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The Use of Remote Sensors to Relate Biological and Physical Indicators to Environmental and Public Health Problems

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PREFACE

The purpose of this research was to determine what reliable relationships exist between biological, ecological and botanical structures, and disease organisms and their vectors which might be detected and measured by remote sensing. Since trees are some of the world's largest organisms and since trees often show distinct preferences for certain environmental factors, it was originally thought that certain single trees of given species could be used to pinpoint given diseases. Examples of such close associations of trees or large observable plants include: the yellow fever mosquito's association with both the false banana plants and the cocoa yam in Africa; the association of both malaria and yellow fever mosquitos with the water-holding epiphytes (Bromeliaceae) of the cuipo trees of Central America; and the Solacca palm-*Anopheles balabacensis* association as observed in Thailand by Scanlon and Sandhinand. In addition to the use of trees as indicators of disease or potential disease, we have attempted to identify environmental factors such as soil moisture and soil and water temperatures as they relate to disease or health problems and may be detected by remote sensing.

Towards these goals, computerized searches of the pertinent literature were made at the start and at monthly intervals during the contract period. From these searches, leads were followed by intense personalized studies by NASA fellows.

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After considering and eliminating hundreds of diseases and health problems as unapproachable by remote sensing, the NASA team at the University of West Florida concentrated upon the three diseases and one major health problem contained in this report. Malaria, Rocky Mountain spotted fever, Encephalitis and Red Tide appear to be the health problems of the United States that warrant further study and consideration as approachable through remote sensing. In all the cases we find that no single species of vascular plant nor any one environmental factor can be used as *the* indicator of the disease or health problem. Entire vegetation types, successional stages and combinations of factors must be used. In each case we have recommended that feasibility studies be done. We have identified the agencies best able to undertake such tests of our theories.

Joe A. Edmisten

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Introduction and General Conclusions

The principal efforts of the University of West Florida NASA research team have centered around four major health problems whose detection and investigation can be approached through remote sensing techniques. The problems studied are: Rocky Mountain spotted fever, encephalitis, malaria and "red-tide." The latter area is of importance not only to public health per se, but to our marine fisheries resources, recreation, and environmental conservation.

The body of this final report consists of in-depth analyses of each area of study. In addition, we have attempted to locate and briefly describe those agencies which most reasonably might be expected to conduct test projects (feasibility studies) in the remote sensing of human health problems. Several test projects are proposed in this report.

Our team has searched the pertinent literature in order to ascertain whether remote sensing might be applied to the detection and/or prevention of human diseases other than those given special emphasis in the present report. Toward that end, we have considered the diseases listed in _The Control of Communicable Diseases in Man_ by A. S. Genenson (1970) and referred to other current NASA work in the form of the University of Texas final report (Contract No. NAS 9-11522).

In that report the following list of diseases was reported as unlikely prospects for remote sensing applications:

Table 1. Diseases listed in Control of Communicable Diseases in Man, APHA, but eliminated as unlikely prospects for remote sensing applications.

Actinomycosis	Listeriosis	Rickettsialpox[2]
Angiostrongylosis	Lymphocytic choriomengitis	Rubella
Arbovirus[1]	Lymphogranuloma venereum	Salmonellosis
Balantidiasis	Measles	Scabies
Bartonellosis	Meningitis, asceptic	Smallpox
Brucellosis	Meningitis, meningococcal	Sporotrichosis
Candidiasis	Mononucleosis, infectious	Staphlococcal disease
Capillariasis	Muco mycosis	Streptococcal disease
Carditis, viral	Mumps	Syphilis
Cat-scratch fever	Mycetoma	Pneumonia
Chancroid	Nocardiosis	Poliomyelitis
Chickenpox	Paragonimiasis	Psittacosis
Conjunctivitis	Paratyphiod	Q fever
Cytomegalic inclusion	Pediculosis	Taeniasis
Dermatophytosis	Pinta	Tetanus
Diarrhea	Pleurodynia	Toxoplasmosis
Diphyllobothriasis	Granuloma inguinale	Trachoma
Dracontiasis	Hepatitis, viral	Trichinosis
Enterobiasis	Herpangina	Trichomoniasis
Food poisoning	Herpes	Tuberculosis
Gonococcal disease	Rabies	Tularemia[3]
Hydatidosis	Rat-bite fever[2]	Typhus, murine[2]
Influenza	Relapsing fever	Typhus, epidemic
Keratoconjunctivitis	Respiratory disease, viral	Whooping cough
Larva migrans		Wolhynian fever
Leprosy	Rheumatic fever	Yaws

[1]There are over 200 arboviruses now described in varying detail; but for the vast majority of these the ecological data are far too scant to permit comment.

[2]Presumably a number of rat-borne diseases of urban areas are related to numbers of rodents, which in turn may be related to housing quality. However, the relationship appears to be too tenuous to permit analysis.

[3]Partially vector and water-borne, primarily contact.

Our findings are in general agreement with those of the Texas team. We feel, however, that hydatidosis, cutaneous larva migrans, angiostrongylosis cantonensis, psittacosis and perhaps rabies may be usefully investigated utilizing remote sensing techniques.

In the case of rabies (particularly during outbreaks) remote sensing by photography could provide a rapid approximation of common reservoir host densities (foxes, skunks, raccoons and the like). In a similar manner, once echinococcus and multiceps infection rates in rabbits, carnivores, rodents etc. had been established in local areas, monitoring of population movements and density fluctuations by aerial photography could provide good assessments of disease frequency changes. Antaneous larva migrans from cat and dog hookworms is associated with rural communities and cities alike. Population density assessments of dogs and cats in areas where children commonly go barefooted may be made remotely. Angiostrongylosis contonensis is a disease associated with the giant African land snail, rats and mangrove swamps. The snails, which often festoon the branches of mangrove mangles are perhaps large enough to photograph from the air. This disease is a very serious one, and is fairly common in Hawaii and tropical American Pacific territories. Photographic documentation of pigeon densities in urban areas may shed light on the incidence of psittacosis in those areas.

The possible detection of various intestinal helminths by remote sensing mentioned in the Texas report is not wholly supported by the literature. We nonetheless feel that these should be examined by small test projects with special emphasis upon the documentation of human sanitation practices.

The case for the uses of remote sensing in the detection and prevention of anthrax would appear to be even stronger than suspected by the University of Texas team. In addition to the kinds of soil types and temperatures mentioned, there are, in each region of this country, sets of indicator plants that enable one to locate calcareous soils and hence the optimum pH of 7 or 8 associated with incubation areas for Bacillus anthracus. The cabbage palm is such a species for central Florida and red cedar for Tennessee. We strongly suggest an expanded NASA-NDCD project in the Ascension Parish of Louisiana and a similar new project in central Florida.

The University of West Florida team feels that the remote sensing of coccidiomycosis holds very little promise. Our search of the botanical literature indicated little if any association of the causal fungus with Larrea tridentata. Further, the creosote bush is too common and widespread to be of much value.

There is evidence that remote sensing can be applied to the Histoplasmosis problem. In addition to detection of birds and their roosts as mentioned in the Texas report, the detection of Histoplasmosis-bearing caves in Puerto Rico can be routine. A project to map the distribution of such caves in northwest Puerto Rico should be investigated.

Of the nine water-borne diseases considered in the Texas report, only one, schistosomiasis, appears to merit the support of a test project. The eight others are either not associated with remotely sensible objects or they are not important enough in the United States to warrant current concern.

Table 11. Diseases not important enough to warrant concern in U.S.

Amebiasis	Giardiasis	Shigellosis
Cholera	Fascioliasis	Typhoid fever
Diarrhea (various)	Chlonorchiasis now Opisthornchisa	Schistosomiasis

Five years of personal field experience in Puerto Rico, St. Thomas and the American tropics, cause me to endorse the concept that snail hosts for schistosomiasis can be associated with the remotely sensed plant Caladium. In addition to the remote sensing of this plant and the drainage patterns where it is found, it would be of great value to ascertain remotely man's contact with the water. The use of IR and color photography would economically relate man's use of the waters for (1) recreation,

(2) washing garments, (3) transportation (crossings), (4) and the general proximity of his dwellings. It is strongly suggested that NASA support continued efforts in Puerto Rico since this disease will manifest itself in Florida sooner or later if control in Puerto Rico is not achieved.

The Texas report considered the following zoonotic diseases as possible candidates to be approached by remote sensing.

Table 111 Some Diseases of Rodents Transmissible to Man

Disease	Mode of Transmission
South American Hemorrhagic Fevers (Tacaribe and Junin viruses)	Rodent excreta
Korean Hemorrhgic Fever	Unknown
Leptospirosis	Animal excreta in water
Meliodosis	Animal excreta in soil
Plague	Fleas

In our consideration of this catagory of diseases, the literature indicated that only leptospirosis currently is approachable via remote sensing or is of sufficient importance in the U. S. to warrant a test project. We find no consistent indicator plants nor vegetation types associated with rodents and other mammals capable of carrying leptospirosis. The logical approach would appear to use remote sensing to ascertain the spatial location of lakes and farm ponds (used for swimming) in relation to potentially infectious animals. An aerial survey for such spatial arrangements within drainage patterns might help prevent many infections.

Of the 17 arthropod diseases considered by the University of Texas group, only ten appear to be serious in the U.S. and its territories, and are approachable through remote sensing. Five of the ten are viral forms of encephalitis and are covered in detail by NASA fellow Ed Meyer. Our recent field trips to VEE sites in the Everglades hammocks will be used to help interpret Dr. Sudia's findings and utilize more fully the color and IR aerial photography of these will-documented sites. These interpretations and detailed recommendations will be presented below.

Rocky Mountain spotted fever represents an exciting possibility for the use of remote sensing in finding areas where tick bearing rodents can be found by their association with old field succession vegetation types. The proximity of people and their dogs to such possible disease zones can be easily ascertained. This theme is developed more fully in the body of this report by NASA fellow Rob Mattlin.

Although the U.S. is not currently considered malarious, it has all the ingredients to become so rather rapidly. The Texas report reflects the expertise of Dr. John E. Scanlon in the area of malaria. Our findings reconfirm his, and attempt to expand upon them with recommendations for a test project in the TVA system. This section is developed more fully by NASA fellow Fred Pitts.

Trypanosomiasis in Panama appears to be serious enough to warrant attention. The vector (Reduviidae) is consistently associated with substandard housing as established in the University of Texas report. The use of remote sensing in the location and treatment of such sites is apparent.

The University of West Florida team findings support the Texas findings for Onchocariasis and yellow fever. In the case of yellow fever, it is further suggested that the remote sensing of monkey populations in tree tops could be used to help delineate host areas of the jungle type.

Stomoxys calcitrans (known in the southeastern United States as dogfly and in other parts of the world as the stable fly) represents a readily achievable control task via remote sensing. Although this blood-sucking fly has not been associated with the transmission of human disease, it is probable that several diseases could be spread by it since it exhibits great longivity and travels great distances. Aside from the above health reasons, there are great social and economic reasons for possible NASA concern in this case.

The dogfly effectively closes the beaches of west Florida and the mid-Gulf region one to two months prematurely because of its painful bite. During late August or September, the dogflies emerge in great swarms from windrows of rotting turtle grass around the thousands of miles of bays, sounds and inlets of the panhandle section of Florida. During the 1940's, military actions in the mid-Gulf section were greatly curtailed or stopped by these blood-sucking insects.

The most readily feasible means of controlling this pest and potential spreader of disease is the mechanical removal or treatment of the piles of rotting Thallasia (turtle grass). NASA and remote sensing enter the picture here with the ability to locate and map the Thallasia beds during the maximum growing season to predict where the rotting piles (breeding sites) will occur. And finally, the economical location of them for their mechanical removal and/or treatment.

In addition to the above classical disease problems we recommend that some state agency utilize NASA expertise in the Red Tide problem which is covered in detail in the body of this report.

The following charts have been constructed by the NASA team and represent a compact summary of our findings.

LEGEND

D-Directed

R-Related

S-Statistical

T-Typological

/ Sensor Able to Sense Factor

X Sensor Best Able to Sense Factor

Sensors

Environmental Factors		Various Types: Air-Dropped Sensors				Nuclear Resonance: Magnetic Proton Resonance				Conduction: Pulse Induced Currents				Radio: Swept Frequency			
		D	R	S	T	D	R	S	T	D	R	S	T	D	R	S	T
Surface Composition	Bearing Capacity	X	/				/		/		/		/		X	/	
	Surface Traction		/				/		/		/		/		X	/	
	Remolding Characteristics		/				/		/		/		/		/	/	
	Layer Thickness		/				/		/		/		/		X	X	
	Dielectric Properties	/	/				/		/	X	/		/				
	Mineral Deposits										/		/				
Surface Geometry	Microgeometry																
	Macrogeometry																
Hydrologic Geometry	Current Velocity	X															
	Depth of Water	/												X		X	
	Wave Heights																
	Ice Conditions													X		X	
	Bank Configuration																
	Dimensions of Water Body																
	Profile of Bottom	X												X			
	Strength of Bottom	X															
	Temperature of Bottom	/															
Weather	Temperature - Ambient	X															
	Wind Velocity	X															
	Precipitation	X															
	Fog Level		/														
	Light Intensity	X															
	Humidity	X															
	Cloud Cover	/															
	Atmospheric Layering																
	Electrical Disturbance	X															
	Atmospheric Pressure	X															
Vegetation	Distribution of Plants		/														
	Plant Height	/	/											/		/	
	Crown Characteristics		/														
	Foliage Characteristics		/														
	Size of Branches		/														
	Distribution of Branches		/														
	Stem Size		/														
	Tensile Strength of Stemand Branches		/														
Landform	Distribution																
	Size																
	Elevation																
Manmade Features	Roads																
	Bridges																
	Railroads																
	Population Center																
	Airfields																
	Shipyards																
	Existing Telephone Facilities																
	Buildings																
	Lumber Yards																
	Steel Mills																
	Tunnels																

Environmental Factors		Radio: Interpretation of Maps				Radar: Scatterometer				Radar: Swept Frequency				Radar: Interpretation of Maps			
		D	R	S	T	D	R	S	T	D	R	S	T	D	R	S	T
Surface Composition	Bearing Capacity		/		/		/	/	/		X	/			/		/
	Surface Traction		/		/		/	/	/		X	/			/		/
	Remolding Characteristics		/		/		/	/	/		X	/			/		/
	Layer Thickness		/		/		/	/	/		X	X					/
	Dielectric Properties		/		X		/	/	X		X	X			/		X
	Mineral Deposits		X		X										X		X
Surface Geometry	Microgeometry		/	/	/		X	X	/					/	/	/	X
	Macrogeometry	/	/	/	/		/	/	/					/		/	X
Hydrologic Geometry	Current Velocity																
	Depth of Water		/		/					X	X				/		/
	Wave Heights		/	/	/		X	X	/					/	/	/	X
	Ice Conditions		/	/	/				/	X	X			/	/	/	/
	Bank Configuration		/											/			
	Dimensions of Water Body		/		/									/			/
	Profile of Bottom		/							X							
	Strength of Bottom																
	Temperature of Bottom																
Weather	Temperature - Ambient																
	Wind Velocity																
	Precipitation													/			
	Fog Level														/		
	Light Intensity																
	Humidity																
	Cloud Cover														/		
	Atmospheric Layering																
	Electrical Disturbance														/		
	Atmospheric Pressure																
Vegetation	Distribution of Plants	/	/	/	/		/	/	/					/		/	/
	Plant Height		/	/	/				/	/		/					
	Crown Characteristics		/	/	/		/	/	/					/	/	/	/
	Foliage Characteristics		/	/	/		/	/	/						/	/	/
	Size of Branches		/	/	/				/						/	/	/
	Distribution of Branches		/	/	/				/						/	/	/
	Stem Size		/	/	/				/						/	/	/
	Tensile Strength of Stemand Branches		/	/	/				/						/	/	/
Landform	Distribution	/		/	/		/	/	/					/		/	/
	Size	/		/	/		/	/	/					/		/	/
	Elevation	/		/	/		/	/	/					/		/	/
Manmade Features	Roads													X			
	Bridges	/												X			
	Railroads	/												X			
	Population Center	/			/									X			/
	Airfields													X			
	Shipyards	/												X			
	Existing Telephone Facilities													X			
	Buildings	/		/	/		/	/	/					X			X
	Lumber Yards	/			/									X			X
	Steel Mills	/			/									X			X
	Tunnels	X														/	

Environmental Factors		Ultraviolet Visible Infrared: Surface Heating and Gas Spectroscopy				Radiometers (Passive Sensors)				Reflectometers (Active Sensors)				Optical Ranging			
		D	R	S	T	D	R	S	T	D	R	S	T	D	R	S	T
Surface Composition	Bearing Capacity		/				/		/		/		/				
	Surface Traction		/				/		/		/		/				
	Remolding Characteristics		/				/		/		/		/				
	Layer Thickness						/		/								
	Dielectric Properties					/		/	/	X		X					
	Mineral Deposits		X								/						
Surface Geometry	Microgeometry													/		/	/
	Macrogeometry													/		/	/
Hydrologic Geometry	Current Velocity																
	Depth of Water						/										
	Wave Heights													/		/	/
	Ice Conditions					/	/		/		/		/				
	Bank Configuration													/			
	Dimensions of Water Body																
	Profile of Bottom																
	Strength of Bottom																
	Temperature of Bottom					X											
Weather	Temperature - Ambient						X										
	Wind Velocity																
	Precipitation																
	Fog Level																
	Light Intensity																
	Humidity	/															
	Cloud Cover													/			
	Atmospheric Layering	/															
	Electrical Disturbance																
	Atmospheric Pressure																
Vegetation	Distribution of Plants													/		/	/
	Plant Height													/		/	/
	Crown Characteristics													/		/	/
	Foliage Characteristics																
	Size of Branches																
	Distribution of Branches																
	Stem Size																
	Tensile Strength of Stemand Branches																
Landform	Distribution													/			
	Size													/			
	Elevation													/			
Manmade Features	Roads																
	Bridges																
	Railroads																
	Population Center																
	Airfields																
	Shipyards																
	Existing Telephone Facilities																
	Buildings																
	Lumber Yards																
	Steel Mills			/													
	Tunnels																

Environmental Factors		Profilometer				Interpretaion of Maps				Gamma Ray: Photopeak and Photopeak Ratio				Gamma Ray: Interpretaion of Maps			
		D	R	S	T	D	R	S	T	D	R	S	T	D	R	S	T
Surface Composition	Bearing Capacity						X	X	/	X	/				X	/	/
	Surface Traction						X	X	X	X	/				X	/	/
	Remolding Characteristics						X	X	X	X					X	/	/
	Layer Thickness						/		/								
	Dielectric Properties					/			X								
	Mineral Deposits						X		X	/					/		/
Surface Geometry	Microgeometry	X		X	/	/		/	X								
	Macrogeometry	X		/	/	/		/	X								
Hydrologic Geometry	Current Velocity						X		X								
	Depth of Water						/		/								
	Wave Heights	X		X	/	/		/	X								
	Ice Conditions					/	X	/	X								
	Bank Configuration	X			/	/			X								
	Dimensions of Water Body					X			X								
	Profile of Bottom																
	Strength of Bottom								/								
	Temperature of Bottom					/			X								
Weather	Temperature - Ambient																
	Wind Velocity						X		X								
	Precipitation						/		/								
	Fog Level					X			X								
	Light Intensity						X										
	Humidity																
	Cloud Cover					X		X	X								
	Atmospheric Layering																
	Electrical Disturbance																
	Atmospheric Pressure																
Vegetation	Distribution of Plants	/		/	/	X		X	X								
	Plant Height	X		X	/	/	X	/	X								
	Crown Characteristics	/		/	/	X	X	/	X								
	Foliage Characteristics						X	/	X								
	Size of Branches						X	/	X								
	Distribution of Branches						X	/	X								
	Stem Size						X	/	X								
	Tensile Strength of Stemand Branches						X	/	X								
Landform	Distribution	/				X		/	X								
	Size	/				X		/	X								
	Elevation	X				/		/	X								
Manmade Features	Roads					X											
	Bridges					X											
	Railroads					X											
	Population Center					X	/		/								
	Airfields					X											
	Shipyards					X											
	Existing Telephone Facilities					X											
	Buildings					X			X								
	Lumber Yards					X			X								
	Steel Mills					X			X								
	Tunnels							/									

FOLDOUT FRAME 1

FOLDOUT FRAME 2

DISEASES / ENVIRONMENTAL FACTORS

Surface Composition

Disease		Bearing Capacity	Surface Traction	Remolding Characteristics	Layer Thickness	Dielectric Properties	Mineral Deposits
Red Tide	Organism	0	0	0	0	0	0
	Reservoir	0	0	0	−	−	−
Encephalitis	Disease Organism	0	0	0	0	0	0
	Vector	+	+	0	−	−	0
	Reservoir	0	0	0	0	−	0
Malaria	Disease Organism	0	0	0	0	0	0
	Vector	0	0	0	0	0	0
	Reservoir	0	0	0	0	0	0
Rocky Mountain Spotted Fever	Disease Organism	0	0	0	0	0	0
	Vector	+	+	+	0	0	0
	Reservoir	+	+	+	0	0	0

Surface Geometry

Disease		Microgeometry	Macrogeometry
Red Tide	Organism	0	0
	Reservoir	0	0
Encephalitis	Disease Organism	0	0
	Vector	0	0
	Reservoir	0	0
Malaria	Disease Organism	0	0
	Vector	0	0
	Reservoir	0	0
Rocky Mountain Spotted Fever	Disease Organism	0	0
	Vector	0	0
	Reservoir	0	0

Hydrologic Geometry

Disease		Current Velocity	Depth of Water	Wave Heights	Ice Conditions	Bank Configuration	Dimensions of Water Body	Profile of Bottom	Strength of Bottom	Temperature of Bottom
Red Tide	Organism	0	0	+	0	0	0	0	0	+
	Reservoir	0	0	0	0	0	0	0	0	+
Encephalitis	Disease Organism	0	0	0	0	0	0	0	0	0
	Vector	+	+	0	+	+	+	+	0	0
	Reservoir	+	+	0	+	+	+	+	0	0
Malaria	Disease Organism	0	0	0	0	0	0	0	0	0
	Vector	+	0	+	0	0	0	0	0	0
	Reservoir	+	0	+	0	0	0	0	0	0
Rocky Mountain Spotted Fever	Disease Organism	0	0	0	0	0	0	0	0	0
	Vector	0	0	0	0	0	0	0	0	0
	Reservoir	0	0	0	0	0	0	0	0	0

Weather

Disease		Temperature - Ambient	Wind Velocity	Precipitation	Fog Level	Light Intensity	Humidity	Cloud Cover	Atmospheric Layering	Electrical Disturbance	Atmospheric Pressure
Red Tide	Organism	+	+	+	0	−	0	−	0	0	0
	Reservoir	+	+	+	0	−	0	−	0	0	0
Encephalitis	Disease Organism	0	0	0	0	0	0	0	0	0	0
	Vector	+	0	+	−	0	+	+	−	−	0
	Reservoir	+	0	+	−	0	+	+	−	0	0
Malaria	Disease Organism	0	0	0	0	0	0	0	0	0	0
	Vector	+	+	+	0	−	0	0	0	0	0
	Reservoir	+	+	+	0	−	0	0	0	0	0
Rocky Mountain Spotted Fever	Disease Organism	0	0	0	0	0	0	0	0	0	0
	Vector	+	0	0	0	0	0	0	0	0	0
	Reservoir	+	0	0	0	0	0	0	0	0	0

Vegetation

Disease		Distribution of Plants	Plant Height	Crown Characteristics	Foliage Characteristics	Size of Branches	Distribution of Branches	Stem Size	Tensile Strength of Stem and Branches
Red Tide	Organism	0	0	0	0	0	0	0	0
	Reservoir	0	0	0	0	0	0	0	0
Encephalitis	Disease Organism	0	0	0	0	0	0	0	0
	Vector	+	+	+	0	0	0	0	0
	Reservoir	+	+	+	+	+	+	+	+
Malaria	Disease Organism	0	0	0	0	0	0	0	0
	Vector	+	+	0	0	0	0	+	0
	Reservoir	+	+	0	0	0	0	+	0
Rocky Mountain Spotted Fever	Disease Organism	0	0	0	0	0	0	0	0
	Vector	+	+	+	+	+	+	+	0
	Reservoir	+	+	+	+	+	+	+	+

Landform

Disease		Distribution	Size	Elevation
Red Tide	Organism	0	0	0
	Reservoir	0	0	0
Encephalitis	Disease Organism	0	0	0
	Vector	+	+	+
	Reservoir	+	+	+
Malaria	Disease Organism	0	0	0
	Vector	0	0	+
	Reservoir	0	0	+
Rocky Mountain Spotted Fever	Disease Organism	0	0	0
	Vector	0	0	0
	Reservoir	0	0	0

Manmade Features

Disease		Roads	Bridges	Railroads	Population Center	Airfields	Shipyards	Existing Telephone Facilities	Buildings	Lumber Yards	Steel Mills	Tunnels
Red Tide	Organism	0	0	0	0	0	0	0	0	0	0	0
	Reservoir	0	0	0	0	0	0	0	0	0	0	0
Encephalitis	Disease Organism	0	0	0	0	0	0	0	0	0	0	0
	Vector	+	−	0	−	0	0	0	−	−	0	0
	Reservoir	+	0	0	−	0	0	0	−	−	−	0
Malaria	Disease Organism	0	0	0	0	0	0	0	0	0	0	0
	Vector	0	0	0	+	0	0	0	0	0	0	0
	Reservoir	0	0	0	+	0	0	0	0	0	0	0
Rocky Mountain Spotted Fever	Disease Organism	0	0	0	0	0	0	0	0	0	0	0
	Vector	+	0	+	0	0	0	0	0	0	0	0
	Reservoir	+	0	+	0	0	0	0	0	0	0	0

ENVIRONMENTAL FACTORS

+	Positive Correlation
−	Undetermined Correlation
0	No Correlation Evident

FOLDOUT FRAME 1

FOLDOUT FRAME 2

THE RED TIDE PHENOMENON AND IT'S POSSIBLE DETECTION THROUGH REMOTE SENSING

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RED TIDE: Application of Remote Sensing to an Environmental and Health Problem

Introduction

Red Tide has been approached as an environmental and health problem which can be remotely sensed with present resources. This phenomenon is not a new one, and it has not proven to be one which is easily solved. Many hours of research have been involved in understanding the various aspects of Red Tide; in studying its toxic effects; the conditions which may initiate an increase in populations of the organism involved; in testing hypotheses of prediction; and in applying possible solutions to the problem. Many questions have been answered, but many more have been uncovered in the process. Red Tide remains a health problem for which there is not yet an effective solution. NASA's remote sensing capabilities could be feasibly applied to the Red Tide problem and could greatly aid in the quest for solutions to this problem.

All attempts thus far to control Red Tide after it has reached toxic levels have proven unfeasible or ineffective. Such attempts include the use of copper sulfate or damming all contributing waterways to an outbreak area. The prediction of Red Tide outbreaks is the most easily attained goal of remote sensing studies. If ability to forecast Red Tides is realized, further work toward its prevention and/or control should be attempted.

Historical Survey of Red Tide

Discoloration of water masses, both fresh water and marine, has occured in various parts of the world throughout history. The discoloration can be caused by "blooms" or high concentrations of bacteria, diatoms, blue-green algae, dinoflagellates, ciliates, or zooplankton organisms such as copepods. However, mass mortality of marine organisms has usually been associated with dinoflagellates in bloom proportions. A red water condition was reported in Exodus 7: 20-21, which could have been a description of Red Tide:

> "And all the waters that were in the river (the Nile) were turned to blood and the fish that was in the river dies; and the river stank and the Egyptians could not drink of the water of the river."

Both the Red Sea and the Gulf of California (once named the Vermilion Sea) could have acquired their names from associated discolorations of their waters by the blue-green alga, *Oscillatoria erythraea*, which is found in their waters (named by Sverdrup, *et al*., 1942, as *Trichodesmium erythraea*). (An interesting map showing the distribution of discolorations in the sea was published by Hayes and Austin (1951), and reprinted by M. Brongersma-Sanders : 1957 in Hedgpeth's *Treatise on Marine Ecology and Paleocology*). In this volume, Brongersma-Sanders reviewed mass mortalities in the sea caused by noxiousness of water blooms. Her survey included a comprehensive bibliography which is summarized below.

Waterblooms and associated coloration of the water can be accompanied by mass mortality of fishes and other organisms. The mortalities may reach catastrophic proportions, as occured in South Africa in 1880 (Glazier, 1882; Ingersoll, 1882; Moore, 1882; and Walker, 1882). Other mass mortalities of marine animals were observed in Florida on the following dates: 1844, 1854, (Ingersoll, 1882); 1878 (Jefferson, 1978); 1885 (Glennan, 1887); 1908 (Taylor, 1919); 1916 (Taylor, 1919), 1946 and 1947 (Gunter, Smith, and Williams, 1947; Gunter, 1947b; Baughman, 1947b; Anonymous, 1948; Gunter, Williams, and Smith, 1948; Gunter 1948; F.G.W. Smith, 1948). The dinoflagellate causing the mass mortality and discoloration of the Florida coastal waters in the 1946-47 Red Tide, was described by Davis (1948) as Gymnodinium brevis. Galstoff (1948, 1949) published several papers concerning the Red Tide. The 1946-47 outbreak initiated research on the causes of the red water, which are still underway. During the 1916 and 1947 Red Tides, accompanying irritations of respiratory membranes and coughing were reported in the areas of Red Tide blooms (Taylor, 1919; and Woodcock, 1948). Mass mortalities of marine organisms were also reported in 1952, (Slobodkin, 1953; Chew, 1953), and since 1844, discoloration of seawater along the Florida west coast, and marine mortalities have been reported 24 times, the most recent in 1971. The areas affected and the severity varied, but the locations of potential outbreak extend from Appalachee Bay to Dry Tortugas in the Florida Keys (Steidinger, Burklew, and Ingle, In Press). Other localities affected by Red Tide outbreaks, but not necessarily caused by the same species as the Florida Red Tide, are the Malabar coast of India, the coast of Northern Chile and Peru, near Walvis Bay in southwest Africa, Japan, southern California, the Texas coast and the coast of northern Mexico. A ciliate Red Tide was even reported from Barrow, Alaska, without mortality, however, (O. Holm-Hanse, et al., 1970).

The noxious effect of red water has been discussed extensively. Several authors (Nishikawa, 1901; Lindemann, 1924; Marchland, 1928; Chidambaram and Unny, 1944) attributed mortalities to polluted waters caused by dead and decaying plankton. If this were always the case, then blooms would be only indirectly toxic to other organisms. In some phytoplankton blooms, the oxygen is depleted and H_2S is evolved by anaerobic bacteria; however, the direct cause of mortalities during blooms is more likely to be a strong poison (or toxin) produces by living dinoflagellates or blue-green algae. Brongersma-Sanders (1966) reported that blooms can be noxious to fish and invertebrates, and also to air-breathing animals for which lack of oxygen in the water is of no importance. Cattle and chickens may be killed by drinking such waters (Fitch et al., 1934; Steyn, 1945a; 1945b; Prescott, 1948; Stephens, 1948, 1949). A very strong poison was isolated from blooms of blue-green algae (Fitch et al., 1934; Shelubsky, 1951), and dinoflagellate's (Sommer et al., 1937; Sommer et al., 1948; Sommer et al., 1948; Riegel et al., 1949). The dino-flagellate toxins were also isolated from invetebrates which ate the plankton. Mussels and other shellfish can concentrate great quantities of the poison before death; and some if eaten by man, can cause paralytic shellfish poisoning (Sommer et al., 1937; Koch, 1938, 1939). The dino-flagellate usually associated with paralytic shellfish poisoning is *Gonyaulax spp.* which occurs as Red Tide in California and other temperate regions. This subject is discussed from a historical viewpoint by Brongersma-Sanders (1956), and from a pathological point of view by Ray (1971). Shellfish toxicity following blooms of *Gymnodinium breve* were studied by Morton and Burklew (1969). Although toxicity levels were high enough to warrent the closing of shellfish areas by the Florida State Board of Health, no human deaths have been recorded due to *G. breve* toxin in shellfish. The toxin of *G. breve* has been studies by several workers, (Trieff et al., 1971; Sasner et al., 1971). The toxin complex has been extracted and the physiological effects have been studied, but the complex contains several fractions and not all have been isolated and characterized at this time. Work in this area has momentarily slowed down due to a lack of funding, however, the St. Petersburg Marine Laboratory of the Florida Department of Natural Resources plans to initiate a research program in this area in the near future. Florida Red Tide, caused by Gymnodinium breve, kills fish and certain marine invertebrates; is concentrated by certain shellfish and can cause shellfish poisoning (although not of the severity as the California Red Tide organism Gonyaulax spp) and can cause respiratory irritation in man, and is thus a definite health and environmental problem.

ECOLOGY OF RED TIDE

Historical reports and recent work support many of the proposed ecological factors which seem to precede or contribute to Red Tide outbreaks in many localities. These will be discussed along with the prevailing questions which still plague researchers concerning this problem. Temperature, salinity, rainfall, wind, light, upwelling and water currents, nutrients, associated diatom or blue-green algal blooms and the effect of dead fish on the continuance of a bloom all seem to play a part in the drama, with each playing a role of undertermined importance and varying significance in Red Tide outbreaks.

TEMPERATURE. Red Tide outbreaks are usually associated with hot weather This is also indicative of other conditions such as a lack of wind. Rounsefell and Nelson (1966) discussed the general conditions during Red Tide outbreaks, and much of the following summary is from their paper.

Barker (1935) found the optimal range for 14 species of marine dinoflagellates to be between 18 and 35°C. In experiments with Gymnodinium breve, Finucane (1960) found optimum growth between 26 and 28°C., with dense populations also observed at 15 to 18°C. Aldrich (1959) found no survival below 7°C or above 32°C. in experiments with 800 individual cultures exposed to controlled temperatures. He also found that population growth was halted or slowed below 15 and above 30°C.

Isopleth analysis of abundance of _G. breve_ against temperature and salinity (averages from samples of 20 or more) from 7 years of field data, and with the aid of a computer, revealed that the organisms thrive from 16 to 26°C. (Rounsefell and Nelson, 1966).

Cold waves frequently disperse the red water blooms (Finucane, 1958; Taylor, 1917a,b). Gunter (1958) reported that in 1946 a cold wave temporarily broke up the Red Tide.

S^LINITY. Both armored and unarmored dinoflagellate species generally have a wide range of salinity tolerance. "_Gymnodinium breve_ is apparently not estaurine, but neritic. In controlled experiments, Aldrich and Wilson (1960) found that best growth at salinities beween 27 and 37 ppt." (ref.). Populations in nature have been found in a range of salinities from 31 to 37 ppt. Computer analysis of 1954-61 field data revealed no great abundance of the organism below 30.5 ppt. The upper limit varied with temperature, being 37 ppt. as long as the temperature did not exceed about 23C. (Rounsefell and Nelson, 1966).

R^INF^LL. Heavy rainfall has been reported to precede Red Tide occurrences on the Malabar coast of India (Hornell, 1917). Slobodkin (1953) attributed red water to fertilization of coastal waters by river water. In the Florida Red Tide, a good correlation exists between heavy rainfall and Red Tide outbreaks. Although there were two cases where the rainfall was low in years of Red Tide occurrences, it seems that the chance a Red Tide will occur is greater in years with heavy spring and summer rains. The outbreaks usually occur in the very late summer or fall.

Several factors have been found to correspond with heavy rainfall. The salinity of a discharge area (one where an estuary fed by river water empties into a water mass of marine origin, such as the many Florida estuaries along the Gulf of Mexico) depends primarily on two factors;

(a) the volume of river discharge (related to amount of rainfall), and (b) the salinity of the Gulf waters. Ingle and Martin (1971) stated that the actual volume of river discharge may be less important than the contents of the discharge, i.e., the iron concentration and the availability of the iron and other trace metals to phytoplankton organisms. The Peace River which contributes to the Charlotte Harbor estuary, close to Fort Meyers, Florida, was found to contain high concentrations of iron and chelating agents such as tannic acids and humic acids during heavy rainfalls and river discharges. The association between the occurrence of these components in river water and Red Tide outbreaks was called the "Bog hypothesis" (Ingle, 1965). Bogs or inland low areas with standing water accumulate iron and humic acids from decay of vegetable matter. These areas are separated from streams during dry periods, but heavy rainfall and floods leach the contents which overflow into streams and rivers and make their way to the Gulf. Much of the iron is in the form of humic acid complexes (Martin et al., 1971). In cultures of dinoflagellates it has been found that growth was stimulated by the addition of chelated iron (Prakash and Rashid, 1968; Collier et al., 1969). Such observations prompted Ingle and Martin (1971) to propose a means of predicting the Florida Red Tide outbreaks known as the iron index. "This index is defined as the total amount of iron potentially delivered to an outbreak during a three-month period. The critical iron index must be determined for a potential outbreak areas". As a test of this, the index for the Charlotte Harbor area was determined. From the records for the years 1944-1969, the index of 235,000 pounds of iron delivered by the Peace River seems to be a good estimate. However, the effects of other factors on this prediction, i.e. hurricanes or cold waves, prompted an alteration in the index prediction to read: "A Red Tide outbreak may be expected near Charlotte Harbor, Florida, following a critical iron index of 235,000 pounds (as measured at Arcadia, Florida), assuming optimum temperatures of 16-27°C., and an absence of a hurricane or very high winds within 150 miles of the Harbor." This index of prediction may be the answer, or it may prove to be a giant step toward an ability to predict Red Tide outbreaks.

WIND. In most accounts of Red Water conditions and blooms, the lack of wind is mentioned as an environmental factor contributing to the condition. Heavy winds, such as hurricanes, with heavy rains over a period of time, followed by calm seas and clear weather with warm water, are usual combinations of factors which both fisherman and scientists alike agree are conducive to Red Tide outbreaks. Three environmental factors have been found to correlate with the monthly variability of G. breve abundance; salinity, temperature, and onshore winds greater than 7 kts. (Rounsefell and Dragovich, 1966). Wind effects along with certain current patterns have been cited as concentrating factors during a Red Tide (Chew, 1955a). Red Tide patches and windrows, being concentrated, become more dramatic in their effect upon fish entering them. Walker (1884) observed in the fish mortality in the Gulf of Mexico in 1883 "Certain types of fish were killed first, but all seemed to follow the same pattern of dying - suddenly in a matter of minutes after contacting the 'poison water' they would convulse and die." These conditions are similar to those during heavy Red Tide outbreaks along the coast of Florida.

LIGHT. Most phytoplankton organisms, including dinoflagellates, are autotrophic. Therefore, in consideration of environmental conditions for optimum growth, light intensity must be included. Light is, however, not considered a limiting factor to the growth of Gymnodinium breve (Wilson, 1955). Aldrich (1960) reported that there is a minimum light level of 200 ft. c (foot candles) required and that G. breve is autotrophic, requiring light for survival (Aldrich, 1962).

Rounsefell and Nelson (1966) summarized the evidence of light intensity as a factor in blooms of Red Tide organisms, and the following account is from their work. Brongersma-Sanders (1957) stated that sunshine seems to be another requirement for Red Tide. Clemmens (1935) noted that the bloom of Mesodonium in British Columbia was preceded by several weeks of "bright, sunny, calm weather". Conover (1954) listed "high radiation values" as an essential factor in blooms of Gonyaulax. Hornell (1917) stated that Red Tide along the Malabar coast of India required "a continuance of fine weather for a week or ten days, with plenty of sunshine".

UPWELLING AND CURRENTS. Upwelling occurs along many coasts, and some areas of upwellings have associated plankton blooms as a result. However, if Red Tide occurs in such areas, it is usually after the period of upwelling and not during the period. Brongersma-Sanders (1957), said that, "...in areas where upwelling occurs during part of the year only, red water usually developes toward the end or directly after the period of upwelling".

In Florida coastal waters limited upwellings occur in the areas of Red Tide outbreaks. Graham et al. (1954) found that limited upwelling of deep water at certain times had no effect upon the phosphorus content of the water in the euphotic zone.

Convergences may play a role in Red Tide blooms. This type of current is related to wind direction and force and could play a part in concentrating the Red Tide organisms into toxic levels. The occurrence of blooms in streaks with abrupt margins suggest that the organisms are concentrated by some mechanism. Three mechanisms were suggested by Rounsefell and Nelson (1966):

1. Convergences paralleling the shore, set up by gentle onshore winds.
2. Convection cells parallel to steady winds, causing parallel streaks.
3. Convergences at the mouth of passes, where the residual outflow of less saline water near the surface meets the more saline Gulf water.

More evidence that convergences are involved, at least in part, is the fact that outbreaks occur most frequently and consistently adjacent to the mouths of passes where convergences would occur regularly.

NUTRIENTS. The nutrients most often referred to as limiting factors to phytoplankton are phosphates and nitrates. Trace metals and vitamins like vitamin B_{12} can also be limiting and are considered micronutrients. The culturing of an organism demonstrates the growth requirements for that organism in a laboratory environment which may or may not reflect the natural environment. Hints of elements to look for in the natural environment are often productive. The need for iron chelators was revealed by laboratory culturing experiments (Wilson, 1958). In trace metal analysis of Red Tide areas Collier (1953a) found levels of titanium and zirconium present in the Red Tide water not present in the surrounding waters or in other locations. Trace metal analysis becomes very difficult when the minute concentrations required of many trace metals by phytoplankton organisms are realized. It is impossible to determine whether an organism requires a trace metal for growth in a culturing experiment without having a sensitive instrument or analysis method to determine if that metal is actually present in natural waters. Atomic absorption spectrophotometers are reaching greater sensitivities than could have been acquired before in trace metal analysis, but these are very expensive instruments. At any rate, there are nutrients and micronutrients necessary for the growth of phytoplankton populations. These nutrients usually serve as, and thus can maintain population growth at a level which is not harmful. During Red Tide outbreaks, however, it would seem that conditions are ideal for the growth and maintenance of a large population, with the aforementioned limiting factors no longer operating. Perhaps if a limiting factor could be found which could be efficiently controlled, it would be possible to control the population before bloom (and toxic) concentrations are reached.

After interest and research in Red Tide was initiated in 1947, several theories were proposed concerning nutrient levels and Red Tide outbreaks. Ketchum and Keen (1948) found unusual phosphorus concentrations in the Florida Red Tide waters. The total phosphorus content of waters containing dense _Gymnodinium_ populations was found to be $2\frac{1}{2}$ - 10 times the maximum amount to be expected in the sea. Bein (1957) after examining data on total phosphorus concluded that concerning _Gymnodinium breve_, "It is possible that a threshold level of total phosphorus necessary to support dense populations of this organism is lower than originally assumed... It seems very probable that, insofar as phosphorus is concerned, the areas of the west coast of Florida which have recorded Red Tides are, at all times capable of supporting an outbreak..." Numann (1957) stated, "It also appears that a mass outbreak of phytoplankton occurs when freshwater growth-promoting substances (trace elements, enzymes, or other biologically active substances) reach the sea. Due to the presence of a necessary quantity of nutrients in the sea, a precondition of the outbreak of plankton in the sea exists already. Accordingly, these outbreaks occur only near the coast". Rounsefell and Nelson (1966) reported that _G. breve_ does not require much nitrogen either. Lackey and Haynes(1955) stated that Howard Odum failed to find any nitrate nitrogen in a series of about 15 field samples from Red Tide water, taken Oct. 6, 1953. Dragovich (1960b) stated, "No relationship was observed between the incidence of _G. breve_ and nitrate-nitrites." In this discussion also, it must be remembered that the rivers of Florida drain areas high in phosphatic formations, and contain high concentrations of phosphorus (Odum, 1953; Graham _et al._, 1954; Dragovich and May, 1962). Also the problem of eutrophication in the estuaries of the Florida coast is another environmental problem in the area, and the contribution of nitrates must be tremendous to the Gulf waters. We must conclude that these nutrients at least, are never limiting to phytoplankton populations in the Gulf of Mexico.

PRECEDING DIATOM BLOOMS. In many areas of the world, diatoms or blue-green algal blooms seem to appear before the Red Tide organisms, and seem to deplete the waters of nutrients. Ryther (1955) suggests, "...that the dinoflagellates can compete successfully with diatoms under conditions of high temperature, low salinity, and reduced nutrient concentrations. They appear to require the presence of some one or more unknown organic substance and there is some indication that they benefit from the previous existence of a large population of diatoms." Gran (1926, 1927) has proposed that dinoflagellates require less nutrients for growth than the diatoms because of their relatively low rate of metabolism Ryther (1955) suggested also that the flowering of dinoflagellates may be dependent upon the previous bloom of the diatoms. This is a type of succession, and the mechanism is not understood, but probably involves nutrition. Whether the diatoms reduce nutrients or trace metals to concentrations favorable for the growth of dinoflagellates (Pearsall, 1932; Hutchinson, 1944), or the production of external metabolites or "ectocrines" by one group of plankton organisms favors the succession of one population while inhibiting the growth of other competing population (Lucas, 1947; 1949), is open for speculation. The latter suggestion has been demonstrated by Rice (1954) in freshwater. This question is an interesting one which warrents investigation. Karen Stiedinger (pers. comm.), has had extensive experience with Red Tide and _Gymnodinium breve_ in Florida waters, and reports an observation which could be remotely sensed and could prove extremely important in the control of Red Tide. She has encountered blooms of the blue-green algae _Ocillatoria erythraea_ preceeding _Gymnodinium_ breve blooms. It is suggested that perhaps one of the above-discussed relationships exists between this alga and G. breve. Upon discovering the character of a relationship, G. breve populations may be controlled, or at least better understood. In a conversation with Dr. Freida B. Taub, University of Washington, concerning a possible relationship between Oscillatoria erythraea and G. breve, she suggested that perhaps a more complicated preditor-prey relationship exists in the situation. Blue-green algae are known to be toxic to some of the natural phytoplankton consumers. If the population of blue-green algae should measurably reduce the predator (consumer) population, which may also normally feed on G. breve, then this would allow the the population to increase unchecked. This is also a possibility which warrents investigation. There are other possibilities; (1) There may be a natural G. breve consumer which may be depleted by blooms of blue-green algae, thus allowing growth of the population (in the presence of other favorable environmental factors) which may reach Red Tide concentrations. (2) The blue-green alga Oscillatoria erythraea may produce a metabolite favorable for the growth of Gymnodinium breve populations, but inhibit other competitive phytoplankton organisms. (3) The presence of the algal population may deplete nutrients or trace metals to a level favorable for the growth of G. breve. (4) There may be a whole set of factors, all having ranges and optima for the growth of G. breve, which in certain combinations may provide the environment favorable for the growth and maintenance of a concentration of G. breve to toxic levels. There are still other factors (discussed below) that may also play a role in this already complex situation.

Another association between a dinoflagellate and preceding phytoplankton bloom concerns the probability that the diatoms (or other organisms) accumulate nutrients into protoplasm, depleting the water, but providing a concentrated form of nutrients if the population should die due to their own metabolites, or other causes. This theory was suggested by Graham _et al._ (1954).

EFFECT OF DEAD FISH IN CONTINUING A RED TIDE BLOOM. There has been discussion on whether the fish killed by Red Tides perpetuate or spread the bloom. Fish kills may release large amounts of nutrients back to the environment. Rounsefell and Nelson (1966) reported that Collier (1955) squeezed juices from freshly killed fish into a culture he described as about three million organisms per quart; overnight they tripled in number. Wilson (1955) observed that if fish autolysate is added to the original culture media, bacterial growth is stimulated and the culture dies. These observations are interesting, since the fish must be decayed by bacteria before their stored nutrients can be released into the water. Also wind has been reported to have driven the dead fish miles from the water in which they were killed (Finucane, 1958; Anderson, 1958). Large amounts of bacteria have been shown to reduce the toxicity of _G. breve_ cultures (Ray and Wilson, 1957). In experiments with _Prymnesium parvum_, Shilo and Aschner (1953) found that bacteria acted as a detoxicating agent.

FORMS OF GYMNODINIUM BREVE. Wilson (1967) studied and described the forms of the dinoflagellate _Gymnodinium breve_ in cultures. He found that the life cycle of _G. breve_ consists of cell growth and cell division with formation of cysts as the only intervening form. Encystment is the formation of a resting stage which can remain on the bottom or in sediments until conditions are right for its normal life cycle. Wilson also observed encysted forms in states in which cell division would be possible. In this discussion the following should be stressed: *Gymnodinium breve* does not reproduce at a more rapid rate during Red Tide outbreaks. It is a universal misconception that all of a sudden the cells multiply rapidly, raising the numbers of organisms into the millions per milliliter. Wilson reports the division rate to be 0.4 divisions per day with a maximum observed division rate of 0.7 per day. Steidinger (pers. comm.) stressed this also. She found the same situation to be true in samples taken during Red Tide outbreaks. Then the outstanding question remains as to what causes the outbreak, since the cell numbers are found in millions per liter. Two explanations are possible. One is that the encysted forms may become active and contribute to the plankton population from their former benthic existence, resulting in cell concentrations which could yield toxic conditions. The second possibility is the doubling of the population through regular cell division. A less concentrated population of *G. breve* may not color the water, or may cause a greenish discoloration which is not very obvious, while just double that concentration may cause the amber or red discoloration of the water associated with Red Tide. Winds and currents can further concentrate the *G. breve* population. For a Red Tide to develop and persist, however, all environmental conditions must remain favorable for population growth and maintenance. The key to control is somewhere before the population reaches toxic concentrations.

BIOLUMINESCENCE. Another interesting aspect of phytoplankton populations in high concentration is their bioluminescent qualities. *G. breve* has displayed this character. Ryther (1955) found that bioluminescence was displayed by phytoplankton at the greatest intensity at midnight and at the least intensity at noon producing a diel cycle. Their luminescence can be remotely sensed - and the best time to detect this quality would be at midnight. If luminous intensities measured by remote sensing (satellite or aircraft) could be correlated with concentration of *Gymnodinium breve* cells, this would be an extremely effective method of detection.

REMOTE SENSING OF RED TIDE

Red Tide as an environmental and health problem has been documented in terms of historical and scientific literature. The purpose now becomes one of determining which factors are feasible and most important to monitor. A matrix is included which presents the environmental problem, resolution desired, most feasible sensors, the range and resolution of these sensors, and a recommended sensor for each environmental parameter.

The application of remote sensing to the study of Red Tide is an exciting proposition. Remote sensing of the environment has proven extremely valuable and successful. Applications of remote sensing capabilities to fishery and oceanography problems have proven the vast amount of information attainable and resolution possible in such work. It seems possible and feasible to apply remote sensing to every aspect of the Red Tide problem.

The task before remote sensing studies is the detection of environmental parameters leading to the conditions favorable for a Red Tide. A list of the important parameters with probable remote sensing applications seem appropriate.

Oceanographic and normal weather parameters to be monitered:

1. Ocean state
2. Wind velocity and direction
3. Temperature (air and water)
4. Salinity
5. Light intensity
6. Rainfall in areas drained by local rivers

Other environmental parameters associated with Red Tide:

1. With heavy rainfall, tanic acids and humic acids discolor river water and make their way to the Gulf. Sensing of this color change and the progress of river water containing these iron chelating substances toward the Gulf is important. Also an

attempt should be made to correlate river color with ground truth - iron content of the water in the rivers.

2. When heavy rainfall increases the freshwater flow into an estuary, the estuary can in turn spill over with less saline water. The result is a visible plume of water entering the Gulf. This water is often of a different color and it would contain suspended particulate matter which could be remotely sensed.

3. When two water masses of different compositions meet, a type of current or convergence is produced; the wind factor is also involved. Red Tide outbreaks usually occur along these convergences in windrows or patches, so their presence should be monitored.

4. It is possible to detect chlorophyll concentration with remote sensing (Clark and Ewing, 1970). Increases in phytoplankton with time or changes in concentration in space are important in the Red Tide problem. Also, the detection of a different organism in bloom proportions, *Oscillatoria erythraea*, preceeding blooms of *Gymnodinium breve* is extremely important in Red Tide studies.

5. Another interesting aspect of phytoplankton populations in high concentration is their bioluminescent qualities. *G. breve* has displayed this character. Ryther (1955) found that the bioluminescence was displayed by phytoplankton at the greatest intensity at midnight, and the least intensity at noon producing a diel cycle. The luminescence can be remotely sensed - and the best time to detect this quality would be at midnight. If luminous intensities

measured by remote sensing (satellite or aircraft) could be correlated with concentration of _Gymnodinium_ _breve_ cells, this would be an extremely effective method.

6. The precise concentration of _G._ _breve_ detectable by remote sensing would be of immense value in determining the extent of a bloom and whether or not toxic concentrations have been reached. Detecting _G._ _breve_ blooms before harmful concentrations have developed could be the vital step toward control of Red Tide. Control of Red Tide must be possible before toxic conditions are present, since destruction of the toxic population merely releases the toxins at an accelerated rate rather than preventing the damage caused by Red Tide.

7. Ray (1971) reports that since PSP (paralytic shellfish poisoning) (and also the less-toxic-to-humans shellfish poisoning caused by _G._ _breve_) is directly related to the occurrence of toxic dinoflagellates (Sommer _et al._, 1937; Needler, 1949; Prakash, 1963; Wood, 1968), the systematic search for dinoflagellate blooms as indicated by discolored water (Red Tides or red water) and plankton sampling for toxic dinoflagellates may be used to determine where and when poisonous shellfish are likely to occur. This is precisely what remote sensing can accomplish, while attempting at the same time to develop Red Tide predictive ability.

All aspects of the Red Tide problem can be remotely sensed with present resources, either from satellites or aircraft. The application of remote sensing to Red Tide studies is a new proposition;

however, with ground-truth research and remote sensing surveillance of the problem it seems hopeful that the many questions still unanswered concerning this problem will be answered in the near future. A summary of the applications and imagery sensing devices seems appropriate. From these, the most efficient combination of devices coupled with the most effective altitude, distance to be surveyed, and times to increase the frequency of surveillance, a tentative proposal to apply remote sensing and ground-truth to study Red Tide can be offered.

DATA REQUIREMENTS OF PARAMETERS TO BE MONITERED

PARAMETER TO BE MONITERED	RESOLUTION	RANGE	SPACIAL RESOLUTION	COVERAGE FREQUENCY	REMOTE SENSING FEASIBILITY
Surface Roughness	.3m	0-40m	1NM	Daily	2
Wind velocity	± 2 KTS	0-50KTS	5NM	Daily	2
Air Temperature	± .5°C	10°-45°C	1NM	Daily	3
Water Temperature	± .5°C	10°-45°C	1NM	Daily	3
Salinity	5gm/kg H_2O	10-40gms	1NM	Daily	2,1
Light Intensity	5 FC	100-1000FC	1NM	Daily	2
Chlorophyll Content	$1Mg/M^3$	0-10mg	1NM	Bi-Daily	2,1
Bioluminescence	Foot Candles	≅480μ	2NM	Nightly	1
Color Spectra	.01 μ	13-2.0μ	3NM	N/A	3
Mineral Content	Color	spectral	3NM	Daily	1,0
Turbidity	"	"	3NM	Daily	3
River Effluent	Color, Infrared	"	3NM	Daily	3
Surface Currents	Color, Infrared	"	3NM	Daily	3
Water Color	Color	spectral	3NM	Daily	3,1
Barometric Pressure	± Millibar	Normal Atmospheric	3NM	Bi-Daily	0
Rainfall (coastal)	± .5 inches	.5 inches	5NM	As Req.	0

FEASIBILITY NOTES:

3 - Excellent

2 - Good

1 - Needs more research

0 - Ground truth methods

FEASIBILITY OF SENSOR APPLICATIONS

ANTICIPATED SENSOR APPLIED TO RED TIDE PARAMETER (GIVEN REQUIRED RESOLUTION)	Metric mapping camera	Panoramic camera	Multiband Synopic camera	Radar imager	Radar scatterometer	Infrared imager	IR Radiometer/spect	Microwave imager	Microwave radiometer	Laser Instrumentation	Absorption Spectrcscopy	Radar Alt.	Ground truth
Surface roughness	3	3	3		2				2	2	2		
Wind V				2	3			3					3
Temp. (sea surface)	1	1	1			3	3	3	3			3	
Salinity	2	2								2	2		3
Light intensity	2	2	2				3						
Water color	3	3	3								2		
Currents	3	3	3		3	3	2	2					
Biological phenomenon (general)	3	3	3			3	2			1	2		
Upwelling	3					2	1						
Mineral Content	1												3
Nutrient Content	2												
Bioluminescence						1					1		
Turbidity	3	3	3										
River flow	3	3	3			2							
River plumes, Effluents	3	3	3			2							
Barometric pressure													3
Rainfall (coastal)													3

FEASIBILITY:

3 - Excellent - Good by current state of art.
2 - Good - Future development will increase feasibility
1 - May be feasible/needs more study
Blank - Insufficient data precludes conclusion/not considered

Main Sources Used For Feasibility Verification

PARAMETER	BIBLIOGRAPHICAL REFERENCES USED FOR FEASIBILITY VERIFICATION														
	1	3	7	14	18	19	21	22	23	25	27	28	31	32[a]	32[b]
Surface Roughness			X					X	X				X		X
Wind Velocity								X	X						
Air Temperature		X					X	X	X						
Water Temperature	X	X					X	X	X	X	X		X		X
Salinity		X			X										
Light Intensity					X	X								X	X
Chlorophyll Content	X				X				X		X	X		X	X
Bioluminescence								X						X	
Color Spectra		X			X	X			X						
Mineral Content						X									
Turbidity		X			X						X				X
River Effluent	X	X		X	X			X			X				
Surface Currents	X	X		X	X				X		X	X	X		
Water Color	X				X	X			X		X	X			

32[a] Clark: "Spectra of Backscattered Light...as a measure of chlorophyll concentration."; "Measurements of diurnal changes in bioluminescence from the sea to 2000 meters using a new photographic device."

32[b] Johnson: Remote Sensing in Ecology

Whenever resolution is not sacrificed, the least complicated equipment should be used, and whenever the same equipment can gather several sets of data on different parameters, this instrument is desirable. It would seem from the review of the available resources and capabilities, that an aircraft equiped with microwave radiometers (a type of side looking radar), several cameras with the appropriate film, lens and filter combinations for the data in question, could feasibly and efficiently monitor the environmental, oceanographic and weather parameters for Red Tide studies.

The area which should be monitored extends from Apalachicola, Florida to the Florida Keys, with special reference between Tampa and Ft. Meyers, Florida. Ground truth should monitor iron content and iron chelator concentration in the rivers which feed Tampa Bay and Charlotte Harbor and in the north, Apalachicola Bay. Some correlation between river color from remote sensing and the presence and concentration of tannic acids and humic acids should be attempted. Salinity and freshwater flow should be monitored in the estuaries and in adjacent Gulf waters. The times and locations of convergences along with appropriate wind direction and velocity should be noted. Species composition and numbers of phytoplankton populations should be monitored at precise times of aircraft surveillance. Since light attenuation can be attributed to the phytoplankton organisms during times of high standing crops, the backscattered light in the form of spectrum analysis, can reveal the materials (phytoplankton) suspended in the water. Chlorophyll has a recognizable spectral signature. Clark and Ewing (1970) have demonstrated the feasibility and utility of this remote sensing technique to detect chlorophyll over the range of concentrations characteristic of the open ocean. Spectra have been obtained from water masses with concentrations up to 3 mg chlor/m^3 and higher values could easily be recorded. In their study over an area of a mile between the Georges Banks and the Sargasso Sea, the chlorophyll concentration changed from 0.3 to 0.1 mg/m^3 and the temperature from 18°C. to 23°C. The transition was clearly visible at altitudes ranging from 500 ft. to 10,000 ft. A consideration of transparency, bioluminescence and plankton is presented by Clarke (1965). It then seems possible to attempt correlation of these remote sensing measurements with actual phytoplankton concentrations determined from ground-truth data. When resolution is determined then attempts can be made to correlate differences in the population (*Oscillatoria* to *Gymnodinium*), or changes in the *G. breve* concentration from non-toxic to toxic levels. These applications of remote sensing are possible and important.

Time is an important factor in this type of research. General times can be dictated to begin remote sensing and ground truth, but environmental factors will indicate more precise times. So at present it suffices to say that routine surveillance could transmit information on weather and oceanographic data along with some ocean color information throughout the winter months. As rainfall and hurricane information suggests, more intensive surveillance should begin in the spring and summer. Since Red Tide outbreaks occur more often in the very late summer or early fall and continue into October or November, depending upon cold waves and other conditions, these times suggest the most intense surveillance and ground truth. Even in years when Red Tides do not occur, valuable information can be obtained. A study of this magnitude should be carried out for a period of several years (10 years for an estimate), and developed until precise information can be determined from remote sensing alone on the prediction of Red Tide. Even if ultimate control is not possible, the prediction of Red Tide outbreaks by these methods will be of extreme value.

DISCUSSION

We hope to promote this Red Tide Project into existence by supporting the most probable agency to do this research. The Florida Department of Natural Resources has been recommended as the most capable agency to do the ground-truth research and direct remote sensing studies of the Red Tide problem. The head of the Bureau of Marine Science and Technology, Rober M. Ingle, has already expressed written interest in this project in his March 31st, 1972 letter to NASA. The qualifications of this agency and the interest expressed recommend it most highly for this project. Beyond suggesting an agency, the feasibility of the project, and the sensors available and applicable, this final report to NASA can only express the hope that, in the very near future, the agency be funded by NASA, and the project commence.

BIBLIOGRAPHY

Aldrich, David. V. 1959. Physiological studies of red tide. In Galveston Biological Laboratory Fishery Research for the year ending June 30, 1959, p. 69-71. U.S. Fish. Wildl. Serv., Circ. 62. (Cited from Rounsefell and Nelson, 1966).

"A study of the effect of pH on growth of G. breve in bacteria-free cultures shows that growth is unhampered by pH's of 7.5 to 8.3, inclusively. Growth took place at a reduced rate at a pH of 7.3, and lower values were definitely toxic. Medium having pH of 7.2 was 100% lethal to this organism within six days, while 7.0 killed all cells within two days. (p. 69).

Over 800 individual cultures of G. breve have been exposed to specially controlled temperature conditions....the organism did not survive temperatures of 7° C. and below, or 32° and above. Population growth did not occur at 30° (or above) and survival was very poor. Multiplication was visibly slowed at 15° C., but the work which will determine this level more exactly is not yet complete. Optimal growth can occur in a range of temperatures including 20° to 27° C.... (p. 69).

These results strongly suggest that temperature can be an important factor in limiting the geographic distribution of G. breve. In this regard it may also be noted that Florida red tide occurring in the fall have ceased with the advent of the first cold weather of the subsequent winter. (p. 70)."

red tide/pH/G. breve/range of temperatures/Florida

Aldrich, David V. 1962. Photoautotrophy in Gymnodinium breve Davis. Science 137(3534): 988-990. (Cited from Rounsefell and Nelson, 1966).

Extensive experiments failed to show evidence of heterotrophy. G. breve requires light and CO_2 for growth and survival.

"If Florida west coast rivers do not provide direct energy sources for multiplication of G. breve, the organism's vitamin, trace-metal, and chelator requirements assume added ecological significance as factors potentially limiting population growth ...." (p. 990).

photoautotrophy/Gymnodinium breve/light/CO_2/vitamin/trace-metal/chelator/factors potentially limiting

Aldrich, David V., and William B. Wilson. 1960. The effect of salinity on growth of Gymnodinium breve Davis. Biol. Bull. 119(1): 57-64. (Cited from Rounsefell and Nelson, 1966).

Bacteria-free cultures were grown in test tubes in an artificial medium. Tubes inoculated with 100 to 200 G. breve cells. Growth estimated by visual examination with microscope. Classified growth into 11 categories. Three top categories were arbitrarily defined as "peak populations". Rough calibration by actual count showed peak population estimates to contain not less than 750 cells per ml. and usually from 1 to several thousand per ml. Tubes examined at 4, 10, 18, 25, and 35 days. Seldom any growth after 35 days. Five experiments each with 9 salinities, and 10 tubes at each level, were conducted. The first experiment salinities ranged from 6.3 to 41.1 ppt , in the last four experiments, from 22.5 to 46.0 ppt. Their suggested optimum salinity range for good growth of 27 to 37 ppt agrees well with the computer analysis mentioned in the summary.

salinity/Gymnodinium breve/bacteria-free cultures/optimum salinity range/ 27 to 37 ppt

Anderson, William W. 1951. Gulf Fishery Investigation. In Annual report for fiscal year 1951, Branch of Fishery Biology, Fish Wildl. Serv., p. 31-33. (Cited from Rounsefell and Nelson, 1966).

"Plankton collections have been made by conventional methods and by means of a high speed sampler and a newly devised continuous sampler. The latter methods are still in the experimental stage but results are promising...
In comparison to areas like the California coast or the North Atlantic, plantkon in the Gulf is sparse. Tows in those areas produce 8-10 times more plankton than comparable tows in the Gulf. It has become evident, too, that a greater abundance of plankton exists over the continental shelf than exists in waters beyond the shelf. A preponderance of fish eggs and larvae also has been found within the 100-fathom contour.

"Analysis for inorganic phosphate and nitrate have been completed on a total of 371 samples obtained on the first three cruises. It has become evident from these analyses that phosphate and nitrate concentrations are extremely low at all levels inside the 100-fathom contour. In that portion of the Gulf outside the 100-fathom contour, extremely low concentration of phosphate and nitrate exist in surface waters, but rise steadily to a maximum between about 450 to 600 fathoms, below which their concentrations decrease slightly. (p. 31)....

"Results to date lend weight to the theory that, in general waters of the Gulf of Mexico beyond the 100-fathom curve are relatively sterile. It may also be stated tentatively that the economy of our fisheries is closly associated with that portion of the Gulf lying inside the 100-fathom contour, the inshore waters, and contiguous land areas....

"Sampling over a prearranged series of stations extended from the rivers to the 100-fathom contour for a study of the local oceanography, nutrients, and plankton, has been completed... Data collected are being analyzed. Phosphate concentrations in this area are in agreement with those found elsewhere in the Gulf inside the 100-fathom contour.

"All plantkon collected during the past year has been studied and data have been set up on punch cards for analytical studies. (p. 32)....

"Culture studies on nutritional requirements of dinoflagellates and other marine organisms have been continued at the Service's Beaufort, North Carolina, Laboratory. (p. 33)."

plankton collections/high speed sampler/continuous sampler/inorganic phosphate nitrate/culture studies/dinoflagellates

Anderson, William W. 1952. Gulf Fishery Investigations. In Annual Report for the Fiscal Year 1952, Branch of Fishery Biology, Fish Wildl. Serv., p. 16-18. (Cited from Rounsefell and Nelson, 1966).

"Effort expended in a new laboratory being set up for artificial culture of marine microorganisms will be directed toward understanding nutritional and environmental requirements for survival and multiplication of various organisms, particularly dinoflagellates. Results will be used in producing mass cultures to determine the role of various organisms in production and utilization of various organic compounds which are being isolated from sea water. These results in turn, will be applied to studies on young fish survival....

"Red Tide research,- - A theory has been formulated that 'red water' depends on occurrence of isolated nonmixing water masses. A study of small scale 'red waters' in some inland bays and information from various other sources support this hypothesis. (p. 18)."

nutritional/environmental/requirements/dinoflagellates/cultures/Red Tide

Anderson, W. W. 1958. See U.S. Fish Wildl. Serv. (1958).

Anonymous. 1948. The Red Tide. Fla. Board Conserv. Educ. Ser. No. 1, pp 5-14. Revised 1955 & 1966. J. Torpey and R.M. Ingle.

"SUMMARY.

1. Florida Red Tide is caused by the Microscopic organism _Gymnodinium breve_ Davis. Normally present in seawater along the Florida West coast in small concentrations, they may suddenly reproduce at a rapid rate, resulting in astronomically high numbers of individuals. The water then becomes characteristically discolored. The organism produces toxic substances which, during a bloom, are sufficiently potent to kill marine animals.
2. _G. breve_ is a very delicate and fastidious organism. Its requirements and optima must be met on precise levels for it to survive and multiply. Temperature, light, stability of surrounding media, organic nutritional substances, and metals must all be met at the correct level for blooms to develop.
3. Since 1944, Florida Red Tide has occurred at least 16 times in major proportions. There may have been outbreaks that were unreported due to sparce population in the coastal areas and inadequate communication.

4. When Red Tide appears, a slight irritating gas may be noticed. It has been suggested that this may have man-made origin but biological evidence indicates the causative factor is the breakdown of the Red Tide organisms. The irritant effects of the gas are restricted to the sea or beach and are temporary. The slight coughing and other symptoms disappear when Red Tide diminishes.
5. Fishes which are not killed or whose behavior is not noticeably affected by Red Tide are apparently safe for human consumption.
6. Mollusks such as mussels, clams, and oysters that are removed from Red Tide waters must be regarded with suspicion. There is a definite relationship between toxicity in these filter-feeding animals and high concentrations of _G. breve_.
7. Recent studies have indicated that the addition of EDTA (ethylenediamine tetra-acetic acid) and iron to seawater samples containing _G. breve_ promotes survival and growth.
8. An extensive sampling program in North and South Florida has revealed that streams entering the Gulf contain high concentrations of iron and humic acids (coffee-colored substances). The latter may assist in making iron and other metals soluble in seawater just as EDTA does in the laboratory. It is hoped that the present sampling program will provide information on the relationship of land run-off to Red Tide.
9. Financial support for Red Tide investigations for many years was inadaquate and undependable. In 1963 the Florida legislature appropriated funds sufficient for a large scale research project. This support was again provided in the 1965 session. As a result of this assistance much has been learned. Scientists of the Board of Conservation have suggested a method of control. Work now is concerned with verifying the practicality of this method.
10. The control suggested involves the construction of dams across major streams of afflicted areas..."

Florida Red Tide/_Gymnodinium breve_/toxic/irritating/mollusks/mussels/clams/oysters/toxicity/EDTA/and iron/Gulf contain high concentrations of iron and humic acids(coffee-colored substances)

Anonymous. 1970. Bioassay for shellfish toxins. _In_ Recommended Procedures for the Examination of Sea Water and Shellfish. 4th Ed., p. 57-66. Amer. Pub. Health Ass., New York. (Cited from Ray, 1971).

bioassay/shellfish/toxins

Barker, H.A. 1935. The culture and physiology of marine dinoflagellates. Arch. f. Mikrobiol. 6:157-181.

"Abstract - A number of photosynthetic marine dinoflagellates, including species of _Prorocentrum_, _Exuviella_, _Peridinium_, and _Ceratium_ were grown under laboratory conditions. The influence of temperature, light intensity, pH, and concentration of nutrients on division rate was investigated. The N requirements are exceedingly low, less than 0.1 ppm - sufficient to allow a maximum division rate."

(Cited from Rounsefell and Nelson, 1966 after Ryther, 1955). "Barker (1935), who was one of the pioneers in developing successful culture methods for dinoflagellates, observed optimal temperatures for growth of 14 spp. between 18° and 25° C."

culture/physiology/marine dinoflagellates/temperature/light intensity/pH/nutrients

Baughman, J.L. 1947. The Florida Red Tide. Tex. Game Fish. 5 (12): 6, 20-21.

Bein, S. J. 1954. The relationship of total phosphorus concentration in sea water to Red Tide blooms. Bull. Mar. Sci. Gulf Caribb. 7(4): 316-329.

"Abstract - An examination of existing published and unpublished data concerning total P concentration before, during and after Red Tide outbreaks was undertaken. The literature and earlier data have indicated that abnormally high phosphorus content is frequently associated with plankton blooms. An examination of all available data reveals that this is not so in the case of Red Tide outbreaks off the west coast of Florida. It was concluded that waters of the west coast of Florida maintain a sufficient phosphorus content to support a Red Tide at all times of the year and that fluctuations in this have no direct value in predicting outbreaks."

phosphorus/Red Tide/Florida

Bourne, N. 1965. Paralytic shellfish poison in sea scallops (Placopecten magellanicus). J. Fish Res. Bd. Can. 22: 1137-1149. (Cited from Ray, 1971).

paralytic shellfish poison/sea scallops/Placopecten magellanicus

Brongersma-Sanders, Margaretha. 1948. The importance of upwelling waters to vertebrate paleontology and oil geology. Kan. Ned. Ak. Wet. Verh. Afd. Not. (Tweede Sectie). 45(4): 1-112.

"Abstract - In sea water, bloom of dinoflagellates, so called red water, occurs frequently in some regions. The greatest number of cases of mortality in the sea occur in red water of dinoflagellates; dinoflagellates contribute to luminescence of the sea. The occurrence of red water, however, is a sure indication of very high abundance. When a sample of water with "waterbloom" of this flagellate (Noctiluca sp.) was allowed to stand for a little while, organisms settled and formed a gelatinous deposit of jelly-like mass in a rounded inactive form without a flagellum.. "on one occasion (27 Sept., 1922), when the sea was smoothe and calm, the bottom of a depth of 2 or 3' was seen to be covered with deep layers of similar consistency and color." Other similar observations were made with other dinoflagellates.. Blooms of Noctiluca sp. appeared to cause annual mass mortalities in Walvis Bay, South West

Africa, in December. Mortalities were during periods of minimum upwelling and the highest water temperature of the year..."

upwelling/paleontology/oil geology/dinoflagellates/luminescence

Brongersma-Sanders, M. 1957. Mass mortality in the sea, In J.W. Hedgepeth (ed.). Treatise on marine ecology and paleoecology, vol. 1, ch. 29, p. 941-1010. Geol. Soc. Amer., Mem. 67.

Mass mortality in sea caused by noxiousness of waterbloom (p.951). "Red water occurs in very fertile parts of the sea, often during or after unusually warm weather; it developes in succession after a great production of other organisms. Products of decay on the latter might be one of the factors that sets the bloom in motion. Great outbreaks occur particularly in subtropical and tropical regions where the rate of overturn of organic matter is high; in fertile parts of high latitudes, red water, at least of catastrophic proportions, does not occur or is very rare. Plenty of sunshine seems another requirement for red water outbreaks. The areas where red water occurs are somewhat reminiscent of polluted waters; the dead fish will worsen the 'pollution'. Here it is important to note that pòllution by human action also favors red-water outbreaks....

"The greatest outbreaks of red water probably occur toward the end of a phytoplankton season; in areas where upwelling occurs during part of the year only, red water usually develops toward the end or directly after the period of upwelling ..." (p. 953).

mass mortality/noxiousness of waterbloom/pollution/red water/upwelling

Chew, Frank, 1953. Results of hydrographic and chemical investigations in the region of the red tide bloom on the west coast of Florida in November 1952. Bull. Mar. Sci. Gulf Caribb. 2(4): 610-625...

"Abstract - Eleven hydrographic stations were occupied in the Gymnodinium bloom area off Fort Meyers, Florida in Nov. 1952. These data provide the basis of a three-dimensional description of the hydrographic environment where the phenomenon occurred. The current pattern in the area of study was more complex than is generally thought. There was eddying in the area of study, which appears to be seasonal in character. Regions of maximum total P were found to coincide with waters of Gulf origin, while water with greater river influences contain regions of minimum total P. This pattern implies that the included P content probably came from the open Gulf. The total P changed slowly with depth in a slanting water column, and areas of definite Gymnodinium bloom, while high in total P did not coincide with areas of maximum observed total P which was some 10 times the normal value. Three mechanisms capable of effecting the observed total P pattern are given. No proven explanation of the causes of the recurrent plankton blooms is as yet available."

chemical/red tide bloom/Florida/Gymnodinium/hydrographic environment/eddying

Chew, Frank. 1955. On the offshore circulation and convergence mechanism in the Red Tide region off the west coast of Florida. Trans. Amer. Geophysical Union 36(6), Dec. : 1-26.

"Abstract - The offshore water is shown to move as a single column. The sloping bottom and the equation of continuity are then applied to show the existence of a horizontal convergence mechanism which, over a period of several weeks, may effect an increase in concentration of floating particles some several times its initial value. The southbound current in the 'loop' is thought of as a Rossby jet which drives the cyclonic eddy offshore. Consideration of the abbreviated verticity equation, together with the fact of sloping bottom, show that the south-western quadrant of the cyclonic eddy possesses increasing negative vorticity and hence the organisms previously concentrated will tend to wash ashore. Some consideration of the effects of wind are also included."

(Cited from Rounsefell and Nelson, 1966) - "In this article the author discussed a mechanism to concentrate floating particles. He quoted from several observations concerning floating dead fish, and then reached the conclusion that, "The large horizontal dimensions of these patches of dead fish preclude the phenomenon from being oversized windrows or resulting from causes related to the wind (Stommell, 1951)...

He stated,"The observed outbreaks of Red Tide at beaches generally show a sequence of south to north movement..." Recent outbreaks have not shown such a tendency. The author said, "The remaining portion of this paper discusses the offshore circulation in an attempt to find the mechanics of the northward and shoreward movement." (p. 963).

circulation/convergence/Red Tide/Florida/wind/windrows

Chidambaram, K. and M. Mukundan Unny. 1944. Note on the swarming of the planktonic algae Trichodesmium erythraeum in the Pamban area and its effect on the fauna. Curr. Sci., Bangalore 13 (10): 263.

Abstract - "11 spp. of fishes and crabs in large numbers were exphyxiated following the swarming of algae. Putrefaction and pollution caused by the dead algae were additional factors causing the mortality."

swarming/planktonic algae/Trichodesmium erythraeum/mortality

Clarke, G.L. 1965. Transparency, bioluminescence and plankton. In G.C. Ewing (ed). Oceanography from Space. Woods Hole Oceanographic Institution, Ref. 65-10, p. 317-319. (Cited from Clarke, 1969).

bioluminescence/plankton

Clarke, George L. 1969. The significance of spectral changes in light scattered by the sea. In Johnson, Philip L. (ed)... Remote Sensing in Ecology. (Athens: University of Georgia Press), p. 164-172.

"Summary. The spectral distribution of visible daylight entering the sea was determined by means of a special, high-sensitivity radiometer at two locations off New England. Both downwelling and upwelling radiation were measured above the sea surface and at a series of depths from shipboard. Upward scattered light was measured simultaneously from an airplane. Since changes in the spectrum are affected by differences in the plankton and/or in the dissolved and particulate matter in the sea, the procedure suggests a method for the rapid delineation of water masses from the air, and possibly of high productivity..."

Clarke, G.L. and G.C. Ewing. 1970. Remote sensing of ocean color from aircraft. In 3rd Annual Earth Resources Program Review, Volume III, Hydrology and Oceanography; presented at the NASA Manned Spacecraft Center, Houston, Texas., pp 59-2 - 59-12.

These investigations have demonstrated the feasibility and utility of using the relationship between light extinction and biological productivity (in regions with high standing crops of phytoplankton, the euphotic layer is thin and most of the light attenuation can be attributed to plants) to detect chlorophyll over the range of concentration characteristic of the open sea, (Clark, Ewing, and Lorence, 1970). Spectra have been obtained from water masses with concentrations up to 3mg chlorophyll/m^3.

In this study over a distance of one mile, the chlorophyll concentration changed from 0.3 to 0.1 mg/m^3 and the temperature changed from 18^o to 23^o C. (In the transition between the coastal water south of Georges Bank and the Sargasso Sea). "Spectra were taken on two sides of this transition at altitudes ranging from 500 ft. to 10,000 ft. Although the shape of the spectra changed characteristically with altitudes, the differences between members of each pair and their contrast ratio remained nearly the same and clearly showed the location of the transition."

remote sensing/ocean color/aircraft/feasibility/light extinction/biological productivity/chlorophyll

Clarke, G.L., G.C. Ewing and C.J. Lorence. 1970. Spectra of backscattered light from the sea obtained from aircraft as a measure of chlorophyll concentration. Science 20:1119-1121. (Cited from Clarke and Ewing, 1970).

spectra/backscattered light/aircraft/chlorophyll concentration

Clarke, G.L. and M.G. Kelly, 1965. Measurements of diurnal changes in bioluminescence from the sea surface to 2000 meters using a new photometric device. Limnol. Oceanog. 10 (suppl.): R54-R66. (Cited from Clarke, 1969).

diurnal/bioluminescence/photometric device

Clemens, W.A. 1935. Red "water-bloom" in British Columbia waters. Nature 135:473.

(from B. Brongersma-Sanders, 1957, p. 980.) - "Clemens observed red water of ciliates (Mesodinium rubrum Lohmann) near Nanaimo, British Columbia, on April 28, 1933; damage was not recorded. (According to Bary and Studkey (1950, p.90) the causitive organism is not Mesodinium, but Cyclotrich meunier Powers.)"

(from Rounsefell and Nelson, 1966) - "In Nature of September 22, 1934, there is a communication from Mr. T. Hart describing the occurrence of a red water bloom caused by Mesodinium in South African seas. It may be of interest to record an occurrence of blood-red water at Nanaimo, British Columbia, during the week of April 28, 1933. The water in a channel immediately north of the harbour was colored crimson red in great patches. Examination of a sample of the water revealed a pure culture of a ciliate, indentified by Mr. G.H. Wailes as Mesodinium rubrum Lohmann.

"About this time oysters in Ladysmith Harbour, fifteen miles south of Nanaimo, were reported to contain red "worms". Investigation disclosed the fact that the crystalline styles were coated with red colored matter, evidently as a result of feeding upon Mesodinium. Examination of the styles of local clams showed a similar condition.

"The appearance of this 'bloom' of Mesodinium followed a period of a couple of weeks of bright, sunny, calm weather. No discoloration was observed in 1934."

red "water-bloom/British Columbia/ciliates

Collier, Albert, W. 1953. Gulf Fishery Investigations. In Annual Report for Fiscal Year 1953, Branch of Fishery Biology, Fish Wildl. Serv., p. 20-21.

"Red Tide research - Data collected during the November 1952 red tide outbreak, which also killed millions of fish off western Florida in 1946 and 1947 and has been ascribed to the dinoflagellate Gymnodinium brevis, show that Caloosahatchee River effluents are important agents in such blooms and that organic content and physical attributes cause such activity. Experimental tank work indicates a mass growth of dinoflagellates as well as other organisms, requires high light intensity, vitamin B_{12} and sulfides.

"An examination of tidal streams, marshes and estuaries produced _Gymnodimium brevis_ in Barfield Bay, south Florida. Field culture of this species was unsuccessful. Water from Lake Okeechobee was heavily loaded with dissolved organic substances.

"Daily collections and physical and chemical observations were made on dinoflagellates in Galveston, Texas, lagoons. _Gymnodinium splendens_, used in experiments as nearest to _Gymnodium brevis_, was found.

"Microbiology. - Light levels above those generally reported for algal cultures have been found necessary for culture of some dinoflagellates indigenous to the Gulf Coast. A ten-fold increase in now in use. Large-scale tank studies have proven valuable adjuncts to standard tube and dish cultures.

"Experimental ecology. - These experiments have been confined to a study of red tide. Large tanks have been set up for use as a steppingstone from test tubes to open sea. Findings on light intensity levels and values of certain inorganic nutrients have resulted from this approach. These are important in analyzing inter-specific relationships. This work provides a basis for advanced studies of larval shrimp and fish behavior, survival and growth." (p.21).

red tide/Florida/_Gymnodinium brevis_/Caloosahatchee River/dinoflagellates

Collier, Albert W. 1955. Gulf Fishery Investigations. _In_ Annual Report for Fiscal Year 1955, Branch of Fishery Biology, Fish Wildl. Serv., p. 29-32.

"Support for the theory that residues of dead fish compound the division rate of _G. breve_ comes from an explosive bloom in the laboratory which was created by adding juices from fish killed experimentally by a relatively low concentration of _G. breve_. The initial concentration was about 3 million cells per quart; with the addition of juices they tripled in number overnight.

"Red Tide Control - If control is possible, it will come after development of techniques for predicting conditions which are conducive to a red tide outbreak and for economical distribution of chemical or physical agents lethal to _G. breve_. Predictions are necessary to make the latter possible.

"A search for lethal agents has revealed that metalic copper and copper salts are most toxic. Copper sulphate at approximately 0.12 ppm (copper equivalent 0.05 ppm) in sea water is lethal to _G. breve_ in a few seconds. An experiment in which fine copper sulphate was spread over the sea surface with crop-dusting planes was successful in eliminating the organisms for approximately one fourth of a square mile." (p. 31).

dead fish/_G. breve_/red tide control/metalic copper/copper sulphate/crop-dusting planes

Collier, A., W. Wilson, and M. Borkowski. 1969. Responses of Gymnodinium breve Davis to natural waters of diverse origin. J. Phycol. 5.

Gymnodinium breve

Conover, S. A. M. 1954. Observations on the structure of red tides in New Haven Harbor, Connecticut. J. Mar. Res. 13(1): 145-155.

"...High concentrations of red tide organisms, here two species of Gonyaulax, were found to be associated with stable water masses of inner harbor origin. The configuration of the harbor permits the development and retention of water masses; this tendency is reinforced by large volumes of nutrient-rich fresh water entering the inner harbor, by certain wind patterns, and by high radiation values. Adequate time, essential for red tide development..." (p 145).

red tides/New Haven Harbor, Connecticut/Gonyaulax/nutrients/temperatures

Copenhagen, W. J. 1953. The periodic mortality of fish in the Walvis region: A phenomenon within the Benguela current. Department Comm. Fisheries, Union So. Africa, Div. Fish. Invest. Report No. 14, 35pp. Also cited, So. Afr. Jour. Sci., vol. 49(11): 330-331. (Cited from Brongersma-Sanders 1957).

mortality/fish/Walvis region

Davis, C.C. 1948. Gymnodinium brevis sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico. Bot. Gaz. 109: 358-360.

Along the lower Florida west coast in 1947, a species of the genus Gymnodinium was found associated with a yellowish-green discoloration of water and mortality of marine animals. This dinoflagellate was enormously abundant, occuring in numbers as high as 60,000,000 per liter. This organism appeared to be a new species to science. It was described and drawn and named Gymnodinium brevis. (which was, incidently, changed by Davis to breve because the brevis did not conform genitively with Gymnodinium, at a later date)

"In April 1947, there were further reports of fish mortality in the Gulf of Mexico off the Florida Keys...

"...off Key West (near Content Keys) fish mortality was occurring in a situation in which the count of Gymnodinium was 420,000 cells per liter...Furthermore, the mortality of fish and other animals occurred sporadically over a period of 9 months from Nov. 1946 to July, 1947..." (p. 358).

Gymnodinium brevis/discolored water/animal mortality/Gulf of Mexico/Florida

Doig, M.T., III and Dean F. Martin. 1971. Effect of humic acids on iron analysis in natural waters. In Water Research 5: 689-692. (Great Britain: Pergamon Press).

"Abstract - Florida river samples containing high and low concentrations of humic acids, naturally occuring chelators, were analyzed for iron content. The samples were subjected to automated microanalysis of soluble iron. Through statistical analysis of many replicate samples, it was possible to evaluate the error of analysis of low and high concentrations of iron in waters containing low and high concentrations of humic acid. Statistical evidence is presented to show that the presence of humic acid does not interfere in the precision of analysis of soluble iron and that changes in the iron content can be detected after storage for 2 months at 10°C..."

humic acids/iron/Florida/chelators

Dragovich, Alexander. 1960. Hydrology of Tampa Bay and adjacent waters. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 48-51. U.S. Fish Wildl. Serv., Circ. 92. (Cited from Rounsefell and Nelson, 1966).

"Comparison of the water temperatures with incidence of *G. breve* indicates that a relation to temperature may exist, especially during the cold periods. During winter (59-60) the temperature of water 20-40 miles offshore was higher than that of inshore waters. This may be important in the survival of *G. breve* offshore..." (p. 48).

It was suggested that "the size of a *G. breve* population may be important for its survival in Tampa Bay during the onset of a rainy season when a drastic reduction of salinity occurs." (p. 49).

It was also suggested that it is possible for surface waters with a slightly reduced salinity to exist at 30 to 40 miles offshore.

The author said that the greatest amount of phosphorus is brought into Tampa Bay by the Alfia River, and the greatest production of phosphorus is introduced at the beginning of the rainy season.

"...No relationship was observed between the incidence of *G. breve* and nitrate-nitrites." (p. 51).

hydrology/Tampa Bay/temperatures/*G. breve*/salinity/phosphorus/Alfia River/nitrate-nitrites

Dragovich, Alexander, and Billie Z. May. 1962. Hydrological characteristics of Tampa Bay tributaries. U.S. Fish Wildl. Serv., Fish Bull. 62:iv+p. 163-176. (Cited from Rounsefell and Nelson, 1966).

Higher concentrations of total and inorganic phosphorus occurred in the Alfia, Little Manatee, and Manatee Rivers, which flow through a phosphatic district, than in the Hillsborough River. All of the rivers entering Tampa Bay have higher phosphorus than the Peace and Caloosahatchee Rivers.

"...Results of this investigation have shown that the average concentration of copper for all rivers combined is well below the toxic levels for G. breve..." (p. 175).

hydrological/Tampa Bay/phosphorus/G. breve

Eldred, Bonnie, Karen Steindinger, and Jean Williams. 1964. A collection of data in reference to red tide outbreaks during 1963. 3. Preliminary studies of the relation of Gymnodinium breve counts to shellfish toxicity. Fla. Bd. Conserv. Mar. Lab., p. 23-52.

Toxicity of oysters rose when red tide occured in April to December, 1963 and decreased rapidly when red tide diminished.

red tide/Gymnodinium breve/shellfish toxicity/oysters

Evans, M.H. 1969. Spinal reflexes in cat after feeding intravenous saxitoxin and tetrodotoxin. Toxicon 7: 131-138. (Cited from Ray, 1971).

spinal reflexes/cat/intravenous'saxitosin/tetrodotoxin

Finucane, John H. 1958. Occurrence of red tide organisms. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958. U.S. Fish Wildl. Serv., p. 68-69. (Cited from Rounsefell and Nelson, 1966).

"...Concentrations of the organism in fish-killing density have, so far, been found in the neritic areas adjacent to major river drainages. The slope of the West Coast Florida continental shelf is very gently , so that a depth of 60 feet lies 25-45 miles offshore; consequently, the neritic zone is broad.

"During periods of relatively light concentrations, tremendously dense sampling is necessary to validate the presence of the organism. For example, on two different occasions, samples taken every hour in the same water mass for periods of twenty-four hours showed the organism present in but 3 out of 50 samples in one location, and in but 2 out of 48 in the other. Even during periods of heavy concentrations associated with fish kills, when samples were in an area of dying fishes, the counts varies from 0 to over 1 million per quart, further indicating the extreme patchiness of the organism's distribution in sea water."

Two series of hourly samples taken over 24-hour periods tend to show that the organism appears to concentrate at the surface during daylight and to move downward at night.

red tide/Florida/fish kills/patchiness

Finucane, John H. 1959a. Field ecology relating to red tide. In Galveston Biological Laboratory fishery research for the year

ending June 30, 1959, p. 76-79. U.S. Fish Wildl. Serv., Circ. 62. (Cited from Rounsefell and Nelson, 1966).

"Since October, 1958, the dominant phytoplankton associated with G. breve in the water samples were recorded qualitatively in the inshore and offshore waters of Tampa Bay. Quantitative counts (commenced in January 1959) of dinoflagellates, diatoms, and algae, made from preserved organisms stained on millipore filters, will be used to supplement these qualitative data." (p. 79).

ecology/red tide/G. breve/Tampa Bay

Finucane, John H. 1959b. Fishing and staining of dinoflagellates. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 108. U.S. Fish Wildl. Serv., Circ. 62. (Cited from Rounsefell and Nelson, 1966).

"Due to the extreme fragility of living G. breve, we are experimenting on techniques for the preservation of plankton samples in the field which will permit more precise quantitive and qualitative analysis of samples...

"Field samples were fixed immediately after collection with 0.5 ml. of 2% osmic acid in 1% chromic acid solution per 50 ml. of sample. So far this fixative has been the most effective in preserving G. breve and other phytoplankton.

"Fixed water samples were stored under refri geration at 36°F. These samples were later filtered under reduced pressures, using HA gridded millipore filters. After serial washes and the application of a mordanting solution, the organisms were stained on the millipore filter pad. The 3 most promising stains have been 1% Fast Green FCF, ½% Gentian Violet, and ½% Crystal Violet. These filters are first cleared in cedar oil or Cargille oil, then cut in half, and mounted with balsom or Permount on a glass slide. A permanent slide index of the phytoplankton taken since January 1959 at selected stations is being maintained. There is some tendency for G. breve cells to round up during filtration, but no distortion of diatoms was noted.

'This technique can be used to supplement living counts of G. breve and associated phytoplankton and may be valuable during extended offshore sampling trips when large changes in the number of organisms could occur before examination of the samples."

staining/dinoflagellates/G. breve/techniques

Finucane, John, H. 1960. Field ecology related to red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 52-54. U.S. Fish Wildl. Serv., Circ. 92. (Cited from Rounsefell and Nelson, 1966).

"The 1959 red tide outbreak started during the last part of September and continued through November. The initial pattern of distribution was similar to the 1957 outbreak with blooms of G. breve first occurring outside the islands. The first fish kill was reported September 29, offshore from St. Petersburg Beach. The greatest observed numbers of G. breve (480,000-1,330,000 per liter) were found in the neritic waters 3-10 miles west of Egmont Key, September 30. By October there was a rapid decline in both numbers and incidence of G. breve, 10-40 miles west of Egmont Key. This was particularly noticeable at stations 10 miles offshore where the numbers dropped from 1,120,000 per liter in September to less than 100 per liter during October. The coastal waters north of Egmont Key to Clearwater had a high count of only 33,000 per liter as compared to 540,000 per liter at the stations south of Egmont Key to Venice the same month. The last recorded fish kill during this outbreak occurred October 22, 1959, 3 miles off Egmont Key. (p. 52).

"The incidence of G. breve decreased in Tampa Bay and the nearshore waters during November, but blooms of this organism to 400,000 per liter still occurred 10 miles west of Egmont Key. Following the advent of weather fronts accompanied by lower water temperatures and turbulant sea conditions, G. breve incidence and numbers declined during December 1959 and January 1960.

"From February to April 1960 G. breve increased again in numbers and distribution. In March, 35 miles west of Egmont Key, a bloom of 6,320,000 per liter was observed. Scattered dead fish extended 15-35 miles offshore. No further fish kills were reported in April and May. The highest population encountered at that time was 21,000 per liter 10 miles west of Egmont Key.

"The neritic nature of G.breve was indicated by its presence to depths of 123 feet in numbers ranging from 7,000-16,100 per liter, 40 miles west of Egmont Key, November 1959 and March 1960.

"Organisms were present in the nearshore and offshore waters throughout the year during non-bloom periods...G. breve was completely absent from the middle of Tampa Bay except during the blooms of September-October 1959 and February-March 1960. This suggests that G. breve is primarily a neritic organism found in estuarine waters only when special conditions exist.

"Organisms were generally present in lower than normal salinities, ranging from approximately 30-35°/oo during blooms. Waters having values less than 24°/oo did not contain blooms of G. breve in Tampa Bay. While salinity may have served as a barrier for G. breve in estuarine waters, it does not normally seem to be a limiting factor in neritic waters.

"Water temperatures above 22°C. seem to be favorable for blooms of G. breve with the optimum around 26°-28°C. However, during February and March 1060, dense populations of G. breve developed at temperatures between 15°-18°C. Since G. breve has been observed in waters as cold as 9°C., low water temperatures normally may not be an absolute limiting factor for the existence of this organism. Temperatures below 14°C. and above 30°C. may inhibit blooms. (p. 53).

"Blooms of Prorocentrum micans and Ceratium furca occurred during November and December 1959 in Tampa Bay...blooms of Gymnodinium splendens were present March 29, 1960, in upper and middle Tampa Bay...

"Skujella erythraeum continued to be the dominant blue-green alga in the surface waters from Tampa Bay to 40 miles west of Egmont Key during the summer and fall fo 1959." (p. 54).

G. breve/Egmont Key/Tampa Bay/fish kills/salinities/temperatures/Skujella erythraeum

Fitch, C. P., L. M. Bishop, W.L. Boyd, R. A. Gortner, C. F. Rogers, and J. E. Tilden. 1934. 'Waterbloom' as a cause of poisoning in domestic animals. Cornell Veterinarian, 24:30-39. (Cited from Brongersma-Sanders, 1957).

waterbloom/poisoning/domestic animals

Galtsoff, P.S. 1948a. Emergency survey report on Florida's "Red Tide". Fishing Gazette 65(1):66-67.

"Abstract - Florida's 'Red Tide' was caused by appearance in nearby coastal waters of enormous numbers of Gymnodinium, giving the sea water a reddish or amber color. Mass destruction of fish, accompanying red tide, was caused by toxin of unknown chemical composition liberated by Gymnodinium into the water. Poison was also carried inland in windborn spray, causing extreme discomfort among human population (irritation of mucus membranes). Total P content of water samples from affected areas was 5-10 times as high as from uncontaminated areas. P is essential to growth of Gymnodinium. Abnormally high P content probably caused rapid reproduction of Gymnodinium. Nine previous plagues have been recorded over the past 100 years, which discounts the theory of chemical pollution of the water from dumped munitions. Red waters were eventually dispersed by mid-September (1947) hurricanes. Affected spp. included all fish, oysters, and horseshoe crabs; true crabs were unharmed."

Florida's/Red Tide/Gymnodinium/toxin

Galtsoff, P.S. 1948b. Red Tide. Progress report on the investigations of the cause of the mortality of fish along the west coast of Florida conducted by the U.S. Fish Wildlife Service and cooperating organizations. U.S. Dept. Int. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. No. 46: 1-44.

During the 1946-47 outbreaks: All kinds of animals perished in the red water, including a small number of turtles and porpoises. Windrows of dead fishes piled on beaches comprised a great variety of common commercial and noncommercial varieties.

Likewise, the pelagic and bottom invertebrates succumbed to the unknown poison. Large numbers of shrimp were seen dead, as well as common blue crabs, fiddler and mud crabs, barnacles, oysters and coquinas. Observations made by the author in March 1947, around Fort Meyers area, disclosed that about 80% of the oysters, Ostrea virginica, grown on piles, were dead.

"No mortality was observed among the hard shell clams, Venus mercenaria, and no reports were received of the destruction of ducks, gulls, and other birds inhabiting the inshore waters. Later during the summer information was received from residents of Largo, Florida, that 'thousands of sea fowls and pelicans died from eating the fish poisoned by the red tide.' The correctness of this observation has not been verified by the author. (p. 10-11).

In June 1947, W.W. Anderson reported the species killed in the Fort Meyers area to be 50% catfish; also included were pinfish, moonfish, spot, mullet, eel, sand-beam, whiting, thread herring, hogchoker, tongue fish, yellow-tail, tripletail, red fish, and drum. Also very noticeable were carcasses of horseshoe crabs.

"...Sponge divers working last winter off Marco, Florida, reported that the bottom was littered with dead mackerel, although rarely were these fish found on the beaches. (p. 13).

"Although few dead crabs were observed by Anderson, this may be due to the fact that these animals tend to sink upon death and would, therefore, be less noticeable. On the other hand, he frequently observed small species of crabs swimming in the infected waters in apparently good condition. On several occasions crabs were observed feeding on dead fish at the surface. He thinks that it is entirely possible that these crustaceans were less affected by the red water than were the fish. Horseshoe crabs (Limulus polyphemus), however, suffered a heavy mortality and thousands were washed onto the beaches... (p. 13-14)

"...the water had an oily appearance. When dipped up and allowed to stand for 5 to 10 minutes, it became thick, sometimes almost of a consistency of Karo syrup, and slimy to the touch... (p. 15)...Counts made in the field by Woodcock and Anderson show that the number of Gymnodinium in the surface layer of red water varied at this time from 13,000,000 to 56,000,000 per liter... (p. 19).

"... Dinoflagellates, like other Protozoa, are very sensitve to copper sulphate and hypochlorite. Kofoid and Swezey (1921) state that copper sulphate in a concentration of 1 part per million killed all Ceratium hirundinella. This method was used by the Japanese biologists in their attempts to control the red water in the Goskasho Bay and in Gulf of Konsa. Miyajima (1934) states that all dinoflagellates are instantly killed by copper sulphate solution in the concentration of 2 parts per million. The concentration of 1 part per million kills them within a few minutes. In practice the copper sulphate was applied by attaching bags filled with this salt to the sides of motor launches which were run back and forth in the bay. After the treatment large numbers of destroyed dinoflagellates were found floating in the water. (p. 34).

"To prevent the growth of bacteria which may develop after the destruction of dinoflagellates, the Japanese biologists suggest the use of 10% solution of calcium hypochlorite or the addition of liquid chloride. Both solutions can be used simultaneously and their effective concentrations, according to Kominarui, (quoted from Miyajima) should be adjusted to the salinity and temperature of the water. He states that at 13.6°C. ordinary bleaching powder containing from 34 to 35% of free chlorine is effective in killing dinoflagellates at the concentration of 1: 500,000. At 10°C. the concentration should be increased to 1: 400,000. In combination with copper sulphate the concentration of hypochlorite can be reduced to 1 part per million. It is interesting to note that after the red water was destroyed by chemical treatment the Japanese noticed the appearance of another dinoflagellate of the genus Polykrikos which apparently was harmless to pearl oysters.

"...it appears promising to try the spraying of red water from airplanes or from boats with a solution of copper sulphate or dusting it with powdered calcium hypochlorite. Other chemicals, harmless to fish and shellfish, may be tried. The use of powdered calcium oxide (unslackened lime) suggested itself, for its addition to sea water will raise the pH to a level which is beyond the tolerance of the dinoflagellate and, at the same time, it is unlikely that the increased concentration of Ca salts in the water will adversely affect fish or shellfish, for the excess of Ca in sea water will be rapidly precipitated.

"Advantage may be taken of the fact that the greatest concentration of dinoflagellates appear in patches which are, probably, the centers of their more rapid propagation..." (p. 34-35).

mortality of fish/Florida/red water/windrows/invertebrates/Ostrea virginica

Galtsoff, Paul S. 1949. The mystery of the red tide. Sci. Month. 68(2): 108-117.

"Abstract - Discoloration of the ocean, called 'blooming', is caused by rapid multiplication of any of a variety of organisms, diatoms, blue-green algae, sulfur bacteria, (under certain conditions), or dinoflagellates. There have been several outbreaks along the west coast of Florida. In a very extensive one from Nov. 1946 to March 1947, the multiplying organism was Gymnodinium brevis. It poisoned all the fishes and most other marine organisms, and spray from the waves was very irritating to man. A concentration extracted of the red water was lethal to fish in aquaria. The direct cause of the outbreaks may be an increase in the concentration of P in the water."

red tide/blooming/Florida

Glazier, W.C.W. 1881. On the destruction of fish by polluted waters in the Gulf of Mexico. Proc. U.S. Nat. Mus. 4: 126-7.

"U.S. Marine Hospital Serv., Dist. of the Gulf Port of Key West, Florida, Servions Office, Nov. 25, 1880. Dear Sir... fishermen returning from the coast of Florida with fish...have had them die suddenly on reaching a certain kind of water distinguished by its color...in 1865 & 1878...

"There is nothing known as to the origin of the poisonous qualities of the waters that affect the fish in this way... opinion seem to be...something is emptied into the beds of the freshwater courses from volcanic or geyser-like springs, and that as soon as the water thus impregnated reaches the sea it kills every living thing that comes under its influence..."

destruction of fish/polluted waters/Gulf of Mexico

Glennan, A.H. 1887. 4,--Fish killed by poisonous water. U.S. Fish Comm., Bull. 6: 10-11.

"A report of fish killed by 'poisoned water' of a reddish color during October, 1885. Large shoals of dead fish were reported between Egmont Key Light and Charlotte Harbor. Also reported was that in some of the freshwater creeks fish were caught by placing bags of the bruised bark of the swamp dogwood (Cornus sericea) in still water, and that the fish will revive if allowed to remain in it for a short time only." (p. 11).

poisoned water/dead fish/Egmont Key Light/Charlotte Harbor/dogwood

Graham, Herbert W. 1954. Dinoflagellates of the Gulf of Mexico. In Gulf of Mexico, Its origin, water, and marine life. Fishery Bull. of U.S. Fish and Wildl. Serv. 55, Bull No. 89: 223-316. (Cited from Rounsefell and Nelson, 1966).

"Toxic red water such as occurs regularly in the pearl oyster beds in Japan (Mitsukuri, 1904) could be disastrous to the vast oyster industry in the Gulf, but apparently the Gulf oysters have been spared any such visitation so far.

"Reports of red water on Campeche Banks off Yucatan, are made occasionally by fishermen in that area, but to date it has not been possible to ascertain the causative agent..." (p. 225).

dinoflagellates/Gulf of Mexico/toxic/red waters/Yucatan

Graham, H.W., J.M. Amison, and K.T. Marvin. 1954. Phosphorus content of waters along the west coast of Florida. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 122, v + 43p. (Cited from Rounsefell and Nelson, 1966).

Total, inorganic, and organic phosphorus was determined for waters of the Peace and Caloosahatchee Rivers, Charlotte Harbor, and 10 stations in the Gulf of Mexico off the west coast of Florida extending to 120 miles offshore. The period covered was May 1949 to January 1951, inclusive. Water samples were also analyzed for salinity, oxygen, and pH. This report contains only the phosphorus data; the remainder were published by Marvin (1955).

The authors stated "No high degree of accuracy is claimed for the analysis of the river water, specially at Station 2 (Peace River). Concentrations there were frequently so high that dilutions with salt solutions were necessary. Futthermore, yellowish or greenish tints often developed in the samples so that addition of dyestuffs to the standards was necessary in order to effect a match in color.

"In an effort to clarify the water some river samples were centrifuged. It was found that not only the total, but also the inorganic phosphorus was less in these samples, indicating that some of the inorganic phosphorus occurs in particulate form..." (p. 2).

The authors pointed out the possible role of Skujaella (=Trichodesmium) in concentrating phosphorus. "...This filamentous blue-green algae is always present in the plankton there, and frequently occurs in bloom proportions. It grows in the water and on the surface...Its propensity for floating on the surface is the feature which is of importance to the present problem...

"Since it accumulates at the surface it is driven by the wind. Sometimes it piles up in such abundace as to create a nuisance at bathing beaches..." (p. 40).

In four samples of water containing blooms of Skujaella, the inorganic phosphorus ranges from 0.05 to .20µg. at/l., and the total phosphorus from 1.75 to 10.20 µg. at./l. showed only 2.35 µg. at./l. of total phosphorus and only 0.05 of inorganic phosphorus. These analyses indicated that the alga can grow well in water containing scarsely measurable inorganic phosphorus and accumulate a high quantity of phosphorus and high values of phosphorus in unfiltered samples of water containing red tide may have little bearing on the need of any specific amount for a bloom.

The authors observed Skujaella floating in bands several hundred yards wide and miles long. They speculated that if conditions at any time suddently became unfavorable for Skujaella a great mass of organic matter would become avalaible to decompose and release large quantities of nutrients that might cause blooms of other organisms.

Limited upwelling of deep water seemed to have little or no effect on the phosphorus content of water in the euphotic zone.

red tide/blooming/Florida/Skujaella(=Trichodesmium)/blue-green algae

Gran, H.H. 1929. Investigation of the production of plankton outside the Ronsdalsfijord 1926-1927, 112p. Cons perma, Int. Explor. Mer., Rapp. Proc. Verb. Reun. 56(Cited from Ryther, 1955).

plankton/Romsdalsfijord

Gunter, Gordon. 1947. Catastrophism in the sea and its paleontological significance, with special reference to the Gulf of Mexico. Amer. J. Sci. 245(11): 669-676.

"Abstract - The importance of catastrophism and mass mortality in paleontology has been emphasized by certain recent writers. On the Gulf Coast of the United States mass mortalities of marine animals of shallow water, catastrophic in nature, are brought about every ten years or so by hard cold spells, plankton blooms, and excessively high salinities; the latter case being confined to the Laguna Madre of Texas. The vastness of the mortality, which may cover several square miles, low temperatures, high salinities and silting due to high winds or heavy drainage from land, which may accompany the mortalities in various combinations, are conditions prejudicial to fossilization. Such events may occur thousands of times in a million years. Catastrophic mass mortalities of marine animals in the Gulf of Mexico are important factors in fossilization of the fauna of the region."

catastrophism/paleontological/Gulf of Mexico/mass mortality/ Laguna Madre of Texas

Gunter, Gordon. 1949. The red tide and the Florida Fisheries. Proc. Gulf and Carrib. Fish. Inst., Inaug. Session, pp. 31-32.

red tide/Florida/fisheries

Gunter, G., F.G. W. Smith, and R.H. Williams. 1947. Mass mortality of marine animals on the lower west coast of Florida, Nov. 1946 - Jan. 1947. Science. 105(2723): 256-257.

"Abstract - Catastrophic death involving millions of fish occurred between Nov. 1946 and Jan. 1947 on the south Florida Gulf coast. Many other spp. of marine organisms were also killed. All kinds of fish succumbed. The mass death was associated with the presence of streaks of discolored water. Analysis of the water showed it to be unusually rich in copepods and invertebrates larvae; there were large quantities of diatoms with *Coscinodiscus* *sp*. as the dominant organism, and smaller numbers of naked flagellates, particularly *Gymnodinium*. The water contained no unusual salinities. Its temperatures ranged from 22.5^{o} - 26^{o}C., with a pH close to 8.2,a low O_2 content, and variable reports of the presence of H_2S. An odorless but acrid gas was detected by boiling samples of water."

mass mortality/marine animals/Florida/*Gymnodinium*

Gunter, G., R.H. Williams, C.C. Davis, and F.G. Walton Smith. 1948. Catastrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, Nov. 1946 - Aug. 1947. Ecol. Mong. 18: 309-324.

(from Bio-Abstracts) "The progress of the red tide phenomenon and the damage caused by it are described in detail. During the period in question it is estimated 50 million fish were killed. A study of the species found dead indicates a transition from a temporate to a tropical fauna in this area. The immediate cause of death shown to be toxic substance associated with Gymnodinium brevis Davis, a dinoflagellate which was present in concentrations exceeding 60 million cells per liter. This organism caused the sea water to appear yellowish-brown and to become abnormally viscous."

mass mortality/marine animals/phytoplankton bloom/Florida/red tide/ Gymnodinium brevis

Halstead, B.W. 1965. Poisonous and Venomous Marine Animals of the World: Invertebrates. Vol. I, 994 pp. U.S. Govt. Printing Office, Washington, D.C. (Cited from Ray, 1971).

poisonous/venomous/marine animals/invertebrates

Halstead, B.W. 1967. Poisonous and Venomous Marine Animals of the World; Vertebrates, Vol. II, 1070 pp. U.S. Govt. Printing Office, Washington, D.C. (Cited from Ray, 1971).

poisonous/venomous/marine animals/vertebrates

Hayes, Helen Landau, and Thomas S. Austin. 1951. The distribution of discolored sea water: Texas Jour. Science. 3(4): 530-541, map. (Cited from Brongersma-Sanders, 1957).

Reprinted in Brongersma-Sanders (1957) In Tretise on Marine Ecology and Paleoecology: Vol I Ecology. J.W. Hedgepeth (ed.). (from Rounsefell and Nelson, 1966) - "Contains 225 references pertaining to the occurrence and causes of the overblooming of plankton, with special emphasis on dinoflagellates."

discolored sea water/overblooming/plankton/dinoflagellates

Hedgepeth, J.W. (ed.). 1957. (Reprinted, 1966). Tretise on Marine Ecology and Paleoecology: Vol. I, Ecology. Geol. Soc. Amer. Washington, D.C.: Nat. Acad. Sci., Nat. Res. Coun., Comm. of the Div. of Earth Sci., pp. viii + 1296.

Chapter by M. Brongersma-Sanders contains subheading on mortalities in the sea due to noxiousness of waterbloom. Review of red water occurrences all over the world with complete references. An extremely valuable historical review.

Holm-Hansen, O., F.J.R. Taylor and R.J. Barsdate. 1970. A ciliate red tide at Barrow, Alaska. Mar. Biol. 7: 37-46.

An unidentified ciliated protozoan caused an extensive red water condition, the first such occurrence reported in the Artic Ocean, in September 1968, in the vacinity of Point Barrow, Alaska. No marine fatalities were reported as a result of this condition. Hydrographic conditions, water analysis, and a complete organism description were presented.

ciliate/red tide/Barrow,Alaska

Hornell, James. 1917. A new protozoan cause of widespread mortality among marine fishes. Madras Fish. Dep., Bull. 11(2): 53-66.

"Widespread fish mortality is a well known phenomenon on the Malabar and South Kanara coasts; its recurrence yearly along certain stretches of the coastline is regular, though its intensity varies within wide limits...

"...all Malabar fishermen whom I have questioned agree in that every year after the passing of the rainy season and the subsidence of the southwest monsoon, if there be a continuance of fine weather for a week or ten days, with plenty of sunshine, and a weak coastal current, the water inshore becomes turbid and discolored, brownish or reddish in tint; that this water has such poisonous effects upon fish that large numbers become affected and eventually die..." (p. 53).

protozoan/mortality/marine fishes/Malabar/South Kanara coasts

Hutchinson, G. Evelyn. 1944. Limnological studies in Connecticut. VII. A critical examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology 25(1): 3-26. (Cited from Ryther, 1955).

Ingersoll, Ernest. 1882. On the fish-mortality in the Gulf of Mexico: Proc. U.S. Nat. Mus. vol. 4, pp. 74-80. (1881).

In discussing the mortality of fish along the western coast of Florida which occured in the fall of 1880, the writer points out a conversation with one of the oldest residents on the Florida coast, Mr. Benjamin Curry, of Manatee. The writer was told by Mr. Curry that as far back as 1844 a wide-spread destruction of all sorts of salt-water animal life occurred, apparently due to conditions similar to the 1880 mortalities. Another mass-mortality was remembered to have occurred in 1854. 1878 brought a worse mortality than the one under consideration in 1880. In the 1878 mortalities, the Florida west coast sponge industry was practically wiped out. The 1880 incident occurred after a terrible hurricane; the fish and other marine life "suddenly began dying in hordes all along the southern (eastern) shore of Tampa Bay, on the coast", which was the northern most limit. The Tortugas in the south were even effected by the condition. "The oysters at the mouth of Manatee River in Tampa were spoiled...A graphic account" had been given to the writer in a letter from Mr. Charles Moore, Jr. the keeper of the lighthouse on Egmont Key at the entrance of Tampa Bay. Mr. Moore writes:

"Feb. 20, 1881...The fish began dying on Sunday, October 17 as the tide came in. From the 25th of October to the 10th of November, all kinds of fish were dying and the stench was so bad that it was impossible to go on the beach." They shut themselves in their rooms and "kept burning tar, coffee, sulfer, rags, etc., night and day in order to stand it...It was warm, damp, and calm weather."..."In regard to the cause of their dying" the light keeper said he had "made up his mind it was caused by the fresh water, as there was immense quantities of freshwater coming down the bay, and the water there was nearly fresh on the surface, while the water under it was salty." He proposes "if the freshwater could have passed off into the Gulf without being disturbed by winds", it would have diffused and "caused no trouble.. But on the 7th day of October, a heavy gale with southwest winds blew" and prevented normal water flow. The light-house keeper noticed, "a few days before the fish commenced to die, a peculiar smell on the water, something like the smell of bilgewater, and the color of the water was a dirty green, mixed with small sediment.' On examining the first of the dead fish he noticed their gills were all glued together with a limy substance of a whitish color."

Other fishermen reported "brownish," discolored water, "thick and glutinous..., lay in streaks drifting with the tide..."

fish-mortality/Gulf of Mexico/Florida/sponge industry/hurricane/oysters / Tampa Bay

Ingle, Robert M. 1965. Red Tide research at the Florida state laboratory. <u>In</u> Sykes (ed.), Bureau of Commercial Fisheries Symposium on red tide. U.S. Fish Wildl. Serv., Spec Sci. Rep. Fish. No. 521.

red tide/Florida

Ingle, R.W., R.F. Hutton, H.E. Shafer, Jr., and R. Goss., 1959. The airplane as an instrument in marine research. Part I. Dinoflagellate blooms. Fla. State Bd. Conserv., Spec. Sci. Rep. 3,25p. (annotation from Rounsefell and Nelson,1966).

The authors reported that semicircular surface structures were common features of the 1957 red tide outbreak near the mouths of passes. "The muddy bay water...lay proximal to the passes. Dead fish were not abundant in the muddy, less saline water. Typically, the interface between the water masses was filled with a line of dead fish." (p. 3).

"In every case observed by the authors (R.M.I. and R.F.H.) the discoloration, denoted a high concentration of dinoflagellates, and due to their frequency of occurrence, interfaces may well serve to rejuvenate and sustain red tides once they begin. If this is true, control measures directed to the specific areas of junction of dissimilar water masses may serve a useful purpose." (p. 5).

This report states that after October 15, 1957, spraying of copper sulfate crystals was discontinued and control measures consisted of suspending bags of copper sulfate off bridges etc. in 27 passes between Clearwater and Naples.

airplane/dinoflagellate blooms/discoloration/dinoflagellates/copper sulfate

Ingle, Robert M. and Dean F. Martin. 1971. Prediction of the Florida Red Tide by means of the iron index. Environmental Letters 1(1): 69-74.

A new means of predicting the occurrence of Florida red tide outbreaks: the iron index, was proposed. "This index is defined as a total amount of iron potentially delivered to an outbreak area during a three-month period. The critical iron index must be determined for a potential outbreak area." A modified critical iron index was proposed for the area in which this was tested as follows: "A red tide outbreak may be expected near Charlotte Harbor, Florida, following a critical iron index of 135,000 pounds (as measured at Arcadia, Florida) assuming optimum temperatures (16° - 27°C.), and assuming an absence of a hurricane (or very high winds) within 150 miles of the Harbor." The test of this method of predicting red tide awaits.

prediction/Florida Red Tide/iron index/optimum temperatures

Jefferson, J.P. 1879. On the mortality in the Gulf of Mexico in 1878: Proc U.S. Nat. Mus., vol.1, pp. 363-364.

(from Hutton, 1956, originally from Ingle, personal file)
"This publication consists of a letter from J.P. Jefferson Lieutenant 5th Reg. Art., to Prof. Spencer F. Baird, Smithsonian Institution, Washington, D.C. The letter was written in December, 1878, and describes 'discolored water' moving down along the coast, across Florida Bay, to Tortugas (about November 20) and extending to at least as far as Key West. Dead fish were reported from Fort Jefferson and neighboring keys, the north side of the island of Key West, and about 15 miles out in the Gulf Stream. In Tampa Bay oysters were killed. It was reported that the Caloosahatchee River over flowed its banks in October and the whole countryside was flooded."

mortality/Gulf of Mexico/discolored water/Key West/Tampa Bay/oysters

Jefferson, J.P., Joseph Y. Porter, and Thomas Moore. 1879. On the destruction of fish in the vicinity of Tortugas during the months of September and October, 1878. Proc. U.S. Nat. Mus. 1: 244-246. (Cited from Rounsefell and Nelson, 1966).

"...On the 9th instant (October 1878), the sailing-vessel which connects us with Key West met water of a dark color about midway between here (Dry Tortugas) and there, but saw no dead fish. On her return, on the night of the 11th, she struck it off Rebecca Sholes, about 25 miles east of here, and found it extended some 10 miles out in the Gulf. That same night it came down upon us here, and the next morning the beach and surface of the water, as far as the eye could see, were covered with dead fish...From the fact that almost all the fish that first came ashore were small and of such varieties as frequent shoal water, I infer that the dark water must have been of less density than the sea...The destruction must have been very great, for here, on a key containing but a few acres, and with a very limited extent of beach, we have buried at least twenty cart-loads..." (p. 244).

The letters also alluded to fish dying in Florida Bay and to death of almost all the conchs around Dry Tortugas.

destruction of fish/Tortugas

Jensen, E.T., (ed). 1959. Proceedings of the Shellfish Sanitation Workshop. 72 pp. U.S. Pub. Health Ser., Washington, D.C. (Cited from Ray, 1971).

Johnson, H.L. and G. Mulberry. 1966. Paralytic shellfish poison: serological assay by passive hemoglutination and bentonite flocculations. Nature (London) 211: 747-748. (Cited from Ray, 1971).

paralytic shellfish poison/serological assay/hemoglutination

Kao, C.Y. 1966. Tetrodotixin, saxitoxin and their significance in the study of excitation phenomena. Pharmacol. Rev. 18: 997-1049. (Cited from Ray, 1971).

tetrodotoxin/saxitoxin/excitation phenomena

Kao, C.Y. 1967 Comparison of the biological actions of tetrodotoxin and saxitoxin. In Animal Toxins (F. E. Russell and P.R. Saunders, eds.), pp. 109-114. Macmillan (Pergamon), New York. (Cited from Ray, 1971).

biological actions/tetrodotoxin/saxitoxin

Ketchum B.H., and Jean Keen, 1948. Unusual phosphorus concentrations in the Florida "Red Tide" sea water. Sears Found. Mar. Res., 17-21.

The total phosphorus content of waters containing dense populations of Gymnodinium, was found to be $2\frac{1}{2}$ - 10 times the maximum to be expected in the sea.

phosphorus/Florida/Red Tide

Koch, H.J. 1938. Verlammende vergiftiging door mosselen. Arch. Soc. Gen. Hyg., Tijdschr. Path. Phys. Arbeid, No. 9, pp. 796-805. (Cited from Brongersma-Sanders, 1957).

Koch, J.J. 1939. La cause des empoisonnements paralytiques provoques par les moules. C.R. Assn. Franc. Av.Sc., 63rd session, pp. 654-657. (Cited from Brongersma-Sanders, 1957).

Lackey, James B., and Jacqueline A. Haynes. 1955. The Florida Gulf coast red tide. Fla. Eng. Ind. Exp. Sta., Coll. Eng., Eng. Progr. Univ. Fla. 9(2): 1-23, Bull. 70, 23 p.

"The work detailed in this bulletin represents an attempt to evaluate the effects of Gymnodinium brevis, its behavior and its distribution; some investigation of factors which may cause its phenominal growth and of factors which may help in its control..." (p. 3).

"There have also been rumors of enteric troubles due to eating shellfish from a Red Tide infected area. This point of human illness is emphasized by La Cossitt in a popular journal, but it should be stressed that there has been no definite tracing of any human illness to brevis, and there has been no widespread illness when the Tide was present... No toxic effects like those due to Gonyaulax on the California coast have been demonstrated." (p. 6).

"...one cannot detect a discoloration of the water at the surface until the number of brevis exceeds 250,000 or more per liter...Much attention has been directed toward recognition of red water from boats and planes...it is frequently possible to spot patches in this way..." (p. 13).

"Organic acids (humic, tannic) are abundant in runoff from the West Coast, and (viewed) from the air, the brown discoloration as this water comes out of the passes is spectacular..." (p. 21).

Florida/red tide/Gymnodinium brevis/human illness/organic acids (humic, tannic)

Lindemann, E. 1924. Der Bau der Hulle bei Heterocapsa und Kryptoperidinium foliaceum (Stein). Bot. Archiv., 5(½): 114-120. (Cited from Brongersma-Sanders, 1957).

Lorenzen, C.J. 1970. Light extinction from the ocean by phytoplankton. Contribution No. 2558 from the Woods Hole Oceanographic Institution, In Press.

light extinction/phytoplankton

Lucas, C.E. 1947. The ecological effects of external metabolites. Biol. Rev. Cambridge Phil. Soc. 22(3): 270-295.

Evidence of the "exclusion" and inhibition of animals by abundant planktonic plants is reviewed. Earlier suggestions that this is mediated by plant excretions are reinforced by recent knowledge of the release of metabolites into their environments by a variety of organisms and of the influence of such metabolites on their fellows. Such relationships have been most studied in microscopic organisms, but they also occur among larger forms. Free metabolites (enzymes, hormones, and vitamins, etc.) may stimulate or inhibit different processes, their influence ranging from stimulation of eggs to sex-determination (e.g. by carotenoids), and from ecological competition by root-excretions to paracitism. During evolution many organisms must have adapted themselves to tolerate or take advantage of the external metabolites of their neighbors, just as some organs respond to endocrine products of others. Organisms which failed to adapt must have evolved avoiding reactions or perished. Stimulating and inhibitory relationships have arisen in this way, concerning community integration, competition, succession, and symbiosis. Such relationships are termed non-predatory, and the appropriate metabolites "ectocrine". In plankton ecology such as "animal exclusion", "succession", initiation of the spring diatom crop, and productivity, the possible influence of carotenoids and sterols is suggested, both in free communities and in there relationships between animals and their symbiotic algae.

ecological effects/external metabolites/exclusion/inhibition/non-predatory/ectocrine

Lucas, C.E. 1949. External metabolites and ecological adaptation. Symp. Soc. Biol. III. Selective toxicity and antibiotics, p. 336-356. Academic Press, Inc., New York. (Cited from Ryther, 1955, by Rounsefell and Nelson, 1966).

external metabolites/ecological adaptation/toxicity/antibiotics

Lund, E.J. 1936. Some facts relating to the occurrences of dead and dying fish on the Texas Coast during June, July, and August in 1935. In ann. Rep Game Fish, and Oyster Comm. (1934-35): 47-50. (Cited from Rounsefell and Nelson, 1966).

"The escape of irritating 'gas' dissolved in the sea water was facilitated by prevailing winds blowing on shore. Appearance of 'gas' was always associated with the simultanious or immediately previous appearance of dead fish...(p.48)."

"...an examination of the Weather Bureau reports on Texas during 1934-35 shows that rainfall and flood levels of the rivers were at unusual maxima during May and June 1935. A maximum of the resulting outflow of water of very low salinity through the passes occurred during the last week in June and therefore just preceding the first appearance of dead fish on Padre Island..." (p. 49).

irritating gas/dead fish/rainfall/salinity

Marchand, J.M. 1928. The nature of the sea-floor deposits in certain regions of the West coast. Special Rept. No. 5, Fish and Mar. Biol. Surv., Union So. Africa, Rept. No. 6: 11 pp. (Cited from Brongersma-Sanders, 1957).

Martin, D.F. and A.B. Chatterjee. 1969. Isolation and characterization of a toxin from the Florida red tide organism. Nature 221: 59.

isolation/characterization/toxin/Florida/red tide

Martin, D.F. and A.B. Chatterjee. 1969. Some chemical and physical properties of two toxins from the red tide organism, _Gymnodinium breve_. Fish. Bull. 68: 433-443.

chemical/physical/properties/two toxins/red tide/_Gymnodinium_ _breve_

Martin, D.F., M.T. Doig, III, and R.H. Pierce, Jr. 1969. Variation of selected trace metals in some west Florida streams. Reprints of papers presented at the 158th National ACS meeting, Division of Water, Air and Waste 9: 124-127. (cited by M.T. Doig III and Martin, 1971).

variation/trace metals/west Florida/streams

Martin, D.F., M.T. Doig III and R.H. Pierce, Jr.. 1971. Distribution of some naturally occurring chelator (humic acids) and selected trace metals in some west coast Florida streams, (1968-1969). Fla. Bur. Mar. Sci. and Tech. Prof. papers, Ser. No. 12. (cited from Doig and Martin, 1971).

distribution/chelators/humic acids/selected trace metals/Florida/streams

Medcof, J.C., A.H. Leim, A.B. Needler, and A.W.H. Needler. 1947. Paralytic shellfish poisoning on the Canadian Atlantic Coast. Bull Fish. Res.Bd. Can. 75, 32pp. (Cited from Ray, 1971).

paralytic shellfish poisoning/Canadian Atlantic

Meyer, K.F., H. Sommer, and P. Schoenholz. 1928. Mussel poisoning. J. Prev. Med. 2: 365-394. (Cited from Ray, 1971).

mussel/poisoning

McFarren, E.F. 1959. Report on collaborative studies of the bio-assay for paralytic shellfish poison. J. Ass.Office. Arg. Cham. 42: 263-271. (Cited from Ray, 1971).

bio-assay/paralytic shellfish poison

McFarren, E.F., M.L. Schafer, J.E. Campbell, K.H. Lewis, E.T. Jensen, E.J. Schantz. 1960. Public health significance of paralytic shellfish poison. Advan. Food Res. 10: 135-179. (Cited from Ray, 1971), (annotation from Rounsefell and Nelson, 1966).

In this report it is stated that the only known case of shellfish poisoning from eating oysters occurred in Baynes Sound (western side of the Gulf of Georgia), British Columbia from eating cultivated oysters (Japanese), _Crassostrea_ _gigas_.

"...The appearance of the poison in the oysters was accompanied by a much higher level of toxicity in butter clams in adjacent areas, while little neck clams, razor clams, and cockles exhibited a relatively lower level of toxicity. In this instance, the oysters appeared to rid themselves of the poison more rapidly than other bivalves after the ingestion of the toxic plankton had ceased." (p. 145).

public health/paralytic shellfish poison/oysters/toxicity/butter clams/ toxic plankton

McFarren, E.F., E.J. Schantz, J.E. Cambell, K.H. Lewis. 1958. Chemical determination of paralytic shellfish poison in clams. J. Ass. Office Agr. Chem. 41: 168-177. (Cited from Ray, 1971).

chemical determination/paralytic shellfish poison/clams

McFarren, E.F, I.I. Tanabe, F.J. Silva, W.B. Wilson, J.E. Cambell, and K.H. Lewis. 1965. The occurence of a ciguatera-like poison in oysters, clams, and *Gymnodinium breve* cultures. Toxicon 3: 111-123. (Cited from Ray, 1971).

ciguatera-like poison/oysters/clams/*Gymnodinium breve*/cultures

Mold, J.D., J.P. Bowden, D.W. Stanger, J.E. Mourer, J.M. Lynch, R.S. Wyler, E.J. Schantz, and B. Riegerl. 1957. Paralytic shellfish poison. VII. Evidence of the purity of the poison isolated from toxic clams and mussels. J. Amer. Chem. Soc. 79: 5235.

paralytic shellfish poison/purity/poison/isolated/toxic clams/mussels

Moore, M.A. 1881. Fish mortality in the Gulf of Mexico. Proc. of U.S. Nat. Mus. 4: 125.

"Braidtown P.O., Manatee County, Florida, November 30, 1880. Sir...About 2 years ago certain portions of our Gulf became poisoned in some way that caused the death of all the fish that came in contact with it...

"This state of affairs has occurred again; the waters of some portions of the Gulf became so noxious as to kill the fish. The poison seems to be confined to certain localities and currents for the time being, as sometimes this state of affairs is observed more marked at one place and sometimes at another. However, there seems to be more of it about the mouth of Charlotte Harbor and off Punta Rossa than elsewhere.

"When this condition of water prevails, the surface of the water is covered with dead fish, and the beach is covered with them in such numbers that sometimes the stench is intolerable...The principle game of the fishing-smack are the grouper, and the snapper. These, with the perch, king-fish, trout...seem to be much more affected than the mullet, or the pompano...Numbers of sharks and rays, eel and catfish are thrown up dead on the beach... own opinion - condition caused by volcanic action."

fish mortality/Gulf of Mexico/poison/Charlotte Harbor

Morton, R.A. and M.A. Burklew. 1969. Florida shellfish toxicity following blooms of the dinoflagellate Gymnodinium breve. Florida Department of Natural Resources, Technical Series 60, 26pp.

"Abstract - Two related occurrences of Florida shellfish poisoning during August and November 1967, and January 1968, following Red Tide outbreaks of Gymmodinium breve Davis on the west coast of Florida, provided an opportunity to study relationships between toxicity and G. breve, salinity, and tide. Nineteen stations were established from Tampa Bay to Cape Romano. Toxicity of shellfish was determined by mouse bioassay. Related data collected included salintiy, tide, and cell counts of G. breve. Highest toxicity recorded was more than 60 mouse units (MU) while G. breve counts were as high as one million cells per liter. In general, toxicity rose following an influx of G. breve into an area, and fell soon after G. breve was no longer recorded. Shellfish toxicity was indirectly related to salinity and tides. Long-term monitors of affected areas demonstrated no toxicity during non-bloom periods.

"A review of the chemical nature of the Gymnodinium breve toxin shows that two or more fractions are present and determination of the identical or non-identical nature of G. breve poison and Florida shellfish will be accomplished with final chemical characterization of these two toxins."

Florida/shellfish toxicity/blooms/dinoflagellate/Gymnodinium breve/mouse/bioassay/salinity/tides

Needler, A.B. 1949. Paralytic shellfish poisoning and Goniaulas tamerensis. Jour.Fish. Res. Bd. Canada 7(8): 490-504.

It is believed that periodic paralytic poisoning produced by molluscs in certain areas of the Bay of Fundy is caused by G. tamarensis in the food of the molluscs. The abundance of G. tamerensis is shown to be principally affected by water temperature, by the abundance of the predatory ciliate, Favella ehrenbergii, and possibly by the diatom population.

paralytic shellfish poisoning/Goniaulax tamarensis/molluscs/Bay of Fundy/temperature

Nishikawa, T. 1901. Gonyaulax and the discolored water in the Bay of Agu., Annot. Zoological Japonensis. 4: 31-34. (cited from Brongersma-Sanders, 1957).

(from Rounsefell and Nelson, 1966) - "An outbreak of red water bt Gonyaulax Polygamma did no damage; earlier outbreaks in some localities were reported to be highly destructive to pearly oysters, fishes, and crustaceans."

discolored water/Bay of Agu./Gonyaulax polygamma/pearl oysters/fishes/crustaceans

Numann, Wilhelm. 1957. Naturliche und kunstliche "red water" mit anschliessenden Fischsterben im Meer. (Natural and artificial "red water" with associated fish mortalities in the sea). Arch. Fischereiwiss. 8(3): 204-209. (Summarized from a translation by Alexander Dragovich, in Rounsefell and Nelson, 1966).

"The outbreaks of red water never occurs in the open sea, but always in bays and coastal areas which are rich in nutrients. According to all reports, outbreaks of red water most obviously occur in coastal areas a short time after precipitation. The bloom of Exuviella occurred in the coastal area of Angola after heavy rainfall in the hills of Binnenland. The Congo and Cuanza Rivers brought much water which was spread throughout the surface layers of coastal waters.

"It also appears -- and this is our final conclusion -- that a mass outbreak of phytoplankton occurs when freshwater growth-promoting substances (trace elements, enzymes, or other biologically active substances) reach the sea. Due to the presence of a necessary quantity of nutrients in the sea, a pre-condition for the outbreak of plankton in the sea exists already. Accordingly, these outbreaks occur only near the coast."

red water/nutrients/bloom/heavy rainfall/growth-promoting substances

Odum, Howard T. 1953. Dissolved Phosphorus in Florida waters. Florida Geol. Survey, Rept. No. 9 Misc. Studies, Part 1: 1-40.

"Abstract - A basic survey has been made of the concentrations of dissolved phosphorus in many types of Florida's surface waters. The extensive deposits of phosphate rock in Florida lead to unusually high dissolved phosphorus content in the streams and lakes which drain these areas. Thus these waters are potentially of high fertility for growth of aquatic organisms. Additional quantities of dissolved phosphorus are being added by sewage and industry in some areas, although little recognition has been made of the possibility of large biological effects that relatively small amounts of added phosphorus can have on those areas which are not receiving drainage from phosphate areas. The moderately low phosphorus content of basic springs in contrast to acid surface streams suggest a controlling role of pH in phosphorus rainwaters are continually concentrating phosphorus in the layers just beneath the surface as the acid rainwater becomes basic. The natural and artificial phosphates contributing to Florida's surface streams hypothetically seem to be of the magnitude to contribute to red tide phenomenon and the rapid growth of water hyacinths in prescribed areas."

dissolved phosphorus/Florida/surface waters/phosphate rock/pH/red tide

Pearsall, W.H. 1932. Phytoplankton in the English lakes. II. The composition of the phytoplankton in relation to dissolved substances. J. Ecol. 20(2): 241-262. (cited from Ryther, 1955).

phytoplankton/English lakes/dissolved substances

Porter, Joseph V. 1881. On the destruction of fish by poisonous water in the Gulf of Mexico. Proc. U.S. Nat. Mus. 4: 121-123.

"January 21, 1879...It seem to be the general opinion in this section among non-scientific men that the destruction of fish has been due to the saturated condition of the water with dogwood (Cornus florida)." Increased rainfall with flooding inland, contaminated the Gulf water. Another opinion is expressed in the same communication allocating the cause of mortality to volcanic action. On answering this communication in Forest and Stream the editor repeats the problem of fish mortality and states "the polluting substance, whatever it may be, is evidently most subtle, for its influence is seen for a distance of 200 miles, dead fish covering the surface of the ocean wherever the eye rests. One proof of this volcanic origin is that the water so polluted is of a 'red brick' color. At a distance of less than a mile from the shore, while the interval of water along the land is natural in color and taste."

fish/poisonous water/Gulf of Mexico/dogwood/rainfall/flooding

Prakash, A., 1963. Source of paralytic shellfish toxin in the Bay of Fundy. J.Fish. Res. Bd. Can. 20: 983-996. (Cited from Ray 1971).

paralytic shellfish toxin/Bay of Fundy

Prakash, A. and M.A. Rashid. 1968. Influence of humic substances on the growth of marine phytoplankton: dinoflagellates. Limnol. Oceanog. 13: 598-606.

"Abstract - Humic substances in small amounts exert a stimulatory effect on marine dinoflagellates that is reflected in increased yield, growth rate, and C uptake. Humic acid was found to be more active than fulvic acid; in both cases the growth responses were dependent on concentration of the various fractions isolated, the low molecular weight fractions of humic acid produced the greatest growth response in unialgal cultures of dinoflagellates.

The positive effect of humic substances on phytoplankton growth is, for the most part, independent of nutrient concentration and cannot be attributed entirely to chelation processes. It appears that growth enhancement in the presence of humic substances is linked with stimulation of algal cell metabolism. Because of their high concentrations in coastal waters, humic substances may thus be regarded as an ecologically signigicant entity influencing phytoplankton productions."

humic substances/growth/marine phytoplankton/dinoflagellates

Precott, G.W. 1948. Objectionable algae with reference to the killing of fish and other animals. Hydrobiologia, the Hague vol. 1(1): 1-13. (cited from Brongersma-Sanders, 1957).

objectionable algae

Pringle, B.H. 1966. Analytical procedures for paralytic shellfish poison. In Proceedings, Joint Sanitation Seminar on North Pacific Clams, Jureau, 1965 (W.A. Felsing, Jr. Ed.), pp. 16-17. Alaska Dep. Health and Welfare, U.S. Pub. Health Serv., Washington, D.C. (cited from Ray, 1971).

analytical procedures/paralytic shellfish poison

Quayle, D.B. 1969. Paralytic shellfish poisoning in British Columbia. Bull. Fish. Res. Bd. Can. 168: 68pp. (cited from Ray, 1971).

paralytic shellfish poisoning/British Columbia

Ray, Sammy M. 1971. Paralytic shellfish poisoning; A status report. In Current Topics in Comparative Pathobiology, vol. 1, Academic Press, New York, T.C. Cheng (ed.), pp. 171-200.

(from introduction and summary of paper)

"Severe and often fatal human intoxications following the ingestion of bivalve molluscs occur sporadically in widely scattered areas throughout the world. This illness, generally referred to clinically as paralytic shellfish poisoning (PSP), is most prevalent in temperate regions. Other designations, such as mussel, clam, or gonyaulax poisoning, paresthetic shellfish poisoning, and mytiloin toxication are used for the same illness. Certain species of dinoflagellates, especially those of the genus _Gonyaulax_, have been definitely established as a source of the toxin. Filter-feeding molluscs i.e. mussels, clams, oysters, scallops, etc., accumulate the toxin without harm to themselves, by ingesting toxic dinoflagellates. A number of reviews (McFarren _et al_., 1960; Schantz, 1960; Halstead 1965; Russell, 1965; Kao, 1966; Evans 1969a; Quayle, 1969) of various aspects of PSP have appeared in recent years. Halstead (1965) provides an excellent and especially comprehensive review. This report does not consider other types of shellfish poisoning: gastrointestinal or choleratic, erythematous or allergenic, venerupin, collistin, and minamata desease. General accounts of these forms of shellfish poisoning are presented by Halstead (1965). Consult Halstead (1967) for a brief account of and references dealing with minamata disease, which is caused by the ingestion of shellfish that have accumulated mercury. With the exception of minamata disease, the other types of shellfish poisoning do not cause paralysis or neurotoxic symptoms such as those that characterize PSP. Because of its relatively low incidence, PSP does not constitute a major public health concern. According to Halstead (1965), more than 957 cases of PSP, which resulted in more than 222 deaths, have been reported to have occurred between 1793 and 1962. Other cases of low mortalities have been reported from various parts of the world during the same time interval and since 1962. There have been 3 confirmed incidences of PSP on the west coast of the United States in recent years with no resulting fatalities. PSP is definitely a problem of the temperate regions of the World. A few cases of mild human illness have been associated with consumption of oysters and clams taken during red tide outbreaks caused by _G. breve_ on the west coast of Florida (Eldred _et al_., 1964; McFarren _et al_., 1965). The symptoms observed were similar to the early symptoms of PSP, but according to McFarren _et al_. (1965) the toxin was more similar to ciguatera, which is found in certain fishes in tropical areas, than to PSP. The consumption of bivalve molluscs, especially mussels and clams, is the most common cause of recorded incidents of PSP (Halstead, 1965). Because of their great filtering capacity, bivalve molluscs are unquestionable the most serious cause of poisoning. Rates of accumulation and loss of toxin by molluscs, as well as its anatomical distribution, vary from species to species (Sommer et al., 1937; Sommer and Meyer, 1937; Medcof et al., 1947; Quayle, 1969). Nontoxic organisms have been known to become toxic within a day or two in both natural and experimental conditions (Meyer et al., 1928; Prakash, 1963). Generally the digestive glands (hepatopancreas, liver, or dark gland) accumalate the greatest concentration of the poison, and it appears to be eliminated without appreciable accumulation in other organs. Some species, i.e. the butterclam (S. giganteus), accumulate the toxin in the siphon following initial accumulation in the digestive gland (Medcaf et al., 1947; Quayle, 1969). Scallops may become highly toxic for long periods (Medcof et al., 1947; McFarren, 1959; McFarren et al., 1960; Halstead, 1965; Anonymous, 1970). A mouse unit is defined as the amount of poison injected intraperitoneally that will kill a 20 gm. mouse in 15 minutes with typical symptoms of paralysis and respiratory failure. Conc. of less than 200 mouse units/ 100 gm of shellfish cannot be accurately measured by this method. A chemical method for quantitating PSP, based on the Jaffe test, has been developed by McFarren et al., (1958), and a serological test has been developed by Johnson and Mulberry (1966). Pringle (1966) concluded that the mouse bioassay is still the most suitable method developed thus far to quatitate PSP. With purification of clam and mussel toxins (Mold et al., 1957), Schantz et al. (1958) recommended the use of purified clam toxin to standardize the mouse bioassay. The purified clam toxin is known as saxitoxin since it is extracted from siphons of butter clams (S. giganteus). Thus the amount of toxin may be reported by weight (micrograms) rather than mouse units. McFarren et al. (1960) gives the average conversion factor (CF) obtained by several laboratories as 0.191μg of poison/mouse unit. Therefore the previously accepted tolerance level of 400 mouse units/100 gm of shellfish = 80μg/100 gm shellfish (Jensen, 1959). Cooking does not destroy PSP. Since PSP are directly related to the occurrence of toxic dinoflagellates (Sommer et al., 1937; Needler, 1949; Prakash, 1963; Wood, 1968), the systematic search for dinoflagellate blooms as indicated by discolored water (red tides or red water) and plankton sampling for toxic dinoflagellates may be used to determine where and when poisonous shellfish may be likely to occur."

paralytic shellfish poisoning/human intoxications/bivalve molluscs/ Gonyaulax/dinoflagellates/mild human illness/oysters/clams/red tids/ G. breve/Florida/toxin/ciguatera/digestive glands

Ray, S.M. and W.B. Wilson. 1957. Effects of unialgal and bacteria-free cultures of Gymnodinium brevis on fish and notes on related studies with bacteria. Spec. Sci. Rep. U.S. Fish. Wildl. Serv. Fish., 211: 50 pp.

Extensive experiments were performed to prove that Gymnodinium breve produces a toxin that kills fish. Experiments showed that cultures of G. breve killed fish, while cultures of G. splendens and of Prorocentrum sp. did not.

Experiments with Flavobacterium piscicida failed to show any toxic effects. Lasker (Bein, 1954) had isolated this red-pigmented bacterium; Bein's experiments indicated 24-hour cultures killed several species of marine fish. Experiments showed that water already made toxic does not lose its toxicity for some time after the removal of G. breve. Likewise, the occurrence of any condition unfavorable to the organism may cause disintegration of the cells so that the water may be toxic even though it contains only fragmentary remains of G. breve cells that are not readily indentifiable.

Filtrates of G. breve passed through a millipore filter were more toxic than filtrates passed by gravity through filter paper. The authors suggested this difference may be due to more organisms being retained intact by the filter paper.

They found no indication that fish kills by G. breve result from depletion of oxygen by the great masses of the organism.

Degree of toxicity of G. breve cultures was influenced, aside from concentration, by such factors as the growth phase of the culture, the pH of the culture during the growth and the test periods, temperature and salinity of the test culture, the size and number of the test fish, the volume of the test culture, and bacterial growth.

"Bacteria-free cultures of G. breve with concentrations varying from 2.3 to 4.8 million organisms per liter were toxic to two species of test fish. Five species of fish were killed when subjected to unialgal G. breve cultures containing 0.6 to 2.1 million organisms per liter..." (p. 495).

unialgal/bacteria-free cultures/Gymnodinium brevis/toxin

Riegel, Byron, D. Warren Stanger, Donald M. Wikholm, James D. Mold, and H. Sommer. 1949. Paralytic shellfish poison. V. The primary source of poison the marine plankton organism, Gonyaulax catenella. Jour. Biol. Chem. 177(1): 7-11.

A large scale collection of marine plankton rich in G. catenella, was made with super centrifuges from Monterey Bay waters, California. The poison was extracted with alcohol. Choline, trimethylamine, and an unidentified base were isolated from the non-toxic fraction of the extract.

paralytic shellfish poison/poison/marine plankton/Gonyaulax catenella/ Monterey Bay/California

Rice, Theodore R. 1954. Biotic influences affecting population growth of planktonic algae. Fish Wildl. Serv., Fish. Bull. 54: i + p. 227-245. (from Rounsefell and Nelson, 1966).

"It is concluded that antagonistic substances arising from the metabolism of phytoplankton are important, at least in fresh-water ponds, in influencing the seasonal fluctuations in total phytoplankton numbers and in the numbers of each species, as well as in causing a definite succession of species." (p. 244).

biotic influences/population growth/planktonic algae/metabolites

Rounsefell, George A. and Walter R. Nelson. 1966. Red-Tide research summarized to 1964 including an annotated bibliography. U.S. Dept. of Int., Fish. and Wildl. Serv., Spec. Sci. Rept. Fish. No. 535, pp. 85.

"Abstract. This paper summarizes from published and unpublished data and reports the status of research on the Florida red tide up to 1964. It contains 292 references, mostly annotated, on red tide and closely related subjects. The relation of oceanographic conditions to red tide blooms, the seasonal and coastwise distribution of the Florida red tide, and progress in various aspects of research are discussed."

Florida/red tide/annotated/blooms

Russell, F. E. 1965. Marine toxins and venomous and poisonous marine animals. Advan. Mar. Biol. 3: 255-384. (cited from Ray, 1971).

marine toxins/venomous and poisonous marine animals

Ryther, J.H. 1955. Ecology of autotrophic marine dinoflagellates with reference to red water conditions. *In* The Luminescence of Biological Systems (F. H. Johnson, ed.) AAAS Washington, D.C., pp. 387-414. Also in collected reprints, Woods Hole Oceanographic Inst. Contri. No. 712.

"The dense populations of dinoflagellates which create 'red water' conditions are known only in the tropics or temperate water during the warmer (and usually warmest) time of the year..."

"Such fragmentary physiological evidence as is available concerning the temperature relations of dinoflagellates appears to support the view that they are predominantly a warm-water group. Barker (1935), who is one of the pioneers in developing successful culture methods for dinoflagellates, observed optimal temperatures for the growth of some 14 spp. between 18° and $25^{\circ}C$. Braarud and Pappas (1951) noted a temperature optimum for *Peridinium triquetrum* at $18^{\circ}C$., while Norsli (1953) found that *Ceratium fustus* and *C. furca* grew most rapidly at temperatures of 15° and $20^{\circ}C$. respectively. Provasoli (personal communication) finds temperatures of 20-$25^{\circ}C$ most suitable for growing *Gyrodinium californicum*..." (p. 389-390).

Salinity ranges were found to be wide and include both open ocean and estuarine salinities within the tolerences of most dinoflagellates.

"The dinoflagellates have often been credited with the ability to utilize and flourish in extremely low concentrations of nitrogen and phosphorus (Gran, 1926-27; Gilson, 1937). This concept has stemmed from observations that dinoflagellate maxima follow spring diatom flowering when nutrients are almost depleted...Gran (1926-27) has proposed that the dinoflagellates require less nutrition for growth than the diatoms on account of their relatively low rate of metabolism." (p. 391-392).

The author suggested that growth of dinoflagellates may be dependent upon, or at least benefited by, the previous flowering of diatoms. This he suggested (cited Pearsall, 1932, and Hutchinson,

1944) as possibly caused by the reduction of the concentrations of one or more of the nutrients or trace metals by diatoms to a level favorable for dinoflagellates. On the other hand, Lucas (1947, 1949) proposed that the production of external metabolites, or "ectrocrines" by one group of plankton organisms may benefit the succeeding population, but inhibit competing organisms.

Ryther suggested three means by which organisms accumulated at the surface of the water may be further concentrated:

"(1) Prevailing onshore winds: Surface water driven shoreward by prevailing onshore winds establishes a circular pattern, sinking at the waters edge and returning seaward at lower depths. Bouyant organisms will accumulate in windrows along shore or at the region of descent.

(2) Where brackish coastal water, particularly in the vicinity of river mouths, meets open ocean water, there is a mixing and sinking of the two water masses along a line of convergence. Both types of water flow toward this line, and bouyant organisms will accumulate at or near the convergence line, producing streaks of floating material.

(3) Convection cells: Wind-driven vertical convection cells may be established which rotate alternately clockwise and counter-clockwise with their vertical axes perpendicular to the direction of the prevailing wind. Floating objects will accumulate in the region between the descending components of two such adjoining cells. Under these conditions parallel streaks of floating matter are produced. "Langmuir, 1938; Stommel, 1949) (p. 409).

ecology/autotrophic marine dinoflagellates/red water/culture methods/optimal temperatures/salinity ranges/nutrients/trace metals/external metabolites/ectrocrines/windrows/convergence/convection cells

Sasner, J.J., Jr., Miyoshi, Ikawa, F. Thurberg, and Maktoob Alam. 1971. Physiological and chemical studies on _Gymnodinium_ _breve_ Davis toxin. Toxicon (In Press).

"Abstract. The marine dinoflagellate _Gymnodinium_ _breve_ was cultured under completely defined conditions and provided toxic material for chemical and physiological studies. Ether extracts from cultures, when bioassayed using mice and fish, confirmed that potency was related to numbers of cells extracted. A toxic component was isolated from these extracts and partially characterized by chromatographic and spectral methods. A molecular weight of 179 was determined by both osmometry and mass spectrometric analysis. The active material blocks neuromuscular transmission in frog sartorious preparations before rendering the nerve and then the muscle inexcitable to the nerve and then the muscle inexcitable to stimule but does not alter the transmembrane potential. Synaptic effects are blocked by curare. The primary site of action appears to be at the end plate although the specific mode of action is not yet completely clear. Physiological and pharmacological studies using mammalian intestine, vertebrate and invertebrate heart preparations, and human serum indicate anticholinesterase-like activity."

Gymnodinium _breve_/toxin/molecular weight/anticholinesterase-like activity

Schantz, E. J. 1960. Biochemical studies on paralytic shellfish poisons. Ann. N.Y. Acad. Sci. 90: 813-155. (cited from Ray, 1971).

paralytic shellfish poisons

Schantz, E.J. 1966. Chemical studies on shellfish poison. In Proceedings Joint Sanitation Seminar on North Pacific Clams. Juneau, 1965 (W.A. Felsing, Jr., ed.), pp. 18-21. Alaska Dep. Health and Welfare, U.S. Pub. Health Serv., Washington D.C. (cited from Ray, 1971).

shellfish poisons

Schantz, E.J., E.F. McFarren, M.L. Scharer, K. H. Lewis. 1958. Purified shellfish poison for bioassay standardization. J. Ass. Offic. Agr. Chem. 41: 161-168. (cited from Ray, 1971).

shellfish poison/bioassay

Schantz, E.J., J.D. Mold, D.W. Stanger, J. Shabel, F.J. Riel, J.P. Bowden, J.M. Lynch, R.W. Wyler, B. Riegel, and H. Sommer. 1957. Paralytic shellfish poison. VI. A procedure for the isolation and purification of the poison from toxic clam and mussel tissues. J.Amer. Chem. Soc. 79: 5230. (cited from Ray, 1971).

paralytic shellfish poison/toxic clam/mussel

Shelubsky, M. 1951. Observations on the properties of toxin produced by *Microcystis*. Verh. Intern. Ver. Theor. Ang. Limnol. 11: 362-366. (cited from Brongersma-Sanders, 1957).

Shilo (Shelubsky), M., and M. Aschner (1953). Factors governing the toxicity of cultures containing the phytoflagellate *Preymnesium parvum* Carter. J. Gen. Microbiol. 8(3): 333-343. (Reference from Rounsefell and Nelson, 1966).

Concerning this paper Ray and Wilson (1957, p. 488) stated: "Another role for which bacteria must be considered in that of a detoxicating agent. Shilo and Aschner (1953) found that bacteria decreased the toxicity of cultures of *Prymnesium parvum*, a marine and brackish water chrysomonad that is toxic to fish. Similarly, bacterial activity may influence the toxicity of *G. breve* in the laboratory and in nature."

toxicity/cultures/*Prymnesium parvum*/bacteria/detoxicating agent

Slobodkin, L.B. 1953. A possible initial condition for red tides on the coast of Florida. J. Mar. Res. 12(1): 148-55.

"Abstract. It seems likely that the occurrence of a discrete mass of water, with a salinity lower than that of normal Gulf of Mexico surface water, is a necessary prerequisite for the occurrence of red tide off the Florida coast."

initial condition/red tides/Florida/salinity

Smith, R.C. and J.E. Tyler. 1967. Optical properties of clear natural water. J. Optical Soc. Amer. 57: 589-595. (Cited from Clarke, 1969).

optical properties/natural water

Sommer, H. and Francis N. Clark. 1946. Effect of red water on marine life in Santa Monica Bay, California. Calif. Fish and Game 32(27): 100-101.

Occurrence of red waters caused by _Ceratium tripos_ and _Polykrikos schwartzi_ along southern California shores in June 1945 is reported, with heavy mortality of shore animals, especially the spiny lobster, _Panulirus interruptus_.

red water/marine life/Santa Monica Bay, California/_Ceratium tripos_/_Polykrikos schwartzi_/heavy mortality/spiny lobster/_Panulirus interruptus_

Sommer, H. and K.F. Meyer, 1937. Paralytic shellfish poisoning. Arch. Pathol. 24: 560-598. (cited from Ray, 1971).

paralytic shellfish poisoning

Sommer, H., R.P. Monnier, B. Riegel, D.W. Stanger, J.D. Mold, D.M. Wikholm, and E.S. Kiralis. 1948. Paralytic shellfish poison. I. Occurrence and concentration by ion exchange. Jour. Am. Chem. Soc. 70: 1015-1018.

Sommer, H., B. Riegel, D.W. Stanger, J.D. Mold, D.M. Wikholm, and M. B. McCaughey. 1948. Paralytic shellfish poison, 2. Purification by chromatography. Jour. Am. Chem. Soc. 70: 1019-1021.

Sommer, H., H.W. Weldon, D.A. Kofoid, and R. Stohler. 1937. Relation of paralytic shellfish poison to certain plankton organisms of the genus _Gonyaulax_. Arch. Pathology 24: 537-559.

Spikes, John J. 1971. Extraction, concentration, and biological effects of a toxic material from _Gymnodinium breve_ . PhD. thesis to the University of Texas Medical Branch, Galveston.

"Summary and Conclusions.

1. Material extracted from cultures of _Gymnodinium breve_ with ether at pH 5.5 has shown to be toxic to frogs, mice, rats and dogs. This extracted material was partially purified by: (1) precipitation of some impurities with acetone, (2) three separate TLC migrations using different pH and developing solutions.
2. The LD_{50} of the partially purified toxin was 0.50 ± 0.01 mg/kg intraperitoneally in mice. The stability to both heat (100°C. for 60 min.) and time (30 days at 4°C.) has been established.
3. The actions have been studied with both _in vivo_ and _in vitro_ preparations in mice, rats and frogs and found to be (1) inauguration of action potentials then inhibition of conduction in somatic motor nerves, probably by membrane depolorization, (2) generalized skeletal muscle fasciculation, and (3) respiratory failure.

4. The effects of intravenous injection of the toxin in dogs were found to be (1) a period of directly related dose-dependent apnea, (2) bradycardia, (3) a triphasic vasodepressor-pressor-depressor-response, (4) cardiac irregularities, including increased automaticity and ventricular fibration, and (5) generalized muscle fasciculation.
5. Using various ganglionic blocking agents, vagotomy and acetylcholine antagonist in dogs, it was shown that the bradycardia was probably the result of increased vagal activity brought about either by direct or reflex stimulation of central vagal centers.
6. Using various autonomic blocking agents in dogs, it was shown that the depressor effect was probably the result of reflexes initiated by the bradycardia, plus an effect through the sensory nerve endings in heart and lung or chemoreceptors in the corotid body and aortic arch.
7. The pressor response to the toxin was probably the result of catecholamine release as demonstrated in dogs, using an alpha adrenergic blocking agent and reserpine.
8. The mode of action producing the secondary depressor effect has not yet been delineated and this response may be a continuation of the initial depressor action following an intervening superimposed pressor effect.
9. It is proposed that the toxin had a direct effect on the myocardium in dogs, producing arrhythmias, increased automatically and ventricular fibrillation. The fibrillation was probably due to first sensitizing the myocardium to catecholamine and then releasing catecholamine.
10. Employing evidence obtained with _in vitro_ cholinesterase determinations and _in vivo_ acetylcholine potentiation studies in dogs, it was concluded that the toxin employed in this study did not inhibit the enzyme cholinesterase.
11. It is proposed that the effects seen on somatic-motor nerves, the sympathetic and parasympathetic nervous systems are the results of membrane depolarization similar to that seen by Sasner (1966).

extraction/concentraion/biological effect/toxic material/_Gymnodinium breve_

Steidinger, K.A., M.A. Burklew, and R.M. Ingle. 1971. The effects of _Gymnodinium breve_ toxin on Estuarine animals. Florida Dept. of Nat. Res. Mar. Res. Lab. St. Petersburg, Florida. To appear in Marine Pharmacognosy, Academic Press, Padilla and Martin (eds.). (In Press)

The ecological background data on Florida Red Tide and _Gymnodinium breve_ are presented as preliminary information for a review of literature and research of the characterization of _G. breve_ toxin, and the pathological and physiological characters of the toxin. A suggestion of research needed and methodology available in toxin studies are reviewed.

Gymnodinium breve/toxin/estuarine animals

Stephens, E.L. 1948. Microcystis toxica sp. nov. a poisonous alga from the Transvaal and the Orange Free State. Hydrobiologia, 1: 14. (cited from Brongersma-Sanders, 1957).

Microcystis toxica/poisonous alga/Transvaal/Orange Free State

Steyn, Douw G. 1945a. Poisoning of animals and human beings by algae. So. African Jour. Sci. 41: 243-244. (cited from Brongersma-Sanders, 1957).

poisoning/animals/human beings/algae

Steyn, Douw G. 1945b. Poisoning of animals by algae (scum or water bloom) in dams and Pans. Pamphlet Dept. Agricult. Pretoria, 9pp. (cited from Brongersma-Sanders, 1957).

poisoning/animals/algae/water bloom

Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1946. The Oceans, their physics, chemistry, and general biology. x + 1087pp., 265 figs. New York: Prentice-Hall.

Taylor, H.F. 1917. Mortality of fishes on the west coast of Florida Rep. U.S. Comm. Fish. for 1917, append. 3. 24p. also in Science 45(1163): 367-368. (cited from Gunter, 1947).

mortality/fishes/Florida

Trieff, N.M., J.J. Spikes, S.M. Ray, and J.B. Nash. 1971. Isolation and purification of Gymnodinium breve toxin. In Toxins of Plant and Animal Origin. pp. 557-577. A. DeVries and E. Kochua, eds. Gordon and Breach, London (In Press)

isolation/purification/Gymnodinium breve/toxin

Trieff, N.M., N. Venkatasubramanian, and S.M. Ray. 1971. Purification of Gymnodinium breve toxin - dry column chromatography technique. Presented in part at the Texas Academy of Science 74th Annual Meeting. Macogdoches, Texas, March, 1971. unpublished manuscript., 14 pp.

"Abstract - A method of purification of Gymnodinium breve toxin is described which utilizes the techniques of dry column chromatography and thin layer chromatography. Data on toxicity determinations by mouse bio-assay were used to calabrate LD_{50}'s for various stages of purification. Elemental analytical and molecular weight data are also presented."

Gymnodinium breve/toxin/dry column chromatography/purification/mouse bio-assay

Tyler, J.E. and R.C. Smith. 1967. Spectroradiometric characteristics of natural light under water. J. Optical Soc. Amer. 57: 595-601. (cited from Clarke, 1969).

U.S. Fish and Wildlife Service. 1958. Red Tide symposium, Galveston, Texas, March 5-7, 1958. 72 pp.

Walker, S.T. 1884. Fish mortality in the Gulf of Mexico. Proc. U.S. Nat. Mus., 6: 105-109. (1883).

Many species of fish were killed in the 1883 mortalities. Certain types were killed first, but all seemed to follow the same pattern of dying - suddenly in a matter of minutes after contacting the poison water, they would convulse and die. The following are brief observations by the writer:

"1. The dead fish were most numerous about the mouths of rivers, decreasing gradually as one approached such places.

2. The dead fish were most numerous on the outside beaches and on the inside beaches of the outer line of keys.

3. That the poisoned water was not diffused, generally, but ran in streams of various sizes, as proven by fish dying in vast numbers instantly upon reaching such localities.

4. That the fish were killed by a specific poison, as proven by the sickness and death of birds which ate of the dead fish (terns, gulls, frigate birds, cormorants) and (ducks and vultures).

5. The fish dying on the outside beaches first.

6. The examination of many hundred recently-dead fish revealed no signs of disease. -color normal, flesh firm, gill's rosy, and stomach and intestines normal."

fish mortality/Gulf of Mexico

Wilson, William B. 1958. Compounds toxic to red tide organisms. In Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish Wildl. Serv., p. 66-67.

Discusses progress on factors affecting the toxicity of copper to *G. breve*.

"Tests on the toxicity of fluorescine dye to *G. breve* indicates that it is not toxic in concentrations of 100 parts per million. These results indicate that flourescine dye can be used as a marker in field experiments without altering the results." (p. 67).

toxic/red tide organisms/fluorescine dye/*G. breve*

Wilson, William G. 1959a. Evaluating toxicity of dissolved substances to microorganisms using dialysis membranes. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 100-102. U.S. Fish. Wildl. Serv., Circ. 62.

To test the effects of copper in the field, known concentrations of *Prorocentrum sp*. were placed in bags made of dialysis membrane. The bags were suspended inside perforated polyethylene bottles for protection from microorganisms.

"...Between two and five hours were required for the inside concentration to approach 0.8 g. at. Cu/l. with an outside concentration of 0.8 g. at. Cu/l. did not raise the inside concentration to a comparable amount within 24 hours." (p. 101-102.).

toxicity/dissolved substances/microorganisms/dialysis membranes/copper
Prorocentrum sp.

Wilson, William B. 1959b. Nutritional effects on red tide. In Galveston Biological Laboratory fishery research for the year ending June 30, 1959, p. 72-74. U.S. Fish Wildl. Serv., Circ. 62.

"The minimum calcium content of media in which G. breve grew was approximately one-sixth the amount of standard sea water (salinity - 35.5^{o}/oo), or approximately 70mg/l. (1.7mg at/l). An increase in calcium to twice the amount of open ocean water was not detrimental as long as the phosphorus content was less than 5μg at /l. If the calcium content is between 140 and 400 mg/l, cultures have grown very well in most concentrations of phosphorus. There was some limitation of growth if the phosphorus was less than 0.04μg at/l or more than 100μg at/l. In the latter case, the high phosphorus content caused precipitation, as did excessive calcium. When precipitation occurred, G. breve did not grow.

"The results of the calcium-phosphorus experiments indicate that if the calcium concentration was the same as that of normal open ocean water (approximately 400 mg/l), inorganic phosphorus content should be 0.4μg at. per liter or greater for the medium to support good growth of G. breve. Optimum growth occurred within a range of 0.4 to 40 μg at/l of phosphorus if the calcium content was between 140-250 per liter. On the other hand, media with calcium concentration as high as 1,000 mg per liter supported good growth if the phosphorus content was between 0.04 and 4.0μg at/l. The above values for calcium and phosphorus should be revised slightly upward (less than 0.01 percent) because of the occurrence of these elements as contaminants in the other components of the medium. (p. 72).

"Vitamins. Three water soluble vitamins, thiamin (B_1), biotin (B_3) and cobalamine (B_{12}), have been used consistently in artificial sea water media for bacteria-free G. breve. Results of earlier experiments indicated that G. breve would not grow in these media unless these vitamins were added. In addition, thiamin was the most effective of the three vitamins, but a combination of thiamin and biotin supported better growth than thiamin alone. During the past year, a series of nine experiments were conducted to define more clearly the role of these vitamins in the growth of G. breve. (p. 72-73).

"Results of these experiments are similar in many ways to the results of previous work in that thiamin was the most active of the three vitamins and a combination of thiamin and biotin was better than thiamin alone. However, these experiments indicate that the inclusion of cobalaminealong with the thiamin and biotin further improved growth. In the earlier experiments, we had omitted cobalamine in ten serial subcultures without diminution of growth. In recent experiments, omission of cobalamine has resulted in lesser growth. To ascertain the source of the apparent discrepancy in these results we will initiate growth experiments using cobalamine and the other vitamins from more than one supply house."(p. 73).

"The need for thiamin is pronounced in the experiments conducted to date. There is a possibility that similar organic compounds will substitute for thiamin and we plan to conduct experiments to determine if such is the case. If not, assays of this vitamin in the field may be valuable for forecasting red tides." (p. 73-74).

"Trace elements. In earlier experiments we were unable to grow G. breve in artificial sea water media unless a group of trace elements was added. We have attempted to determine the elements of this group that are necessary for growth, but to date the results are inconclusive. Some elements, notably zinc, titanium, zirconium, and manganese and boron may be required by G. breve. The results of experiments using these as additives indicate that they may improve growth. Media containing copper, nickel, rubidium, molybdenum and barium have on occasions supported better growth than media to which they were not added. The addition of iron has not improved growth regardless of the concentration or form in which it was added. This does not mean that iron is not needed by the organism because it is a common contaminant of the major salts used in preparing the medium."

"Aged sea water collected from an area of G. breve bloom will substitute for the group of trace elements. The addition of twenty milliliters of this water per liter of medium will support growth of G. breve when used to replace the trace elements. These results indicate that this water contains a relatively high concentration of the required group."

"These elements, with the possible exception of zirconium, are normally present in sea water, and their absence would probably not be a limiting factor for red tides. The form and factor of red tides. We must add metal chelators or metal for G. breve, in most instances. Therefore, the occurrence of natural metal chelators or metal complexes may be necessary for red tides to develop." (p. 74).

Effect of some vitamins and a group of trace elements on the growth of G. breve in artificial sea water medium. (Numbers represent percent of cultures with each addition in each growth category)

Additives	None to slight	Slight (less than 0.5)	Fair (0.5 to 1.0)	Good (more than 1.0)
No addition	100	0	0	0
B_{12}	100	0	0	0
B_1	50	22	28	0
B_3	92	2	4	2
T	100	0	0	0

(table continued)

Additives	None to Slight	Slight	Fair	Good
B_1 and B_{12}............	50	20	30	0
B_3 and B_{12}............	70	4	26	0
T and B_{12}.............	72	6	22	0
B_1 and B_3.............	10	50	25	15
B_1 and T..............	28	35	28	9
B_3 and T..............	80	10	10	0
B_1, B_3, and B_{12}.......	23	0	22	55
B_3, T, and B_{12}.......	92	0	0	8
B_1, B_3, and T.........	15	55	14	16
B_1, B_3, B_{12}, and T....	15	0	0	85

B_1 (Thiamine), B_3 (Biotin), B_{12} (Cobalamine), T (Trace element group) (from Rounsefell and Nelson, 1966)

red tide/calcium/G. breve/calcium-phosphorus/vitamins/trace elements

Wilson, William B. 1960. Red tide investigation. In Galveston Biological Laboratory fishery research for the year ending June 30, 1960, p. 39. U.S. Fish Wildl. Serv., Circ. 92.

Summary of fiscal year progress given in detail in other reports.

Wilson, William B. 1967. Forms of the dinoflagellate *Gymnodinium breve* Davis cultures. Contri. in Mar. Sci. 12: 120-134.

Morphological features of forms of the marine dinoflagellate *G. breve* observed during culture, conditions of cultures and life cycle of the organism were presented. The life cycle of *G. breve* consists of cell growth and cell division with formation of cysts as the only intervening form. Encystment is the formation of a resting stage which can remain on the bottom or in sediments until conditions are right for its normal life cycle. Encysted forms were observed to be in a state of cell division. The cell division rate is 0.4 divisions per day with a maximum observed rate of 0.7 per day.

forms/dinoflagellate/*Gymnodinium breve*/cultures/life cycle/encystment/cell division rate

Wilson, William B. and Albert Collier. 1955. Preliminary notes on the culturing of *Gymnodinium breve* Davis. Science 121 (3142): 394-395. (from Rounsefell and Nelson, 1966).

"...Titanium and zirconium were added to the mixture, although they are not normally present in measurable amounts in sea water, because these metals were found abundantly in water of *G. breve* blooms. (p. 394).

"Laboratory cultures of *G. breve* have attained homogeneous concentrations exceeding 2 million cells per liter. This concentration is far below the highest report, the values cannot be compared. Among other reasons, *G. breve* in cultures concentrate to form masses that we dispense by shaking before making counts. A similar tendency to concentrate, but on larger scale, may be expected in nature. Counts of a sample from such a concentration would be high..." (p. 395).

Gymnodinium breve/titanium/zirconium/laboratory cultures

Wilson, W.B., and Sammy Ray. 1958. Nutrition of red tide organisms. *In* Annual report of the Gulf Fishery Investigations for the year ending June 30, 1958, U.S. Fish. Wildl. Serv., p. 62-65. (from Rounsefell and Nelson, 1966).

Discussion of the development and the formula for an artificial sea water medium for growing bacteria-free cultures of *G. breve* were offered.

"*G. breve* requires phosphorus for growth in this artificial medium, but the absolute amount needed for growth has not been determined because the major salts contain phosphorus as an impurity. Cultures grew well without adding phosphorus until we recrystalized the sodium chloride to increase its purity. Increasing the phosphorus additions above the minimum amount necessary for growth does not increase the number of organisms. The addition of 0.1 microgram atom of phosphate phosphorus per liter (0.1 μg. at P/1) is sufficient to support good growth. Chemical analysis of the medium for total phosphorus with this amount added indicate that it contains between 0.1 and 1.0 μg at P/1. Therefore, the amount of phosphorus required for maximum growth in this medium is apparently about 1.0 μg at P/1 or less..." (p. 64).

nutrition/red tide/artificial sea water medium/bacteria-free cultures/ *G. breve*/phosphorus

Wood, P.C. 1968. Dinoflagellate crop in the North Sea. Nature (London) 220: 21-27. (cited from Ray, 1971).

dinoflagellate/North Sea

Woodcock, A.H. 1948. Note concerning human respiratory irritation associated with high concentrations of plankton and mass mortality of marine organisms. Jour. Mar. Res. 7(1): 56-61.

Nose and throat irritations, similar to those naturally occuring in areas of red tide outbreaks, were obtained in laboratory studies with airborne "red water" of known concentration. The irritant passed through a fine bacteria filter. Very small concentrations ceased to effect respiratory membranes.

(after Rounsefell and Nelson, 1966) - Experiments showed that the red water, when sprayed into the nostrils or when breathed as an aerosol, caused coughing and a burning sensation in the nose and throat. Similar aerosols were formed when waves broke on the beach during Red Tide outbreaks. Breathing through a 2-cm pad of cotton prevented irritation. Unconcentrated "red water" containing 56 million G. breve cells per liter retained its irritating qualities unaltered after storage for several weeks. The irritant passed through a fine bacteria filter (opening, 1 to 1.5 microns).

human respiratory irritation/plankton/mass mortality/marine organisms/ red tide outbreaks

Woodcock, A.H. 1955. Bursting bubbles and air pollution. Sewage Ind. Wastes 27 (10): 1189-1192. (from Rounsefell and Nelson, 1966).

"At relative humidities commonly found over the sea, droplets of sea water of this size (1-200μ) will evaporate quickly to form nuclei of about 1 to 45μ in diameter. Such nuclei fall slowly (0.01 to 13 cm. per sec.), and atmospheric turbulence and winds cause them to be carried many miles and hundreds of feet into the air...(p. 1189).

"Microscopic examination of the aerosols from 'red water' revealed that their surface tension was much reduced, compared to the surface tension of droplets of relatively clear sea water, and that some of the droplets contain parts of plankton organisms..." (p. 1191).

bursting bubbles/air pollution/aerosols/red water

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ROCKY MOUNTAIN SPOTTED FEVER AND ITS POSSIBLE DETECTION THROUGH REMOTE SENSING

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INTRODUCTION

Rocky Mountain spotted fever, a tick-borne Typhus, is a rickettsial disease; the causative agent is *Rickettsia rickettsii*. Of the rickettsial diseases prevalent in the world today, Brill's disease, murine typhus, Q fever and rickettsialpox as well as Rocky Mountain spotted fever are the forms presently found within the United States. Of these five, Rocky Mountain spotted fever is the only one causing a significant mortality, accounting for over 90% of the total for these five rickettsial diseases. Though the incidence of Rocky Mountain spotted fever is down from a high of almost 600 cases annually for the years between 1954 and 1964, the disease is again on an upward trend with 498 cases reported in 1969, and 380 cases reported in 1970.

The name Rocky Mountain spotted fever in itself tends to be misleading: in recent years there have been more cases reported from southern and southeastern states of the country than from the Rocky Mountain states. For example, in 1970, 276 of the reported 380 cases reported were from this general region.

The disease proves to be fatal on an average of 20% of the time in untreated cases. The range of fatalities varies from 5% to 80% in untreated cases, in that there are different strains of *Rickettsia rickettsii*, each of which demonstrates a different degree of virulence (Weinburgh, 1966).

The vectors for the disease within the United States include, but are not limited to *Dermacentor andersoni*, *D. variabilis*, and *Amblyomma americanum*. Sometime during their life cycle, these ticks parasitize small mammals such as rodents, hares and rabbits. These mammals are common inhabitants of "old field" and meadow type ecosystems.

Suburbs are continuing to spread, and they are encroaching upon old field communities and abandoned agricultural fields. It is in these fields that a family pet is liable to pick up an infective tick, as is an unprotected person such as a child at play. Statistics for Virginia (1969) show that 68% of those infected with Rocky Mountain spotted fever were under 21 years of age, while 46% were under 11 years of age (Peters, 1971).

While it appears to be unfeasible to try to identify the specific ticks by remote sensing, it is feasible to use remote sensing to detect specific mammals and /or their habitats. This can be facilitated by the use of infrared and full color photography from moderate altitudes. By this method, specific habitat types such as shrubbery, grasses, trees and other foliage, as well as the topography of the land itself can be easily detected. From these data a correlation can be made between the ecosystem type and the potential tick vectors the area would support. Using this information, the proper public health organizations can plan a specific tick eradication program as well as vaccination programs for those areas they deem necessary before the problem becomes acute.

Description of Disease and Pathology

The disease is transmitted to man either by the physical bite of the tick or by the crushing of an infected tick on the skin (Leclercq, 1969). The tick itself shows little or no ill effects from *Rickettsia rickettsii* (Grissom, 1971). However, once the rickettsae find their way to a human host, they can become a serious medical problem; so much so that

Rocky Mountain spotted fever has been described as being one of the most sever of all infections (Rosenblum *et al*, 1952).

R. rickettsii penetrates the endothelial cells of blood vessels and enters the nuclei, causing destruction of the cells. The escaping rickettsae enter the blood stream and perivascular tissues spreading to other points of the body. The resulting infiltration can lead to gangrene (Craig and Faust, 1970). The damage done to the skin, subcutaneous tissues, and the brain is greater due to Rocky Mountain spotted fever than any of the other rickettsial diseases (Weinburgh, 1966). Further, in some cases, residual damage caused by Rocky Mountain spotted fever may linger for one year or more and may ultimately be considered to be permanent (Rosenblum *et al*. 1952).

The disease requires an incubation period of two to five days in severe cases, two to 14 days in the less severe cases (Craig & Faust, 1970). Fevers of 104° F. to 105° F. or higher are common, and generally temperatures do not fall until the end of the third week, or until the end of the second week in mild cases (Cox, 1959).

The rash caused by Rocky Mountain spotted fever may be confused with that of unrelated as well as related diseases, such as measles, meningococcal meningitis, scarlet fever, smallpox, typhoid fever, septicemic conditions, certain drug rashes, rickettsialpox and murine typhus (Cox, 1959).

Maintenance and Transmission In Nature

The causative agent for Rocky Mountain spotted fever, *Rickettsia rickettsii*, is maintained in nature in several ways. Burgdorfer (1963) found strains of *R. rickettsii* passed through generations of ticks transovarially. Philip (in Craig & Faust, 1970) lists three other methods as well as transovarial transmission. These are simultaneous feeding by an infected and non-infected tick, transmission through host animals by ticks which do not infect man, and by infection of females by males during copulation.

Though it is not infective to man, the tick Haemaphysalis leporispalustris has been shown to pass the rickettsia to non-infected hosts. The adults are highly specialized for rabbits and hares (Sylvilagus spp. and Lepus spp. respectively), while immature forms will also parasitize certain birds and rarelysmall rodents. Dermacentor parumapertus also does not infect man, but appears to pass the causative agent in nature. The tick primarily parasitizes the specific jack rabbit L. californicus and cotton tail rabbits (Sylvilagus spp.); immature stages have been recovered from some rodents such as Dipodomys spp., the kangaroo rats.

The hosts for the ticks responsible for the transmission of Rickettsia rickettsii to man consist of various rodents and other mammals, and, in some cases, birds. Dermacentor andersoni is one which does not parasitize avians. However, it can parasitize almost any mammal. The immature stages are found on rodents as well as rabbits and hares, while the adult parasitizes large animals, such as cattle, horses, goats, dogs, elk, deer, cats, bears, and man (Burgdorfer, 1969). D. andersoni appears to be more abundant where smaller animals live in the same area as the larger animals. Burgdorfer et al.(1962) found small mammals in the Bitter Root Valley of Montana to carry various strains of R. rickettsii in the wild. They included the golden-mantled ground squirrel (Citellus lateralis tescorum), the chipmunk (Eutamias amoenus), the snowshoe hare (Lepus americanus), and the Columbian ground squirrel (C. columbianus columbianus).

The immature stages of Dermacentor variabilis feed on mice, especially meadow mice (Microtus spp.), whitefooted mice (Peromyscus spp.), and to a considerably less extent on other rodents, hares, squirrels, cats, and rabbits. The adults feed primarily on dogs, but will parasitize cattle, horses, mules, deer, hogs, sheep, coyotes, raccoons, cats, badgers, wolves, foxes, skunks, and rabbits (Burgdorfer, 1969).

A strain of Rickettsia rickettsii was isolated in an eastern cottontail rabbit captured in Virginia (Shirai et al.,1969). Further, Bozeman, et al. (1967) isolated strains of R. rickettsii from six different mammals captured in Virginia (within the range of D. variabilis). These consisted of the oppossum (Didelphis marsupialis virginiana), eastern cottontail rabbit (Sylvilagus floridanus), white-footed mouse (Peromyscus leucopus), cotton rat (Sigmodon hispidus), meadow vole, (Microtus pennsylvanicus), and the pine vole (Pitymys pinetorum).

All of the above animals can be found in meadow and lightly wooded areas, (areas of old field succession), with the exception of the oppossum which is likely to be found in more heavily wooded areas. The golden-mantled ground squirrel prefers a habitat of open timber, or timber bordering on a meadow, as does the chipmunk and the Columbian ground squirrel, while the snowshoe hare can be found in more heavily wooded areas. The lone-star tick, Amblyomma americanum, feeds on large and medium-sized animals such as deer, cattle, horses, dogs, and man. The immature stages feed on rabbits, squirrels, foxes, raccoons, skunks, and certain birds as poultry and quail (Burgdorfer, 1969).

Ranges

Dermacentor andersoni ranges in the mountainous regions of the United States west, the southern parts of British Columbia, Saskatchewan, and Alberta. D. variabilis is found in California, southwest Oregon, and from the great plains to the east coast (Burgdorfer, 1969). Amblyomma americanum ranges in the south eastern and south central United States (Larson, 1955). Haemaphysalis leporispalustris is found throughout North America in conjunction with its specific hosts. D. parumipeuta ranges through the American southwest (Burgdorfer, 1969).

Life Cycles

Dermacentor andersoni has a two-year life cycle. The adult ticks come out of hibernation in March and April, climb on vegetation, and wait for a suitable host. Attached ticks feed during the spring and early summer. If the adult has not found a suitable host by June or July, it will crawl into the litter and wait until the following spring to re-emerge. Those adults which find hosts will feed for seven to nine days, and will mate. When engorged, they will drop off the hosts. Approximately seven days later, females will lay 5000 to 7000 eggs. The eggs hatch after approximately 35 days, at which time the larvae attach to small rodents and feed for 2-6 days. They then fall off and undergo metamorphasis, emerging two weeks later as nymphs, seek a suitable host and feed for about seven days, after which they drop off and develop into an adult. The adults do not feed for seven to nine weeks, hence they again go into the litter to overwinter (Burgdorfer, 1969). Many ticks are able to withstand starvation remarkably well. D. andersoni larvae are able to fast for 21-117 days, the nymphs 300 plus days, and the adults about 413 days (Soulsby, 1969).

The life cycle of D. variabilis is similar, with the adult activity starting in April, having a peak in June or July, and ceasing in August or September. Larval activity starts in March or April, with a maximum during April or May. During the summer, activity slows, with an increase in August and September. The larvae in the spring are from overwintered individuals, while those in August and September are from those which hatched during the spring and early summer (Burgdorfer, 1969). D. variabilis is also resistant to starvation, with the larvae being able to survive 14-540 days, nymphs 29-584 days, and adults up to 1053 days (Soulsby, 1969).

The adults of Amblyomma americanum are active starting in February, with a peak during April, May, or June. The nymphs are active during the spring from March through May, and again in August. The larvae are active from June to August and September, when they reach a peak of activity (Burgdorfer, 1969). The larvae are able to withstand starvation for 48-279 days, nymphs 3-476 days, and adults 393-430 days (Soulsby, 1960).

Incidence of Rocky Mountain Spotted Fever

During the height of prevalence of Rocky Mountain spotted fever within the Bitter Root Valley of western Montana, the fatality rate for nonvaccinated adults who contracted the disease averaged approximately 80%, while that of nonvaccinated children was approximately 37.5%; overall the disease being more severe in patients over 40 years old (Cox, 1959). However, as stated earlier, the average for fatalities is 20% in untreated cases. With the introduction of antibiotic treatment, the average fatality rate declined to the vicinity of 6% (Weinburgh, 1966).

It was at one time felt that Rocky Mountain spotted fever caused more fatalities in the west than in the east. Topping (1941 in Weinburgh, 1966) investigated this concept by comparing data from two western states, Idaho and Montana, with data from two eastern states, Maryland and Virginia. From 1930-1939 inclusive, the western states had 747 reported cases of Rocky Mountain spotted fever with 210 deaths, resulting in a fatality rate of 28.1%. The eastern states (data for Virginia are for 1933-1939 inclusive) reported 661 cases with 122 deaths, for a fatality rate of 18.4%. In the western states, 14.4% of the reported total were patients under 15 years of age, while 46.8% of the cases within the eastern states were patients under 15 years of age. For the 15-39 age group, the western states had 35.3% of their total reported cases, the eastern states having 28.5%. Finally, for the 40 year old and older age category, the western states showed 50.2% of the reported cases, 83.5% were male and 16.5% were female for the west, while 60.6% were male and 29.4% were female for the east.

The higher incidence of infection in women and children in the east as compared to the west may be explained by the prevalent tick vectors found in the two different sections of the country. Dermacentor andersoni is the tick generally regarded as responsible for Rocky Mountain spotted fever in the western states. This tick is generally found in areas away from human habitation, thus, persons exposed to the tick would be those persons who enter rural and wilderness areas either due to their profession or for recreation. The tick generally thought to be responsible for Rocky Mountain spotted fever in the eastern states is D. variabilis, the American dog tick. This tick is commonly found in areas of human habitation. D. andersoni is less likely to be found in areas of human habitation since the adult is more commonly, though not exclusively, found on larger mammals, while the adult of D. variabilis is found primarily on dogs, though it will parasitize a host of other mammals.

During the years 1960-1964, 1,106 cases of Rocky Mountain spotted fever were reported for a yearly average of 221 cases. During this period, 82 cases were reported from the mountain states, while 715 cases were reported from the Appalachian states. The national average of reported cases for 1960-1964 was one case per million population with the average rising to 1.5 cases per million population for 1964 (Weinburgh, 1966).

For the years 1966-1970, 1,749 cases of Rocky Mountain spotted fever were reported, for a yearly average of approximately 350 cases; an increase of 129 cases annually as compared to the years 1960-1964.

For the first 23 weeks of 1972 (through the week ending 10 June 1972) there have been 89 cases reported to the Center for Disease Control, Atlanta Georgia, as compared to 63 reported cases for the first 23 weeks of 1971. Regarding the 89 reported cases to date, the breakdown by state is as follows: New Jersey-1, Pennsylvania-2, Ohio-4, Kansas-1, Maryland-12, Virginia-15, North Carolina-18, South Carolina-6, Georgia-4, Tennessee-9, Alabama-1, Arkansas-3, Oklahoma-11, Texas-2.

Possible Method of Study Utilizing Remote Sensing

While it is not feasible to try to detect the vectors of Rocky Mountain spotted fever, it is possible to detect the tick's hosts. This would have merit since ticks are found only in areas that support their required hosts. External sensors can then be used to identify specific vegetation types which can possibly by correlated with the distribution of certain mammals. This also holds true for terrain types, animal burrows, nest and trails, and the particular successive stage of the area in question. Sensors can also be used to record the temperature and humidity of the study area. Therefore, a project should be set up, possibly utilizing the following points.

The area to be studied should include suburban residential areas, cultivated areas, different stages of old-field succession, wooded areas, fields and meadows.

The animal population of the project area should be extensively studied as to which mammals are present, their individual habitats, their numbers, and whether or not they harbor ticks. This can be accomplished by live-trapping the animals, and carefully removing the external parasites. The size and location of nests, dens, and trails of the animals should be recorded. Further, ticks should be collected, counted, identified, and the specific habitat in which they were found recorded (unengorged ticks will come readily to a block of dry ice).

Photographs, including color, color infrared and multipleband scanning should be taken of the research area. Once these data have been gathered a detailed comparison can then be made between baseline data taken on the ground and those data collected by external sensors. Correlations can then be made between the baseline data and sensory data with regard to locations and identification of specific mammals, their burrows or nests, habitats and trails. Once this is accomplished, the best method or methods of sensing can be used on other, similar areas, and predictions made as to the kinds and numbers of mammals one might expect to find.

While these data would not give the numbers of ticks in an area, they could give the investigator an idea of how many ticks the area might support by knowing the numbers and types of mammals present.

Further, a particular ecosystem may seem to harbor more ticks than another. Knowing this, external sensors can be used readily to locate such habitats.

Even though the disease is far more prevalent during the summer months, the study should be carried out over an entire year, in that some particular identifying aspect of the environment may be more easily detected in the winter.

Possible Investigators

Mr. John Sexton is presently working at the University of Minnesota with remote sensing as a means of vector control. He may possibly be interested in working with NASA on the practical aspects of the problem. Dr. Daniel E. Sonenshine is an authority on Rocky Mountain spotted fever, and may also be interested in the problem. He is presently at the Old Dominion University, Norfolk, Virginia 23508.

Dr. H. Janney Nichols, Assistant Director for Planning, Institute of Science and Technology, The University of Michigan, Post Office Box 618, Ann Arbor, Michigan, 48107, has expressed an interest in such a project, and would probably have the facilities for carrying the project to completion.

Dr. Paul F. Krumpe is presently investigating 2 - 2½ million acres in northern California through the use of external sensors. He also expressed an interest in such a project. His address is: Dr. Paul F. Krumpe, Associate Specialist, Plant Ecology, Forestry Remote Sensing Laboratory, University of California, Berkeley, California. 94720.

Conclusions

No definite correlation has been observed between actual numbers of ticks and the prevalence of Rocky Mountain spotted fever; this statistic is less important than the number of ticks in an area which are infected with the rickettsia. In this regard, generally less than 1% of the ticks in an area are infected, and an infection rate of 5% is considered very high (Weinburgh, 1966).

Rocky Mountain spotted fever appears to be increasing steadily, hence maintaining itself as a definite health hazard. The only present method of combating the disease is the vaccination of people frequenting an area where they might contact the disease. Mammal control has not reduced the incidence of Rocky Mountain spotted fever in the past, and is not economically feasible (Weinburgh, 1966). Further, extensive mammal control would not be environmentally sound with the repercussions from such a project far outweighing a possible reduction in the disease. Tick control is possible on a limited scale, though not over large geographic areas.

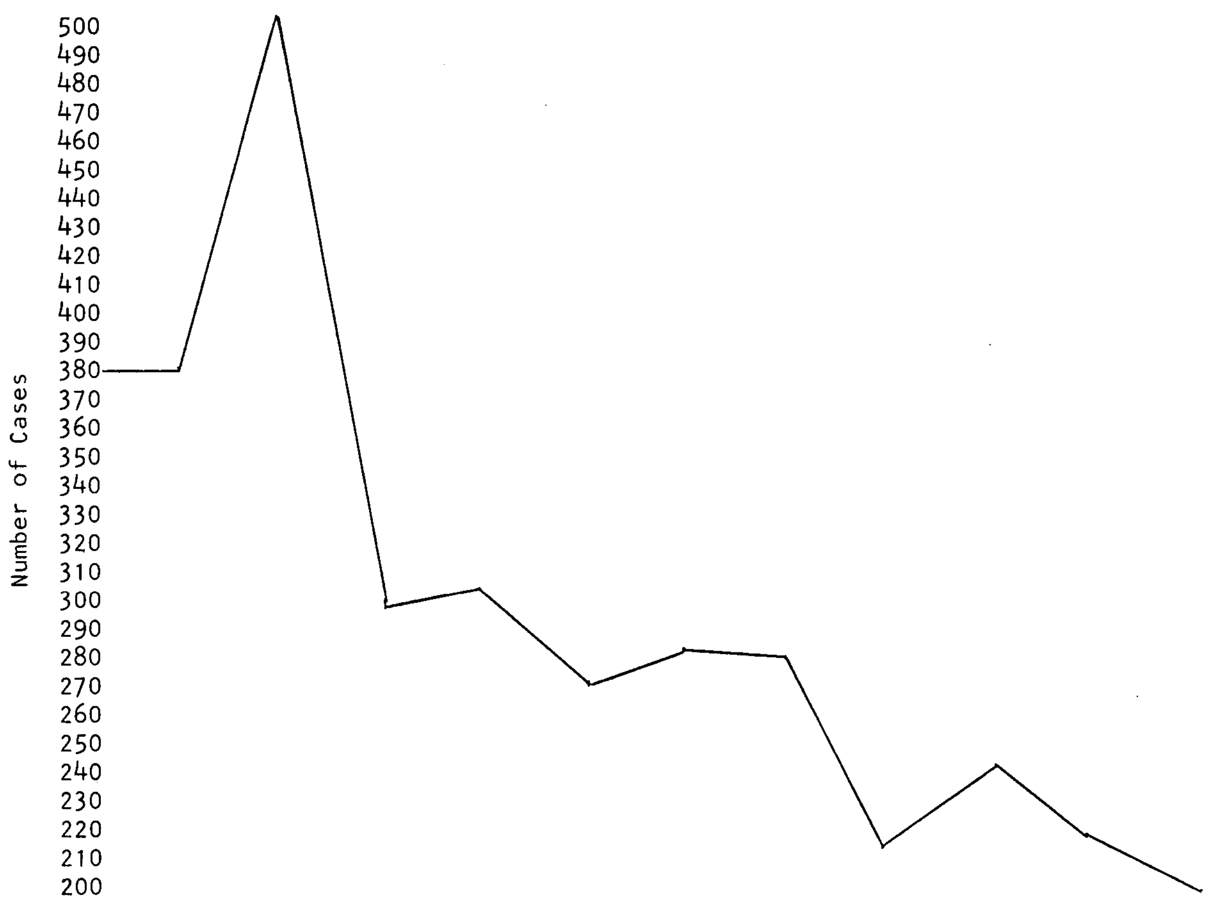
The potential problem of Rocky Mountain spotted fever is extensive, in that ticks capable of transmitting the disease to humans are found thoughout the United States. The problem is amplified since virtually all "out-of-doors" areas are capable of supporting one or more of the mammals which act as hosts for the ticks.

However, if areas of large populations of host mammals could be detected close to areas of human population or visitation, precautions could be taken against the disease. Therefore, such a project could be of value not only with regard to Rocky Mountain spotted fever, but also for the knowledge gained in the location of specific mammal populations and habitats through the use of external sensors.

Broomsedge (Andropogon) stage of old field succession. Cotton rat (Sigmodon) and the whitefooted mouse (Peromyscus) may be expected to serve as tick hosts in this sere.

Shrub-tree stage of old-field succession. In this sere one might find additional tick hosts such as squirrel (Citellus) and opossum (Didelphis).

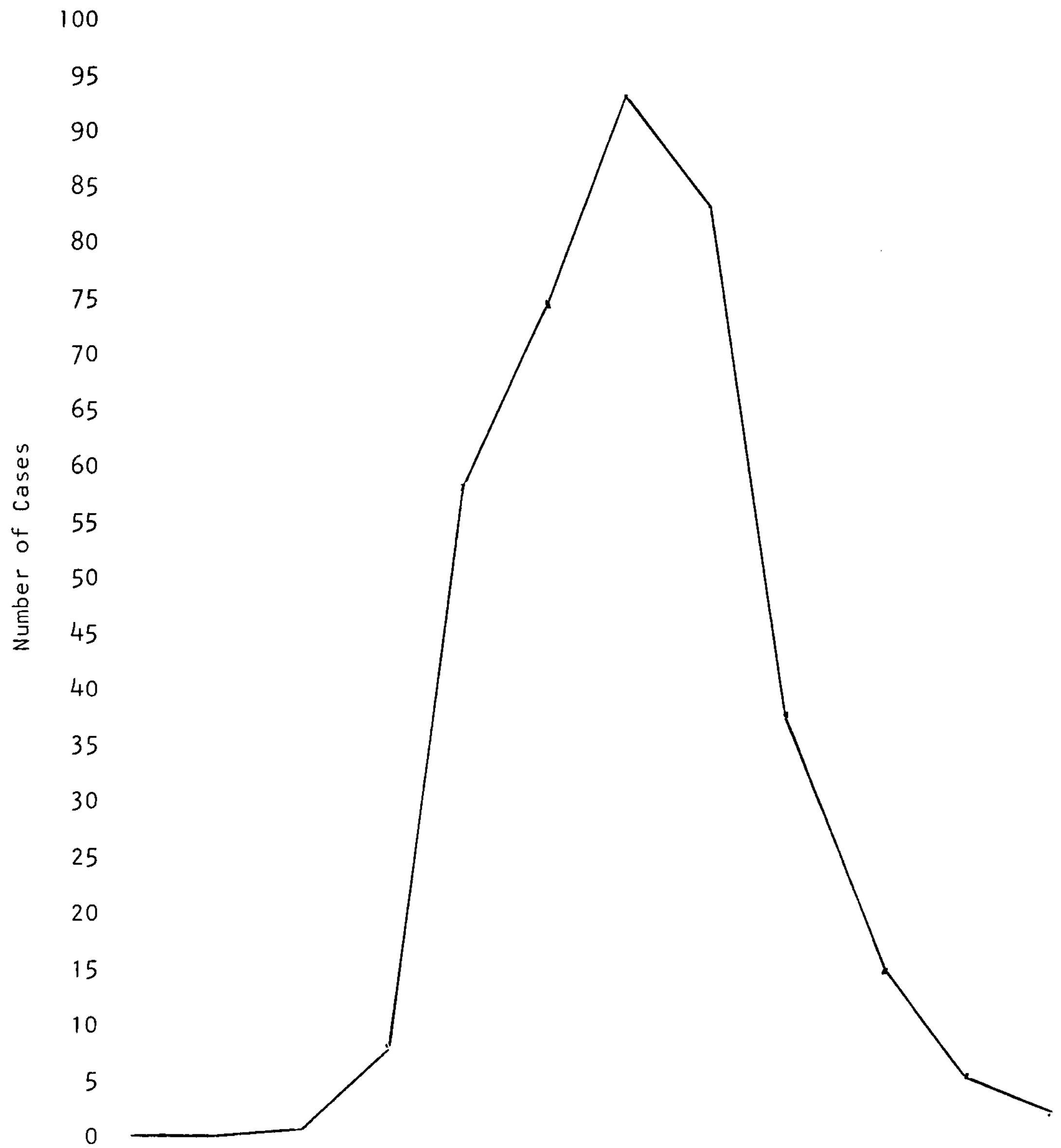
Annual incidence of Rocky Mountain spotted fever 1960-1970



Year	1970	'69	'68	'67	'66	'65	'64	'63	'62	'61	'60
Number of cases	380	498	294	305	268	281	277	216	240	219	204

Statistics from CDC Morbidity and Mortality Reports, Annual Supplement 1970. Vol. 19, No. 53. and Annual Supplement 1969. Vol. 18, No. 54.

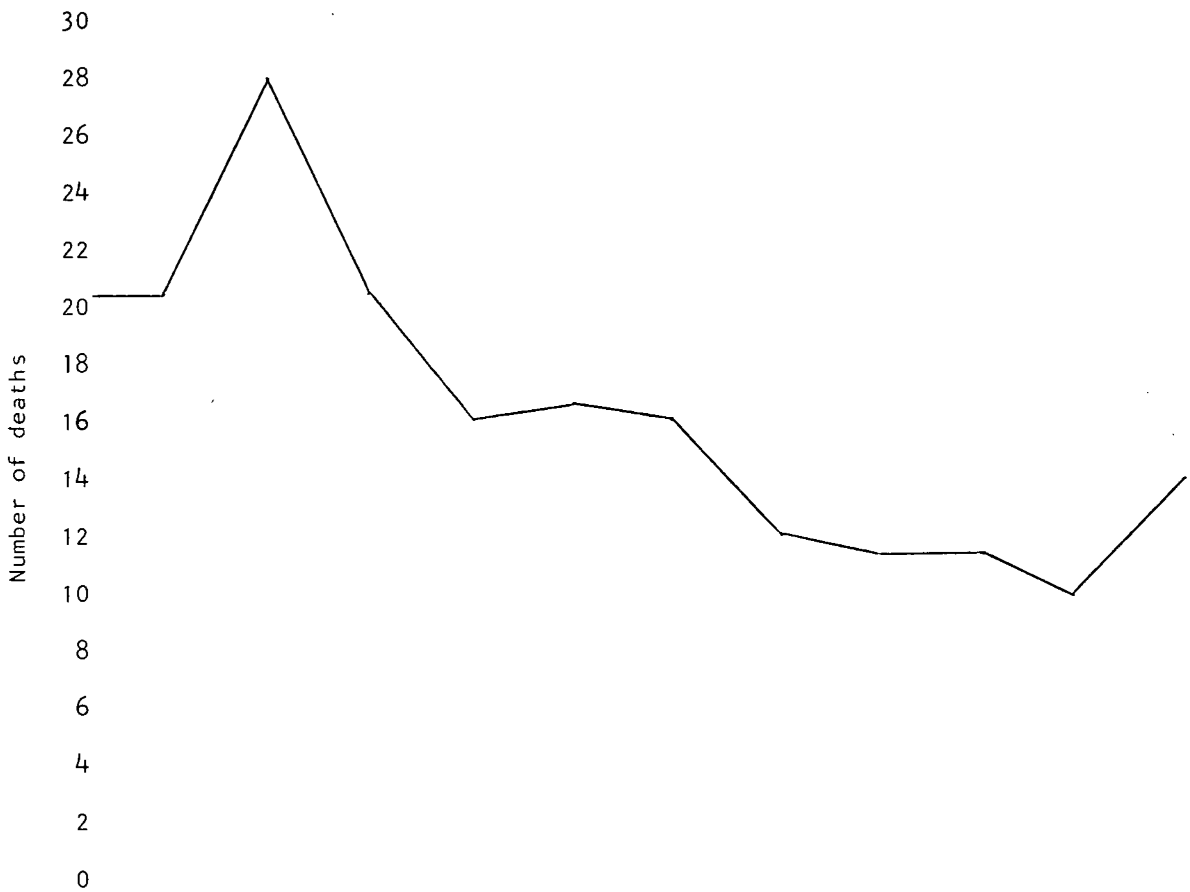
Monthly incidence of Rocky Mountain spotted fever for 1970



Month	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.
Number of Cases	0	0	1	9	58	73	92	83	38	15	7	4

Statistics from CDC Morbidity and Mortality Reports, Annual Supplement 1970. Vol. 19, No. 53.

Deaths Attributed to Rocky Mountain spotted fever 1958-1968



Year	1968	'67	'66	'65	'64	'63	'62	'61	'60	'59	'58
Deaths	21	28	21	16	17	16	12	11	11	10	14
Percent * Fatalities	7%	9%	8%	6%	6%	7%	5%	5%	5%		

Statistics from CDC Morbidity and Mortality Reports, Annual Supplement 1970. Vol 19, No. 53 and Annual Supplement 1969. Vol. 18, No. 54.

* Percent rounded off to nearest whole number

Regional breakdown of cases of Rocky Mountain spotted fever for 1970

New England
Massachusetts - 2

Middle Atlantic
Upstate New York - 6
New Jersey - 4
Pennsylvania - 10

East North Central
Ohio - 20
Illinois - 6

West North Central
Iowa - 2
Missouri - 2
Kansas - 1

South Atlantic
Delaware - 4
Maryland - 24
Virginia - 59
West Virginia - 5
North Carolina - 88
South Carolina - 35
Georgia - 20
Florida - 1

East South Central
Kentucky - 3
Tennessee - 22
Alabama - 12
Mississippi - 3

West South Central
Arkansas - 8
Louisiana - 1
Oklahoma - 23
Texas - 7

Mountain
Montana - 2
Idaho - 4
Wyoming - 1
Colorado - 3

Pacific
California - 2

Statistics from CDC Morbidity and Mortality Reports, Annual Supplement 1970. Vol. 19, No. 53.

Mammals found to contain antibodies for spotted fever

Lepus americanus	Snowshoe rabbit
L. californicus	Blacktailed jackrabbit
Sylvilagus floridanus	Eastern cottontail
S. nuttalli	Nuttall cottontail
S. auduboni	Desert cottontail
Marmota monax	Woodchuck
Citellus leucurus	Antelope ground squirrel
C. columbianus	Columbian ground squirrel
Eutamias minumus	Least chipmunk
E. dorsalis	Cliff chipmunk
E. amoenus	Yellow-pine chipmunk
Perognathus longimembris	Little picket mouse
P. parvus	Great Basin pocket mouse
P. formosus	Long-tailed pocket mouse
Dipodomys ordi	Ord Kangaroo rat
Microtus pennsylvanicus	Meadow vole
Peromyscus crinitus	Canyon mouse
P. leucopus	White-footed mouse
P. maniculatus	Deer mouse
P. truei	Pinon mouse
Pitymys pinetorum	Pine mouse
Neotoma lepida	Desert Woodrat
Sigmodon hispidus	Cotton rat
Blarina brevicauda	Short-tailed shrew
Canis familiaris	Domestic dog
Vulpes fulva	Red fox
Urocyon cinereoargentus	Gray fox
Procyon lotor	Raccoon
Mephitis mephitis	Striped skunk
Didelphis virginiana	Opossum
Odocoileus virginianus	White-tailed deer

(Anonymous, 1960; Dorer, *et al.*, 1964 in Weinburgh, 1966)

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It is believed that the tick records obtained were extensive enough to have value as an indication of seasonal and host distribution of Dermacentor and Haemaphysalis ticks within the collection area. In order to demonstrate a more nearly complete pattern of distribution, the data obtained from other records were supplemented with data from other works. (author abstr.)

Bozeman, F.M., A. Shirai, J.W. Humpries, and H.S. Fuller. 1967. Ecology of Rocky Mountain spotted fever II. Natural infection of wild animals and birds in Virginia and Maryland. Am.J. Trop. Med. Hyg., 16(1): 49-59.

The initial results of a coordinated field and laboratory investigation of the ecologic factors associated with the maintenance, distribution, and dispersion of R. rickettsii indicate the widespread occurrence of spotted-fever infection in the indigenous wild fauna of Virginia and Maryland. Seven strains of spotted-fever rickettsiae were recovered from six species of native wild mammals trapped in Virginia: one from a cottontail rabbit, one from an opossum, and five from four species of wild rodent. Spotted-fever group antibodies were detected in the sera of 15 different species of mammal included among 5 different orders. Similarly, complement-fixing antibodies were found in 18 species of bird belonging to three different orders, mostly Passeriformes. These findings amply indicate the complexity of the ecosystem in which R. rickettsii is maintained and also identify some of the communities within the ecosystem involved in this tick-borne rickettsiosis. (author abstr.)

Burgdorfer, W. 1970. Hemolymph test. A technique for detection of rickettsiae in ticks. Am.J. Trop. Med. Hyg., 19(6): 1010-1014.

The tick hemolymph test is designed to detect rickettsial pathogens in experimentally and naturally infected adult ticks and to provide a means for rapid flourescent identification of the antigenic group to which the pathogens belong. The test consists of obtaining hemolymph from a wound produced by amputating the distal portion of one or more legs. The hemolymph is collected on a slide, heat fixed, stained by Gimenez' method, and examined microscopically. Validity of the test was established with ticks that had been infected experimentally with Rickettsia rickettsii or Rickettsia canada by feeding them as larvae or nymphs on rickettsemic rodents. Ticks with positive and negative tests were triturated separately and suspensions were injected into guinea pigs.

Only ticks with positive tests produced infections typical of these pathogens. The test was successfully applied also to field ticks. In this connection it was found that Dermacentor andersoni from western Montana may harbor a rickettsia-like agent with an antigenic relation to R. rickettsii but not pathogenic for quinea pigs. The hemolymph test is an economical, rapid technique for detecting rickettsiae in adult ticks. Because its application leaves ticks undamaged, infected specimens can be used to identify rickettsial agents. (author abstr.)

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The author reviews the natural history of the tick vectors of American spotted fever. The discussion concerns the ecology of the Rocky Mountain wood tick, Dermacentor andersoni, the American dog tick, Dermacentor variabilis, and the lone-star tick, Amblyomma americanum, all of which are proven vectors of Rocky Mountain spotted fever to man. Also included are the rabbit tick, Haemaphysalis leporispalustris and Dermacentor parumapertus which very rarely bite man but which are considered of importance in maintaining and distributing Rickettsia rickettsii, the etiological agent of Rocky Mountain spotted fever, in nature. Brief reference is also made to recently developed techniques for studying the ecology of tick vectors. (author abstr.)

Burgdorfer, W., R.L. Anacker, R.G. Bird, and D.S. Bertram. 1968. Intranuclear growth of Rickettsia rickettsii. J. Bacterial, 96(4): 1415-1418.

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Burgdorfer, W., K.T. Friedhoff, and J.L. Lancaster Jr. 1966. Natural history of tick-borne spotted fever in the USA. Bull. Wld. Hlth. Org., 35: 149-153.

The authors analyse the susceptibility of various species of small mammals to virulent R. rickettsii and evaluate their efficiency as sources of infection for larval ticks. The results demonstrate thatmeadow-mice, Columbian ground-squirrels, golden -mantled ground squirrels, chipmunks and snowshoe hares (the latter to a lesser extent), when bitten by infected ticks, respond with rickettsiaemias of sufficient length and degree to infect normal larval D. andersoni. High infection rates were obtained in ticks that fed during periods of high rickettsial concentrations in the blood. (author abstr.)

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In a quantitative study of transovarial passage of Rickettsia rickettsii to the progeny of experimentally and naturally infected wood ticks, Dermacentor andersoni, it was found that all infected female ticks tested passed rickettsiae via eggs to almost 100% of their offspring. Infection was throughout the filial generation and was again transmitted by all F_1 females tested to 100% of their progeny.

Examination of flourescent-antibody stained sections of ovarian tissues of infected female ticks revealed the presence of rickettsiae in every ovum; organisms were regularly found in the cytoplasm but never in the nuclei of developing eggs.

During the study, infectivity of the strains of R. rickettsii remained unchanged, as indicated by inoculation of tick eggs into chick embryos and by feeding of ticks on guinea pigs. (author abstr.)

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ENCEPHALITIS AND ITS POSSIBLE DETECTION THROUGH REMOTE SENSING

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ENCEPHALITIS

INTRODUCTION

Arthropod-borne animal (arbor) viruses are defined as viruses which have the capacity to infect certain vertebrates - mammals and birds - and to multiply in the body of arthropods. Except under unusual circumstances, these viruses are not capable of spreading from vertebrate to vertebrate without the agency of an arthropod. The arthropod is the vector and becomes infected, generally, by ingesting blood from a vertebrate host at a time when the virus circulates in the latter. After a period of days, designated extrinsic incubation, the vector, by biting, can transmit the disease to a new susceptible host.

In the past 30 years, nearly 50 distinct viruses have been found to be arthropod-borne, and continuing searches add new viruses to the group every year. Eight of these belong to Group A arthropod-borne viruses: western, eastern, and Venezuelan equine encephalomyelitis, Semliki Forest, Sindbis, Mayaro, Chikungunya and Middelburg. Of these diseases, the encephalitides caused by western, eastern, and Venezuelan equine encephalitis viruses are of particular interest to health officials in the United States.

Western equine encephalitis is observed as a summer viral infection of animals, causing disease in horses and mules. The virus is transmissible to humans in whom a malady is produced closely resembling that of St. Louis encephalitis, but in its antigenic behavior the virus more closely resembles that of chikungunya, a dengue-like disease. Forty-one percent of human WEE cases occur in infants aged 4 years or younger.

For more than 85 years, epizootics of encephalitis have been observed in equine animals in the United States. WEE was first isolated from the central nervous system of affected horses in California by Meyer et al. (1931). The most extensive human epidemic occurred in 1941, chiefly in North Dakota, Minnesota and adjacent provinces of Canada. Over 3,000 persons were attacked with a mortality rate of eight to 15 percent. At the present time, an endemic focus exists over most of the western United States, particularly along the Pacific coast. The disease has occurred in horses during each summer since its discovery in 1930.

Human infections with WEE virus have occurred principally in states west of the Mississippi River and in the Canadian prairie provinces, Central and South America and the Caribbean.

Along the eastern seaboard of the U.S.A., increasing evidence of the spread of WEE virus has been obtained during recent years. These states include Massachusetts, New Jersey and Florida.

In nature, humans, horses and mules have shown signs of infection, and the virus has been isolated, in addition, from squirrels, deer, pigs and birds. The disease prevails chiefly from early June to mid-September.

There is solid evidence that the primary vector in the western U.S. is a culicine mosquito, *Culex tarsalis.* This mosquito has been found naturally infected in California, Washington, Nebraska, Montana, North Dakota, Minnesota, Colorado and Manitoba. The mosquito conveys the infection from bird-to-bird as a clandestine infection, thus maintaining the virus in nature; and from birds to other vertebrates including man and horse, both of which are paratenic hosts but can exhibit symptoms of the disease.

Venezuelan equine encephalitis is observed as a disease primarily of equine animals; its causal agent is transmissable to humans in whom it usually induces a mild disease of variable syndrome, rarely associated with classical encephalities.

VEE was first recovered by Bech and Wyckoff, 1938, from brains of animals that had died during the severe epizoltic that swept over Colombia and Venezuela that year. The disease has also been reported in Brazil, Ecuador, Mexico, Panama, Trinidad and the southwestern United States.

Two fatal encephalitis infections of man possibly due to VEE occurred in 1943 in Trinidad. In Venezuela between November, 1962, and May, 1964, 31,966 cases of VEE were reported among human residents. Neurologic upsets were observed in 1,199 cases, and 190 deaths were recorded.

The most recent epidemic of VEE was experienced by the United States and Mexico in the summer of 1971. June, July,and August, 1971, saw the spread of VEE from Mexico to the southwestern United States. The disease killed 80 to 90 per cent of the horses infected, leaving 8,000 horses dead in Texas and 9,000 dead across the Rio Grade in Mexico. The virus also struck down 100 Texans and over 2,500 Mexicans with an ailment similar to influenza. One death (a small girl) has been attributed to VEE. The hardest hit was Texas, with possible spread and deaths in 10 other States.

Aedes taeniorhynches and Culex tarsalis appear to be the major mosquito vectors transmitting the disease to horses and humans. Mansonia titillans and Psorphora confinnus may also act as vectors for the virus.

Clinical and Pathologic Features

The equine viruses (WEE, VEE, EEE) are agents which are serologically different from each other. However, one of the essential points of similarity among the three is that ordinarily the encephalitis in man is unusual or accidental, with infection occurring more frequently in certain occupational situations. (See chart #1.). The usual form of infection being, at least with WEE and VEE, asymptomatic, abortive, or systemic. Indeed, VEE is almost always a systemic disorder, often resembling in its clinical picture influenza or denque, although horses may show encephalities. For WEE and EEE its order of susceptibility is probably first woodland animals (especially birds), then horses and last, human beings.

Although the clinical features of established cases of encephalitis due to infection with EEE and WEE viruses are indistinquishable, the fatality rate following symptomatic infection with EEE approaches 80%, while it ranges between .5% and 15% for WEE infection. In California, about 27% of WEE cases occurred in infants less than one year of age, but in New Jersey, EEE viruses affected all age groups relatively evenly (Rhodes and Van Rooyen, 1968).

Antibody surveys for Group A, arbor viruses, made under conditions favorable for proper interpretation despite cross-reaction, reveal that large numbers of the general population in endemic and epidemic areas develop clinically inapparent infections. This is true of the virus of EEE with which, on the earlier surveys, there seems to be an increasing number of reports of persons that have antibodies in the absence of recognizable encephalitis.

OCCUP^TIONAL SITU^TIONS ASSOCIATED WITH CERTAIN ARBORIRUS INFECTIONS OF MAN

	EEE	WEE	VEE
group complex	A	A	A
vector	mosquito	mosquito	mosquito
Environment			
geographic	Northeastern Central America; Caribbean	North and South America	Littoral South America and Caribbean
climatic	Humid, mesothermal, tropical rainy	Humid, mesothermal, dry, tropical, rainy	Tropical, rainy
ecologic	Littoral, marsh pasture, swamp, forest	Irrigated crop and pasture, swamp and marsh, urban	Rural, swamp, marsh, pasture, jungle, suburban
Gainful Employment	Outdoor, farming forestry, wildlife management	Agriculture	Outdoor, stock raising, agriculture, insect collectors, medical aid
Avocation	Game, bird farming	Agriculture, urban, gardening	Hunting, fishing, and agriculture
Childs Play	Probable	Reported	Reported
Sport	Probable	Probable	Probable
Rest	Probable	Probable	Reported

(Adapted from Work, 1964)

OCCUPATIONAL EXPOSURE OF MAN TO ARBOVIRUS INFECTION

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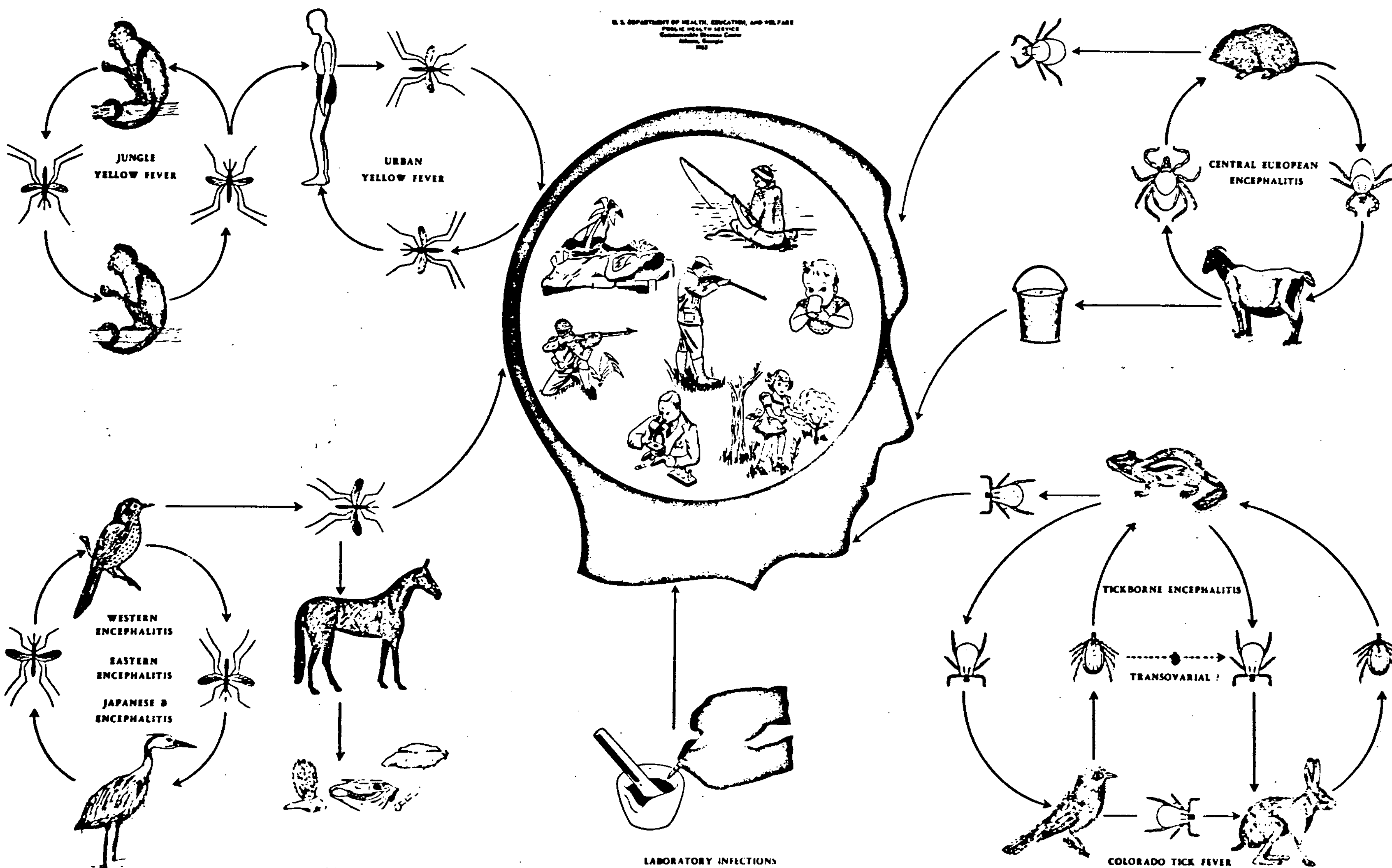

(U.S. Dept. of Health, Education and Welfare, Public Health Service, Atlanta, Ga. 1963.)

Epidemiology

During the past three decades large outbreaks of encephalitis have occurred among human beings and horses in many parts of North America. For reasons of geography, the two causative viruses were designated eastern and western equine encephalomyilites, following isolation from the central nervous system of horses. In general, cases of EEE occur principally along the Atlantic Coast of the U.S. from New Hampshire to Texas, but cases have occurred as far inland as Wisconsin. Infection with EEE viruses has also been encountered in the Caribbean and Central and South America. In contrast, human infections of WEE virus have occurred principally in states west of the Mississippi River and in the Canadian prairie provinces, Central and South America, and the Caribbean. However, along the eastern seaboard of the USA, increasing evidence of its spread has been obtained with the isolation of WEE virus in Massachusetts, New Jersey, and Florida.

Until recently, infection with VEE virus was thought not to occur north of Panama, and its occurrence in man was considered rare. A Venezuelan epidemic that began in the District of Goajira in 1962 and continued throughout the country in 1963 and 1964 resulted in 31,966 cases and 190 deaths to 28 May 1964. The virus is now known to be actively transmitted in Veracruz, Mexico, and in southern Florida. Recently a case of VEE infection in a 53-year old black woman was reported in Homestead, Florida, and there is serological evidence of infection of Seminole Indians near Lake Okeechobee.

In the United States the disease prevails chiefly from early June to September, with peak months being August and September.

Properties of the Virus

Electron microscopic studies demonstrate that the viral particle consists of a .30 mμ core separated by a zone of lesser density from a sharply defined peripheral membrane; over-all diameter is 45-48 mμ. Percursor particles, 22 mμ in diameter, differentiate at sites close to membranes bordering cytoplasmic vacuoles and either pass into the lumen of the vacuole or are extruded through the surface of the cell wall, meanwhile acquiring a coat and membrane. Degeneration of the host cell may or may not occur during release of virus (Rhodes and Van Rooyen, 1968).

The viruses multiply readily after intracerebral or peripheral inoculation of suckling or weaned mice, causing death within 184 days after injection, depending on the dose. Fatal infections may occur in horses, but cows usually do not develop symptoms following mosquito bites.

Domestic fowls and most species of wild birds develop symtomless viremia at titers sufficient to infect *Aedes aegypti* and *A. triseriatus* mosquitoes. Veremia is first detected one day after being bitten by infected *A. aegypti* and persists 4 to 5 days. Subsequently, antibody can be detected in sera by neutralization and antihemaglutinin tests.

Experimental Infection - Host Range

One of the distinguishing characteristics of the arthropod-borne viruses is that of a fairly wide host range. By definition, these viruses are capable of infecting both invertebrates and vertebrates. Among the vertebrates, many species of mammals and birds may be infected with these viruses. However, each virus tends to have one class of preferred hosts (Kissling, 1958).

WEE

The western virus has a very wide host range. In nature, human beings, horses, and mules have shown signs of the infection, and the virus has been isolated, in addition, from squirrels, deer, pigs, and birds. The experimental infection can be induced in most mammals with the exception of sheep and cats which are apparently resistant.

Hammon *et al*. (1951) found that viremia was present in English sparrow, house finches, tricolored red-winged blackbirds, and white-crowned sparrows following subcutaneous inoculation of virus. The western virus was recovered from some individuals as late as 9 and 10 days after inoculation. Most recoveries of virus were made during the first four days after inoculation, with the maximum titers of 10^4 to 10^6 LD_{50} occurring during the first two days. Similar results were found with other birds by Kissling *et al*. (1957) and Kaplan, Winn, and Palmer (1955). Domestic fowl have been shown to circulate sufficient virus in their blood to allow infection of *Culex tarsalis* (Hammon and Reeves, 1943).

In case of WEE virus, it appears that birds are the primary hosts of the virus, wild birds being especially incriminated. Domestic poultry may play a secondary role, depending upon the vector's accessibility to them.

EEE

Horses have been found to circulate EEE virus in their blood after experimental infection (Giltner and Shahon, 1936). The virus appears with a fair degree of regularity, but its presence is of short duration, usually for one to three days only. The maximum virus titers observed have ranged from $10^{0.5}$ to $10^{5.2}$ LD_{50}. Horse-to-horse transmission through the bite of mosquitoes has been shown experimentally (Sudia et al., 1956).

Investigations on avian hosts (Kissling, 1954), have demonstrated that birds differ in their response to infection with EEE virus in several significant ways. In general, the small marsh birds and song birds (red-winged blackbird, cardinal, sparrow) manifest exceptionally high blood virus titers, but the majority succumb to a culminating disease within two to three days. Other species (ibis, egret, purple grackle) develop few or no signs of infection and exhibit a lower viremia range. The virus is present in the blood stream of birds for periods up to about 120 hours, but only for one-third to one-half of that period is the titer adequate for infection of mosquitoes.

Bird-to-bird transmissions via the bite of mosquitoes were accomplished with relative ease in those birds carrying optimum levels of virus for mosquito infection, but such birds as the ibis and egret usually had insufficient blood virus concentration for infection of the test mosquitoes (*Aedes aegypti*). Birds with higher virus titers are therefore effective sources of infection although the duration of the infective interval may be rather short due to the rapid and high mortality rate which usually occurs among such birds.

VEE

Venezuelan equine encephalitis virus is one of the arthropod-borne viruses that seem to multiply with greater efficiency in mammals than in birds.

Horses infected experimentally with VEE virus circulate four to six days (Kissling _et al._, 1956). Maximum blood virus titers were found to range from 10^4 to $10^{7.5}$ LD_{50}. These high titers were maintained for longer periods of time than were the maximum blood virus titers in horses infected with EEE virus. No difficulty was experienced in infecting certain species of mosquitoes by allowing them to feed upon horses in the viremic state. The wide spread of VEE through Guatemala and contiguous countries in the 1969 epidemic appears to have been assisted by the movement of the viremic horses themselves (Sudia, 1971).

Very little has been done with other species of mammals, but Sudia (1968) has found wild rodents to be the apparent natural hosts of VEE in the Everglades. In this case, hammocks with high rodent populations may be correlated with the presence of VEE.

Wild birds, especially those native to North America, when infected with VEE do not have viremia levels as high or of as long durations as horses (Chamberlain _et al._, 1956). Birds in the viremic phase of the disease seldom had sufficient blood virus present to allow mosquito infection. VEE virema periods in these birds rarely exceeded three days.

Interepidemic Survival of Encephalitis

The bird-mosquito-bird cycle source of encephalitis is generally accepted with a mammalian component suspected in certain foci, especially with VEE. Reptiles and amphibians have come into serious consideration and experimentation as possible key elements in the little understood mechanism of overwintering.

Epidemics of these diseases occur irregularly in time and location. In temperate areas, where most epidemics occur, mosquito populations are greatly reduced or absent during winter months. A number of different mechanisms of virus survival have been postulated.

Virus transmission between birds and mosquitoes may persist in small areas of especially favorable habitat where some mosquitoes are active throughout the year. A continual supply of susceptible birds may move into such areas for food or water or by ordinary movement of migratory birds. Migrant birds may then transport viruses from these areas to others favorable for transmission during spring and summer months. Investigations of this mechanism have yielded negative results to date but have been conducted on a scale too small to make an evaluation (Stamn and Newman, 1963).

Survival of these viruses through winter months in hibernating mosquitoes has been shown in at least _Culex tarsalis_ and _C. quinquefasciatus_ (Bellamy _et al._, 1958). These mosquitoes were able to transmit WEE by bite after being kept under natural winter temperture three to four months in Kern County, California.

Survival of mosquito-borne viruses in bird mites or in ticks has been suggested. While virus has been isolated from several species of birds mites, it has not been possible to show transmission of the virus by their bite (Reeves _et al._, 1955; Sulkin _et al._, 1955; Chamberlain and Sikes, 1955). Syverton and Berry (1941) succeeded in transmitting the disease to animals by means of experimentally infected wood ticks, _Dermacentor andersoni_; however, there has been no epidemilogic evidence thus far that the tick is an important vector.

Small mammals, including bats, have been investigated to some extent as hosts of overwintering virus. Laboratory studies have confirmed the possibility that this mechanism can operate, but the occurrence of such a cycle in nature has not been demonstrated (Sulkin *et al.*, 1963). Recently, however, evidence has appeared in Colorado, New Jersey, and Florida that small rodents act as hosts for the virus, especially during winter months.

The persistence of virus in some birds, perhaps in a latent form, has been demonstrated by isolation of virus from tissues, including blood, between 55 and 306 days after the initial infection. It has not been demonstrated, however, that sufficient concentration of the virus circulated a second time in birds to infect mosquitoes and re-initiate the natural cycle (Reeves and Hammon, 1962).

The garter snake, *Thamnophis ordinoides*, develops viremia between three and eight days after being bitten by *Culex tarsalis* mosquitoes infected with WEE virus. Virus was isolated from the blood of snakes after periods of hibernation for five to six months out-of-doors with minimum temperatures between -8 and -18° C., followed by a further holding period in the laboratory of 8 to 16 days at 22°C. (Gebhart and Hill, 1960. Thomas and Eklund, 1962). Although virus has not yet been isolated from the blood of naturally infected garter snakes, this experiment suggests that snakes may serve as additional vertebrate reservoirs of encephalitis in regions of North America which undergo extensive freezing during winter.

THE USE OF REMOTE SENSING IN CONTROL OF WEE, VEE and EEE

INTRODUCTION

Control measures for WEE, VEE, and EEE can be directed either toward preventing dissemination of the virus through an attack on the mosquito vector or toward increasing the resistance of the exposed group through immunizing procedures.

Effective prophylaxes against WEE and VEE infections have been achieved by multiple injections of formalinized suspensions of infected guinea pig or horse brains. However, this material is unsatisfactory for use in humans. Even in horses, the vaccination of thousands of horses can be immensely expensive. Injections are often given too late after the spread of the disease to be effective, as evidenced in the recent Texas epidemic. Therefore,control measures through an attack on the mosquito vector have been advocated and used extensively in certain endemic areas.

The use of remote sensing in detection of suitable breeding sites of vector mosquitoes appears to be the best method to initiate mosquito control, and thus, the control of VEE, WEE, and EEE. It is generally accepted that the breeding stages of many mosquito species may frequently be keyed to certain plant and water quality associations, including aquatic, marginal and terrestrial vegetation. It is probable that the distribution of immature mosquitoes and vegetation both reflect responses to such environmental determinants as salinity, soil moisture, pH, water quality and other factors. It is hoped that remote sensing may provide a rapid means of identifying some of these chemical and physical elements, as well as identifying the vegetation types present. If these can in turn be shown to relate directly to the mosquito population, a means may be provided for the rapid identification of potential mosquito breeding sites for selected species. Thermal infrared scanning, color-infrared, color, and multiband cameras may be used to locate breeding sites and test for types and concentrations of vegetation and pollutants present.

BREEDING SITE ECOLOGY

The most important mosquito vectors of WEE, VEE, and EEE include: *Culex tarsalis* and *Psorophora confinnis*.

Gunstream and Chew (1970) found adult *Culex tarsalis* and *Psorophora confinnis* to be nearly ubiquitous throughout the Sonoran Desert, California. *C. tarsalis* was found to be present throughout the year, while *P. confinnis* was present only April or May through October or November.

P. confinnis is the most abundant mosquito in the desert agricultural regions of southeastern California. The aquatic stages develop in shallow temporary pools formed by irrigation water, especially in crops irrigated by flooding. Usually these pools persist only 1 to 5 days. In the Coachella Valley, *P. confinnis* can tolerate water temperatures of 32-25°C. and higher, and complete their aquatic stages in 80 to 120 hours. This is a necessary rate of development if the individuals are to be able to complete their development within the usual period of persistence of irrigation water in the summer. However, survival to adult emergence is optimum at a lower temperature, 24-29°C. (Gunstream and Chew, 1967).

P. confinnis larvae are usually most abundant in shallow waters that temporarily flood areas grown up to grasses (Aqawi and Chew, 1959). Areas covered by rice provide good oviposition sites, whereas areas bare of vegetation are of little importance. Chew and Gunstream

(1964) found that a homogenate of fresh grass incorporated into rearing medium greatly enhanced the development of *P. confinnis*. The importance of vegetation of successful breeding is a habitat correlation that may be readily observed using remote sensing.

The maximum number and length of presence of the mosquito is directly related to the amount of temporary water available. Gunstream (1964) has shown an abundance of irrigation water and a proximity to cattle and horses to be necessary for the development of large populations of *P. confinnis*. Here again, remote sensing techniques are readily available to detect such associations.

In California, adults are present from April to October when the mean weekly air temperature averages 82.8^{O}F. Adults are no longer present in the fall when the mean weekly air temperature drops below 70^{O}F.

The hatchability of the eggs of *P. confinnis* must be primarily controlled by the conditioning or deconditioning action of the annual cycle of temperature. A mean weekly air temperature of about 70^{O}F. probably is the threshold for the conditioning of overwintering eggs. Increasing numbers of eggs will be conditioned as the temperatures continue to rise in early summer. All eggs must be conditioned when summer temperatures reach a weekly mean of 90^{O}F. The decline in temperature in later summer and early autumn deconditions the eggs so that they pass the winter in a dormant state. The actual hatching of eggs is triggered by flooding, with the percent of eggs hatching being dependant on the temperature of the flooding medium and independant of dissolved oxygen concentration.

Gunstream and Chew (1967) found the developmental time, eclosion to emergence, for *P. confinnis* to be from 78 to 126 hours with a mean of 97 hours at average water temperatures of 77-88^{O}F. In 38% of the broods observed in irrigation ditches, all pupae were stranded on mud by the disappearance of open water. However, 50-95% of these metamorphosed successfully even though stranded for as much as 15 hours. Thus, in summary, standing water needs to persist only 3 to 5 days to permit emergence.

Hagstrum and Workman (1971) found the developmental time needed for *Culex tarsalis* to range from 12 to 24 days. The developmental time was 5.5 to 8.1 days shorter at 30°C than at 20°C.

Chemical characteristics of natural waters limit occurrence of mosquito larvae by influencing oviposition and larval development. Hagstrum and Gunstream (1971) analyzed the water chemistry for 52 permanent and semipermanent sources in the arid regions of Imperial and Riverside Counties, California. Mosquito larvae were absent from waters of low mean ion concentration or organic nitrogen, probably because there are smaller amounts of available food in such waters.

Of the eight species collected, two, *Culex tarsalis* and *Psorophora confinnis*, are important as encephalitis vectors. *P. confinnis* occurred in water with lower mean concentrations of ions than the more widely distributed *C. tarsalis*. The mean concentrations of ions in the water tested for *P. confinnis* and *C. tarsalis* are given in table I.

Table I - Mean concentrations of ions (mg equiv./L x 10^{-1}) in water tested

Species	Ca	Mg	K	Na	NH_4	CO_3	HCO_3	SO_4	NO_3	Org. N	Cl
P. confinnis	101	39	14	131	0.4	0	49	108	0	14	122
C. tarsalis	134	1.34	20	1037	0.4	0.7	62	414	.04	81	862
No larvae present	140	106	16	1366	1.3	0.6	60	218	0.9	9	1433
Mean of all samples	142	121	17	972	0.5	0.6	59	310	0.1	49	878

The concentration of various ions for water samples where the widely distributed species _C. tarsalis_ was collected, do not appear to vary appreciably from the mean concentration of all water samples taken or from the mean concentration of ions for water samples taken where no mosquito larvae were collected. The similarity between the aforementioned means for given ions and the large standard deviations found by Hagstrum suggests that larvae of _C. tarsalis_ have a broad tolerance and show little preference for particular concentrations of ions encountered in south-eastern California.

Culex (_Melanoconion_) from certain hammocks produce the greatest yield of VEE in South Florida (Sudia _et al._, 1969). VEE positive areas over three years were Mahogany Hammock, Royal Palm Area, Snake Bite Road, Big Ficus Hammock, and Turner River Jungle Gardens, all within the Everglades National Park System. Not only did the results show presence of the virus year after year in the same areas, but throughout the entire year. In Mahogany Hammock, for example, isolations have been made from January through November.

Culex mosquitoes of the subgenus _Melanoconion_, are localized in habitat, are nocturnal, and apparently feed to a considerable extent if not preferentially upon ground-dwelling vertebrates, especially wild rodents. Few indications were found that this VEE virus strain can be maintained outside the southern Everglades habitat. The virus was not found at Gossman's Hammock, which lies out of the true Everglades habitat or at Corkscrew Swamp, lying north and west of the Park. In fact, it was taken only once beyond the Park boundries, at a site on the Turner River near the Tamiami Trail where the habitat type was an extension of that further south. Sudia (pers. Comm., CDC, Atlanta) suggests that the presence of VEE is positively correlated with hammocks at a salt water - fresh water interface.

POTENTIAL PROJECTS IN REMOTE SENSING OF VECTOR MOSQUITOES

Two main geographical areas hold the most promise for successful remote sensing of vector breeding sites. These are the Florida Everglades and the area including southern California and northern Mexico. In the first region the viral infection of greatest concern is VEE, while in the latter it is WEE.

Study plan for Southern California - Northern Mexico Region

In this area the primary vectors of WEE are *Culex tarsalis* and *Psorophora confinnis*. To date very little is known about the habitat preference and overall ecology of *C. tarsalis*. Much ground work on its ecology must be completed before any reliable correlations can be made between the abundance of this species and environmental parameters detectable by remote sensing.

More promising is *Psorophora confinnis*. The ecology and habitat preference of this vector mosquito is better understood than that of *C. tarsalis*. Several conditions favorable for the development of large populations of this vector may be detected by remote sensing.

These are as follows:

1) most abundant in shallow water, usually temporary flooded areas covering grasses. (especially irrigation ditches).

2) the persistance of standing water for 3 to 3.5 days necessary for emergence. (calculated from water depth and rate of evaporation at ambient temperature, humidity, and wind speed)

3) an optimum water temperature of 24-29°C. with an upper limit of 35°C.

4) air temperature of at least 70°F. for adult survival.

5) hatching is initiated by flooding; water must be 70°F. or warmer (increased percentage of hatching with increasing temperature).

6) absent from water of low mean ionic concentration

7) absent from water of low organic nitrogen

8) proximity to cattle and/or horses necessary for the development of large populations.

Though there is not a 100% correlation between the presence of P. confinnis and these parameters, they do, however, indicate where the organism is either likely to be absent or most likely to be present in large numbers.

A proposed study would of necessity have to include a great deal of ground work using standard sampling techniques such as light traps, larval dipping, and resting collections. Other more indirect methods should also be tested for their predictive capabilities. For example, long term observations on ground and surface water levels, rainfall, irrigation practices, etc., have permitted limited predictive models to be made for Culex tarsalis in California. These models have thus far met with little success, but when more is learned about the ecology of C. tarsalis, better models may be formulated.

Types of remote sensing such as IR, ultraviolet, radiometers, sonobouy, radar, and radio (swept frequency type), photo interpretation, and multispectral photometry should be used in conjunction with the ground experiments to test the effectiveness of conventional, direct, and remote sensing techniques. The distribution of vector mosquitoes might be better understood by studying associations between ecological conditions as determined remotely than by direct methods alone.

Such institutions as the University of California, School of Public Health, Berkeley and Los Angeles along with the Viral and Rickettsial Disease Laboratory, California State Department of Public Health could be instrumental in helping NASA tackle the encephalitis problem.

Study Plan For The Florida Everglades

VEE is endemic in South America, Central America and Florida; however the distribution of antibody is discontinuous and in many areas is restricted to relatively local foci (Sudia *et al*. 1969). Hammocks located along a fresh water - salt water interface in the Everglades are thought to be the exclusive breeding sites of *Culex* (*Melanoconion*), the important vector of VEE in this area. Remote sensing offers a rapid technique for identifying and plotting such hammocks.

VEE appears to be unique in this area in that the main reservoir is thought to be the rodent population rather than the avian population as in other equine encephalitides. The three most important reservoir genera are *Oryzomys*, the rice rats; *Peromyscus*, the white footed mice; and *Sigmodon*, the cotton rats. Epidemics are correlated with years of high rodent populations as estimated by release-recapture techniques of estimating population density.

Sudia (pers. comm.) has suggested that the numbers of paths through the sawgrass caused by rodents may be indicative of the rodent population density. These paths are easily visible on black and white photographs (see attached photos) taken at ground level, and may well be detectable in low aerial photographs covering a greater area.

It is suggested that an institution such as the University of Florida or University of Miami, in conjunction with Dr. Sudia of CDC, Atlanta, be approached to study this problem. In this way a means of remotely and rapidly estimating rodent population may be developed.

Sawgrass marsh near Mahogany Hammock, Everglades National Park. The pathways may be seen in aerial photography and might be used to estimate mammal populations of the hammock in the background.

A closer view of a rat-rabbit pathway leading into Mahogany Hammock. The small mammal populations of this and other hammocks have been estimated by CDC personnel.

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Rivers, T.M. and F.L. Horsfall. 1959. Viral and Rickettsial Infections of Man. J.B. Lippincott Col, Philadelphia, Pp. 286-303.

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Studies on mosquitoes and wild vertebrates in the everglades of south Florida have shown that a VEE-like virus and at least four other new "tropical" arboviruses of Group C, Guama and Patois are maintained there enzootically. Culex (Melanoconion) mosquitoes are the enzootic vector species and wild rodents the apparent natural hosts. Aedes taeniorhynchus, a vicious biter and possible epidemic vector, was also taken infected with VEE virus on several occasions.

Chew, R.M. and S.E. Gunstream. 1970. Geographical and seasonal distribution of mosquito species in southeastern California. Mosquito News, 30(4): 552-562.

The distribution of 15 species of mosquitoes are described for the agricultural and natural areas of the Sonoran Desert, for July 1968 through July 1969. Patterns of distribution vary with mosquito abatement practices, the effectiveness of the drainage systems, the amount of natural waters, the type of agriculture, and less obvious factors, within the total situation. Culex tarsalis, ubiquitous in the study area. (author abstr.)

Gunstream, S.E. 1965. The ecology of Psorophora confinnis in southern California. I. The seasonal nature of hatching. Ann. Ent. Soc. Amer., 58(5): 663-667.

The seasonal hatching of eggs is controlled by the annual cycle of temperature. All eggs are conditioned when held at 90°F. for 1-2 weeks and deconditioned after 4 weeks at 60°. Conditioning temperature and may be as low as 70°F. The combined effects of preflooding and flooding temperatures upon the hatching of the eggs control the seasonal occurrence of adults.

Gunstream, S.E. and R.M. Chew. 1964. Contribution to the ecology of Aedes vexans in the Coachella Valley. Calif. Ann. Ent. Soc. Amer., 57: 383-387.

A. vexans is abundant only in areas with shrubs or trees and a dense undergrowth of herbs. Significant catches were made only after temperatures reached 30°C with peak densities in late August. An oviposition preference for tall grasses was found. Total time for development averaged 124.2 hours when the mean water temperature was 27.8C. Feeding responses were not marked until the third day; oviposition occurred 3 days after feeding.

Gunstream, S.E. and R.M. Chew. 1967. A comparison of mosquito collection by Malaise and miniature light traps. J. Med. Ent., 4(4): 495-496.

The catches of a Malaise trap and a miniature light trap were compared over a 6-week period. Both traps caught the same 7 species but in very different proportions. The species varied 54-fold in their attraction to the light trap. Females were much less photopositve when engorged, and their response varied with reproductive condition. The Malaise trap is recommended for comparative studies of mosquito ecology. (author abstr.)

Gunstream, S.E. and R.M. Chew. 1967. The ecology of *Psorophora confinnis* in Southern California. II. Temperature and development. Ann. Ent. Soc. Amer., 60(2): 434-439.

The developmental times of 18 broods observed in irrigated date groves in the Coachella Valley, Calif., ranged from 78 to 126 hours with a mean of 97 hours at an average water temperature of 77-88^{o} F. In 38% of the broods, all pupae were stranded on mud for as much as 15 hours, but 50-95% metamorphased. The first and second instar larvae were most susceptible to temperature extremes. Total development was fastest (86-89 hrs.) at 90-95^{o}F.

Hagstrum, D.W. 1971. A model of the relationship between densities of larvae and adults in an isolated population of *Culex tarsalis* (Diptera: Culcidae). Ann. Ent. Soc. Amer., 64(5): 1074-1077.

The existence of a stable age distribution and the effectiveness of the Malaise trap as an adult sampling device were established. The mortality between successive instars was calculated from differences in densities of successive instars. The daily egg production and daily adult emergence were calculated from the densities of instar II and pupae, respectively. Two Malaise traps collected a mean total number of adults equivalent to 22.4 and 22.0% of the estimated mean daily emergence.

Hagstrum, D.W. and S.E. Gunstream. 1971. Salinity, pH, and organic nitrogen of water in relation to presence of mosquito larvae. Ann. Ent. Soc. Amer., 64(2): 465-467.

The six species of mosquitoes with limited distribution in southern Calif. occurred in water with lower mean concentrations of ions than the two more widely distributed species *C. tarsalis* and *Culiseta inornata*. This supports the hypothesis that successful species of mosquitoes must be less selective and more tolerant with respect to mean concentrations of ions in their breeding water.

Hagstrum, D.W. and E.B. Workman. 1971. Interaction of temperature and feeding rate in determining the rate of development of larval *C. tarsalis*. Ann. Ent. Soc. Amer., 64(3): 668-671.

The duration of larval stages of *C. tarsalis* shows a linear relationship to feeding rate at 20°C. and 30°C. Pupae were 12 and 18% heavier at 20°C. than at 30°C. The shortening of the duration of larval stages at 30°C. over 20°C. was accompanied by a greater decrease in the duration of stages I and III than of stages II and IV.

Kissling, R.E. 1958. Host relationship of the arthropod-borne encephalitides. Annals N.Y. Acad. Sci., 70(3): 320-327.

A review of the literature on experimental infection of birds and horses with SLE, WEE, EEE, and VEE. WEE virus multiplies to higher levels in the blood of birds than SLE with wild birds being more important reservoirs than domestic birds. With EEE smaller birds are more efficient hosts than are larger birds. VEE virus multiplies more rapidly in mammals than birds. Birds are excellent sources of virus for mosquitoes when infected with SLE, WEE, and EEE viruses but are rather poor hosts in this respect during the viremic phase of VEE infection.

Kissling, R.E., R.W. Chamberlain, D.B. Nelson, and D.D. Stamm. 1956. Venezuelan equine encephalomyelitis in horses. Am. J. Hyg., 63: 274-287.

The results of a year-round sampling of mosquitoes and birds in an area endemic for equine encephalitis in southern Louisiana are given. EEE was isolated once from a mosquito (*Anopheles crucians*) and two times from birds (catbird, cardinal, and hermit thrush). WEE was isolated three times from mosquitoes (once from *Culisera melanura* and twice from *Aedes infirmatus*) and three times from birds (loggerhead shrike, cardinal, and Carolina chickadee). All occurred between the months of March and August and were more prevalent in migratory than permanent residents.

Several possibilities for virus survival are discussed.

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Aedes aegypti were fed on hanging drops containing VEE virus and their tissues were studies for the presence of virus by electron microscopy. Virus penetrated the digestive tract and reached the brain within 48 hours after the infective feeding. Although VEE virus appears to be pantrophic in tissues of *A. aegypti*, it showed a preference for the salivary glands, where it was markedly concentrated by the 18th day after infection.

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Textbook with chapters on arboviruses, group A arboviruses. eastern and western encephalomyelitis, and Venequelan equine encephalomyelitis. Includes a bibliography with each chapter.

Rivers, T.M. and F.L. Horsfall. 1959. Viral and Rickettsial Infections of Man. J.B. Lippincott Co., Philadelphia. Pp. 286-303.

A textbook on viral and rickettsial infections of man including a chapter on arthropod-borne group A virus of man with an extensive bibliography.

Stamm, D.D. 1958. Studies on the ecology of equine encephalomyelitis. Amer. J. Public Health, 48(3): 328-335.

When the results of studies made on EEE in wild birds in different localities over the course of several years are summarized, two differing patterns of activity appear to prevail. The first is the progression of the virus through a wild bird population at a normal endemic maintenance rate. In the second the virus spread to 45-54% of the bird population, appeared outside its geographical limits, and involved equines. It is probable that it is the entrance into the transmission cycle of other highly efficient mosquito species in large numbers which produces an epidemic situation.

Stamm, D.D. 1966. Relationships of birds and arboviruses. Auk, 83(1): 84-97.

At least 52 species of birds are susceptible to EE virus, 51 to WEE virus, and 24 to SLE virus. By the end of the transmission season up to 70% of the birds in local populations have been involved. Virus transmission between birds and mosquitoes may persist in small areas of especially favorable habitat where some mosquitoes are active throughout the year. Overwintering may occur in hibernation mosquitoes or in reptiles. Especially needed from ornithologists is information on bird population abundance, dynamics, and movements.

Sudia, W.D., R.D.Lord, V.F. Newhouse, D.L. Miller, and R.E. Kissling. 1971. Vector-host studies of an epizootic of VEE in Guatemala, 1969. Amer. J. of Epidemiol., 93(3): 137-143.

An epizootic of VEE occurred in the equine population of Guatemala during the summer of 1969. VEE virus isolations were made from several mosquitoes. *Psorophora confinnis* was found to be an excellent vector and to have been a significant transmitter of the virus in areas where it was abundant. VEE was also isolated from a horse, a mule, and a young calf.

Work, T.H. 1964. Arbovirus impingement on the natural history of man. In: Occupational Diseases Acquired From Animals, 1964. Univ. of Michigan School of Public Health.

General account of the arboviruses causing disease in man. Includes a diagramatic interpretation of occupational exposure of man to arbovirus infection and an extensive chart listing the occupational situations associated with certain arbovirus infections of man.

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MALARIA AND ITS POSSIBLE DETECTION THROUGH REMOTE SENSING

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MALARIA

INTRODUCTION

According to a book published in 1947 by the United States Public Health Service and the Tennessee Valley Authority (which will hereafter be referred to as "TV^ (1947)", the word "malaria" was used in 1927 to describe "...febrile illnesses associated with swampy places." It was used previously to describe illnesses thought to have been caused by exposure to emanations from the swamps themselves. Malaria is a general term which refers to four different illnesses all caused by species of the genus Plasmodium. The Plasmodium parasites are transmitted to the human host by mosquitoes of the genus Anopheles. TVA (1947) stated that, "Malaria occurs in almost every part of the world where physiographic factors tend to produce and to maintain aquatic environments favorable to anopheline mosquito propagation, and where the agricultural economy of the region is associated with a relatively low standard of living."

Malaria was, according to Howard (1901), brought to the United States from Europe originally. TVA (1947) was more specific in its statement that malaria was introduced here in, "...colonial days by emigrants from highly endemic centers in the Old world" and the supply of carriers was maintained for the next 200 years by the importation of Negro slaves.

Although malaria has not been a real health problem in this country for many years, it has affected Americans in foreign countries (particularly in Vietnam). According to Canfield (1970) malaria is

"...probably the major cause of medical disability in Vietnam". Canfield further stated that since 1965 there have been more than 30,000 cases of malaria with 60 deaths. Holway (1970), reporting on studies in Vietnam involving American troops on active duty there, found infection rates as high as 53/1000/day during a five day period. Dover (1970) reported that there have been only 20 fatalities in the United States during the four year period ending December 1969, all of which were due to Plasmodium falciparum. Eleven of the 20 were civilians, two of whom died as the result of contaminated blood transfusions administered in the United States. One of the suspected donors was an asymptomatic Vietnam veteran with an indirect flourescent antibody titer against P. falciparum. All of the cases were of foreign origin.

Notwithstanding the foreign origin of malaria in the United States at present, a real malaria potential still exists. TVA (1947) stated, "...malaria may well recur where high anophelism is allowed to prevail".

The distribution and range of important vectors in the United States is known (Fig. 1.), and a good deal of knowledge has been amassed concerning the relative densities of vector species in their general ranges. Where there is water there can be mosquitoes, but there are certain ecological conditions which favor high anopheline production. While these ecological conditions are known and understood, both independently and in mutual interaction, it is quite difficult constantly to monitor those conditions by conventional methods. That is to say that an efficient, rapid and thorough monitoring system for studies over wide areas has not yet been developed.

OBJECTIVE

It is relatively easy to determine whether or not a vector species lives in a given area. Specimens of the resident mosquitoes can be captured and species determinations can be made. However, determination of the density of the vectors per area is another matter. The presence of the vector species offers presumptive evidence of malaria potential but affords no basis for statistical inference. Once the density of the vector has been determined sufficient to constitute a hazard to human health, one may draw conclusions as to what action must be taken to eradicate the species. If it is assumed that a dense vector population might be equated with a possible malaria outbreak, then one needs only to know what conditions ultimately lead to high anopheline production in order to anticipate future problem areas. The problem is that there is not currently in use a system of monitoring which can quickly identify future problem areas except in the most obvious of cases.

In order to create a monitoring system which would provide information leading to the anticipation of problem areas, as well as expose existing areas of high vector density, it would be necessary to construct a model of ecological parameters which together favor anopheline production. The ecological parameters would than be studied by remote sensing techniques and the data correlated to yield information saying that area "X" favors high anopheline production, and area "Y" does not. Once area "X" is shown to favor a high vector density, the appropriate control measures could be more effectively administered over the specific area. Further, as in the case of control by flooding or drainage, post-control information for the continued maintenance of the area could be supplied by the same rapid monitoring system. The feasibility of this approach will be discussed in the "proposal" section of this paper.

SUMMARI^L REVIEW OF THE LITERATURE

While hundreds of papers have been written bearing on the subject of malaria, few deal directly with the applications of remote sensing to malarial control. In search of pertinent literature, two weeks were spent at the Woods Hole Oceanographic Institution. While rather disappointing with regard to the recovery of relevant literature, the results were encouraging in the realization that the use of remote sensing techniques in control of human health problems is a new field of endeavor.

After having corresponded with several scientists in the field of malaria, and after having read their papers and others, it soon became evident that the most likely pursuit which might lead to an eventual solution was that of mosquito bionomics.

Russell, *et al*., (1963) stated that there are some sixty-five known anopheline vectors, but only three species are considered important in the United States. These three are *A. albimanus* common in Texas and Florida, *A. freeborni* which is found in the western United States, and *A. quadrimaculatus* the range of which extends across the central and eastern United States. Russel, *et al*., (1963) regarded *A. albimanus* as an incidental vector, and TVA (1947) recognized only the other two. TVA (1947) gave the distribution of *A. quadrimaculatus* in significant densities "...east of the Mississippi River from the Great Lakes to the Gulf of Mexico, and for some distance west of the Mississippi, being most prevalent in the Mississippi River Valley and the Southern States", and gave the distribution of _A. freeborni_ in the Southwest and the river valleys of California principally associated with irrigated lands. The CDC in Atlanta has provided a pictorial representation of the distribution of these vectors across the entire United States (Fig. 1).

LIFE HISTORY

1. The Egg.

Howard (1901) states that eggs are laid in water in masses of 40-100, unattached, and during a period of about three days. TVA (1947) reported that the eggs are laid in "batches of 50-300 with several batches being laid by one female during her lifetime" and the period may vary from several days to several months depending on the species. Russell _et al_. (1963), stated that all anopheline species lay their eggs, numbering up to 350 depending on the species, at night or just before sunrise. They are either singly deposited or in loose groups on the water surfaces; and often, in the case of _A. quadrimaculatus_ without regard for the presence of chemicals, extremes of pH, presence of vegetation, etc. A blood meal often but not always precedes the production of eggs. The eggs of the latter species have been shown to respond drastically to temperature, such that development cannot be completed below 53°F, while the eggs of other species may be less susceptable to temperature changes. Hall (1971a) reported that areas of water favorable for ovipositing are those with the surface broken into quiet cells.

2. The Larvae.

Howard (1901) described the feeding process of larvae, saying that algal spores and minute bits of debris are brought to the mouth by a current generated by the action of the mouth parts. TVA (1947) remarked that practically all mosquito larvae breath through an air tube which penetrates the surface film. Russel *et al.* (1963), wrote that the larvae of anopheline species may survive for a short time on moist surfaces but essentially require an aquatic environment. There are several factors important in larval development which include flora, fauna, water movement and temperature, sunlight, shade, chemical composition, turbidity, and contaminants.

a. Flora

TVA (1947) offered a classification of plant types associated with anopheline production. The 10 ecological types are quoted below: (Plates 1-10).

"1. Woody -- having woody supporting tissue, typically with perennial aerial stems.

2. Erect leafy -- standing erect with relatively firm stems and an abundance of well-defined leaves.

3. Erect naked -- standing erect and usually lacking well-defined leaves, or if leaves are present, they are linear and erect.

4. Flexuous -- having stems which are relatively weak and flexuous, or if firm and erect, possessing lax leaves or flexuous terminal stems.

5. Carpet -- with relatively short shoots forming dense attached mats.

6. Pleuston -- minute plants (such as duckweeds) floating freely at water surface.

7. Floating mat -- composed of relatively large plants forming a mat which floats at the water surface.

8. Floating leaf -- consisting of attached plants bearing floating leaves with relatively long flexuous petioles.

9. Submerged -- typically growing with the vegetative parts largely submerged.

10. Microscopic -- plants which must be identified by the use of the microscope even though some of them either individually or collectively, may be visible to the naked eye."

TVA (1947) further provided specific preferrences of A. quadrimaculatus for the ecological types of flora, but stated that the dominant factor in the production of the species is its "intersection line", or the "...line of intersection between plants (or flotage) and the water surface." TVA (1947) stated that almost any plants growing in, or inundated by water, will create a favorable environment for the production of A. quadrimaculatus.

According to Russell, et al. (1963), A. quadrimaculatus prefers floating vegetation such as Azolla, Lemma and waterlilly. Darsie and Springer (1957) reported it commonly in association with swampdock, cattail, rosemallow, phragmites, coontail (Ceratophyllum demersum), duckweed, pondweeds, algae, switchgrass, and wild millet. Hall (1971b) indicated that the greater anopheline density should occur with flexuous, submersed and floating-mat floral types, but pointed out that submersed varieties become important only when the plants reach and intersect with the water surface; intermediate production should occur with free-floating and erect leafy types, and the least production should be found in the presence of erect-naked, floating-leaf, and bottomland forests of water-tolerant woody species. Productivity is encouraged by the presence of significant quantities of flotage and discouraged by clean vegetation-free water.

A. albimanus is commonly found in association with Pistia stratiotes in quiet water, and often uses artificial containers, animals hoof-prints, tree leaves, and the like; and in lakes and slow rivers with matted vagetation. _A. freeborni_ prefers fresh, clear seepages, irrigation ditches, certain contained streams, etc.

b. _Fauna_.

The principal importance of fauna is that of predation upon anopheline larvae. Examples of predators are the fish _Gambusia_, certain amphibians, and beetles of the family Hydrophilidae.

c. _Water movement_.

Most vectors are vulnerable to water velocity, and generally require relatively still water which encourages oviposition.

Siltation is probably less important in turbidity than the water currents themselves which serve to move the larvae into unfavorable environmental conditions.

d. _Sunlight and shade_.

Russell _et al_. (1963) reported that _A. freeborni_ is strongly heliophilic (sun-loving), while others prefer some shade. This feature is probably related more to adult ovipositing behavior than to larval tropisms.

e. _Temperature_.

TVA (1947) stated that "The best physical requirements for the occurance of malaria are water and an average atmospheric temperature higher than 68° F for at least 2 months of the year". Russell _et al_. (1963) put the most favorable temperature for larval survival of _A. quadrimaculatus_ at 88° F.

f. _Surface tension_.

While surface tension of the water is reduced by the input of certain insecticides, detergents, etc., the larvae of anopheline vectors show certain responses. *A. quadrimaculatus* has been shown to change its feeding habits to some extent in response to changes in surface tension, such that it feeds interfacially during high tension or by the eddy mechanism during reduced tension (Russell *et al.*, 1963). The larvae of most mosquitoes depend upon surface tension in order to stay at the surface where they breathe.

g. Hydrogen-ion concentration.

The larvae of most species can tolerate a rather wide range of pH, but according to Russell *et al.* (1963) *A. quadrimaculatus* prefers an intermediate range. Darsie and Springer (1957) found the species in water having a pH as low a 6.2, as high as 9.3 and with a mean of 7.2 in impounded waters in Delaware.

h. Salinity.

A. albimanus has been found abundantly in lagoons with 15-25 percent sea-water concentrations. Darsie and Springer (1957) considered *A. quadrimaculatus* to be a permanent-water, fresh-water species. They reported *A. albimanus* as having a low salinity tolerance.

i. Pollution.

Pollution is important in that it can affect surface tension, oxygen content, etc.,and is related not only to larval growth but to the vegetation types as well. However, the effects of pollution are variable.

j. Larval food.

Larvae eat principally unicellular algae, flagellates, ciliates, and other floating life.

3. The adult

Male anophelines are relatively short lived. Their life spans may range from a few days in the tropics to one or two months in cooler zones. The flight range of anophelines varies; _A. albimanus_ has been known to range three to four miles from its breeding area; _A. quadrimaculatus_ may transmit malaria two or three miles away. _A. freeborni_ might fly as much as eight miles in its spring, post-hibernation flight.

Since rainfall increases the number of breeding sites, the rainy seasons tend to favor greater numbers of _Anopheles_.

DISCUSSION

Many of the ecological factors listed above could be monitered by remote sensing apparatuses, and it is these with which this paper is primarily concerned. (Table 1). Several other factors which are important in anopheline production (e.g. "fauna"), would not only be difficult to monitor but would be of little significance in the present accounts.

Floral types are generally considered ecologically rather than taxonomically, which makes their monitoring less complicated. A variable such as salinity would be monitored only if there is the possibility of salt-water intrusion in a given research area.

In considerations of whether or not a given area poses a threat to human health, a study of the vector density, followed by a study of human populations within the flight range of the vector species in the area is necessary.

ECOLOGICAL CONSIDERATIONS	SPECIFICS	RELATIVE VALUES TO ANOPHELISM
Flora	Flexuous, submersed and floating mat	+++
	Free-floating and erect leafy	++
	Erect-naked, floating-leaf, and bottomland forest of water-tolerant woody species.	+
Water Quality	Clean and Vegetation-free	-
	With significant quantities of flotage	+
Water Reservoirs	Many per area, or large reservoirs	++
	Few per area, or small reservoirs	+
Reservoir Type	Permanent (lakes, pools, rivers)	++
	Temporary (created by rainfall)	+
Water Velocity	Still	+++
	Slow	++
	Rapid	-
Air Temperature	At least 68° F for at least two months	+
	Less than a mean of 68° F year round	-
Salinity	No possibility of salt-water intrusion	+
	Possibility of salt-water intrusion	-

Table 1. The ecological considerations which produce favorable areas of Anopheline production and which could be monitored by remote sensing techniques, are provided. The comparative values ralative to increased Anophelism are given in plus and minus symbols.

PROPOSAL

The feasibility of the applications of remote sensing to malaria control should be rigorously tested in the field. It is therefore suggested that a twin pilot study be launched in two separate areas, and that the research be conducted simultaneously and identically.

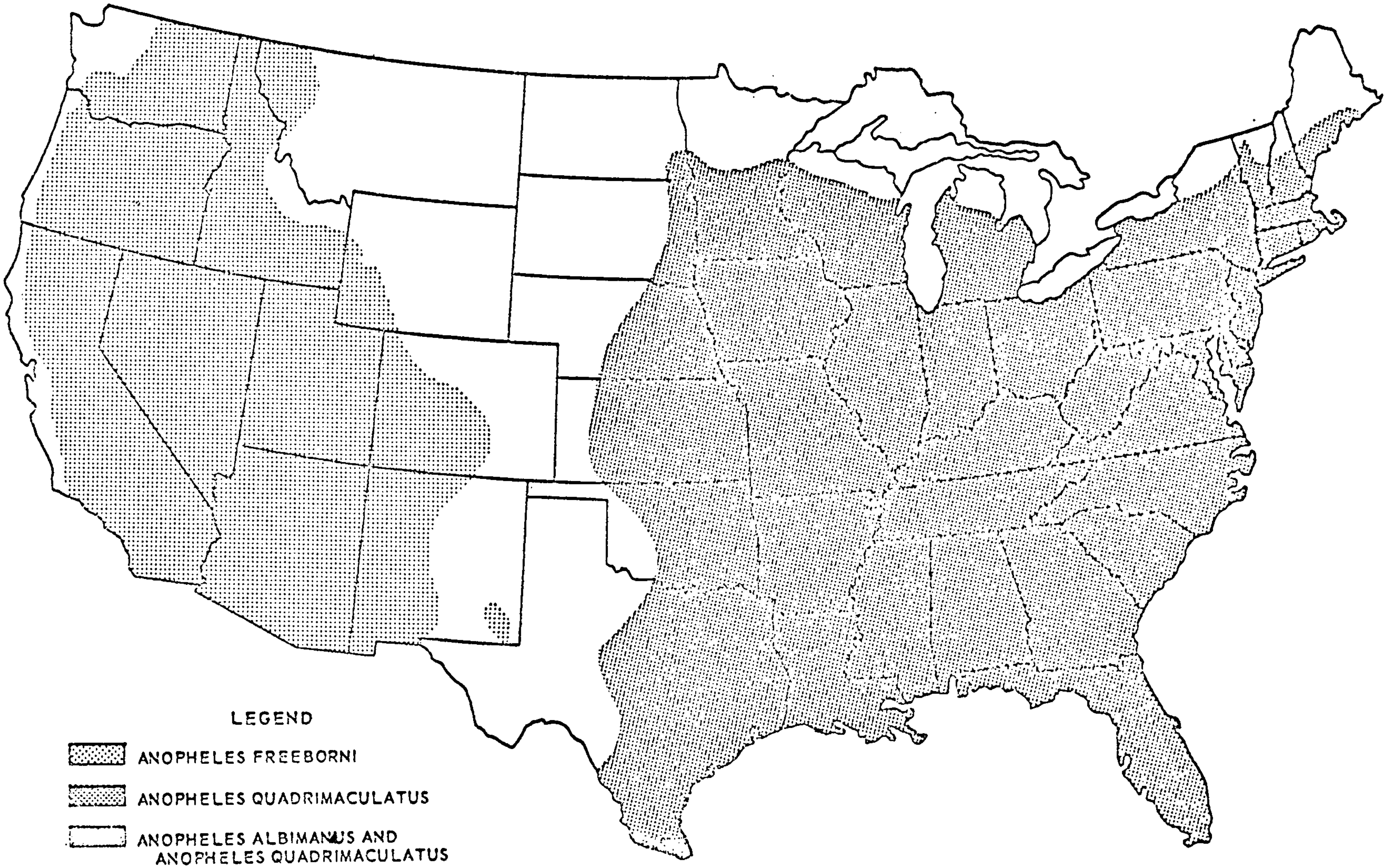
Dr. Sudia of the CDC in Atlanta has expressed considerable interest in this type of project, and is currently engaged in some infrared studies in certain regions of Florida.

Dr. T.F. Hall of the Tennessee Valley Authority, during two private telephone converstions, expressed similar interest regarding his malaria studies in the Tennessee River Valley. Dr. Hall, working under Dr. W.W. Barnes (Chief of Environmental Biology Branch), is in charge of the Planned Study Section.

The two areas mentioned would make excellent test sites in that they both meet the ambient temperature requirements for high anopheline productivity, and because considerable work on the subject has already been done in these areas.

Using remote sensing techniques, ecological considerations could be effectively and rapidly monitored (Table 1.). An ecological model could be constructed as it would relate to remote sensing, and data from periodic monitorings could be correlated with the physical data of vector density. As monitorings of changing conditions were correlated with density changes over time, it might be possible to achieve probability values capable of predicting vector density under a particular set of conditons. It would be possible to use the same monitoring systems in areas where no active malaria research was in progress to predict the probabilities of malaria activity and vector density in those areas.

The possibility of such predictions could have an invaluable impact upon malaria control. The monitoring system could yield information to be used as presumptive evidence that a given area would or would not need attention, and the system would also suggest possible control measures.



DISTRIBUTION OF MALARIA VECTORS IN THE U. S.
1966

U. S. Department of Health, Education, and Welfare
Public Health Service

ANNOTATED BIBLIOGRAPHY

Canfield, C.J. 1970. Malaria: Host-defense mechanisms and complications. Ann. Internal Med., 73: 295-306.

The paper deals with malaria affecting military personnel on foreign assignments, particularly Vietnam, and discusses cases and complications.

Darsie, R.R., and P.F. Springer. 1957. Three year investigation of mosquito breeding in natural and impounded tidal marshes in Delaware. Univ. Delaware Agr. Exp. Stn. Bull., 320 (tech.), : 1-65.

This lengthy and fact-filled paper deals with the mosquito production of the area relative to ecological conditions.

Hall, T.G. 1971a. Some relationships between plants and anopheline production. (Unpublished).

Research conducted in El Salvador, Central America, during the rainy season in late August to early September, and in the dry season in the middle of March 1971. The relationships between vegetation types and the production of _A_. _albimanus_ and _A_. _pseudopunctipennis_ is discussed.

Hall, T.F. 1971b. The influence of plants on anopheline breeding. Inter-American Malaria Res. Symp. San Salvador. November, 1971.

The relationships between plant types and Anophelism are disucussed, as well as mechanical and biological controls.

Howard, L.O. 1901. _Mosquitoes_. New York: McClure, Phillips and Co.

This is an early but comprehensive book which summarized the knowledge available on the general subject of mosquitoes. Malaria vectors received particular attention.

Dover, A.S. 1970. Fatalities due to malaria in the United States, 1966-1969. J. Infect. Diseases, 121(5): 573-575.

The numbers of cases and their nature is discussed.

Holway, R.T. 1970. Vector densities and malaria rates in the Republic of Vietnam. Mosquito News. 30(2): 131-134.

The paper regards research conducted in southeast Asia on United States military troops. Infection rates from _Plasmodium vivax_ and _P_. _falciparum_ are given. Vector mosquitoes are listed as probably _A_. _heyporiensis candidiensis_, _A_. _maculatus_, _A_. _aconitus_, and possibly _A_. _sinensis_.

Russell, P.F., L.S. West, R.D. Manwell, and G. MacDonald. 1963. Practical Malariology. Oxford University Press, London.

Comprehensive. Considerable detail is given on mosquito binomics, life cycles, control and epidemiology.

TVA. 1947. Malaria Control on Impounded Water. United States Public Health Service and Tennessee Valley Authority. Govt. Printing Office, Washington.

The book is principally concerned with the relationship between malaria and impounded water, but gives much information on control measures and plant relationships.

ADDENDUM

Carmichael, G.T. 1971. Anopheline control through water management. Inter-American Malaria Res. Symp., San Salvador.

The success of malarial control through water management in Pakistan, Haiti, India, and El Salvador is discussed as well as means by which the water management was administered.

Cohn, E.J. 1971. Assessing the costs and benefits of anti-malaria programs. Inter-American Malaria Res. Symp., San Salvador.

The author takes the position that control is cheaper than eradication in the long run. The various costs involved are given and discussed.

Conly, G.M. 1971. Difficulties confronting malaria eradication. Inter-American Malaria Res. Symp., San Salvador.

In studies of working families with and without malarial influence, the economic importance of malaria in Paraguay is discussed.

Galbaldon, A. 1971. Difficulties confronting malaria eradication. Inter-American Malaria Res. Symp., San S lvador.

Such problems connected with the vector as physiological resistance and intense exophilism are considered most important. Other difficulties are mentioned.

Galbaldon, A. 1969. Global eradication of malaria: changes of strategy and future outlook. Am. J. Trop. Med. Hyg., 18(5): 641-656.

The author deals with the problems involved in global eradication, and discusses the non-feasibility of the notion.

Johnson,R. 1969. Malaria surveillance methods, their use and limitations. Inter-American Malaria Symp., San Salvador.

The nature and uses of surveillance (detection and control) are discussed; also discussed are the advantages and short-comings of surveillance.

UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
ENTOMOLOGY RESEARCH DIVISION
1600 S. W. 23RD DRIVE
P. O. BOX 1268
GAINESVILLE, FLORIDA 32601

December 14, 1971

Mr. Fred E. Pitts
NASA-Fellow
Department of Biology
The University of West Florida
Pensacola, Florida 32504

Dear Mr. Pitts:

Receipt is acknowledged of your letter of December 8 to Dr. Donald E. Weidhaas. We are enclosing a memo-copy of Dr. Weidhaas' paper you requested. This paper should not be cited as a reference until the Proceeding of the Malaria Symposium has been published.

In May 1969 a Conference on Anopheline Biology and Malaria Eradication was held at the Walter Reed Army Institute of Research, Washington, D. C. The following reference gives the proceeding of the Conference.

> Ward, Ronald A., and John E. Scanlon. 1970
> Conference on Anopheline Biology and Malaria Eradication.
> Misc. Publications of Entomol. Soc. Amer. Vol. 7(1): 1-196.
> $6.75

If your library does not have this publication, it can be obtained from Ralph W. Bunn, Managing Editor, Entomological Society of America, 4603 Calvert Road, College Park, Maryland 20740.

If we can be of further assistance, please write.

Sincerely,

Irwin H. Gilbert

Irwin H. Gilbert
Acting-in-Charge

Enclosure

TENNESSEE VALLEY AUTHORITY
MUSCLE SHOALS, ALABAMA 35660

December 14, 1971

Mr. Fred E. Pitts
Graduate Student
Biology Department
The University of West Florida
Pensacola, Florida 32504

Dear Mr. Pitts:

We wish to acknowledge your inquiry of December 8, 1971. We are sending along to you the following reference material: Malaria Control on Impounded Waters, "The Influence of Plants on Anopheline Breeding," and "Some Relationships Between Plants and Anopheline Production in El Salvador, Central America."

If we can be of further help to you in any way, please feel free to call upon us. If at any time it is possible for you to visit with us, we will be glad to have you do so.

With best wishes for the Holiday season and continued success in your studies,

Sincerely yours,

T. F. Hall

T. F. Hall, Ph.D
Botanist
Environmental Biology Branch

DEPARTMENT OF STATE
AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D.C. 20523

December 15, 1971

Mr. Fred E. Pitts
NASA-Fellow
The University of West Florida
Pensacola, Florida 32504

Dear Mr. Pitts:

In response to your request I am enclosing a copy of the paper on assessing malaria eradication costs and benefits which I delivered last month in San Salvador. I am also enclosing a longer paper on the economic aspects of the Indian malaria eradication program which I participated in evaluating a year ago and on which I drew heavily in preparing the talk I gave in San Salvador.

Unfortunately, I don't have the other types of information you requested; I suggest you write to the CDC in Atlanta.

Sincerely yours,

EJ Cohn

Edwin J. Cohn
Civic Participation Division
Bureau for Program and
Policy Coordination

Enclosures

WORLD HEALTH ORGANIZATION

1211 GENEVA 27 - SWITZERLAND
Telegr.: UNISANTE-Geneva

Tél. 34 60 61 Télex. 22335

ORGANISATION MONDIALE DE LA SANTÉ

1211 GENÈVE 27 - SUISSE
Télégr.: UNISANTÉ-Genève

In reply please refer to:
Prière de rappeler la référence:

15 December 1971

Dear Mr Pitts,

In the absence of Dr Pull from Geneva I have read your letter of 17 December and I enclose herewith a copy of Dr Pull's paper and a few extracts from correspondence that will give you an indication of our line of thought on the problem on which you are working at present.

You may wish to consider that the ecology of certain important malaria vectors, such as Anopheles nunez tovari and Anopheles b. balabacensis and a few other species, has a definite significance in the amount of malaria they can distribute. It is a known fact that the amount of malaria they can distribute is linked with changes in the ecology introduced by man. More specifically it is at the beginning of deforestation when settlers arrive and the distance of their dwellings from the forest does not exceed the range of the normal flight of these vectors that there are intense malaria developments. The screening of this initial deforestation endeavour both at the edge or inside the forest area could certainly provide at a glance an indication of where the malaria problem is more acute. In those areas malaria usually disappears or becomes more vulnerable to control measures when the deforestation has so progressed that dwellings are at a distance from the forest that exceeds the normal flight range of the vector.

I am unable to be more precise at present but I believe that this is an endeavour in which a lot of experience in screening and ground verification is required before one can judge the practical applicability of remote sensing to programmes of malaria.

Yours sincerely,

Dr G. Gramiccia
Chief, Epidemiological Assessment
Division of Malaria Eradication

Mr Fred E. Pitts
Gamma College
Faculty of Biology
The University of West Florida
Pensacola, Florida 32504
USA

BROWN UNIVERSITY Providence, Rhode Island • 02912

DEPARTMENT OF SOCIOLOGY

December 16, 1971

Mr. Fred E. Pitts
Faculty of Biology
The University of West Florida
Pensacola, Florida 32504

Dear Mr. Pitts:

Thank you for your letter of December 7. I regret that I have no more copies of my paper on "Problems Related to Human Ecology" which I gave at the recent Malaria Symposium in San Salvador. I understand, however, that the proceedings of that conference are soon to be published through the Pan American Health Organization. It might also be possible that the Malaria Program, Center for Disease Control in Atlanta who administratively sponsored the meetings might have a spare copy of my paper.

I frankly have little competence in the whole problem of equating malaria with specific vegetation types or other ecological settings. On this point you might wish to correspond with Dr. Andrew Arata, Ecology Unit, Division of Research in Epidemiology and Communication Sciences, World Health Organization in Geneva. I am sure that he would be in position to give you useful advice on this point.

Sincerely,

Albert F. Wessen

Albert F. Wessen
Professor of Sociology

AFW:NM

ORGANIZACION PANAMERICANA DE LA SALUD
Oficina Sanitaria Panamericana, Oficina Regional de la
ORGANIZACION MUNDIAL DE LA SALUD

CASILLA DE CORREO 839 - ASUNCION - PARAGUAY - TELEFONO 4802
Dirección Cablegráfica: OFSANPAN

20 December 1971

Mr. Fred E. Pitts
Faculty of Biology
The University of West Florida
Pensacola. Florida 32504

Dear Mr. Pitts:

I have received your kind letter of 7 December and am pleased to send you enclosed a copy of the presentation of provisional results of our project on "The Economic Impact of Malaria". I fear it will be of little use to you in your field of investigation.

It would seem to me that what would best serve your purpose would be to familiarize yourself with the general foundation of the epidemiology of malaria and the methods available for its control and eradication. The best work I know of for this purpose is a book titled "Practical Malariology", by P. F. Russell, L. S. West, R. D. Manwell and G. Macdonald. Despite this list of authors, the work is generally referred to as "Macdonald". It's from the Oxford University Press, and the second edition dates from 1963. There are, of course, other useful works, including that of Pampano, but "Practical Malariology" is as up-to-date as you will find and exceedingly thorough in its coverage.

A valuable source of detailed information, much of it relating to entomology which should, I presume, serve as connecting link between remote sensing and malaria control, is the series of papers put out by the World Health Organization and referred to as "WHO/MAL". There have been several hundred such papers; they are not collected in any publication nor does their printing by WHO constitute "publication"; but it should be possible to obtain a list of them from the WHO in Geneva, Malaria Eradication Division, and then request copies from Geneva or consult those which are available in Washington at the headquarters of the Pan American Health Organization. It is quite possible that another set is available at the Communicable Disease Center of the US Public Health Service in Atlanta, Georgia, which also has a department of Malaria Eradication.

Frankly I am not very hopeful that remote sensing will be useful in connection with malaria work; each anopheline mosquito has its particular preferences and in any case the campaign is not directed against the vector in general. Field reconnaissance is well advanced in all malaria campaigns with the possible exception of the African countries, most of which do not yet have malaria eradication campaigns.

Should you wish to communicate with someone specialized in entomology of malaria control, I would suggest Mr. Roy Elliott, who has been in this field for many years in both Africa and the Americas. His address is

Mr. Roy Elliott
AMRO-0203
Oficina Sanitaria Panamericana
Edificio ETISA 3er piso
12 Calle 7-38, Zona 9
Guatemala, Guatemala

I'll be glad to help you in any way I can. If any need occurs to you, please don't hesitate to write again.

Sincerely yours,

Gladys N. Conly

Gladys N. Conly
OPS/OMS

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
HEALTH SERVICES AND MENTAL HEALTH ADMINISTRATION

December 20, 1971

CENTER FOR DISEASE CONTROL
ATLANTA, GEORGIA 30333
TELEPHONE (404) 633 3311

Mr. Fred E. Pitts
Department of Biology
University of West Florida
Pensacola, Florida 32503

Dear Fred:

During our discussions at CDC on December 3 you expressed an interest in the paper by Dr. T.F. Hall entitled "The Influence of Plants on Anopheline Breeding" prepared for the Inter-American Malaria Research Symposium in El Salvador. A copy of this paper is enclosed for your use.

If you have any questions regarding Dr. Hall's work, you may wish to write directly to him at the following address:

Dr. T.F. Hall, Botanist
Environmental Biology Branch
Tennessee Valley Authority
Muscle Shoals, Alabama 35660

We hope that your studies seeking ways to utilize remote sensing for antimalarial work will be fruitful. Incidentally, one of our Public Health Service Officers attending the University of Minnesota, Mr. John D. Sexton, presently living at 3700 53rd Avenue North, Brooklyn Center, Minnesota 55429, is interested in applications of remote sensing to vector-borne disease control work. I believe that you expressed an interest in getting in touch with him, so I'll send him a copy of this letter.

If we may be of assistance to you, do not hesitate to write. We would enjoy another visit from you, Dr. Edmisten, and your colleagues. Hopefully we will have better weather next time!

Sincerely yours,

Donald R. Johnson
Sanitarian Director
Malaria Program

Enclosure

cc: Dr. T.F. Hall
Mr. J.E. Sexton
Dr. Joe A. Edmisten

CITY OF NEW ORLEANS
DEPARTMENT OF HEALTH
DIVISION OF MOSQUITO CONTROL
6601 LAKESHORE DRIVE
NEW ORLEANS, LA. 70126

MOON LANDRIEU
MAYOR

GEORGE T. CARMICHAEL
ADMINISTRATIVE DIRECTOR

December 21, 1971

Mr. Fred E. Pitts
Department of Biology
University of West Florida
Pensacola, Florida 32504

Dear Mr. Pitts:

This is in answer to your letter of December 8, 1971, requesting a copy of my paper from the Malaria Symposium in El Salvador. A copy of the paper is enclosed.

I was interested to note your study of remote sensing, particularly as it relates to human health. This is a subject which we are trying to relate to mosquito control at the present time. We are working with NASA, but have no results on the project.

Very truly yours,

George T. Carmichael

George T. Carmichael,
Mosquito Control Administrator

GTC:jf

Enc.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

NATIONAL
COMMUNICABLE DISEASE CENTER
Central America Malaria Research Station
USAID/CDC, c/o U.S. Embassy
San Salvador, El Salvador

January 6, 1972

Mr. Fred E. Pitts
Faculty of Biology
The University of West Florida
Pensacola, Florida 32504

Dear Mr. Pitts:

Thank you for your recent letter telling me of your interest in remote sensing. It would appear that the technique offers some promise in detecting mosquito habitats with special applicability in detecting seasonal and spatial distributions of populations significant to malaria transmission. Such knowledge combined with, and confirmed by, ground observations should be quite useful. In this connection, I am sending a copy of my graph showing some of the patterns which we have already observed at ground level.

I am sorry that I do not yet have copies of my Symposium paper, but this will be published soon and I'll see that you get a copy as early as possible.

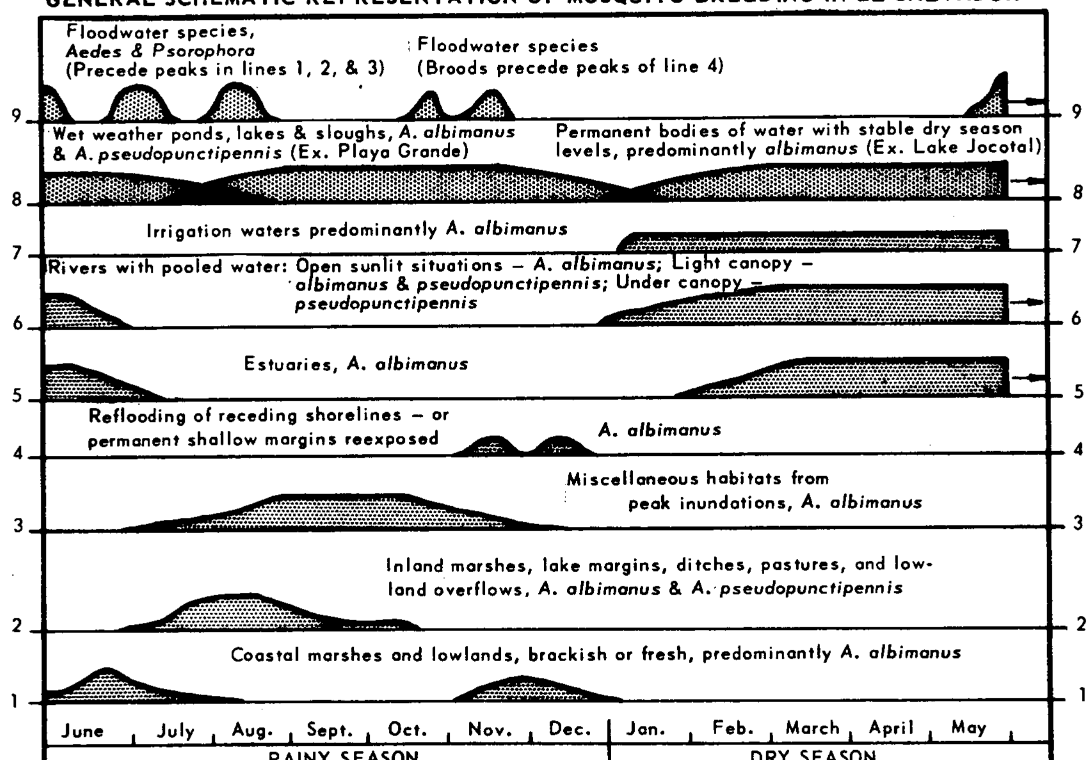
Good luck in your work.

Sincerely yours,

Samuel G. Breeland

Samuel G. Breeland
Research Entomologist

GENERAL SCHEMATIC REPRESENTATION OF MOSQUITO BREEDING IN EL SALVADOR*



*Lines 1-8, Breeding of *Anopheles*; Line 9, breeding of floodwater species; *Culex* follows pattern of *Anopheles*. Based on data taken from more than 2,000 collections between January, 1968 and June, 1971.

ORGANIZACION PANAMERICANA DE LA SALUD
Oficina Sanitaria Panamericana, Oficina Regional de la
ORGANIZACION MUNDIAL DE LA SALUD

12 CALLE F-38
ZONA 9 o APARTADO 383

CENTRO AMERICA Y PANAMA
ZONA III
GUATEMALA, GUATEMALA

CABLES: OFSANPAN, GUATEMALA
TELEFONO: 64911
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REFERENCIA:

10 January 1972

Mr. Fred E. Pitts
NASA-Fellow
The University of West Florida
Pensacola, Florida 32504
U. S. A.

Dear Mr. Pitts:

Thank you for your letter of 8 December 1971; the paper is still in press, but I will include a copy of the draft.

Your field sounds interesting; I know one can attach radios to bears, etc. to monitor their movements, but most disease vectors seem unlikely candidates for this. However, people have watched mosquitos through sniperscopes and fluorescent pigments can be seen on them with UV light at some distance.

To relate malaria to specific vegetation types is not easy, since the variety of vectors allows them to exploit a wide range of ecotypes. In the Americas, the bosque seco tropical (Holdridge system) supports cotton and Anopheles albimanus, which has adapted well to the cloud of insecticides in which this crop is perpetually bathed. This makes a nice problem from Mexico to the north of Colombia, to which the answer is not yet known.

South of the isthmus, there is a vector cocktail. In the Andean valleys A.pseudopunctipennis, rice and man live in a sort of symbiosis. In the low country under forest there is A.darlingi with its headquarters in Brazil; in Ecuador and Colombia A.punctimacula. The first seems to favour the climate where African oil-palm thrives, with rain most months; the second seems especially associated with bananas and cacao. Where the forest is replaced by pasture, in northern Colombia and eastern Venezuela, one member of the complex still lumped as A.nuneztovari is a powerful vector. But you can get all of them in one spot, depending on season and local conditions, with the proportions varying according to little understood factors.

Additionally, A.aquasalis exploits coastal brackish water, and the weird psychedelic-coloured Kerteszias live in bromeliads. All quite different from Africa, where 2 species (s.l.) carry so much malaria that other vectors are hard to incriminate.

I think of malaria as a symptom of socio-economic imbalance, afflicting people who have not come to terms with their environment, pioneers and shifting cultivators. European and U. S. malaria history comes to mind. And shifting cultivation is far from extinct. Much highly publicised development consists of clearing forest, a few years of crops followed by pasture which is too poor to carry enough beasts per acre to keep out the scrub. They then apply herbicides instead of fertilizers, but the scrub turns to secondary forest. In an area of Colombia colonised by immigrants in 1948, by 1960 the only remains were the ruins of splendid model farm houses about one to 500 ac., surrounded by thick bush, which some optimists were clearing to start another round of the spiral.

One of the most depressing places I've seen was a worked out oilfield, where fear of malaria and Chagas'disease was depopulating a village built round a pig-growing scheme that had been set up during the oil days...very interesting set of concrete ruins about 20 years old.

I hope these rather vaguely expressed thoughts may be of some use to you; any specific queries will be answered as well as I can manage.

Yours sincerely,

Roy Elliott

Encl.

PERSONNEL INVOLVED IN THE PROJECT

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The following personnel have been involved in the work associated with contract # NAS-9-11870. The first category (A) includes University of West Florida personnel paid from the NASA contract. The second category (B) includes University of West Florida personnel who have been given logistic support from NASA funds but have not been salaried. The third category (C) includes non-University of West Florida personnel who have given of their time and talents to this project. This recognition of these persons in no way associates them with responsibility with the contract of our report but merely recognizes and thanks them for help.

(A) UWF salaried personnel:

Dr. Joe A. Edmisten - Project Manager. Salaried Summer 1972

Dr. Sneed Collard - Editor of Final Report 2 weeks, Summer 1972

Mrs. Susan L. Wallace - Associate Editor, Summer 1972

Mrs. Carolyn Hopkins - NASA Secretary 1971-72

Miss Christine Newkirk - NASA Typist, Summer 1972

Mrs. Sandra Miller - NASA Fellow. Red Tide 1971-72

Mr. Robert Mattlin - NASA Fellow. Rocky Mountain spotted fever 1971-72

Mr. Fred Pitts - NASA Fellow. Malaria 1971-72

Mr. Ed Meyer - NASA Fellow. Encephalitis 1971-72

Mr. Wayne Hansen - NASA Fellow. Aeronautical Systems 1971-72

Mr. John Marshall - NASA Fellow. Aeronautical Systems 1971-72

Mrs. Alice Long - Proofreader. Summer 1972

(B) <u>UWF personnel - travel support</u>

Dr. Jerry Moshiri - Aquatic ecology advisor

Dr. John Kerr - Vertebrate ecology advisor

Dr. Walter Stanaland - Remote sensing advisor

Dr. Sneed Collard - Parasitology advisor

Dr. Jesse Harvard - Remote sensing advisor

Mr. Tim Simmons - Remote sensing advisor

Mr. Bob Hannah - Remote sensing advisor

(C) <u>non-University of West Florida personnel</u>

Dr. Dan Sudia CDC - encephalitis

Dr. Robert Godfrey FSU - vegetation