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force gusts in the northern Keys. Seas between 15-18 feet were reported by NOAA Weather Radio at offshore reefs. At its center Hurricane Kate developed sustained winds of over 110 mph.

Although Kate was a late season storm and relatively mild for a hurricane, significant reef damage was observed during a November 26, 1985 reconnaissance dive at Molasses Reef. The damage consisted of areas of broken and smashed corals, changes in the distribution of sediment, and damage to other flora and fauna. Significant accumulations of storm generated rubble were also formed as a result of the heavy wave activity.

Damage from so-called "natural" causes to the grounding site was deemed pertinent for investigation for a number of reasons. Reef conditions had changed, in some cases significantly, from their pre-hurricane state. Furthermore, remobilization of sediment and rubble from the hard grounding and cable damage areas was suspected to have caused damage additional to what might have been expected under natural circumstances. In at least one report (Sharp, 1985) NOAA scientists apparently are suggesting the presence of the Wellwood damage acted to increase the effects of damage caused by Hurricane Kate.

Therefore, as part of Phase II investigations, it was proposed to conduct an in water survey/assessment of hurricane damage to Molasses Reef and, for comparison, to other reefs within the Key Largo National Marine Sanctuary (KLNMS). This survey was completed in late Dec., 1985. It was concluded that considerable damage on Molasses Reef in the vicinity of the Wellwood grounding area was created from the passage of Hurricane

Kate. A maximum approximate areal extent of 2,200 m^2 of new damage was estimated to have been generated from the storm. Gross reef damage may have been increased by nearly 50% to approximately 7,200 m^2.

Although the Wellwood grounding damage may have contributed to this additional storm generated damage, we lacked information on the extent of damage which might have occurred in the absence of the Wellwood grounding site.

Phase IIA Goals

In Jan., 1986 MMI proposed the following scientific field and analytical procedures be carried out to collect data for further assessment of the Hurricane Kate and Wellwood grounding damage. This work, designated as Phase IIA, was in addition to the other efforts described in the original contract and was approved as a contract addition. Items 1 and 6 were added to the approved contract tasks at a later date and were subsequently approved by counsel to the Wellwood Shipping Company.

1) Prior to finalization of assessment plans, a hurricane damage survey of reefs to the south of Molasses Reef, KLNMS, would be undertaken over a several day period.

2) All Wellwood site semi-permanent assessment transects which were accomplished prior to Hurricane Kate would be re-occupied and re-photographed. Assessment would include ground truthing where appropriate and video fish-transects. This work was deemed necessary for eventual establishment of a new baseline of information on the reef's status and for quantitative estimation of the effects of Hurricane Kate to Molasses Reef and

the Wellwood grounding site.

3) At least two semi-permanent photo-transects (75 m length) would be established on French Reef in areas of high hurricane damage. In addition, quantitative measurements of the aerial extent of damage on French Reef would be attempted. Additional air photography was also proposed.

4) The additional Molasses Reef sediment samples taken immediately after Hurricane Kate's passage would be analyzed.

5) A sediment/rubble survey would be conducted on French Reef.

6) Coral specimens would be cored to obtain skeleton for growth rate determinations. At the court hearing for MMI's initial entry for Phase II work, this project had been already scheduled for Fall, 1986.

Permitting Process

After the South reefs survey was accomplished in early March, 1986, it was concluded that French Reef was the most appropriate reference site for comparison of hurricane effects at Molasses Reef. Because any activities at French Reef were not covered under the court order, William Thomas at NOAA Washington was contacted for requirements to obtain permission. Thomas indicated a formal request should be sent Dr. Nancy Foster, Chief of the Sanctuaries division, and this was done.

In April, 1986 NOAA's response consisted of a formal permit to conduct specified activities. The permit, however, required submission of cruise logs and project summaries. After discussion with Mr. John Keller, MMI responded in May, 1986 with

acceptance of the permit without the logs and summaries requirements. In June, 1986 NOAA replied that research access would be denied without fulfillment of permit requirements which included logs and summaries. On June 30, after clarification from NOAA concerning the project summary and log requirements, and after consultation with Mr. Keller, the permit was signed by MMI and returned to NOAA.

METHODS AND MATERIALS

South Reef Survey

Figure 1 shows Key Largo National Marine Sanctuary, Molasses Reef, and reefs to the south. Reefs to the north of Molasses Reef were surveyed as part of Phase II activities. Prior to inception of the study plan of Phase IIA, reefs to the south of Molasses Reef were surveyed to verify that French Reef would serve as the most appropriate reference site. In March, 1986 three scientists inspected the Reefs: Pickles, Davis, Conch, Little Conch, Crocker, Aligator, Coral Gardens, and Hen and Chickens. Visual assessments were performed by scientists using snorkle or SCUBA diving.

Molasses Reef

Figure 2 is an air photograph view of the Wellwood grounding area on Molasses Reef. Figure 3 is a sketch map of the reef and grounding site showing locations of assessment transects that were performed in Phase II and Phase IIA.

Transect locations had previously been emplaced using steel rods and pneumatic drill. Each was relocated and 10 m sections of marked line was strung between stakes for the length of the

transect (typically 75 m).

Stony Coral and Other Flora/Fauna Assessment

Populations of stony corals and other flora and fauna were assessed using the photographic quadrat method described in the Phase II report. In brief, a quadrat frame 0.5 x 0.75 m (.375 m^2) attached to a tripod was used in conjunction with a Nikonos V amphibious camera with strobe to produce sequential photographs at the same scale along six 10 m segments of each of the 5 major transects. Two additional 40 m phototransects were conducted in undamaged reference areas of Molasses Reef. To insure accuracy of photographic data, the species composition of representative quadrats was confirmed by scientists in situ. Samples of organisms that could not be identified positively in the field were taken for laboratory analysis.

Fish Assessment

The populations of fishes were assessed by three different, yet complimentary, visual censusing techniques: the random point census method of Bohnsack and Bannerot (1982), the rapid visual censusing method as described by Jones and Thompon (1978), and a repeated "video transects" method conducted along 75 m transect lines. These assessment methods are further described in the Phase II report.

Sediment Analysis

During the Phase II assessment 5 sediment samples composed of 47 subsamples were collected at various reef positions on Molasses Reef. During the initial post-hurricane survey in Nov., 1985, an additional 45 sediment subsamples were taken from the same locations for later analysis. Techniques included sieving

and weighing for size class and weight percent determinations.

French Reef

After preliminary surveys of French Reef, transect locations were chosen near Sanctuary mooring buoys F7 and F8. Stakes were emplaced as previously described resulting in two transects each 75 m in length. Care was taken to ensure that each of the steel stakes used to mark the transects was emplaced in such a manner so as to leave 6 inches or less material protruding from the substrate. This was at the direct request of NOAA in the issued research permit.

Flora/fauna transect locatons were surveyed as above for stony corals and other reef flora and fauna.

Fish assessment methods as described above were completed on the transect locations.

A total of 5 sediment samples consisting of 20 subsamples were collected for analysis at marked reef locations.

Coral Coring

The court order allowing MMI's research entry into Molasses Reef specified that 10 coral skeleton samples (5 from the Wellwood site and 5 from a reference site) showing well-resolved X-radiograph revealed density banding would be obtained by core drilling. Harold Hudson of the U.S. Geological Survey was specified to perform the coring of corals selected by MMI scientists.

In August, 1986 MMI scientists met in the field with Harold Hudson (USGS), Texas A&M representative Steve Gittings, and John Halas (Sanctuary biologist). The areas desired for coral coring

were discussed. Specimens close to and landward of the Wellwood hard grounding area were desired to assess possible subsequent turbidity/sedimentation effects of Wellwood grounding damage. There are numerous scientific literature reports which indicate that coral growth is adversely affected by high sedimentation rates. Therefore selection of specimens near the Wellwood site which might have been subjected to higher than normal sedimentation was deemed the correct approach.

Specimens which had been directly impacted by the Wellwood grounding (e.g., scratched, crushed, affected by propwash) were not desired because damage was obvious and it was not clear how such external damage might be reflected in the growth records. In addition, coring of previously physically damaged corals would have involved sampling specimens marked and under study by the Texas A&M scientists. Although tentative agreement from these scientists to allow coring of these specimens had been obtained, we concluded that it would be desirable to avoid possible complications with on-going NOAA research.

Hudson initially vigorously objected to the desired core locations in the Wellwood site, but later agreed. MMI scientists inspected corals adjacent to the Wellwood grounding area and selected five large specimens approximately 10 m landward of the hard grounding area.

Five other control coral specimens were selected in an area well away from possible Wellwood effects. Each of these 10 specimens identified for coring was buoyed for identification by a NOAA Sanctuary diver (John Halas). The purpose of buoying

these corals was to ensure that Mr. Hudson would know which corals had been determined to be acceptable specimens for coring.

Coring procedure involved use of a hydraulic powered underwater drill with core barrel 2.5" outside diameter and 10" long. Each specimen was cored at the top and the skeleton sample removed and labled. A second skeleton core of short length using a slightly bigger barrel was then taken from the side of the living coral. The short core plug with living tissue was placed in the top core hole. A cement plug was driven in the bottom hole.

Presumably, the rationale for this dual coring was to provide an eventually aesthetically pleasing appearance for the cored coral under the assumption that plug tissue would merge after a period with top tissue margins. While this may be true, the second core must add to the effects of normal bioerosion processes which act to weaken a coral colony's attachment to the substrate, and possibly to shorten the life of the colony.

Twelve cores were collected. (An additional coral was cored twice in the reference area. Cores of this specimen were not transmitted to us by Hudson because of stated heavy bioerosion to the coral skeleton.) Cores were taken by Hudson to the USGS Fisher Island lab for sectioning to yield parallel sided slabs. Cores and slabs were then transfered to R.E. Dodge on Oct. 1, 1986. Slabs were X-radiographed onto Kodak AA-2 industrial X-ray film using a source to subject distance of .75 m and exposures at 70 KvP of 10-20 seconds. Negatives were developed and printed onto photographic paper for growth band observation. Fig. 4 shows a typical core slab X-radiograph (of good quality). Four

of the cores were later reslabbed by Hudson upon our request and these new slabs were X-radiographed as above.

Air photography

Additional high altitude air photography of the Key Largo National Marine Sanctuary Reef Tract was proposed in order to obtain the material for more accurate estimates of areal extent of reefs. In addition, lower-level air photography of French was included for more precise knowledge of transect placement.

In March, 1986, preliminary air photograph runs using various combinations of lenses, focal lengths and altitude were accomplished by Air Photos International. Appropriate settings were selected and the firm was commissioned to complete air photography under the criteria specified.

RESULTS: DATA COLLECTED TO DATE

South Survey

Although scattered instances of hurricane damage were noted, relatively major occurrences such as at Molasses Reef or French Reef were not observed. In addition, for the most part, these reefs were not biologically similiar to Molasses and French.

Transects: Fauna/flora/fish Assessments

Table 1 lists for both sites the transect names and types of data collected during each assessment period (including the latest Phase IIA). Over 1,000 individual quadrat photographs were obtained during the Phase IIA assessment covering 375 m^2 of reef surface. Over 525 m of fish transects were also completed.

Coral Cores

Slabs from core samples were X-radiographed and six samples are acceptable and available for measurement. Preliminary inspection and evaluation of the X-radiographs indicated three unacceptable cores from the Wellwood area and one unacceptable core from the reference area. Mr. Hudson was sent copies of the X-radiographs and apprised of this conclusion. He agreed with three of the four "unacceptable" determinations and also agreed to perform additional sectioning of all questionable cores in hopes of obtaining better results. These additional slabs have been X-radiographed, however growth band quality remains low.

Sediments

Twenty sediment samples were collected at French Reef. Figure 5 shows collection sites. These are in the process of analysis.

Air photography

Preliminary air photography of Molasses Reef has been completed. Low-level air photography of French Reef and high level air photography of the Key Largo National Marine Sanctuary Reef tract will be completed by Air Photos International. When available, transect locations and other information will be ground truthed to the French Reef air photographs.

NOAA INFORMATION REVIEW

Materials Currently Available

The following is a listing of recently available materials concerning NOAA's research programs on the Wellwood grounding

from Freedom of Information Act and Court Order sources. These discuss aspects of NOAA's research program from September, 1984 to January, 1986.

-- Bright letter (Sept., 84)

-- Harrigan memo on grounding (Oct., 84)

-- Causey memo on grounding (undated)

-- Jaap (State) memo/trip report (Oct., 84)

-- Bright & Andryszak report on coral populations (Sept., 84)

-- Bright, Dennis, & Andryszak, Nov. 84 and Jan. 85 performance report (Jan., 85)

-- Bright, coral proposal (Oct., 84)

-- Texas A&M Fish baseline studies, (Jan, 1985)

-- Bright & Dennis, 2nd Yr Funding Request Corals & Fish (Oct., 85)

-- Bright et al., Interim Annual Report (Jan., 85)

-- Dennis & Bright, Fish Report (Jan., 86)

-- Littler et al., Algae & Exp. Design, (Sept., 85)

-- Hanisak, Algae proposal (not dated, presumably Feb., 85)

-- Hanisak, Algae renewal proposal (Jan., 86)

-- Hudson, Preliminary Fracture Survey (June 85)

-- Hudson, Transplanting Proposal?, (not dated) (before Hurricane Kate, after July, 85)

Review and Implications

NOAA scientists have already amassed and continue to generate a large amount of information. On-going interpretation has been an integral part of their data collection. Data interpretation is a critical factor in scientific research

because it indicates new research directions, validates preliminary working hypotheses, and gives rise to improved methodologies. Our study, although of high quality, is limited in terms of data collection in comparison to that of NOAA. In addition, although preliminary results are available, lack of data interpretation has made us unable to supply quantitative estimates for the various ecological parameters involved in accurate damage determinations. Depending upon the status of the legal arguements and issues, our interpretation efforts of available data should begin as soon as possible.

The following represents a brief (and non exhaustive) review of NOAA's findings coupled with implications about our data collection, interpretation and research strategies.

Jaap (10/10/84) presents measurements estimating damage in the Wellwood site. These are:

519.5 yds^2 : inbound path of Wellwood

2486.9 yds^2: grounding site

2813.1 yds^2: shifting of Wellwood aground

5819.5 yds^2 : Total

While the number of significant figures is questionable, these data are roughly similar to ours if the inbound path figure is deleted for consistency. Thus Jaap's estimate becomes 5300 yds^2 compared to our 4920 +/- 800 m^2. This difference is not unreasonable and is probably accounted for by the estimation error and irregularity of the damage zone boundaries. Although we have not yet quantified the damage to the in-bound path, we have suggested it was relatively small, consisting primarily of hits to 10 large coral heads (Harrigan's 10/10/84 report).

Jaap's 500 yds^2 estimate would therefore appear high for this area. If this becomes an important issue, more work may be required in this area since Harrigan states that coral coverage in the in-bound tract was 50% which was totally or nearly totally destroyed. From our personal observation of the area 50% coral coverage is very unlikely as is nearly total damage. We have photo transects very near, but not actually in this area.

Jaap further reports 4166.7 yd^2 shallow cable damage and 80,000 yds^2 of deep cable damage. Bright (9/3/85) also states that "thousands" of barrel sponges were sawed off by cables. Although it is admitted that this damage is patchy and nowhere massive, NOAA may be intending to argue that the Wellwood is responsible for an additional percentage of this area. No specific estimates of damage, however, are presented for total cable damage. Our estimates covered a much small zone (14,000 m^2) and we estimated a 1% destruction figure. Because our research priority was concentrated on the hard grounding area, we did not complete extensive cable area evaluations. In light of the above information and depending upon additional information from NOAA, it may be advisable that additional site evaluations be completed over a several day period.

Jaap mentions unspecified damages from Wellwood discharge of Mississippi River ballast water during attempts to free the ship, which resulted in salinity and oxygen stress to nearby corals. Both Bright and Jaap also variously refer to shading damage of corals, especially M. annularis (20 colonies). Other literature in the scientific press suggest that 4-6 weeks of shading is

necessary to produce mortality effects. The Wellwood was only aground for 12 days. The corals were apparently showing recovery in 1986 (1st interim report, 2/86). It should also be realized that the more extensive study by Bright will superceed that of Jaap and presumably be more heavily relied on by NOAA attornies. Precise information on Bright's results is not yet available.

In terms of fish assessments, Bright (fish study proposal, 10/84) indicates that no significant damage was incurred by the reef within the Acropora zone. This is at odds with our preliminary data. In general the fish information indicates that NOAA intends to utilize estimates of biomass, size distrbutions, activity patterns, and community structure in their case. This suggests we will need similar information or their conclusions will go unchallenged. Our fish data needs reduction and interpretation to supply similar information. We will also need to be able to discuss the limitations of their methodologies used to obtain these data, which may in some cases require sustantial reference research and summarization.

Bright's proposal for continued funding proposes a number of studies relative to assessing value of the reef: 1) a spatial complexity index, 2) biomass estimates, 3) a species list, 4) analysis of variance statistical comparisons, 5) recruitment rates, 6) number of individuals, and 7) species diversity calculations. Some of these have been already completed (interim report, 2/86). We will need to critically evaluate their calculations, especially in regard to octocoral species (which are notorously difficult to identify). Spatial diversity is an important parameter which we have not quantified. We will be

able to obtain some information from our data. Other information may have to be collected, depending upon the nature of their arguements. Bright's work also contains quantitive estimates of losses of various species to each area of the Wellwood site. At present, we can not judge the validity of these conclusions due to lack of processing and interpretation of our data.

Some minor points which are interesting by their omission are: all budgets are deleted from the NOAA reports and proposal, no permits application requests or permits have been included.

Hurricane Effects

Bright's (2/86) interim report notes damage effects from Hurricane Kate. Data collected following the hurricane will be compared to pre-hurricane assessments. Tissue damage to coral was noted from waterborne debris along with storm effects to study stations. A strong implication is made that Wellwood damage was exacerbated by Hurricane Kate effects. An important point is that the NOAA scientists already have begun a coral transplant study. This information is apparent from discussions of damage to the transplants and in the Hudson reports. Although little specifics are available, consideration should be given to the possibilities of beginning a small-scale transplant project, either at the Wellwood site or elsewhere in a similar environment.

INTERPRETATION STRATEGIES

It is recommended that data interpretation, at least in a limited fashion, be initiated immediately. Our data collection is now extensive. It should be realized, however, an even larger

amount of information is available to (and continues to be collected by) NOAA (coupled with extensive and sophisticated analysis). If we do not begin data reduction soon, we run the risk of being unprepared or less than optimally prepared for eventual court arguements.

We suggest 1) initiation of data reduction, 2) every effort be made to gain NOAA information to date, 3) evaluation of this and past NOAA information, and 4) integration of our data analysis with regard's to NOAA for most efficient interpretation, and 5) additional data collection (if appropriate).

POSSIBLE MITIGATION PLANS

From the onset, MMI has proposed mitigation as a way to ameliorate damages to the Key Largo National Marine Sanctuary caused by the grounding of the M/V Wellwood.

Mitigation might be accomplished by employing any one or a combination of the following techniques.

Construction and installation of artificial benthic substrate (artificial reefs).

Construction and installation of small-scale fish aggregating devices (FADs).

Transplantation of hard corals from outside KLNMS to affected reef areas.

It is understood that installation of benthic reefs and small-scale FADs would not restore the reefs within the KLNMS to their original esthetic state and appearance; however, we can assure that the original density and diversity of the fish

assemblages, altered by loss of habitat, can be restored if not improved upon. If corals were to be successfully transplanted in conjunction with the installation of man-made reefs, the impact of "foreign" material introduction into the Sanctuary would be lessened considerably.

In order to demonstrate project effectiveness, a pilot program could begin on a reef site outside of the KLNMS. This would avoid many permitting and legal issues, and would prove project feasibility and reliability.

A comprehensive program, ie., all items mentioned above, would cost in the vicinity of $150,000 to design, assemble, construct, and install. Additional funds would be required to monitor the project to ensure engineering integrity of each man-made component and habitat enhancement system as well as to assess floral/faunal/fishery recovery. At a minimum, this monitoring project would require quarterly site visits over a three year period. A monitoring budget would be developed after a mitigation scope of work was approved.

A detailed proposal is available upon request.

TABLE 1

SUMMARY OF DATA COLLECTION TO DATE

DATA CODES:

C = CORALS & OTHER FLORA/FAUNA; G = GROUND TRUTHED
F = FISH ASSESSMENT (V = VIDEO; O = OTHERS)
S = SEDIMENTS; * = IN PROGRESS, NUMBER = METERS TRANSECTED

MOLASSES REEF

STAKED TRANSECTS	ABBR.	ASSESSMENT DATES: SEPT, 85	NOV, 85	AUG, 85
DAMAGE	D	CG60F75(VO)S	CG60S	CG60F75(VO*)
A.PALMATA	AP	CG60F75(VO)S	CG60S	CG60F75(VO*)
OUTER	MO	CG60F75(VO)S	S	CG60F75(VO*)
INNER	MI	CG60F75(VO)S	S	CG60F75(VO*)
CABLE DAMAGE	C	CG60F75(VO)S	S	CG60F75(VO*)
NON-STAKED TRANS.				
A PALMATA REFERENCE	APC	CG40F75(VO)S	CG40S	CG40
CABLE CONTROL	CC	CG40F75(VO)S	S	CG40
A PALMATA N. REF			CG40	
FRENCH REEF				
STAKED TRANSECTS	NAME			
FRENCH 1	F7			CG60F75(VO*)S*
FRENCH 2	F8			CG60F75(VO*)S*

FIGURES

FIGURE 1a,b. Sketch map of Reefs within Key Largo National Marine Sanctuary (KLNMS) (1a) and Reefs to the South (1b).

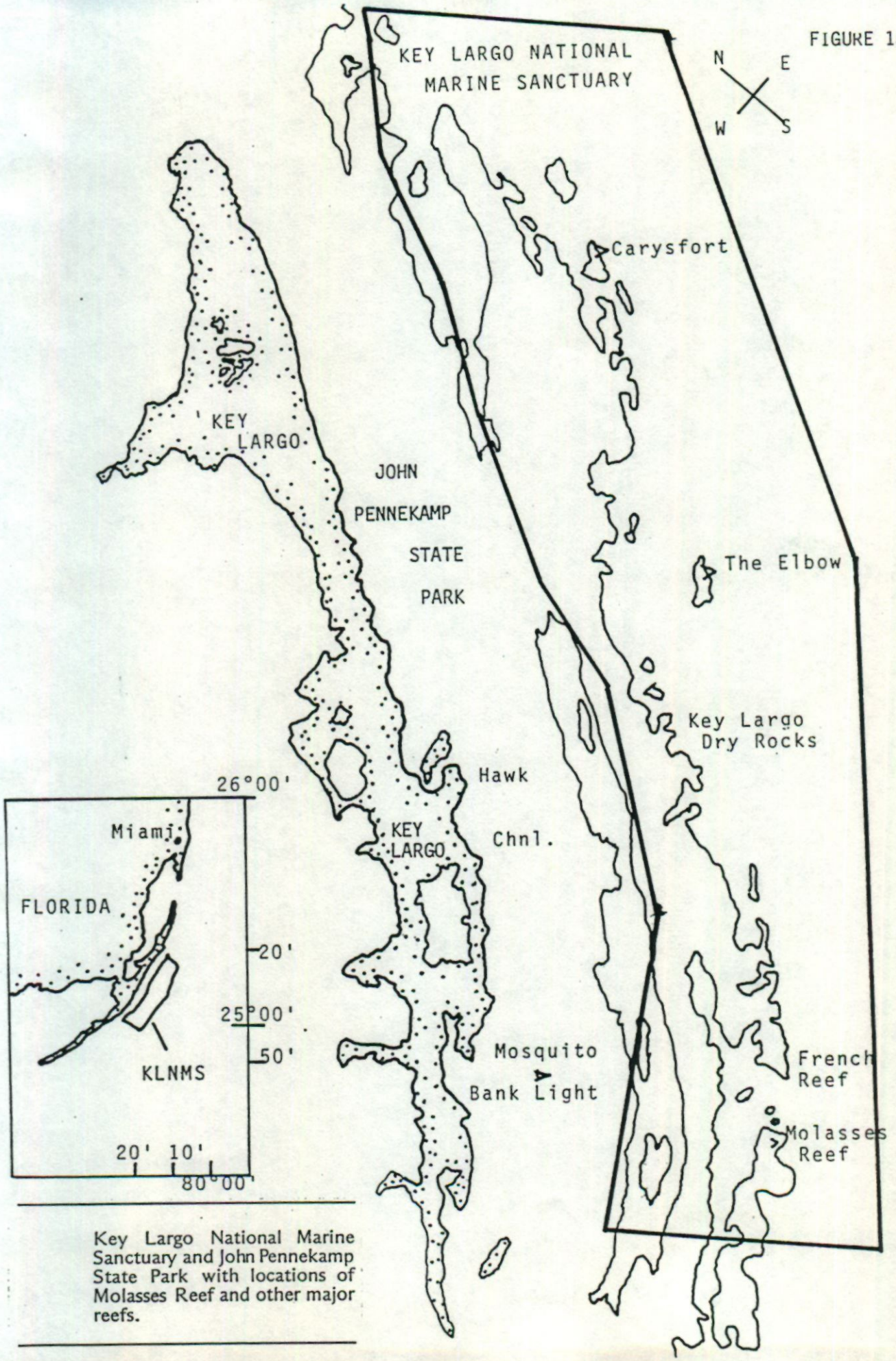
FIGURE 2. Airphotograph Molasses Reef with Wellwood damage site.

FIGURE 3: Sketch map of Molasses Reefs indicating transect positions.

FIGURE 4: Sample X-radiograph positive.

FIGURE 5: Sketch map of French Reef showing transect positions and sediment collection sites.

FIGURE 1a



Key Largo National Marine Sanctuary and John Pennekamp State Park with locations of Molasses Reef and other major reefs.

FIGURE 1b

Sketch Map of reefs inspected south of Molasses

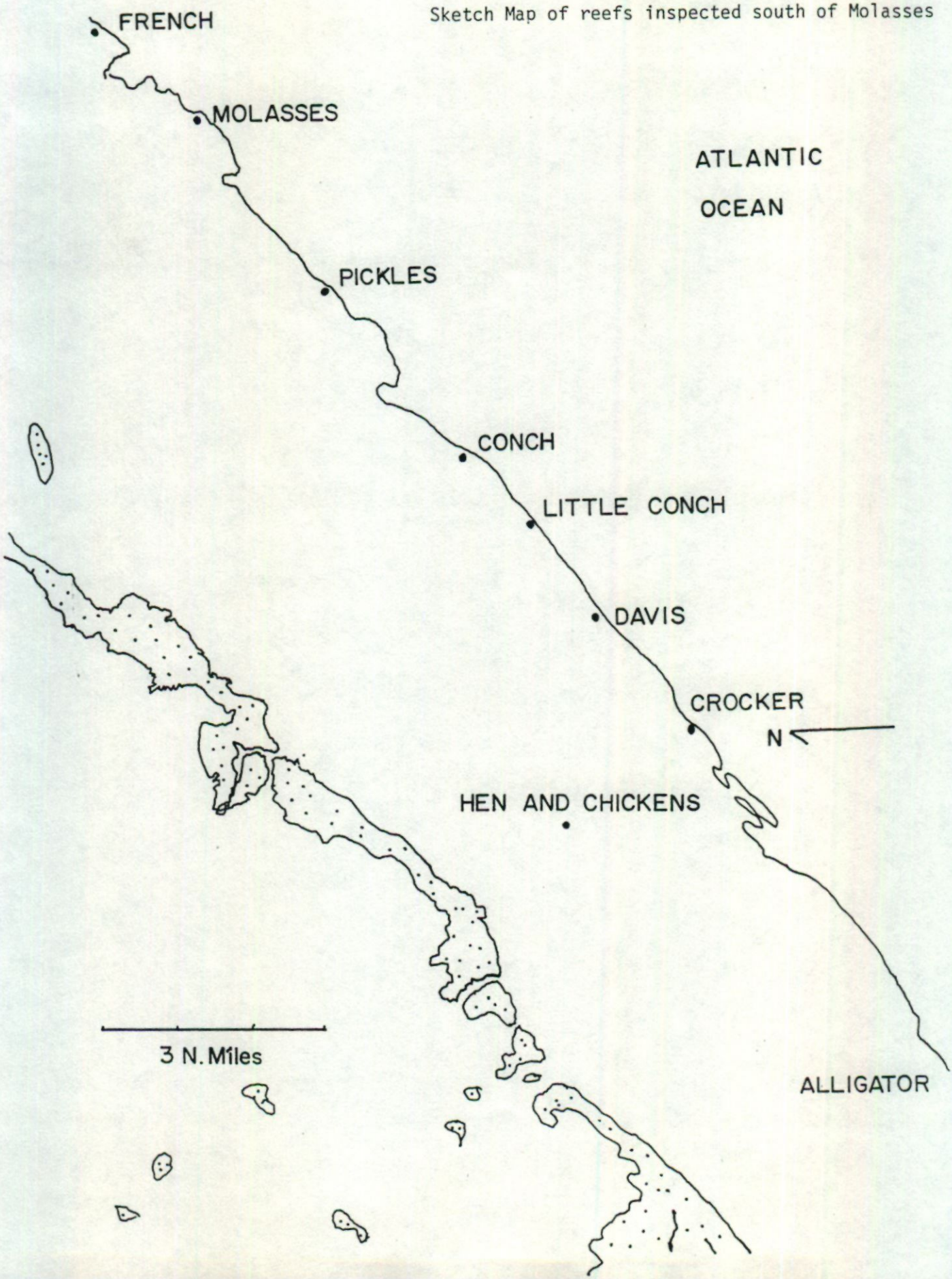
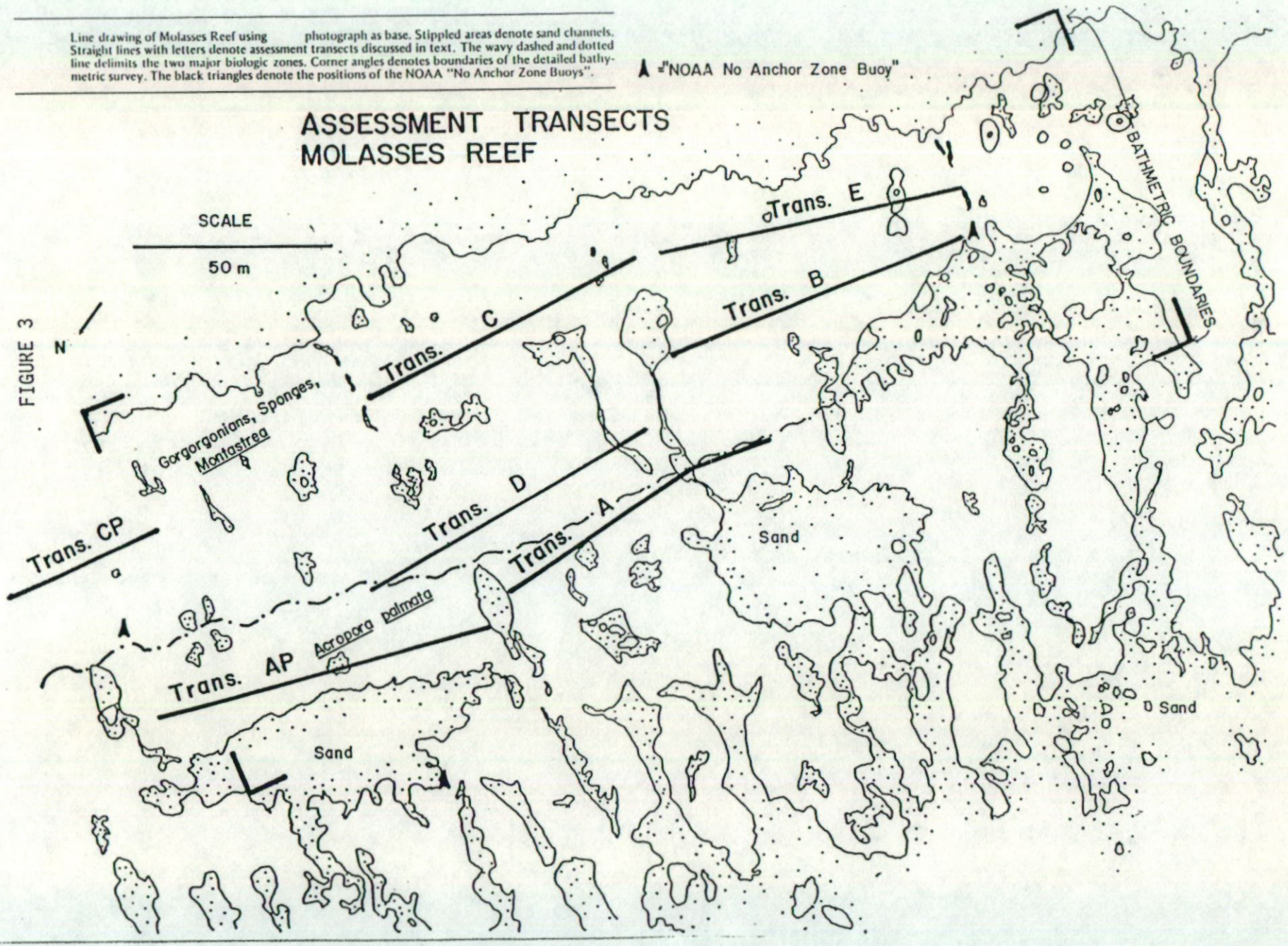
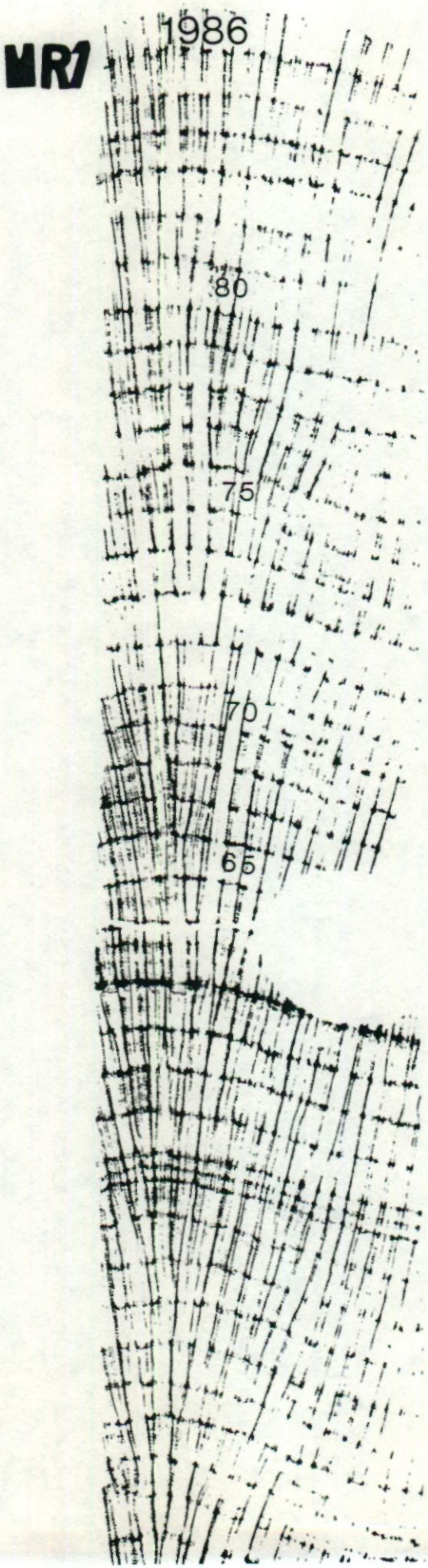


Fig.2: Enlargement of a portion of air photograph showing Molasses Reef and Wellwood grounding site.



Line drawing of Molasses Reef using photograph as base. Stippled areas denote sand channels. Straight lines with letters denote assessment transects discussed in text. The wavy dashed and dotted line delimits the two major biologic zones. Corner angles denotes boundaries of the detailed bathymetric survey. The black triangles denote the positions of the NOAA "No Anchor Zone Buoys".

FIGURE 4



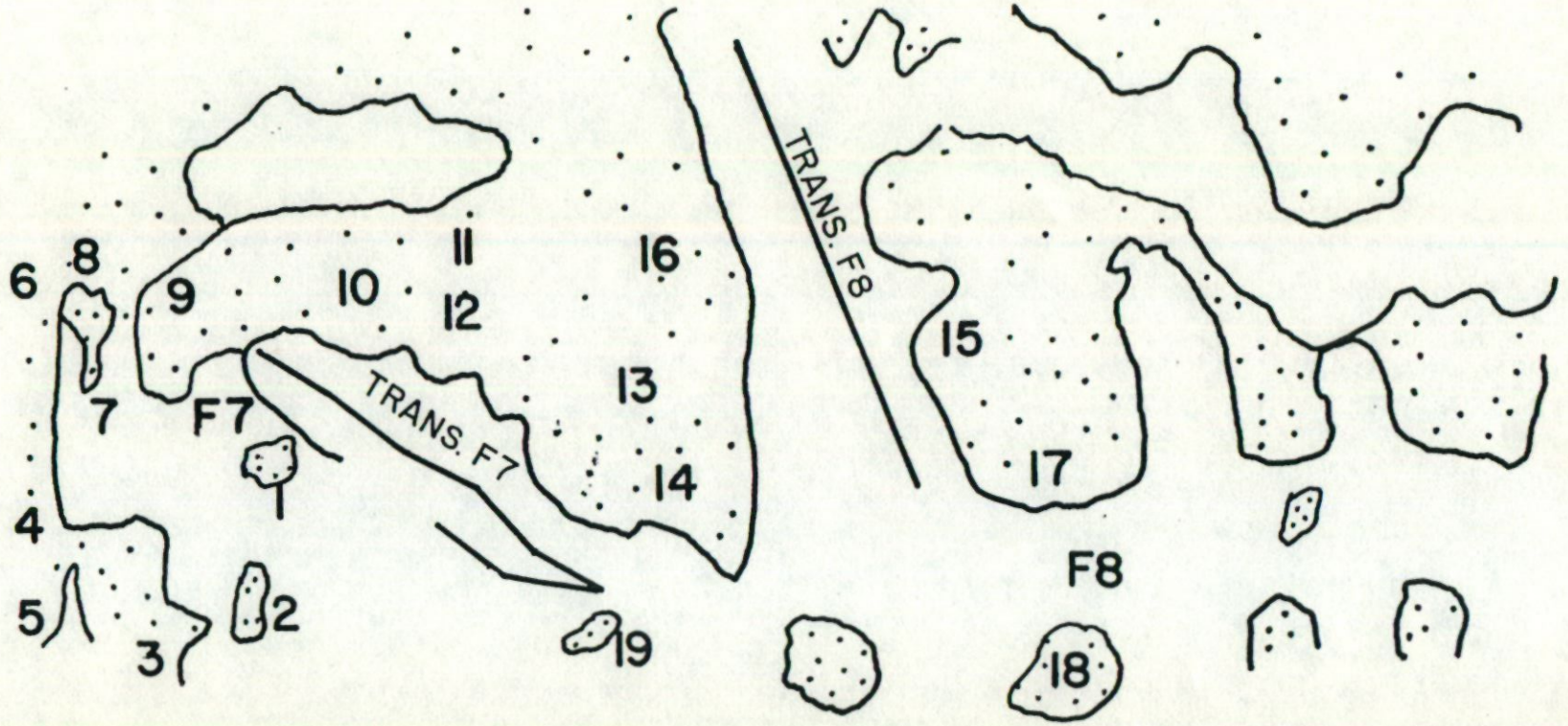
X-radiograph positive of coral skeletal core MR-1 (from Wellwood site).

A couplet of dark and light bands is the extent of coral skeleton formed over 1 year.

The circular void at mid right of the core represents the trace of a boring clam.

While this core was acceptable for coral growth measurement, four other cores were not.

FIGURE 5



SKETCH MAP OF FRENCH REEF

Transects are 75 m long. Mooring buoys F7 and F8 and indicated. Areas with dots indicate sediment. Numbers are sediment samples.