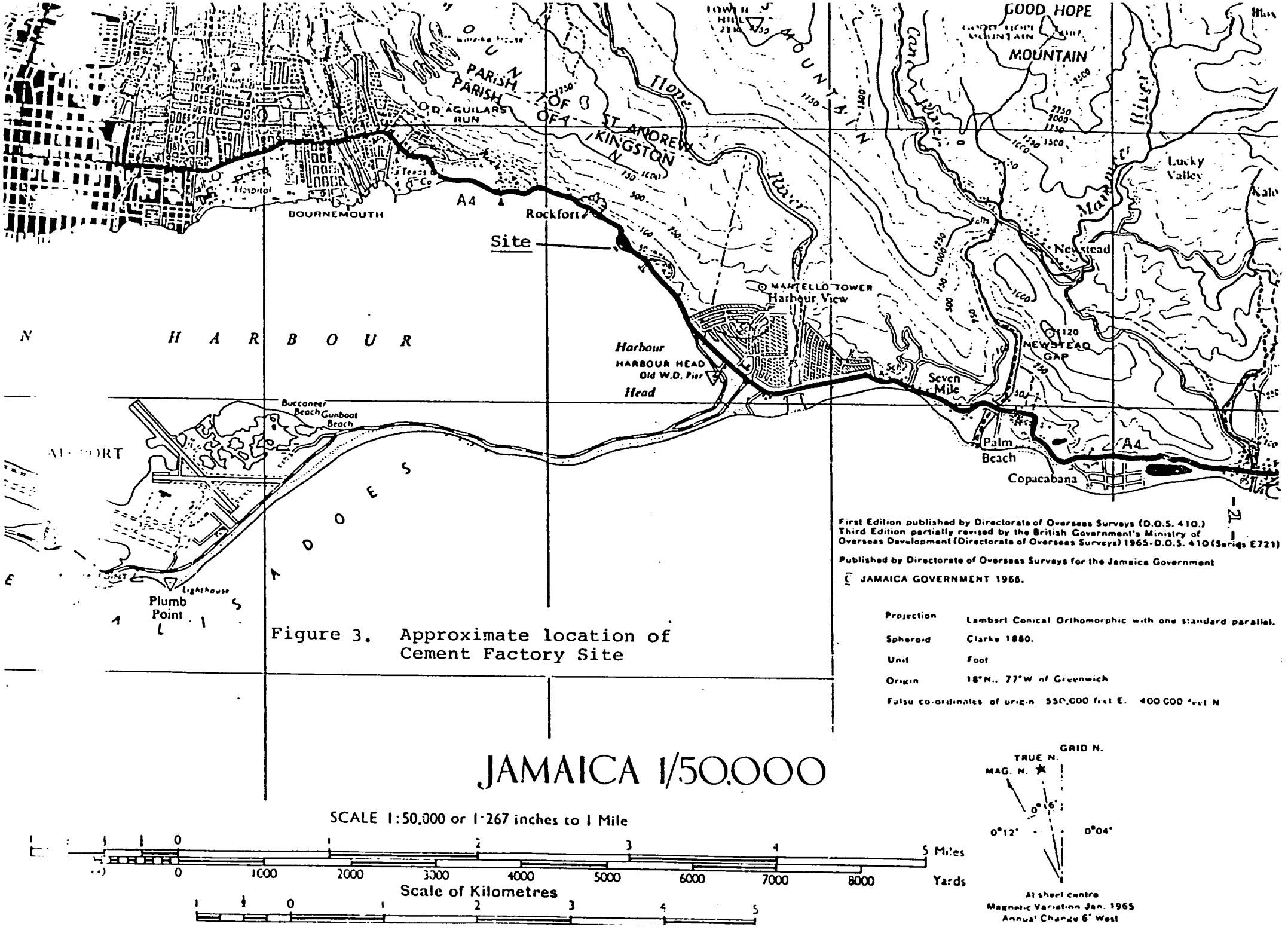


Figure 3. Approximate location of Cement Factory Site

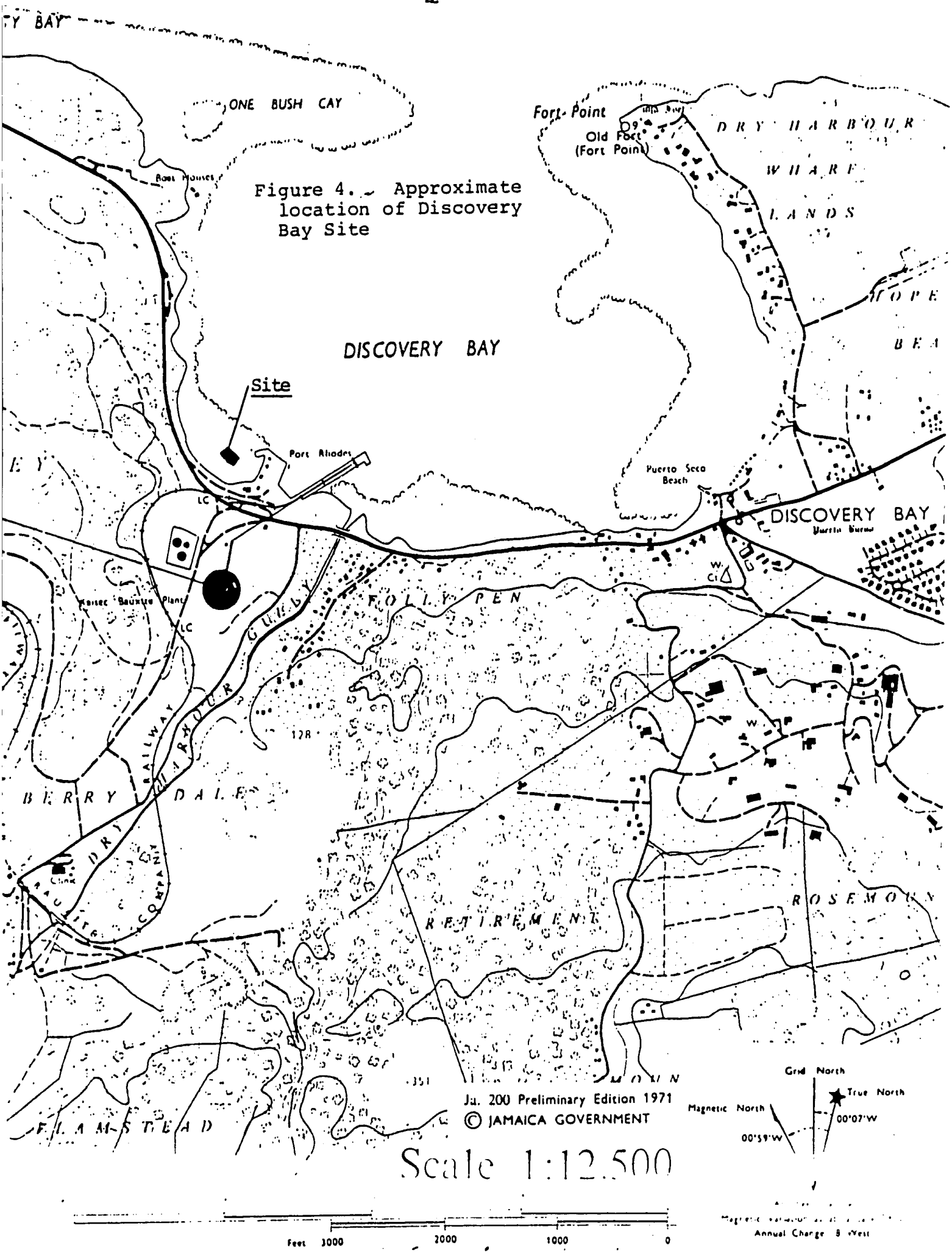


Figure 4. - Approximate location of Discovery Bay Site

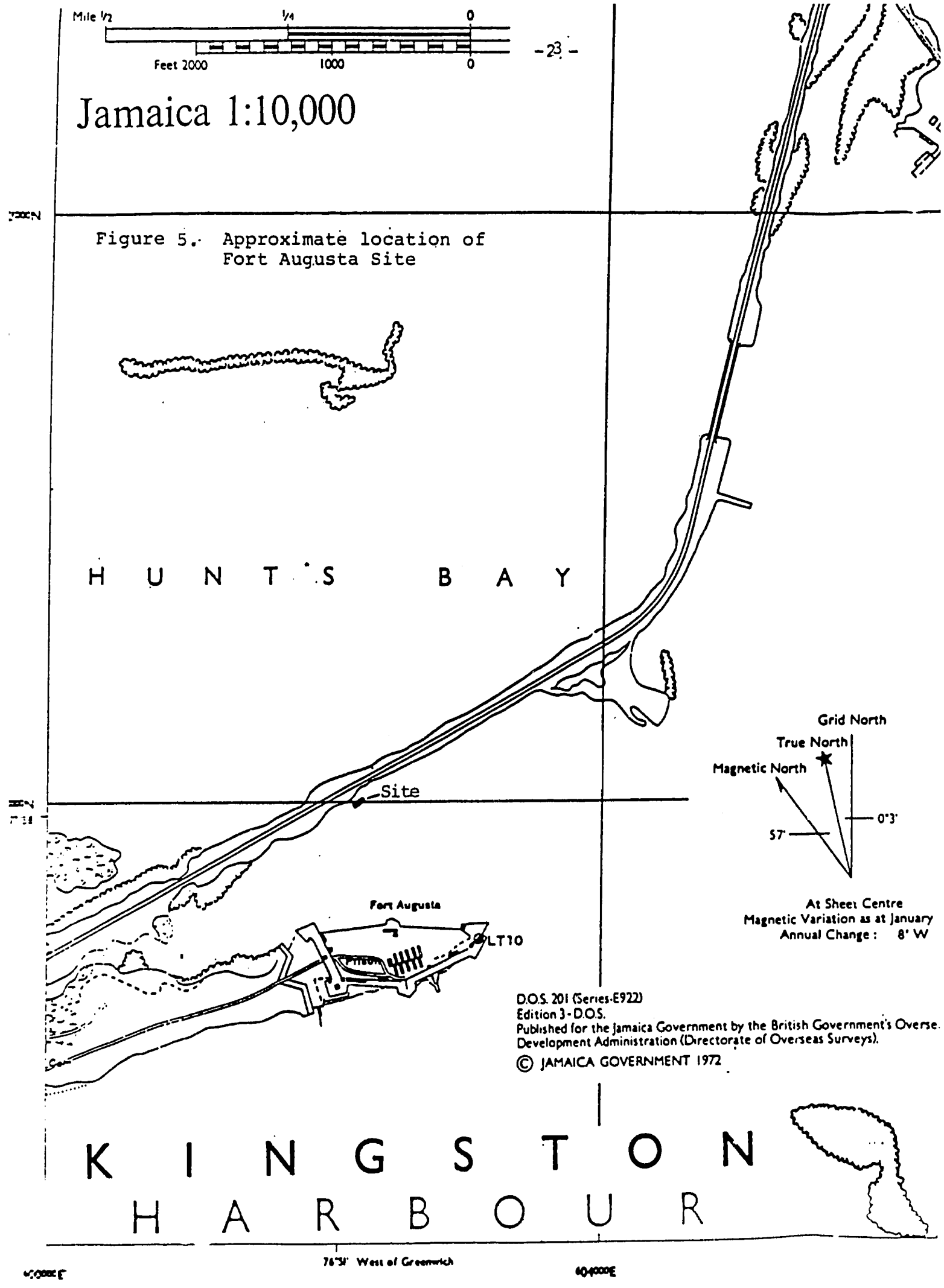


Figure 5. Approximate location of Fort Augusta Site

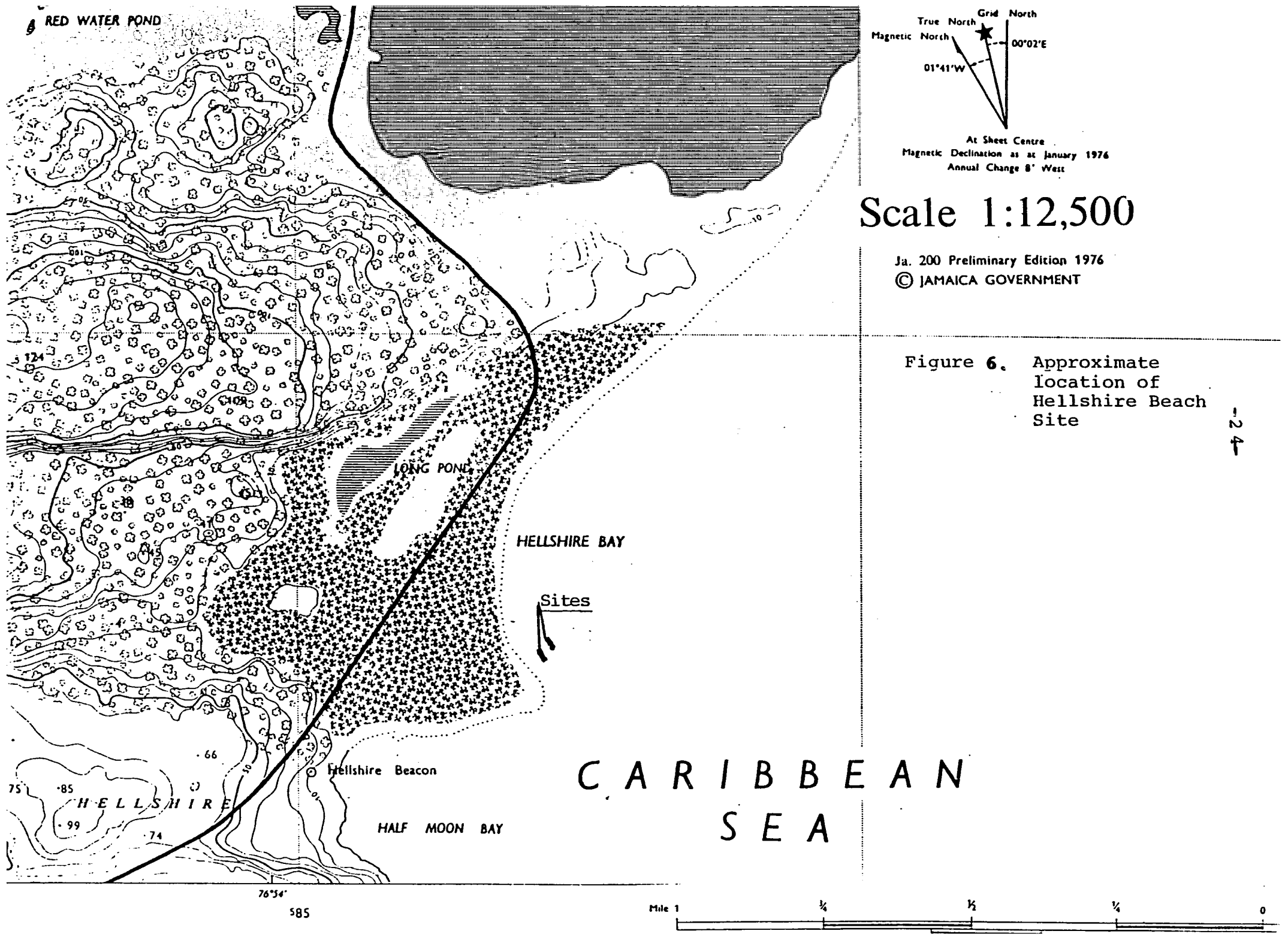


Figure 6. Approximate location of Hellshire Beach Site

Figure 7. Approximate location of Negril Point Site and the South Negril River Site

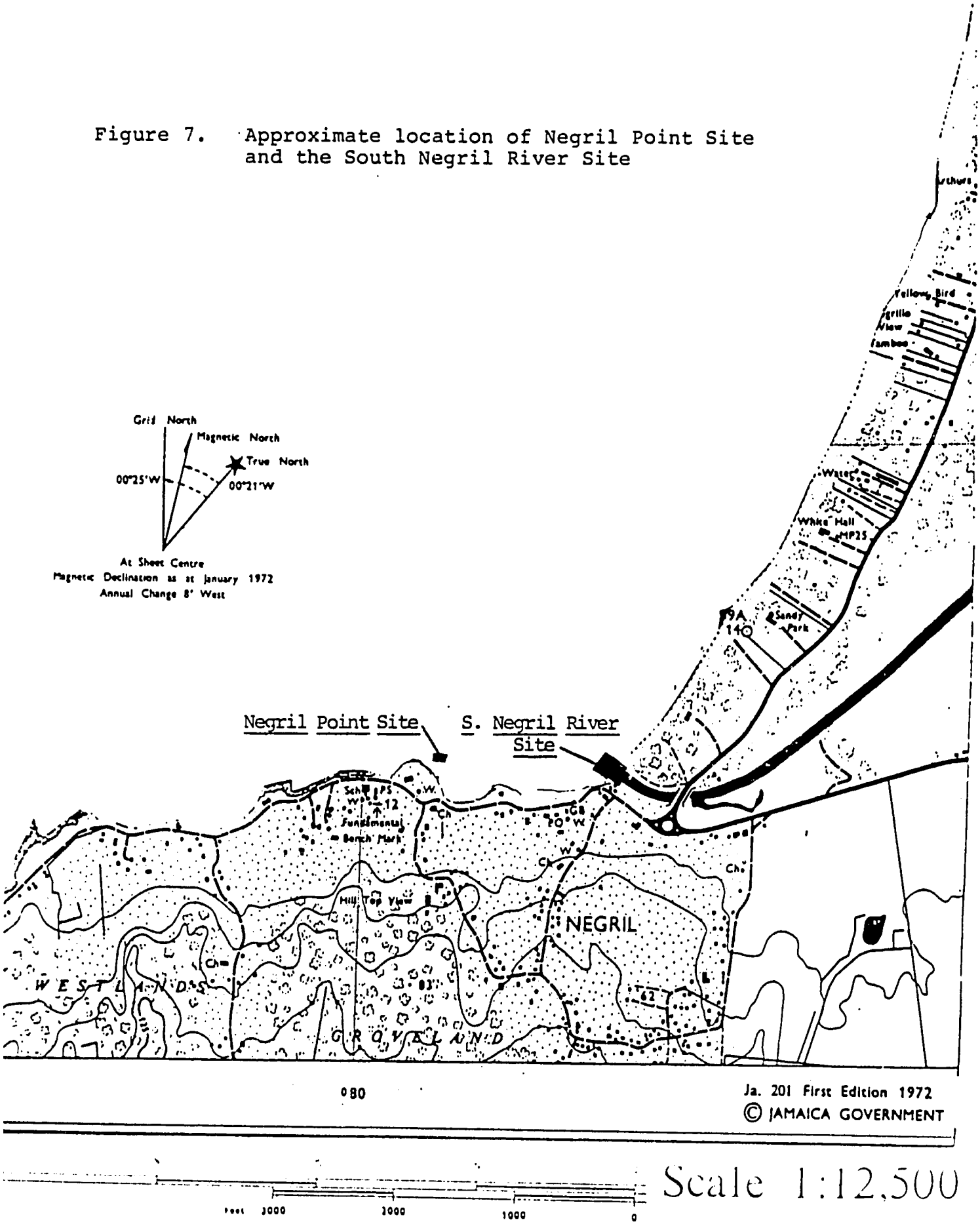
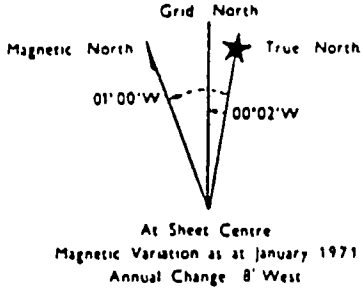


Figure 8. : Approximate location of Ocho Rios Site



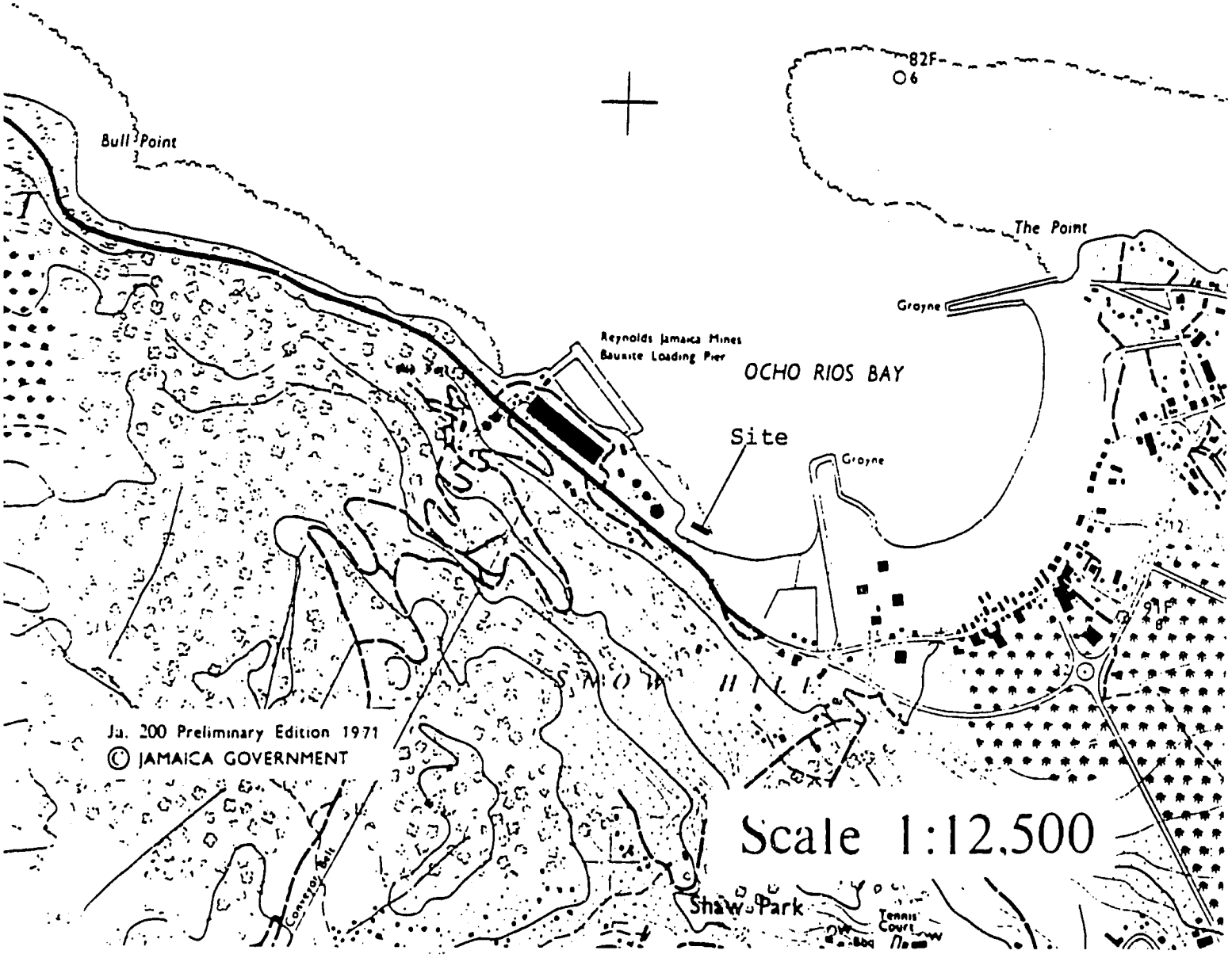
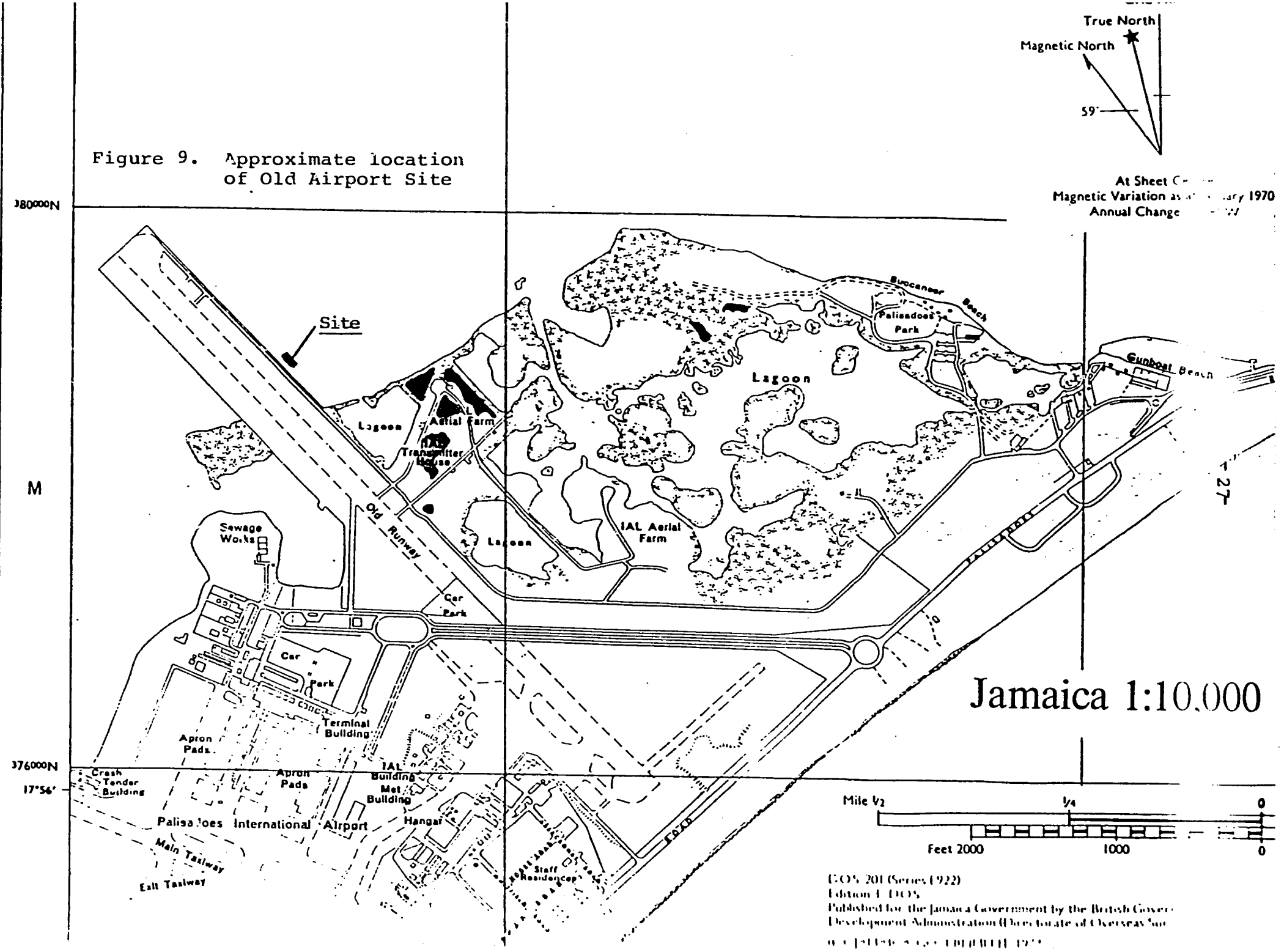


Figure 9. Approximate location of Old Airport Site



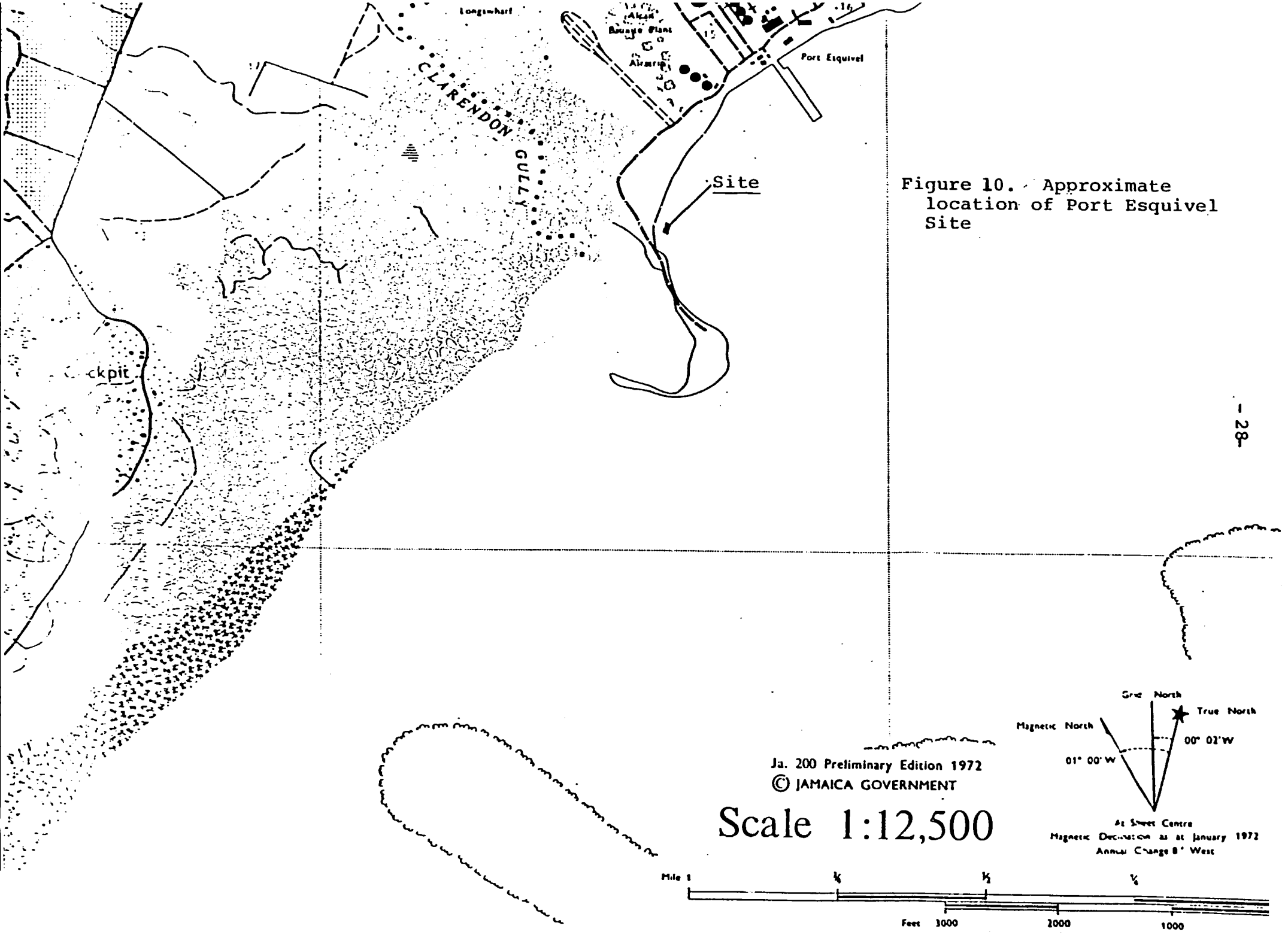


Figure 10. Approximate location of Port Esquivel Site

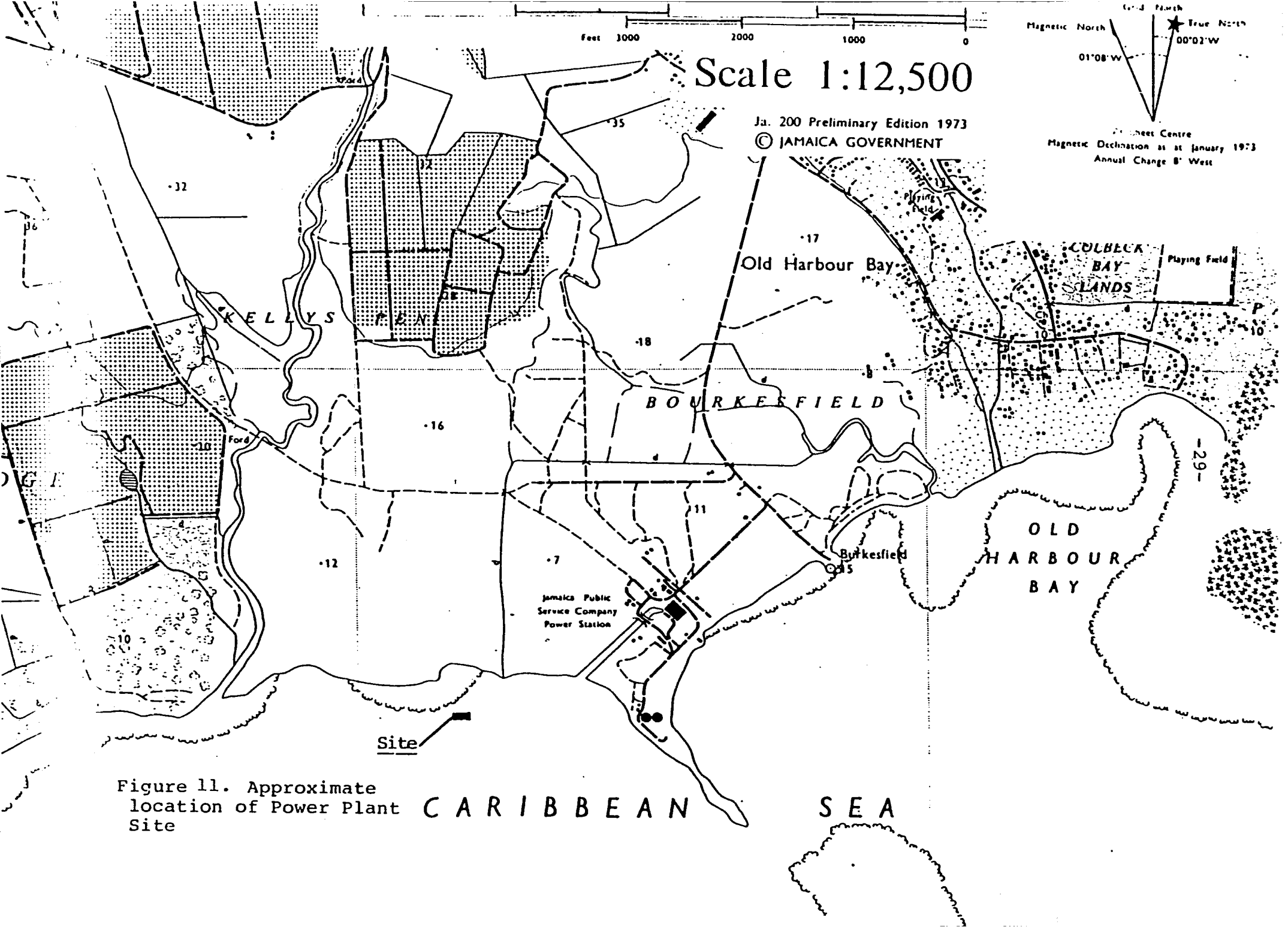


Figure 11. Approximate location of Power Plant Site

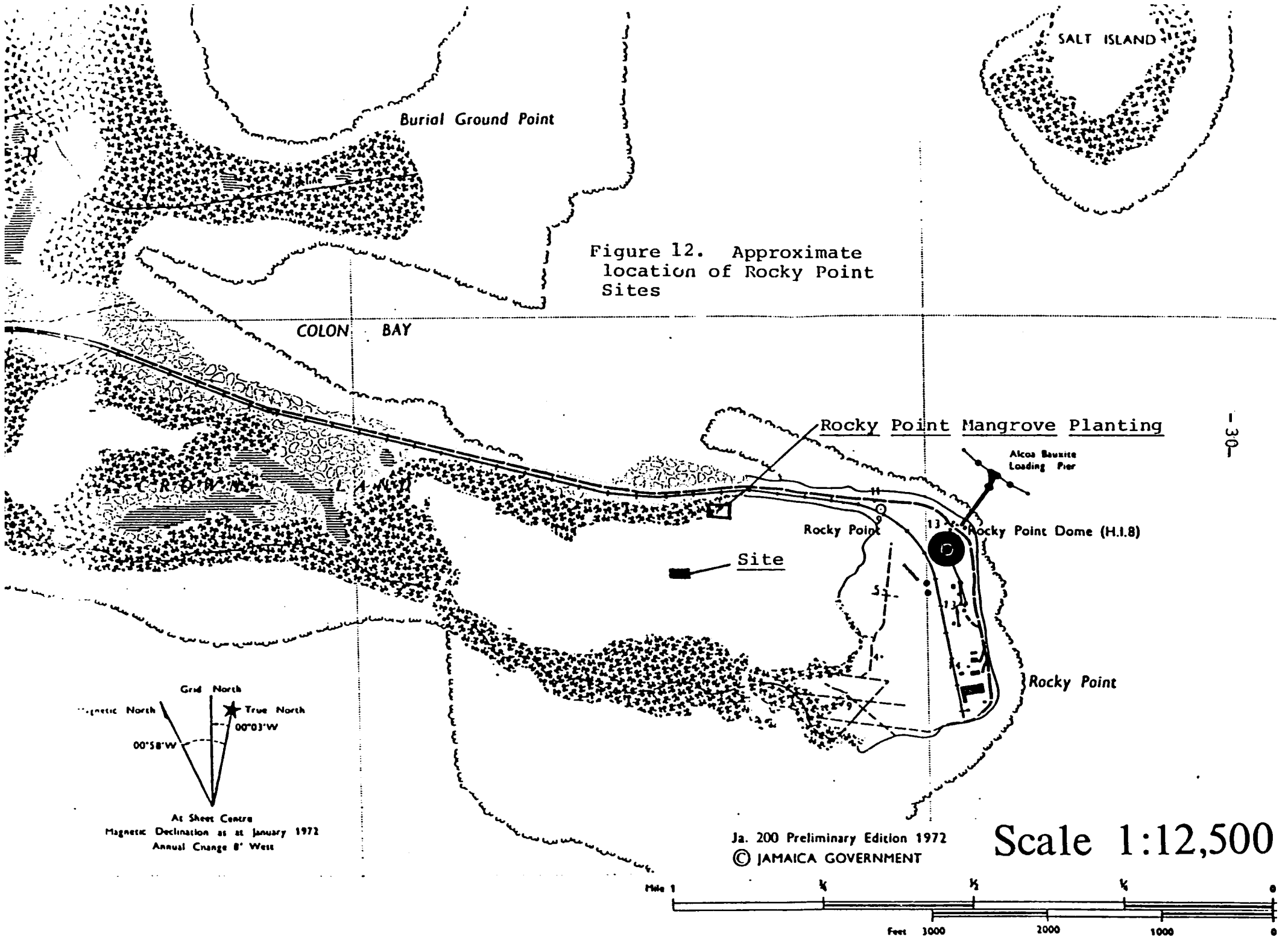


Figure 12. Approximate location of Rocky Point Sites

D.O.S. 201/1 Edition 1-D.O.S.
Published by Directorate of Overseas Surveys for the Jamaica Government.

© JAMAICA GOVERNMENT 1971.

SHEET HISTORY

Edition 1 prepared by the British Government's Ministry of Overseas Development (Directorate of Overseas Surveys) 1970 (D.O.S.201/1).
Field Survey Data supplied by Survey Department, Jamaica.
Air Photography by Spartan Air Services Ltd., Canada, January and March 1968.
Field Completion by Survey Department Jamaica, May 1970.

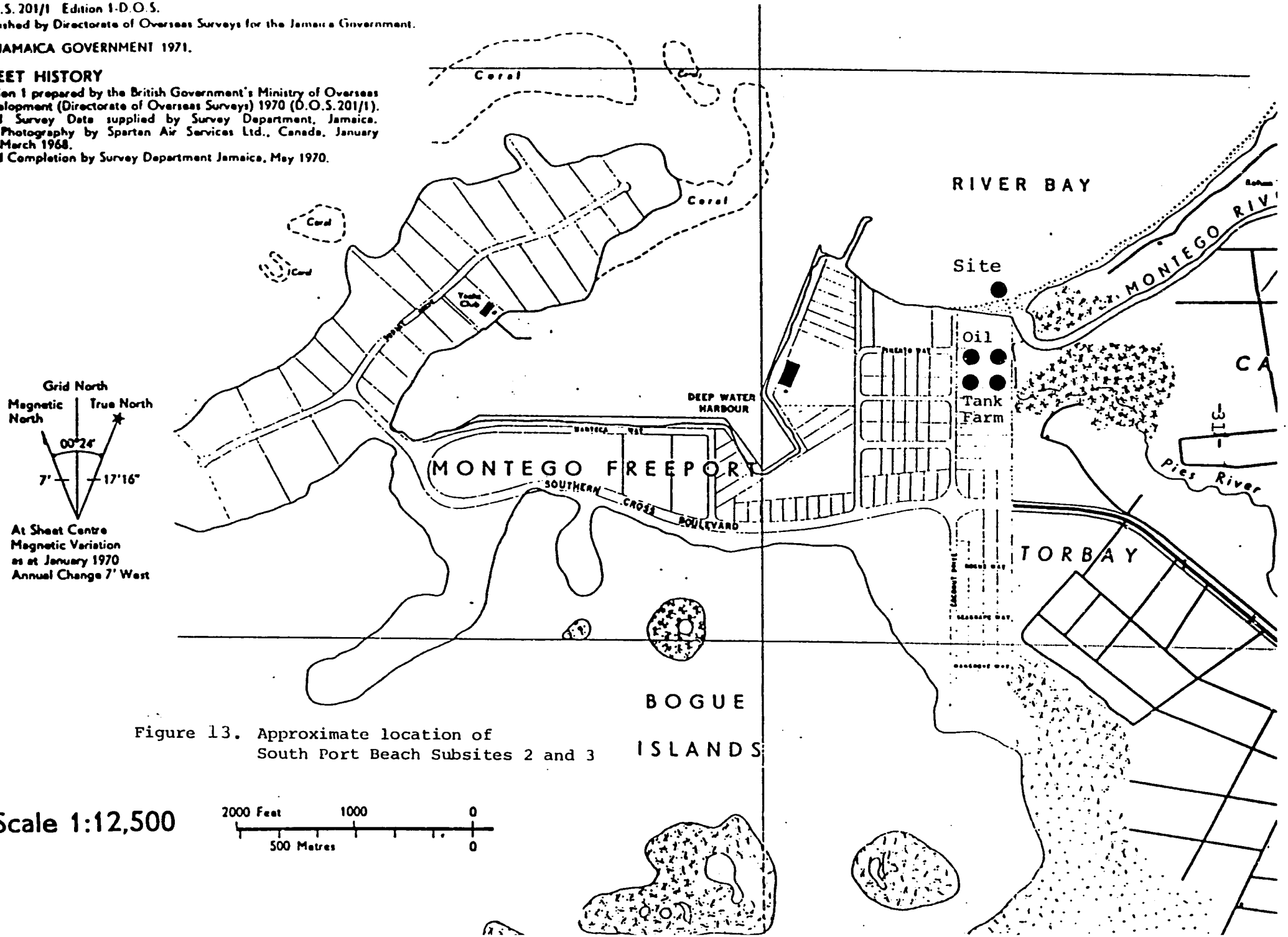


Figure 13. Approximate location of South Port Beach Subsites 2 and 3

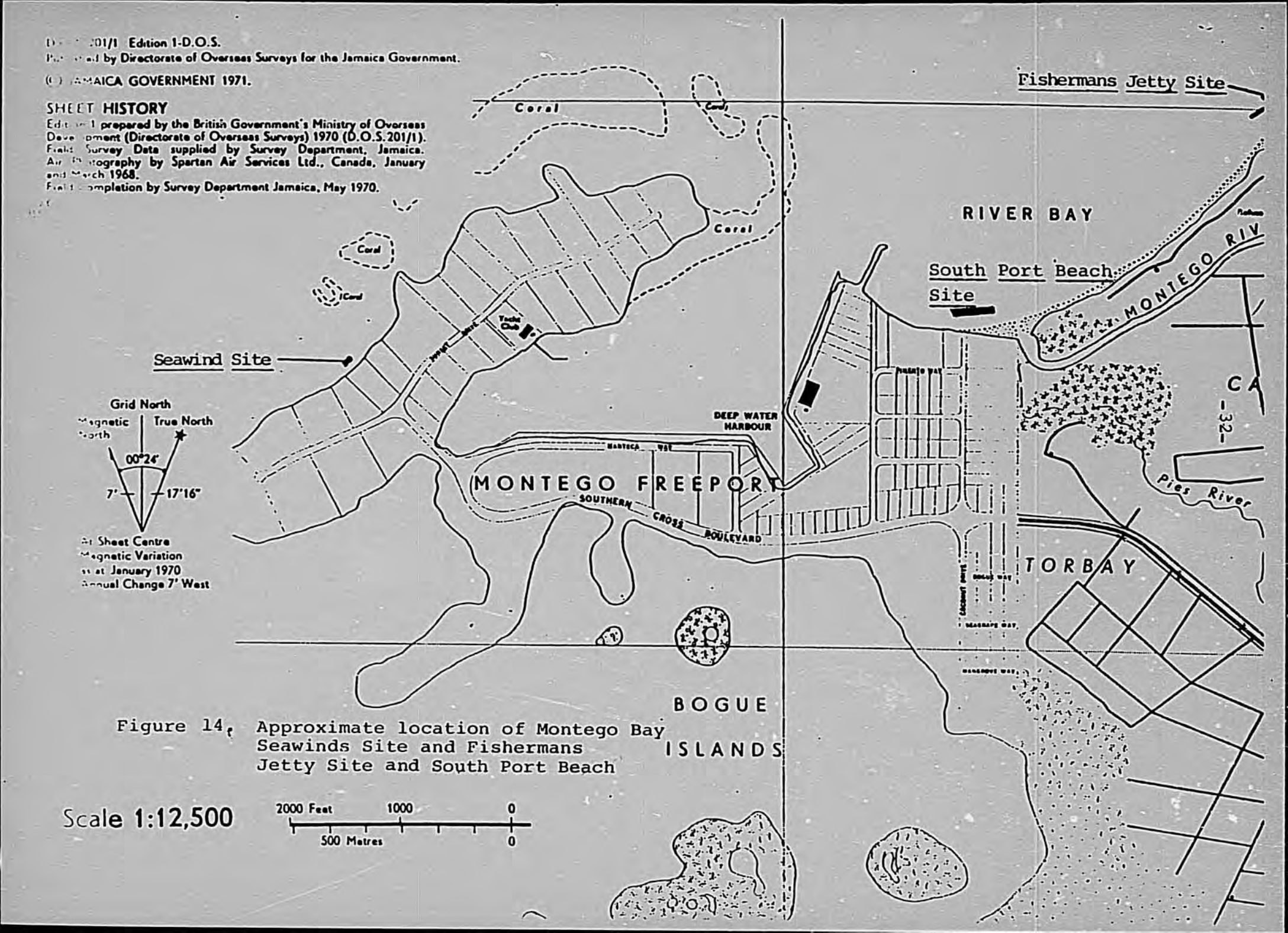
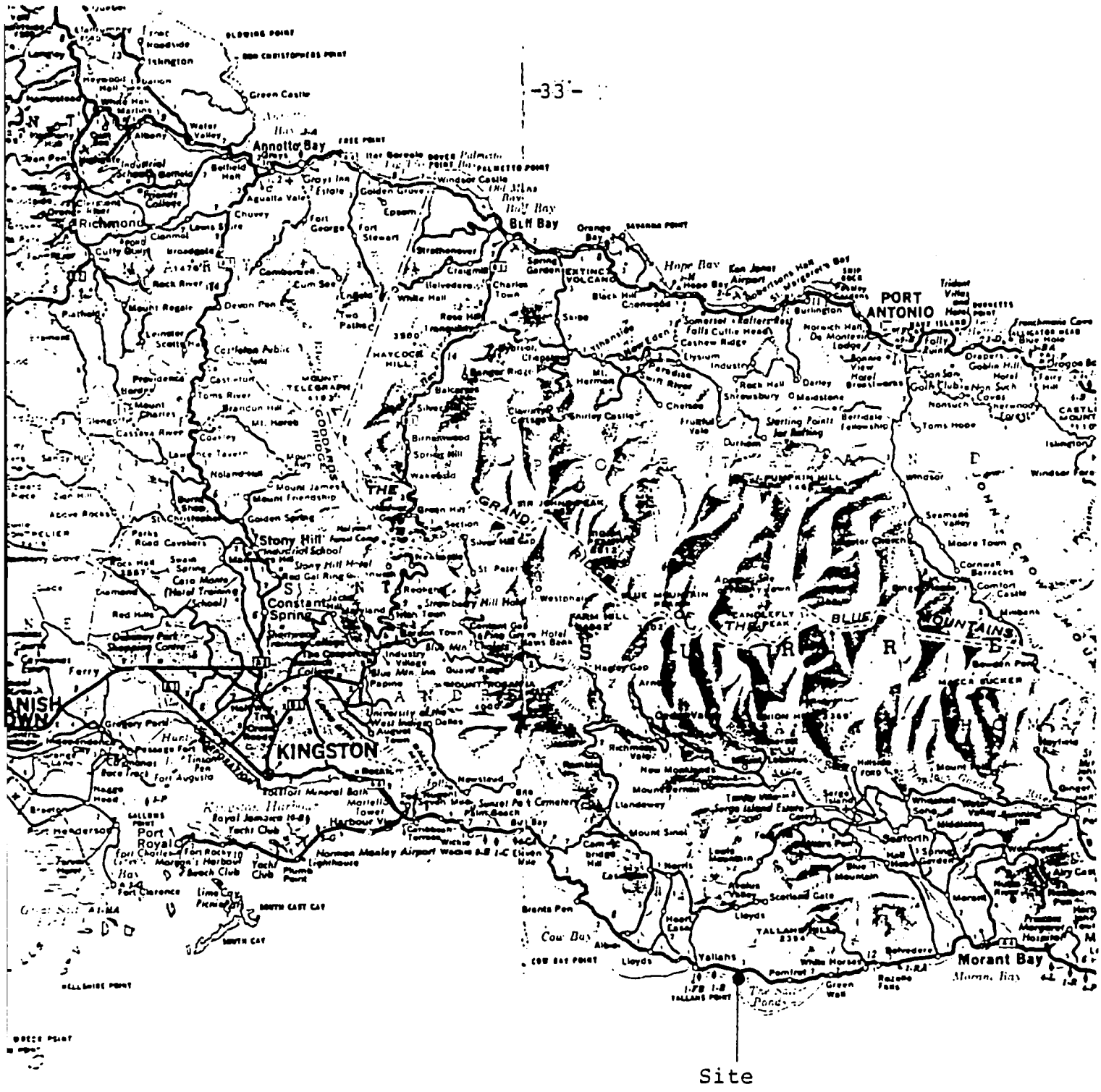


Figure 14. Approximate location of Montego Bay Seawinds Site and Fishermans Jetty Site and South Port Beach



N

Figure 15. Approximate location of Yallahs Ponds Site

Elevations on map are shown in feet

Distances on map are shown in miles

One inch equals approximately 4.8 miles

Scale 0 1 2 3 4 5 10 miles

Copyright © by Rand McNally & Co
Lithographed in U.S.A.
All rights reserved. 1975 Edition

Sediment Particle Distribution

Figure 16. Alligator Pond

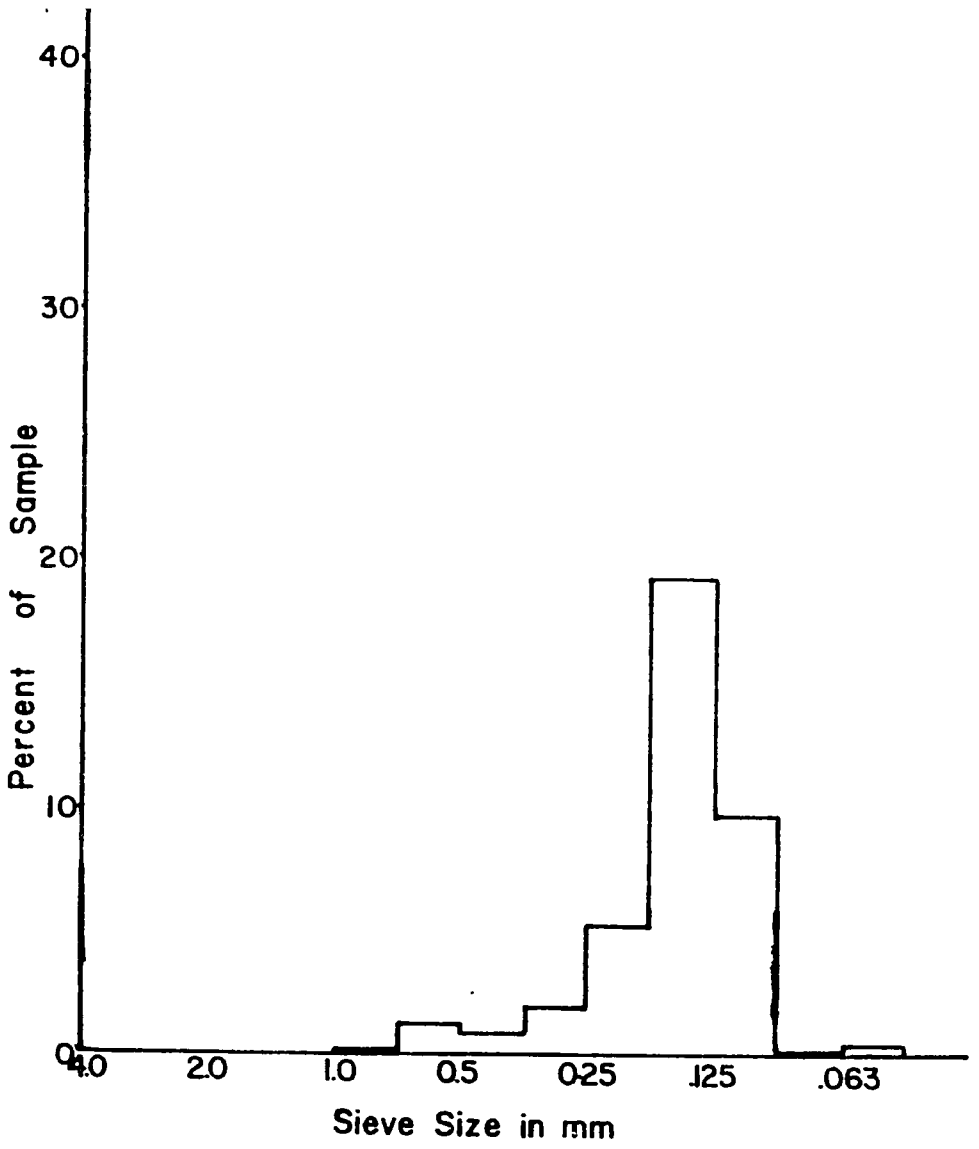


Figure 17. Carlyle Beach

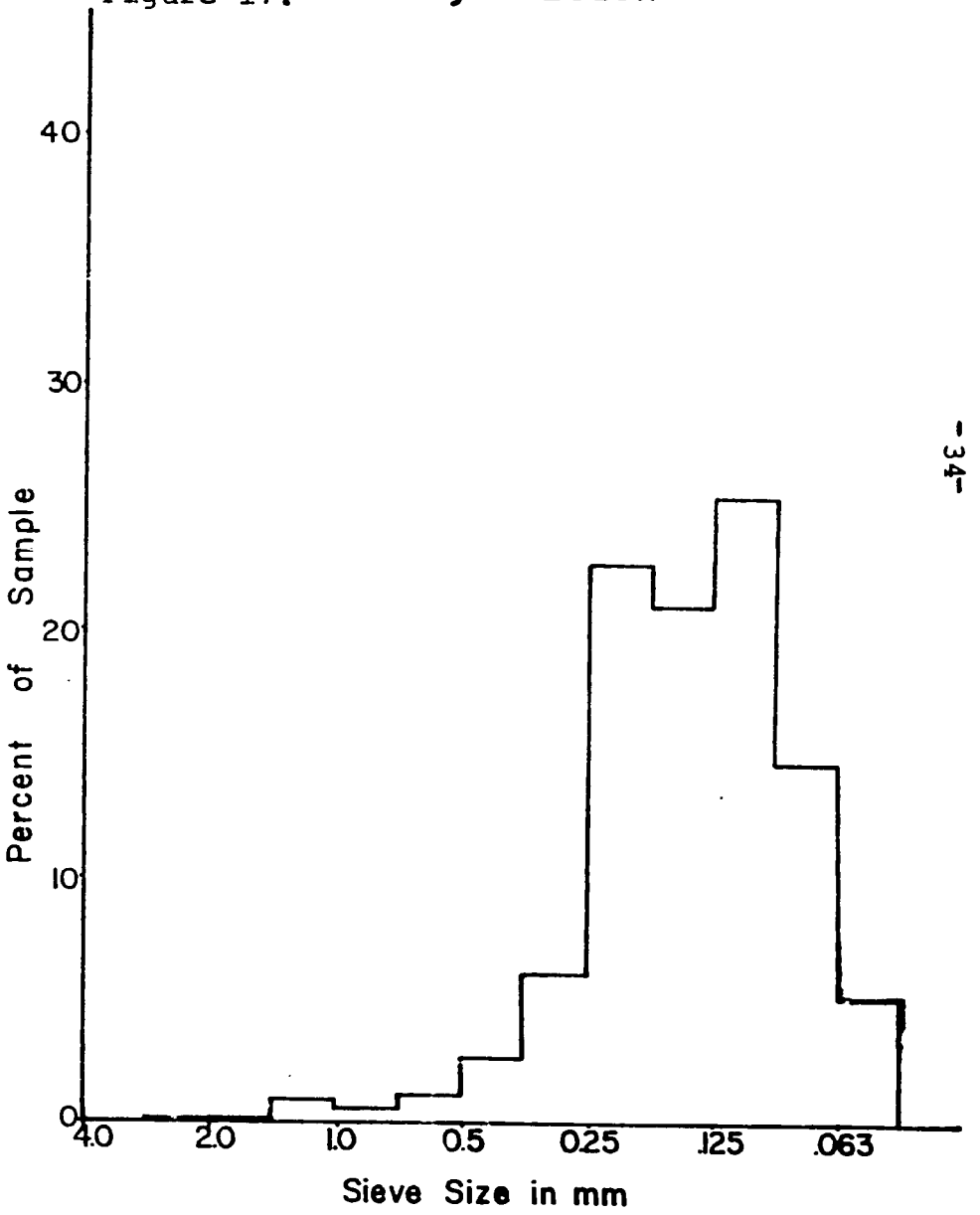


Figure 18. Cement Plant

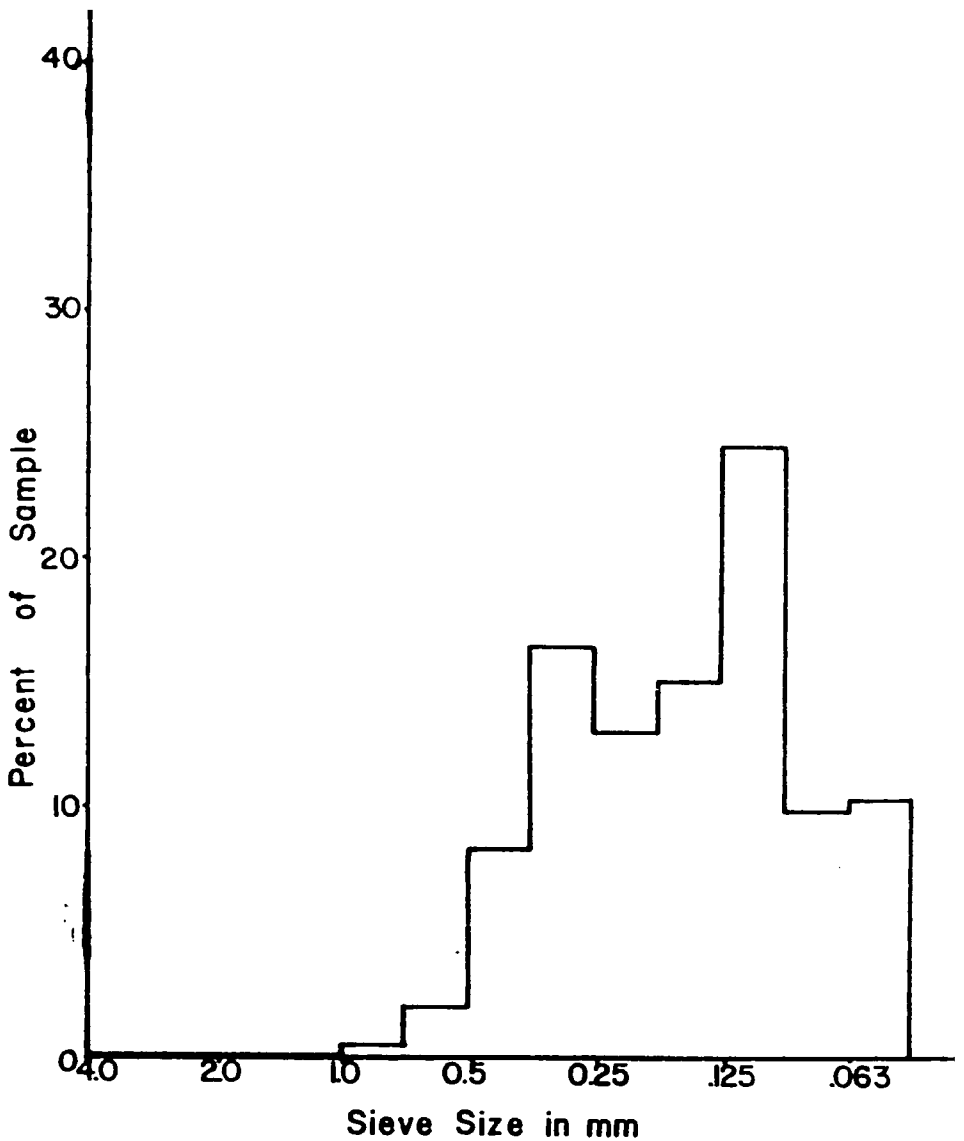
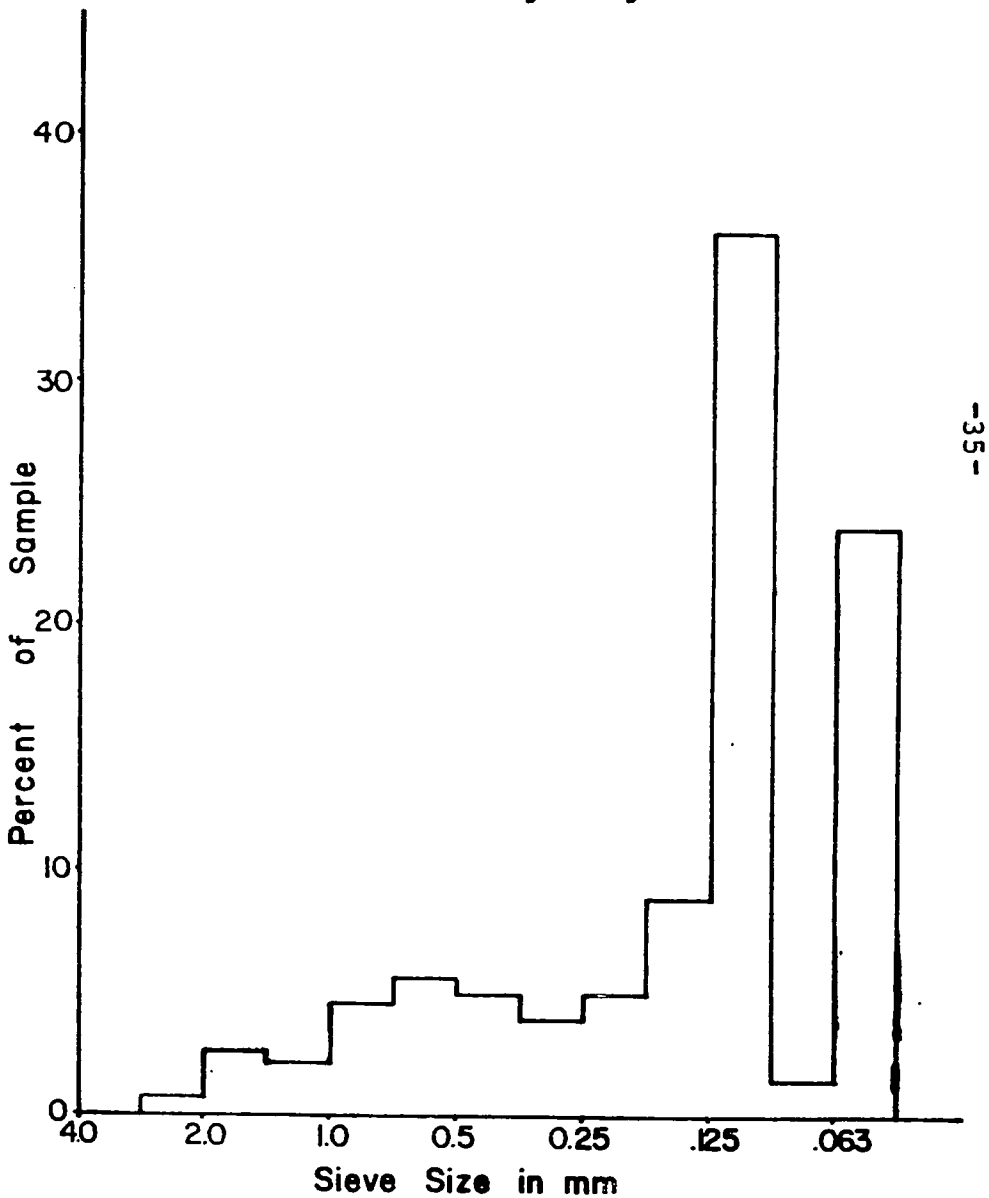


Figure 19. Discovery Bay



Sediment Particle Distribution

Figure 20. Fort Augusta

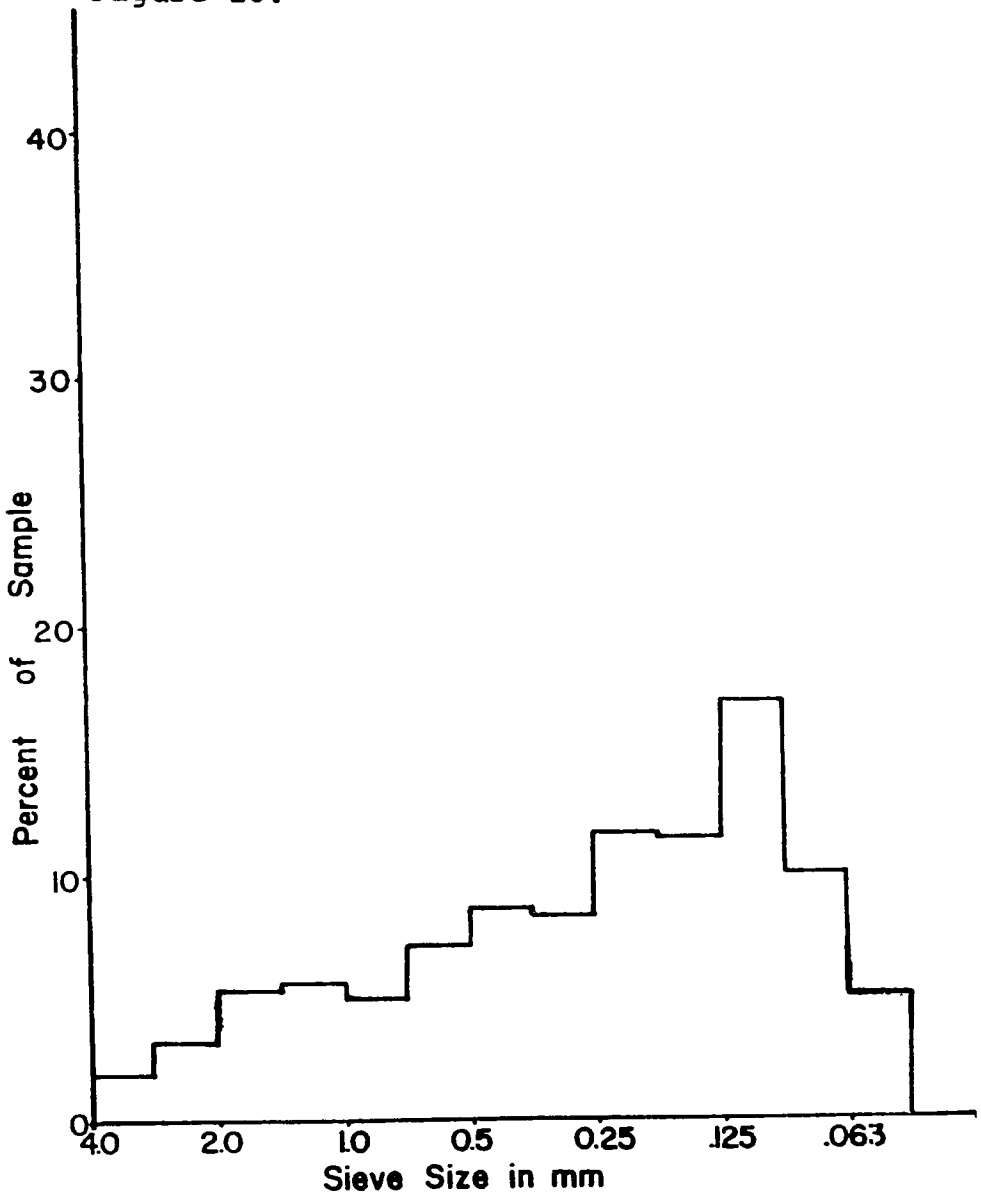
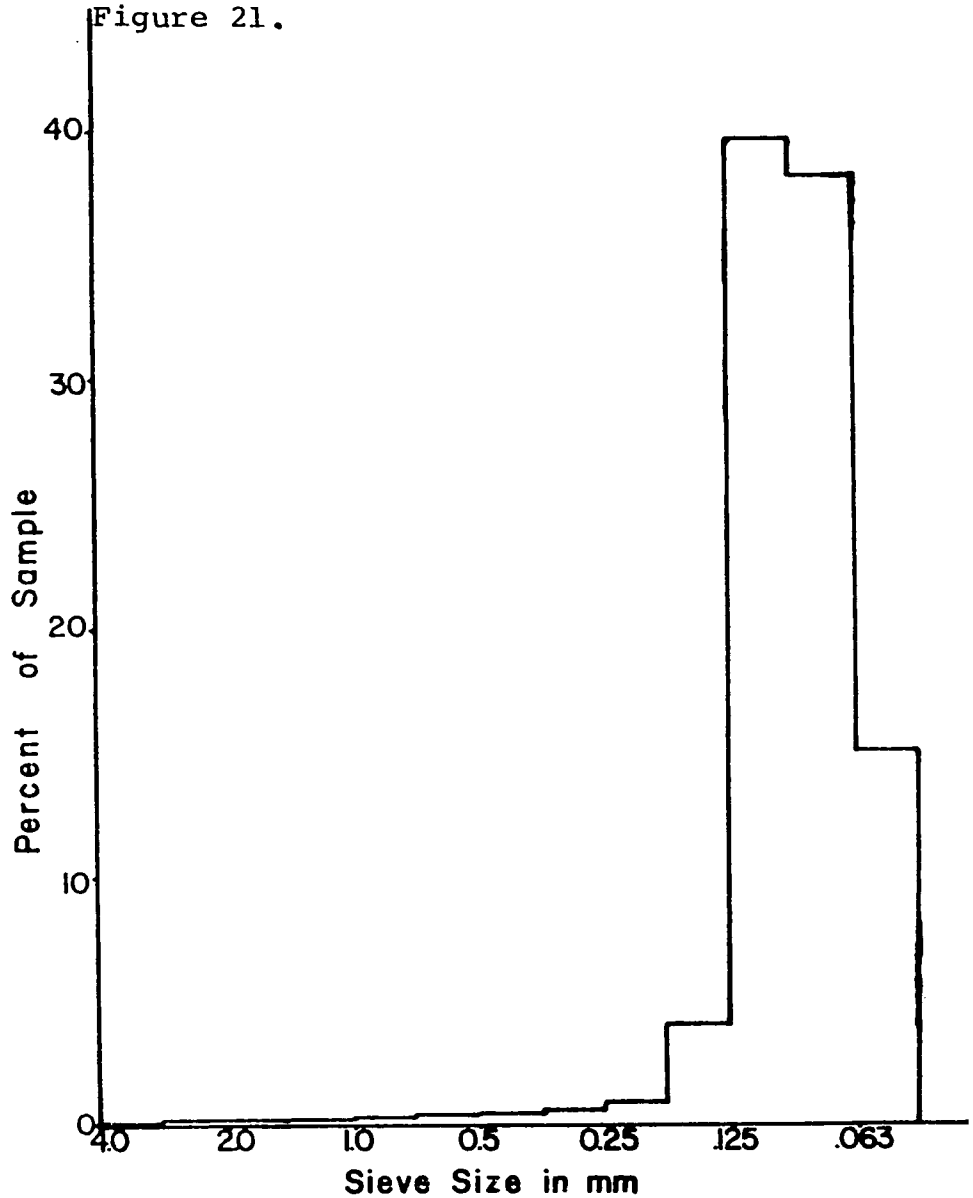


Figure 21. Hellshire



Particle Size Distribution

Figure 22. Negril River

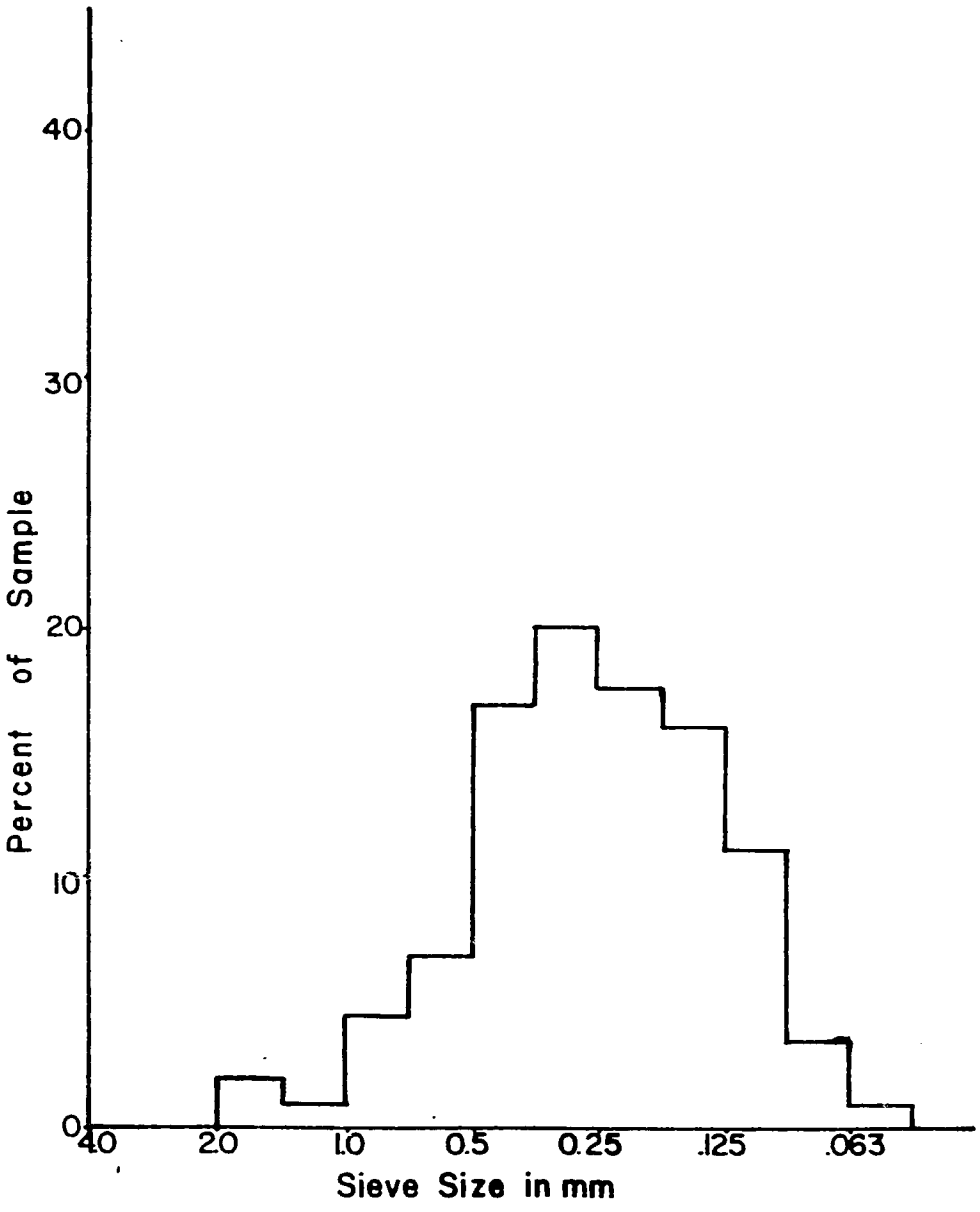
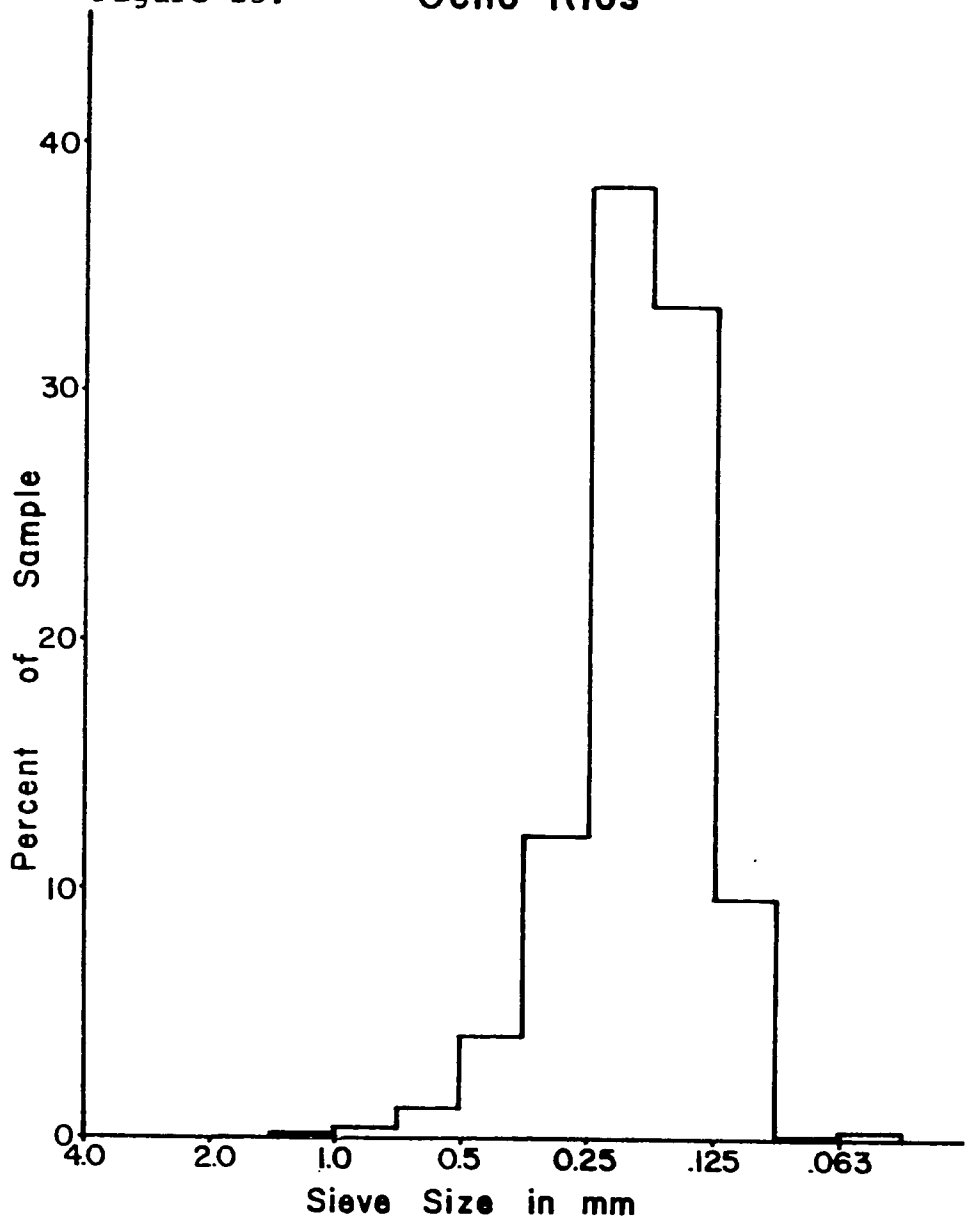


Figure 23. Ocho Rios



Particle Size Distribution

Figure 24.

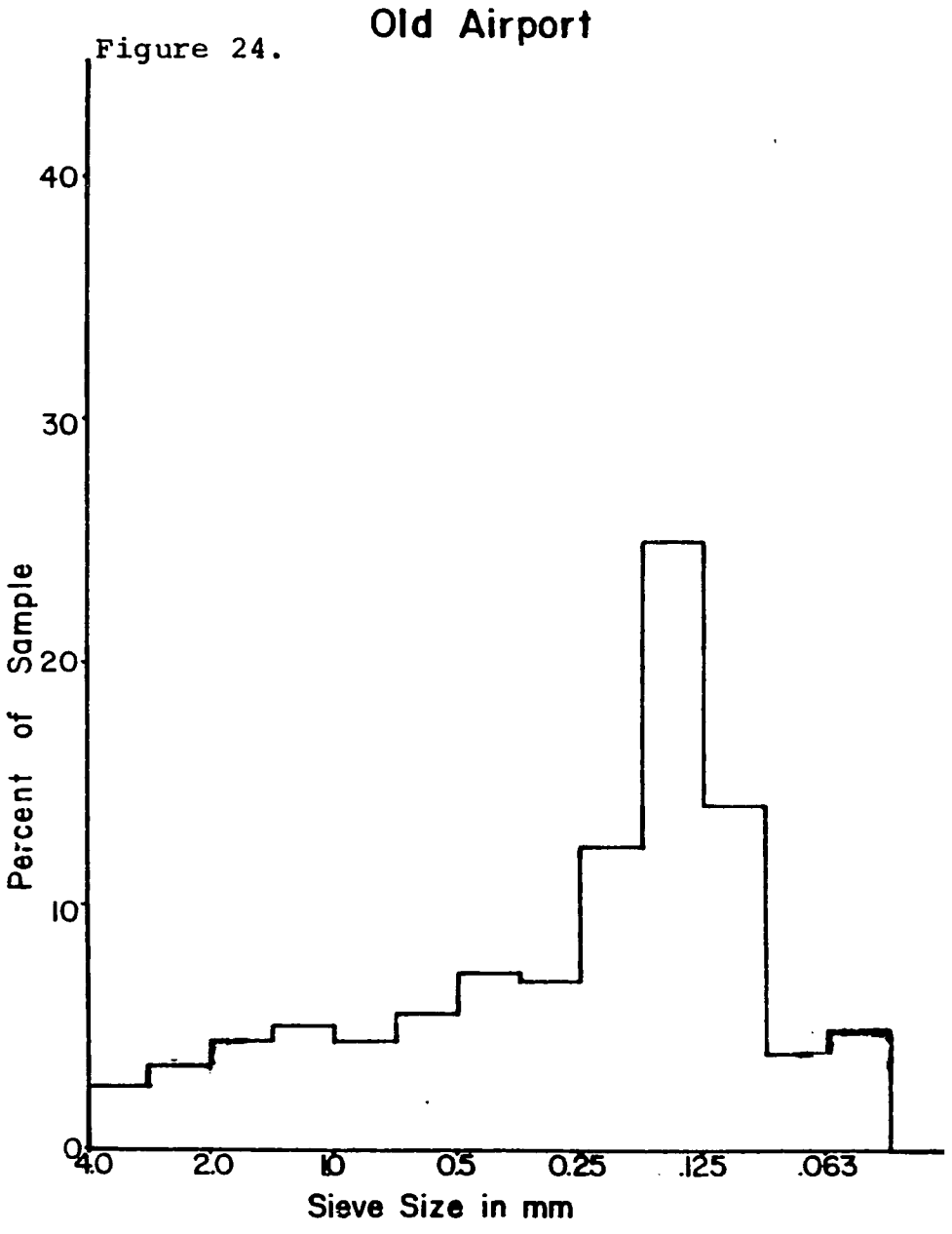
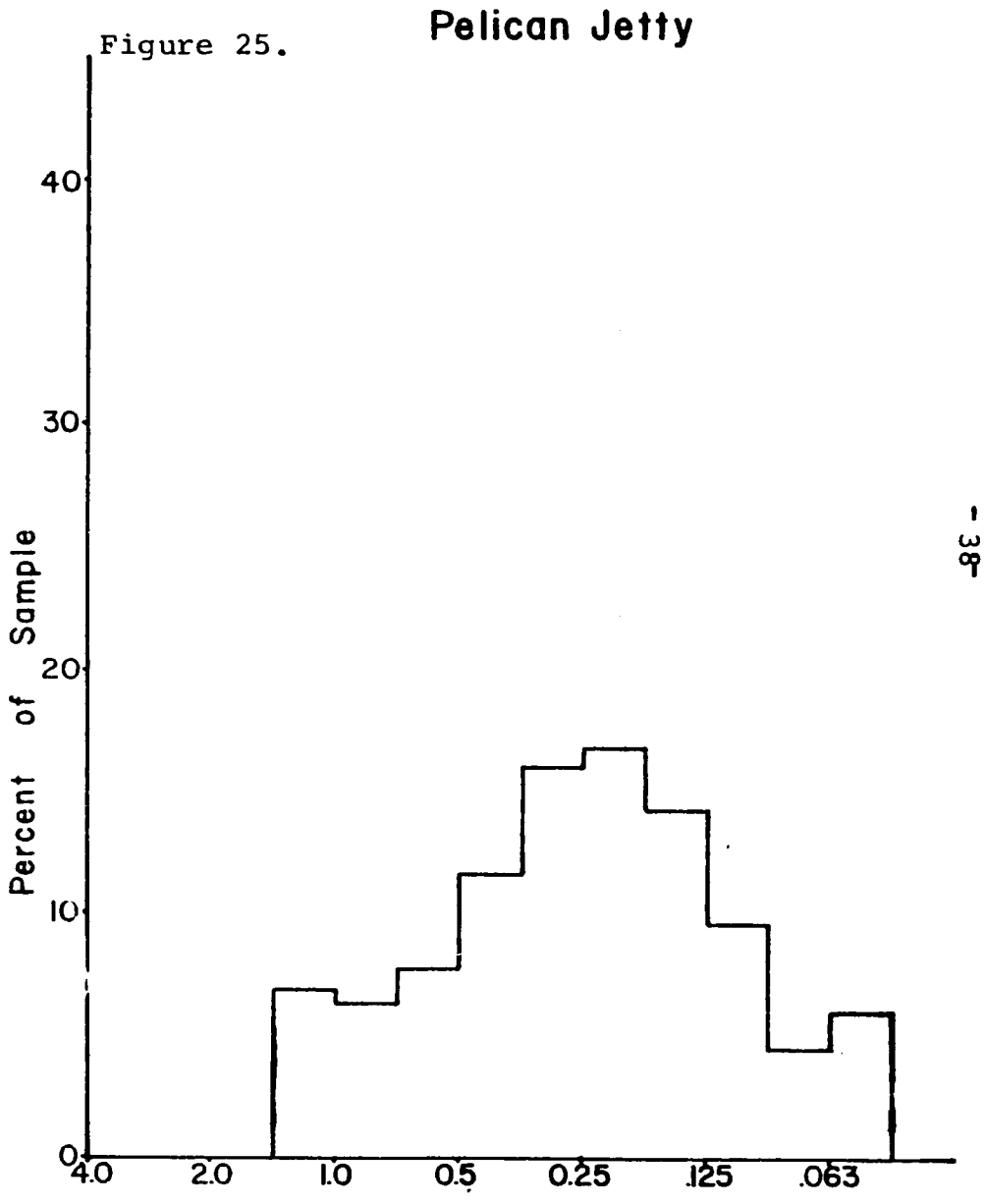


Figure 25.



Particle Size Distribution

Figure 26.

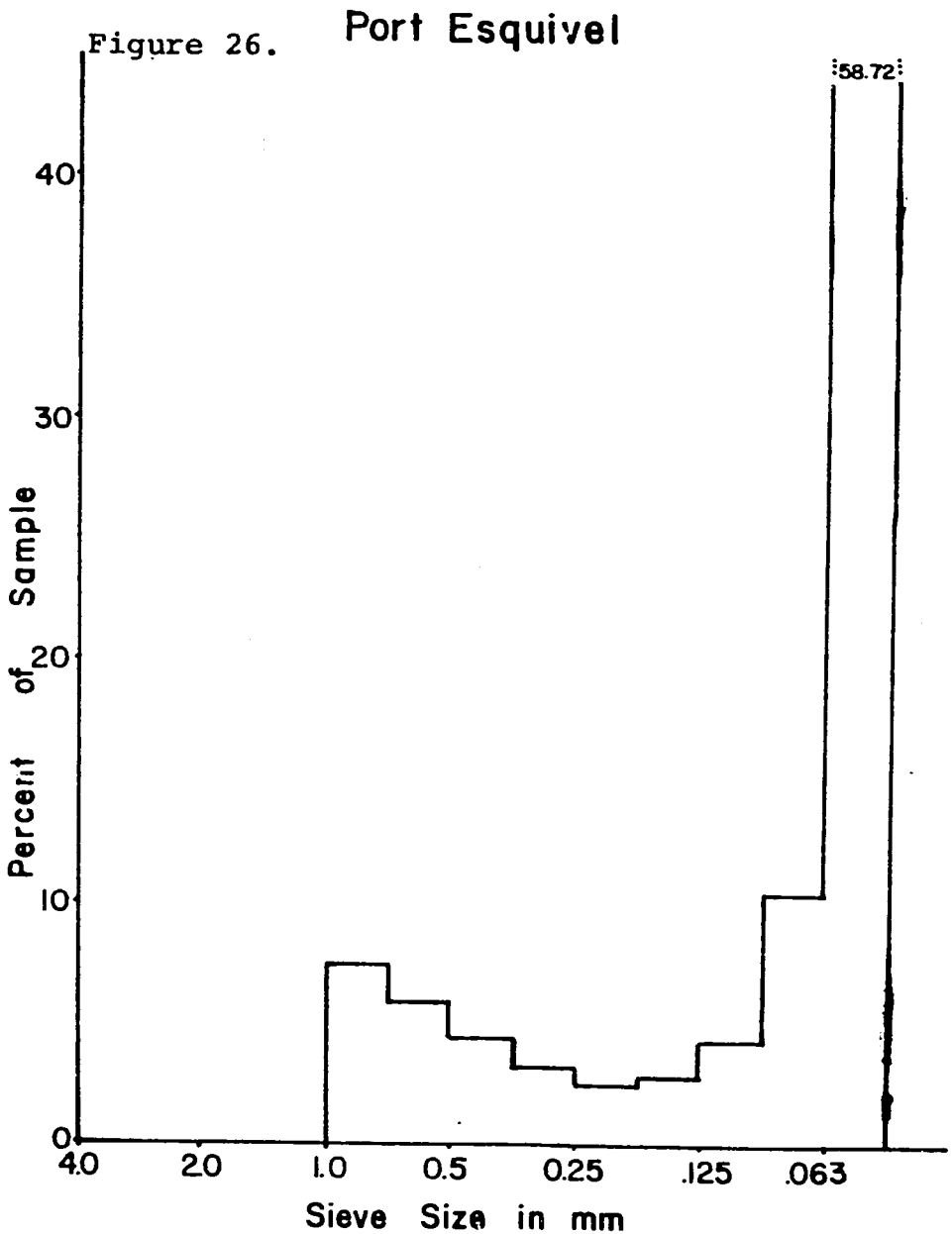
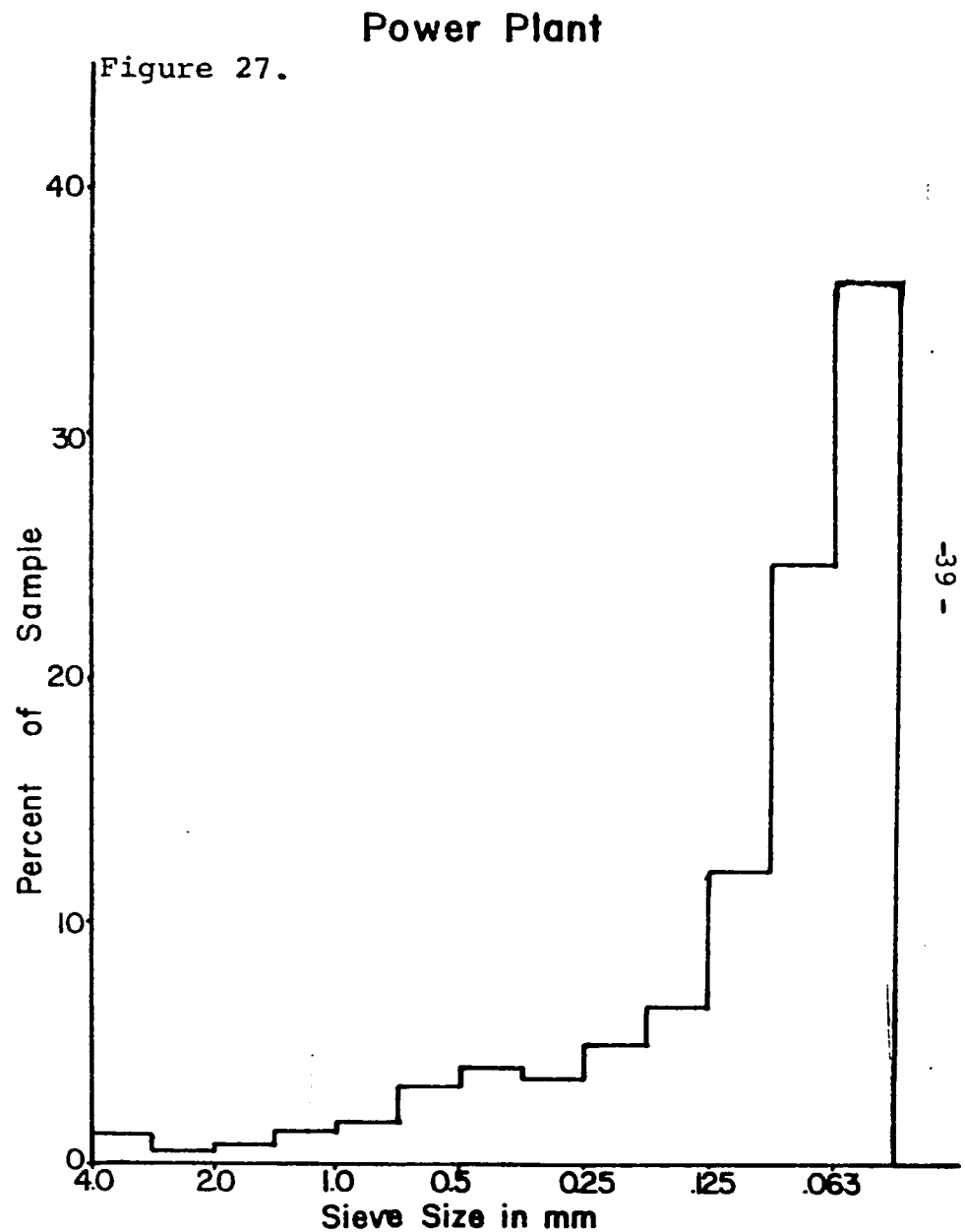


Figure 27.



Particle Size Distribution

Figure 28.

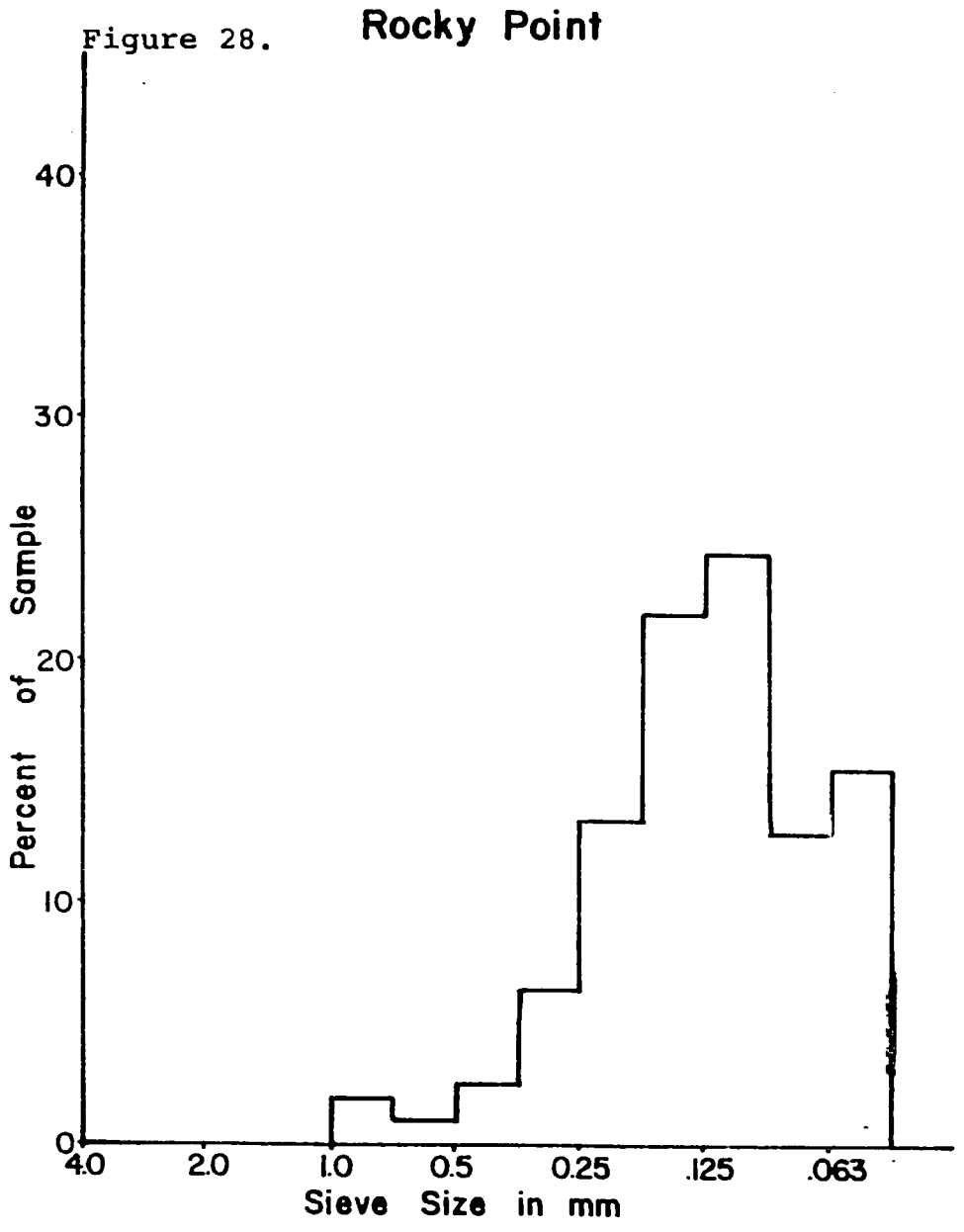


Figure 29.

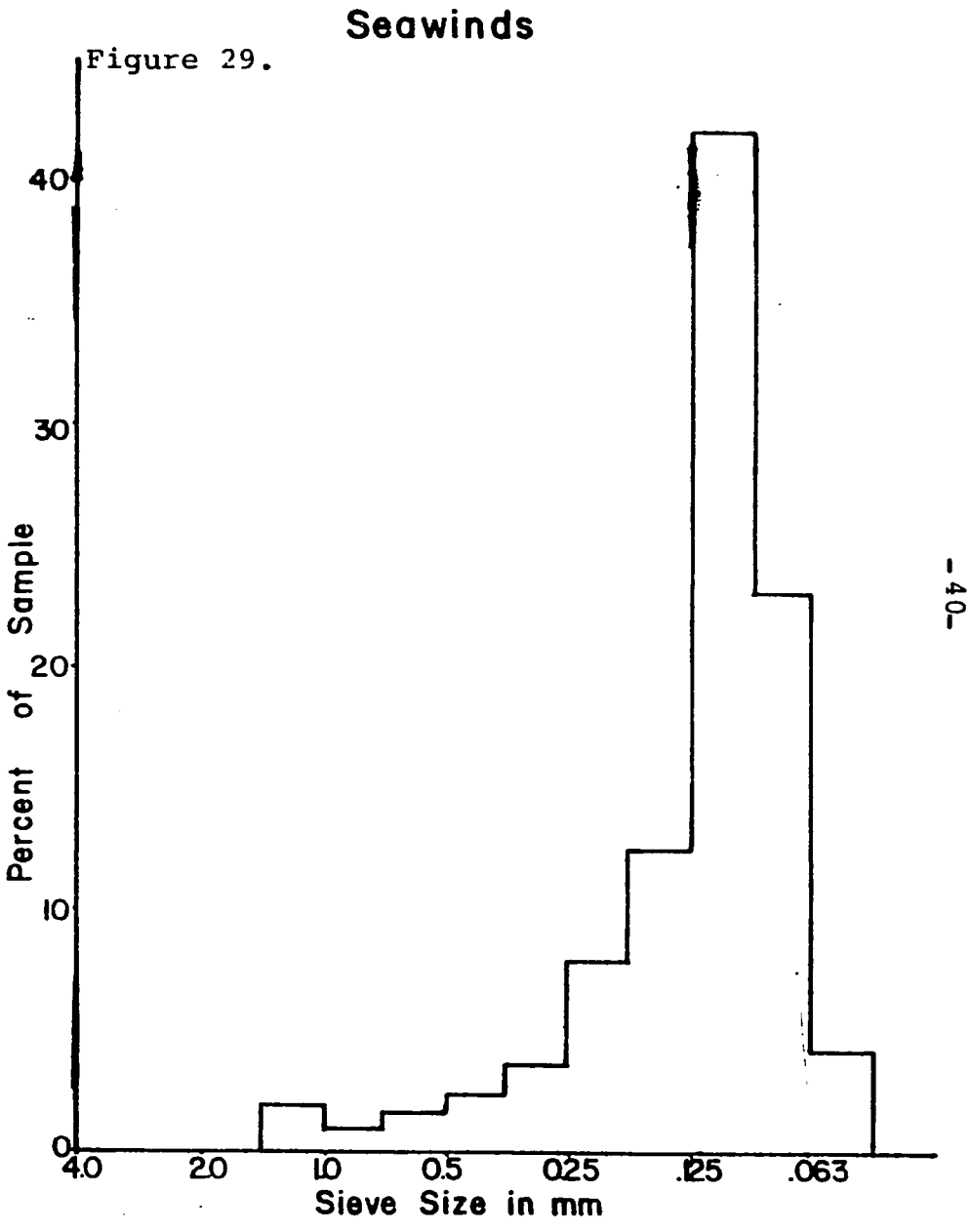


Figure 30.

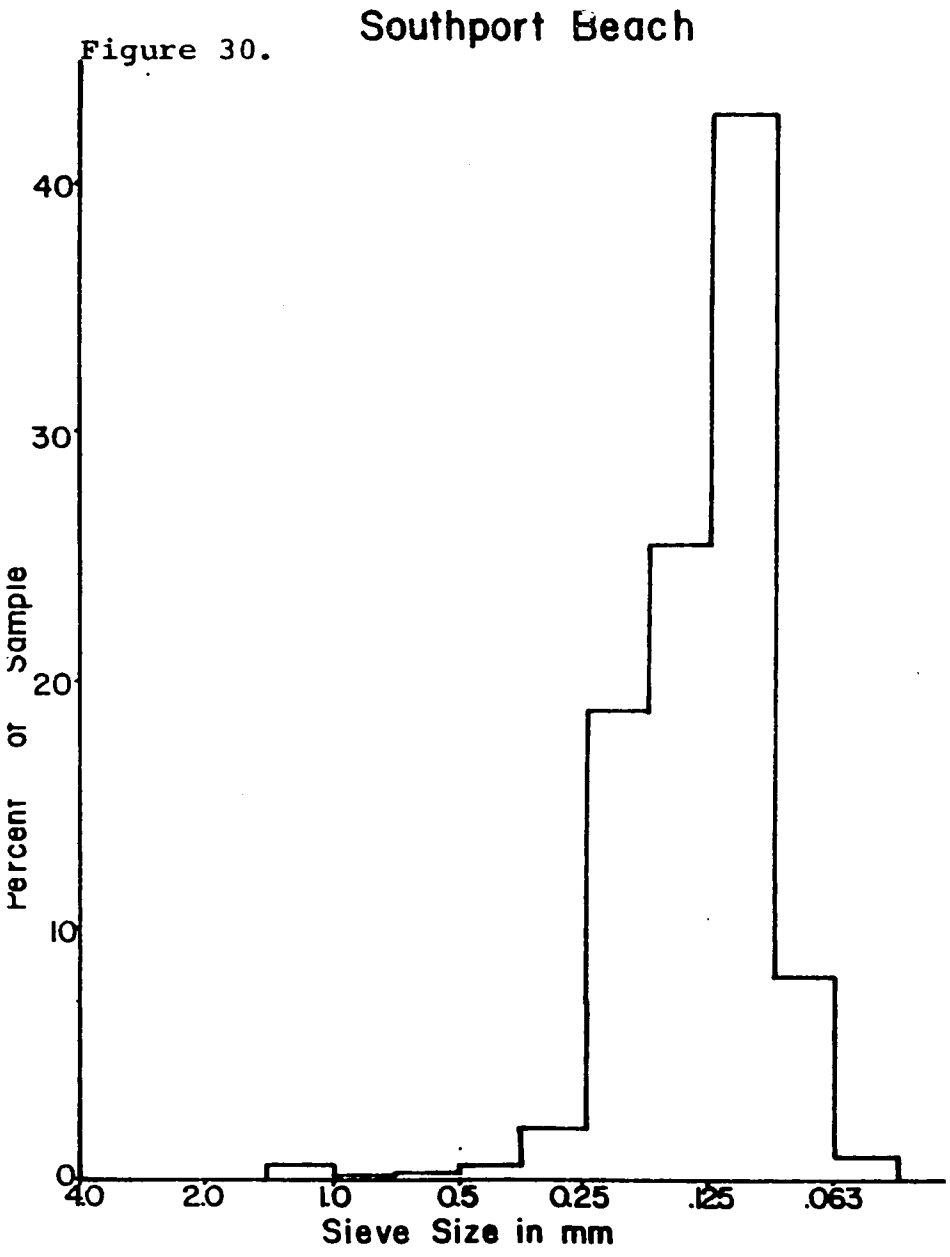
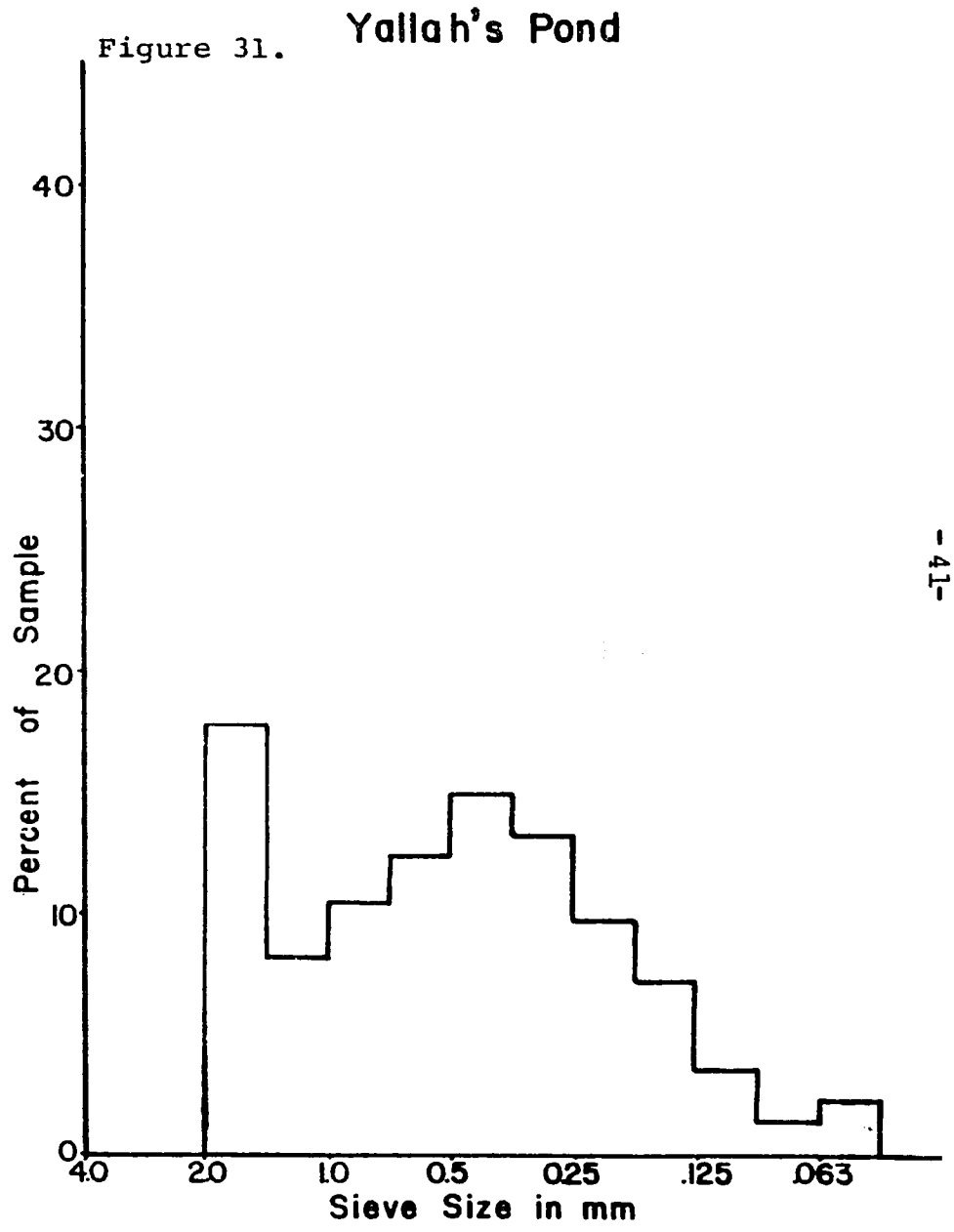


Figure 31.



B. Season.

Fall and spring plantings were carried out; growth per season varied depending on site. The following sites responded better to spring planting: Carlyle Beach, Hellshire, Negril Point and River, Old Airport, Port Esquivel, Pelican Jetty, and the power plant. The following sites responded better to fall planting: Fort Augusta, Discovery Bay, Rocky Point, and Seawinds Hotel. The differences between spring and fall planting are not all significant. Other sites were only planted once or did not survive either planting (tables 3 and 4).

A seasonal fluctuation of seagrass blade abundance was seen in control measurements with winter low and spring-summer peaks. The detailed results of spring versus fall for each species/method combination anaylzed by a single classification analysis of variance follow.

1. Discovery Bay

The difference between subsites (planting season) for Halodule shoots and plugs is significant ($p < 0.05$), but is not significant between subsites for either Thalassia seeds of shoots ($p > 0.05$). None of the Thalassia seeds or Halodule plugs survived in subsite 2 (spring planting) after 12 months.

The Halodule shoots in subsite 1 (fall planting) had about 20 times higher a Shtn* than in subsite 2, while the plugs in subsite 1 had only about 10 times more shoots/m^2 than the sprigs in subsite 2.

The Thalassia shoots in subsite 1 had twice as many shoots per m^2 than in subsite 2. The Shtn for the Thalassia seeds in subsite 1 approximately equal the Thalassia shoots in subsite 2.

2. Fort Augusta

The number of shoots per m^2 for all species/method combinations is slightly greater for the fall planting, but only the Shtn for the Halodule plugs is significantly different. The mean number of shoots per m^2 for the plugs in the fall planting is about 3,000 while it is about 2,000 for the spring planting. The other species/method combinations are about equal.

3. Old Airport

A seasonal difference for Syringodium and Thalassia

* Shtn = Number of shoots m^{-2}

C. Species

All three species can be successfully restored in Jamaican coastal areas. Thalassia shoots did the best of all species/techniques. Halodule and Syringodium grew laterally more rapidly than Thalassia since Thalassia produces far more subsediment biomass while growing laterally. Table 5 shows lateral spread after 13 months. Thalassia shoots had both higher survival percentages and good frowth at more stations than other species.

Various species responded to different pollutant types (tables 6,7). All three species were capable of being restored to dredge and fill. Only Halodule survived thermal effluents. At erosion sites Thalassia survived the best. Thalassia and Halodule appeared at bauxite sites after restoring, Thalassia grew better. Cement tailings and very high salinities were not able to be restored. River mouths differed; where a light urban and periodic turbidity load was carried (Negril River) all three species did well or where heavy turbidity and sewage was carried none survived (Montego Bay River and Fisherman's Jetty). In saline ponds as salinities were rising between $35^0/00$ and $60^0/00$ survival of Halodule and Ruppia was higher, whereas very high salinities did not have any seagrass surviving.

D. Restoration Techniques

Three basic techniques were tested: 1) sprigs with apical meristems; 2) plugs; and 3) seeds. Thalassia shoots had a higher survival rate at more stations than any other technique. Thalassia seeds also had a higher number of stations for survival. Growth was not as vigorous for seeds as shoots.

Halodule shoots survived about the same as plugs (mean of 6 stations). At the highest growth stations a coalesced bed occurred in four months (Fort Augusta with 1 acre plugs) The highest shoot densities and rhizome growth occurred with clip species and the two techniques. Syringodium shoots survived well at five stations with high growth.

In general shoots was the highest survival/growth technique at most stations. Plugs and seeds did well, although seeds did not grow as rapidly as shoots, but survived at as many sites as shoots. Plugs had the highest percentage of survival within sites where they survived (70%) and grew rapidly to coalesced beds. Thus, depending upon sites, all three were viable techniques (Tables 3, 4).

Table 3. Survival of Seagrass in percentage at test sites for Fall and Spring.

Site	Thalassia				Halodule				Syringodium	
	shoots		seeds		shoots		plug		shoots	
	F	S	F	S	F	S	F	S	F	S
Alligator Pond	0	0	0	0	0	0	0	0	n.p.	n.p.
Carlyle Beach	40	6	14	34	0	0	0	22	n.p.	n.p.
Cement Plant	0	0	0	0	0	0	0	0	0	n.p.
Discovery Bay	28	72	52	62	46	34	20	24	n.p.	n.p.
Fisherman's Jetty	0	0	0	0	0	0	0	0	n.p.	n.p.
Fort Augusta	80	52	60	70	100	100	100	100	100	66
Hellshire	0	4	0	16	11	0	0	0	0	16
Negril Point	0	0	0	0	0	0	n.p.	n.p.	0	0
Negril River	0	90	0	50	0	100	0	100	0	70
Old Airport	64	56	0	70	0	0	0	0	0	32
Ocho Rios	n.p.	24	n.p.	56	n.p.	40	n.p.	54	n.p.	n.p.
Pelican Jetty	24	52	14	10	72	60	78	28	n.p.	n.p.
Port Esquivel	44	60	28	52	60	48	68	94	0	76
Power Plant	0	0	0	0	52	52	100	52	0	0
Rocky Point	0	0	0	0	0	0	0	0	0	0
Seawinds Hotel	0	0	0	0	0	0	n.p.	n.p.	n.p.	n.p.
S. Port Beach	0	0	0	0	0	0	n.p.	n.p.	n.p.	n.p.
Yallah's Pond	0	0	0	0	0	0	0	0	n.p.	n.p.
mean at surviving sites	43.4	49	37.3	45.5	54.4	58.8	70	53.3	100	52

Table 4. Shoot Abundance per species per meter square at all sites for Fall and Spring.

	Thalassia				Halodule				Syringodium	
	shoots		seeds		shoots		plug			
	F	S	F	S	F	S	F	S	F	S
Alligator Pond	0	0	0	0	0	0	0	0	n.p.	n.p.
Carlyle Beach	0	0	0	0	0	0	0	0	n.p.	n.p.
Discovery Bay	61.9	2.6	3.4	0	6.4	6.4	1.9	0	n.p.	n.p.
Fisherman's Jetty	0	0	0	0	0	0	0	0	n.p.	n.p.
Fort Augusta	37.8	19.2	5.6	2.2	1777	1366	2748	1977	2645	827
Hellshire	0	0	0	0	6.0	0	0	0	0	0
Negril Point	0	0	0	0	0	0	0	0	0	0
Negril River	0	2.7	0	0	0	650	0	630	0	306
Old Airport	6.9	33.4	0	3.4	0	0	0	0	0	215
Ocho Rios	n.p.	0 0	n.p.	0 0	n.p.	568	n.p.	1403	n.p.	n.p.
Pelican Jetty	2.4	1.9	0.4	0.6	633	357	130	132	n.p.	n.p.
Port Esquivel	2.2	6.1	0	0.2	0	701	379	584	n.d.	889
Power Plant	0	0	0	0	2114	1323	1209	1588	0	0
Rocky Point	0	0	0	0	0	0	0	0	0	0
S. Port Beach	0	0	0	0	0	0	0	0	n.p.	n.p.
Seawinds Hotel	0	0	0	0	0	0	0	0	n.p.	n.p.
Yallah's Pond	n.p.	0	n.p.	0	n.p.	0	n.p.	0	n.p.	0

Table 5. Rhizome Length per species in cm after 9 months.

Site	Thalassia		Halodule		Syringodium
	shoot	seed	shoot	plug	shoot
Alligator Pond	0	0	0	0	n.p.
Carlyle Beach	0	3.6	0	n.d.	n.p.
Discovery Bay	20	27	4.8	0	n.p.
Fisherman's Jetty	0	0	0	0	n.p.
Fort Augusta	60	10	coalesced	coalesced	88
Hellshire	17	18	19	0	78
Negril Point	0	0	0	0	0
Negril River	7.6	0	coalesced	coalesced	84
Old Airport	67	2.2	7.7	0	77
Ocho Rios	0.4	0	62	coalesced	n.p.
Pelican Jetty	3.2	1.0	coalesced	coalesced	n.p.
Port Esquivel	31	19	coalesced	coalesced	coalesced
Power Plant	0	0	coalesced	coalesced	0
Rocky Point	0	0	0	0	0
S. Port Beach	0	0	0	0	n.p.
Seawinds Hotel	0	0	0	0	n.p.
Yallah's Pond	0	0	0	0	n.p.

Table 6. Survival of Seagrass versus Pollutant Type.

Dredge & Fill:	Thalassia		Halodule		Syringodium
	shoot	seed	shoot	plug	shoot
Port Augusta	80	70	100	100	100
Old Airport	64	70	0	0	32
Pelican Jetty	52	14	72	78	n.p.
Port Esquivel	60	52	60	94	76
Bauxite:					
Port Esquivel	60	52	60	94	76
Ocho Rios	24	56	40	54	n.p.
Discovery Bay	72	62	46	24	n.p.
Thermal:					
Power Plant	0	0	52	100	0
Cement:					
Cement Plant	0	0	0	0	0
Oil:					
Alligator Pond	0	0	0	0	0
Urban:					
Negril River	90	50	100	100	70
S. Port Beach	0	0	0	n.p.	n.p.
Erosion:					
Hellshire	4	16	11	0	16
Carlyle Beach	40	34	0	22	n.p.
Seawinds Hotel	0	0	0	n.p.	
S. Port Beach	0	0	0	n.p.	0
River Mouth:					
Negril River	90	50	0	100	70
Fisherman's Jetty	0	0	0	0	0
Saline Ponds:					
Rocky Point	0	0	0	0	0
Yallah's Pond	0	0	0	0	0

Table 7. Shoot abundance for planting at various pollutant types.

Dredge & Fill:	Thalassia shoot	Thalassia seed	Halodule shoot	Halodule plug	Syringodium shoot
Fort Augusta	37.8	5.58	1777	2748	2645
Old Airport	33.4	3.38	0	0	215
Pelican Jetty	2.4	0.60	633	132	n.p.
Port Esquivel	6.1	2.64	701	584	889
Bauxite:					
Port Esquivel	6.1	2.64	701	584	889
Ocho Rios	1.3	0	298	1103	n.p.
Discovery Bay	61.9	3.38	6.4	1.9	n.p.
Thermal:					
Power Plant	0	0	2114	1588	0
Cement:					
Cement Plant	0	0	0	0	0
Oil:					
Alligator Pond	0	0	0	0	n.p.
Urban:					
Negril River	2.7	0	650	630	306
S. Port Beach	0.3	0	0	0	n.p.
Erosion:					
Hellshire	4.0	0.67	15.1	0	656
Carlyle Beach	0 0	0 0	0	0	n.p.
Seawinds Hotel	1.5	0 0	0	0	n.p.
S. Port Beach	0.3	0 0	0	0	n.p.
River Mouth:					
Negril River	2.7	0	650	630	306
Fisherman's Jetty	0	0	0	0	n.p.
Saline Ponds:					
Rocky Point	0	0	0	0	0
Yallah's Pond	0	0	0	0	n.p.

is apparent at this site, however, none of the Halodule plugs or shoots survived in either subsite after 12 months. The Syringodium shoots planted in the fall (subsite 1) failed to survive, but the Syringodium shoots on rods and clips planted in the spring had a Shtn of 135 and 215 per m^2, respectively. The Thalassia seeds and shoots from the spring planting had about three times more shoots/m^2 than the ones from the fall planting, and the differences are both highly significant ($p < 0.01$).

4. Port Esquivel

A seasonal difference is also apparent at this site for all species/method combinations. The spring planting had more shoots per m^2 for all species except Thalassia seeds, and all the differences are significant. The shoots per m^2 of Halodule plugs and sprigs from the spring planting are about twice that of the fall planting. For Syringodium shoots on clips, the Shtn for the spring planting is 205 times greater than the fall planting, and for Syringodium shoots on rods or inert material, the Shtn is almost 25 times greater for the spring compared to the fall. The Thalassia seeds from the fall planting had three times more shoots/m^2 than the spring planting. The Shtn for Thalassia shoots (sprigs), however, is about 3.5 times greater for the spring planting than the fall.

5. Pelican Jetty

The results of comparing Shtn for seasonality are mixed at this site. The Shtn for Halodule plugs is greater for the fall planting, but the difference is not significant. The Shtn, however, for Halodule shoots (sprigs) is greater for the spring planting (about 2 times greater) and the difference is significant ($p < 0.01$). The Thalassia seeds and shoots (sprigs) Shtn is slightly greater for the fall planting, but the difference is not significant.

6. Power Plant

Only the Halodule plugs and shoots survived at this station after 12 months. The Shtn for both methods is greater for the spring planting, but it is not significantly different.

7. Seawinds

No survival of any species/method combination after 12 months.

The first anchoring types used for shoots were chiefly 11 g steel rods versus 8 cm U-shaped clips at some sites. The two were used with a subplot (for the same species/method/ season). Comparative statistics were carried out for number of shoots/ m^2 produced at Carlyle Beach, Fort Augusta, and Hellshire Beach; there was no significant difference for any of the three species. At Old Airport Syringodium and Thalassia on clips were significantly higher than rods. At Pelican Jetty Halodule on clips was significantly higher than rods.

Cement anchors and 11 g steel rods were used for Thalassia seeds. Survival and the number of shoots were the measured comparisons for statistical analysis. For the mean of all sites there is no significant difference after 9 months between the two methods (lumped sites Carlyle Beach, Discovery Bay, Fort Augusta, Old Airport, Port Esquivel, Pelican Jetty and Seawind).

E. Environmental Variables

Table 8 shows light transmission compared with plant growth measurements at some sites. Light transmission to the bottom ranged from 99.64% at Rocky Point Lagoon to 1.2% at Yallah's Pond. Many sites had light transmissivity of 60% or above, especially sites where high growth occurred. There was a general correlation between high growth and high light. On the other hand, current, salinity, and temperature did not appear as correlated with high growth as survival, except in three cases: 1) Yallah's Pond; 2) Rocky Point Lagoon; and 3) Power Plant. The very high salinities in Rocky Point and Yallah's Pond were far beyond the recorded limits for the sea-grasses. At Rocky Point plants survived until salinities clibed above $50^0/_{00}$. The Power Plant fall plantings survived until late spring when the temperature reached 33^0C.

Sediment at the sites are seen in Figures 16 to 31. A general correlation of survival with small and medium particle size may have less to do with the sediment itself than high energy conditions causing a wash-out of plants as well as larger-particle size. Thus, both plants and sediments are effected by the energy regime.

Table 9 shows some nutrient chemistry at major sites around Kingston. High PO_4 and NO_3 are evident especially in inner Kingston Harbor at Old Airport.

Table 8. Sites Ranked for Light Transmission versus Number of Shoots m^{-2}

Site	Transmissivity %	Thalassia		Halodule		Syringodium	
		shoot	seed	plug	shoot	clip	rod
Ocho Rios	89.8	0	0	1403	568	----	----
Hellshire	86.5	0	0	0	0	0	0
Fort Augusta	83.4	19.5	3.9	2943	1698	791	1004
Negril River	81.1						
Pelican Jetty	80.7	2.8	2.6	231	176	----	----
Old Airport	73.8	33.4	3.4	0	0	215	135
Carlyle Beach	64.5	0	1.4	28.5	0	----	----
Power Plant	63.8	0	0	1128	1232	0	0
Port Esquivel	59.3	6.1	0.3	584	701	889	880
Discovery Bay	56.2	5.2	2.3	78.7	197	----	----
Negril Point	22.8	0	0	0	0	0	0

Table 9. Nitrogen and Phosphorus Analysis of Water

Site	NO_3-N (μ g at/l)	NO_2-N (μ g at/l)	PO_4-P (μ g at/l)
Fort Augusta	0.670	0.378	5.42
Hellshire Beach	0.724	0.324	5.97
Old Harbour	0.724	0.324	6.51
Cement Plant	0.832	0.216	6.51
Old Airport	0.724	0.324	11.37

F. Growth.

Growth was very vigorous for all three species at the major sites, especially dredge and fill bauxite sites (Figures 32 - 44, Table 4). Highest immediate growth was seen for spring plantings. Both spring and fall plantings reached appreciable growth at dredge and fill, bauxite, urban (Negril River), and thermal (Halodule only) sites.

Some areas showed no growth. These were chiefly high energy (frequently rapidly eroding sites such as Alligator Pond, Carlyle Beach, Hellshire Point, South Port Beach, Seawinds Hotel, high salinity (Rocky Point and Yallah's Pond), cement pollution (Cement Plant), and a deep site with peat runoff (Negril Point). The high salinity site of Rocky Point was particularly interesting because plants survived well but did not grow as salinities increased (a one-in-fifty year drought was experienced).

Growth was not always correlated with survival. In some sites, especially high erosion, relatively high growth was seen with relatively low numbers of surviving plants (Hellshire: Thalassia; Seawinds: Thalassia; Carlyle Beach: Thalassia).

Growth in shoots per meter squared for Thalassia shoots ranged from 71.2 (Old Airport) to 0.33 (South Port Beach); for Thalassia seeds from 37.8 (Fort Augusta) to 0.33 (South Port Beach); for Halodule shoots from 1777 (Fort Augusta) to 6.43 (Discovery Bay); for Syringodium shoots from 2645 (Fort Augusta) to 30.6 (Negril River) (Table 4).

Growth of rhizomes in general correlated with growth of the number of shoots per meter squared. Rhizomes were far more difficult to measure, thus not as accurate as shoot counts (Table 5).

Controls were taken in natural beds in areas surrounding the barren recipient sites (Table 10). The 13 or 18 month periods for (Spring and fall) plantings respectively were not sufficient to achieve full maximum densities as seen in the controls, except for Halodule (Table 10). In our opinion, a 24 to 36 month period will probably be necessary. It is important to note that no growth was found in "barren" controls, that is barren plots set aside to note natural recolonization.

Statistical analyses of shoots m^2 showed no significant differences between restored sites and controls for Halodule at Fort Augusta and Power Plant where concentrations of restored Halodule grew high. At one site with high background Halodule, restored Halodule died (Old Airport). (Not background control Halodule was available at Port Esquivel).

Survival and Growth of Plant Species

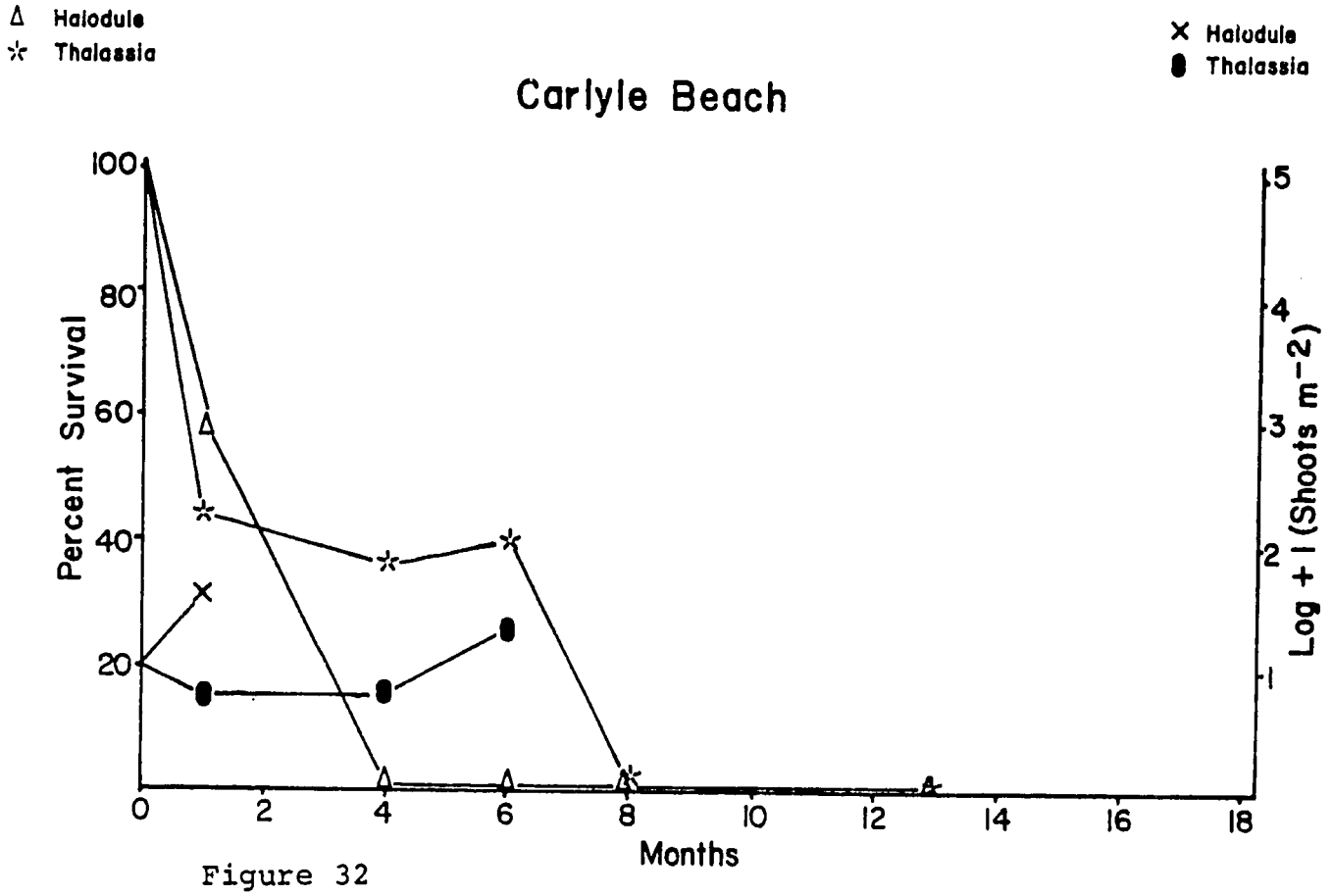


Figure 32

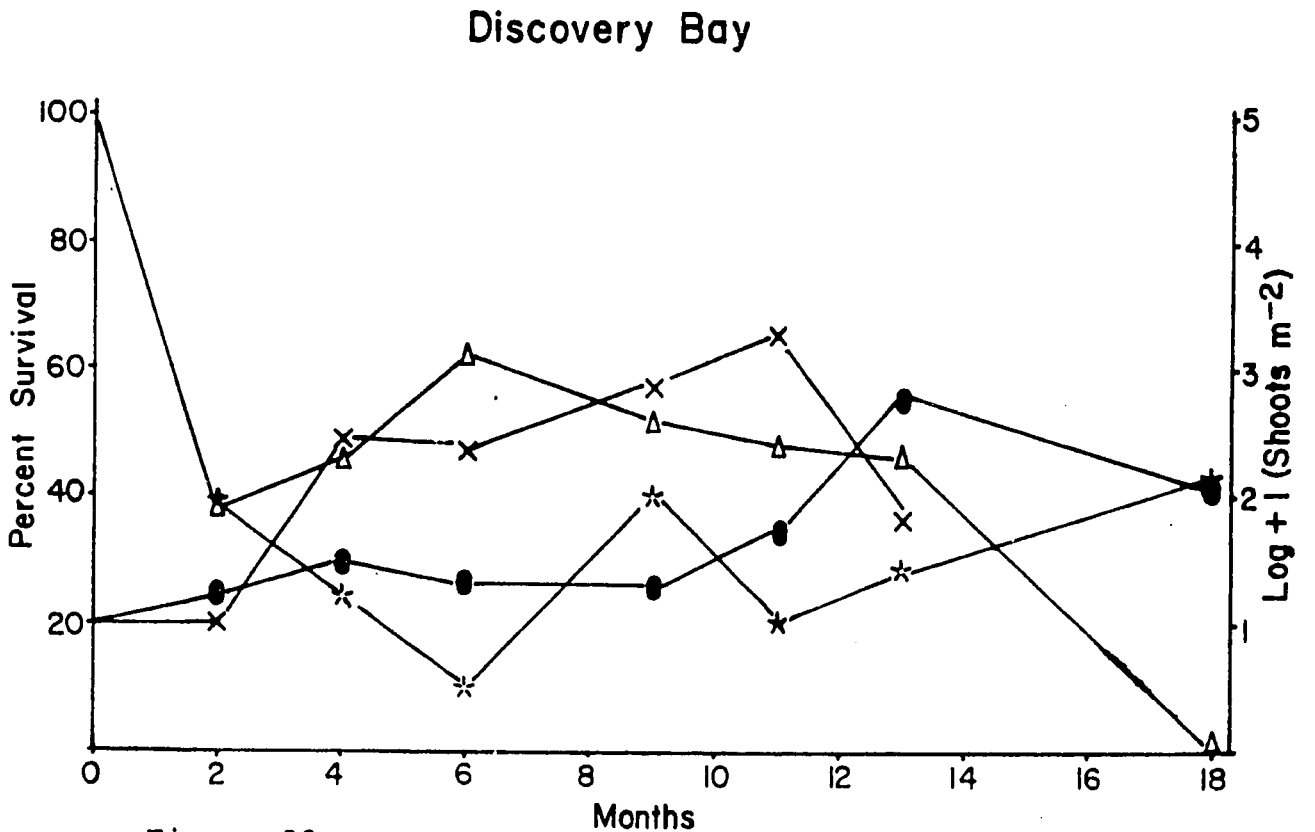


Figure 33

Survival and Growth of Plant Species

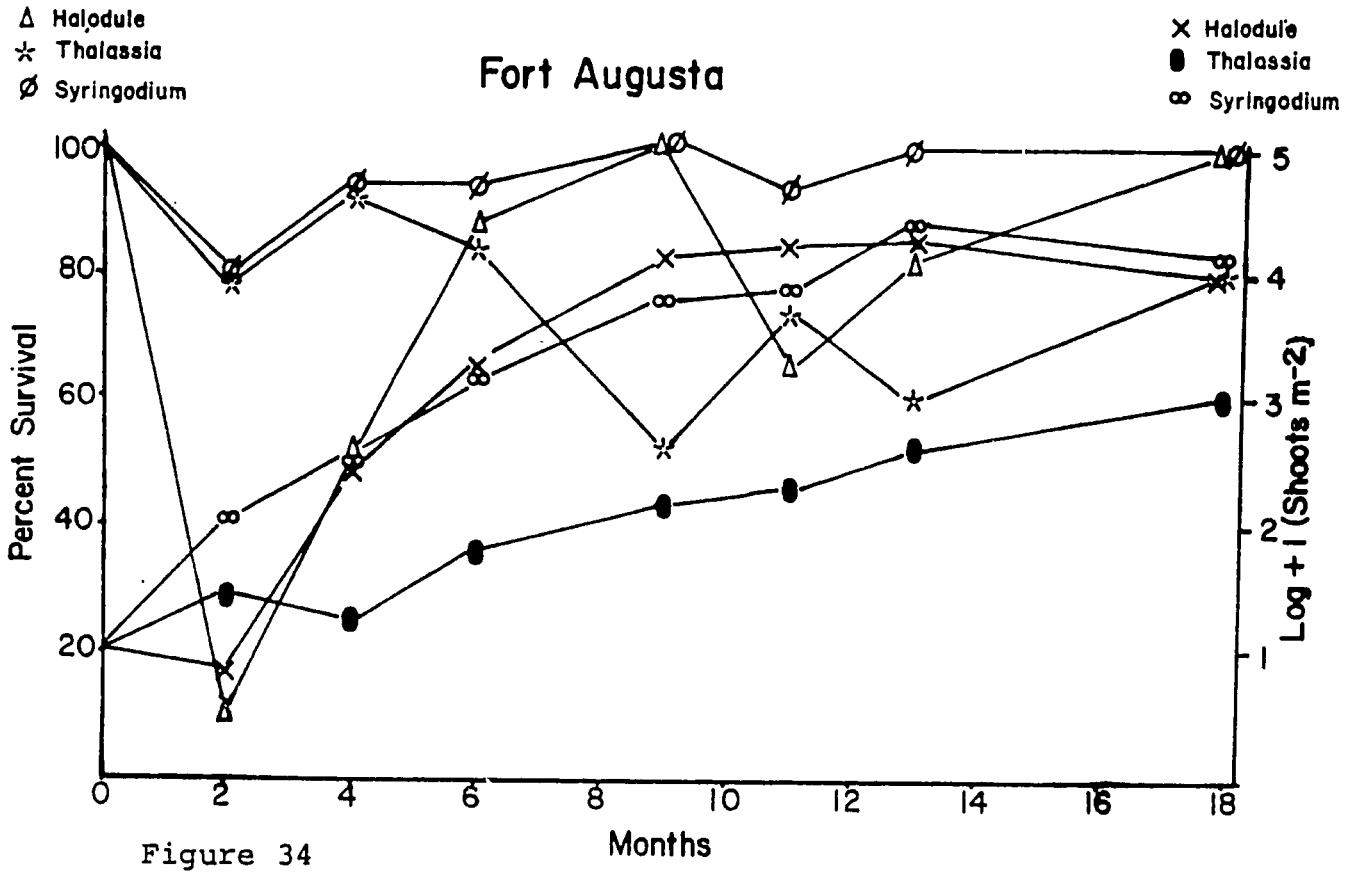


Figure 34

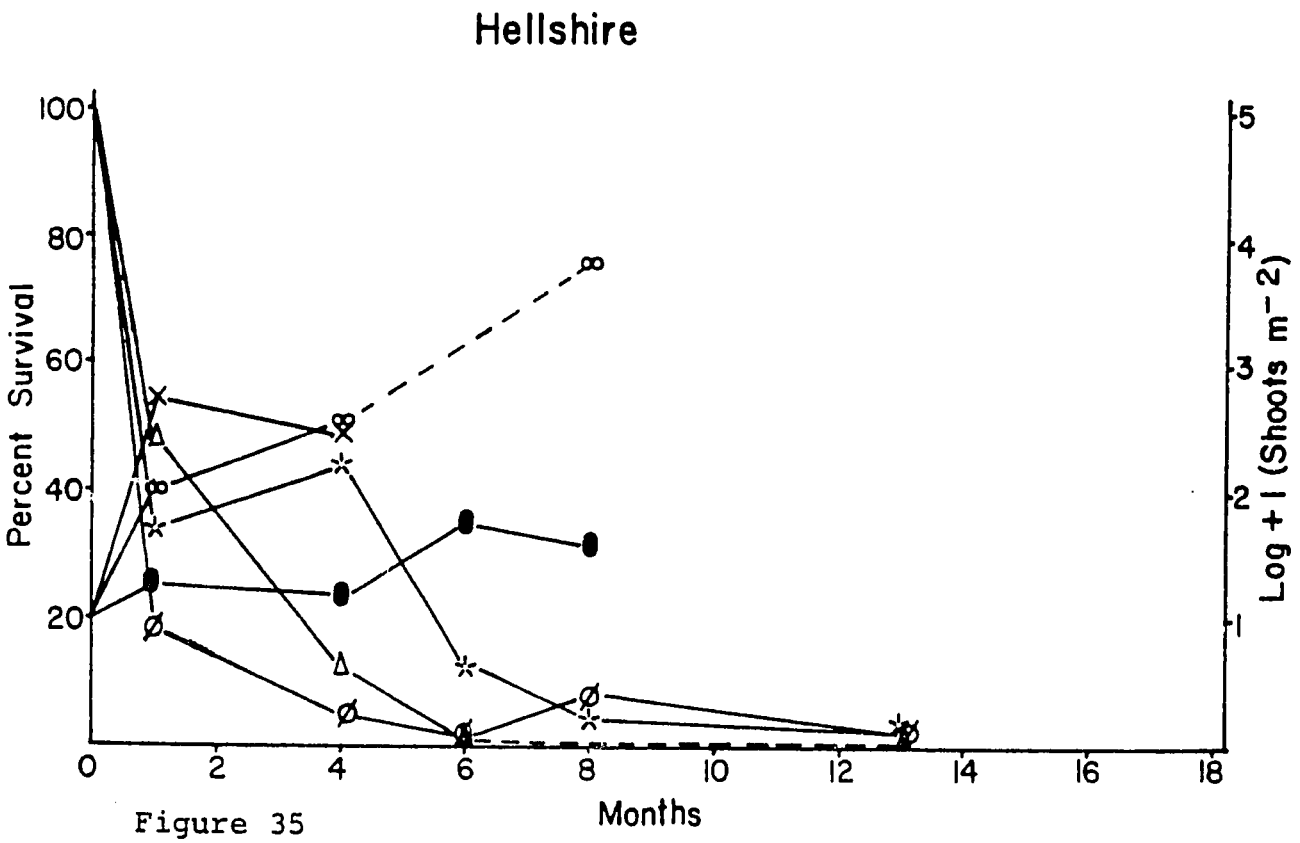


Figure 35

Survival and Growth of Plant Species

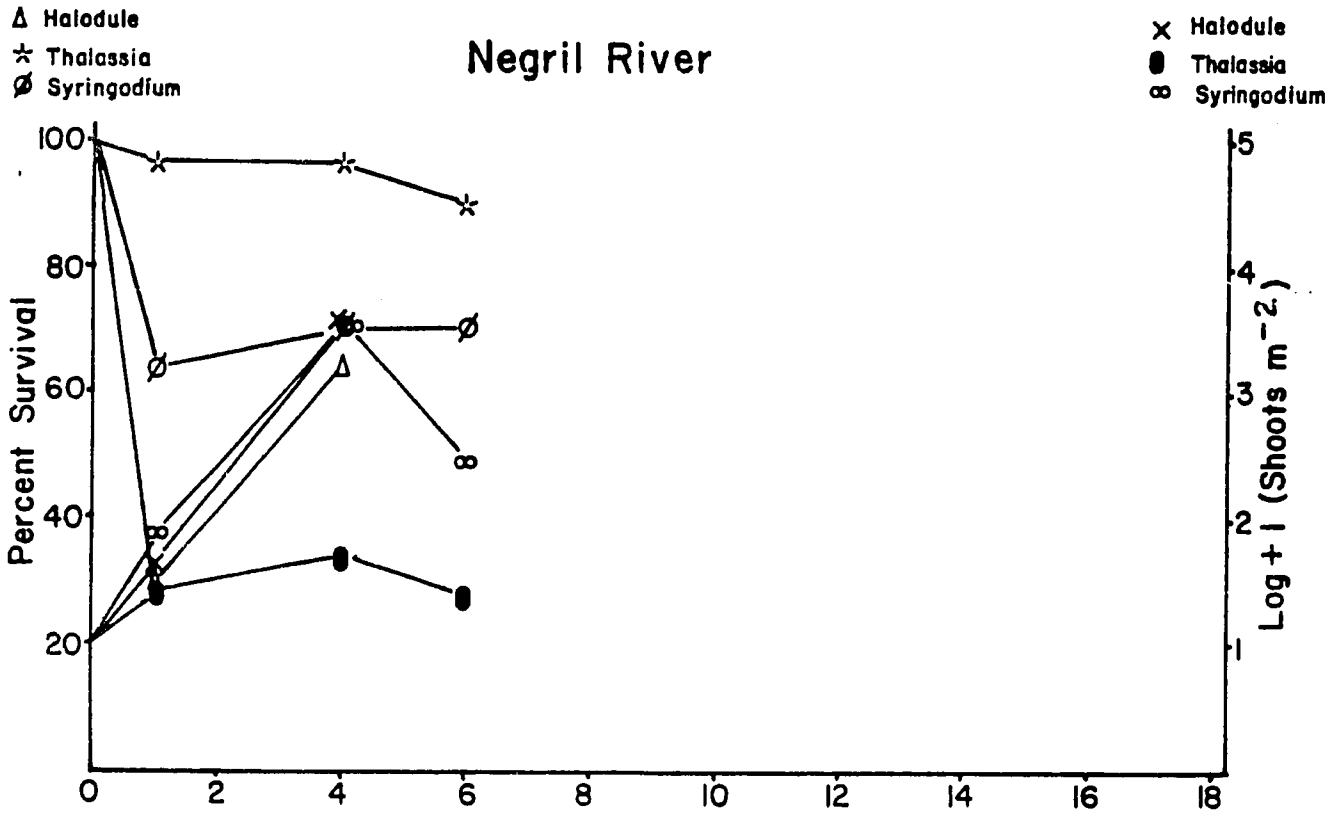


Figure 36

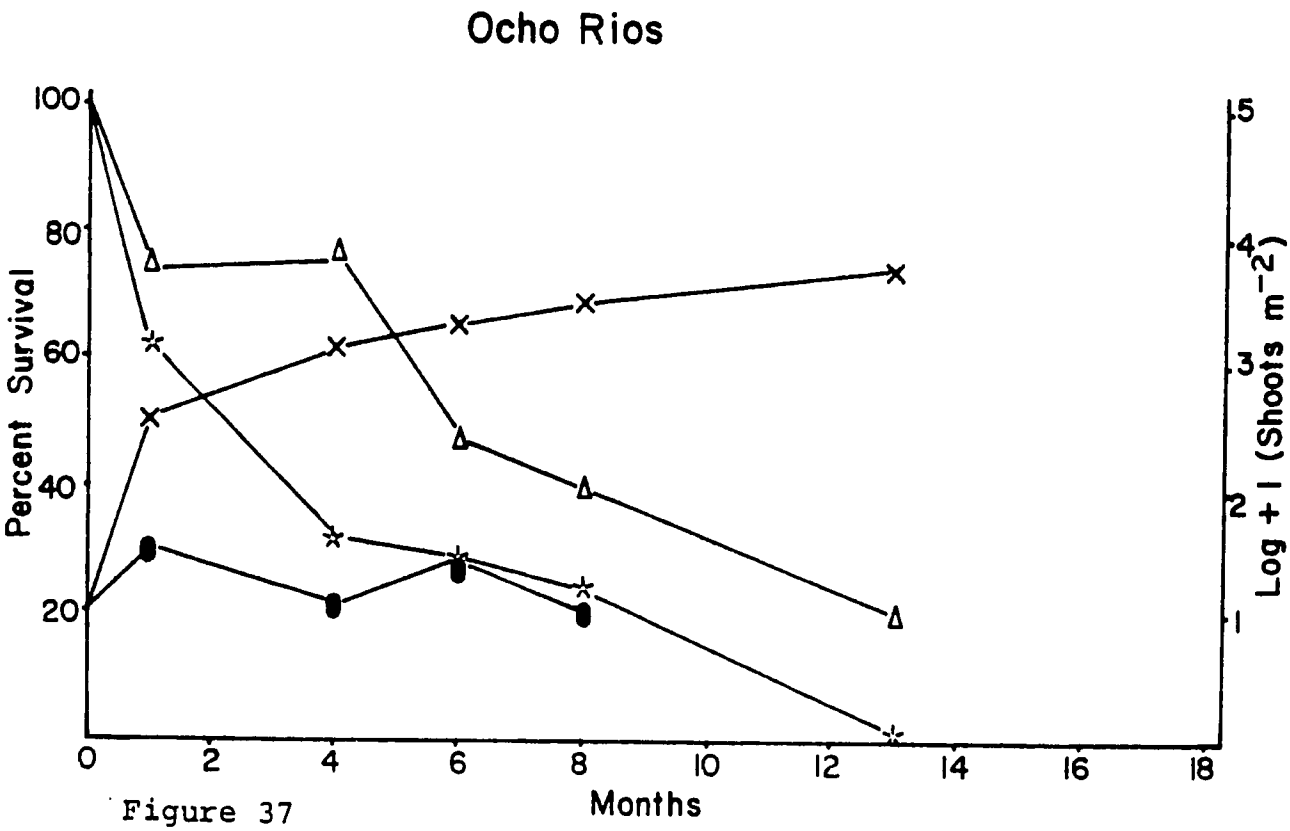


Figure 37

Survival and Growth of Plant Species

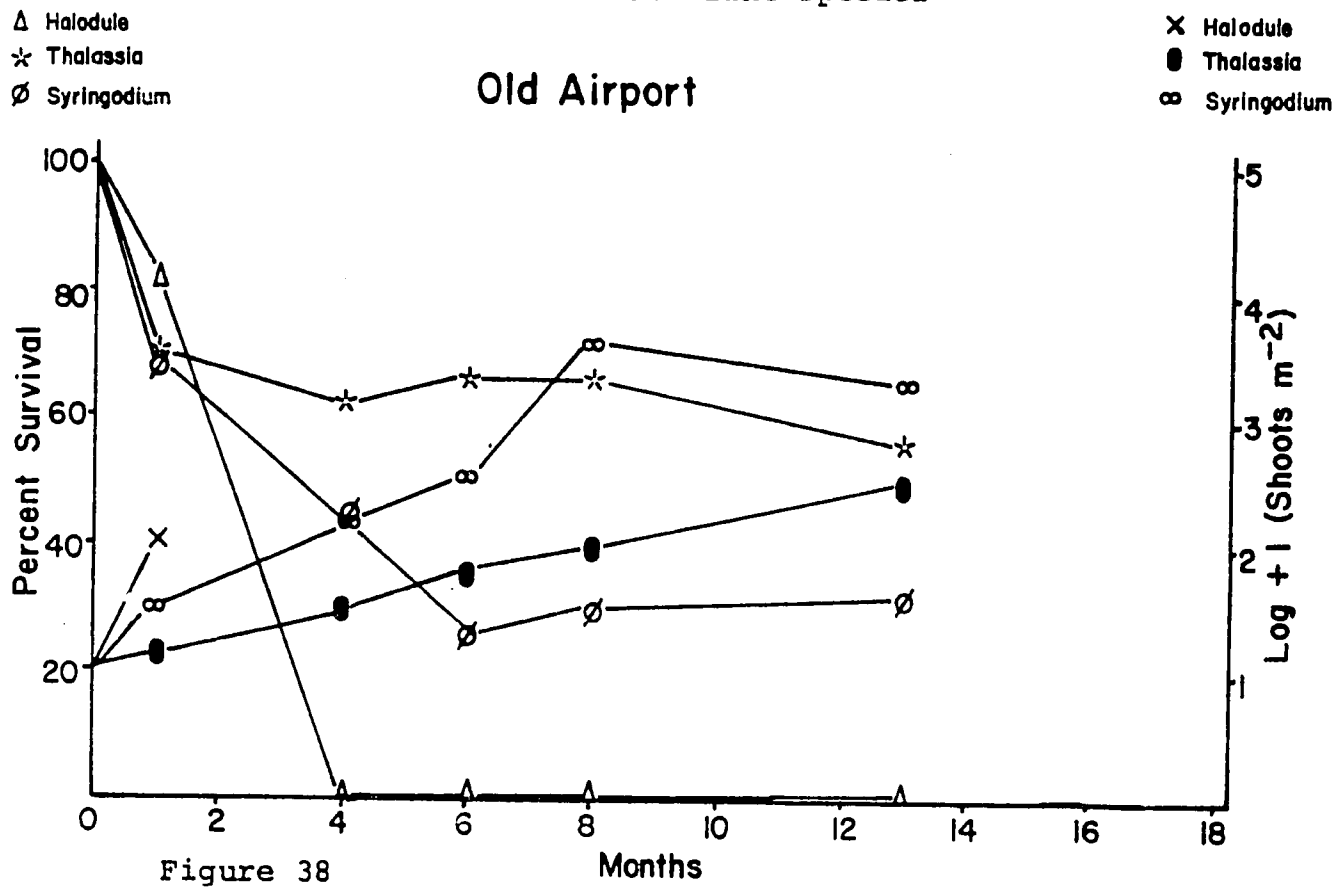


Figure 38

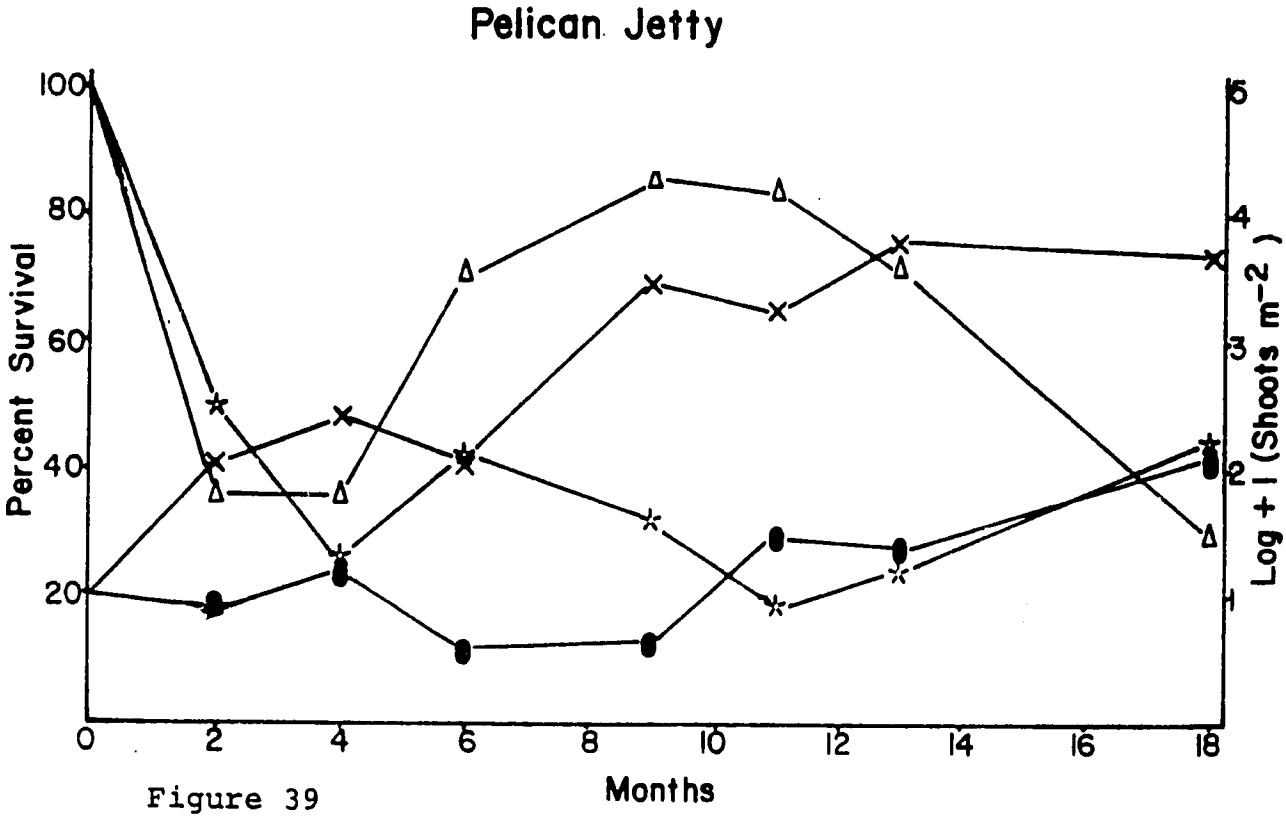


Figure 39

Survival and Growth of Plant Species

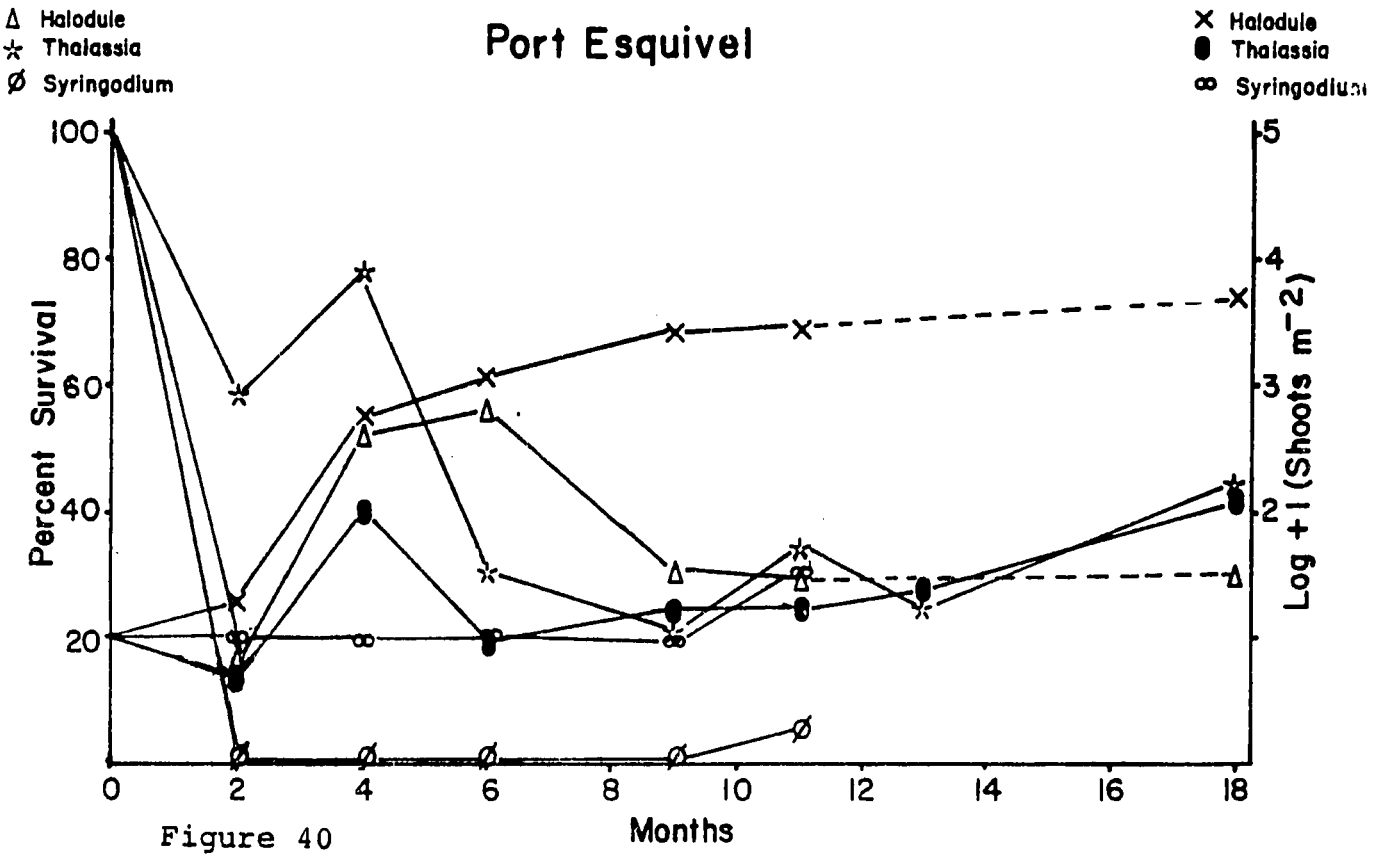


Figure 40

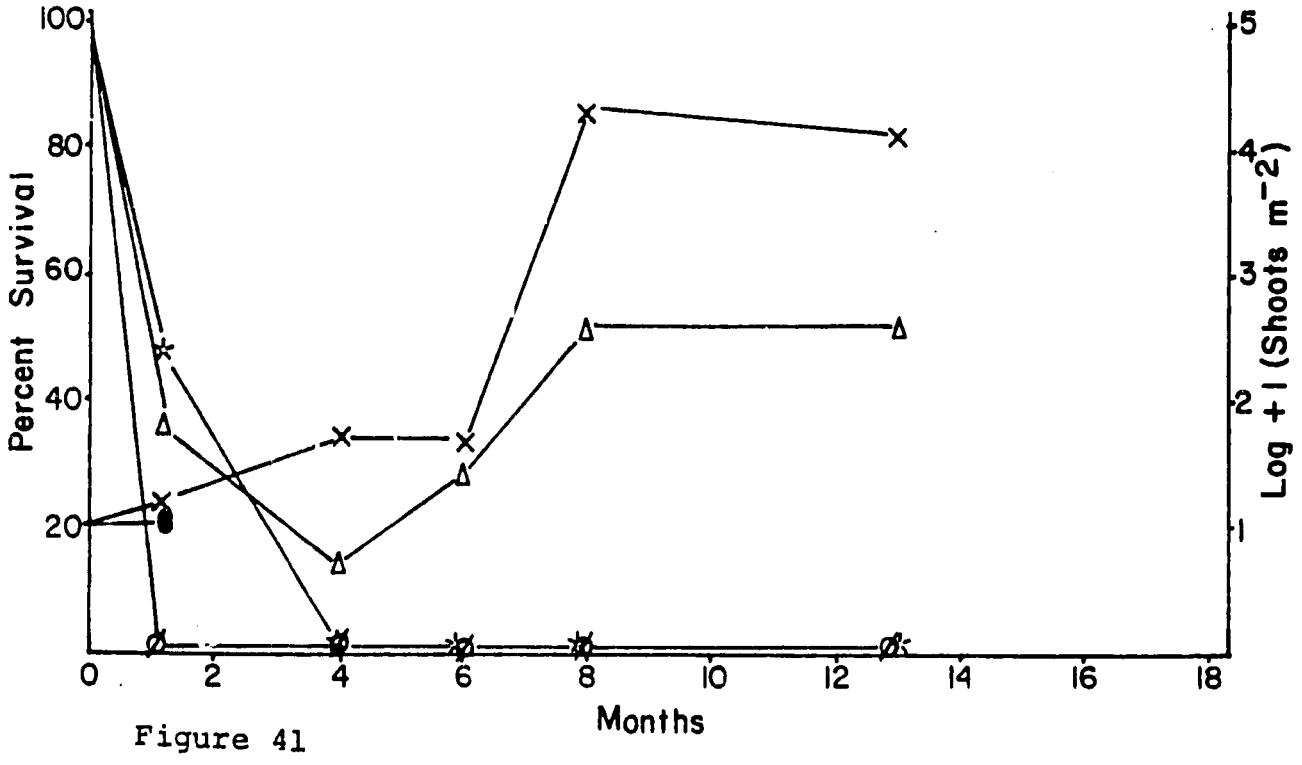


Figure 41

Survival and Growth of Plant Species

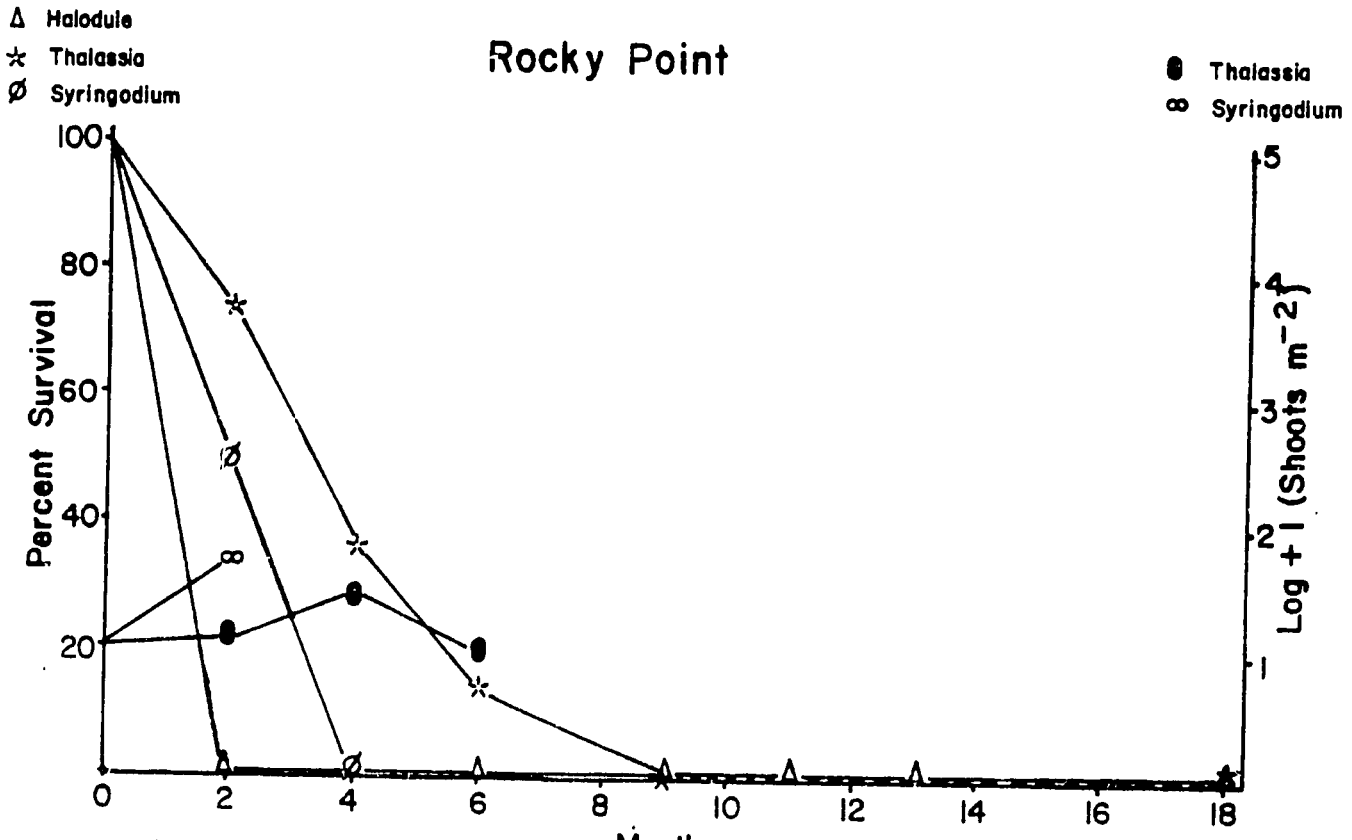


Figure 42

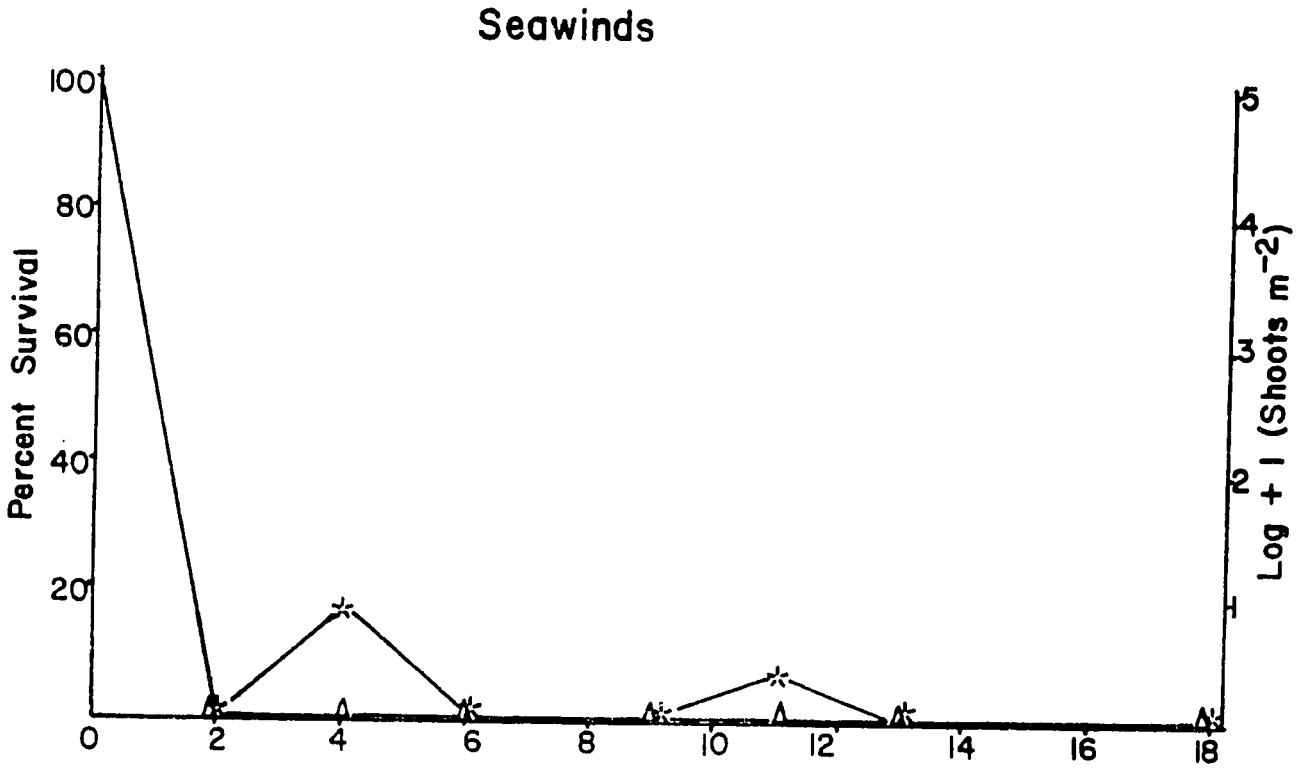


Figure 43

Survival and Growth of Plant Species

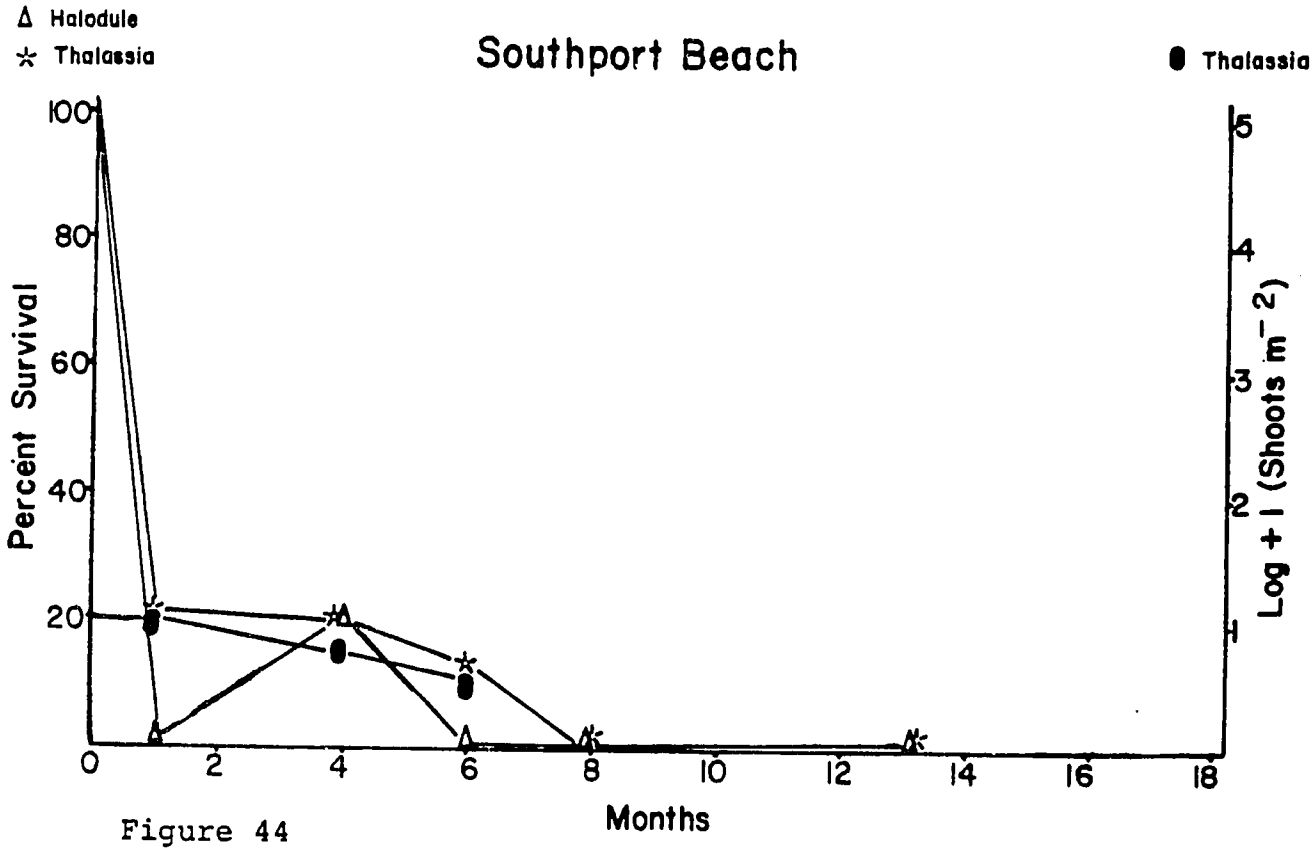


Figure 44

Table 10. Control Density (Sht m^{-2})

Site	Thalassia	Halodule	Syringodium
Alligator Pond	0	0	0
Carlyle Beach	356	0	0
Discovery Bay	342	685	0
Fort Augusta	466	1817	0
Hellshire	423	2784	1368
Negril Point	0	0	87
Negril River	0	0	0
Old Airport	280	2055	0
Ocho Rios	0	0	0
Pelican Jetty	203	1006	0
Port Esquivel	222	409	593
Power Plant	625	1898	1443
Rocky Point	0	0	0
S. Port Beach	0	0	0
Seawinds Hotel	427	1452	0
Yallah's Pond	0	0	0

Statistical analyses of shoots m^2 for restored subplots showed restored Thalassia significantly less than controls at Discovery Bay, Fort Augusts, Hellshire Beach, Old Airport, Port Esquivel, and Power Plant. Similarly restored Syringodium was significantly less at Fort Augusta and Old Airport.

G. Pollutant Types

In several dredge and fill, bauxite, and thermally (for Halodule) polluted sites, plants survived and grew best. Some erosion sites (Carlyle Beach and Hellshire) had intermediate survival and moderate growth (Tables and). The dredge and fill sites could be restored by any technique of any of the three species. Bauxite sites favored Thalassia shoots and Halodule plugs. At erosional sites, Thalassia shoots had higher survival and growth. River mouths had differential results. At Negril River, with a light to medium sediment and sewage load, plants did well. At Fisherman's Jetty in Montego Bay, with a heavy seasonal turbidity load and medium to high sewage outfall, all plants died. At the thermal plant, where thermal effluents were being emitted, growth and survival was definitely high for Halodule (a thermally tolerant species). In the fall planting Thalassia survived until spring temperatures went above 32-33^{0}C, but could not survive the summer temperatures. Two sites were not scientifically suitable tests for the originally attempted test variable because of an intervening variable of considerable magnitude (Alligator Pond, originally chose for oil spill, but with a very high energy regime, and Rocky Point originally chosen for bauxite spill and dredging, but with very high salinity.

It should be noted that restoration of high erosion sites had previously been attempted with low success rates. Seagrass restoration at sites of high salinity, oil, cement, and bauxite pollution had never before been attempted.

H. Larger Planting.

At the Fort Augusta site in April, 1983, a one acre site was restored using Halodule plugs, and fishermen to facilitate labor. By the next monitoring period in mid June, 1983, blade densities were 52 blades m^2. Much of the area had coalesced and fishermen were actively fishing (seining) the area for crabs, shrimp, and small fish. By May, 1984, the area was a dense seagrass bed of 1977 blades m^{-2}, a completely solid seagrass cover of normal densities for the area (compared to 1817 blades m^{-2} in control Halodule beds). Seeds of Thalassia planted into the plugs grew well having high survival and high blade and rhizome growth. Fishermen plugged efficiently and

technically well. Since fishermen earn $25 to $40 JA per day, this will decrease prices per acre substantially from U.S. prices for shallow-water plugging sites.

I. Thalassia Seeds Barren Versus Halodule Planting.

Thalassia seeds planted at the same time on barren sand bottom versus within Halodule plugs at Fort Augusta showed the following results after nine months:

1) Barren: survival, 70%; blade length, 17 cm; shoot number, 2.2; rhizome length, 5.9 cm; number of rhizomes, 1.7.

2) In Halodule: survival, 70%; blade length, 21 cm; shoot number, 0.85; rhizome length, 2.35 cm; number of rhizomes, 0.7.

No statistically significant difference between seeds occurred in the two plantings. Numerically longer blades and shorter rhizomes occurred in the Halodule matrix seeds.

J. Erosion and Sediment.

The test sites included a wide variety of sediment types from fine to coarse particles (Figures 16 - 32) from high to low organic composition. No correlations with fine to medium sediment types were seen. In coarser sediments, survival was lower.

The high energy regime required that plants be anchored with a variety of anchoring types including clips, metal bars, cement anchors, coral, and cement blocks in varous patterns surrounding the plantings. The problem of attaining high survival at high erosion sites was not competely solved. Heavier, inert anchors appeared to be far more effective. Thalassia responded best at these sites.

Accretion of sediment within the test plots was apparent at most of the sites. At the Fort Augusta one acre planting site about 6 cm accretion appeared in nine months.

X. Scientific Discussion and Conclusions

The transfer of technology of seagrass restoration to the tropics was successful for the first time. This was also the first attempt to heal the effects of pollution of seagrass beds in any developing nation.

Restoration in a variety of pollutant types was attempted. The previous work in temperate and subtropical areas had only attempted restoration in a portion of these. Thus some of this testing was the first recorded attempt to restore under the following: 1.) Power plant while thermal effluents were being emitted. 2.) Bauxite spills. 3.) Cement tailing areas. 3.) Urban run-off. 4.) Saline ponds. These were potentially difficult situations.

Successful test sites occurred both on north and south coasts. The bays and estuaries survived higher than open coastal sites. Dredge and fill, bauxite, termal, urban, river mouths, and some erosions sites had survival and growth. The pollutant types where clear negative results occurred were cement tailings and high saline lagoons. Further work on these as well as high energy sites is warranted (See Section IV).

Comparison to survival and growth of test plots in south Florida (Thorhaug, 1974, 1978, 1984; Eleuterius, 1974) showed similar results on estuarine dredge and fill projects and high energy erosion sites. Jamaican seagrass grew more rapidly, especially in the winter months thus rate of restoration was more rapid.

Since successful types of restoration are now available to Jamaica for many of the main coastal degradtion problems of loss of seagrass, thus of fisheries nurseries, policy for implementing this technology was studied by the two principals. A draft policy for zero-loss of seagrasses was a logical outcome of this project (Sections II and III).

XI. Literature Cited

Eleuterius, L. N., 1974. A study of plant reestablishment. Final Report, Corps of Engineers.

Thorhaug, A., 1974. Transplantation of the seagrass Thalassia testudinum König. Aquaculture, 4: 177-183.

_____, 1984. Large scale seagrass restoration in a damaged estuary: Test plot program. Nar. Poll. Bull.

Thorhaug, A. and B. Austin, 1978. The economic costs of transplanting seagrasses: Thalassia. pp. 69-75, in: R. Lewis and D. Cole (eds.), Proc. 4th Ann. Conf. on Restoration of coastal vegetation in Florida. Hillsborough College Press, Tampa, FL.

XI. Appendices

Appendix I. Policies and Regulations Reviewed for Formulating Jamaican Draft Policy

1. United Naitons Environmental Program Global Conservation Strategy
2. United Nations Environmental Program Caribbean Action Plan
3. U.S. Department of Commerce, National Marine Fisheries Service's Habitat Conservation Policy 1983
4. U.S. National Marine Fisheries Service Guidelines and Criteria for Proposed Wetland Alterations
5. U.S. Corps of Engineers Mitigation Policy
6. State of Florida draft policy for Mitigation (Sec. 403)

THERMAL POLLUTION EFFECTS ON AN ESTUARY IN A DEVELOPING NATION: IMPACT AND REHABILITATION OF SEAGRASS

A. Thorhaug, Ph.D.
Department of Biological Sciences
Florida International University
Miami, Florida 33199
U.S.A.

EXTENDED ABSTRACT

The investigations of thermal effluents in the developed nations have been studied and documented in detail [1]. The developed nations are chiefly in the temperate zone where thermal effluents have a different effect from in the tropics [2,3,4]. The review by Thorhaug [4] of thermal pollution in the tropics shows that only a few studies have been done, chiefly in the U.S.A., Australia, India, and several Caribbean locations. This present study is to increase our knowledge of tropical thermal effluents.

A complex of four turbines were sited on a major Jamaican estuary between 1968 and 1973 The power plant is the major electricity producer for urban and industrial Kingston, and is administered by the Jamaica Public Service Company. The four turbines can produce a total of 213.5 megawatts of electricity, and the plant can pump 408,000 gallons of water per minute for coolant. In February 1984, the temperature of the effluent entering the 212 m cooling canal was 35°C. The cooling canal discharges into a corner of a major southwest estuary called Old Harbour. The natural vegetation prior to impact was a mangrove shoreline with the seagrasses Halodule wrightii (intertidal), Thalassia testudinum, and Syringodium filiforme (subtidally).

Current conditions were wind and tide produced. The effluent current carried the heated water along the shore for approximately 300 m, and then turned seaward. Tidal inflow into this shallow area created a thermocline during high tide conditions were cooler bay water intruded under the effluent on the outer portion of the area, whereas at low tide the entire area was affected by the heated effluent. In February 1983, the water temperature at the power plant (185 m down current from cooling canal mouth) was 30°C and ambient bay temperature was 28°C. In April and June 1983, temperature at the power plant was 34°C and ambient bay temperature was 29° and 28°C. In September and November 1983, temperature at the power plant was 35° and 34.5°C, and ambient bay temperature was 28° and 30.4°C. In January 1984, temperature at the power plant was 33.5°C and ambient bay temperature was 27°C.

The seagrasses in the zone directly at the mouth of the cooling canal were absent. Concentric zones of seagrasses were found from the power plant along shore that followed the effluent.

The first zone was a patchy Halodule wrightii; second, H. wrightii in relatively dense abundance; third, Thalassia testudinum and H. wrightii mixed; fourth, T. testudinum and Syringodium filiforme mixed; and fifth, either pure T. testudinum or pure S. filiforme. The zones were tongue-shaped and conforming to the flow of effluent along-shore west of the plant. Size and seasonality will be discussed.

In addition, restoration of seagrasses was attempted. This is the first time that seagrasses have been rehabilitated at a power plant while the effluent was being released. Three species of seagrasses, T. testudinum, H. wrightii, and S. filiforme were planted in November 1982 and April 1983 in 9.1 x 9.1 m test plots, each by two methods. Survival of planting after 14 months for the fall planting and 10 months for the spring planting showed H. wrightii to have far higher survival and growth. S. filiforme did very poorly. T. testudinum did moderately in the fall planting, but did not survive the summer high temperatures of 34 - 35°C.

ACKNOWLEDGEMENT

I thank the U.S. Agency for International Development for supporting this research grant. I also thank the Biology Department at Florida International Univeristy and the Natural Resources Conservation Department of Jamaica for sponsoring this research grant.

REFERENCES

1. Coutant, C. 1970. Biological aspects of thermal pollution, P.I. entrainment and discharge canal effects. CRC Critical Reviews in Environmental Control 1: 341.

2. Bader, R., A. Thorhaug, and M. Roessler. 1971. Thermal pollution of a tropical marine estuary. IN: FAO Symposium on Marine Pollution, Marine Pollution and Sea Life. London: Fishing Books, Ltd., pp. 425-8.

3. Thorhaug, A., M. Roessler, and D. Segar. 1973. Impact of a power plant on a subtropical estuarine environment. Bull. Mar. Poll. 7(11): 166-9.

4. Thorhaug, A. 1980. Biological effects of thermal effluents in the marine environment: Tropics and subtropics with a guideline. FAO Report, Rome.

Management and Rehabilitation of Coastal Resources in the Third World: Jamaican Model

B. Miller
Principal Director
Natural Resources Conservation Department
Ministry of Environment, Science, and Technology
Kingston 10, Jamaica

A. Thorhaug, Ph.D.
Department of Biological Sciences
Florida International University
Miami, Florida 33199
U.S.A.

EXTENDED ABSTRACT

The World Conservation Strategy launched by UNEP and the Caribbean Action Plan of 1982 emphasized the importance of wise resource use and pointed out the importance of coastal resources to environmental health of the Caribbean. These documents emphasized sustainability of fisheries and coastal vegetation in the face of development.

Some developing nations such as Jamaica already had realized the importance of their coastal resources. Jamaica, the second largest island nation in the Caribbean Sea has approximately 200 miles of coastline which is fringed by mangrove forests and beaches, has large seagrass meadows and offshore corals. An extensive coastal plain exists backed by a major mountain range. Large estuaries and bays have long made this an extremely attractive island.

Development has occurred over a long period of time. Estuaries were made into ports where cities developed. Large plantations were created from coastal plains and uplands. Bauxite and limestone for cement have been mined intensively with loading ports along the coastline. Infrastructure such as causeways, roads, bridges, airports, ports, power and sewage treatment plants have been built on the edge of the coastline causing shoreline and subtidal impacts. Effluents of sewage, chemicals, urban run-off have historically been discharged into the estuaries around which the major urban centers were built. Tourism is a major industry, but confined mainly to the north and west coastlines.

The Natural Resources Conservation Department of the Ministry of Environment, Science, and Technology has reponsibility for creating policy, regulating, planning, and doing scientific research on environmental resources in Jamaica. This investigation was a portion of their plan to bring for the first time the important resources of estuarine and offshore seagrass meadows into a sustainable balance for the future. The World Conservation Strategy estimated that the cost of damage to U.S. marine fisheries caused by degradation of coastal wetlands has been

almost $86 million a year. Seagrasses play an important role by serving as a fisheries nursery, controlling erosion, and by providing a matrix for habitat.

In the process of development of urban centers, infrastructure, and industries, tens of thousands of acres of seagrasses have been decimated. An important step in making seagrass resources and their fisheries nursery function sustainable was to transfer the technology of seagrass rehabilitatic to Jamaica. It had never before been attempted in the tropics or the Third World.

A set of twenty test locations for seagrass rehabilitation were jointly decided upon by Mrs. B. Miller, NRCD senior staff, a botanist from the University of the West Indies, Dr. Barry Jupp, and Dr. A. Thorhaug, seagrass rehabilitation expert. The sites included various portions of the coastline, various major types of pollution impacts, and different environments (open ocean, coastline, and estuary). At each site, the major types of seagrasses found in the area were planted, each by two methods. The planting methods included seasonal planting and planting by fishermen to test cost effectiveness. Sites were monitored for survival and growth rates by a joint team at two month intervals.

The results of this project show that the technology of seagrass rehabilitation can be transferred to the tropics. Test plots grew well on a variety of impacts. In some cases, seagrass beds coalesced in four months.

The problem of managing seagrass resources are threefold. 1. Preservation wherever possible of existing beds from direct removal, effluents, and accidental toxic spills. 2. Zero-loss of seagrasses when necessary development must occur by replacing seagrasses in a previously damaged site once having seagrasses. 3. Rehabilitation of degraded and obliterated seagrass beds when physical and chemical conditions still permit. (In some cases, a different species must be replaced because the original species will not tolerate present conditions.)

The results of impact rehabilitation and policy considerations will be discussed.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the Agency for International Development of the United States Department of State for supporting this research grant. The authors also thank the Department of Biological Sciences and the Natural Resources Conservation Department for sponsoring this research grant.

Newspaper article from the Daily Gleaner, December 2, 1982, page 15, Kingston, Jamaica.

U.S $170.000 seagrass project underway

A US$170,000 project to examine the potential for using seagrass to restore environmentally damaged nearshore areas has been launched by the Aquatic Resources Division of the Natural Resources Conservation Department (NRCD).

The seagrass restoration project is to be carried out on some 17 coastal sites across the island over the next 18 months and is being funded by the Florida International University (FIU), U.S. AID and the Natural Resources Conservation Department, according to a Jamaica Information Service (JIS) release.

Outlining the project on Monday, the Principal Director of NRCD, Mrs Beverly Miller, pointed to various types of marine pollution, including urban abuse, industrial accidents; bauxite and oil spills, which have contributed to the degradation of the island's costal resources.

The project, Mrs Miller said, was important in that seagrasses provided a nursery for the nearshore coastal eco-system. It helped to stabilise nearshore sediment, including beaches and shorelines, and the disappearance of the seagrass would mean the disappearance of a large portion of the nearshore marine life.

Dr Anitra Thorhaug, marine biologist at FIU and consultant to the project, explained that the project would seek to determine which of the three types of seagrasses present in Jamaica survived better under adverse conditions and was more easily restored after an industrial accident. This knowledge would not only help to reverse past damage but develop new techniques for preventing future damage to seagrass and the nearshore marine environment.

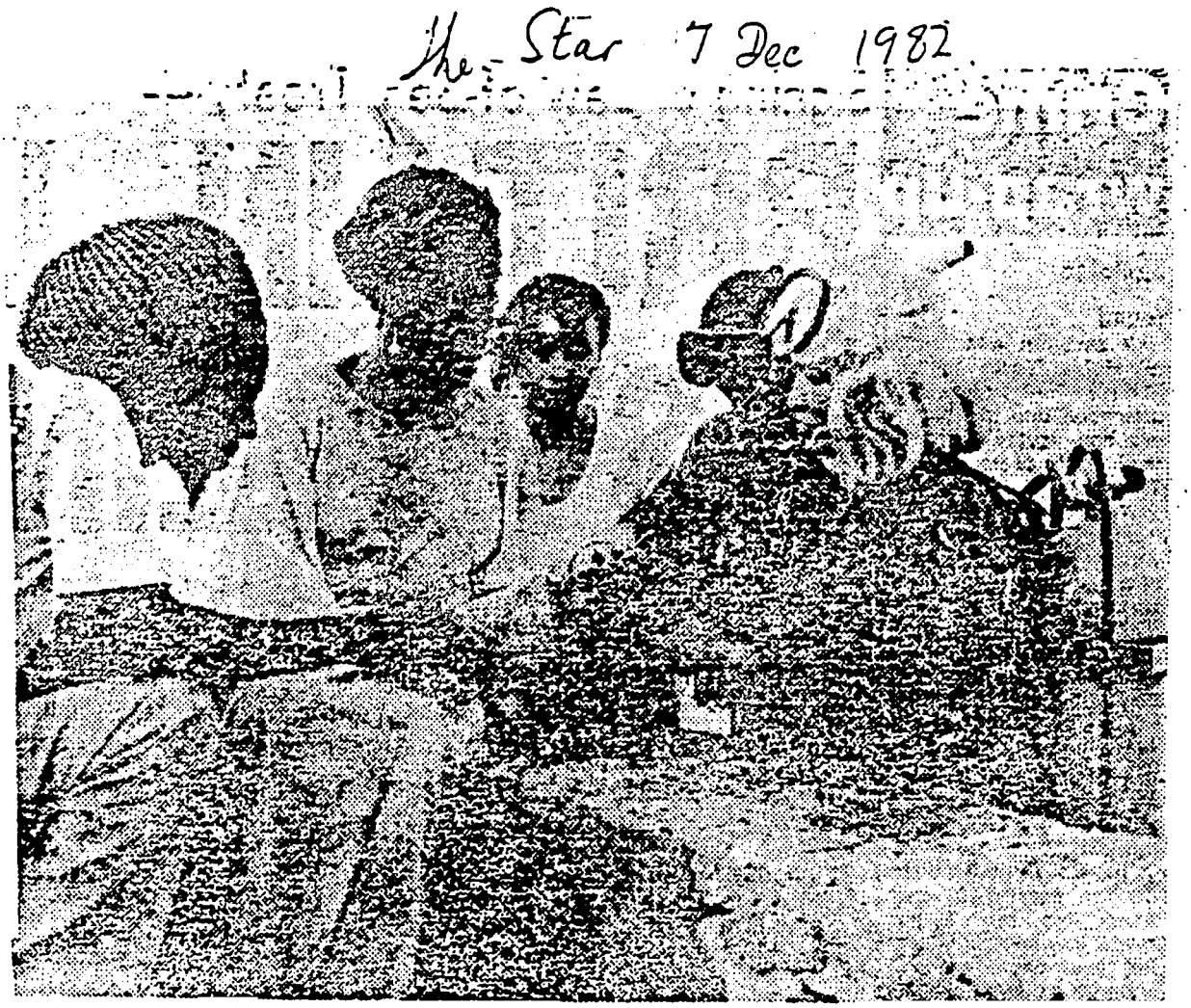
She further noted that the success of this project would not only provide the country with a cheaper source of protein from nearshore fishing, but would also provide a model for other Caribbean countries to adopt.

A similar project was successfully carried out in Florida by a team from FIU headed by Dr Thorhaug, but Jamaica is the first Caribbean country to carry out such an experiment and, if successful, it could provide employment opportunities in a new wetland industry, the JIS said.

The sites chosen for the project include sections of Kingston Harbour, Montego Bay, Discovery Bay, Portland Blight, Alligator Pond, Ocho Rios, Old Harbour, Hellshire and Negril.

The project is being coordinated with the assistance of Dr Barry Jupp, consultant to the NRCD and lecturer in the Department of Botany at the U.W.I.

Newspaper photograph and caption from The Star, December 7, 1982, Kingston, Jamaica.



SEAGRASS PROJECT:
Dr. Anita Thorhaug, Marine Biologist at Florida International University(FIU) examines a handful of seagrass as part of a USAID-sponsored project to restore environmentally near-shore areas, across Jamaica. The Seagrass Restoration Project is to be carried out on some 17 coastal sites across the Island over the next 18 months at a cost of about U.S. $170,000. The project is being co-ordinated by the Natural Resources Conservation Department. (NRCD), Florida International University, and the Department of Botany, UWI. Looking on are (from left to right), Mr. Paul Carroll,(NRCD); Mrs. Beverley Miller, Principal Director, NRCD and Mrs. Barbara Chow and Mr. Everton Kelly also from the NRCD.

Healing Caribbean Coastlines

AN INTERVIEW WITH

Anitra Thorhaug

Anitra Thorhaug is professor of biological sciences at Florida International University in Miami. She obtained a PhD in chemical and biological oceanography from the University of Miami, followed by postdoctoral work in biophysics and chemical oceanography. Her special interests include thermal pollution, trace metal ecology, coastal resource management and Caribbean nearshore ecology.

The Siren: What is the present state of seagrass beds in the Caribbean?

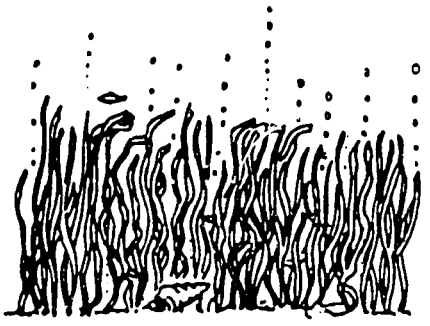
Anitra Thorhaug: Not very good. Large areas have been completely denuded of seagrass, especially those near urban centres.

Q: Why has this happened?

A: Seagrasses are particularly vulnerable to pollution, and they tend to grow close to shore where they are first to feel its effects. Also, they have been rather neglected in terms of conservation, in spite of their importance.

Q: How important are they?

A: Seagrasses are the dominant marine and estuarine submerged plants. They are a major source of food for coastal organisms, and contribute enormously to coastal productivity. They produce up to 2000 grams of dry weight per square meter per year, which rivals the productivity of a mangrove forest.



In addition, seagrasses are essential for coastal erosion control. Their roots help stabilize the sediments, which is particularly important in areas like the Caribbean which are susceptible to hurricanes.

And they provide a habitat for the larval and juvenile stages of innumerable marine organisms, including many commercially-important fish species. For this reason, managing a fishery has to begin with management of seagrasses.

Q: What kind of pollution is threatening Caribbean seagrass communities?

A: Particulate and chemical pollution from dumping and urban runoff are especially damaging. Another factor is the circulation of foreign substances from offshore waters; for example, from oil spills or dumping from ships. But the major cause of seagrass destruction is probably the modification of upland areas. Urbanization, deforestation, industrialization, and changing agricultural practices all contribute to an enormous pollutant load in the rivers -- and therefore of the estuaries and coastal waters.

Q: Is it really possible to restore seagrass communities?

A: It is not only possible, but it is being done. And although it is a relatively new technique, begun only in 1945, it is now commonly used in in the United States, England, Australia, France and Canada.

But the most recent success story occurred in Jamaica, which was the first developing country to receive and test an extensive technology of coastal rehabilitation with seagrasses. This was also the first time seagrass restoration had been successfully accomplished in the tropics.

Q: How was this programme carried out?

A: The Jamaica project was sponsored by U.S.AID and the Jamaican Natural Resources Conservation Department of the Ministry of Mining, and carried out by myself and my research team from Florida International University. We were assisted by government workers from NRCD as well as by faculty and students from the University of the West Indies.

We began by selecting sites according to Jamaica's major coastal problems. We chose areas where seagrass beds had been destroyed by industrial pollution (bauxite, oil spills, cement plants, and thermal effects); urban development (filled areas, jetties, turbidity, river runoff, sewage); and general coastal development (causeways, ports, channels, airports).

Test plots of the three major seagrasses were planted at twenty different sites around the Jamaica coastline, using different anchoring and planting methods.

Q: What seagrass species did you use?

A: The dominant species in the Caribbean is Thalassia testudinum, or turtle grass, which is interspersed with other species such as Halodule wrightii and Syringodium filiforme. Most of our tests involved these three species, although a euryhaline species, Ruppia maritima, was tested at a high salinity site.

Q: With what success?

A: All three species grew at many of the sites for the three planting methods used (seeds, plugs, and shoots). Other sites demonstrated specificity for both species and planting method, according to the particular pollution problem in that area.

We found that Thalassia is best for sites threatened by erosion and bauxite spills; Halodule is best for thermal pollution since it is most tolerant of high temperatures. Ruppia, as expected, is best in areas of high salinity.

Q: Is thermal pollution a problem in the Caribbean?

A: Potentially it is, because the upper lethal limit for seagrasses is only a few degrees above the summer ambient temperature. This case illustrates very well why we cannot adopt in tropical areas technology and pollution standards developed for temperate regions. A temperature change of a few degrees which might be innocuous -- or even beneficial -- to a temperate community could be devastating to a tropical community.

Q: Where else has seagrass restoration been successful?

A: After power plant effluents had destroyed a seagrass area off the tip of South Florida, 6000 seeds were planted in the restoration zone. It took only four years for both the seagrasses and the associated animal community to recover completely in the restored area.

Q: But wouldn't the seagrass eventually recover by natural means, once the pollutant source was removed?

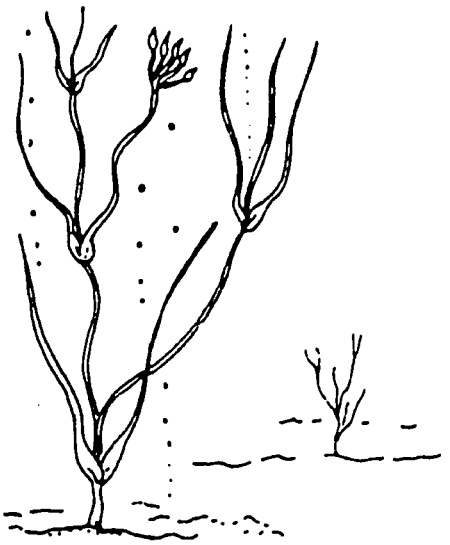
A: In one area of Biscayne Bay, near Miami, a dredge and fill operation destroyed a seagrass bed. Twenty years later still no seagrass was growing in the area. However, three years after planting Thalassia seeds the grass was growing and spreading densely.

Q: Is seagrass restoration economical?

A: It is certainly far more expensive than initial planning and conservation would be. The cost varies between US$ 2,000 and 10,000 per acre in the U.S., although in Jamaica we were able to cut the costs to about $500 per acre.

On the other hand, UNEP estimates that the resource value of the seagrass bed is $86,000 per acre. So yes, it is worth the effort.

Unfortunately, many of the Caribbean nations are not yet aware of the value of their seagrass beds, or of their importance for the Caribbean artisanal fishery, which produces about 500,000 metric tons of fish per year. It is difficult to put a dollar value on the protection that seagrasses give the shoreline from hurricanes, or on the tourism that is stimulated by the clear water.



Q: How did you cut the costs so drastically of the Jamaican restoration programme?

A: In order to ascertain the maximum cost-efficiency of seagrass restoration in Jamaica, we studied the feasiblity of training unemployed fishermen to plant the seagrass. This idea proved very successful, because the fishermen were enthusiastic and already had sufficient water skills to enable them to pick, sort and plant the seagrass easily.

Perhaps more important, the members of this ready-made labour force also had a great deal of understanding of the relationship between a thriving seagrass bed and the availability of the fish, crustaceans and molluscs they caught for a living. They had seen first-hand the destruction of seagrass beds around Jamaica brought on by development, and the subsequent effect on fisheries.

These people were willing to work very hard to bring back the seagrass and the fishery. Involving them and other local people in restoration projects is one way the costs can be reduced, but substantial funding will still be needed.

We will keep monitoring the results of the Jamaica project to determine the most cost-efficient formulas for each type of problem area. In the meantime, we hope that our work will convince others of the need to protect their seagrass communities, and of the feasibility of restoring those that have already been destroyed.

the Science Advisor (SCI) sponsored a $159,000 research project in Jamaica which is restoring seagrasses destroyed by pollution. In what is the first attempt at such an undertaking in any developing country, the SCI-funded project is rehabilitating 19 shoreline sites.

Seagrasses are especially vulnerable to the noxious effects of pollution because they tend to grow relatively close to the shore in shallow waters. They are important to the coastal ecosystem because they supply food for coastal organisms and help combat erosion. At the same time, they provide a habitat for the early stages of many marine organisms, including commercially important fish.

In Jamaica seagrasses had been destroyed or damaged by oil spills, sewage, waste from bauxite mining and cement plants, filling for urban development, and port and coastal development including dredging for channels and causeways.

According to SCI grantee Anitra Thorhaug of the Florida International University in Miami, Jamaican fishermen already are seining (using a net to fish) in one of the 19 sites being rehabilitated.

Test plots of Jamaica's three major seagrasses were planted using different methods. But regardless of the method used, all three species grew at many of the sites.

Seagrasses do not restore themselves. In Florida coastal areas, for example, seagrass had not returned in 20 years since it was destroyed by dredging and filling. Yet, within three years, a well-planned restoration

Before planting seagrasses along the coast of Jamaica (above), SCI grantee Anitra Thorhaug oversees their preparation (below). Using unemployed fishermen in the project has proven very successful.

From: AID "Front Lines"
April, 1984

these same sites.

Restoration, however, is much more expensive than conservation. In the United States, it costs $2,000-$10,000 to restore an acre. In Jamaica, the cost is roughly $500 per acre. The United Nations Environmental Program estimates that the resource value of one acre of seagrass is $86,000, a sum that would suggest restoration is well worth the cost.

An unexpected benefit of the SCI-funded project in Jamaica was that it provided unemployed fishermen jobs planting seagrass at test sites. "This idea proved very successful because the fishermen were enthusiastic and already had sufficient water skills to enable them to pick, sort and plant seagrass easily," Thorhaug reported. "Members of this ready-made labor force also had a great understanding of the relationship between a thriving seagrass bed and the availability of fish," she said.

The fishermen had seen not only the destruction of the seagrasses and associated fish, but also the disappearance of their jobs. Thus, they were willing to work hard to bring back the seagrass which would rejuvenate the fishing industry.

The AID mission in Jamaica is in the process of adding its own support to the project by funding a larger-scale restoration. The effort will restore 6-10 acres using 25 unemployed fishermen, and Jamaican government staff as supervisors. As part of a coordinated effort, the Natural Resources Conservation Department of Jamaica has planned a five-year program to rehabilitate seagrasses. This program includes labor-intensive activities that will provide more jobs for unemployed fishermen.

—Howard A. Minners