Estuary Studies
Training Manual

EPA-430/1-76-007

ESTUARY STUDIES

TRAINING MANUAL

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS

EPA-430/1-76-007
April 1976

ESTUARY STUDIES

This course is offered to professional specialists having an operational or administrative responsibility for the studies of estuaries.

ENVIRONMENTAL PROTECTION AGENCY
Office of Water Programs
TRAINING PROGRAM

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THE AQUATIC ENVIRONMENT

Part 1 The Nature and Behavior of Water

I INTRODUCTION

The earth is physically divisible into the lithosphere or land masses, and the hydrosphere which includes the oceans, lakes, streams, and subterranean waters

A Upon the hydrospere are based a number of sciences which represent different approaches. Hydrology is the general science of water itself with its various special fields such as hydrography, hydraulics, etc. These in turn merge into physical chemistry and chemistry

B Limnology and oceanography combine aspects of all of these, and deal not only with the physical liquid water and its various naturally occurring solutions and forms, but also with living organisms and the infinite interactions that occur between them and their environment

C Water quality management, including pollution control, thus looks to all branches of aquatic science in efforts to coordinate and improve man's relationship with his aquatic environment

II SOME FACTS ABOUT WATER

A Water is the only abundant liquid on our planet It has many properties most unusual for liquids, upon which depend most of the familiar aspects of the world about us as we know it. (See Table 1)

TABLE 1

UNIQUE PROPERTIES OF WATER

Property	Significance
Highest heat capacity (specific heat) of any solid or liquid (except NH_3)	Stabilizes temperatures of organisms and geographical regions
Highest latent heat of fusion (except NH_3)	Thermostatic effect at freezing point
Highest heat of evaporation of any substance	Important in heat and water transfer of atmosphere
The only substance that has its maximum density as a liquid (4°C)	Fresh and brackish waters have maximum density above freezing point This is important in vertical circulation pattern in lakes
Highest surface tension of any liquid	Controls surface and drop phenomena, important in cellular physiology
Dissolves more substances in greater quantity than any other liquid	Makes complex biological system possible Important for transportation of materials in solution.
Pure water has the highest di-electric constant of any liquid	Leads to high dissociation of inorganic substances in solution
Very little electrolytic dissociation	Neutral, yet contains both H^+ and OH^- ions
Relatively transparent	Absorbs much energy in infra red and ultra violet ranges, but little in visible range Hence "colorless"

B Physical Factors of Significance

1 Water substance

Water is not simply "H_2O" but in reality is a mixture of some 33 different substances involving three isotopes each of hydrogen and oxygen (ordinary hydrogen H^1, deuterium H^2, and tritium H^3; ordinary oxygen O^{16}, oxygen 17, and oxygen 18) plus 15 known types of ions. The molecules of a water mass tend to associate themselves as polymers rather than to remain as discrete units. (See Figure 1)

SUBSTANCE OF PURE WATER

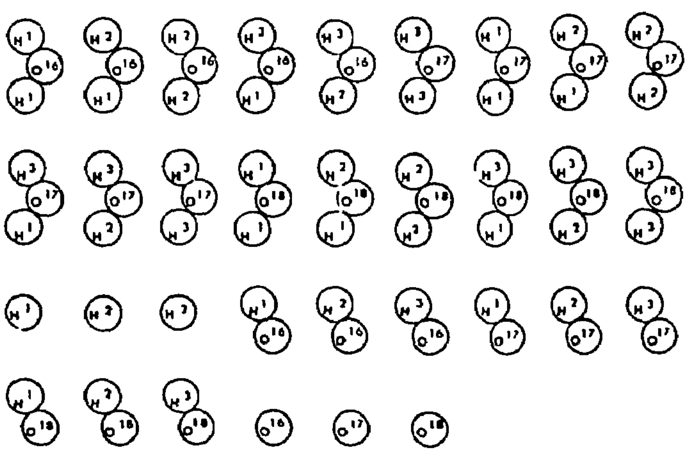

Figure 1

TABLE 2

EFFECTS OF TEMPERATURE ON DENSITY OF PURE WATER AND ICE*

Temperature (°C)	Density Water	Density Ice**
-10	.99815	.9397
- 8	.99869	.9360
- 6	.99912	.9020
- 4	.99945	.9277
- 2	.99970	.9229
0	.99987----	.9168
2	.99997	
4	1.00000	
6	.99997	
8	.99988	
10	.99973	
20	.99823	
40	.99225	
60	.98324	
80	.97183	
100	.95838	

* Tabular values for density, etc., represent estimates by various workers rather than absolute values, due to the variability of water.

** Regular ice is known as "ice I". Four or more other "forms" of ice are known to exist (ice II, ice III, etc.), having densities at 1 atm. pressure ranging from 1.1595 to 1.67. These are of extremely restricted occurrence and may be ignored in most routine operations.

2 Density

a Temperature and density: Ice. Water is the only known substance in which the solid state will float on the liquid state. (See Table 2)

This ensures that ice usually forms on top of a body of water and tends to insulate the remaining water mass from further loss of heat. Did ice sink, there could be little or no carryover of aquatic life from season to season in the higher latitudes. Frazil or needle ice forms colloidally at a few thousandths of a degree below 0° C. It is adhesive and may build up on submerged objects as "anchor ice", but it is still typical ice (ice I).

1) Seasonal increase in solar radiation annually warms surface waters in summer while other factors result in winter cooling The density differences resulting establish two classic layers the epilimnion or surface layer, and the hypolimnion or lower layer, and in between is the thermocline or shear-plane.

2) While for certain theoretical purposes a "thermocline" is defined as a zone in which the temperature changes one degree centigrade for each meter of depth, in practice, any transitional layer between two relatively stable masses of water of different temperatures may be regarded as a thermocline.

3) Obviously the greater the temperature differences between epilimnion and hypolimnion and the sharper the gradient in the thermocline, the more stable will the situation be.

4) From information given above, it should be evident that while the temperature of the hypolimnion rarely drops much below 4^{o} C, the epilimnion may range from 0^{o} C upward.

5) When epilimnion and hypolimnion achieve the same temperature, stratification no longer exists. The entire body of water behaves hydrologically as a unit, and tends to assume uniform chemical and physical characteristics. Even a light breeze may then cause the entire body of water to circulate. Such events are called overturns, and usually result in water quality changes of considerable physical, chemical, and biological significance. Mineral-rich water from the hypolimnion, for example, is mixed with oxygenated water from the epilimnion This usually triggers a sudden growth or "bloom" of plankton organisms.

6) When stratification is present, however, each layer behaves relatively independently, and significant quality differences may develop.

7) Thermal stratification as described above has no reference to the size of the water mass, it is found in oceans and puddles.

b The relative densities of the various isotopes of water influence its molecular composition. For example, the lighter O_{16} tends to go off first in the process of evaporation, leading to the relative enrichment of air by O_{16} and the enrichment of water by O_{17} and O_{18}. This can lead to a measurably higher O_{18} content in warmer climates. Also, the temperature of water in past geologic ages can be closely estimated from the ratio of O_{18} in the carbonate of mollusc shells.

c Dissolved and/or suspended solids may also affect the density of natural water masses (see Table 3)

TABLE 3
EFFECTS OF DISSOLVED SOLIDS
ON DENSITY

Dissolved Solids (Grams per liter)	Density (at 4^{o}C)
0	1.00000
1	1.00085
2	1.00169
3	1.00251
10	1.00818
35 (mean for sea water)	1.02822

d Types of density stratification

1) Density differences produce stratification which may be permanent, transient, or seasonal.

2) Permanent stratification exists for example where there is a heavy mass of brine in the deeper areas of a basin which does not respond to seasonal or other changing conditions.

3) Transient stratification may occur with the recurrent influx of tidal water in an estuary for example, or the occasional influx of cold muddy water into a deep lake or reservoir.

4) Seasonal stratification is typically thermal in nature, and involves the annual establishment of the epilimnion, hypolimnion, and thermocline as described above.

5) Density stratification is not limited to two-layered systems, three, four, or even more layers may be encountered in larger bodies of water.

e A "plunge line" (sometimes called "thermal line") may develop at the mouth of a stream. Heavier water flowing into a lake or reservoir plunges below the lighter water mass of the epiliminium to flow along at a lower level. Such a line is usually marked by an accumulation of floating debris.

f Stratification may be modified or entirely suppressed in some cases when deemed expedient, by means of a simple air lift.

3 The viscosity of water is greater at lower temperatures (see Table 4). This is important not only in situations involving the control of flowing water as in a sand filter, but also since overcoming resistance to flow generates heat, it is significant in the heating of water by internal friction from wave and current action. Living organisms more easily support themselves in the more viscous (and also denser) cold waters of the arctic than in the less viscous warm waters of the tropics. (See Table 4).

TABLE 4

VISCOSITY OF WATER (In millipoises at 1 atm)

Temp. °C	Dissolved solids in g/L			
	0	5	10	30
-10	26.0	----	----	----
- 5	21.4	----	----	----
0	17.94	18.1	18.24	18.7
5	15.19	15.3	15.5	16.0
10	13.10	13.2	13.4	13.8
30	8.00	8.1	8.2	8.6
100	2.84	----	----	----

4 Surface tension has biological as well as physical significance. Organisms whose body surfaces cannot be wet by water can either ride on the surface film or in some instances may be "trapped" on the surface film and be unable to re-enter the water.

5 Heat or energy

Incident solar radiation is the prime source of energy for virtually all organic and most inorganic processes on earth. For the earth as a whole, the total amount (of energy) received annually must exactly balance that lost by reflection and radiation into space if climatic and related conditions are to remain relatively constant over geologic time.

a For a given body of water, immediate sources of energy include in addition to solar irradiation· terrestrial heat, transformation of kinetic energy (wave and current action) to heat, chemical and biochemical reactions, convection from the atmosphere, and condensation of water vapor.

b The proportion of light reflected depends on the angle of incidence, the temperature, color, and other qualities of the water, and the presence or absence of films of lighter liquids such as oil. In general, as the depth increases arithmetically, the light tends to decrease geometrically. Blues, greens, and yellows tend to penetrate most deeply while ultra violet, violets, and orange-reds are most quickly absorbed. On the order of 90% of the total illumination which penetrates the surface film is absorbed in the first 10 meters of even the clearest water, thus tending to warm the upper layers.

6 Water movements

a Waves or rhythmic movement

1) The best known are traveling waves caused by wind. These are effective only against objects near the surface. They have little effect on the movement of large masses of water.

2) Seiches

Standing waves or seiches occur in lakes, estuaries, and other enclosed bodies of water, but are seldom large enough to be observed. An "internal wave or seich" is an oscillation in a submersed mass of water such as a hypolimnion, accompanied by compensating oscillation in the overlying water so that no significant change in surface level is detected. Shifts in submerged water masses of this type can have severe effects on the biota and also on human water uses where withdrawals are confined to a given depth. Descriptions and analyses of many other types and sub-types of waves and wave-like movements may be found in the literature.

b Tides

1) Tides are the longest waves known, and are responsible for the once or twice a day rythmic rise and fall of the ocean level on most shores around the world.

2) While part and parcel of the same phenomenon, it is often convenient to refer to the rise and fall of the water level as "tide," and to the resulting currents as "tidal currents."

3) Tides are basically caused by the attraction of the sun and moon on water masses, large and small, however, it is only in the oceans and possibly certain of the larger lakes that true tidal action has been demonstrated. The patterns of tidal action are enormously complicated by local topography, interaction with seiches, and other factors. The literature on tides is very large.

c Currents (except tidal currents) are steady arythmic water movements which have had major study only in oceanography although they are most often observed in rivers and streams. They are primarily concerned with the translocation of water masses. They may be generated internally by virtue of density changes, or externally by wind or terrestrial topography. Turbulence phenomena or eddy currents are largely responsible for lateral mixing in a current. These are of far more importance in the economy of a body of water than mere laminar flow.

d Coriolis force is a result of interaction between the rotation of the earth, and the movement of masses or bodies on the earth. The net result is a slight tendency for moving objects to veer to the right in the northern hemisphere, and to the left in the southern hemisphere. While the result in fresh waters is usually negligible, it may be considerable in marine waters. For example, other factors permitting, there is a tendency in estuaries for fresh waters to move toward the ocean faster along the right bank, while salt tidal waters tend to intrude farther inland along the left bank. Effects are even more dramatic in the open oceans.

e Langmuir circulation (or L. spirals) is the interlocking rotation of somewhat cylindrical masses of surface water under the influence of wind action. The axes of the cylinders are parallel to the direction of the wind.

To somewhat oversimplify the concept, a series of adjoining cells might be thought of as chains of interlocking gears in which at every other contact the teeth are rising while at the alternate contacts, they are sinking (Figure 2).

The result is elongated masses of water rising or sinking together. This produces the familiar "wind rows" of foam, flotsam and jetsam, or plankton often seen streaking windblown lakes or oceans. Certain zoo-plankton struggling to maintain a position near the surface tend to collect in the down current between two Langmuir cells, causing such an area to be called the "red dance", while the clear upwelling water between is the "blue dance".

This phenomenon may be important in water or plankton sampling on a windy day.

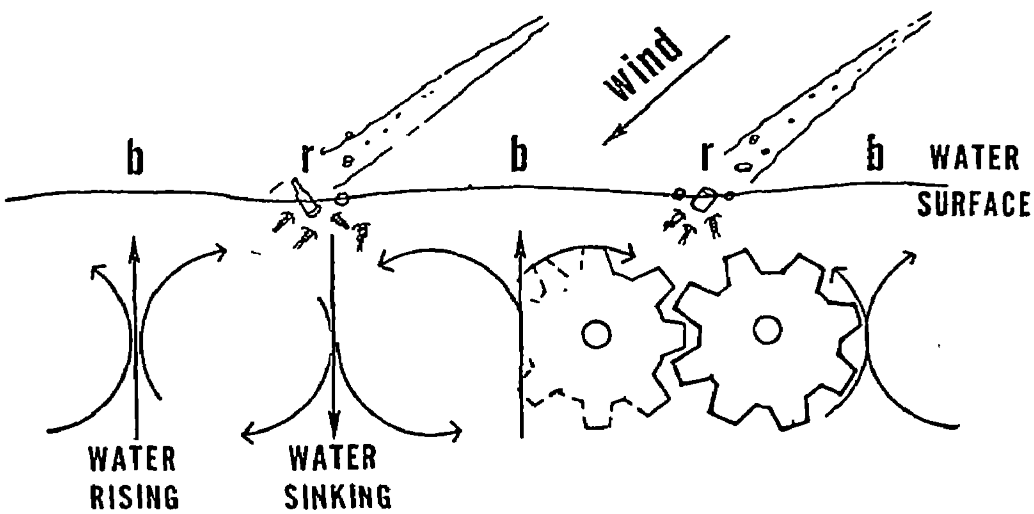

Figure 2. Langmuire Spirals
b. Blue dance, water rising. r. Red dance, water sinking, floating or swimming objects concentrated.

6 The pH of pure water has been determined between 5 7 and 7 01 by various workers. The latter value is most widely accepted at the present time. Natural waters of course vary widely according to circumstances.

C The elements of hydrology mentioned above represent a selection of some of the more conspicuous physical factors involved in working with water quality. Other items not specifically mentioned include: molecular structure of waters, interaction of water and radiation, internal pressure, acoustical characteristics, pressure-volume-temperature relationships, refractivity, luminescence, color, dielectrical characteristics and phenomena, solubility, action and interactions of gases, liquids and solids, water vapor, phenomena of hydrostatics and hydrodynamics in general.

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I INTRODUCTION

Part 1 introduced the lithosphere and the hydrosphere. Part 2 will deal with certain general aspects of the biosphere, or the sphere of life on this earth, which photographs from space have shown is a finite globe in infinite space.

This is the habitat of man and the other organisms. His relationships with the aquatic biosphere are our common concern.

II THE BIOLOGICAL NATURE OF THE WORLD WE LIVE IN

A We can only imagine what this world must have been like before there was life.

B The world as we know it is largely shaped by the forces of life.

1 Primitive forms of life created organic matter and established soil.

2 Plants cover the lands and enormously influence the forces of erosion.

3 The nature and rate of erosion affect the redistribution of materials (and mass) on the surface of the earth (topographic changes).

4 Organisms tie up vast quantities of certain chemicals, such as carbon and oxygen.

5 Respiration of plants and animals releases carbon dioxide to the atmosphere in influential quantities.

6 CO_2 affects the heat transmission of the atmosphere.

C Organisms respond to and in turn affect their environment. Man is one of the most influential.

III ECOLOGY IS THE STUDY OF THE INTERRELATIONSHIPS BETWEEN ORGANISMS, AND BETWEEN ORGANISMS AND THEIR ENVIRONMENT.

A The ecosystem is the basic functional unit of ecology. Any area of nature that includes living organisms and nonliving substances interacting to produce an exchange of materials between the living and nonliving parts constitutes an ecosystem. (Odum, 1959)

1 From a structural standpoint, it is convenient to recognize four constituents as composing an ecosystem (Figure 1).

a Abiotic NUTRIENT MINERALS which are the physical stuff of which living protoplasm will be synthesized.

b Autotrophic (self-nourishing) or PRODUCER organisms. These are largely the green plants (holophytes), but other minor groups must also be included (See Figure 2). They assimilate the nutrient minerals, by the use of considerable energy, and combine them into living organic substance.

c Heterotrophic (other-nourishing) CONSUMERS (holozoic), are chiefly the animals. They ingest (or eat) and digest organic matter, releasing considerable energy in the process.

d Heterotrophic REDUCERS are chiefly bacteria and fungi that return complex organic compounds back to the original abiotic mineral condition, thereby releasing the remaining chemical energy.

2 From a functional standpoint, an ecosystem has two parts (Figure 2)

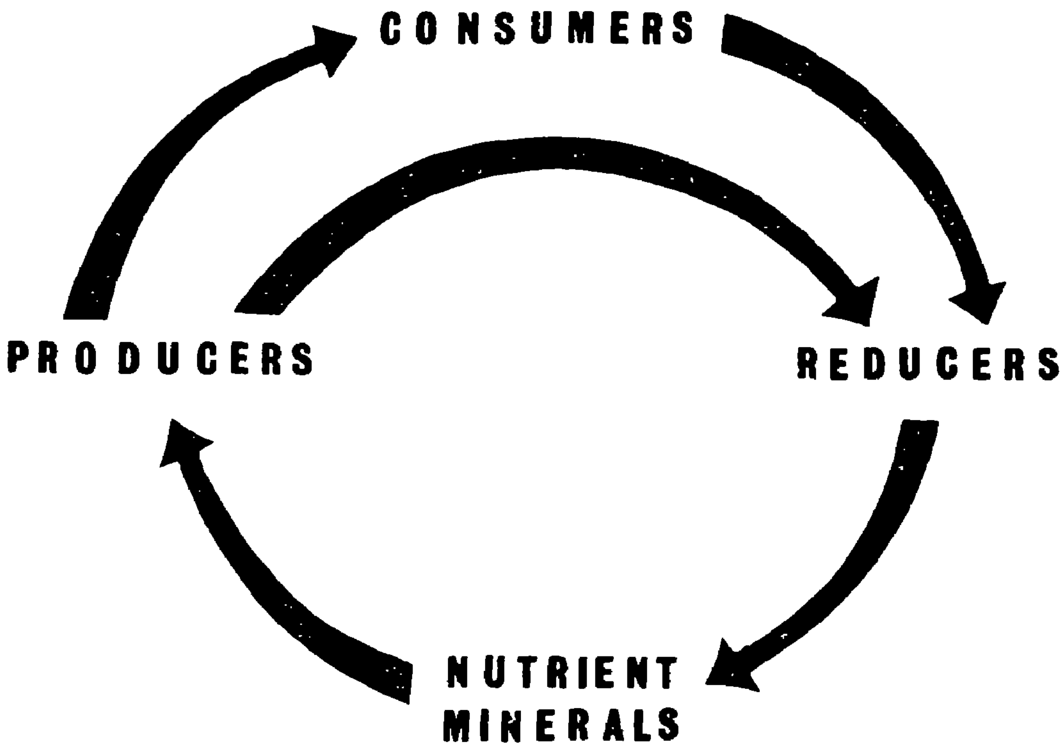

FIGURE 1

a The autotrophic or producer organisms, which construct organic substance.

b The heterotrophic or consumer and reducer organisms which destroy organic substance.

3 Unless the autotrophic and heterotrophic phases of the cycle approximate a dynamic equilibrium, the ecosystem and the environment will change.

B Each of these groups includes simple, single-celled representatives, persisting at lower levels on the evolutionary stems of the higher organisms. (Figure 2)

1 These groups span the gaps between the higher kingdoms with a multitude of transitional forms. They are collectively called the PROTISTA.

2 Within the protista, two principal subgroups can be defined on the basis of relative complexity of structure.

a The bacteria and blue-green algae, lacking a nuclear membrane may be considered as the lower protista (or Monera).

b The single-celled algae and protozoa are best referred to as the Higher Protista.

C Distributed throughout these groups will be found most of the traditional "phyla" of classic biology.

IV FUNCTIONING OF THE ECOSYSTEM

A A food chain is the transfer of food energy from plants through a series of organisms with repeated eating and being eaten. Food chains are not isolated sequences but are interconnected.

RELATIONSHIPS BETWEEN FREE LIVING AQUATIC ORGANISMS

Energy Flows from Left to Right, General Evolutionary Sequence is Upward

PRODUCERS	CONSUMERS		REDUCERS
Organic Material Produced, Usually by Photosynthesis	Organic Material Ingested or Consumed Digested Internally		Organic Material Reduced by Extracellular Digestion and Intracellular Metabolism to Mineral Condition
ENERGY STORED	ENERGY RELEASED		ENERGY RELEASED
Flowering Plants and Gymnosperms	Arachnids	Mammals	Basidiomycetes
	Insects	Birds	
Club Mosses, Ferns	Crustaceans	Reptiles	
	Segmented Worms	Amphibians	
Liverworts, Mosses	Molluscs	Fishes	Fungi Imperfecti
Multicellular Green Algae	Bryozoa	Primitive Chordates	
	Rotifers		Ascomycetes
	Roundworms	Echinoderms	
Red Algae	Flatworms		
	Coelenterates		Higher Phycomycetes
Brown Algae	Sponges		

DEVELOPMENT OF MULTICELLULAR OR COENOCYTIC STRUCTURE

H I G H E R   P R O T I S T A

	Protozoa		
Unicellular Green Algae	Amoeboid	Ciliated	Lower Phycomycetes
Diatoms	Flagellated, (non-pigmented)	Suctoria	(Chytridiales, et al)
Pigmented Flagellates			

DEVELOPMENT OF A NUCLEAR MEMBRANE

L O W E R   P R O T I S T A

(or Monera)

Blue Green Algae	Actinomycetes
Phototropic Bacteria	Spirochaetes
Chemotropic Bacteria	Saprophytic Bacterial Types

FIGURE 2

BI ECO pl 2a 1 69

B A food web is the interlocking pattern of food chains in an ecosystem. (Figures 3, 4) In complex natural communities, organisms whose food is obtained by the same number of steps are said to belong to the same trophic (feeding) level.

C Trophic Levels

1 First - Green plants (producers) (Figure 5) fix biochemical energy and synthesize basic organic substances. This is "primary production".

2 Second - Plant eating animals (herbivores) depend on the producer organisms for food.

3 Third - Primary carnivores, animals which feed on herbivores.

4 Fourth - Secondary carnivores feed on primary carnivores.

5 Last - Ultimate carnivores are the last or ultimate level of consumers.

D Total Assimilation

The amount of energy which flows through a trophic level is distributed between the production of biomass (living substance), and the demands of respiration (internal energy use by living organisms) in a ratio of approximately 1:10.

E Trophic Structure of the Ecosystem

The interaction of the food chain phenomena (with energy loss at each transfer) results in various communities having definite trophic structure or energy levels. Trophic structure may be measured and described either in terms of the standing crop per unit area or in terms of energy fixed per unit area per unit time at successive trophic levels. Trophic structure and function can be shown graphically by means of ecological pyramids (Figure 5).

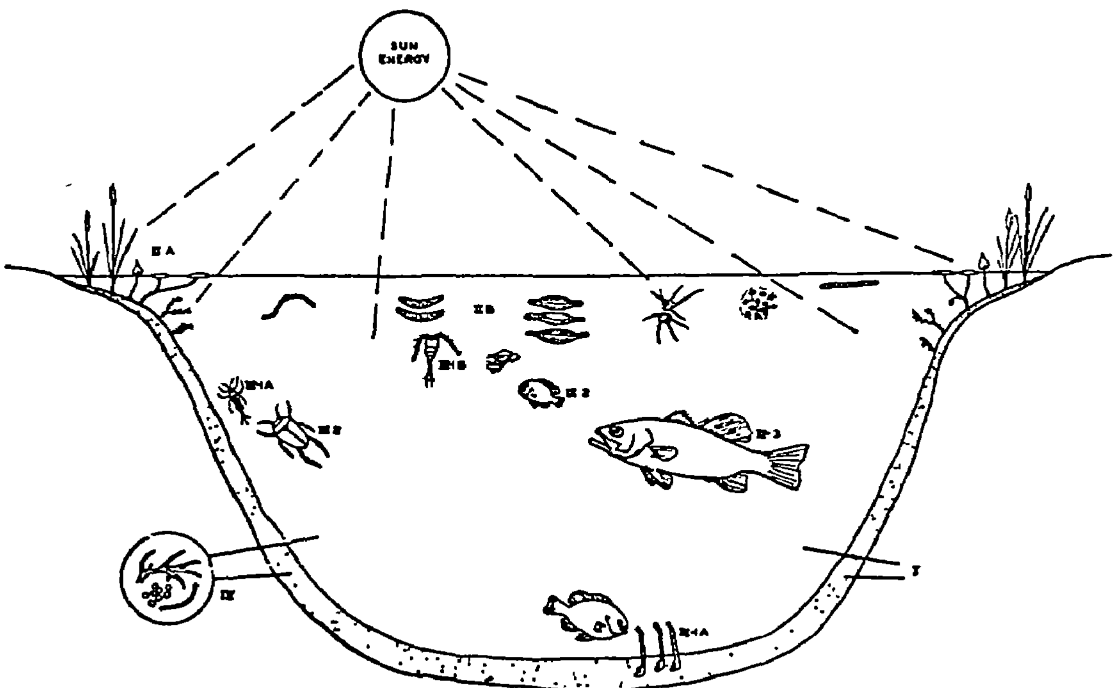

Figure 3. Diagram of the pond ecosystem. Basic units are as follows. I, abiotic substances–basic inorganic and organic compounds; IIA, producers–rooted vegetation, IIB, producers–phytoplankton, III-1A, primary consumers (herbivores)–bottom forms; III-1B, primary consumers (herbivores)–zooplankton, III-2, secondary consumers (carnivores); III-3, tertiary consumers (secondary carnivores); IV, decomposers–bacteria and fungi of decay.

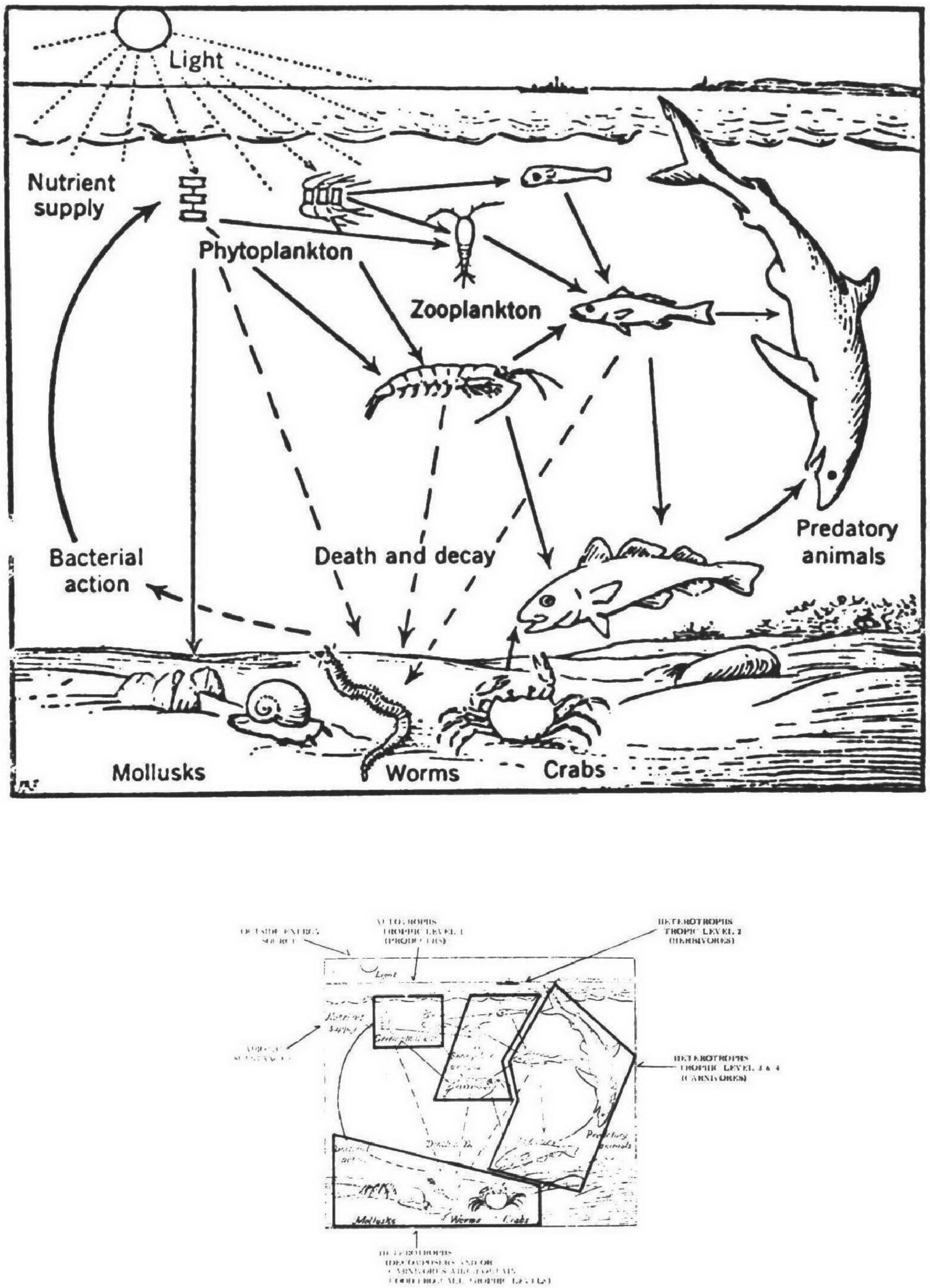

Figure 4. A MARINE ECOSYSTEM (After Clark, 1954 and Patten, 1966)

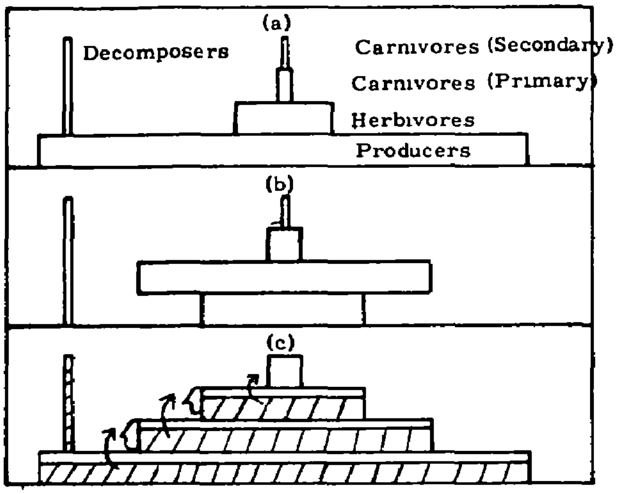

Figure 5. HYPOTHETICAL PYRAMIDS of (a) Numbers of individuals, (b) Biomass, and (c) Energy (Shading Indicates Energy Loss).

V BIOTIC COMMUNITIES

A Plankton are the macroscopic and microscopic animals, plants, bacteria, etc., floating free in the open water. Many clog filters, cause tastes, odors, and other troubles in water supplies. Eggs and larvae of larger forms are often present.

1 Phytoplankton are plant-like. These are the dominant producers of the waters, fresh and salt, "the grass of the seas".

2 Zooplankton are animal-like. Includes many different animal types, range in size from minute protozoa to gigantic marine jellyfishes.

B Periphyton (or Aufwuchs) - The communities of microscopic organisms associated with submerged surfaces of any type or depth. Includes bacteria, algae, protozoa, and other microscopic animals, and often the young or embryonic stages of algae and other organisms that normally grow up to become a part of the benthos (see below). Many planktonic types will also adhere to surfaces as periphyton, and some typical periphyton may break off and be collected as plankters.

C Benthos are the plants and animals living on, in, or closely associated with the bottom. They include plants and invertebrates.

D Nekton are the community of strong aggressive swimmers of the open waters, often called pellagic. Certain fishes, whales, and invertebrates such as shrimps and squids are included here.

E The marsh community is based on larger "higher" plants, floating and emergent. Both marine and freshwater marshes are areas of enormous biological production. Collectively known as "wetlands", they bridge the gap between the waters and the dry lands.

VI PRODUCTIVITY

A The biological resultant of all physical and chemical factors in the quantity of life that may actually be present. The ability to produce this "biomass" is often referred to as the "productivity" of a body of water. This is neither good nor bad per se. A water of low productivity is a "poor" water biologically, and also a relatively "pure" or "clean" water; hence desirable as a water supply or a bathing beach. A productive water on the other hand may be a nuisance to man or highly desirable. It is a nuisance if foul odors and/or weed-chocked waterways result, it is desirable if bumper crops of bass, catfish, or oysters are produced. Open oceans have a low level of productivity in general.

VII PERSISTENT CHEMICALS IN THE ENVIRONMENT

Increasingly complex manufacturing processes, coupled with rising industrialization, create greater amounts of exotic wastes potentially toxic to humans and aquatic life.

They may also be teratogenic (toxicants responsible for changes in the embryo with resulting birth defects, ex., thalidomide), mutagenic (insults which produce mutations, ex., radiation), or carcinogenic (insults which induce cancer, ex., benz pyrenes) in effect.

A Metals - current levels of cadmium, lead, and other substances whose effects on humans and fish and wildlife are not fully understood constitute a mounting concern. Mercury pollution, for example, has become a serious national problem, yet mercury has been present on earth since time immemorial. More research is needed, yet we dare not relax our standards until definitive answers have been provided.

B Pesticides

1 A pesticide and its metabolites may move through an ecosystem in many ways. Hard (pesticides which are persistent, having a long half-life in the environment includes the organochlorines, ex., DDT) pesticides ingested or otherwise borne by the target species will stay in the environment, possibly to be recycled or concentrated further through the natural action of food chains if the species is eaten. Most of the volume of pesticides do not reach their target at all.

2 Biological magnification

Initially, low levels of persistent pesticides in air, soil, and water may be concentrated at every step up the food chain. Minute aquatic organisms and scavengers, which screen water and bottom mud having pesticide levels of a few parts per billion, can accumulate levels measured in parts per million—a thousandfold increase. The sediments including fecal deposits are continuously recycled by the bottom animals.

a Oysters, for instance, will concentrate DDT 70,000 times higher in their tissues than it's concentration in surrounding water. They can also partially cleanse themselves in water free of DDT.

b Fish feeding on lower organisms build up concentrations in their visceral fat which may reach several thousand parts per million and levels in their edible flesh of hundreds of parts per million.

c Larger animals, such as fish-eating gulls and other birds, can further concentrate the chemicals. A survey on organochlorine residues in aquatic birds in the Canadian prairie provinces showed that California and ring-billed gulls were among the most contaminated. Since gulls breed in colonies, breeding population changes can be detected and related to levels of chemical contamination. Ecological research on colonial birds to monitor the effects of chemical pollution on the environment is useful.

C "Polychlorinated biphenyls" (PCB's). PCB's are used in plasticizers, asphalt, ink, paper, and a host of other products. Action has been taken to curtail their release to the environment, since their effects are similar to hard pesticides.

D Other compounds which are toxic and accumulate in the ecosystem:

1 Phalate esters - may interfere with pesticide analyses

2 Benzapyrenes

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I INTRODUCTION

The freshwater environment as considered herein refers to those inland waters not detectably diluted by ocean waters, although the lower portions of rivers are subject to certain tidal flow effects.

Certain atypical inland waters such as saline or alkaline lakes, springs, etc., are not treated, as the main objective here in typical inland water.

All waters have certain basic biological cycles and types of interactions most of which have already been presented, hence this outline will concentrate on aspects essentially peculiar to fresh inland waters.

II PRESENT WATER QUALITY AS A FUNCTION OF THE EVOLUTION OF FRESH WATERS

A The history of a body of water determines its present condition. Natural waters have evolved in the course of geologic time into what we know today.

B Streams

In the course of their evolution, streams in general pass through four stages of development which may be called. birth, youth, maturity, and old age.

These terms or conditions may be employed or considered in two contexts: temporal, or spatial. In terms of geologic time, a given point in a stream may pass through each of the stages described below or: at any given time, these various stages of development can be loosely identified in successive reaches of a stream traveling from its headwaters to base level in ocean or major lake.

1 Establishment or birth. This might be a "dry run" or headwater stream-bed, before it had eroded down to the level of ground water.

During periods of run-off after a rain or snow-melt, such a gulley would have a flow of water which might range from torrential to a mere trickle. Erosion may proceed rapidly as there is no permanent aquatic flora or fauna to stabilize streambed materials. On the other hand, terrestrial grass or forest growth may retard erosion. When the run-off has passed, however, the "streambed" is dry.

2 Youthful streams. When the streambed is eroded below the ground water level, spring or seepage water enters, and the stream becomes permanent. An aquatic flora and fauna develops and water flows the year round. Youthful streams typically have a relatively steep gradient, rocky beds, with rapids, falls, and small pools.

3 Mature streams. Mature streams have wide valleys, a developed flood plain, are deeper, more turbid, and usually have warmer water, sand, mud, silt, or clay bottom materials which shift with increase in flow. In their more favorable reaches, streams in this condition are at a peak of biological productivity. Gradients are moderate, riffles or rapids are often separated by long pools.

4 In old age, streams have approached geologic base level, usually the ocean. During flood stage they scour their beds and deposit materials on the flood plain which may be very broad and flat. During normal flow the channel is refilled and many shifting bars are developed.

(Under the influence of man this pattern may be broken up, or temporarily interrupted. Thus an essentially "youthful" stream might take on some of the characteristics of a "mature" stream following soil erosion, organic enrichment, and increased surface runoff. Correction of these conditions might likewise be followed by at least a partial reversion to the "original" condition).

C Lakes and Reservoirs

Geological factors which significantly affect the nature of either a stream or lake include the following:

1 The geographical location of the drainage basin or watershed.

2 The size and shape of the drainage basin.

3 The general topography, i.e., mountainous or plains.

4 The character of the bedrocks and soils.

5 The character, amount, annual distribution, and rate of precipitation.

6 The natural vegetative cover of the land is, of course, responsive to and responsible for many of the above factors and is also severely subject to the whims of civilization. This is one of the major factors determining run-off versus soil absorption, etc.

D Lakes have a developmental history which somewhat parallels that of streams. This process is often referred to as <u>natural eutrophication.</u>

1 The methods of formation vary greatly, but all influence the character and subsequent history of the lake.

In glaciated areas, for example, a huge block of ice may have been covered with till. The glacier retreated, the ice melted, and the resulting hole became a lake. Or, the glacier may actually scoop out a hole. Landslides may dam valleys, extinct volcanoes may collapse, etc., etc.

2 Maturing or natural eutrophication of lakes.

a If not already present shoal areas are developed through erosion and deposition of the shore material by wave action and undertow.

b Currents produce bars across bays and thus cut off irregular areas.

c Silt brought in by tributary streams settles out in the quiet lake water

d Algae grow attached to surfaces, and floating free as plankton. Dead organic matter begins to accumulate on the bottom.

e Rooted aquatic plants grow on shoals and bars, and in doing so cut off bays and contribute to the filling of the lake.

f Dissolved carbonates and other materials are precipitated in the deeper portions of the lake in part through the action of plants.

g When filling is well advanced, mats of sphagnum moss may extend outward from the shore. These mats are followed by sedges and grasses which finally convert the lake into a marsh.

3 Extinction of lakes. After lakes reach maturity, their progress toward filling up is accelerated. They become extinct through:

a The downcutting of the outlet.

b Filling with detritus eroded from the shores or brought in by tributary streams.

c Filling by the accumulation of the remains of vegetable materials growing in the lake itself. (Often two or three processes may act concurrently)

III PRODUCTIVITY IN FRESH WATERS

A Fresh waters in general and under natural conditions by definition have a lesser supply of dissolved substances than marine waters, and thus a lesser basic potential for the growth of aquatic organisms. By the same token, they may be said to be more sensitive to the addition of extraneous materials (pollutants, nutrients, etc.) The following notes are directed toward natural geological and other environmental factors as they affect the productivity of fresh waters.

B Factors Affecting Stream Productivity (See Table 1)

TABLE 1

EFFECT OF SUBSTRATE ON STREAM PRODUCTIVITY*

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Marl	6
Fine Gravel	9
Gravel and silt	14
Coarse gravel	32
Moss on fine gravel	89
Fissidens (moss) on coarse gravel	111
Ranunculus (water buttercup)	194
Watercress	301
Anacharis (waterweed)	452

*Selected from Tarzwell 1937

To be productive of aquatic life, a stream must provide adequate nutrients, light, a suitable temperature, and time for growth to take place.

1 Youthful streams, especially on rock or sand substrates are low in essential nutrients. Temperatures in mountainous regions are usually low, and due to the steep gradient, time for growth is short. Although ample light is available, growth of true plankton is thus greatly limited.

2 As the stream flows toward a more "mature" condition, nutrients tend to accumulate, and gradient diminishes and so time of flow increases, temperature tends to increase, and plankton flourish.

Should a heavy load of inert silt develop on the other hand, the turbidity would reduce the light penetration and consequently the general plankton production would diminish.

3 As the stream approaches base level (old age) and the time available for plankton growth increases, the balance between turbidity, nutrient levels, and temperature and other seasonal conditions, determines the overall productivity.

C Factors Affecting the Productivity of lakes (See Table 2)

1 The size, shape, and depth of the lake basin. Shallow water is more productive than deeper water since more light will reach the bottom to stimulate rooted plant growth. As a corollary, lakes with more shoreline, having more shallow water, are in general more productive. Broad shallow lakes and reservoirs have the greatest production potential (and hence should be avoided for water supplies).

TABLE 2

EFFECT OF SUBSTRATE ON LAKE PRODUCTIVITY *

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Pebbles	4
Clay	8
Flat rubble	9
Block rubble	11
Shelving rock	77

* Selected from Tarzwell 1937

2 Hard waters are generally more productive than soft waters as there are more plant nutrient minerals available. This is often greatly influenced by the character of the soil and rocks in the watershed and the quality and quantity of ground water entering the lake. In general, pH ranges of 6.8 to 8.2 appear to be most productive.

3 Turbidity reduces productivity as light penetration is reduced.

4 The presence or absence of thermal stratification with its semi-annual turnovers affects productivity by distributing nutrients throughout the water mass.

5 Climate, temperature, prevalence of ice and snow, are also of course important.

D Factors Affecting the Productivity of Reservoirs

1 The productivity of reservoirs is governed by much the same principles as that of lakes, with the difference that the water level is much more under the control of man. Fluctuations in water level can be used to deliberately increase or decrease productivity. This can be demonstrated by a comparison of the TVA reservoirs which practice a summer drawdown with some of those in the west where a winter drawdown is the rule.

2 The level at which water is removed from a reservoir is important to the productivity of the stream below. The hypolimnion may be anaerobic while the epilimnion is aerobic, for example, or the epilimnion is poor in nutrients while the hypolimnion is relatively rich.

3 Reservoir discharges also profoundly affect the DO, temperature, and turbidity in the stream below a dam. Too much fluctuation in flow may permit sections of the stream to dry, or provide inadequate dilution for toxic waste.

IV CULTURAL EUTROPHICATION

A The general processes of natural eutrophication, or natural enrichment and productivity have been briefly outlined above.

B When the activities of man speed up these enrichment processes by introducing unnatural quantities of nutrients (sewage, etc.) the result is often called cultural eutrophication. This term is often extended beyond its original usage to include the enrichment (pollution) of streams, estuaries, and even oceans, as well as lakes.

V CLASSIFICATION OF LAKES AND RESERVOIRS

A The productivity of lakes and impoundments is such a conspicuous feature that it is often used as a convenient means of classification.

1 Oligotrophic lakes are the younger, less productive lakes, which are deep, have clear water, and usually support Salmonoid fishes in their deeper waters.

2 Eutrophic lakes are more mature, more turbid, and richer. They are usually shallower. They are richer in dissolved solids; N, P, and Ca are abundant. Plankton is abundant and there is often a rich bottom fauna.

3 Dystrophic lakes, such as bog lakes, are low in Ph, water yellow to brown, dissolved solids, N, P, and Ca scanty but humic materials abundant, bottom fauna and plankton poor, and fish species are limited.

B Reservoirs may also be classified as storage, and run of the river.

1 Storage reservoirs have a large volume in relation to their inflow.

2 Run of the river reservoirs have a large flow-through in relation to their storage value.

C According to location, lakes and reservoirs may be classified as polar, temperate, or tropical. Differences in climatic and geographic conditions result in differences in their biology.

VI SUMMARY

A A body of water such as a lake, stream, or estuary represents an intricately balanced system in a state of dynamic equilibrium. Modification imposed at one point in the system automatically results in compensatory adjustments at associated points.

B The more thorough our knowledge of the entire system, the better we can judge where to impose control measures to achieve a desired result.

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Part 4. The Marine Environment and its Role in the Total Aquatic Environment

I INTRODUCTION

A The marine environment is arbitrarily defined as the water mass extending beyond the continental land masses, including the plants and animals harbored therein. This water mass is large and deep, covering about 70 percent of the earth's surface and being as deep as 7 miles. The salt content averages about 35 parts per thousand. Life extends to all depths.

B The general nature of the water cycle on earth is well known. Because the largest portion of the surface area of the earth is covered with water, roughly 70 percent of the earth's rainfall is on the seas. (Figure 1)

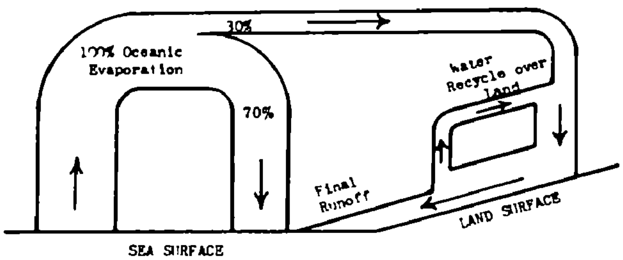

Figure 1. THE WATER CYCLE

Since roughly one third of the rain which falls on the land is again recycled through the atmosphere (see Figure 1 again), the total amount of water washing over the earth's surface is significantly greater than one third of the total world rainfall. It is thus not surprising to note that the rivers which finally empty into the sea carry a disproportionate burden of dissolved and suspended solids picked up from the land. The chemical composition of this burden depends on the composition of the rocks and soils through which the river flows, the proximity of an ocean, the direction of prevailing winds, and other factors. This is the substance of geological erosion. (Table 1)

TABLE 1

PERCENTAGE COMPOSITION OF THE MAJOR IONS OF TWO STREAMS AND SEA WATER

(Data from Clark, F.W , 1924, "The Composition of River and Lake Waters of the United States", U.S. Geol Surv., Prof Paper No. 135, Harvey, H W., 1957, "The Chemistry and Fertility of Sea Waters", Cambridge University Press, Cambridge)

Ion	Delaware River at Lambertville, N.J.	Rio Grande at Laredo, Texas	Sea Water
Na	6 70	14.78	30.4
K	1.46	85	1.1
Ca	17.49	13 73	1 16
Mg	4 81	3 03	3 7
Cl	4 23	21 65	55 2
SO_4	17 49	30.10	7.7
CO_3	32.95	11 55	+HCO_3 0 35

C For this presentation, the marine environment will be (1) described using an ecological approach, (2) characterized ecologically by comparing it with fresh-water and estuarine environments, and (3) considered as a functional ecological system (ecosystem).

II FRESHWATER, ESTUARINE, AND MARINE ENVIRONMENTS

Distinct differences are found in physical, chemical, and biotic factors in going from a freshwater to an oceanic environment. In general, environmental factors are more constant in freshwater (rivers) and oceanic environments than in the highly variable and harsh environments of estuarine and coastal waters. (Figure 2)

A Physical and Chemical Factors

Rivers, estuaries, and oceans are compared in Figure 2 with reference to the relative instability (or variation) of several important parameters. In the oceans, it will be noted, very little change occurs in any parameter. In rivers, while "salinity" (usually referred to as "dissolved solids") and temperature (accepting normal seasonal variations) change little, the other four parameters vary considerably. In estuaries, they all change.

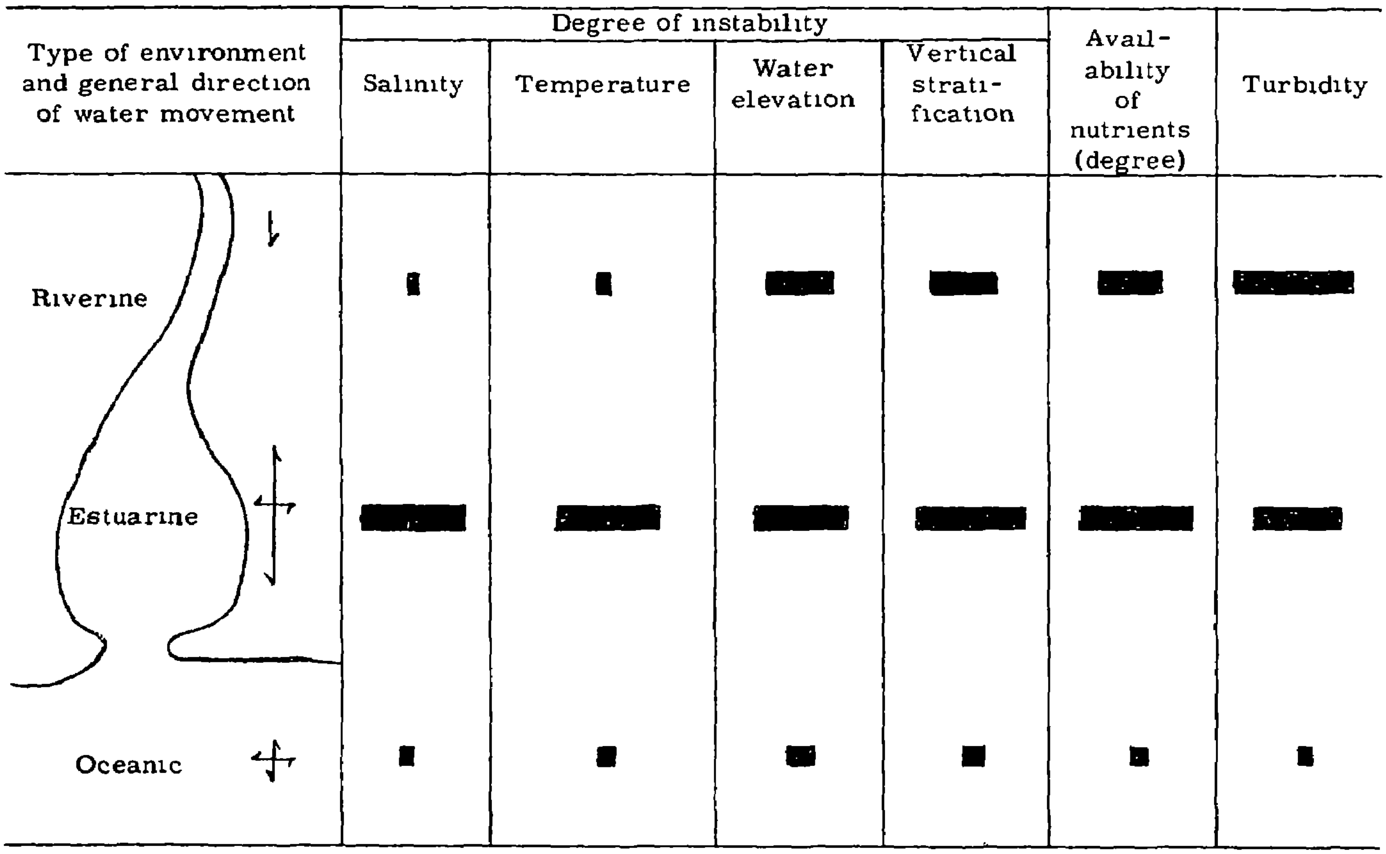

Figure 2 . RELATIVE VALUES OF VARIOUS PHYSICAL AND CHEMICAL FACTORS FOR RIVER, ESTUARINE, AND OCEANIC ENVIRONMENTS

B Biotic Factors

1 A complex of physical and chemical factors determine the biotic composition of an environment. In general, the number of species in a rigorous, highly variable environment tends to be less than the number in a more stable environment (Hedgpeth, 1966).

2 The dominant animal species (in terms of total biomass) which occur in estuaries are often transient, spending only a part of their lives in the estuaries. This results in better utilization of a rich environment

C Zones of the Sea

The nearshore environment is often classified in relation to tide level and water depth. The nearshore and offshore oceanic regions together, are often classified with reference to light penetration and water depth. (Figure 3)

1 <u>Neritic</u> - Relatively shallow-water zone which extends from the high-tide mark to the edge of the continental shelf.

MARINE ECOLOGY

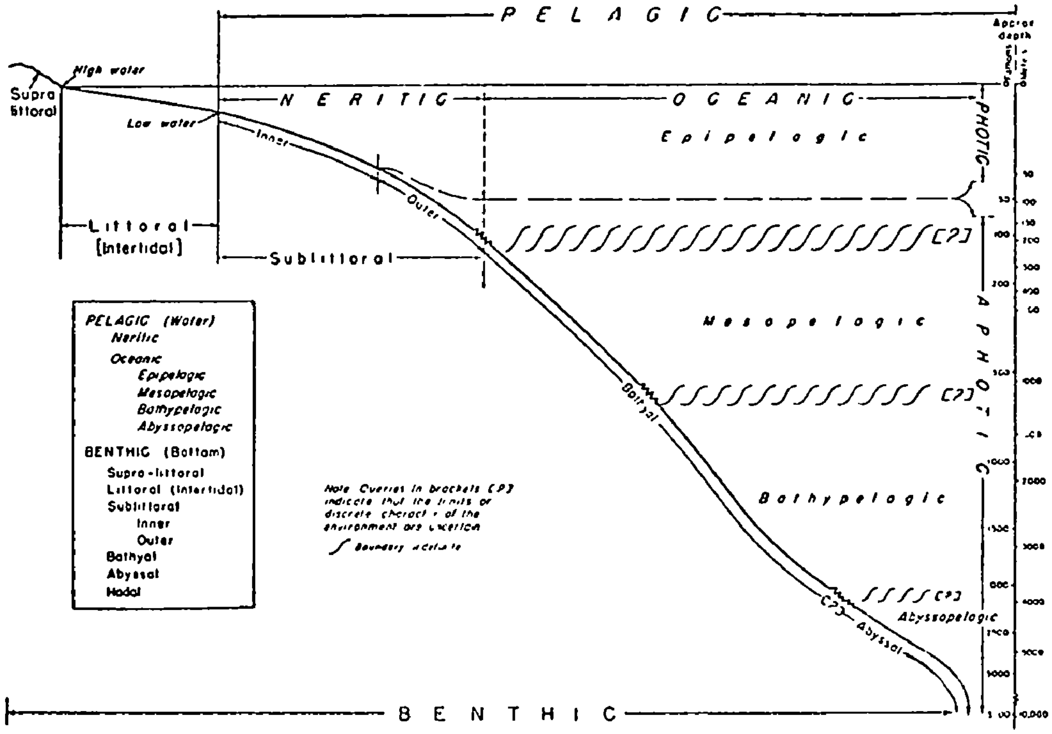

FIGURE 3—*Classification of marine environments*

a Stability of physical factors is intermediate between estuarine and oceanic environments.

b Phytoplankters are the dominant producers but in some locations attached algae are also important as producers.

c The animal consumers are zooplankton, nekton, and benthic forms.

2 Oceanic - The region of the ocean beyond the continental shelf. Divided into three parts, all relatively poorly populated compared to the neritic zone.

a Euphotic zone - Waters into which sunlight penetrates (often to the bottom in the neritic zone). The zone of primary productivity often extends to 600 feet below the surface.

1) Physical factors fluctuate less than in the neritic zone.

2) Producers are the phytoplankton and consumers are the zooplankton and nekton.

b Bathyal zone - From the bottom of the euphotic zone to about 2000 meters.

1) Physical factors relatively constant but light is absent.

2) Producers are absent and consumers are scarce.

c Abyssal zone - All the sea below the bathyal zone.

1) Physical factors more constant than in bathyal zone.

2) Producers absent and consumers even less abundant than in the bathyal zone.

III SEA WATER AND THE BODY FLUIDS

A Sea water is a remarkably suitable environment for living cells, as it contains all of the chemical elements essential to the growth and maintenance of plants and animals. The ratio and often the concentration of the major salts of sea water are strikingly similar in the cytoplasm and body fluids of marine organisms. This similarity is also evident, although modified somewhat in the body fluids of fresh water and terrestrial animals. For example, sterile sea water may be used in emergencies as a substitute for blood plasma in man.

B Since marine organisms have an internal salt content similar to that of their surrounding medium (isotonic condition) osmoregulation poses no problem. On the other hand, fresh water organisms are hypertonic (osmotic pressure of body fluids is higher than that of the surrounding water). Hence, fresh water animals must constantly expend more energy to keep water out (i.e., high osmotic pressure fluids contain more salts, the action being then to dilute this concentration with more water).

1 Generally, marine invertebrates are narrowly poikilosmotic, i.e., the salt concentration of the body fluids changes with that of the external medium. This has special significance in estuarine situations where salt concentrations of the water often vary considerably in short periods of time.

2 Marine bony fish (teleosts) have lower salt content internally than the external environment (hypotonic). In order to prevent dehydration, water is ingested and salts are excreted through special cells in the gills.

IV FACTORS AFFECTING THE DISTRIBUTION OF MARINE AND ESTUARINE ORGANISMS

A Salinity. Salinity is the single most constant and controlling factor in the marine environment, probably followed by temperature. It ranges around 35,000 mg. per liter, or "35 parts per thousand" (symbol: 35‰) in the language of the oceanographer. While variations in the open ocean are relatively small, salinity decreases rapidly as one approaches shore and proceeds through the estuary and up into fresh water with a salinity of "0 ‰ (see Figure 2)

B Salinity and temperature as limiting factors in ecological distribution.

1 Organisms differ in the salinities and temperatures in which they prefer to live, and in the variabilities of these parameters which they can tolerate. These preferences and tolerances often change with successive life history stages, and in turn often dictate where the organisms live: their "distribution."

2 These requirements or preferences often lead to extensive migrations of various species for breeding, feeding, and growing stages. One very important result of this is that an estuarine environment is an absolute necessity for over half of all coastal commercial and sport related species of fishes and invertebrates, for either all or certain portions of their life histories. (Part V, figure 8)

3 The Greek word roots "eury" (meaning wide) and "steno" (meaning narrow) are customarily combined with such words as "haline" for salt, and "thermal" for temperature, to give us "euryhaline" as an adjective to characterize an organism able to tolerate a wide range of salinity, for example; or "stenothermal" meaning one which cannot stand much change in temperature. "Meso-" is a prefix indicating an intermediate capacity.

C Marine, estuarine, and fresh water organisms. (See Figure 4)

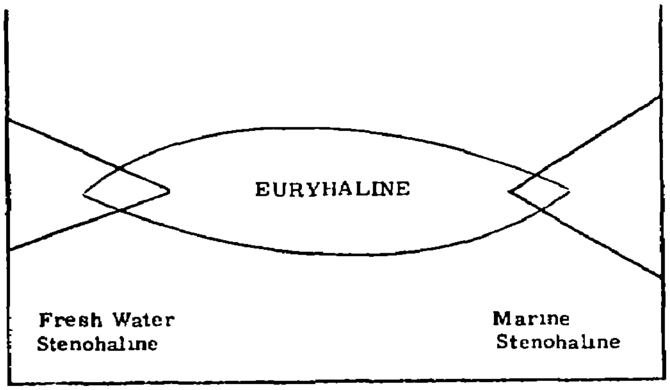

Figure 4. Salinity Tolerance of Organisms

1 Offshore marine organisms are, in general, both stenohaline and stenothermal unless, as noted above, they have certain life history requirements for estuarine conditions.

2 Fresh water organisms are also stenohaline, and (except for seasonal adaptation) meso- or stenothermal. (Figure 2)

3 Indigenous or native estuarine species that normally spend their entire lives in the estuary are relatively few in number. (See Figure 5). They are generally meso- or euryhaline and meso- or eurythermal.

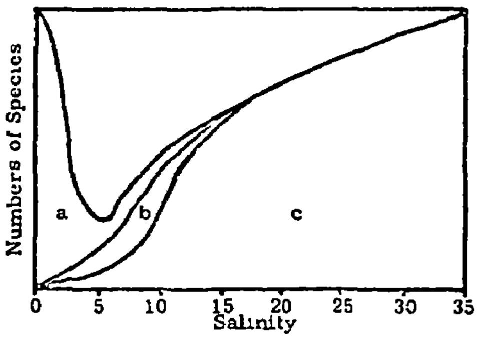

Figure 5. DISTRIBUTION OF ORGANISMS IN AN ESTUARY

a Euryhaline, freshwater
b Indigenous, estuarine, (mesohaline)
c Euryhaline, marine

4 Some well known and interesting examples of migratory species which change their environmental preferences with the life history stage include the shrimp (mentioned above), striped bass, many herrings and relatives, the salmons, and many others. None are more dramatic than the salmon hordes which lay their eggs in freshwater streams, migrate far out to sea to feed and grow, then return to the stream where they hatched to lay their own eggs before dying.

5 Among euryhaline animals landlocked (trapped), populations living in lowered salinities often have a smaller maximum size than individuals of the same species living in more saline waters. For example, the lamprey (Petromyzon marinus) attains a length of 30 - 36" in the sea, while in the Great Lakes the length is 18 - 24".

Usually the larvae of aquatic organisms are more sensitive to changes in salinity than are the adults. This characteristic both limits and dictates the distribution and size of populations.

D The effects of tides on organisms.

1 Tidal fluctuations probably subject the benthic or intertidal populations to the most extreme and rapid variations of environmental stress encountered in any aquatic habitat. Highly specialized communities have developed in this zone, some adapted to the rocky surf zones of the open coast, others to the muddy inlets of protected estuaries. Tidal reaches of fresh water rivers, sandy beaches, coral reefs and mangrove swamps in the tropics; all have their own floras and faunas. All must emerge and flourish when whatever water there is rises and covers or tears at them, all must collapse or retract to endure drying, blazing tropical sun, or freezing arctic ice during the low tide interval. Such a community is depicted in Figure 6.

SNAILS

- Littorina neritoides
- L. rudis
- L. obtusata
- L. littorea

BARNACLES

- Chthamalus stellatus
- Balanus balanoides
- B. perforatus

Figure 6

Zonation of plants, snails, and barnacles on a rocky shore. While this diagram is based on the situation on the southwest coast of England, the general idea of zonation may be applied to any temperate rocky ocean shore, though the species will differ. The gray zone consists largely of lichens. At the left is the zonation of rocks with exposure too extreme to support algae; at the right, on a less exposed situation, the animals are mostly obscured by the algae. Figures at the right hand margin refer to the percent of time that the zone is exposed to the air, i.e., the time that the tide is out. Three major zones can be recognized: the Littorina zone (above the gray zone); the Balanoid zone (between the gray zone and the laminarias); and the Laminaria zone. a. Pelvetia canaliculata; b. Fucus spiralis; c. Ascophyllum nodosum; d. Fucus serratus; e. Laminaria digitata. (Based on Stephenson)

V FACTORS AFFECTING THE PRODUCTIVITY OF THE MARINE ENVIRONMENT

A The sea is in continuous circulation. Without circulation, nutrients of the ocean would eventually become a part of the bottom and biological production would cease. Generally, in all oceans there exists a warm surface layer which overlies the colder water and forms a two-layer system of persistent stability. Nutrient concentration is usually greatest in the lower zone. Wherever a mixing or disturbance of these two layers occurs biological production is greatest.

B The estuaries are also a mixing zone of enormous importance. Here the fertility washed off the land is mingled with the nutrient capacity of seawater, and many of the would's most productive waters result.

C When man adds his cultural contributions of sewage, fertilizer, silt or toxic waste, it is no wonder that the dynamic equilibrium of the ages is rudely upset, and the environmentalist cries, "See what man hath wrought"!

ACKNOWLEDGEMENT:

This outline contains selected material from other outlines prepared by C. M. Tarzwell, Charles L. Brown, Jr., C. G. Gunnerson, W. Lee Trent, W. B. Cooke, B. H. Ketchum, J. K. McNulty, J. L. Taylor, R. M. Sinclair, and others.

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I INTRODUCTION

A Broadly defined, wetlands are areas which are "to wet to plough but too thick to flow." The soil tends to be saturated with water, salt or fresh, and numerous channels or ponds of shallow or open water are common. Due to ecological features too numerous and variable to list here, they comprise in general a rigorous (highly stressed) habitat, occupied by a small relatively specialized indigenous (native) flora and fauna.

B They are prodigiously productive however, and many constitute an absolutely essential habitat for some portion of the life history of animal forms generally recognized as residents of other habitats (Figure 8). This is particularly true of tidal marshes as mentioned below.

C Wetlands in toto comprise a remarkably large proportion of the earth's surface, and the total organic carbon bound in their mass constitutes an enormous sink of energy.

D Since our main concern here is with the "aquatic" environment, primary emphasis will be directed toward a description of wetlands as the transitional zone between the waters and the land, and how their desecration by human culture spreads degradation in both directions.

II TIDAL MARSHES AND THE ESTUARY

A "There is no other case in nature, save in the coral reefs, where the adjustment of organic relations to physical condition is seen in such a beautiful way as the balance between the growing marshes and the tidal streams by which they are at once nourished and worn away " (Shaler, 1886)

B Estuarine pollution studies are usually devoted to the dynamics of the circulating water, its chemical, physical, and biological parameters, bottom deposits, etc

C It is easy to overlook the intimate relationships which exist between the bordering marshland, the moving waters, the tidal flats, subtidal deposition, and seston whether of local, oceanic, or riverine origin

D The tidal marsh (some inland areas also have salt marshes) is generally considered to be the marginal areas of estuaries and coasts in the intertidal zone, which are dominated by emergent vegetation. They generally extend inland to the farthest point reached by the spring tides, where they merge into freshwater swamps and marshes (Figure 1). They may range in width from nonexistent on rocky coasts to many kilometers.

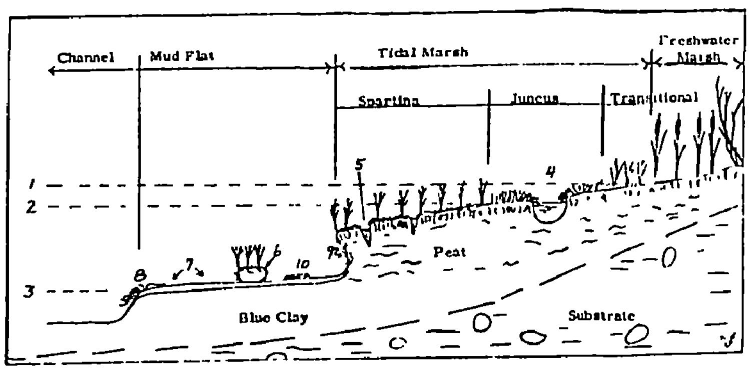

Figure 1 Zonation in a positive New England estuary 1 Spring tide level, 2 Mean high tide, 3 Mean low tide, 4 Dog hole, 5 Ice cleavage pool, 6 Chunk of Spartina turf deposited by ice, 7 Organic ooze with associated community, 8 eelgrass (Zostera), 9 Ribbed mussels (modiolus)-clam (mya) - mud snail (Nassa) community 10 Sea lettuce (Ulva)

III MARSH ORIGINS AND STRUCTURES

A In general, marsh substrates are high in organic content, relatively low in minerals and trace elements. The upper layers bound together with living roots called turf, underlaid by more compacted peat type material.

1 Rising or eroding coastlines may expose peat from ancient marsh growth to wave action which cuts into the soft peat rapidly (Figure 2).

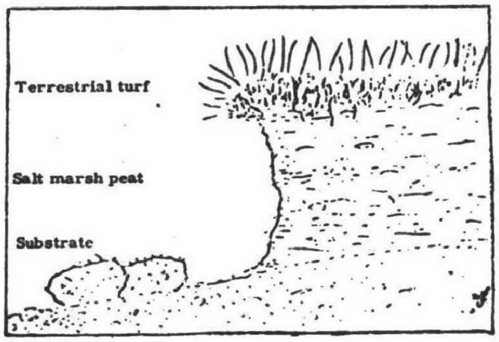

Figure 2. Diagrammatic section of eroding peat cliff

Such banks are likely to be cliff-like, and are often undercut. Chunks of peat are often found lying about on harder substrate below high tide line. If face of cliff is well above high water, overlying vegetation is likely to be typically terrestrial of the area. Marsh type vegetation is probably absent.

2 Low lying deltaic, or sinking coastlines, or those with low energy wave action are likely to have active marsh formation in progress. Sand dunes are also common in such areas (Figure 3). General coastal configuration is a factor.

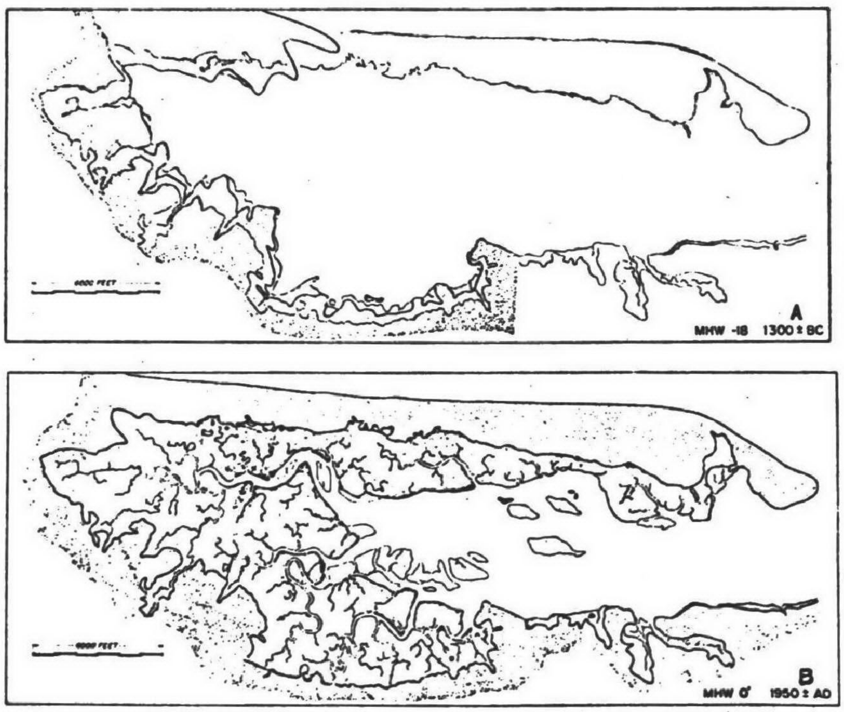

Figure 3

Development of a Massachusetts Marsh since 1300 BC, involving an 18 foot rise in water level. Shaded area indicates sand dunes. Note meandering marsh tidal drainage. A: 1300 BC, B: 1950 AD.

a Rugged or precipitous coasts or slowly rising coasts, typically exhibit narrow shelves, sea cliffs, fjords, massive beaches, and relatively less marsh area (Figure 4). An Alaskan fjord subject to recent catastrophic subsidence and rapid deposition of glacial flour shows evidence of the recent encroachment of saline waters in the presence of recently buried trees and other terrestrial vegetation, exposure of layers of salt marsh peat along the edges of channels, and a poorly compacted young marsh turf developing at the new high water level (Figure 5).

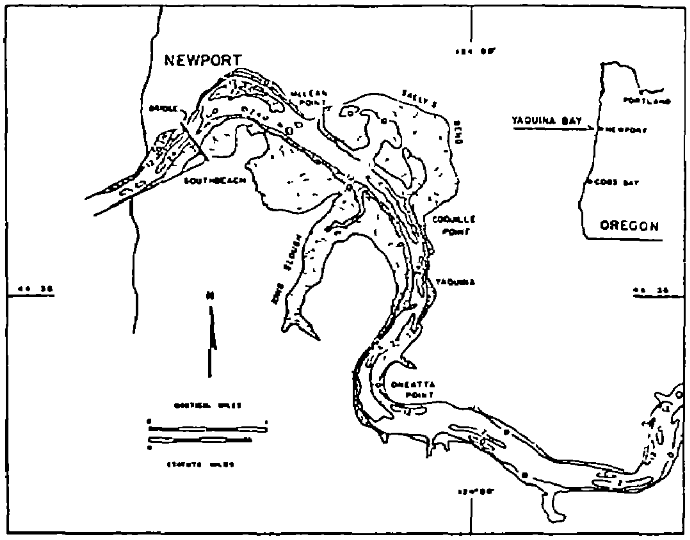

Figure 4 A River Mouth on a Slowly Rising Coast Note absence of deltaic development and relatively little marshland, although mud flats stippled are extensive

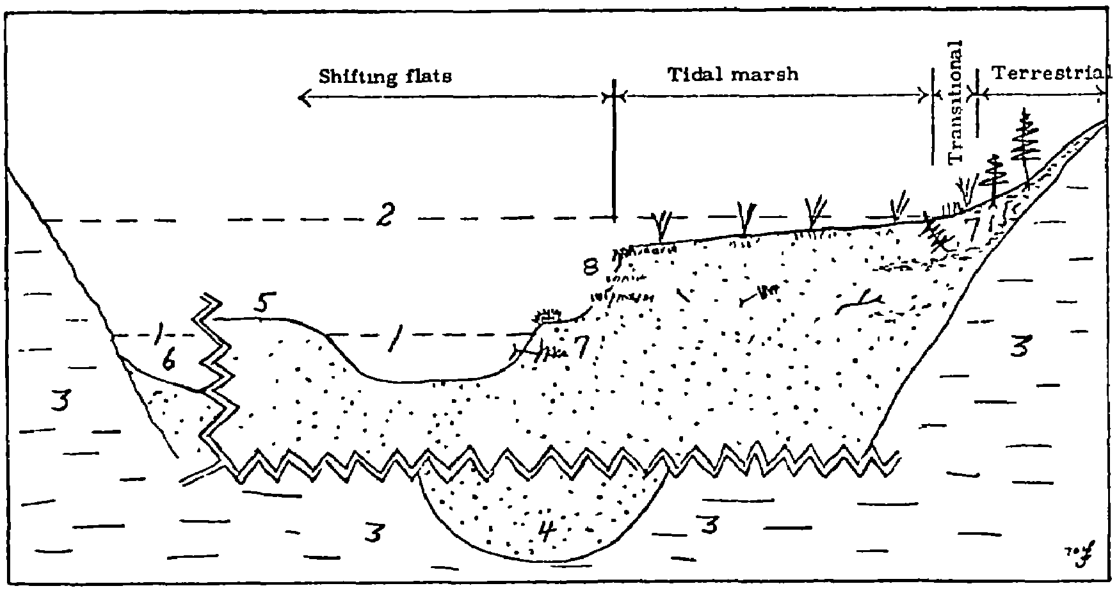

Figure 5 Some general relationships in a northern fjord with a rising water level 1. mean low water, 2. maximum high tide, 3. Bedrock, 4. Glacial flour to depths in excess of 400 meters, 5. Shifting flats and channels, 6. Channel against bedrock, 7. Buried terrestrial vegetation, 8. Outcroppings of salt marsh peat.

b Low lying coastal plains tend to be fringed by barrier islands, broad estuaries and deltas, and broad associated marshlands (Figure 3).

Deep tidal channels fan out through innumerable branching and often interconnecting rivulets. The intervening grassy plains are essentially at mean high tide level.

c Tropical and subtropical regions such as Florida, the Gulf Coast, and Central America, are frequented by mangrove swamps. This unique type of growth is able to establish itself in shallow water and move out into progressively deeper areas (Figure 6). The strong deeply embedded roots enable the mangrove to resist considerable wave action at times, and the tangle of roots quickly accumulates a deep layer of organic sediment. Mangroves in the south may be considered to be roughly the equivalent of the Spartina marsh grass in the north as a land builder. When fully developed, a mangrove swamp is an impenetrable thicket of roots over the tidal flat affording shelter to an assortment of semi-aquatic organisms such as various molluscs and crustaceans, and providing access from the nearby land to predaceous birds, reptiles, and mammals. Mangroves are not restricted to estuaries, but may develop out into shallow oceanic lagoons, or upstream into relatively fresh waters.

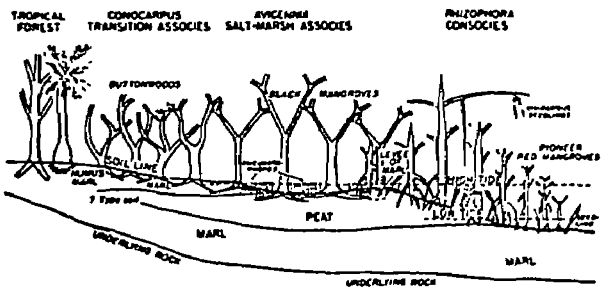

Figure 6 Diagrammatic transect of a mangrove swamp showing transition from marine to terrestrial habitat

IV PRODUCTIVITY OF WETLANDS

A Measuring the productivity of grasslands is not easy, because today grass is seldom used directly as such by man. It is thus usually expressed as production of meat, milk, or in the case of salt marshes, the total crop of animals that obtain food per unit of area. The primary producer in a tidal marsh is the marsh grass, but very little of it is used by man as grass (Table 1)

The nutritional analysis of several marsh grasses as compared to dry land hay is shown in Table 2.

TABLE 1. General Orders of Magnitude of Gross Primary Productivity in Terms of Dry Weight of Organic Matter Fixed Annually

Ecosystem	gms/M²/year (grams/square meters/year)	lbs/acre/year
Land deserts, deep oceans	Tens	Hundreds
Grasslands, forests, eutrophic lakes, ordinary agriculture	Hundreds	Thousands
Estuaries, deltas, coral reefs, intensive agriculture (sugar cane, rice)	Thousands	Ten-thousands

TABLE 2. Analyses of Some Tidal Marsh Grasses

T/A Dry Wt	Percentage Composition Protein	Fat	Fiber	Water	Ash	N-free Extract
Distichlis spicata (pure stand, dry)						
2 8	5 3	1 7	32 4	8 2	6.7	45 5
Short *Spartina alterniflora* and *Salicornia europaea* (in standing water)						
1 2	7 7	2.5	31 1	8 8	12 0	37 7
Spartina alterniflora (tall, pure stand in standing water)						
3 5	7 6	2 0	29 0	8.3	15 5	37 3
Spartina patens (pure stand, dry)						
3 2	6.0	2 2	30 0	8.1	9 0	44 5
Spartina alterniflora and *Spartina patens* (mixed stand, wet)						
3 4	6.8	1 9	29 8	8.1	10 4	42 8
Spartina alterniflora (short, wet)						
2 2	8.8	2 4	30 4	8.7	13 3	36 3
Comparable Analyses for Hay						
1st cut	6 0	2 0	36 2	6 7	4 2	44 9
2nd cut	11 0	3 7	20 5	10 4	5 9	30 5

Analyses performed by Roland W. Gilbert, Department of Agricultural Chemistry, U.R.I.

B The actual utilization of marsh grass is accomplished primarily by its decomposition and ingestion by micro organisms. (Figure 7) A small quantity of seeds and solids is consumed directly by birds

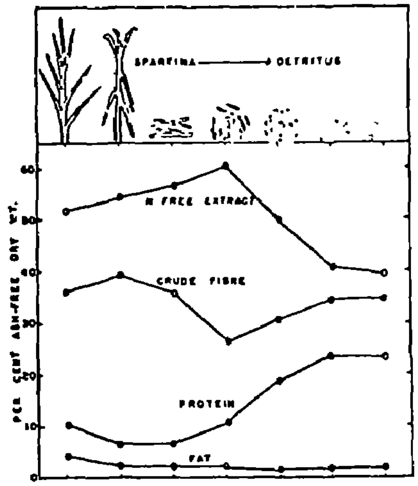

Figure 7 The nutritive composition of successive stages of decomposition of Spartina marsh grass, showing increase in protein and decrease in carbohydrate with increasing age and decreasing size of detritus particles.

1 The quantity of micro invertebrates which thrive on this wealth of decaying marsh has not been estimated, nor has the actual production of small indigenous fishes and invertebrates such as the top minnows (Fundulus), or the mud snails (Nassa), and others.

2 Many forms of oceanic life migrate into the estuaries, especially the marsh areas, for important portions of their life histories as is mentioned elsewhere (Figure 8). It has been estimated that in excess of 60% of the marine commercial and sport fisheries are estuarine or marsh dependent in some way.

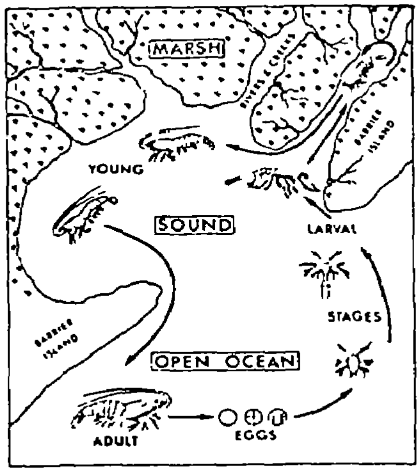

Figure 8 Diagram of the life cycle of white shrimp (after Anderson and Lunz 1965).

3 An effort to make an indirect estimate of productivity in a Rhode Island marsh was made on a single August day by recording the numbers and kinds of birds that fed on a relatively small area (Figure 9). Between 700 and 1000 wild birds of 12 species, ranging from 100 least sandpipers to uncountable numbers of seagulls were counted. One food requirement estimate for three-pound poultry in the confined inactivity of a poultry yard is approximately one ounce per pound of bird per day.

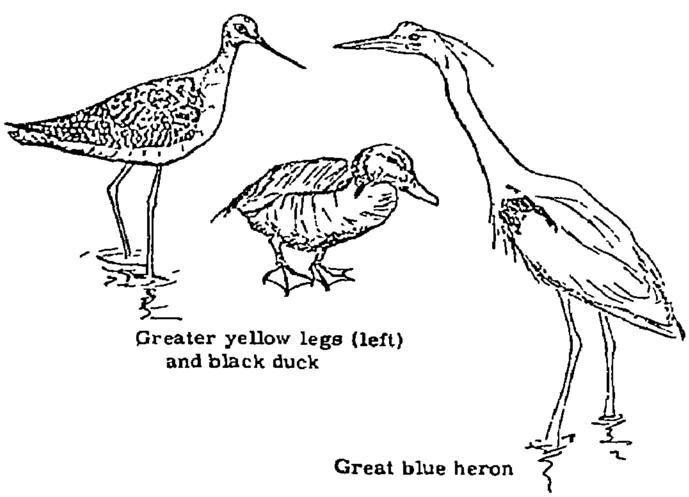

Figure 9 Some Common Marsh Birds

One-hundred black bellied plovers at approximately ten ounces each would weigh on the order of sixty pounds. At the same rate of food consumption, this would indicate nearly four pounds of food required for this species alone. The much greater activity of the wild birds would ooviously greatly increase their food requirements, as would their relatively smaller size.

Considering the range of foods consumed, the sizes of the birds, and the fact that at certain seasons, thousands of migrating ducks and others pause to feed here, the enormous productivity of such a marsh can be better understood.

V INLAND BOGS AND MARSHES

A Much of what has been said of tidal marshes also applies to inland wetlands. As was mentioned earlier, not all inland swamps are salt-free, any more than all marshes affected by tidal rythms are saline.

B The specificity of specialized floras to particular types of wetlands is perhaps more spectacular in freshwater wetlands than in the marine, where Juncus, Spartina, and Mangroves tend to dominate.

1 Sphagnum, or peat moss, is probably one of the most widespead and abundant wetland plants on earth. Deevey (1958) quotes an estimate that there is probably upwards of 223 billions (dry weight) of tons of peat in the world today, derived during recent geologic time from Sphagnum bogs. Particularly in the northern regions, peat moss tends to overgrow ponds and shallow depressions, eventually forming the vast tundra plains and moores of the north.

2 Long lists of other bog and marsh plants might be cited, each with its own special requirements, topographical, and geographic distribution, etc. Included would be the familiar cattails, spike rushes, cotton grasses, sedges, trefoils, alders, and many, many others.

C Types of inland wetlands.

1 As noted above (Cf: Figure 1) tidal marshes often merge into freshwater marshes and bayous. Deltaic tidal swamps and marshes are often saline in the seaward portion, and fresh in the landward areas.

2 River bottom wetlands differ from those formed from lakes, since wide flood plains subject to periodic inundation are the final stages of the erosion of river valleys, whereas lakes in general tend to be eliminated by the geologic processes of natural eutrophication often involving Sphagnum and peat formation. Riverbottom marshes in the southern United States, with favorable climates, have luxurient growths such as the canebrake of the lower Mississippi, or a characteristic timber growth such as cypress.

3 Although bird life is the most conspicuous animal element in the fauna (Cf: Figure 9), many mammals, such as muskrats, beavers, otters, and others are also marsh-oriented. (Figure 12)

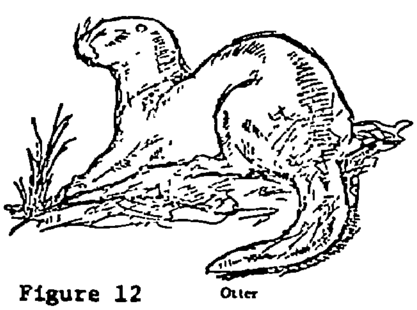

Figure 12 Otter

VI POLLUTION

A No single statement can summarize the effects of pollution on marshlands as distinct from effects noted elsewhere on other habitats.

B Reduction of Primary Productivity

The primary producers in most wetlands are the grasses and peat mosses. Production may be reduced or eliminated by:

1 Changes in the water level brought about by flooding or drainage.

a Marshland areas are sometimes diked and flooded to produce freshwater ponds. This may be for aesthetic reasons, to suppress the growth of noxious marsh inhabitating insects such as mosquitoes or biting midges, to construct an industrial waste holding pond, a thermal or a sewage stabilization pond, a "convenient" result of highway causeway construction, or other reason. The result is the elimination of an area of marsh. A small compensating border of marsh may or may not develop.

b High tidal marshes were often ditched and drained in former days to stabilize the sod for salt hay or "thatch" harvesting which was highly sought after in colonial days. This inevitably changed the character of the marsh, but it remained as essentially marshland. Conversion to outright agricultural land has been less widespread because of the necessity of diking to exclude the periodic floods or tidal incursions, and carefully timed drainage to eliminate excess precipitation. Mechanical pumping of tidal marshes has not been economical in this country, although the success of the Dutch and others in this regard is well known.

2 Marsh grasses may also be eliminated by smothering as, for example, by deposition of dredge spoils, or the spill or discharge of sewage sludge

3 Considerable marsh area has been eliminated by industrial construction activity such as wharf and dock construction, oil well construction and operation, and the discharge of toxic brines and other chemicals.

C Consumer production (animal life) has been drastically reduced by the deliberate distribution of pesticides. In some cases, this has been aimed at nearby agricultural lands for economic crop pest control, in other cases the marshes have been sprayed or dusted directly to control noxious insects.

1 The results have been universally disastrous for the marshes, and the benefits to the human community often questionable.

2 Pesticides designed to kill nuisance insects, are also toxic to other arthropods so that in addition to the target species, such forage staples as the various scuds (amphipods), fiddler crabs, and other macroinvertebrates have either been drastically reduced or entirely eliminated in many places. For example, one familiar with fiddler crabs can traverse miles of marsh margins, still riddled with their burrows, without seeing a single live crab.

3 DDT and related compounds have been "eaten up the food chain" (biological magnification effect) until fish eating and other predatory birds such as herons and egrets (Figure 9), have been virtually eliminated from vast areas, and the accumulation of DDT in man himself is only too well known.

D Most serious of the marsh enemies is man himself. In his quest for "lebensraum" near the water, he has all but killed the water he strives to approach. Thus up to twenty percent of the marsh--estuarine area in various parts of the country has already been utterly destroyed by cut and fill real estate developments (Figures 10, 11).

E Swimming birds such as ducks, loons, cormorants, pelicans, and many others are severely jeopardized by floating pollutants such as oil.

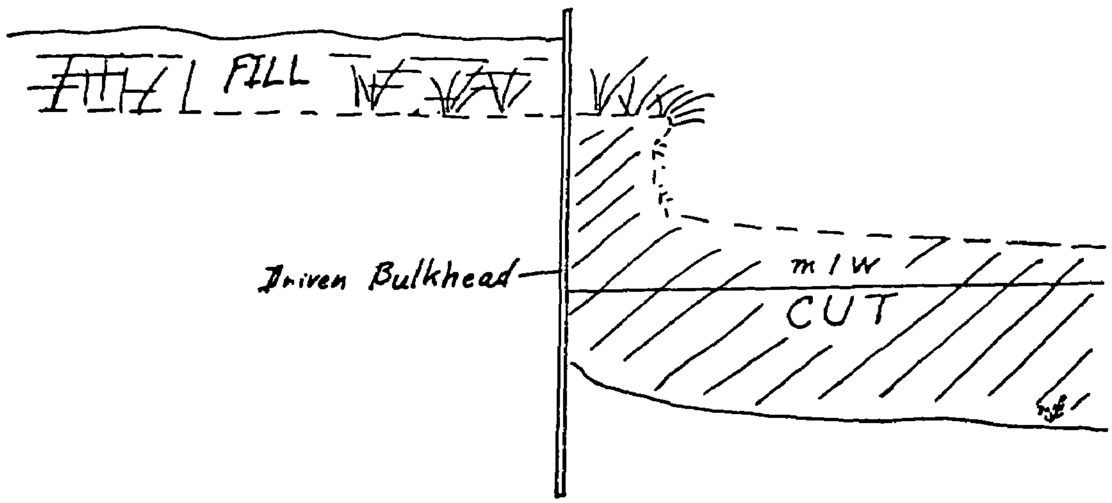

Figure 10. Diagrammatic representation of cut-and-fill for real estate development. mlw = mean low water

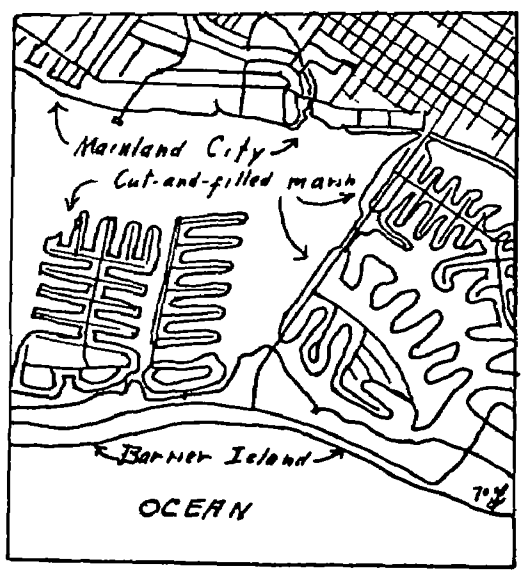

Figure 11. Tracing of portion of map of a southern city showing extent of cut-and-fill real estate development.

VII SUMMARY

A Wetlands comprise the marshes, swamps, bogs, and tundra areas of the world. They are essential to the well-being of our surface waters and ground waters. They are essential to aquatic life of all types living in the open waters. They are essential as habitat for all forms of wildlife.

B The tidal marsh is the area of emergent vegetation bordering the ocean or an estuary.

C Marshes are highly productive areas, essential to the maintenance of a well rounded community of aquatic life.

D Wetlands may be destroyed by:

1 Degradation of the life forms of which it is composed in the name of nuisance control.

2 Physical destruction by cut-and-fill to create more land area.

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This outline was prepared by H. W. Jackson, former Chief Biologist, National Training Center, and revised by R. M. Sinclair, Aquatic Biologist, National Training Center, MPOD, OWPO, EPA, Cincinnati, OH 45268.

Descriptors: Aquatic Environment, Biological Estuarine Environment, Lentic Environment, Lotic Environment, Currents, Marshes, Limnology, Magnification, Water Properties

I WHAT IS AN ESTUARY?

A Historically - Lower Tidal Reaches of a River

B Physical Characteristics

1 Geomorphological considerations - coastal indentation with a 3-dimensional shape based on erosion, deposition, structure, and biological activity

2 Environmental considerations

a Normal - fresh to brackish to saline, circulation dependent on river discharge and tidal circulation

b Inverse - hypersaline to saline, evaporite deposits, climate changes

C Biological Characteristics

1 Monotonous population as compared to sea

2 Unspecialized organisms able to penetrate and exist in an unstable and shifting biotope

D Definition - "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage." (Pritchard in Lauff, 1967)

II ESTUARINE CLASSIFICATION BASED ON GENESIS

A Drowned River Valleys - Chesapeake Bay, Tampa Bay, St. Johns' Estuary

B Fjords - New England Coast

C Bar-built - Pamlico Sount, Gulf Coast Estuaries

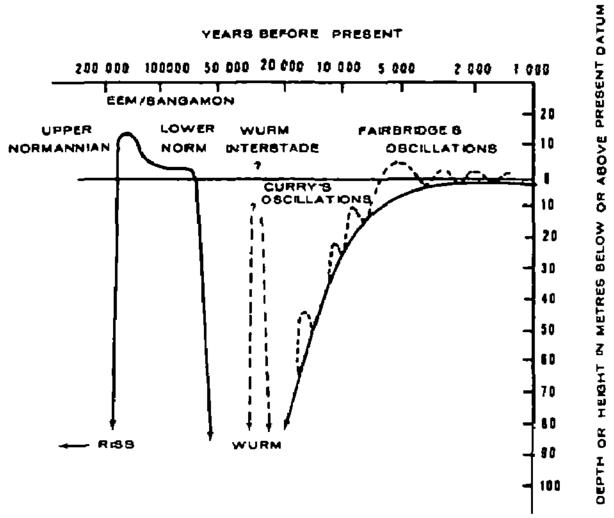
D Structural - San Francisco Bay

E Circulation Subdivided

III ESTUARINE EVOLUTION

A Effects of Sea Level Rise and Fall

1 Pleistocene eustatic changes



General custatic curve for the last 200, 000 years Largely conjectural. Semi log scale. (After Guilcher, 1969)

2 Tectonic effects

B Effects of varying rates of discharge

1 Drainage basin characteristics - size, plant cover, agriculture, rock type

2 Climate - rainfall and temperature control, plant cover and weathering

3 Circulation

a Estuarine - rates of flushing, maximum velocity

b Nearshore - longshore currents and drift

4 Deposition

a Bay-head delta encroachment - function of rate of sediment supply vs. rate of sediment removal b Periestuarine deposition - bay month bars, splits, barrier islands, beaches, and chenier plains

c Biological influences - reefs, grass, salt marshes

5 Human interactions - cultivation, dredge and fill, drainage and shipping channels, dams and flood control

C Ontogeny

1 Lowering sea level - valley down-cutting, coarse-grained sediments

2 Rising sea level - valley alluviation, fine-grained sediments

a Still stands - bay month bars, spits, barriers, and other periestuarine deposition

3 Destruction - delta fills river valley and builds out onto shell

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This outline was prepared by Dr. Grant Goodell, Department of Oceanography, Florida State University, Tallahassee, FL.

HYDRODYNAMICS OF ESTUARIES

I DEFINITION OF AN ESTUARY[2]

A semienclosed enbayment, connected with the ocean, which contains an appreciable amount of sea salt.

II INFLOW AND EVAPORATION

It is common to designate as positive, an estuary with significant dilution (river inflow), and as negative or inverse, an estuary where evaporation dominates. Pritchard suggested that the intermediate sort of estuary where neither process dominates is designated as neutral.

III SHAPE OF ESTUARIES

A Drowned River Valley

B Fjord Type

C Bar-built

IV CAUSES OF WATER EXCHANGE AND MIXING BETWEEN ENBAYMENT AND OCEAN

A Forces Acting for Any Type of Estuary

1 Wind induced circulation

2 Tidal motion

a Mixing

b Inflow and outflow

3 Seasonal temperature and salinity changes

B Source or Sink of Fresh Water

V STUDY OF WATER EXCHANGE

A Salt Balance

B Water Balance

VI DISTRIBUTION OF SALT AND TEMPERATURE

A T-S Diagram

B Vertical and Horizontal Salinity and Temperature Distribution

C Equations Useful in Describing Salt and Mass Conservation

VII FIELD OF MOTION

Equations useful in representing fields of motion, and Mixing processes and mathematical representation of such processes.

VIII MODELING OF ESTUARIES

(Ref. Keulegan's article in Ippen's book.)

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This outline was prepared by Dr. Raymond Staley, Associate Professor of Oceanography, Florida State University, Tallahassee, Florida.

THE PHYSICAL FACTORS OF THE ESTUARY

I CIRCULATION AND DIFFUSION

A Methods of Observation

B Types of Estuarine Circulation

1 Salt wedge estuary

2 Two-layer flow with entrainment

3 Two-layer flow vertical mixing

4 Vertically homogeneous estuaries

5 Exceptional cases

C Basic Principles of Circulation and Mixing

II SALT BALANCE AND CIRCULATION

III SALINITY MEASUREMENTS IN THE ESTUARIES

A Purpose of Salinity Measurements

B Conductivity Measurements

C Salt Injection for Circulation and Diffusion Studies

D Salinity Measurement Instrumentation

E The Use of Estuarine Salinity Measurements

IV CURRENT MEASUREMENTS IN THE ESTUARY

A Methods of Observation

B Current Measurement Instrumentation

This outline was prepared by B Burke, Bissett-Berman Corporation, Miami, Florida.

PHYSICAL CHARACTERISTICS OF ESTUARIES

I INTRODUCTION

During most of the history of physical oceanography, prime emphasis has been directed toward an understanding of the structure and circulation of the open ocean.

Within the last 50 years increasing effort has been directed toward the study of inshore regions and the environmental factors affecting the movement and fate of wastewater pollutants after they have been discharged into estuarine water.

II DEFINITION

A No definite agreement exists as to the proper definition of what constitutes an estuary.

1 Finch and Trewartha define an estuary as "embayments resulting from submergence."

2 Ketchum defines an estuary as "any region in which seawater is measurably diluted by land water drainage."

3 An estuary is defined here as "a body of water bordered by, and partly cut off from, the ocean by land masses originally shaped by non-marine agencies, and where river water mixes with and measurably dilutes seawater.

The most significant characteristic of estuaries is the general prevalence of steep gradients in nearly all parameters. The above may be interpreted to refer to the body of water extending from a line between the outermost headlands to the farthest upstream penetration of seawater, but it must also be recognized that.

a The latter point may vary with seasonal or meteorological conditions, stream flow, etc.

b Tidal action may extend inland far beyond any salinity penetration (to the "fall line").

c Estuarine generated tidal currents and water qualities may extend far out to sea.

d Bottom topography, current patterns, quality characteristics, etc., may be changed drastically by the process of nature (as with delta formation) or may be changed by the action of man.

B Bays are relatively simple, usually broad, indentations in a coastline in which there is little or no admixture of fresh water, and into which oceanic water circulates freely with no significant change in quality.

C Flats. In relatively protected portions of bays and estuaries, broad deltaic deposits may build up to the point of intertidal exposure called tidal flats, which tend to stabilize. Flats may be of mud, sand, or a mixture of both. If covered with emergent brackish water vegetation, it is a salt marsh, in the tropics often a mangrove swamp.

III CLASSIFICATION OF ESTUARIES IN TERMS OF FRESHWATER INFLOW AND EVAPORATION

A Positive Estuary - coastal indentures in which there is a measurable dilution of seawater by land drainage.

Freshwater inflow + precipitation > Evaporation

B Inverse Estuary - type of estuary in which the evaporation exceeds the land drainage (freshwater inflow) plus precipitation.

Evaporation > Freshwater + precipitation input

C Neutral Estuary - type of estuary where neither the freshwater inflow nor the evaporation dominates.

IV CLASSIFICATION OF ESTUARIES IN TERMS OF GEOMORPHOLOGICAL STRUCTURE

Geomorphology - an area of physical geography which deals with the form of the earth, the general configuration of the surface of the earth.

A Coastal Plain Estuaries

1 Formed by drowning of former river valleys, either from subsidence of the land or from a rise in sea level.

2 Usually an elongated indenture of the coast line with the river flowing into the upper end.

3 Usually has shallow depths and shoal areas with a dendritic or branching shore line.

4 Sediments can be transported into the estuary either from the river at the head of the estuary or from the mouth by action of ocean currents and waves.

Examples of Coastal Plain Estuaries:

a Chesapeake Bay and tributaries

b Lower Colorado River

c Lower Hudson River

d St. Lawrence River

e San Francisco Bay

f Tampa Bay

g Galveston Bay

B Fjord Estuaries

1 Elongated indentures of the coast line.

2 Glacially-cut formations which can exceed 1000 feet in depth.

3 Contain one or more sills which define deep interior basins, with a shallow sill at the mouth.

4 U-shape cross section with very steep sides.

5 Generally positive type estuary but a few inverse estuaries of this type are found in arid regions.

6 Sediments are transported into estuary by rivers and shoreline erosion.

7 Examples of Fjord Estuaries in North America include Puget Sound and many inlets of British Columbia and Alaska.

C Bar-Built Estuaries or Lagoons

1 Results from the development of an offshore bar on a shoreline of low relief and shallow water.

2 Usually a very narrow channel exists between the open sea and the estuary.

3 These estuaries may be positive or inverse depending on the freshwater input and the climate of the region.

4 This type of estuary is common on the eastern and Gulf Coasts of the United States.

V CLASSIFICATION OF ESTUARIES IN TERMS OF THE PREDOMINANT MIXING PROCESS

A Mixing caused by tides - in the majority of estuaries the predominant cause of movement and mixing appears to be the tide, upon which is superimposed a weaker river flow.

In some of the large estuaries, such as the Bay of Fundy, or Cooke Inlet, Alaska, the periodic flooding action of the tides is supplemented by seiche (or long stationary) waves in which the node is at the opening to the sea and the antinode (point of maximum vertical movement) near the head. The result may be tides of ten to twenty meters with corresponding tidal currents contributing.

B Mixing caused by meteorological conditions - in many of the shallower bar-built estuaries or sounds, the movement and mixing of water appear to depend primarily on the wind.

C Mixing caused by river flow The position of the wedge of salt water which intrudes into the mouths of the Mississippi or the Delaware Rivers, for example, depends upon the flow of the river.

D Bores are common in tidal channels with relatively narrow entrances, long reaches, and high tides. As a result of such circumstances, the volume and velocity of the ebb flow may hold back the advance of the flood tide until it has built up a sufficient head to overflow the ebb current and advance rapidly up the estuary as a wall or continuously breaking wave of from a few centimeters to a meter or more in height (eight meters has been reported).

E In many estuaries no single cause of movement and mixing predominates, i.e., in some bar-built estuaries the tidal motion will dominate near the channel connecting the estuary with the ocean, but within the estuary both wind and tide may contribute appreciably to the motion and mixing as in San Francisco Bay or Chesapeake Bay.

VI SUMMARY

The type of estuary is important in wastewater disposal because the movement of pollutants (flushing rate) to the open ocean varies with the type of estuary under investigation.

The classification of an inshore region as an estuary is dependent upon the geomorphological characteristics, amount and location of freshwater input, evaporation rates, meteorological conditions and the mechanisms involved in the movement and mixing of the estuarine waters.

A clear definition of the estuary under consideration for reception of wastewater discharges is essential to successful ultimate disposal to the ocean.

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This outline was prepared by P.F. Atkins, Jr., SA Sanitary Engineer, formerly with FWPCA Training, SEC and revised 1970 by H.W. Jackson, Chief Biologist, National Training Center, Water Programs Operations, EPA, Cincinnati, OH 45268.

I SEDIMENTOLOGY

A Textural Considerations

1 Definitions

a Size - millimeters vs. phi scale

	mm	phi
Pebbles	> 4	< - 2
Granules	4 to 2	- 2 to - 1
Sand	2 to 1/16	- 1 to 4
Silt	1/18 to 1/256	4 to 8
Clay	< 1/256	> 8

b Histograms and cumulative curves

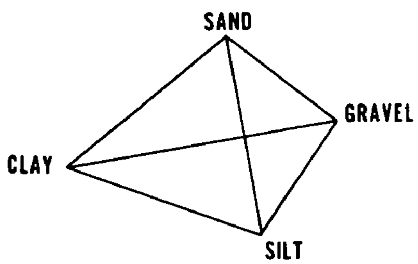
c Shape - physical vs. hydrodynamic

2 Descriptive sedimentary statistics

a Measures of central tendency - mean, median

b Measures of dispersion - standard deviation, skewness, kurtosis

3 End member concept



4 Textural classifications (See figure on following page)

5 Composition of size grades

a Multicomponent grains

b Monomineralic grains

c Clay mineralogy - illite, chlorite, montmorillonite, kaolinite and their degraded and crystallographically mixed counterparts

d Biological components

1) Shell and tests

2) Partially degraded organic matter

B Hydrodynamics of Sediment Transport

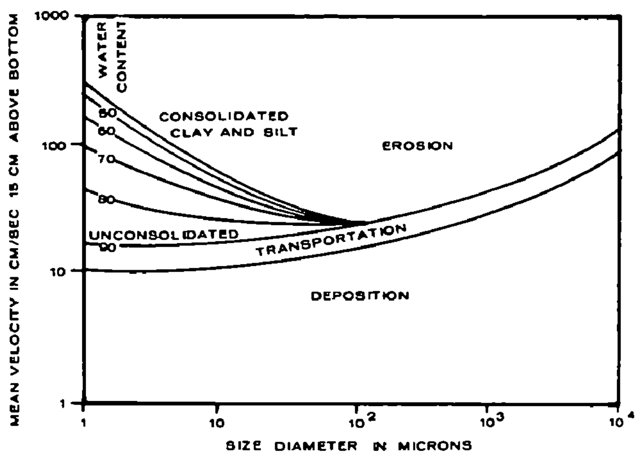
1 Settling velocity

a Stokes' law $v = Cd^2$

b Impact law $v = Cd^{1/2}$

c Variables

1) Particle size, shape and density



Erosion transportation and deposition velocities for different grain sizes The diagram indicates possible values for various stages of consolidation (Data from various authors in Sundborg (1956) and observations of the author) (Postma in Lauff 1967)

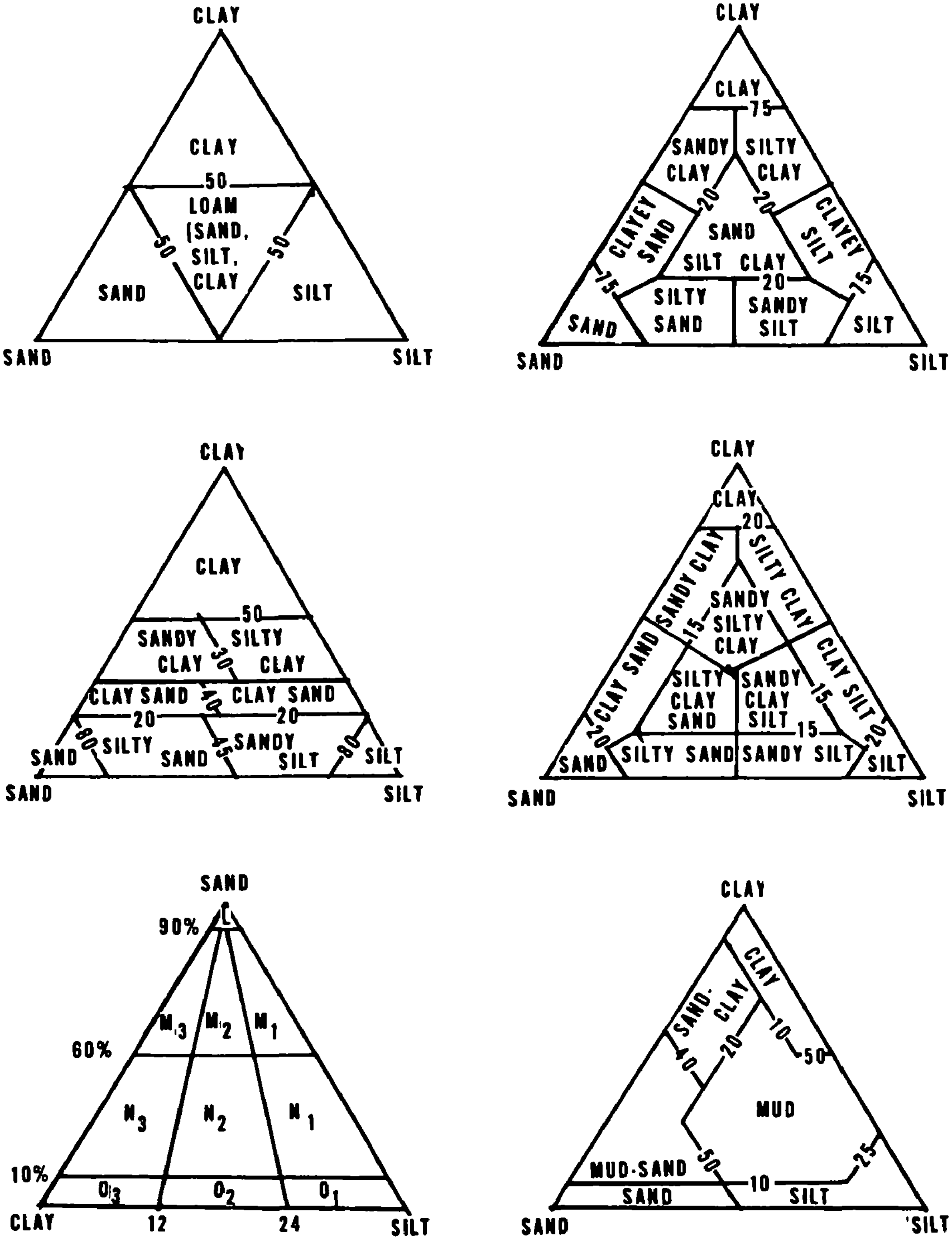
2 Fluid flow characteristics

a Fluid properties

b Laminar vs turbulent flow

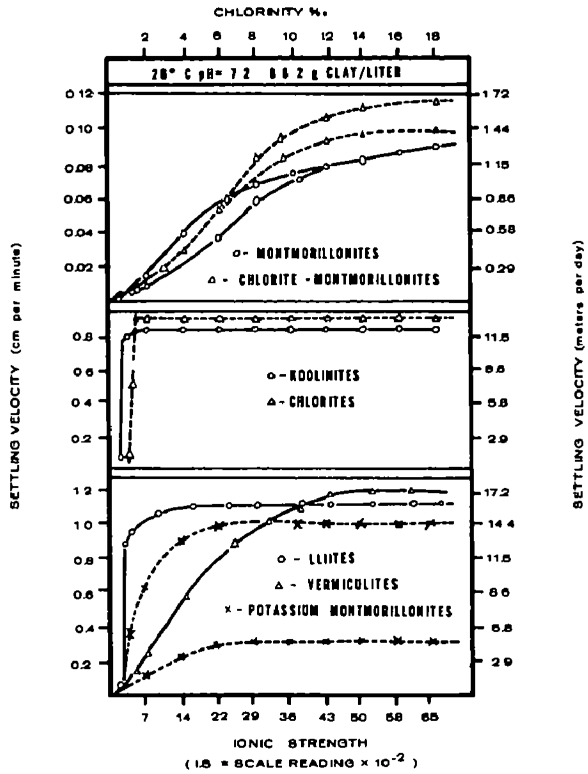
c Scale and intensity of turbulence

Textural Classifications



Nomenclature of sand, silt, and clay mixtures. A: After Robinson (1949). B: After Shepard (1954). C: After Army Engineers. D: After Trefethen (1950). E: After Folk (1954). F: After A.P.I. Project 51 (Shepard, 1954). Pettijohn, 1957.)

3 Suspended load and flocculation



IONIC STRENGTH

(I.S. = Scale Reading $\times 10^{-2}$)

Settling velocities of clay minerals in seawater at different chlorinities (Whitehouse et al., 1960). (After Postma in Lauff, 1967)

4 Traction load

a Bed dilation

5 Lag effects

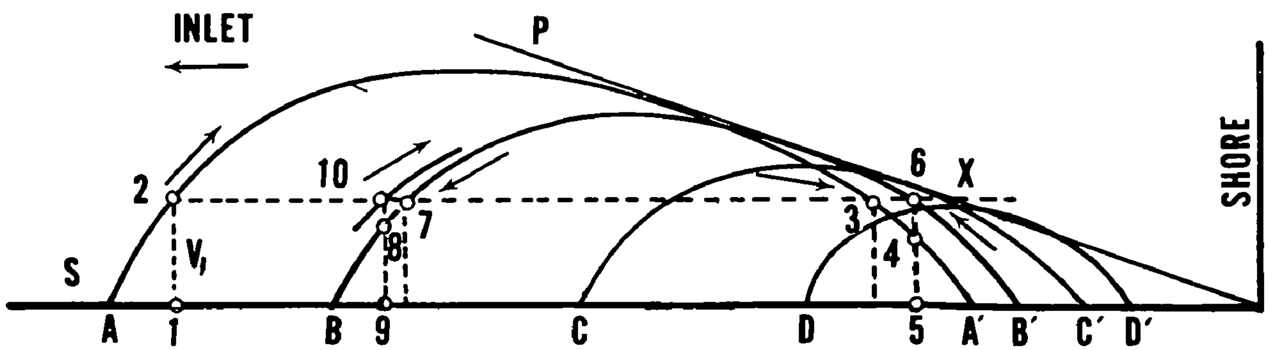
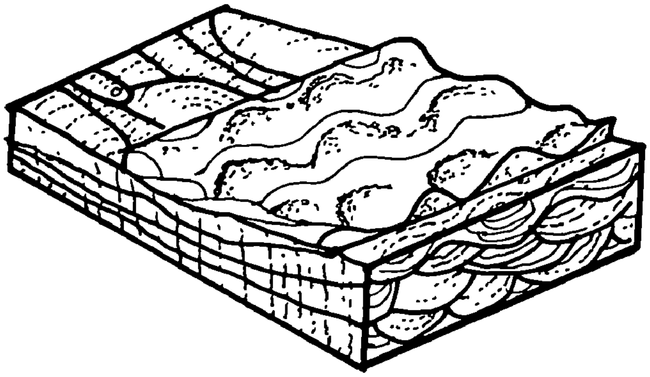


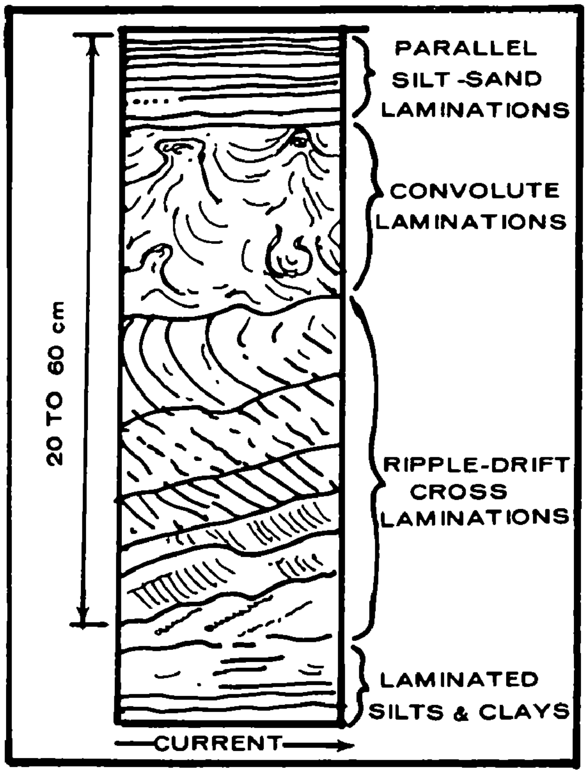
Diagram showing the velocities with which different water masses move with the tides at each point along a section through a tidal area from the inlet to the shore. The curves apply only to idealized, average conditions. This illustrates the effects of settling lag and scour lag (Van Straaten and Kuenen, 1958). (After Postma in Lauff, 1967)

C Primary Structures

1 Ripple marks



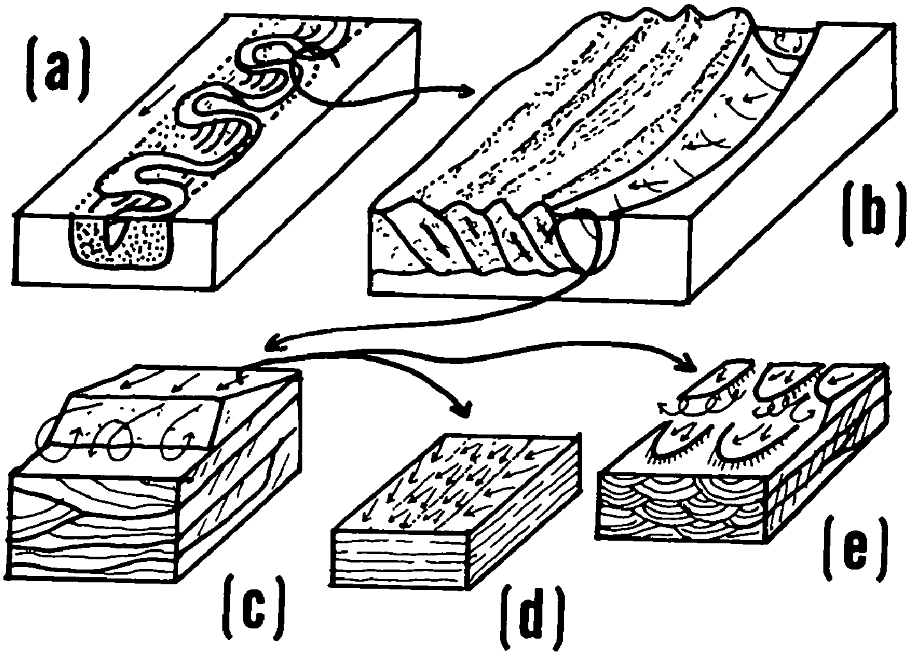
Origin of ripple bedding from current ripples. Plane a: Surface section of ripples with crests having opposing apical directions. This section cuts into the foremost ripple and the cut is shifted forward about half the ripple length to show the structure which exists beneath the ripple. Plane b: Front view of the structure yields festoon bedding. Plane d: Horizontal view of the remaining structure. The forepointing parts of the cosets disappear (compare surface a), eroded from the bottom of the ripple troughs, leaving only the structure of the backpointing part of the lee laminae intact.



Sequence of structures produced by increasing current conditions. (After Coleman and Gagliano in Lauff, 1967)

2 Cross bedding

3 Scour, cut and fill



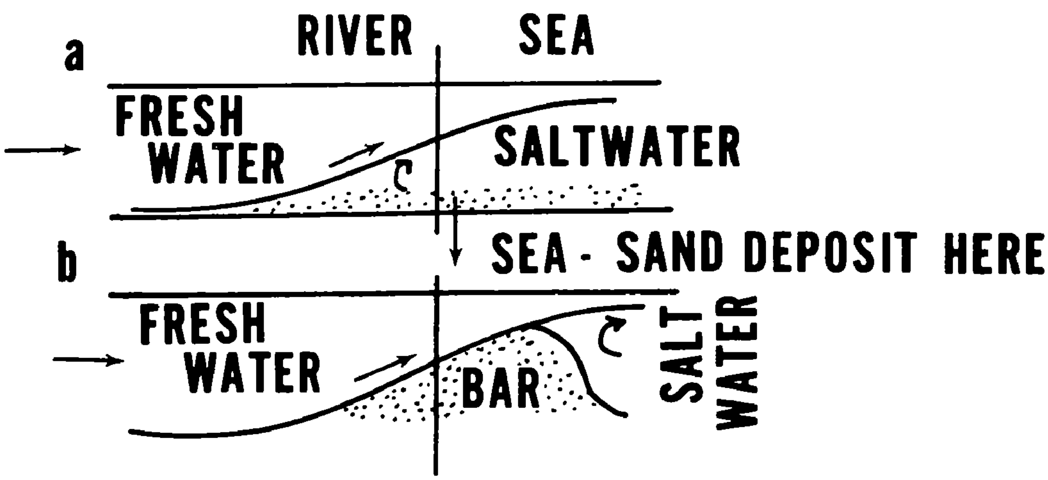
An association of bed forms (and internal structures) commencing with point bars and ending with small scale ripples and parting lineations. (Allen, 1968)

4 Apositional fabric

D Depositional Geomorphology

1 River deltas

2 Bars



Formation of a bar in a salt wedge (Van Veen, 1950)
(Postma in Lauff, 1967)

3 Tidal deltas

4 Periestuarine phenomenon

a Splits, barrier islands, cheniers, beaches, dune fields, nearshore littoral sediments

E Rates of Deposition

1 Factors affecting

a Discharge - climate

b Sediment load - drainage basin

c Circulation - physical conformation

d Man

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II SAMPLING

A Population - class of data from which a sample is drawn

1 Normal or gaussian

2 Binomial - most percentage data

3 Poisson - rarely occurring events

4 Transformations - stabilizes the variance

B Meaning of Randomness - not an intrinsic property of the data but of the process which generated it

1 Formalization procedures insures:

a Validity of measures of accuracy and precision and statistical tests

b Elimination of personal bias

c Elimination of allocation of samples

2 Applies to analysis of data as well as its collection

C Unrestricted Random Sampling - suitable when the population being sampled is reasonably homogeneous

D Stratified Sampling - suitable when natural subdivisions (i.e., bathymetry) of the population are present. Involves dividing target population into non-overlapping segments (strata) which together comprise the population.

E Systematic Sampling - suitable when rather uniform distribution over a traverse or area is desired. Randomization occurs through selection of first sample site or through a combination with B.

F Cluster Sampling - suitable when a level of variability is sought. Involves collecting a group of closely spaced samples at each major sampling point. Randomization occurs in selection of main sampling point and of individual points in cluster.

G Multi-Level (nested) Sampling - suitable when a precise level of variability is sought on which to base long-term monitoring by systematic sampling. An extension of cluster sampling wherein sampling is accomplished in a hierarchical spacial (or temporal) design

III ANALYSIS OF DATA

A Generation of Numbers

1 Accuracy and precision

B Mechanical vs. Hydrological Textures

C Analysis of Variance - basis for decision making. Do two (or more) populations differ from one another (significantly)?

1 Must know characteristics of population

D Regression and Correlation - in theory regression considers the frequency distributions of one variable when another is held fixed at several levels which correlation considers the joint variation of two variables.

1 Assumes linearity, normalcy (more important for correlation), homogeneity of variance (more important for regression)

Scatter diagrams

2 Non-linear and multiple regression

a Polynomial to nth power require n + 1 variables

b Non-linear multiple regression

$$y = f(x_1, x_2, x_3 \ldots . x_n)^z$$

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This outline was prepared by Dr. Grant Goodell, Department of Oceanography, Florida State University, Tallahassee, FL.

PERIESTUARINE FEATURES

I DEFINITION: Features which are peripheral to estuaries, such as beaches and barrier islands

II BEACHES, DUNES AND BEACH-DUNE RIDGES

A Definitions

B Materials: Different Sands, Gravel (Shingle)

C Sources of Materials, Man's Influence

D The Dynamic Air-Sea-Land Interface

E The Beach, a River of Sand

F Beach Ridges and Dune Ridges Ridge Systems. Dune Vegetation

III BARRIER ISLANDS AND BEACHES CHENIERS, BAYMOUTH BARS, SPITS

A Definitions

B Development of these Peripheral Features

C Importance of these Peripheral Features for the Estuaries which they enclose

IV COASTAL MARSHES

A Preconditions for the Development of Coastal Marshes

1 Geographic setting and climatic conditions

2 Geologic conditions

B Coastal-marsh Sediments

1 Inorganic components

2 Organic components

C The Interaction between Vegetation and the Substrate

D Some Physical Mass Properties of Marsh Seds

V NATURAL PROCESSES OF EROSION AND DEPOSITION. MAN'S IMPACT

A Waves and Longshore Currents. Wind

B Hurricanes: Betsy, Alma and Camille as Examples

C Modification of Erosional and Depositional Processes by Man

D Greatest Threat to the Periestuarine Environment: The Civil Engineer

E Development and Settlement of Beach Areas: What to do and mainly what not to do

F Development and Settlement of Marsh Areas. Dredge and Fill Operations

G Direct Changes of the Not-Settled, Adjoining Areas through Siltation and Modification of the Longshore Drift System

H Indirect Changes Imposed on the Hydrography of Adjoining Areas

I The Need for Long-Range Planning plus Specific Investigations of Areas to be Developed

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This outline was prepared by Dr. D. Warnke, Assistant Professor of Oceanography, Florida State University, Tallahassee, FL.

I Clay minerals are best described chemically as hydrous aluminum silicates. These minerals are made up of two fundamental units which are

A Tetrahedral or Silica Layers (Si_2O_5) - these tetrahedra are composed of silica in four fold coordination with oxygen. In clays the tetrahedra are connected at three corners in the same plane to form hexagonal rings (Figure 1).

B Brucite or Gibbsite Layers ($Mg_3(OH)_6$ or $Al_2(OH)_6$) - these units having magnesium or aluminum ions octahedrally coordinated between two planes of hydroxyl ions. In the brucite or trioctahedral layer all the octoctahedral positions are filled with magnesium ions. In the gibbsite or dioctahedral layers only 2/3 of the octahedral positions are filled to maintain charge balance in the structure. The octahedral layer is illustrated in Figure 2.

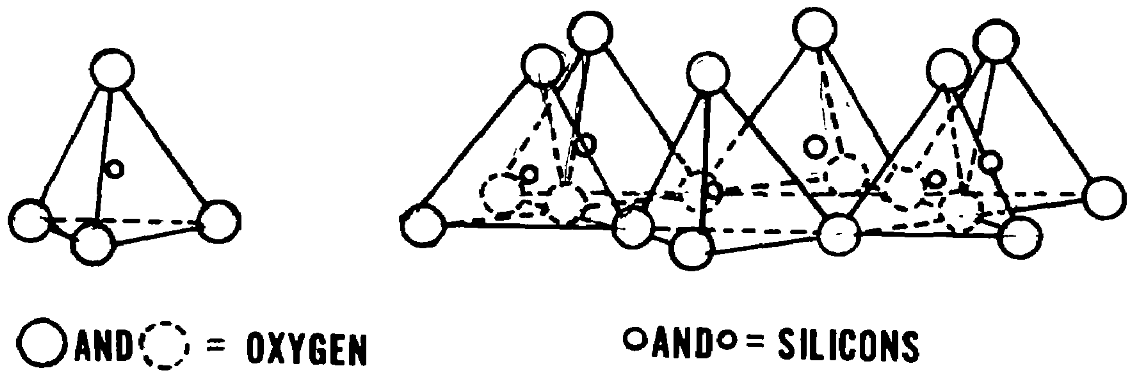


Figure 1. Diagram of the tetrahedral sheet, or silica sheet, of phyllosilicate structures (The left-hand diagram is a single tetrahedral unit) Source· Grim, 1958, page 44

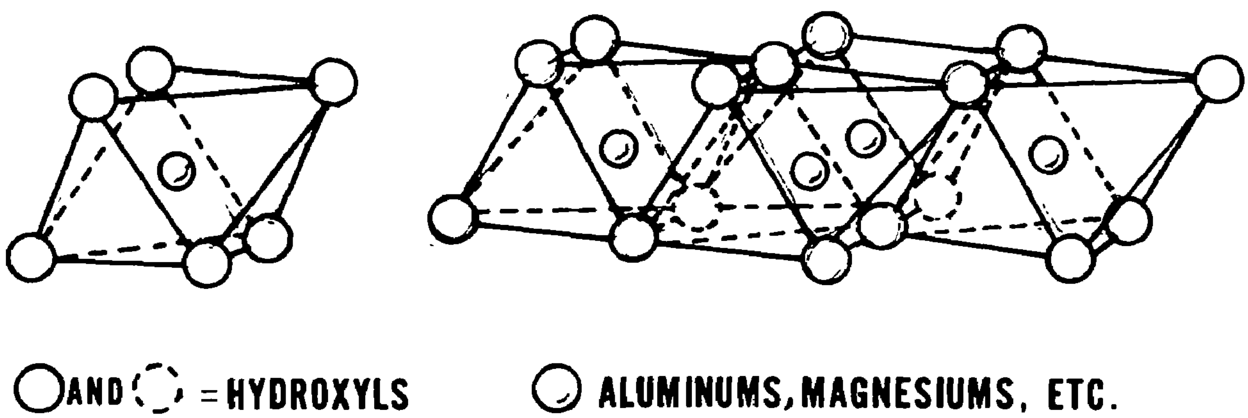


Figure 2 Diagram of the Octahedral sheet, or gibbsite sheet, of phyllosilicate structures. (The left-hand diagram shows a single octahedral unit) When Al^{3+} occupies the centers of the octahedra, only two-thirds of the possible sites are filled, when Mg^{++} occupies these positions, all sites are filled Source Grim, 1958, page 48

All clays basically originate by a combination of the two units described above. The layers are combined in such a way that the unbonded oxygens of the Si_2O_5 sheets replace 2/3 of the hydroxyls in one plane of the octahedral layer. This relationship is illustrated below.

		Charge
OOOOOO	6 OH^-	- 6
oooo	4 Al^{5+}	+12
OOOOOO	$4O^=$, $2OH^-$	-10
oooo	4 Si^{4-}	+16
OOOOOO	6 $O^=$	-12

C Three basic criteria for the classification of clay minerals:

1 Type of combination of Si_2O_5 layers with brucite or gibbsite layers, 1 octahedral: 1 tetrahedral or two octahedral: 1 tetrahedral.

2 Cation content of the octahedral layer (Al or Mg).

3 Manner or perfection of stacking of the fundamental (1:1 or 2:1) units upon each other.

D Structural Classification of Common Clay Minerals

1 Two layer (1:1) silicates -

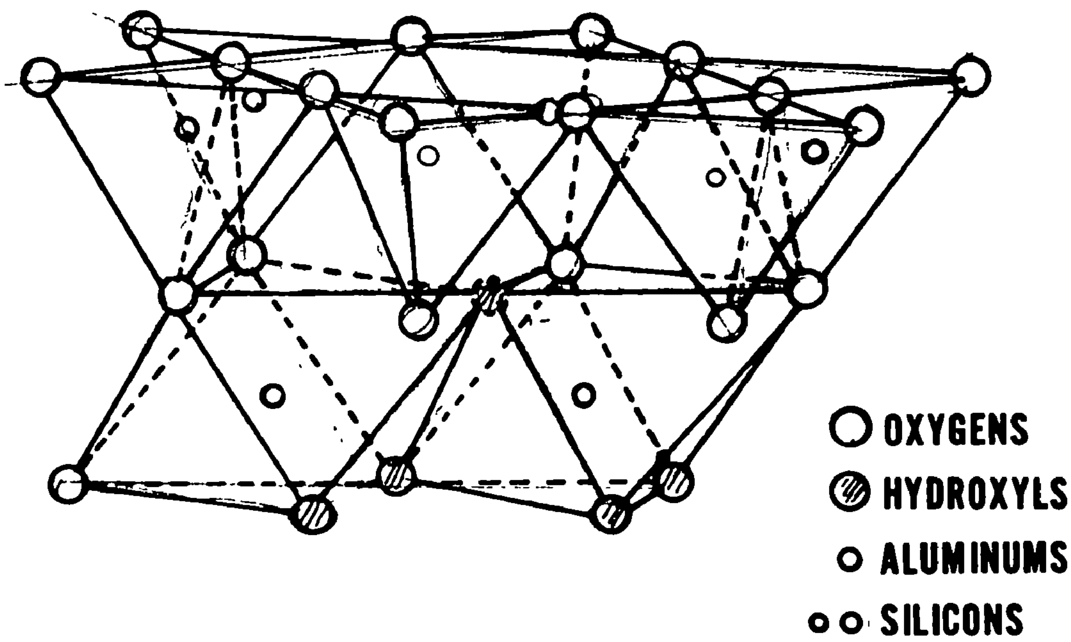
dioctahedral ($Al_4Si_4O_{10}(OH)_8$

kaolinite
nacrite
dickite
halloysite

trioctahedral ($Mg_6Si_4O_{10}(OH)_8$

serpentines

The various members of the dioctahedral group differ only in the stacking along the c-axis and morphology. A diagram of the kaolinite structure is given below.



2 Three layer (2.1) silicates -

<u>dioctahedral</u>

montmorillonite ($Al_2Si_4O_{10}(OH)_2 \cdot xH_2O$)

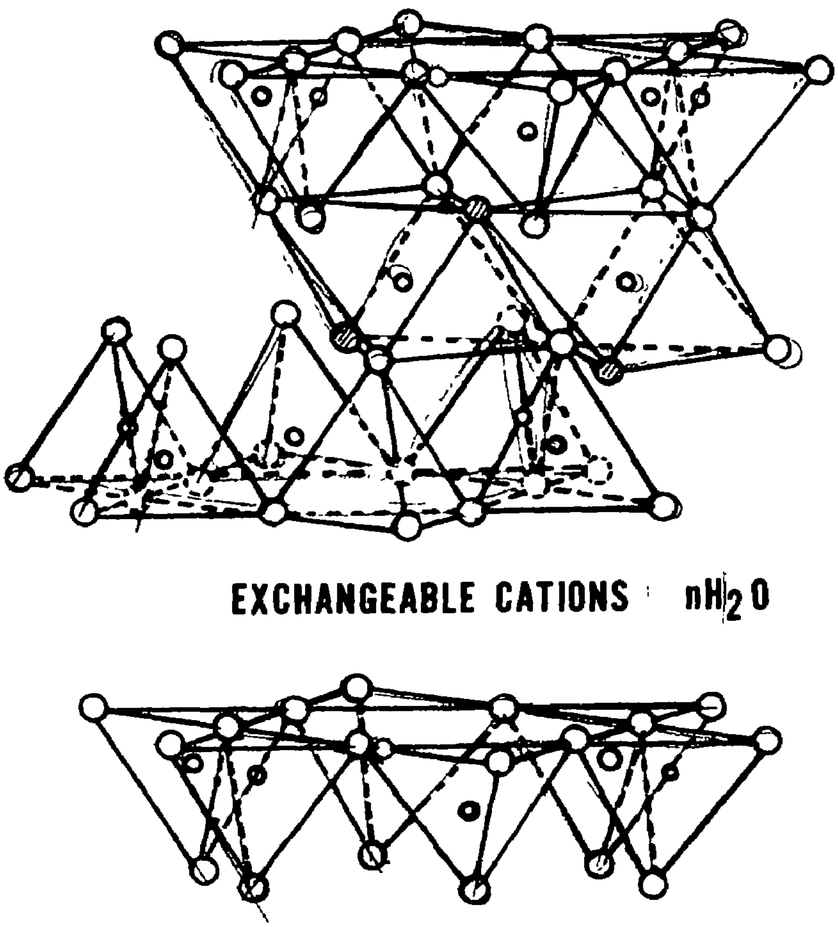
muscovite ($KAl_2\ (Al, Si)_3O_{10}(OH)_2$)

<u>trioctrahedral</u>

talc ($Mg_3Si_4O_{10}(OH)_2$)

vermiculite ($Mg_3Si_4O_{10}(OH)_2 \cdot xH_2O$

The montmorillonite structure is shown in the diagram below.



○OXYGENS ◍ HYDROXYLS ○ ALUMINUM, IRON, MAGNESIUM
○ AND ○ SILICON, OCCASIONALLY ALUMINUM

Three layer (special structure)

chlorite $(Mg_5Al(Al, Si)_3O_{10}(OH)_8$ - contains octahedral layer between 2.1 units.

illite $(K_{0-2}Al_4(Si_{8-6}Al_{0-2})O_{20}(OH)_4$ - in many cases illite is a clay containing alternate layers having a montmorillonite and a muscovite type structure.

E Important Characteristics of Certain Clay Groups

1 The two layer dioctahedral minerals are all essentially pure hydrous aluminum silicates. For example, kaolinite always has a composition approximating the ideal formula $Al_4Si_4O_{10}(OH)_8$.

2 The three layer clays show extensive isomorphous substitution and almost never have a composition near the ideal formula. These clays often have less than 2/3 of the possible interlayer cation population and thus exhibit variable basal spacings. The common substitution in the tetrahedral sheets of montmorillonite is Al^{3+} for Si^{4+}, the amount of substitution being limited to about 15%. In the octahedral sheets a much greater variety of substitution is possible; the common substitutions being Mg^{2+} and Fe^{3+}, and the rarer ones are Zn^{2+}, Ni^{2+}, and other transition metals. A more realistic formula for montmorillonite is $(Al, Mg, Fe)_4(Si,Al)_8O_{20} \cdot xH_2O$. The substitution of Al^{3+} for Si^{4+} or of Mg^{2+} for Al^{3+} leaves a deficiency of positive charge in the montmorillonite units. The net negative charge is compensated for in various ways including: 1) replacement of $O^=$ by OH^-, 2) by introduction of excess cations into the octahedral layer (Al in the ideal structure fills only 2/3 of the available positions), and 3) by adsorption of cations onto surfaces and in interlayer positions.

II SEDIMENT, SOURCE, AND ORIGIN

A The type, composition, and reactivity of sediment transported to estuaries by rivers is dependent on the nature of chemical and physical weathering processes in individual watersheds. The primary inorganic phases in river sediments which are thought to participate extensively in mineral-water reactions are the clay minerals, ferromanganese oxides, and x-ray amorphous aluminosilicate material. To establish models which can predict the capacity of mineral buffer systems in river and estuarine environments two questions must be considered. What is the mineral composition and concentration in the aqueous system and how stable is the composition of the system?

B The investigations of Kennedy (1965), Griffin (1962), Nelson (1960), Neiheisel and Weaver (1967) provide a good survey of clay mineral abundances in watersheds from most areas of the United States. Illite is the dominant clay mineral with smaller amounts of kaolinite, vermiculite, and aluminum-interlayer clay minerals in streams and estuaries of the eastern United States. Illite, Kaolinite, vermiculite, montmorillonite, and chlorite are observed in central Atlantic coast estuaries. In the southeastern United States kaolinite is the dominant clay mineral in most rivers with lesser amounts of montmorillonite. The clays in the central and west-central part of the country consist mainly of montmorillonite, vermiculite and mixed layer clays. The mineralogy of west coast streams and estuaries has not been extensively investigated but is reported to be extremely variable as a result of the great range in weathering environments (Kennedy, 1965).

C Regional variations in clay mineral composition are related to variations in parameters which control clay mineral formation such as climate, parent rock type, topography, vegetation, and the age of the soil mantle. An excellent study by Barshad (1966) quantitatively demonstrated the importance of precipitation rate and parent rock type on clay mineral genesis. In considering long term water quality controls it should be kept in mind that most soils are disequilibrium mineral assemblages and an evolution in water and clay mineral composition of any watershed can be expected as weathering continues. A comparison of water composition and soil mineralogy to theoretical mineral-water equilibrium diagrams enabled Harriss and Adams (1966) to establish the equilibrium status of soils in several watersheds of the southeastern and central United States.

D If natural sediments are to be utilized in water quality control planning for estuaries then variations in composition and concentration of the reactive minerals must be considered. Weaver (1967) demonstrated large variability in the suspended clay suites of the Arkansas River over a two year period. The composition of the clay mineral suite was related to the storm pattern in the watershed.

III MINERAL-WATER REACTIONS IN ESTUARIES

A The following paragraphs will consider the general characteristics of ion exchange and sorption-desorption reactions in estuaries and the role of mineral water reactions on the regulation of certain cations in sea water.

B Ion Exchange Reactions

1 Experimental studies by Weaver (1958), Potts (1959), Powers (1959), and Carroll and Starkey (1960) indicate that during the transfer of clay minerals from river to sea water the minerals attempt to adjust to changes in solution composition. Exchangeable calcium is partially released to sea water primarily in exchange for magnesium and amounts of sodium and potassium. The changes in exchangeable cations as a result of treating sediment from the Neuse River, North Carolina, in sea water for six months are presented in Table 1.

These results are similar to those obtained by Potts (1959) with Missouri River sediment treated with sea water for 86 hours. The kinetics of these ion exchange reactions appear to be rapid with an apparent equilibrium reached in less than 86 hours. The exact compositional changes in the exchange sites on the clays will be dependent on the mineralogy of the sediment as discussed in the above references. Keller (1964) has demonstrated that the changes observed in exchangeable cations on treatment of river clays to sea water are in qualitative agreement with thermodynamic calculations.

Muller (1964), Porrenga (1967), McCrone (1967), and Ragland et al., (1970) have measured exchangeable cations on natural fresh water, estuarine, and marine clays and found, in agreement with the experimental studies, up to 50 percent increase in exchangeable magnesium and smaller increases in sodium and potassium on marine clays compared to fresh water clays.

2 The total exchange capacity of sediment mineralogy and the amount and chemical characteristics of any organic matter present. McCrone (1957) determined exchange capacities of 30-40 milliequivalents per 100 grams sediment in the Hudson River estuary. In Hudson Estuary sediment approximately 75 percent of the exchange sites are occupied by hydrogen ions rather than magnesium or sodium ions. McCrone suggests that organic coatings inhibit exchange reactions on clays. In contrast to the Hudson Estuary results, Ragland et al., (1970) found that the ratio of exchangeable sodium in Pamlico Sound sediment to dissolved sodium in coexisting interstitial water followed a Nernst distribution up to a salinity of approximately 12 parts per thousand. The exchange sites of Pamlico Sound sediment, which consists of kaolinite, illite, chlorite, mixed layer clays, and minor amounts

of montmorillonite, are saturated at this salinity and will not act as an effective alkali or alkaline earth buffer at higher salinities.

C Sorption-Desorption Reactions

1 Hundreds of analyses of fresh water, estuarine, and marine sediments have been obtained, primarily in attempts to discover empirical relationships between elemental concentrations in sediments and the salinity of the coexisting water (Degans et al., 1957, 1958; Keith and Degans, 1959, Potter, et al., 1963, Nota and Loring, 1964, Shimp et al., 1968.) These studies indicate that B, Cr, Cu, Ga, Ni, V, Li, F and S are higher in marine than fresh water sediments. The mechanisms for enrichment of these trace elements in marine sediments not known. Turekian and Scott (1967) have demonstrated for Cr, Ag, Mo, Ni, Co, and Mn that the concentration of these elements in suspended sediment is independent of their concentration in coexisting river water indicating disequilibrium.

2 Laboratory studies by Carritt and Goodgal (1954), Bien et al., (1958), Fleet (1965), Pomeroy et al., (1965, Lerman (1966), Karkar et al., (1968), and Mackenzie et al., (1967), indicate that detrital clays can take up and release numerous constituents in the marine environment including P, Si, B, Co, Ag, and Se.

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This outline was prepared by Dr. Robert Harriss, Assistant Professor, Department of Oceanography, Florida State University, Tallahassee, FL.

STABLE CARBON ISOTOPE RATIO VARIATIONS AS INDICATORS OF POLLUTION*

I Stable isotope ratio variations for several of the light elements have provided insight into many natural geochemical processes. These variations can also serve as indicators of man's activity in cases where the natural stable isotope ratios have been shifted by significant addition or removal of material with different and characteristic stable isotope ratios. This effect has so far been demonstrated only for stable carbon isotopes However, the prospects of detecting very subtle changes in geochemical reservoirs of major biologically active elements by this technique appear promising.

A Background

1 The major elements which show non-radiogenic isotope ratio variations in nature along with their stable isotope abundances are shown in Table 1. If there were no isotope effects in physical and chemical processes all natural materials would have these exact isotopic abundances. Isotopes effects do occur so the exact isotope ratio of a given sample for these elements will depend on the chemical and physical history of the sample.

2 Two types of chemical isotope effects operate in natural systems, the equilibrium isotope effect and the kinetic isotope effect. The chemical basis of the equilibrium isotope effect is well understood (Urey, 1947). Isotope equilibrium constants may be calculated provided the necessary spectral data is available (Bigeleisen and Mayer, 1947, Bigeleisen, 1958). In exchange reactions which have an equilibrium isotope effect the heavy isotope concentrates in one of the chemical species because the chemical properties of each isotopic species are slightly different. As an example, consider the exchange between carbon dioxide and bio-carbonate at equilibrium.

$$C^{13}O_2(g) + HC^{12}O_3^-(aq) = C^{12}O_2(g) + HC^{13}O_3^-\ (aq) \qquad (1)$$

The equilibrium constant for this reaction is

$$K = \frac{(HC^{13}O_3/HC^{12}O_3)}{(C^{13}O_2/C^{12}O_2)}$$

where the concentrations are the same as abundance ratios. In this case if there were no isotope effect K would be one. The reference already given forms the basis for the calculation of this type of equilibrium constant. In practice it is usually more useful to measure equilibrium constants than to calculate them. The isotope equilibrium constant for reaction (1) has been measured by several workers (Hoering, 1960, Vogel, 1961, Deuser and Degens, 1967, Wendt, 1968). The experimental quantity is the fractionation factor, α. The equilibrium constant is readily derived from α.

For reaction 1,

$$\alpha = \frac{(C^{13}/C^{12})HCO_3^-}{(C^{13}/C^{12})CO_2}$$

and

$$\alpha = K, \text{ but in general}$$

$$\alpha = K^{1/n} \qquad (2)$$

where n is the number of equivalent exchangeable atoms under consideration. K and hence α is dependent on

*Much of this discussion is taken directly from Parker (1970).

temperature but not on the conditions of the reaction or its mechanism.

Table 1

PERCENT ISOTOPIC ABUNDANCES FOR BIOLOGICALLY ACTIVE ELEMENTS*

Carbon		Oxygen	
12	98.893	16	99.759
13	1.017	17	0.0374
		18	0.2039
Nitrogen		Sulfur	
14	99.634	32	95 0
15	0.366	33	0.760
		34	4.22
		36	0.014

*G. Friedlander, J.W. Kennedy and J.M. Miller, Nuclear and Radiochemistry. 2nd ed. Wiley, N.Y. 1964.

3 Data in the field of isotope geochemistry is expressed in terms of δ (del), the per mil (parts per thousand) difference between the isotope ratio of the sample and a standard material. While this terminology may seem awkward at first, its merits soon become obvious. Del is the quantity that most isotope ratio mass spectrometers yield. Del is all that is required to relate calculated equilibrium constants and experimentally determined fractionation factors. Del-C^{13} is defined as

$$\delta C^{13} = \frac{(C^{13}/C^{12})\ \text{sample} - (C^{13}/C^{12})\ \text{std}}{(C^{13}/C^{12})\ \text{std.}} \times 1000 \qquad (3)$$

Similar definitions can be written for isotope pairs of other elements. Isotope reference standards are available from the National Bureau of Standards. NBS20 is the carbon standard used in this chapter. Based on this definition stable isotope ratio variations will be expressed as small positive and negative numbers. A negative δ means the sample is enriched in the light isotope relative to the standard while a positive δ means the sample is likewise depleted in the light isotope. Modern isotope ratio mass spectrometers will measure δ to within $\pm$ 0.1 to 0.5 per mil on a routine basis.

4 As a result of the equilibrium isotope effect in reaction (1), atmospheric CO_2 is about 7 per mil enriched in C^{12} relative to the bicarbonate of sea water. This is illustrated in Figure 1 where atmospheric CO_2 (g) is -7 and sea water bicarbonate is near zero. The small amount of CO_2 (g) dissolved in sea water, and the large amount in fresh water, will remain at -7 per mil so long as it is in isotopic equilibrium with atmospheric CO_2. These two reservoirs constitute the two major biologically active reservoirs of inorganic carbon. It will be seen later that the activities of man have changed the C^{13}/C^{12} ratio, i.e. δC^{13}, of both these reservoirs in some environments.

5 The kinetic isotope effect is the second type of chemical process which brings about variations in δ values in natural systems. Kinetic isotope effects, being mechanism dependent, are not as readily calculated as equilibrium isotope effects. Organic chemists have studied reaction mechanisms by comparing measured and calculated isotope effects (Bigeleisen and Wolfsberg, 1958).

Kinetic isotope effects are the result of competitive isotope reaction of the general type

$$\begin{aligned} A_1 + B &\xrightarrow{k_1} P_1 \\ A_2 + B &\xrightarrow{k_2} P_2 \end{aligned} \qquad (4)$$

where the subscripts 1 and 2 refer to the light and heavy isotopic species. A and B are the reactants and P the product. Due to the kinetic isotope effect the molecule with the light isotope generally reacts significantly

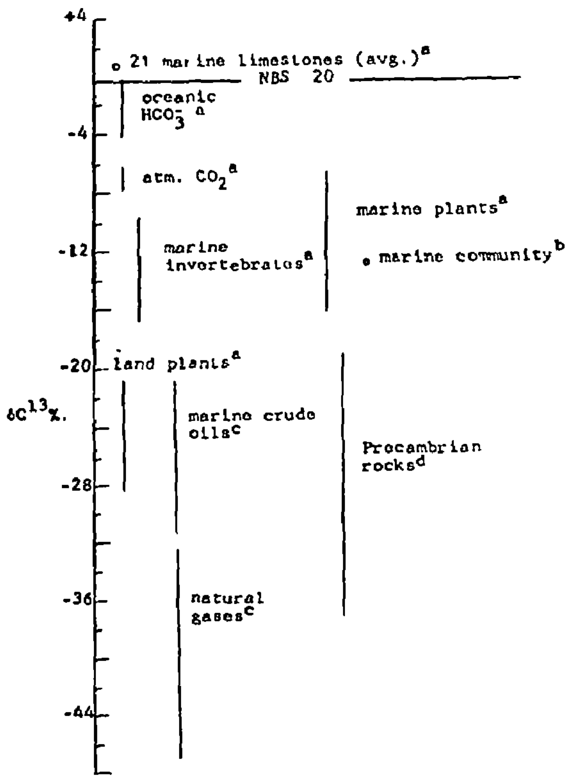

Figure 1

faster than the heavy one. In this case the isotope effect is given by the ratio of rate constants, k_1/k_2. If the reservoir of A is large enough to not become depleted, the fractionation factor, α is

$$\alpha = \frac{(\text{heavy/light})\ P}{(\text{heavy/light})\ A} \qquad (5)$$

If the product (P) is taken as the sample and the reactant (A) as the standard in (3) then

$$\alpha = 1 + \frac{\text{sample}}{1000}$$

Kinetic isotope effects in biological cycles are responsible for most of the isotope ratio variations observed for the elements carbon, nitrogen, sulfur and for the δO^{18} of atmospheric O_2. A very excellent review of stable isotope chemistry and geochemistry as well as a discussion of experimental techniques are given in a recent publication by McMullen and Thode (1963).

The overall results of the equilibrium and kinetic isotope effects in the various chemical reactions of carbon, which constitute the carbon cycle in nature, are shown in Figure 1. Natural carbon has been separated into a series of reservoirs each with a more or less characteristic isotope ratio.

B Stable Isotope Ratios as Indicators

Del-C^{13} of atmospheric CO_2 has been shown to be almost constant with regard to time and location (Keeling, 1961). This is not the case for aquatic inorganic carbon (IOC). IOC is the total CO_2 that can be released by an excess of acid. Del-C^{13} of IOC in fresh water at pH 7 is present as CO_2 (aq) it should have the same δC^{13} as atmospheric CO_2, -7. The values for estuaries then will vary depending on the mixture of fresh and marine waters. Fresh water IOC - δC^{13} values as negative as -8 and -9 have been reported (Sackett and Moore, 1966). They are more negative than -7 due to the contribution of CO_2 derived from the oxidation of organic matter. If normal marine waters with IOC - δC^{13} values near zero or even normal fresh waters with IOC - C^{13} values of -7 to -9 receive large amounts of IOC derived from organic carbon as a result of man's activity the IOC - δC^{13} of the normal system will be shifted. This is especially so for the marine system.

Reimers (1968) studied the δC^{13} values of various chemical fractions of the effluents of sewage treatment plants The effluent IOC - δC^{13} range was -9.3 to -13.9. The average value was -11.2. The marine bay, Corpus Christi Bay, which received these effluents had an IOC -δC^{13} range from + 0.3 to - 4.7 per mil with - 2.0 being the average over a five month period. The open Gulf of Mexico has IOC - δC^{13} values of ± 0.5. The negative values of the Bay are the result of the sewage effluent and the input of normal river IOC The pH of the bay was always 8 so that bicarbonate would be the chief molecular form of inorganic carbon. It is clear that even in this shallow bay the IOC is not in isotopic equilibrium with the atmospheric CO_2. Exchange is not as fast as input. At equilibrium, reaction (1) would generate IOC with a δC^{13} close to zero. In cases where large amounts of sewage effluent are being put directly into marine waters, as in offshore California, the IOC - δC^{13} may well serve as an indicator of man's activity If the effluent is introduced well below the air-sea boundary, so that atmospheric exchange is eliminated, then the IOC - δC^{13} may serve as a tracer of the water mass receiving the effluent.

Petroleum and natural gas have the most negative δC^{13} values of any of the major geochemical reservoirs of carbon (Figure 1). Calder and Parker (1968) demonstrated that petrochemicals derived from petroleum and natural gas retain this negative δC^{13} They found that fourteen petrochemicals taken from a plant had an average δC^{13} of -27.2 while the dissolved organic carbon (DOC) in the effluent from the same plant ranged between -25.7 and -39 3 The same relationships hold for refinery effluents because crude oil is almost as negative as petrochemical carbon. Most of the 128 crude oils reported by Eckelman et al. (1962) had δC^{13} values between -26 and -29 with a good many in the -30 to -33 range

Normal marine organic carbon has the most positive δC^{13} value of the organic reservoirs. Therefore the aquatic system consisting of a marine bay receiving effluents from oil refineries and petrochemical plants is an ideal case to demonstrate the use of stable isotope ratio variations as indicators of man's activity. Calder and Parker found that the organic carbon in the Houston Ship Channel shows the predicted relationships

The δC^{13} of the organic carbon for the Houston Ship Channel is shown in Table 2. The average DOC -δC^{13} was -30.5 This contrasts with a value of -20 for DOC -δC^{13} of normal marine water found by these authors, and -22 found for Pacific Ocean water (Williams, 1968). When normal and pollutant carbon are mixed, as in the Ship Channel, the δC^{13} of the mixture is given by the expression:

$$\delta_m = \frac{C_n \delta_n + C_p \delta_p}{C_n + C_p} \qquad (6)$$

where C = concentration of carbon mg per liter

$$\delta = \delta C^{13}$$

and n refers to normal carbon, p to pollutant carbon, and m to the mixture. Still following Calder and Parker the ratio of the amount of pollutant carbon to normal carbon in the mixture is given by·

$$\frac{C_p}{C_n} = \frac{\delta_n - \delta_m}{\delta_m - \delta_p}$$

Trial values put into equation (6) indicated that between 50 to 85 percent of the carbon atoms in the Houston Ship Channel are derived from petrochemical pollution.

Much more research needs to be done on this approach. It would be very important to establish base line data for DOC - δC^{13} for a number of our major rivers, estuaries and near shore marine waters. As man continues to use the marine environment it may well be that the DOC - δC^{13} and IOC - δC^{13} values will gradually shift, if indeed they have not already done so.

Table 2

DEL-C^{13} AND CONCENTRATION OF DISSOLVED AND PARTICULATE ORGANIC CARBON IN THE HOUSTON SHIP CHANNEL*

	DOC		POC	
Station	mg C/liter	C^{13}	mg C/liter	C^{13}
1	5.8	-26	20	-19.8
2	5.6	-31.2	4.2	-21.3
3	3.9	-31.5	3.2	-24.2
4	4.0	-29.3	2.6	-23.1
5	9.0	-30.1	19	-26.3
6	26	-26.9	12	-24.4
7	3.1	--	4.0	-23.3
8	11	-48.8	8.8	-27.4
9	3.8	-29	2.4	-24.7
10	8.4	-27.1	3.8	-25.9
11	6.0	-27.5	2.9	-24
12	4.1	-28.2	3.6	-25.2
13	2.7	-28.2	4.0	-26
14	19	-32	16	-25.8
15	2.9	--	2.2	-23.0
16	1.4	-24.8	2.7	-23.3
17	2.1	-24.9	4.4	-21.1

*Calder and Parker (1968)

Reimers (1968) studied DOC - δC^{13} of sewage plant effluents However it appears that this ratio is not characteristic enough to be useful as a tracer. The potential use of IOC - δC^{13} of sewage effluents has already been pointed out. We have done a preliminary study of paper mill effluent DOC - δC^{13} values which suggest that this may be a useful parameter for these systems (Table 3). It was found that the tall oil fraction of the plant studied has a δC^{13} of -27. DOC - δC^{13} of the plant effluent was -27.4. This plant did not recover its tall oil. A marine bay receiving substantial quantities of this type of effluent would have its DOC - δC^{13} shifted. The same effect might be observed on a river by comparing data taken up-stream and downstream from a papermill.

Friedman and Irsa (1967) have shown that air rich in automobile exhaust can show an 8 per mil enrichment in C^{12} for carbon dioxide. Again this shift toward a more negative δC^{13} is due to the introduction of carbon dioxide derived from petro-chemical products.

Table 3

DEL C^{13} VALUES FROM A PAPER MILL*

Fraction	Hardwood		Pine
Chips	- 24.5		- 24.8
Black Liquor	- 25.2		- 24.9
Bleached Cellulose	- 23.4		- 23.0
Lime Mud		- 23.4	
Tall Oil		- 27.0	
Effluent		- 27.4	

*Calder, 1969

The δC^{13} method gives no information about the chemical structures of organic pollution or its toxic properties. Its greatest usefulness is that it gives insight into the over-all carbon flux of very large systems from relatively few and simple measurements. It is a subtle indicator of man's impact on nature.

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I INTRODUCTION

A The Biological Nature of the World We Live In

1 We can only imagine what this world must have been like before there was life.

2 The world as we know it is largely shaped by the forces of life.

a We (man, a living organism) cultivate the lands and waters and manage the plants and animals.

b Plants cover the lands and enormously influence the forces of erosion.

c The nature and rate of erosion affect the redistribution of materials (and mass) on the surface of the earth (topographic changes).

d Organisms tie up vast quantities of certain chemicals, such as carbon and oxygen.

e Respiration of plants and animals releases carbon dioxide to the atmosphere in influential quantities.

f CO_2 affects the heat transmission of the atmosphere.

g The interrelationships between the total heat budget of the earth and such phenomena as oceanic circulation patterns, long term climatic cycles, and weather, are far from understood.

3 If we are to manage our environment, we must understand the nature of all factors affecting it.

B Many kingdoms or basic patterns of life may be discerned in nature, each contributing to the final synthesis. Since the organisms of any one place can only be understood in their relationships to all organisms, much of the following sections will be very general.

II THE GENERAL RELATIONSHIPS OF LIVING ORGANISMS

A Living organisms have been long grouped into two kingdoms Plant and Animal. Modern developments, however, have made this simple pattern technically untenable. It has become evident that there are as great and fundamental differences between certain other groups and these (two), as there are between traditional "plant" and "animal." The accompanying chart (Figure 1) consequently shows the fungi as a third "kingdom."

B The three groups are essentially defined as follows on the basis of of their nutritional mechanisms.

1 Plantae. photosynthetic, synthetizing their own organic substance from inorganic minerals. Ecologically known as PRODUCERS.

2 Animalia ingest and digest solid particles of organic food material. Ecologically known as CONSUMERS.

3 Fungi: extracellular digestion (enzymes secreted externally). Food material then taken in through cell membrane where it is metabolized and reduced to the mineral condition. Ecologically known as REDUCERS.

C Each of these groups includes simple, single celled representatives, persisting at lower levels on the evolutionary stems of the higher organisms (as well as the higher and more complex types).

1 These groups span the gaps between the higher kingdoms with a multitude of

RELATIONSHIPS BETWEEN FREE LIVING AQUATIC ORGANISMS

Energy Flows from Left to Right, General Evolutionary Sequence is Upward

PRODUCERS	CONSUMERS		REDUCERS
Organic Material Produced, Usually by Photosynthesis	Organic Material Ingested or Consumed Digested Internally		Organic Material Reduced by Extracellular Digestion and Intracellular Metabolism to Mineral Condition
ENERGY STORED	ENERGY RELEASED		ENERGY RELEASED
Flowering Plants and Gymnosperms	Arachnids	Mammals	Basidiomycetes
	Insects	Birds	
Club Mosses, Ferns	Crustaceans	Reptiles	
	Segmented Worms	Amphibians	
Liverworts, Mosses	Molluscs	Fishes	Fungi Imperfecti
Multicellular Green Algae	Bryozoa	Primitive Chordates	
	Rotifers		
	Roundworms	Echinoderms	Ascomycetes
Red Algae	Flatworms		
	Coelenterates		Higher Phycomycetes
Brown Algae	Sponges		

DEVELOPMENT OF MULTICELLULAR OR COENOCYTIC STRUCTURE

H I G H E R   P R O T I S T A

	Protozoa		
Unicellular Green Algae	Amoeboid	Ciliated	Lower Phycomycetes (Chytridiales, et al.)
Diatoms	Flagellated, (non-pigmented)	Suctoria	
Pigmented Flagellates			

DEVELOPMENT OF A NUCLEAR MEMBRANE

L O W E R   P R O T I S T A

(or Monera)

Blue Green Algae	Actinomycetes
Phototropic Bacteria	Spirochaetes
Chemotropic Bacteria	Saprophytic Bacterial Types

FIGURE 1

BI ECO pl 2a 1.69

transitional form. They are collectively called the PROTISTA.

2 Within the Protista, two principle subgroups can be defined on the basis of relative complexity of structure:

a The bacteria and blue-green algae, lacking a nuclear membrane may be considered as the lower protista (or Monera).

b The single celled algae and protozoa are best referred to as the higher protista.

D Distributed throughout these groups will be found the traditional "phyla" of classic biology.

III PLANTS

Having chlorophyll, these organisms produce organic matter by photosynthesis.

A The vascular plants are usually larger and possess roots, stems and leaves.

1 Some types emerge above the surface.

2 Submerge types typically do not extend to the surface.

3 The most familiar marine representatives of this group are the eel grases (Zostera, Phyllospadix).

B Algae

1 Algae in general may be defined as small plant-like organisms or relatively simple structure. Actually the size range is extreme: from only a few microns to over three hundred feet in length. Commonly observed examples include the greenish pond scum or frog spittle of freshwater ponds, much of the golden brown slime covering rocks in a trout stream, and the great marine kelps and seaweeds. Such freshwater forms as Nitella and Chara or stonewort are also included.

2 Algae approach ubiquity in distribution In addition to their presence in commonly observed bodies of water, certain algae also live in such unlikely places as thermal springs, the surface of melting snow, on the hair of the three toed sloth in Central America, and in conjunction with certain fungi to form lichens.

3 Marine and estuarine algae may be arranged in six groups, four scientific categories named below, and two loose groupings of similar types.

a Blue-green algae or Cyanophyceae. These are typically small and lack an organized nucleus, pigments are dissolved in cell sap. Structure very simple. Often found in polluted waters.

b Diatoms or Bacillariophyceae. These have pillbox like structure of SiO_2 - may move. Extremely common. Many minute in size, colonial forms may produce hairlike filaments. Golden brown in color.

c Brown algae or Phaeophyceae. This is a predominantly marine group and includes the giant kelps and rockweeds.

d Red algae or Rhodophyceae. This group is almost exclusively marine. Many delicately structured and many deep water forms included.

e The "pigmented flagellates" include representatives of several scientific categories all are motile by virtue of possessing one or more flagellae. The marine organisms causing red tides and paralytic shellfish poisoning (Dinoflagellates) are included in this group.

f "Nonmotile green algae" have no locomotor structure or ability in mature condition. Like the pigmented flagellates, this is an artificial grouping.

1) Unicellular representatives may be extremely small.

2) Multicellular forms may produce great floating mats of material.

3) The "sea lettuce" of rich estuarine water is a familiar example.

IV FUNGI

Lack chlorophyll and consequently most are dependent on other organisms. They secrete extracellular enzymes and reduce complex organic material to simple compounds which they can absorb directly through the cell wall.

A Schizomycetes or bacteria are typically very small and do not have an organized nucleus.

1 Autotropic bacteria are atypical in that they can synthetize basic food materials from inorganic substrates. They may be photosynthetic or chemosynthetic.

2 Heterotropic bacteria are most common. They require the presence of organic material on which to feed.

B "True fungi" usually exhibit hyphae as the basic of structure.

V ANIMALS

A Lack chlorophyll and consequently feed on or consume other organisms. Typically ingest and digest their food.

B The Animal Phyla

1 PROTOZOA are single celled organisms; many resembling algae but lacking chlorophyll (cf: illustration in "Oxygen" lecture).

2 PORIFERA are the sponges, both marine and fresh water representatives.

3 COELENTERATA include corals, marine and fresh water jelly fishes, and the fresh water hydra.

4 PLATYHELMINTHES are the flat worms such as tape worms, flukes and Planaria. Some important human parasites are included.

5 NEMATHELMINTHES are the round worms and include both free-living forms and many dangerous parasites.

6 ROTIFERS are multicellular microscopic predators.

7 BRYOZOA are small colonial sessile forms, marine or fresh water.

8 MOLLUSCA include snails and slugs, clams, mussels and oysters, squids and octopi.

9 BRACHIPODS are bivalved marine organisms usually observed as fossils.

10 ANNELIDS are the segmented worms such as earthworms, sludge worms and many marine species.

11 ECHINODERMS include starfish, sea urchins and brittle stars. They are exclusively marine.

12 CTENOPHORES, or comb jellies, are delicate jelly-like marine organisms.

13 ARTHROPODA the largest of all animal phyla. They have jointed appendages and a chitinous exoskelton.

a CRUSTACEA are divided into a cephalathorax and abdomen, and have many pairs of appendages.

1) CLADOCERA include Daphnia, a common fresh water microcrustacean, swim by means of branched antennae.
2) PHYLLOPODS are the fairy shrimps, given to eruptive appearances in temporary pools.
3) COPEPODES include both marine and fresh water microcrustacea--swim by means of unbranched antennae.
4) OSTRACODS are like microscopic "clams with legs." Generally bottom livers.

5) ISOPODES are dorsoventrally compressed, called sowbugs. Terrestrial and aquatic marine and fresh water.
6) AMPHIPODA - known as scuds, laterally compressed. Marine and fresh water.
7) DECAPODA - crabs, shrimp, crayfish, lobsters, etc. Marine and fresh water.

b INSECTA - body divided into head, thorax and abdomen, 3 pairs of legs, adults typically with 2 pairs of wings. Only one rare marine species. Nine of the twenty odd orders include species with fresh-water-inhabiting stages in their life history as follows.

1) DIPTERA - 2 winged flies
2) COLEOPTERA - beetles
3) EPHEMEROPTERA - mayflies
4) TRICHOPTERA - caddis flies
5) PLECOPTERA - stone flies
6) ODONATA - dragon flies and damsel flies
7) NEUROPTERA - alder flies, Dobson flies and fish flies
8) HEMIPTERA - true bugs, sucking insects such as water striders, electric light bugs and water boatman
9) LEPIDOPTERA - butterflies and moths

c ARACHINDA - body divided into cephalothorax and abdomen, 4 pairs of legs - spiders, scorpions, ticks and mites. Few aquatic representatives except for the fresh water mites and tardigrades.

C CHORDATA

1 PROCHORDATES - primitive marine forms such as acorn worms, sea squirts and lancelets.

2 VERTEBRATES - all animals which have a backbone.

a PISCES or fishes, including such forms as sharks and rays, lampreys, and higher fishes, both marine and fresh water.

b AMPHIBIA - frogs, toads and salamanders - marine species rare.

c REPTILA - snakes, lizards and turtles.

d MAMMALS - whales and other warm-blooded vertebrates with hair.

e AVES - birds - warmblooded vertebrates with feathers.

VI THE CLASSIFICATION OF ORGANISMS

A There are few major groups of organisms that are either exclusively terrestrial or exclusively aquatic. The following remarks will therefore apply in large measure to both, but primary attention will be directed to aquatic types.

B One of the first questions usually posed about an organism seen for the first time is "What is it?" usually meaning "What is its name?" The naming or classification of biological organisms is a science in itself (taxonomy). Some of the principles involved need to be understood by anyone working with organisms however.

1 Names are the "key number," "code designation," or "file references" which we must have to find information about an unknown organism.

2 Why are they so long and why must they be in Latin and Greek? File references in large systems have to be long in order to designate the many divisions and subdivisions. There are over a million and a half items (or species) included in the system of biological nomenclature (very few libraries have as many as a million books to classify).

3 The system of biological nomenclature is regulated by international congresses.

a It is based on a system of groups and super groups, of which the foundation (which actually exists in nature) is the species. Everything else has been devised by man and is subject to change and revision as man's knowledge and understanding increase.

b The categories employed are as follows

The species is the foundation.

Similar species are grouped into genera (singular: genus)

Similar genera are grouped into families

Similar families are grouped into orders

Similar orders are grouped into classes

Similar classes are grouped into phyla (phylum)

Similar phyla are grouped into kingdoms

Other categories such as subspecies, variety strain, division, tribe, etc. are employed in special circumstances.

4 The scientific name of an organism is its genus name plus its species name. This is analogous to our system of surnames (family names) and given names (Christian names).

a The generic (genus) name is always capitalized and the species name written with a small letter. They should also be underlined or printed in italics when used in a technical sense. For example:

Homo sapiens - modern man

Homo neanderthalis - neanderthal man

Esox niger - chain pickerel

Esox lucius - northern pike

Esox masquinongy - muskellunge

b Common names do not exist for most of the smaller and less familiar organisms. For example, if we wish to refer to members of the genus Anabaena (an alga), we must simply use the generic name, and·

Anabaena plactonica,

Anabaena constricta, and

Anabaena flos-aquae

are three distinct species which have different significances to water treatment plant operations.

5 A complete word list of the various categories to which an organism belong to known as its "classification." This may be written as follows for Phacus pyrum a green flagellate, for example:

Kingdom Plantae

Phylum Euglenophyta

Class Euglenophyceae

Order Euglenales

Family Euglenaceae

Genus Phacus

Species Pyrum

a It should be reemphasized that since all categories above species are essentially human concepts, there is often divergence of opinion in regard to how certain organisms should be grouped. Changes result.

b The most appropriate or correct name for a given species is also sometimes disputed, and so species names too are changed. The species itself, as an entity in nature, however, is relatively timeless and so does not change to man's eye.

VII ECOLOGICAL DISTRIBUTION OF ORGANISMS

A Aquatic organisms are distributed around the world as, essentially, marine, or freshwater inhabitants.

B The greatest variety and abundance of animal life is in the oceans and coastal waters, while plants are most diverse on land.

C In the estuaries, marine and freshwater organisms meet and mingle.

D Salinity is the most important single factor determining the distribution of organisms in estuaries (Figure 2).

1 Organisms which are restricted to a narrow range of salinity (either freshwater or saltwater) are called stenohaline.

2 Organisms tolerant of a range of salinities are called euryhaline.

3 Marine-euryhaline organisms comprise the largest group in estuaries.

4 Indigeous (native) estuarine organisms are the smallest group, often called mesohaline.

VIII COMMUNITIES OF LIFE

Major divisions of the aquatic habitat are shown in Figure 3. Some definitions and other associated terms are given below.

A Benthos: organisms living on or associated with the bottom, i. e., bottom organisms.

B Plankton organisms living dispersed in the water in the pelagial zone,

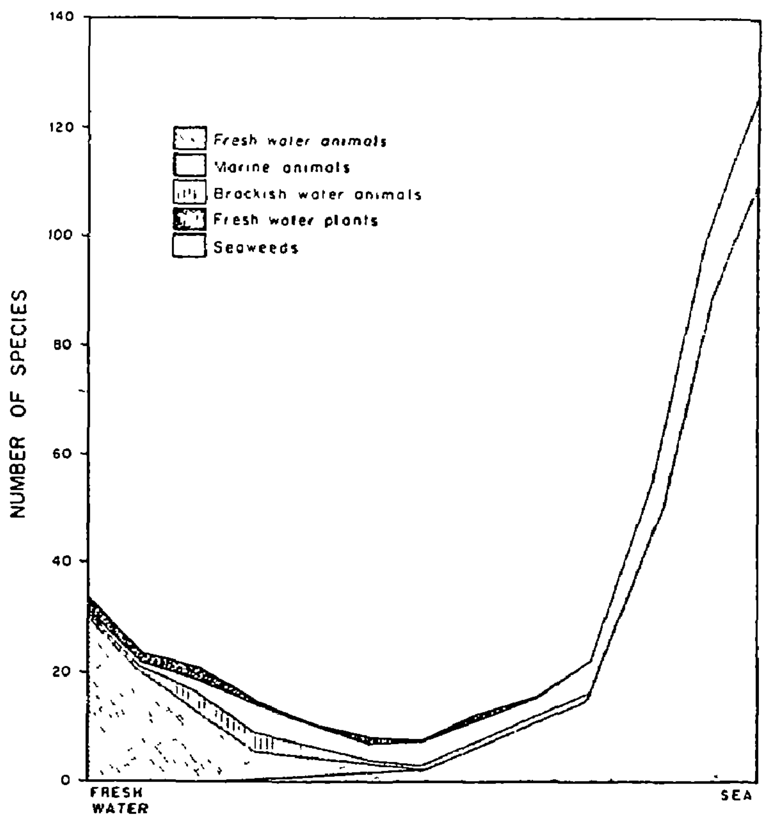
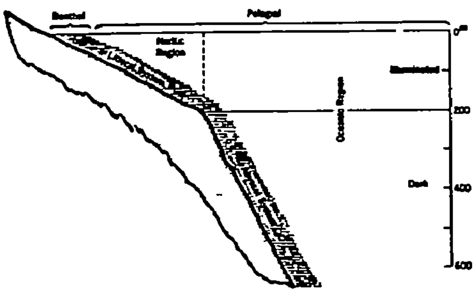


FIGURE 2. Comparative Composition of Freshwater, Mesohaline, and Marine Plants and Animals Along the Tees Estuary, England (After Macan, T T and Worthington, E B, 1951 "Life in Lakes and Rivers," *The New Naturalist Series*, Wm Collins Sons & Co Ltd, London, from Alexander, Southgate, and Bassindale.)



Primary subdivisions of the marine habitat.

Tidal zone: that portion of the littoral between the tides.

Figure 3

which are capable of little or no locomotion. Animal plankton are known as zooplankton, plants as phytoplankton.

C Nekton: active swimming forms like certain fish, prawns, cephalopods, and others. In the sea, the distinction between zooplankton and nekton is often ambiguous.

D Periphyton: The community of microscopic organisms attached to surfaces.

There is considerable interchange between these various communities, especially between plankton and periphyton.

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THE PHYSICAL AND BIOLOGICAL COMPONENTS OF THE ESTUARINE ECOSYSTEM AND THEIR ANALYSIS

I THE BIOTIC COMPONENT OF THE ESTUARINE ECOSYSTEM

A The Problem of Taxonomy

1 Necessity of identifying species

Studies of the ecology of any habitat require the identification of the organisms found in it. One cannot come up with definitive evaluations of stress on the biota of an estuary unless we can say what species constitute the biota. Species vary in their responses to the impact of the environment.

2 Solutions to the problem

a Evasion

Treat the ecosystem as a "black box" -- a unit -- while ignoring the constitution of the system. This may produce some broad generalizations and will certainly yield more questions than answers.

b Compromise

Work only with those taxonomic categories with which one has the competence to deal. Describe the biotic component as a taxocenosis limited to one or two numerically dominant taxonomic categories, bearing in mind that numerically taxa which are ignored may be very important to the ecology of the estuary.

c Comprehensive description

Attempt a comprehensive description of the biota. No one can claim competence to deal with more than one or two groups. The cooperation of experts must be obtained. The Smithsonian Institution has a clearinghouse for this sort of thing[1]. Lists of expert taxonomists can be obtained (2 a, b, c) (3). There will be none for some groups. Also collaboration is time consuming.

B Environmental Classification of Biota

1 Plankton

All motile aquatic organisms, plant or animal, whose powers of locomotion are too feeble to resist the set and drift of currents are classified as plankton.[4]

a Phytoplankton

The term phytoplankton is usually applied to acellular (unicellular) floating plants but strict adherence to the foregoing definition should include all floating cellular plants such as Sargassum.

b Zooplankton

The animal plankters are zooplankton. Some kinds of plankton organisms are equivocal in their conforming to the requirements for classification as plants or animals.

c Holoplankton

Organisms which are classified as plankton at all stages of their life cycles are called holoplankton. The term is applied both to phytoplankton and zooplankton species which conform to this definition.

holoplankters.

d Meroplankton

Planktonic reproductive stages of species which in other stages of the life cycle live on the bottom or are strong swimmers are called meroplankton. These are eggs, larvae, swarming stages, juveniles, or sexual alternates to vegetative stages of a host of marine plants and animals.

e Tychoplankton

Small, weakly motile, bottom-dwelling organisms which are accidentally swept into suspension by turbulent water motion are called tychoplankton. It is easy to see that many of the planktonic species in turbulent estuaries are likely to be tychoplankters.

2 Nekton[5]

Organisms which remain suspended in the water and whose powers of locomotion are great enough to resist the set and drift of currents are called nekton. Only three major taxonomic categories are represented in this classification--the fishes, the cephalopod molluscs (octopuses and squids) and certain crustaceans (shrimps and swimming crabs). Many of these, because of strong affinities for the bottom, may just as easily fit in the benthos (See c). Typical estuarine nekton are shown in Figure 4. Bottom dwelling or reproducing nekton species are called dermersal. Those which live and reproduce suspended in the water are called pelagic.

3 Benthos

Organism which as adults or in the sessile stages of their life-cycles, live on the bottom are called benthos, as, of course, are all whose entire life cycle is spent there. The benthos may also be subdivided

a Epiflora

Plants, cellular or acellular, macro- or micro-, which live attached to or living on the bottom are called epiflora.

b Epifauna

Animals which live on the bottom are called epifauna. Many representatives of the epifauna are permanently attached to the bottom, a phenomenon which does not occur in the terrestrial environment. Many of these are colonial, which is to say, consist of groups of individuals incompletely separated from one another, like Siamese twins. A result is the evolution of life-forms which are more like conventional plants in appearance than like animals. Other epifauna creep about on the bottom. Figure 5 shows typical epifauna and flora.

c Infauna

Animals which live buried in unconsolidated sediments or in burrows in solid substrates are called infauna. Fixed infauna are those which live in permanent burrows while burrowing infauna move about displacing sediment as they go or by creeping or swimming between the sand grains. If they progress by displacing sediment particles, they are called megafauna. If they are adapted to creeping in the interstitial spaces, they are called meiofauna. Organisms which are so small that they can float or swim in the interestitial spaces are called microfauna.

d Inflora

Macroscopic plants are uncommon on bottoms consisting of unconsolidated sediments. The big exception to this rule are the sea "grasses." Microscopic plants are abundant either fixed to sand grains or lying about on or between them. Bacteria are abundant on all bottom surfaces and in the spaces between sediment grains. A variety of mega-infauna are shown in Figure 6, while Figure 7 shows a number of meio- and micro infauna and inflora.

C Ecological Classification of the Biota

Classification of any sort is a matter of convenience to enable us to pigeon-hole items with which we deal. Ecologists have found it convenient and useful to be able to pigeon-hole aquatic organisms - particularly those of estuaries where normal environmental conditions vary greatly, both spatially and temporally--according to the tolerances of those organisms to ranges of variations in environmental properties. Thus we have, as an example, a classification of estuarine organisms based on tolerance to salinity changes

1 Salinity Tolerance[6,7]

As mentioned elsewhere salinity in a true estuary ranges from that of freshwater at the head to that of seawater at the mouth. Few organisms are tolerant of this entire range. Salinity tolerance limits are imposed by a species ability to compensate for osmotic stress imposed by variation in the salt content of its environment

a Limnetic

Limnetic species are freshwater ones characteristic of the river which empties into the head of the estuary. They can tolerate salt content up to 0.5 parts per thousand.

b Oligohaline

Oligohaline species are those derived from freshwater but which have become adapted to living in the head of the estuary where salinity ranged from 0.5 to 5 0 parts per thousand.

c True estuarine

Truly estuarine species are those which can survive in waters ranging from 5.0 to 30.0 parts salinity per thousand. These may be species whose tolerance is purely passive, which is to say, not based on resisting osmotic stress, or species which do possess mechanisms for osmo-regulation. They are species which are really typical of estuaries being unable to tolerate salinities as low as those of the head of the estuary or those of the sea itself. The oyster, Crassostrea virginica is a good example. Some prawns of the genus Palaemonetes are also truly estuarine.

d Marine euryhaline

The great majority of estuarine species are marine species tolerant of salinities ranging from 5.0‰ to those characteristic of the open sea. Passively euryhaline species are those which tolerate fluctuations in salinity without being able to actively adjust. In dilute waters they swell or lose salt, in more saline waters they shrink or passively accumulate salt. Many molluscs and worms are passively euryhaline. Actively euryhaline species are able to control the salt concentrations of their body fluids despite osmotic stress imposed by variation in environmental salinity This is characteristic of many polychaetes, most estuarine fishes, and many crabs.

e Marine stenohaline

Species adapted to living at the mouth of the estuary where salinities range from 25‰ to those of the open sea are called marine stenohaline. Most echinoderms which one finds at the mouth of estuaries are stenohaline. The gribble, a tiny crustacean which destroys dock pilings is stenohaline. Many of the common oyster's worst enemies are stenohaline.

f Mixohaline

The few species which tolerate the full range running from freshwater to the sea are called mixohaline. The blue crab, Callinectes sapidus is a notable example of this as well as all the migrants such as the sturgeons, salmon, striped bass, and river herrings which pass through the entire range on their annual reproductive journeys.

2 Temperature tolerance

In estuaries, where environmental temperatures vary much more widely than in the sea, organisms may also be classified according to temperature tolerance in the same manner. Thus we have oligothermal, eurythermal, and stenothermal species.

II ESTUARINE HABITATS

A habitat is the kind of place in which one normally expects to find a given kind of organism. It may be supposed that, because of the wide variety of assemblages of physical conditions and biotic communities, estuaries contain a number of distinct habitats which will be roughly proportional to the variety of conditions.

A Geomorphological Classification of Estuaries[8, 9]

1 Positive estuaries

Positive estuaries are those in which the influx of freshwater measurably exceeds evaporation, producing the gradient referred to in the preceding section.

a Drowned river valleys

Many of the estuaries on the East Coast of the United States fall into this category. Chesapeake Bay is our largest American East Coast drowned river valley.

b Fjords

Fjords are canyons formerly filled and carved out by mountain glaciers. They, too, are drowned by rise of sea level although their bottoms may never have been above sea level. Fjords are found on the Coasts of Norway, Greenland, British Columbia, Chile, and elsewhere.

c Bar-built estuaries

Bar-built estuaries are drowned river valleys or points of egress of freshwater to the sea which have been partly blocked off by the build-up of barrier islands or spits. The North Carolina Sounds and the Texas lagoons are examples of bar-built estuaries.

d Fault or graben produced estuaries

Where differential lowering of the land occurs along the coast in tectonically active regions, estuaries are formed. Tomales Bay north of San Francisco, which is situated in the San Andreas fault zone is such an estuary. San Francisco Bay is another. The Gulf of California and the Red Sea are similarly formed, but of these only the former could be called an estuary.

2 Neutral estuaries

Neutral estuaries are those in which evaporation more or less equals inflow of freshwater, so salinities remain essentially the same as that of the adjacent seawater. Alligator Harbor, near here, is such as estuary.

3 Negative estuaries

Negative estuaries are those in which evaporation so much exceeds fresh or seawater influx that salinities exceed those of the adjacent sea. The upper reaches of the Laguna Madre of the Texas Coast is a hypersaline lagoon or negative estuary.

B Classification of Estuarine Environments[6, 10]

Many authors have proposed subdivisions of the sea into environmental categories. These have been summarized by Hedgpeth.[10] In estuaries we have

1 Pelagic - environmental subdivisions of the water in estuaries, inhabited by plankton and nekton.

a Neritic - the water overlying the edges of the sea from a depth of about 100 fathoms to the shore. The watery environment of all estuaries except the deeper parts of some fjords and tectonically produced estuaries is neritic.

b Oceanic - seawater which is more than 100 fathoms deep in oceans by definition.

2 Benthic - environmental subdivisions of the bottom of the sea including its farthest landward influence.

a Supralittoral

This is a zone between the truly marine and the truly terrestrial (or freshwater) invaded by seawater only when storm surges push the rising tide higher than predicted. Easy to define on open coasts, it is not easily detectable on the bottoms of estuaries. The supralittoral is, however, clearly defined in the small beaches, rocky headlands and manmade structures and the salt marshes which border estuaries.

b Littoral

The littoral is the intertidal. It is the bottom which is alternately covered and exposed by the spring tides if not by the neaps. Large areas of the shores and bottoms of shallow estuaries fall in the littoral. In estuaries characterized by little turbulence, the rising tide enters the main channel as an underlying wedge of dense saltwater, pushing the lighter, freshwater up. There is therefore a very interesting but hard to detect intertidal zone which is never exposed to air.

c Sublittoral

The sublittoral, by definition, extends from the lowest low water marks to the depth of 100 fathoms. It is that portion of the estuary which is always covered by seawater. Obviously, there is also a special estuarine portion of the bottom which is covered by seawater diluted as a result of turbulent mixing with freshwater coming in from the other end.

C Estuarine Habitats[9]

1 Pelagic

Because of the salinity gradient that develops in a positive estuary characterized by reasonable mixing, there develops also a series of pelagic habitats which are more easily detected by the presence of typical organisms than by other properties.

a Head

This is the low salinity habitat of 0.5 to 5.0‰ occupied by the oligohaline species.

b Upper, middle and lower reaches

These are zones with salinities ranging from 5 to 18, 18 to 25, and 25 to 30‰. Not all truly estuarine species nor all marine euryhaline species are found throughout the entire range. Many will be restricted to, or find best growth in one of these reaches.

c Mouth

This is the zone with marine salinities ranging from 30 to 40‰, and will be inhabited by euryhaline as well as stenohaline marine species.

2 Benthic

a Supralittoral

As noted, rocks and other hard surfaces (like bulkheads, dock pilings, etc.), marshes and beaches will have a zone of transition between the truly marine and the truly terrestrial which is wet only by splash or storm surges.

b Littoral and sublittoral

1) Beaches

Beaches normally are associated with the open coast as they are dependent for their existence on wave action and longshore currents. But the shores of large estuaries may have small beaches which have the same physical and biotic properties as open coast beaches. Because of constantly shifting sand, this is a very limiting habitat for soft bodied megafauna but a safe haven for meio and microfauna.

2) Rocky intertidal

Especially in estuaries, the rocky intertidal (and other hard surfaces) will be characterized by a great diversity of organisms which occur in zones depending on their ability to withstand prolonged periods of exposure to the atmosphere.

3) Sand flats and shoals

Found in the middle and lower reaches and mouth of the estuary, sand flats and shoals which owe their existence to tidal currents without the wave action which makes beaches are habitats for a tremendous diversity of epiflora and fauna and of infauna. The greater stability of the sediment permits the existence there of rooted plants and many kinds of megafauna.

4) Mud flats

In the upper reaches and other places protected from currents and waves, mud flats develop. With a very high organic content, anaerobic conditions prevail below the top two or three millimeters except where oxygenated water is entrained by burrowing organisms. The surface is characterized by intense biological activity.

5) Oyster bars

In positive estuaries where sedimentation precludes establishment of oyster colonies in the zones of estuarine salinity, oysters can grow only near the mouth where salinity is high enough to support oyster predators. The oysters then thrive only in the intertidal and produce large reefs exposed by the falling tide.

6) Mangroves

Along the shores of tropical estuaries great thickets of mangroves provide a peculiar type of intertidal and subtidal habitat. The prop roots of the red mangrove provide substrate for many benthic species and shelter for many pelagic ones.

7) Submarine meadows

The bottoms of many estuaries are covered with extensive growths of marine "grasses" which are seagoing relatives of some of our pond weeds. They provide a habitat for a greater assemblage of species than any other marine habitat except the coral reef.

8) Mussel and barnacle beds

On firm, peaty intertidal bottoms of temperate and boreal estuaries extensive beds of the blue mussel and of barnacles form a special kind of habitat.

9) Salt marshes

On the sides and shores of the upper, middle and lower reaches of drowned river valleys and on the shores of bar built estuaries, salt marshes will be found. Dominated by a single species of grass, but inhabited by a very limited variety of animals, they vie in productivity with Iowa cornfields, nourishing not only their inhabitants but also many organisms in the adjacent lower portions of the estuaries.

10) The interstitial

The interstitial habitat is the space between the grains of sediment occupied by the meio- and micro-infauna. Dependent on turbulence for percolation of oxygenated water it has a greater diversity of organisms on and near beaches.

III THE ESTUARINE ECOSYSTEM[12]

The term ecosystem implies that not only is a particular habitat required by a particular assemblage of organisms but also that the assemblage or community modifies and to a certain extent creates the habitat. The root of the term is perhaps best defined by Watt[11] who says that, "A system is an interlocking complex of processes characterized by many reciprocal cause-effect pathways." The interactions between the biota and the physical properties and among themselves are the processes. Ecosystems vary in size. Theoretically, at least, each could flourish with an input of energy only.

A The Physical Components

1 Substrate

The substrate is that portion of the physical environment on or within which organisms live. It is the ground, the sediment, the rock or other surface. It provides purchase, food, shelter, or attachment.

2 Medium

The medium is the fluid which bathes the organisms. For us it is the atmosphere. For estuarine organisms (except when the tide is out) it is the water. It is the medium through and with which individuals exchange matter and energy.

3 Energy sources

Every ecosystem must have a primary energy source. For terrestrial ecosystems it is ultimately the sun. For small circumscribed systems on earth, the energy input comes as chemical energy. From most ecosystems most of the input energy is lost as heat in a very short time--all of it ultimately.

B The Biological Component--The Community

1 Definition

A biological community is an assemblage of interacting populations of species, all more or less dependent upon each other for their individual and collective survival.

2 Mega- and micro- communities

The biota of an entire estuary, sea, or ocean may be considered a community, just as may be the biota found on a single blade of turtle grass. The essential thing is that the assemblage is so integrated that by mutual support and dependence its constituents could survive without outside input other than energy in some form.

3 Community succession

a Spatial

Just as the gradient of water properties extends from head to mouth of the estuary, so also may be found a succession of different bottom types inhabited by distinct and recognizable assemblages of species. This is spatial succession.

b Temporal

At any one point or station in the estuary, a succession of different assemblages of species may be found with the passage of time. This is particularly true of pelagic species and epifaunal and epifloral organisms and on a seasonal basis. This is temporal succession.

IV ECOSYSTEM DYNAMICS[13, 14]

A Energy Flow and the Cycling of Matter

The essential attribute of ecosystems is change, the result of the constant cycling and recycling of matter accompanied by the degradation and one way passage of energy. Energy enters the system from without and quantitatively passes out of it, after delays ranging from fractions of seconds to millions of years. Matter keeps being recycled as a means of capturing and transferring energy. The estuarine ecosystems are not exceptions.

1 Trophic structure of the community

The biotic component is the principal and certainly the most efficient captor and utilizer of energy. It takes energy as it comes to the ecosystem, in the form of light, converts it to a usable form--the energy of chemical bonds and in so doing makes more life. Its units grow and reproduce. The energy bearing matter changes hands repeatedly. All the while greater or lesser portions of the energy are lost as heat which ultimately is radiated on out (resuming its original journey from the sun) into space as infrared radiation from the dark side of the earth. In each community there are discernible levels between which matter and energy are exchanged.

a Trophic levels

The initial trophic (processor of energy-bearing matter) level is that of the primary producer. Most of these are photosynthetic plants which make new living matter (complex chemical energy-bearing organic compounds) from nonliving matter (simple inorganic compounds) the extra energy required for this coming in the form of light.

Primary consumers are vegetarian animals which (pardon the redundancy) eat plants. They do this because they are dependent for energy entirely on that of chemical bonds, except for what energy they can pick up by sun-bathing. They cannot use light for essential life processes. This is true of all other consumers as well.

Secondary consumers are the meat eaters or carnivores which eat herbivores or other carnivores.

Decomposers are the molds and bacteria which break down organic substances into the inorganic which the primary producers used in the first place. This is not to say that the producers and consumers do not do this too, but the ultimate dissolution of organic to inorganic is performed by the decomposers.

Primary producers are also called autotrophs.

All the others are called heterotrophs, except that some people apply a special term--saprotroph--to the decomposers.

b Food chains and food webs

Because particular consumer species become adapted to consuming particular primary producers and they in turn are peculiarly esteemed as articles of diet by especial species of carnivores, there appear in communities more or less obligate interdependencies which are called food chains. Because these chains become joined by cross linkages, the trophic structure of the community takes on the appearance of a web of interactions.

2 The Eltonian pyramid and the second law

In most organisms, most of the food consumed is used up maintaining the status quo. Only a fraction appears as a growth or reproductive increment. It therefore requires a far greater gross input from any trophic level to achieve the net at the next above. This step by step reduction in realized living matter is called the Eltonian pyramid. Figure 8 shows a theoretical food web. The three Eltonian pyramids shown in Figure 9 demonstrate the different results obtained when the pyramids are erected on the basis of numbers, biomass as weight, and energy content.

B Population and Community Dynamics[15, 16]

Populations are assemblages of individuals of one species. Communities are assemblages of interacting populations. Both populations and communities have measurable properties peculiar to their respective levels of organization. Such properties may be used to estimate the effect on either of stress in any form.

1 Relevant population properties

a Density

Density is the average or mean number of individuals per unit area or volume of the environment.

b Dispersion

Dispersion is the pattern of spatial distribution of individuals in the habitat. It may be aggregated, random or regular.

c Dispersal

Dispersal is the rate at which individuals of a species population spread through the habitat from a point of entry, either as immigrants or as newly reproduced recruits.

d Growth and age at first maturity

This is the average size and age of the population when the individuals first come into reproductive condition.

e Recruitment

Recruitment is a rate also--the rate at which new individuals are added to the population.

f Mortality vs survival

Mortality is the rate at which individuals are removed from the population, by whatever means. The survival rate is the reciprocal of mortality.

g Frequency

Frequency is the rate at which individuals appear in samples, expressed as a percent. It is the number of individuals divided by the number of sampling units (see below) multiplied by 100.

h Fidelity

Fidelity is a measure of the extent to which one may expect to find a species in a sample of the habitat.

2 Properties of associations of populations[17]

a Population pairs (pairs of species)

1) Affinity is a measure of the extent to which a species is a normal constituent of another's environment.

2) Dominance

Dominance is a measure of the extent to which one of a pair of species dominates the other.

3) Relative abundance

Relative abundance is the number of individuals of a population relative to the numbers of individuals of other populations which have been demonstrated to be significant parts of the first population's environment. As a population property, it is also useful to develop ideas about the structure of the community.

4) Concordance

Concordance is a property of pairs of species. It measures the extent to which they agree that the environment in which they are found is a good one to live in. Much less useful is the simple correlation coefficient.

All these are numerical properties. They are defined in terms of numbers the significance of which can be tested objectively.

b Assemblages of populations - communities

1) Diversity

Diversity is a measure of the complexity of the biotic portion of an ecosystem. The greater the diversity the greater the number of ecological niches, or "occupations," occupied by species populations. The magnitude of diversity of a community is a function of time and the stability of the environment--allowing for the evolution, in situ, of niches and of immigration of species from without. This property, which may also be defined mathematically, is at once a means of identifying the community, and a means of correlating its structure with the stability of the environment.

2) Species - abundance curves

If as one takes successive sample units from the habitat he plots the number of species against the natural logarithm of the number of individuals he gets a curve which is a measure of the density of the community. It has been demonstrated that a break in the curve may be interpreted as invasion by the sampler into the habitat of another community.

3) Homeostasis

Homeostasis is the capacity of a community to survive in the face of unusual stress. It is a function of diversity.

V EVALUATION OF CHANGE IN AN ESTUARY

A Criteria

1 Community composition

If the normal species composition of one or more communities is known, even qualitatively, it may be used as a means of estimating the effects of change in environmental conditions.

a Indicator communities

The identification of peculiar communities with particular assemblages of physical environmental conditions may be used to indicate the development of such environmental conditions as a result of natural or man-made change.

b Indicator species

The same concept set forth in the preceding paragraph may be applied to particular species.

2 Population properties

The numerical properties of populations of species known to be obligate inhabitants of estuaries may be used as more objective evaluations of change resulting from alteration of the environment.

3 Productivity

Productivity is a measure of the rate of production of living matter by a population, a community, or of an entire ecosystem. Although it is not easy to measure, it is an attractive criterion upon which to estimate the economic potential of a habitat, or of any of the constituents as well as the effects upon that potential of alterations in the environment.

a Primary or autotrophic productivity[18, 19]

This is the rate of production of new living matter from inorganic substances chiefly by photosynthesizing plants. As will be recalled from our discussion of trophic levels, we have always to distinguish between gross primary production and net, the difference being the consumption of the product by the producer itself.

b Consumer or heterotrophic productivity[20, 21]

This is the rate of production of living matter by herbivores and carnivores. In species where populations are easy to sample, it is not too difficult to do.

c Productivity of the estuary[22]

From an economic point of view it becomes eminently desirable to be able to estimate the capacity of the estuary, as an ecosystem, or of any part of it, through the activities of its inhabitant species, to yield living matter. Obviously, the description of the estuary as an ecosystem--its physical properties and biotic communities--must be at hand in order to use this criterion.

4 Microbiological assays

If the capacity of the water or of the sediment on the bottom of any or all parts of the estuary to support life and economically desirable productivity is known, then the effects of changes in these constituents of the environment can be evaluated by microbiological assays. This, put simply, means assaying the capacity of water or sediment taken from the estuary to support growth of populations under controlled laboratory conditions.

B Necessity of Continuing Periodic Observations

1 Correlation versus regression

If only spot measurements of physical and biotic properties of the estuary are made, one may be lucky enough to obtain significant correlations, but if periodic measurements are made, not only will correlations be more acceptably significant, but also one may be able to plot regression curves, by which change in biotic properties may be linked with combinations of physical properties and their variations over a period of time.

2 Seasonal effects

An obvious reason for basing evaluation of change in an estuary on observations made periodically over a long period of time is that the normal effects of seasonal climatic change have to be taken into account.

3 Succession[24]

One of the effects of seasonal climatic change is the annual succession of populations and communities of organisms in those parts of the estuary where periodic changes are greatest. One community will arise, prosper and fritter away to be supplanted by another. Other forms of stress bring this about. Catastrophic change, as for example the complete covering of an area of bottom by flood borne silt will establish the basis for the beginning of a new succession. Introduction of hard surfaces into the environment, or hurricane destruction of grass beds or oyster bars will do likewise. Knowledge of normal stages of succession is essential to reliable evaluation of change.

VI THEORETICAL ASPECTS OF SAMPLING

A Necessity of Sampling

1 Excision of sampling units

In order to estimate properties, describe the biota, or whatever, it is in most cases necessary to sample--to remove portions of the habitat to see what's in it. Only rarely can one enumerate items in situ, leaving them untouched by the process.

2 Impracticality of whole counts

Even where it is possible to count individuals in situ in the habitat, it is generally physically and economically impractical, so we have to make do with samples.

B Necessity of Programmed Sampling[25, 26]

1 Accuracy and precision

a In any kind of mensuration, it is eminently desirable to do it accurately. Accuracy is a measure of our confidence that the sampling method we employ is free of error, representative of the population we are sampling or that the methods subsequently employed to analyze the sample will yield acceptably close estimates of the properties of the population we have sampled.

b Precision is a measure of the confidence we have that methods employed once will yield unswervingly reliable estimates. This is to say that we are dependent on precision in order to make comparisons.

C Sampling for Community Composition

1 Systematic sampling

When we are only trying to sample for qualitative data--to determine what kinds of things we find in the habitat--and especially when we have a lot of territory to cover, it is best to lay down a geometrically regularly spaced pattern of stations at which to take sampling units.

a Limitations

Systematic sampling is limited to the making of surveys. It is the method of reconnaisance. It is biased and therefore useless or at least very unreliable for the estimate of quantitative properties of populations.

b Advantages

Systematic sampling is the method of choice when time and money are limited and only qualitative data are required. It is the method of reconnaisance.

c Spatial and temporal systematic sampling

In an estuary spatial systematic sampling may be done at the intersections of a grid or at intervals on transects, or merely at regularly spaced intervals on a midline or even with the center of the main channel running from the head to the mouth. Temporal systematic sampling means taking a sampling unit at regularly spaced intervals in time at the same point in space.

D Sampling for Population or Community Properties

1 Necessity for control of bias

Sampling for numerical properties demands freedom from bias. Bias is a measure of inequality of the chances of individuals being picked up in the sample. Freedom from bias is a measure of the equality of opportunity of every individual being taken in the sample. This is one of the criteria for accuracy.

2 Sampling patterns

a Random sampling

Random sampling may be achieved by laying out a grid, for example, numbering the intersections of the grid in a systematic manner and taking samples at intersections whose numbers are ordered by the sequence found in a table of random numbers or the last two or three digits in a series on any page of the Manhattan telephone book. Random sampling gives maximal freedom from bias. But it is difficult and sometimes uneconomical to do.

b Stratified random sampling

A pattern of sampling which is easier to do and still gives a sample almost as free of bias as a random sample, is stratified random sampling. In this case, for example, one may select regularly spaced areas in a habitat and excise units on a random pattern within each.

3 Sampling unit and sample size

The size of the "chunk" for excise from the habitat as well as the number of chunks influence the representativeness of the sample. If the former is too small in relation to the pattern of spatial distribution of what you are sampling you may get a sample which will suggest clumping even though the species is uniformly distributed. If it is too large you may get an erroneous suggestion of uniform distribution. A way in which both birds can be killed with one stone is to sample what seem to be significant species, using three or four sampling unit sizes. As successive lots of five sampling units are taken, the cumulative mean is plotted on the ordinate against the number of units on the abscissa. For an unrealistically large sampling unit, the curve will be level from the beginning. For an unacceptably small unit the curve will fluctuate wildly and never level off. For an optimally sized unit, the curve will fluctuate (or deviate) on either side of a certain value at which it will level off. The intercept with the abscissa of a line dropped from the point of leveling off gives the optimal number of sampling units, or sample size. The point of leveling off gives as near a representation of the true population mean of the species as possible.

4 Estimates of accuracy

In Section B, 1 above we defined accuracy as a property of method. It may also, of course, be defined as a property of the result. In this case it is a measure of the closeness of an estimate to the true value. Minimizing the variance which is the basis of the method described in the preceding paragraph is a practical way of ensuring a mean which is acceptably accurate. Obviously, the larger the sample, the smaller the average deviation from the mean. This is a practical way of evaluating the accuracy of a determination. Another rule of thumb is not to accept an estimate which is less than 2.5 times its standard deviation.

5 Estimating precision

Precision has been defined as an attribute which is achieved when acceptable accuracy is obtained in a succession of samples of the same population. Estimate of precision may be made by the method of testing to determine the probability that a greater difference between the means of two samples could be obtained If an acceptable probability is achieved one may assume that the method is precise and that the two samples are drawn from the same population.

VII PRACTICAL PROBLEMS IN ESTIMATING POPULATION OR COMMUNITY PROPERTIES

A Methods of Collecting

1 Plankton[4, 27, 23]

a Nets

Qualitative plankton nets are funnel shaped devices, closely resembling the airport "wind-sock" with a container on the small end. They are made of monofilament nylon cloth of varying mesh sizes. They may be towed horizontally, vertically or obliquely. Even the finest does not catch all the plankton. Quantitative plankton nets are equipped with opening and closing devices and with meters which make possible an estimate of the amount of water which has been strained.

b Pumps

Pumps are preferable to nets because one can be certain that all the water of the sample goes through the net, if that is employed to filter out the plankton. Within the limits imposed by the lowering of hose, one can know the exact depth from which a sample is obtained. The bulkiness of hose is a disadvantage.

c Traps

Plankton traps are devices which cut off a volume of water, isolating the plankton in it. The many kinds of water bottles used by aquatic scientists fall into this category.

2 Nekton[28]

Nekton means fishes as a general rule. Being nekton they must be captured by conventional fishing methods.

a Tagging

A number of methods for estimating population properties of fishes are based on the principle of the effect of the whole population diluting the concentration of marked individuals. A result is the development of a variety of tags with which live fish are marked and returned to the environment.

b Fishing gear

1) Hook and line

2) Mazes

Mazes range from hoop or fyke-nets to huge stationary fish traps.

3) Entangling nets

Typical entangling nets are trammel nets which consist of three nets in one--two outside ones with large meshes and one inside one with small meshes. The fish swim through the large mesh on one side, push the fine mesh through the large mesh on the other and make a pocket from which they cannot escape. Gill nets are made of mesh of such a size that the fishes push their heads through but are stopped by the dimensions of their bodies. Retreat is impossible because their gill opercula hang up.

4) Encircling nets

These are the seines by which fishes are surrounded and hauled out on the beach. Purse seines are constructed so they can be drawn together on the bottom.

5) Towed nets

The most widely used towed net is the oter trawl which is a funnel shaped net whose mouth is kept open by paravanes as they are towed through the water.

6) Poison

In circumscribed, small bodies of water fairly accurate whole counts of the fish populations can be made by poisoning the water with rotenone.

c Fishing statistics

1) Annual canvass

This is an annual survey conducted to determine not only how many fishes were caught by commercial operators, but also who went out when and with what kind of gear.

2) Sales slip

In some states and countries, there is required by law, that all who sell fish relay to the Conservation Department one copy of every record of sale.

3) Vessel landings

Fishery statistics may be accumulated by obtaining from middlemen the records of vessel landings.

4) Log books

5) Daily delivery sheets

6) Fixed gear records

These are the records of fish taken out of fish traps and pound nets.

7) Sport fishing records

Valuable fishing statistics can be obtained through angler's organizations and the operators of sport fishing lodges, marinas, boats and the like.

3 Benthos[29]

a Gear

1) Dredges

Dredges are rigid box or net like structures dragged along the bottom clipping off the epifauna or digging in slightly to remove the most superficial infauna.

2) Grabs

Grabs are devices which bite out single chunks of the bottom.

3) Sieve, shovel, tongs, rakes

On bottom which may be reached with tools operated by hand, or on which a person may wade, any of a variety of devices may be used to sample the benthos.

b Fishery statistics

For information concerning benthos populations which are exploited commercially, fishery statistics of the sort outlined in the section on nekton may be useful.

B Processing the Collections

1 Plankton[23]

Plankton caught in conventional nets usually need to be diluted to achieve concentrations which are workable in the small containers used on microscope stages. Plankton caught by pump or in traps usually have to be concentrated.

a Filtration

Small volumes as from water bottles can often be quantitatively filtered on membrane filters, the counts and identifications being made when the membrane is transferred to a slide for microscopic study. The plankton may be stained and the filter cleared with cedar oil or with Karo syrup.

b Sedimentation

As filtration often damages delicate organisms, dilute samples may be allowed to settle out in vessels especially designed for the purpose, the collection then being examined preferably by an inverted microscope.

c Centrifugation

A high speed centrifuge of appropriate design will concentrate all but the tiniest plankton organisms. Because the smaller sizes are lost through the meshes of nets and in centrifuging, filtrations and sedimentations are preferable.

2 Nekton

Fishes need only to be preserved. This requires injections of preservative into the body cavity and exposure to appropriate concentrations of the stuff long enough to insure complete infiltration.

3 Benthos

Most benthic organisms are small and collections taken by dragging or grabbing usually require careful sorting or sieving to separate them from sediment or other trash.

C Determinations of Quantitative Properties

1 Plankton

a Density

Density is given by $\frac{\Sigma x}{N}$ in which x is the number of individuals in each sampling unit and N is the number of sampling units expressed as units of area or volume. The values of x may be determined by:

1) Direct counts of aliquots

Small plankton organisms may be counted on counting chambers of the sort used in blood counts; larger kinds may be counted in Sedgwick-Rafter cells or any other small dish or container which may be scribed or calibrated to facilitate counting.

2) Cultures

The population densities of phytoplankton species may be estimated by such methods as the dilution technique.

3) Estimates of chemical parameters

Determination of the chlorophyll, particulate carbon, "organic" phosphate or carbon of samples may be used to estimate population density.

2 Nekton[28]

a Determination of meristic characters

Meristic characters such as the number of vertebrae, the number and distributions of scales, and certain body proportions of fishes have been shown to be related to environmental influences. The important thing to remember is that one should be quite rigid about making his counts in the same places.

b Age determinations

The age of fishes can be determined by any of a number of means.

1) Scales

The scales of bony fishes have annual rings which may be counted.

2) Otoliths

Otoliths are concretions found in the auditory labyrinth of fishes. The successive layers are laid down annually, so sections of these structures reveal the fish's age.

3) Vertebrae

Similar annual concretions are found in the centra of some fishes' vertebrae.

4) Spines and rays

Annual increments of growth can be detected in the bony spines and rays found in fishes' fins.

5) Tagging

By capturing fishes, tagging them with date-bearing devices and releasing them, recapture gives an accurate determination of age since the date of tagging. If fishes known to be in their first year are so tagged, the age in years is of course known completely.

6) Length - frequency

For many fishes--particularly exploited species which occur in estuaries--the average length achieved at particular ages is known. The frequency with which a certain length appears in a sample can thus serve as an estimate of age.

c Estimates of properties[28, 30, 31]

1) Density

a) Area density

This is the number of individuals per unit area, given, as we have seen above by

$\frac{\Sigma x}{N}$.

b) Age frequency

Here one accumulates data on the frequency with which age groups appear in the catch. An age-frequency curve is plotted. From this we get an estimate of mortality--the rate at which individuals are being removed from the population. We then get an estimate of total population density by dividing the total catch by the mortality rate.

c) Capture-mark-recapture

Assuming that tagged fish behave like untagged members of the population in all respects, that loss of tags is proportional in different years, and that there is no variation in fishing activity, population density can be estimated on the basis of dilution of a proportion of tagged fish by the population as a whole. The simplest equation for this method is

$$P = N \times \frac{M}{R}$$

in which P equals the population density, N is the total catch for the season, M is the number of fishes originally marked and released, and R is the number of these which are recaptured. There are more elaborate ways of doing this when the above assumptions break down.

d) Regression

This method is based on the fact that the decrease in the catch per unit effort which results from depletion of the populations, is a function of the extent of the depletion. It is assumed that there is no migration in or out of individuals of the age group in question.

2) Growth and age at first maturity

This property is determined by correlating the length of fishes with the appearance of some structure or state of development of some part of the reproductive system taken to indicate the onset of maturity.

3) Recruitment

Estimates of recruitment depend not only on tabulating the proportions of age-groups in the catch, but also on the catch including the recruits.

4) Mortality versus survival

This, as we have seen, depends on determining the proportions in the total catch of different age groups. A plot of the decrease in numbers of individuals per age group with the passage of time gives a survivorship curve. The reciprocal of this is the mortality.

5) Frequency

Frequency is a statistic which is useful in estimating the status of a population in the community. It is the number of times the species appears in each sampling unit divided by the number of sampling units and multiplied by 100.

6) Fidelity

As we have seen, this is a measure of the consistency with which a species appears in samples. It is a measure of the extent to which a species is restricted to a particular habitat. It may be determined by expressing the difference in frequency of a species in two samples as a proportion of the lesser value. It ranges from 0 to infinity.

3 Benthos

The population properties of benthic species which may be of use in evaluating change in environmental factors are essentially the same as those listed for nekton. There are others, of course.

D Properties of Pairs of Species - Significant Associations

1 Determination of significant associations

a Indices of affinity

One way of estimating affinity is with the 2 × 2 contingency table which will give the expected frequency with which you will get sampling units with A alone, B alone, A and B, and neither. Comparison of the expected with the observed is done and an appropriate test for the probability that you will get a greater difference, or the probability that the difference is due to more than chance gives you an index of affinity. There are others.[34]

b Correlation coefficient

A positive correlation coefficient, the formula for which can be found in any good statistics text, gives an estimate of the necessity for A being a part of B's environment or vice versa. A negative coefficient shows the extent to which one is bad for the other.

c Rank correlation coefficient

This is easier to do. It is also a means of estimating whether one species benefits by the presence of the other or is harmed by it. The procedure can best be obtained by going to the original source.[32]

E Properties of Assemblages of Populations--Communities

1 Properties based on relative abundance

a Dominance

As suggested by Sanders[33], this may be computed by first ordering the species in each sampling unit in terms of the number of individuals. The individuals are then summed in order starting with the most abundant species. Those species which have been included in the summation when it reaches the value of half the total number of individuals present in the unit are the numerical dominants of the unit. The frequency of this dominance is an important estimate of the significance of the species' presence in the community. Other ways of computing dominance are offered by Fager.[17, 34]

b Concordance

As already stated, concordance is an estimate of the extent of agreement between species as to whether or not the habitat in which they are found is a good one in which to live. The method by which it is computed is given by Kendall[32]. While not particularly difficult, it is a bit too elaborate for inclusion here.

2 Properties based on affinity and diversity

a Affinity

One of the most effective ways in which to determine from distributional data what species found in a sample are significant members of the community is Fager's[34] determination of recurrent groups. This is based on the 2 × 2 contingency type of index of affinity. It is not too difficult and is invariably repeatable by any succession of persons who follow the rules.

b Diversity

A number of indices of diversity which are used as a means of distinguishing between communities have been devised. An index based on the relationship of the number of species to the logarithm of the area from which they were collected was proposed by Gleason.[35] Derivatives of this have been proposed by others. Sanders[36] has also developed an index of diversity which cannot be used for distinguishing between communities but which is used to estimate the relation between diversity and environmental stress.

c Species abundance curves

Species abundance curves are obtained by plotting the number of species against the logarithm of the number of individuals as sampling units accumulate. For any one community, a curve of this sort should be a constant.

VIII ESTIMATION OF PRODUCTIVITY

A Primary or Autotrophic Productivity

1 Phytoplankton[18]

a Light and dark bottle method

Replicates of three glass stoppered bottles are filled to overflowing with a phytoplankton suspension. Two are clear; the third is coated all over with light-proof paint. The dissolved oxygen in one of the clear ones is determined. The other two are exposed to light for four hours and the dissolved oxygen in each determined. Since oxygen is a product of photosynthesis and the amount is proportional to the carbohydrate produced, the increase of dissolved oxygen in the second clear bottle corrected for the decrease in the dark bottle is a measure of photosynthesis hence productivity.

b C^{14} Method[18]

A measured amount of radioactive CO_2^{14} as bicarbonate is added to a series of replicates of bottles fitted to overflowing with a phytoplankton suspension. After a period of exposure to light, the contents are filtered through membrane filters. The radioactivity of the latter is a measure of the CO_2 taken up by the phytoplankton. The CO_2 is proportional to the carbohydrate produced by photosynthesis.

2 Higher aquatic plants

a Change in biomass[37, 38]

An increase in biomass as weight of representative samples of the higher plants over a period of time is a measure of productivity.

b Dissolved oxygen[39]

In a narrow, shallow estuary, changes in the oxygen content over a twenty-four hour period of the water flowing over a grass bed can be used as an estimate of the bed's productivity.

3 Salt marshes[40]

a Grass productivity

The productivity of the marsh grass over a period of time is best estimated on the basis of change in biomass.

b Detritus productivity

Periodic collection of detritus carried off the marsh by the falling tide may be used as a basis for estimating, by weight, the amount of detritus produced by the salt marsh.

B Consumer or Heterotrophic Productivity

Consumer, or heterotrophic productivity cannot easily be routinely estimated by laboratory procedures. We are therefore dependent on population statistics obtained by sampling programs or from the fisheries.

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This outline was prepared by Dr. Henry Kritzler, Professor of Biological Oceanography, Florida State University.

I INTRODUCTION

A Due to the nature of ecological interrelationships, methods for the collection of different types of aquatic organisms differ. In general we can recognize those that swim or float and those that crawl, those that are big and those that are little. Each comprises a part of "the life" at any given survey station and consequently a "complete" collection would include all types.

B Field methods in the following outline are grouped under four general categories, the collection of

1 Benthos (or bottom dwelling organisms). These may be attached crawling, or burrowing forms.

2 Plankton (plancton). These are all of the microscopic plants and animals normally swimming or suspended in the open water

3 Periphyton or "aufwuchs". This is the community of organisms associated with the surfaces of objects. Some are attached, some crawl. The group is intermediate between the benthos and the plankton.

4 Nekton. Nekton are the larger, free swimming active animals such as shrimp or fishes.

C Aquatic mammals and birds, in most cases, require still other approaches and are not included.

D There is little basic difference between biological methods for oceanic, estuarine, or freshwater situations except those dictated by the physical nature of the environments and the relative sizes of the organisms. Fish, benthos, and plankton collection is essentially the same whether conducted in Lake Michigan, Jones' Beach, or the Sargasso Sea.

1 Marine organisms range to larger sizes, and the corrosive nature of seawater dictates special care in the design and maintenance of marine equipment. Site selection and collection schedules are influenced by such factors as tidal currents and periodicity, and salinity distribution, rather than (river) currents, riffles, and pools.

2 Freshwater organisms are in general smaller, and the water is seldom chemically corrosive on equipment. Site selection in streams involves riffles, falls, pools, etc , and a unidirectional flow pattern. Lake collection may involve less predictable stratification or flow patterns.

E Definite objectives should be established in advance as to the size range of organisms to be collected and counted, i.e. microscopic only, microscopic and macroscopic, those retained by "30 mesh" screens, invertebrates and/or vertebrates, etc.

II STANDARD PROCEDURES

A Certain standard supplementary procedures are a part of all field techniques. In order to be interpreted and used, every collection must be associated with a record of environmental conditions at the time of collection.

1 Data recorded should include the following as far as practicable.

Location (name of river, lake, etc)

Station number (particular location of which a full description should be on record)

Date and hour

Air temperature

Water temperature (at various depths, if applicable)

Salinity (at various depths, if applicable)

Tidal flow (ebb or flood)

Turbidity (or light penetration, etc.)

Weather

Wind direction and velocity

Sky or cloud cover

Water color

Depth

Type of bottom

Type of collecting device and accessories

Method of collecting

Type of sample (quantitative or qualitative)

Number of samples at each station

Chemical and physical data, e.g., dissolved oxygen, nutrients, pH, etc.

Collector's name

Miscellaneous observations (often very important)

2 All collecting containers should be identified at least with location, station number, sample number, and date. Spares are very handy.

3 Much transcription of data can be eliminated by using sheets or cards with a uniform arrangement for including the above data. The same field data sheet may include field or laboratory analysis.

B Compact kits of field collecting equipment and materials greatly increase collecting efficiency, especially if collection site is remote from transportation.

III PERSONAL OBSERVATION AND PHOTOGRAPHY

A Direct or indirect observation of underwater conditions has become relatively efficient.

1 Diving spheres, pioneered by William Beebe, Cousteau, Honot, Willm, and Manad are proving very important for deep water observations.

2 Use of the aqualung permits direct personal study down to over 200 feet.

3 Underwater television (introduced by the British Admiralty for military purposes) is now generally available for biological and other observations.

4 Underwater photography is improving in quality and facility.

5 Underwater swimming or use of SCUBA is quite valuable for direct observation and collecting.

IV COLLECTION OF BOTTOM OR BENTHIC ORGANISMS

A Shoreline or Wading Depth Collecting Plates I, II

1 Hand picking of small forms attached to or crawling on rocks, sticks, etc. when lifted out of the

BOTTOM GRABS

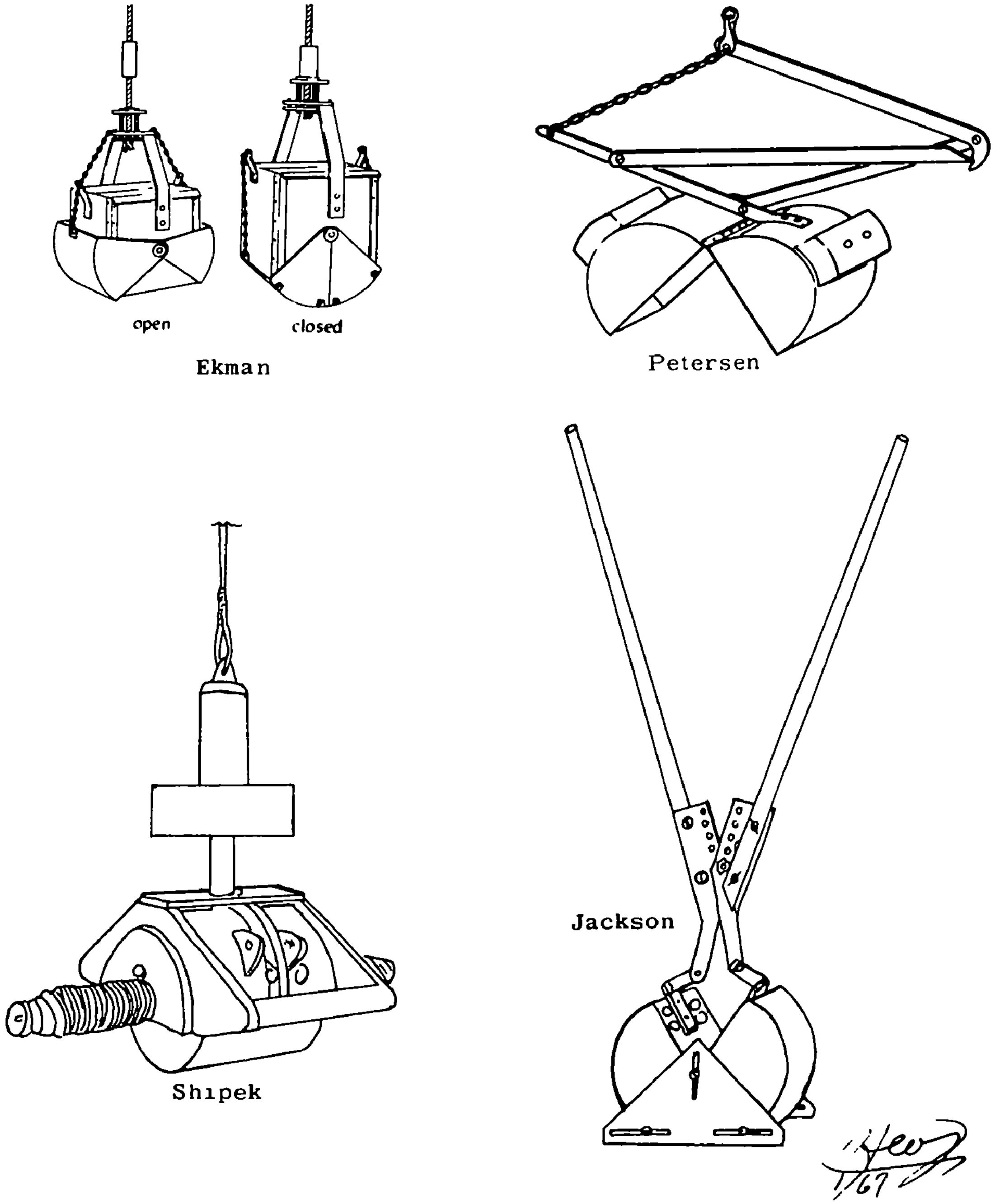


PLATE I

LIMNOLOGICAL EQUIPMENT

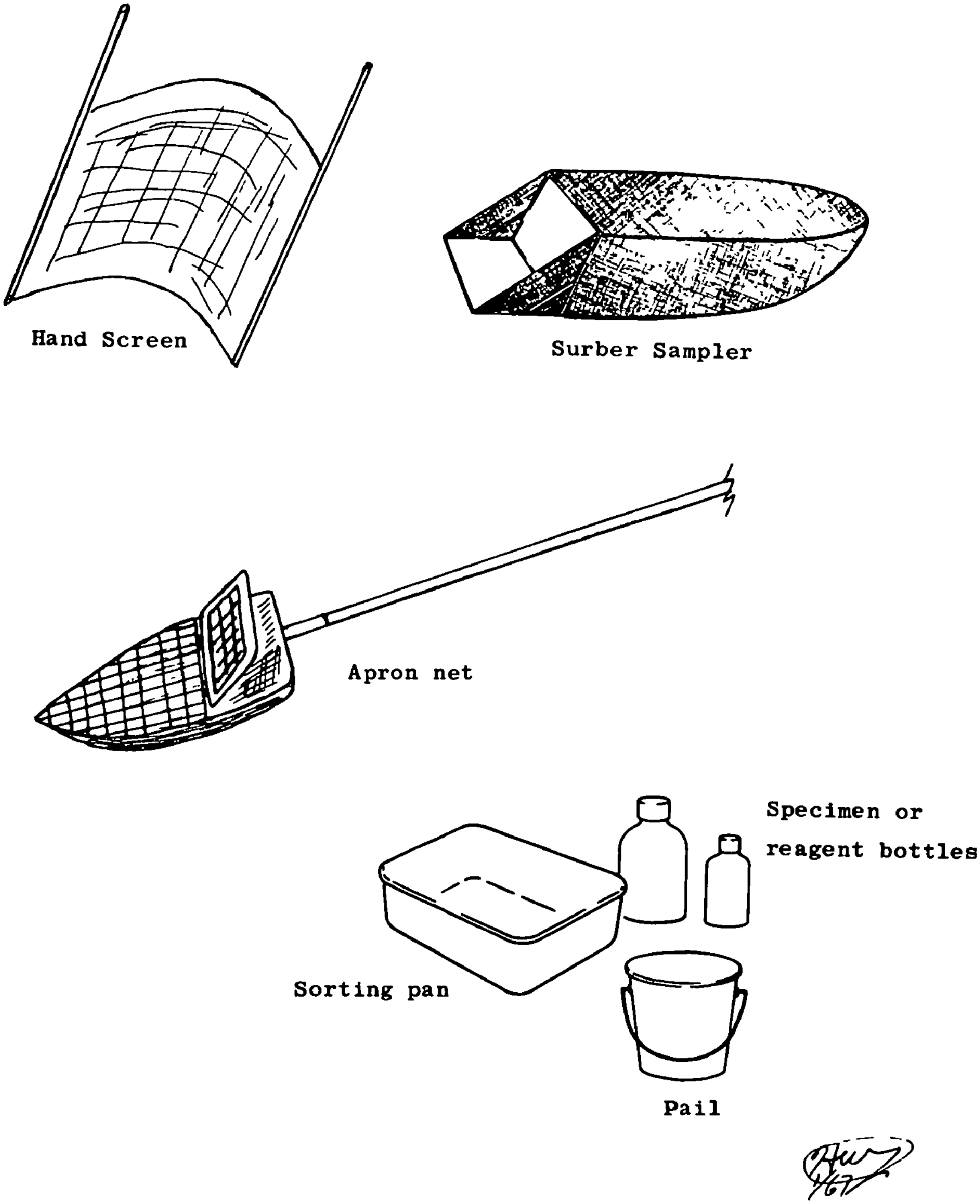


PLATE II

water is a fundamental and much used method for quickly assaying what is present and what may be expected on further search.

2 Patches of seaweed and eelgrass and shallow weedy margins anywhere are usually studied on a qualitative basis only.

a The apron net is one of the best tools for animals in weed beds or other heavy vegetation. It is essentially a pointed wire sieve on a long handle with coarse screening over the top to keep out leaves and sticks.

b Grapple hooks or a rake may be used to pull masses of vegetation out on the bank where the fauna may be examined and collected as they crawl out.

c Quantitative estimates of both plants and animals can be made with a "stove pipe" sampler which is forced down through a weed mass in shallow water and embedded in the bottom. Entire contents can then be bailed out into a sieve and sorted.

d A frame of known dimensions may be placed over an area to be sampled and the material within cropped out. This is especially good for larger plants and large bivalves. This method yields quantitative data.

3 Sand and mud flats in estuaries and shallow lakes may be sampled quantitatively by marking off a desired area and either digging away surrounding material or excavating the desired material to a measured depth. Handle-operated samplers recently developed by Jackson and Larrimore, make for more effective sampling of a variety of bottoms down to the depth of the handles. Such samples are then washed through graded screens to retrieve the organisms.

4 Ekman grabs are most useful on soft bottoms. This is a completely closing clamshell type grab with spring operated jaws. Size of grab is usually 6" × 6" or 9" × 9", the 12" × 12" size is impractical due to its heavy weight when filled with bottom material.

For use in shallow water, it is convenient to rig an Ekman with a handle and a hand operated jaw-release mechanism.

5 The Petersen type grab (described below) without weights will take satisfactory samples in firm muds, but tends to bury itself in very soft bottoms. It is seldom used in shallow water except as noted below.

B Collecting in Freshwater Riffles or Rapids

1 The riffle is one of the most satisfactory habitats for comparing stream conditions at different points.

2 The hand screen is the simplest and easiest device to use in this situation. Resulting collections are qualitative only.

a In use the screen is firmly planted in the stream bed. Upstream bottom is thoroughly disturbed with the feet, or worked over by hand by another person. Organisms dislodged are carried down into the screen.

b Screen is then lifted and dumped into sorting tray or collecting jar.

3 The well-known square foot Surber sampler is one of the best quantitative collecting devices for riffles.

a It consists of a frame one foot square with a conical net attached. It is usable only in moving water.

b In use it is firmly planted on the bottom. The bottom stones and gravel within the square frame are then carefully gone over by hand to ensure that all organisms have been dislodged and carried by the current into the net. A stiff vegetable brush is often useful in this regard.

c From three to five square-foot samples should be taken at each station to insure that a reasonable percentage of the species present will be represented.

4 The Petersen type grab may be used in deep swift riffles or where the Surber is unsuitable.

a It is planted by hand on the bottom, and worked down into the bottom with the feet.

b It is then closed and lifted by pulling on the rope in the usual manner.

5 A strong medium weight dipnet is the closest approach to a universal collecting tool.

a Sweeping Weed beds and Stream Margins

This is used with a sweeping motion, through weeds, over the bottoms or in open water. A triangular shape is preferred by some.

b Stop net or Kicking Technique

This may be used as a roughly quantitative device in riffles by holding the end flat against the bottom and backing slowly up-stream disturbing the substrate with one's feet. A standard period of time is used.

c The handle should be from 4 to 6 feet long, and about the weight of a garden rake handle.

d The ring should be made of steel or spring brass, and securely fastened to the handle. It should be strong but not cumbersome, size of ring stock will depend on diameter of ring.

e The bag or net should be the strongest available, not over 1/8 inch mesh, preferably about 1/16 inch. Avoid 30 or more meshes to the inch, this is so fine that the net plugs too easily and is slow and heavy to handle.

f There should be a wide canvas apron sewed around the rim and protecting the bag. The rim may be protected with leather if desired.

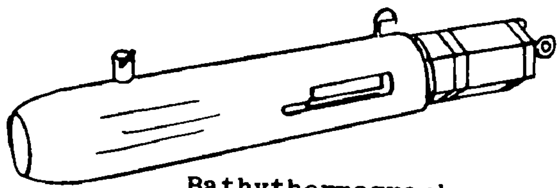
D Deep Water Benthic Collecting Plate III

1 When sampling from vessels, a crane and winch, either hand or power operated, is used. The general ideas described for shallow waters apply also to deeper waters, when practicable.

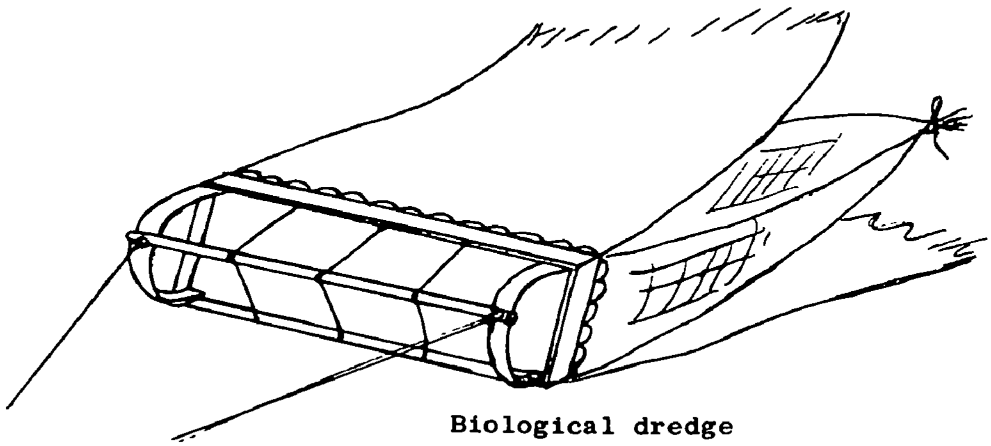
2 The Petersen type grab, seems to be the best all around sampler for the greatest variety of bottoms at all depths, from shoreline down to over 10, 000 meters. (Plate I)

a It consists of two heavily constructed half cylinders closed together by a strong lever action.

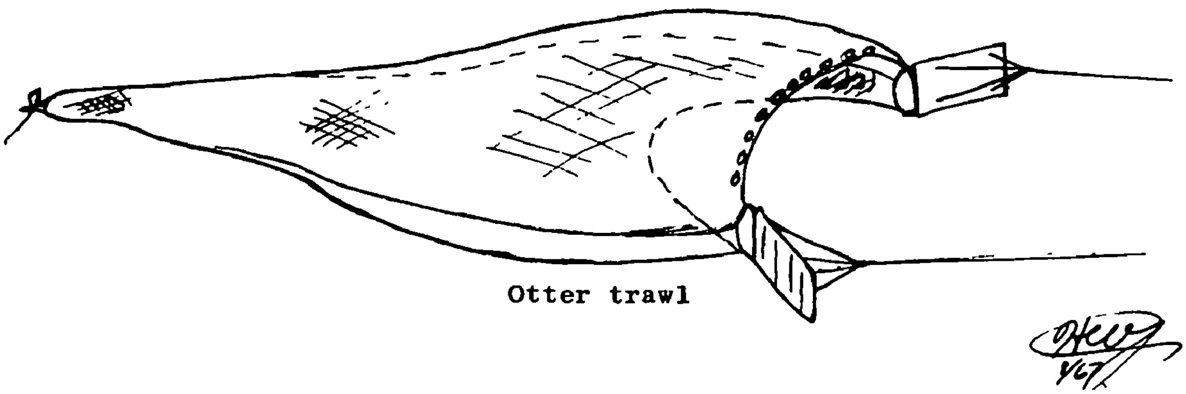
DEEP WATER EQUIPMENT



Bathythermograph



Biological dredge



Otter trawl

PLATE III

b To enable them to bite into hard bottoms, or to be used in strong currents, weights may be attached to bring the total weight up to between 50 and 100 lbs.

c Areas sampled range from 1/5th to 1/20th square meters (1/10 square meter equals approximately 1.1 square ft.)

d A Petersen grab to be hauled by hand should be fitted with 5/8 or 3/4 inch diameter twisted rope in order to provide adequate hand grip. It is best handled by means of wire ropes and a winch.

3 Other bottom samplers include the VanVeen, Lee, Holme, Smith-McIntyre, Knudsen, Ponar, and others.

4 A spring loaded sampler has recently been developed by Shipek for use on all types of bottoms. It takes a half-cylinder sample, 1/25th square meters in area and approximately 4 inches deep at the center. The device is automatically triggered on contact with the bottom, and the sample is completely protected enroute to the surface. (Plate I)

5 Drag dredges or scrapes are often used in marine waters and deeper lakes and streams, and comprise the basic equipment of several types of commercial fisheries. Some types have been developed for shallow streams. In general however, they have been little used in fresh water.

6 The above is only a partial listing of the many sampling devices available. Others that are often encountered are the orange-peel bucket, plow dredge, scallop type dredge, hydraulic dredges, and various coring devices. Each has its own advantages and disadvantages and it is up to the worker and his operation to decide what is best for his particular needs. The Petersen type and Ekman grabs are perhaps the most commonly used.

7 Traps of many types are used for various benthic organisms, especially crabs and lobsters. Artificial substrates (below) are in essence a type of trap.

8 Since most biological communities are not evenly distributed, it is advisable to routinely take at least two and preferably more samples from any one station.

E Artificial substrates rely on the ecological predilection of organisms to grow wherever they find a suitable habitat. When a small portion of artificial habitat is provided, it tends to become populated by all available species partial to that type of situation. The collector can then at will remove the habitat or trap to his laboratory and study the population at leisure.

This versatile research technique is much used for both routine monitoring and exploratory studies of pollution. It is also exploited commercially, especially for shellfish production. Types of materials used include

1 Cement plates and panels.

2 Wood (especially for burrowing forms).

3 Glass slides (ex: Catherwood diatometer).

4 Multiple plate trap (masonite).

5 Baskets (or other containers) holding natural bottom material and either imbedded in the bottom, or suspended in the overlying water.

6 Unadorned ropes suspended in the water, or sticks thrust into the bottom.

F Sorting and Preservation of Collections

1 Benthic collections usually consist of a great mass of mud and other debris among which the organisms are hidden. Various procedures may be followed to separate the organisms.

a The organisms may be picked out on the spot by hand or the entire mess taken into the laboratory where it can be examined more efficiently (especially in rough weather). Roughly equivalent time will probably be required in either case.

b Specimens may be simply observed and recorded or they may be preserved as a permanent record.

c Organisms may be simply counted, weighed, or measured volumetrically, or they may be separated and recorded in groups or species.

2 If separation is in the field, this is usually done by hand picking, screening, or some type of flotation process.

a Hand picking is best done on a white enameled tray using light touch limnological forceps.

b Screening is one of the most practical methods to separate organisms from debris in the field. Some prefer to use a single fine screen, others prefer a series of 2 or 3 screens of graded sizes. The collection may be dumped directly on the screen and the mud and debris washed through, or it may be dumped into a bucket or small tub. Water is then added, the mixture is well stirred, and the supernatant poured through the screen. The residue is then examined for heavy forms that will not float up.

c A variation of this method in situations where there is no mud is to pour a strong sugar or salt solution over the collection in the bucket, stir it well, and again pour the supernatant through the screen. This time, however, saving the flotation solution for re-use. The heavier-than-water solution accentuates the separation of organisms from the debris (except for the heavy shelled molluscs, etc.). A solution of 2-1/2 lbs. of sugar per gallon of water is considered to be optimum.

3 Preservation or stabilization is usually necessary in the field.

a 95% ethanol (ethyl alcohol) is highly satisfactory. A final strength of 70% is necessary for prolonged storage. If the collection is drained of water and flooded with 95% ethanol in the field, a laboratory flotation separation can usually be made later, thus saving much time. Considerable quantities of ethanol are required for this procedure.

b Formaldehyde is more widely available and is effective in concentrations of 3 - 10% of the commercial formulation However, it shrinks and hardens specimens, collector, and laboratory analyst without favor! In order to minimize bad effects from formalin, neutralized formalin is recommended. Mollusc shells will eventually disintegrate in acid formalin

c Properly preserved benthos samples may be retained indefinitely, thereby enhancing their utility.

d Refrigeration or icing is very helpful.

V MICROFAUNA AND PERIPHYTON (OR AUFWUCHS) SAMPLING

A This is a relatively new area which promises to be of great importance The microfauna of mud and sand bottoms may be studied to some extent from collections made with the various devices mentioned above. In most cases however, there is considerable loss of the smaller forms

B Most special microfauna samplers for soft bottoms are essentially modified core samplers in which an effort is made to bring up an undisturbed portion of the bottom along with the immediately overlying water. The best type currently seems to be the Enequist sampler which weighs some 35 kg. and takes a 100 sq cm sample 50 cm. deep.

C Microfauna from the surface of hard sand or gravel bottoms may be sampled by the Hunt vacuum sampler. This has a bell-shaped "sampling" tube sealed by glass diaphragm. On contact with the bottom, the glass is automatically broken and the nearly bottom material is swept up into a trap.

D Periphyton attached to or associated with hard surfaces such as rock or wood may be sampled by scraping or otherwise removing all surface material from a measured area. The periphyton, however, is more effectively quantitatively sampled by artificial substrate techniques described above.

VI THE COLLECTION, OR SAMPLING OF PLANKTON PLATE IV

A Phytoplankton· A Planned Program is Desirable

1 A planned program of plankton analysis should involve periodic sampling at weekly or even more frequent intervals.

2 A well-planned study or analysis of the growth pattern of plankton in one year will provide a basis for predicting conditions the following year since seasonal growth patterns tend to repeat themselves from year to year.

a Since the seasons and the years differ, records accumulated over the years become more useful.

b As the time for an anticipated bloom of some troublesome species approaches, the frequency of analyses may be increased.

3 Detection of a bloom in its early stages will facilitate more economical control.

B Field Aspects of the Analysis Program

1 Two general aspects of plankton analysis are commonly recognized: quantitative and qualitative.

a Qualitative examination tells what is present.

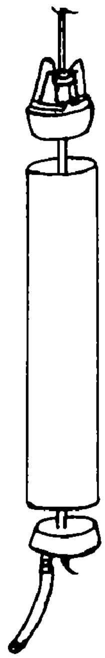
b Quantitative tells how much.

c Either approach is useful, a combination is best.

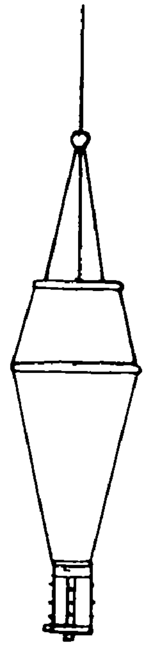
2 Equipment for collecting samples in the field is varied.

a A half-liter bottle will serve for surface samples of phytoplankton, if carefully taken.

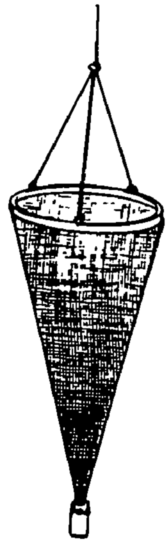
PLANKTON SAMPLERS

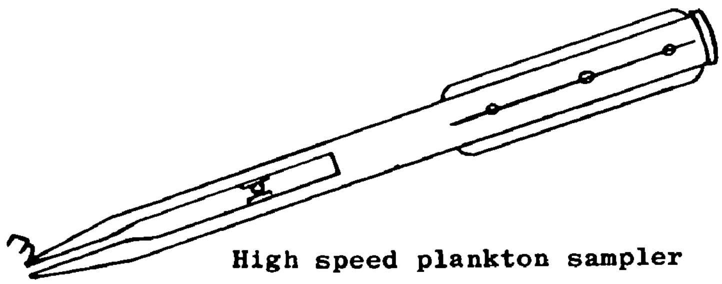


Kemmerer



Wisconsin net





High speed plankton sampler

PLATE IV

b A Kemmerer, Nansen, or other special sampler (small battery operated pumps are time saving) is suggested for depth samples.

c Plankton nets concentrate the sample in the act of collecting and also capture certain larger forms which escape from the bottles. Only the more elaborate types are quantitative however. For phytoplankton, #20 or #25 size nets are commonly used. Usually a net diameter of 5- 10 inches is sufficient. The smaller forms, however, are lost through any net.

C Zooplankton Collecting

1 Since zooplankton have the ability to to swim away from water bottles, etc., nets towed at moderately fast speed are used for their capture. Number 12 nets (aperature size 0.119 mm, 125 meshes 1 inch) or smaller numbered net sizes are commonly used. A net diameter greater than 5" is preferred.

Frequently half meter nets or larger are employed. These may be equipped with flow measuring devices for measuring the amount of water entering the net.

2 Other instruments such as the Clark-Bumpus, Gulf-Stream, Hardy continuous plankton recorder, and high-speed instruments are used for collecting zooplankton also.

3 The devices used for collecting plankton capture both the plant and animal types. The mesh size (net no.) is a method for selecting which category of plankton is to be collected.

D The Location of Sampling Points

1 Both shallow and deep samples are suggested.

a "Shallow" samples should be taken at a depth of 6 inches to one foot. The surface film is often significant.

b "Deep" samples should be taken such intervals between surface and bottom as circumstances dictate. In general, the entire water column should be sampled as completely as practicable, and the plankton from each level recorded separately.

2 For estuarine plankton, it is necessary to sample different periods in the stage of the tide, otherwise samples would be biased to a given time, or type of water carried by the tidal currents.

3 Plankton is subjected to the force of the winds and currents. As a result, the plankton is often in patches or "wind rows" (Langmuir cells). For this reason when using a net, it is often desirable to tow the net at right angles to the wind or current.

4 Nearly all plankton are horizontally discontinuous. Planktonic organisms tend to be numerous near the bottom in daylight, but distributed more evenly through the water column at night. Therefore, a series of tows or samples at different depths is necessary to obtain a complete sampling. One technique often employed is to take an oblique tow from the bottom to the top of the water column.

5 Pilot studies to indicate sampling locations and intervals are often mandatory. Some studies require random sampling points.

6 The number of sampling stations that should be established is limited by the capability of the laboratory to analyze the samples, but should approach the needs of the objectives as closely as possible.

7 Field conditions greatly affect the plankton, and a record thereof should be carefully identified with the collection as in II above.

8 Provisions should be made for the field stabilization of the sample until the laboratory examination can be made if more than an hour or so is to elapse.

a Refrigeration or icing is very helpful, but ice should never be placed in the sample.

b Preservation by 5% formalin is widely used but badly shrinks animals and makes all forms brittle.

c Lugols solution is a good preservative.

d Ultra-violet sterilization is sometimes used in the laboratory to retard the decomposition of plankton.

e A highly satisfactory merthiolate preservative has been described by Weber (1968).

VII COLLECTING FISH AND OTHER NEKTON PLATES V, VI

A Fish and other nekton must be sought in the obscure and unlikely areas as well as the obvious locations in order for the collection to be complete. Several techniques should be employed wherever possible (this is appropriate for all biota). It is advisable to check with local authorities to inform them of the reasons for sampling, because many of the techniques are not legal for the layman. In this area, perhaps more than any other, professionally trained workers are important. Also, there must be at least one helper, as a single individual always has difficulty in pulling both ends of a 20 foot seine simultaneously! The more common techniques are listed below.

B Seines

1 Straight seines range from 4-6 feet and upwards in length. "Common sense" minnow seines with approximately 1/4 inch mesh are widely used along shore for collecting the smaller fishes.

2 Bag seines have an extra trap or bag tied in the middle which helps trap and hold fish when seining in difficult situations.

C Gill nets are of use in offshore and/or deep waters. They range in length from approximately 30 yards upward. A mesh size is designed to catch a specified size of fish. The trammel net is a variation of the gill net.

D Traps range from small wire boxes or cylinders with inverted cone entrances to semi-permanent weirs a half mile or more in length. All tend to induce fish to swim into an inner chamber protected by an inverted cone or V - shaped notch to prevent escape. Current operated rotating fish traps are also very effective (and equally illegal) in suitable situations.

E Trawls are submarine nets, usually of considerable size, towed by vessels at speeds sufficient to overtake and scoop in fish, etc. The mouth of the net must be held open by some device such as a long beam (beam trawl) or two or more vanes or "otter boards" (otter trawl). Plate III

1 Beam and otter trawls are usually fished on the bottom, but otter trawls when suitably rigged are now being used to fish mid-depths.

2 The midwater trawl resembles a huge plankton net many feet in diameter. It is proving very effective for collecting at mid-depths.

FISH NETS

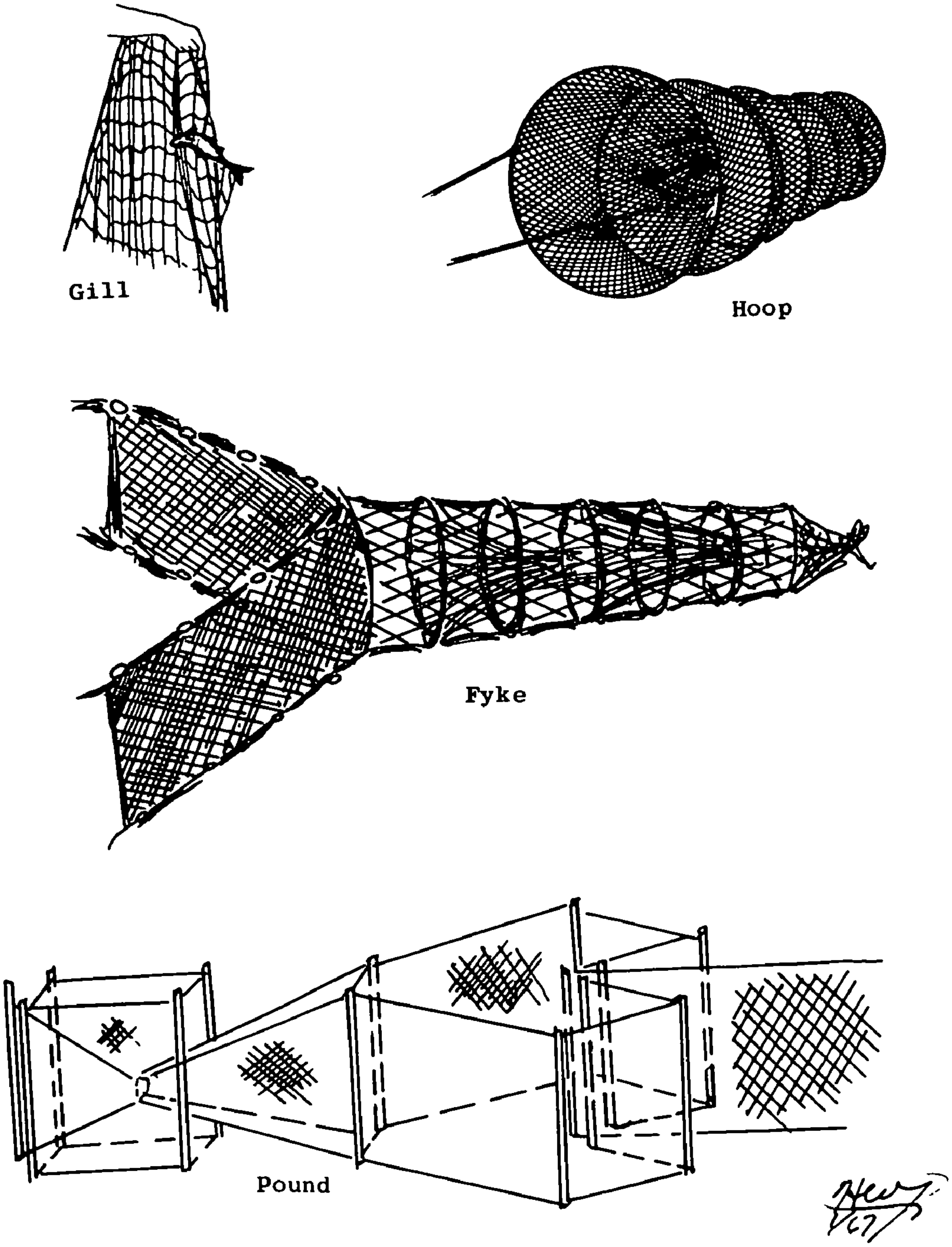
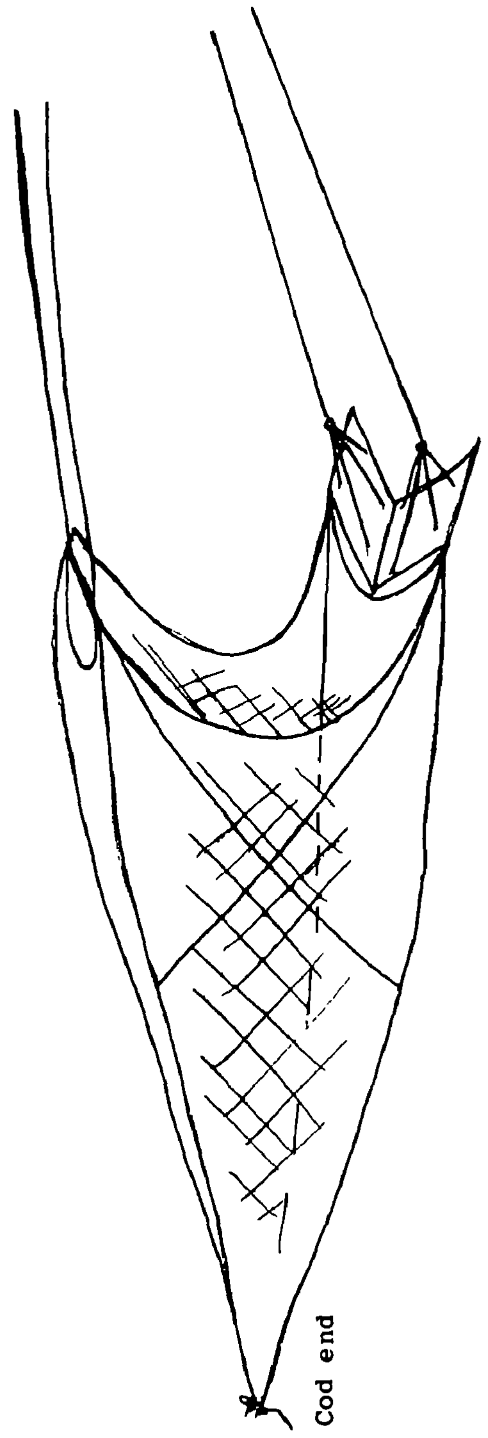


PLATE V



MIDWATER TRAWL

PLATE VI

PLATE VI

Numerous special designs have been developed. Plate VI

F Electric seines and screens are widely employed by fishery workers in small and difficult streams. They may also be used in shallow water like areas with certain reservations.

G Poisoning is much used in fishery studies and management. Most widely used and generally satisfactory is rotenone in varying formulations, although many others have been employed from time to time, and some appear to be very good. Under suitable circumstances, fish may even be killed selectively according to species.

H Personal observation by competent personnel, and also informal inquiries and discussions with local residents will often yield information of real use. Many laymen are keen observers, although they do not always understand what they are seeing. The organized creel census technique yields data on what and how many fish are being caught.

I Angling remains in its own right a very good technique in the hands of the skilled practitioner, for determining what fish are present. Spear-fishing also is now being used in some studies.

J Fish and other nekton are often tagged to trace their movements during migration and at other times. Miniature radio transmitters can now be attached or fed to fish (and other organisms) which enable them to be tracked over considerable distances. Physiological information is often obtained in this way. This is known as telemetry.

VIII SPECIAL REQUIREMENTS ON BOATS

Handling biological collections (as contrasted to chemical and physical sampling) on board boats differs with the size of the craft and the magnitude of operations. Some possible items are listed below. Hoisting and many other types of gear are used in common with other types of collection, and will not be listed.

A Special Laboratory Room(s)

B Constant flow of Clean water for culturing organisms. (Selection of materials and design of a system to insure non-toxic water may be very troublesome but very important.)

C Live Box built into ship at water level

D Refrigeration System(s)

1 For controlling temperature of experimental organisms in laboratory.

2 For deep-freezing and storage of specimens to be examined later.

E Storage Space (Unrefrigerated)

F Facilities for the safe storage and use of microscopes and other laboratory equipment.

G Facilities for the safe storage and use of deck equipment.

H Administrative access to the Captain and Technical Leader in order to coordinate requirements for biological collection (such as a slow plankton tow) with those for other collections.

I Safety of personnel working in and around boats, as well as in other field activities should be seriously considered and promoted at all times.

IX OTHER TYPES OF BIOLOGICAL FIELD STUDIES INCLUDE

A Productivity Studies of Many Types

B Life Cycle and Management

C Distribution of Sport or (potentially) Commercial Species

D Scattering Layers and Other Submarine Sound Studies

E Artificial Culture of Marine Food Crops

F Radioactive Uptake

G Growth of Surface-Fouling Organisms

H Marine Borers

I Dangerous Marine Organisms

J Red Tides

K Others

X SOURCES OF COLLECTING EQUIPMENT

Many specialized items of biological collecting equipment are not available from the usual laboratory supply houses. *Consequently, the American Society of* Limnology and Oceanography has compiled a list of companies handling such items and released it as "Special Publication No. 1, Sources of Limnoligical and Oceanographic Apparatus and Supplies." Available from the Secretary of the Society.

XI SAFETY

The hazards associated with work on or near water require special consideration. Personnel should not be assigned to duty alone in boats, and should be competent in the use of boating equipment (courses are offered by the U. S. Coast Guard). Field training should also include instructions on the proper rigging and handling of biological sampling gear.

Life preservers(jacket type work vests) should be wron at all times when on or near deep water. Boats should have air-tight or foam-filled compartments for flotation and be equipped with fire extinguishers, running lights, oars, and anchor. The use of inflatable plastic or rubber boats is discouraged.

All boat trailers should have two rear running and stop lights and turn signals and a license plate illuminator. Trailers 80 inches (wheel to wheel) or more wide should be equipped with amber marker lights on the front and rear of the frame on both sides.

Laboratories should be provided with fire extinguishers, fume hoods, and eye fountains. Safety glasses should be worn when mixing dangerous chemicals and preservatives.

A copy of the EPA Safety Manual is available from the Office of Administration, Washington, D.C. (Reference: 10)

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This outline was prepared by H. W. Jackson, Former Chief Biologist, National Training Center, MPOD, OWPO, EPA, Cincinnati, OH 45268, and revised by R. M. Sinclair, Aquatic Biologist, National Training Center.

Descriptors:
Aquatic Environment, Analytical Techniques, Sampling, On-Site Investigations, Preservation, Samplers, Water Sampling, Handling, Sample, Surface Waters, Aquatic Life

I Marine disposal of wastes is practiced where it is economically advantageous. In areas where water is being reclaimed within a closed system, marine disposal also provides for salt balance.

II PHYSICAL ASPECTS

A Surface Films

B Wave Action

C Currents

1 Time-averaged velocities of coastal waters are typically of the order of a few tenths of a knot. There are no theoretical tools to predict currents near the coast so that current measurements are required for each study area.

D Dispersion

1 Initial dilution or stirring is due to potential and kinetic energy. Outfall depth and diffuser (port) spacing are selected so as to maximize initial dilution.

a The upper limit of initial dilution is fixed by the amount of new water flowing into the area.

b The initial mixture will spread on the surface or at some intermediate depth where the combined mass is vertically stable.

2 Additional dilution is due to horizontal mixing (diffusion) in vertical stable ocean. This dilution proceeds at an ever-increasing rate. The width of a stream containing about 95% of the contaminant can be predicted from the relationship

$$e\left(\frac{W_1 + W_2}{2}\right)^{4/3} = \frac{W_2^2 - W_1^2}{32\,(t_2 - t_1)}$$

in which W_1 and W_2 are the initial and final widths at times t_1 and t_2 in seconds. When

W is in centimeters,

e = 0.005 or 0.0025 where lateral

restraint such as a shoreline is absent or present.

E Convergences at boundary of water masses of different densities. Divergences (upwelling) bring nutrient-rich waters into euphotic zone.

F Internal waves, surf, and swash strongly affect properties at depth. Internal hydraulic jump and rip currents have been postulated.

G Water transparency is affected by suspended solids in effluent and by increased plankton populations.

II CHEMICAL ASPECTS

A In most pollution studies, concentrations of chemical constituents of seawater may be assumed constant.

1 Chlorinity may be used to calculate dilutions of up to 300:1.

B Dissolved oxygen is generally no problem in coastal waters.

III BIOLOGICAL ASPECTS

A Municipal waste discharges result in marked changes near the outfall. Over a larger area, the general effect is to increase populations of plankton and benthos.

IV BACTERIOLOGICAL ASPECTS

A Salinity is not bactericidal but is important in flocculation and sedimentation.

B Coliform bacteria concentrations in surface waters are reduced by dilution, mortality, and sedimentation.

1 Southern California coastal waters

2 New York Harbor

C Mineralization on bottom of Santa Monico Bay is 50 times as efficient as it is in the water column.

Plant	Treatment	Time in hours for 90% reduction			
		Dilution $T\text{-}90_d$	Mortality $T\text{-}90_m$	Sedimentation $T\text{-}90_s$	Combined T-90
Hyperion	Secondary	20	17.8	21.0	6.5
Hyperion	Primary	20	17.8	5.3	3.4
Organe County	Primary	5 to 10	17.8	2.0 to 2.4	1.5

(NOTE: All unchlorinated effluents)

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This outline was prepared by C G Gunnerson, Formerly Engineer in Charge, Data Utilization Studies, Water Quality Section

ESTUARINE FISHERIES AND POLLUTION

I INTRODUCTION

A A typical estuary is a dynamic system in constant flux.

B Because of abrupt changes and wide variations it is not uncommon to have catastrophic mortalities due to natural causes (usually a combination of adverse physical conditions caused by extremes in temperature, salinity, turbidity, etc.)

C Some of mortalities are from combination of natural causes and adverse conditions caused by man's activity

D Some of the mortalities are directly from man's activity

E Some of the man-made effects on the biota may be termed sub-lethal, in that there is no direct mass mortality at first, but a diminution of the populations at an ever increasing rate. This may be due to a decrease in the food supply, elimination of the spawning and nursery areas and other more subtle factors such as slow accumulation of toxic substances, etc. Mortalities caused by natural factors are usually compensated by the fecundity of the biota resulting in re-establishment of natural populations. Adverse conditions caused by man are often irreversible and the natural resources are destroyed.

F Outright mortality caused by man's activity is dramatic and usually instigates reaction and action before the resource is completely destroyed. Sub-lethal environmental changes are more insidious and cause for more alarm.

II MAN-MADE ADVERSE CONDITIONS

A Dredging and filling cause destruction of the habitats for spawning, for nursery grounds, feeding grounds, destruction of primary producers (plants), etc

1 Much of the shallow estuarine areas, especially in the Gulf of Mexico, are grass flats. These are a source of food and provide a habitat, indispensable to many commercial and sport marine animals, especially as nursery grounds for the young

2 Marshes are very important to the productivity of the estuarine system, both as a habitat and as a nutrient source for the system.

3 Mangrove forests in the more tropical areas fill the same role as the marshes.

B Damming of rivers for industrial reasons or as a source of potable water causes many obvious adverse effects.

1 For those anadromous species (salmon, Atlantic shad, alewife, etc.) the dams effectively eliminate access to the upstream spawning areas

2 Another less apparent effect of damming and diversion of the fresh-water runoff concerns the reduction of the fertility of the estuaries, with resulting decrease in life support. The less dense freshwater tends to flow over the salt water, and in combination with the tidal cycle, results in a tilling of the offshore bottom, with a return of nutrient rich water. In addition the impoundment causes the nutrients brought down in the "runoff" to settle out behind the dam.

3 Damming may result in changes in the salinity gradient, allowing the upward movement of more stenohaline species that may be serious predators or competitors of a fishery resource.

4 Damming may result in increased siltation, both below and above the dam in the reservoir. The effects of impoundment on an estuary are

usually gradual, and the adverse changes are sometimes not seen for several years.

C Pollution

Several types of pollution will be discussed under this heading for convenience, including the discharge of toxic substances, so-called thermal pollution, contamination from atomic wastes, pesticides and domestic sewage.

1 Pulp mills long have been recognized as a major source of pollution with their discharge of toxic wastes. Those animals that are sessile (e.g. oysters) are particularly susceptible. Not only do the effluents cause direct mortality to the fishery but also to organisms in the lower levels of the food chain, effectively reducing the productivity of the entire system.

2 Thermal pollution results from the discharge of water used as a coolant in industrial processes. Thermal pollution is more critical in warmer areas, where many of the organisms are already living within several degrees of their thermal death point. The warmer the water the greater the physiological activity and the less the O_2 content, a combination causing considerable stress. In some instances in colder areas, thermal pollution is called "thermal enrichment" because the heated waters are used to warm the natural waters during the colder periods and extend the breeding and growing periods of some organisms.

3 The "atomic age" period (still with us), before the "space age" period has caused alarm because of the effect of radioactive material on aquatic resources. Investigations showed that organisms accumulate the radioactive materials, manifold that of the surrounding medium. Because of the dangers involved, the use of atomic power has been strictly regulated. Radioactivity in living organisms has occurred, mainly from fall out of earlier atmospheric explosions and from accidents and leakage At the present time the hazards of this type of pollution have been minimized

4 Pollution from pesticides has received a great deal of attention and will not be given here.

5 Pollution from human sewage has been with us for a long time and probably will continue, despite the efforts to treat human wastes. One of the main threats is to human health as untreated sewage allows for the spread of pathogens, both in food and drinking water In addition untreated sewage, upon oxidation, creates a great demand on oxygen, causing O_2 depletion. Another threat from pollution of this type, including the wide use of detergents, is the over fertilization of the water.

III OYSTERS

Oysters of commercial importance are species of two genera, Crassostrea and Ostrea. Species of Ostrea are more stenohaline than those of Crassostrea and are not commonly found in salinities below about 25 ‰, whereas Crassostrea are truly estuarine and occur abundantly in salinities down to about 10 ‰. Besides their tolerance to low salinities species of Crassostrea have other adaptations to estuarine conditions. Species of this genus have efficient morphological and physiological adaptations to live and feed in turbid water, which often occurs in estuarines, and can remain closed for extended periods to withstand such stresses as freshets, etc.

Oysters are sessile animals, except for a relatively brief larval period, and hence unable to escape adverse conditions. Thus they are very susceptible to all types of pollution. There are many instances of the detrimental effects of various types of pollution. Oysters have remained in poor condition because of the destruction of their food supply They are filter feeders and any stress that causes adverse changes in the phytoplankton affect the well being of the oysters A few examples will be given

A The Olympia oyster, Ostrea lurida, is the native species of our west coast and in former years supported a considerable fishery. O. lurida has been mostly replaced by the introduced Crassostrea gigas from Japan. One possible reason for the decline in the native O. lurida is the inability of this species to cope with the increased turbidity caused by man's activity, whereas C. gigas can survive under these conditions.

B Our native oyster on the Atlantic and Gulf coasts is Crassostrea virginica. It has been found that this species (probably better known biologically than any other of either genera) is very selective in its feeding habits, efficiently rejecting antagonistic types of food. In one instance oysters in Great South Bay, Long Island were found to be in very poor condition. Samples of the water showed abundant phytoplankton. Further investigation revealed that the species of phytoplankton that were abundant were rejected by the oysters. They were starving in "a sea of plenty." The "bloom" of the objectionable species of phytoplankton was determined to be caused by the increased nutrient load from the wastes of the duck farms on Long Island.

C Many productive oyster producing areas are condemmed because of health reasons. Untreated sewage increases the fertility of an area and in some areas where such conditions occur the oysters are very productive. As filter feeders, however, oysters concentrate pathogenic bacteria and viruses. The practice of consumption of raw oysters make them a health hazard.

D Industrial wastes, especially from paper mills, have caused direct mortality, as well as preventing growth in oysters. There have been many investigations of this type of pollution and the hazards are well documented.

E Oysters tend to concentrate many of the metals in their tissues. One indication of industrial pollution is the concentration of copper in the body tissues, in severe cases, manifested by a green color in the visceral mass. In such cases the oysters are invariably "poor."

F Oysters concentrate pesticides also, partly from the food source and direct absorption. Experimentally, oysters have been shown to concentrate DDT 150 times that of the surrounding medium.

G There have been instances where oysters have been killed by the silt from nearby dredging operations.

IV SHRIMP

Shrimp are our most valuable commercial seafood and species of the family Penaeidae account for the majority of the catch. Three species of Penaeid shrimp, the white, pink, and brown, are the most important and are caught in commercial quantities from North Carolina around to Texas, both in the estuarines and offshore, especially in the Gulf of Mexico.

The white, pink and brown (and some other species) spawn offshore and the postlarvae and young migrate into the estuaries (the smaller are often found in almost fresh water). The estuaries as nursery grounds are essential to the life history of the shrimp The life cycle is about one year and the estuaries not only serve as a nursery ground but in addition many are caught commercially in the bays and river mouths on their migration to the open water.

Several examples will be given of the effects of pollution.

A The marshes and grass beds are the ecological habitat of the very young shrimp (as they grow larger they move progressively to deeper water and seaward) and anything that destroys these habitats is detrimental to the shrimp. Dredging and filling operations are especially destructive.

B Shrimp are affected by industrial effluents also, but their motility allows them to escape unfavorable conditions. The ecological consequences of escaping unfavorable conditions caused by pollution are many and complicated. The polluted habitat may be necessary for the particular life stage. The escape from such a habitat may result in the movement to a less favorable habitat or if to a similar habitat, may result in overcrowding, especially in regard to the food supply, which is finite.

V SPOTTED SEA TROUT

The spotted sea trout, salt water trout, weakfish of squeteague, Cynoscion nebulosus, is an estuarine fish, especially in the warmer waters, where it seldom migrates seaward. In more northern areas there is a migration to the more stable waters of the near shore sea, during the coldest season. In Florida the spawning is in the less turbulent portions of the more saline estuaries and lagoons. The eggs sink to the bottom and hatching takes place in the bottom vegetation and debris. After hatching,the young scatter and are found in the vegetation; after 6-8 weeks the young begin to school. In Florida it has been found that the fish are largely non-migratory and each estuary has its own discrete population. The trout has a wide tolerance to changes in the estuarine habitat and in Florida has permitted this species to occupy niches that are intolerable to other large carnivorous fishes.

A Any pollution that affects the estuarine areas, including excessive siltation, too much reduction in salinity, toxic wastes, grass bed destruction, etc., would effect the species.

B Because of the non-migratory behavior (at least in Florida and probably other areas of the Gulf of Mexico), an estuary that is made unfit for the fish would not be readily recolonized by new recruits, when and if conditions become favorable again.

VI STRIPED BASS

The striped bass or rockfish, Roccus saxatilis, is a far ranging species and lives under conditions that are not estuarine in some instances (landlocked). The greatest production, however, is from areas where certain estuarine conditions are extensive.

The striped bass is a very valuable sport and commercial fish, especially along the Atlantic coast. The bass has been successfully transplanted to the Pacific coast and is found in certain freshwater impoundments, where the required ecological conditions exist. There is a relatively small population along the Gulf of Mexico and management is aimed at increasing the supply.

Spawning is in fresh water where the eggs are broadcast by the females and fertilized by one or more males. The eggs are semi-buoyant and are kept suspended by currents. If laid in quiet waters the eggs sink, become smothered and die. Hatching occurs in 2-3 days in 15.5-18°C and normally in estuarine areas the young have been carried to low saline water by the time the yolk sac is absorbed. Fresh water seems essential for spawning although eggs can develop normally in salinity up to 4‰.

There are several so-called land-locked populations of striped bass, the best known is in the Santee-Cooper Reservoir in South Carolina. The reason for the continued existence of these populations is that streams flow into the reservoir and the currents keep the eggs in suspension until they hatch. Other reservoirs, although of large size, may lack these streams, and stocking of these has been unsuccessful.

The effects of pollution on aquatic life have been discussed in the preceding examples and only a few specific examples will be given.

A The Chesapeake Bay is the area of greatest numbers of striped bass and the population seems to be increasing despite a continuing increase in pollution. The semibuoyant eggs, kept in suspension by currents, seems well adapted to silted conditions. There is a suggestion that perhaps other competing species do not have the adaptations to survive readily with increased silt load, resulting in an increase in the bass.

B Striped bass are susceptible to industrial pollution, especially during the spawning migrations to fresh water. After spawning the fish are emaciated and the added effect of toxic conditions render the conditions intolerable. Nonspawning fish could escape these stresses through migration.

C Dams are very detrimental to striped bass, in that they are prevented from reaching their spawning grounds. If adults are trapped behind dams or stocked in impoundments, the successful spawning and hatching of the eggs are prevented by the ecological conditions discussed previously.

This outline was prepared by Dr. Winston Menzel, Associate Professor of Biological Oceanography, Florida State University, Tallahassee, FL.

PROCEDURES FOR FISH KILL INVESTIGATIONS

I INTRODUCTION

Fish kills in natural waters, though unfortunate, can in many instances indicate poor water quality leading to investigations which may improve water quality. Prompt investigations should be organized and conducted so that the resultant data implicates the correct cause. Fish kills tend to be highly controversial, usually involving the general public as well as a number of agencies Therefore, the investigator can expect his findings to be disputed, quite possibly in a court of law

The following procedures are presented as a working guide for investigating and reporting fish kills as developed by the personnel of The Lower Mississippi River Comprehensive Project (FWPCA).

II TYPES AND EXTENT OF FISH KILLS

A Natural Mortalities - Those which are caused through natural phenomena such as, acute temperature change, storms, ice and snow cover, decomposition of natural materials, salinity change, spawning mortalities, parasites, and bacterial or viral epidemics.

B Man caused fish kills - Produced by environmental changes through man's activity, and may be attributed to municipal wastes, industrial wastes, agricultural activities and water control activities.

C One dead fish in a stream may be called a fish kill, however, in a practical sense some minimal range in number of dead fish observed plus additional qualifications should be used in reporting and classifying fish kill investigations. The following definitions should be used as guidelines in reporting fish kill investigations. These qualifications are based on a stream approximating 200 feet in width and 6 feet in depth. For other size streams, adjustments should be made.

1 Minor fish kill considered here as NO fish kill and reported so 1 - 100 dead or dying fish confined to a small area or stream stretch. Providing this is not a reoccurring or periodic situation. For example, near a waste outfall in which stream dilution plays its part and nullifies the effect of the deleterious material. If this is a reoccurring situation, it could be of major significance and, therefore, investigated.

2 Moderate fish kill· 100 - 1000 dead or dying fish observed. In a stream where dilution has had the chance to play its role involving a mile or so of stream, a number of species are affected, and apparently normal fish can be collected immediately downstream from the observed kill area.

3 Heavy fish kill 10,000 fish or more observed dead or dying. In a stream where dilution has had the chance to play its part, but ten miles or more of the stream are involved, many species of fish are affected and dying fish may still be observed downstream.

III PREPARATION FOR FIELD INVESTIGATION

A Secure maps of area to be investigated.

1 U.S. Geological Survey maps

a 1/250,000 scale for general location

b 1/24.000 for accurately defining the kill area in the field

2 Navigation maps (appropriate agency)

3 Other sources

4 From the data received from the reporting agency, locate the kill area on the map.

a Determine best access points.

b Locate possible known industries, municipalities, or other potential sources of pollution.

c Estimate the possible area to be traveled or inspected on

1) water

2) land

3) both

B Secure sampling equipment and determine size of investigation team needed.

1 Standard equipment to be taken on all investigations (a standard checklist with space for special equipment will often save embarrassment in the field.)

a Thermometer

b Dissolved oxygen sampler

c D.O. bottles

d Winkler D.O. test kit

e Conductivity test meter

f pH test meter or chemical kit

g Sample bottles

h Pencils and note paper

i Current edition of "Standard Methods for the Examination of Water and Wastewater"

2 If preliminary information is available on the possible cause of the kill, consult the latest edition of "Standard Methods" for specific physical and chemical equipment required for collecting, analyzing, or preserving samples possibly containing the suspected causative agent.

3 Form an investigating party

a If only one man is available to make the investigation, preference for choosing the man should be in this order

1) Specialized professional personnel, such as, engineer, chemist, or biologist who is experienced in investigating fish kills and who is capable of adequately reporting the technical aspects of the investigation.

2) A non-specialized professional engineer, chemist, or biologist who has little or no experience in fish kill investigations, but who is capable of adequately reporting the technical aspects of the investigation.

3) A technician who has considerable field experience in pollution and fish kill investigations and who is capable of reporting some of the technical aspects of the investigation.

4) An office technician or other personnel who has had limited field work in pollution investigations.

b If two or more men are needed for the investigation, the party should include at least one person under category (1) above. Preferably, the team should include:

1) A biologist to make a survey of the biological changes.

2) An engineer to make an evaluation of the physical condition of the fish kill area and to make an investigation of an industry or a municipal wastewater treatment plant if needed.

c If a fish kill is observed in its initial state in the field by any one of the people listed under the classification in Section B.3.a., the project office should be informed immediately (after working hours the project director or deputy director should be informed) so that an adequately equipped, specialized investigating party can be formed if needed.

C Contact personnel of the laboratory or laboratories which will participate in analyzing samples. If possible estimate the following and record on sample form No. 1.

1 The number and size of samples to be submitted

2 The probable number and types of analyses required

3 The dates the samples will be received by the laboratory

4 Method of shipment to the laboratory

5 To whom the laboratory results are to be reported

6 The date the results are needed

IV MAKING THE FIELD INVESTIGATION

A Contact the local lay person or official who first observed the kill and reported it.

1 Obtain any additional information which might be helpful which was not reported previously.

2 If possible, retain the reporting party as a guide or invite him to accompany the investigating team.

B Make a reconnaissance of the kill area.

1 Make a decision as to the extent of the kill and if a legitimate kill really has occurred.

2 If a legitimate kill exists take steps to trace or determine the cause.

a Always perform the following physical or chemical tests, during the initial steps of the investigation

1) Temperature

2) pH

3) Dissolved oxygen

4) Specific conductance

While none of these factors may be directly involved in the kill these tests are performed simply and rapidly in the field and can be used as a baseline or starting point for isolating the cause (s) of the kill.

b Record other physical observations such as

1) Appearance of water, i.e., turbidity, high algal blooms, oily, unusual appearance, etc.

2) Stream flow pattern, i.e., high or low flow, stagnant or rapidly moving water, tide moving in or out, etc. If possible obtain reading from stream gage if one is near kill area.

3) Weather conditions prevailing at the time of the investigation and information on weather immediately prior to the kill

3 Make a rough sketch or define the kill area on a map so that sampling points, sewer outfalls, etc. can be accurately located on a drawing to be included in a final report.

4 Take close-up and distance photographs of:

a Dead fish in the stream in the polluted area.

b The stream above the polluted area.

c Wastewater discharges.

Photographs will often show a marked delineation between the wastewater discharge and the natural flow of water. Pictures taken at a relatively high elevation, (a bridge as opposed to a boat or from a low river bank) will show more and be more effective. Color photographs are also more effective in showing physical conditions of a stream in comparison to black and white prints.

C Sampling Procedures - The extent and method of sampling will depend upon location and upon the suspected cause of the kill.

1 Stream and wastewater sampling.

a Sample the following points when the pollutional discharge is coming from a well defined outfall.

1) The effluent discharge outfall

2) The stream at the closest point above the outfall which is not influenced by the waste discharge

3) The stream immediately below the outfall

4) Other points downstream needed to trace the extent of the pollution

b The sampling should be extensive enough that when all the data is compiled no question will exist as to the source of the pollution which killed the fish.

c The number of samples to be collected at a given cross section will depend principally on the size of the stream.

1) Streams less than 200 feet wide, not in an industrial area usually can be adequately sampled at one point in a section (Figure 1).

2) Streams 200 feet or wider generally should be sampled two or more places in a section immediately above and below the pollutional discharge, where the pollutional waste has adequately mixed with the stream flow one sample may suffice.

3) A number of samples in a cross section may be required on any size of stream to show that the suspected pollutional discharge is coming from a source located in an industrial or municipal complex (Figure 2).

4) Extensive cross sectional sampling on rivers greater than 200 feet wide will be required for kills involving suspected agricultural or other types of mass runoff.

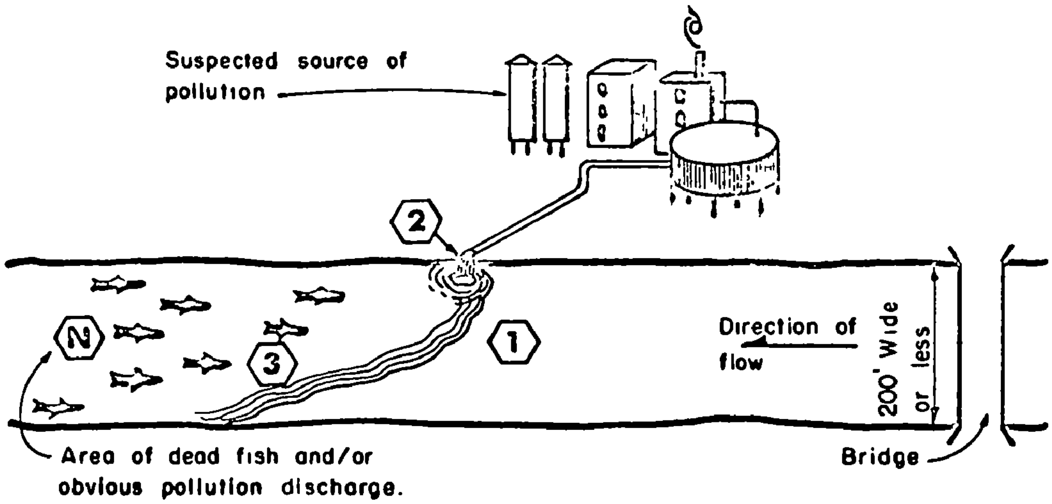

Figure 1 — Minimum Water Sampling Point On Stream 200 Feet Or Less Wide Involving An Isolated Discharge.

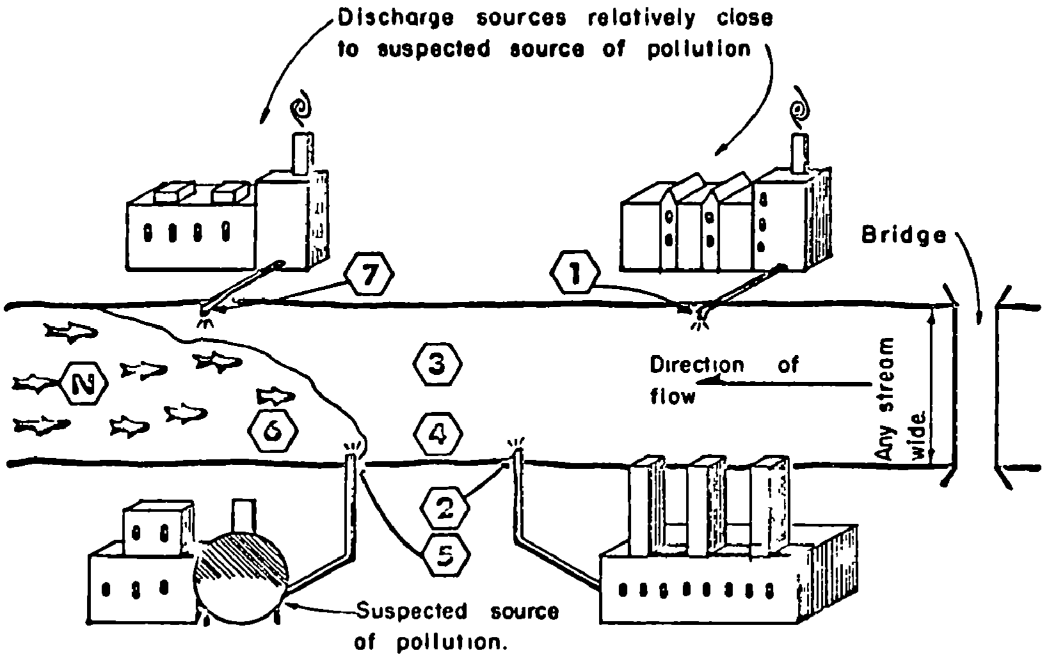

Figure 2 — Minimum Water Sampling Points On A Stream Running Through An Industrial Or Municipal Complex.

PLATE I - RELATIONSHIP OF FISH KILLS TO SOURCE OF TOXICITY

5) Sample depths - On streams 5 feet in depth or less, one mid-depth sample per sampling locations. For streams of greater depths, appropriate sampling judgment should be used, since stratification may be present.

Explanation of Plate I

1) Collection point 1, Figure 1 and points 3 and 4, Figure 2 should be collected as near to the point of pollutional discharge as possible. These points will vary according to stream flow conditions, the pollutional discharges into a slow sluggish stream usually will have a cone of influence upstream of the outfall; whereas, a swift flowing stream usually will not.

2) Collecting an upstream control sample from a bridge within sight of the pollutional discharge would probably be satisfactory in Figure 1 but definitely not in Figure 2.

3) Figures 1 and 2 are given for illustrative purposes only and should be used only as a guide for sampling. Thought must be given to each individual situation to insure adequate, proper sampling. While too many samples are better than too few, effort should be made not to unduly overload the laboratory with samples collected as a result of poor sampling procedures.

2 Biological sampling

a In every investigation of fish or wildlife kills the paramount item should be the immediate collection of the dying or only recently dead organism. This may be done by anyone, sampling and preservation is as follows:

1) Collect 20 plus drops of blood in a solvent rinsed vial, seal same with aluminum foil, cap and freeze.

2) Place bled carcass, or entire carcass if beyond bleeding stage, in plastic bag and freeze. In case no method of freezing is available, icing for a short period prior to freezing may be acceptable. Labeling of both blood and carcass is important.

3) Controls - live specimens of the affected organisms should be obtained from an area within the same body of water which had not been influenced by the causative agent. Once obtained these specimens should be handled in a like manner.

b The number of individuals involved and the species affected should be enumerated in some manner. At most these will be estimates. Depending on the given situation such as area or distance involved and personnel available enumeration of fish kills may be approached in one of the following ways.

1) For large rivers, establish observers at a station or stations (e.g., bridges) and count the dead and/or dying fish for a specified period of time, then project same to total time involved.

2) For large rivers and lakes, traverse a measured distance of shoreline, count the number and kinds of dead or dying fish. Project same relative to total distance of kill.

3) For lakes and large ponds, count the number and species within measured areas, and then project to total area involved.

4) For smaller streams one may walk the entire stretch involved and count observed number of dead individuals by species.

3 Biological sampling Macro-Invertebrates:

a Sampling of benthic organisms after the more urgent aspects of the kill investigation has been completed can prove to be rewarding relative to extent and cause of kill. Since this general form of aquatic life is somewhat sedentary by nature any release of deleterious materials to their environment will take its toll. Thus by making a series of collections up and downstream, the affected stretch of stream may be delineated when the benthic populations are compared to those from the control area. Also the causative agent may be realized when the specifics of the benthic population present are analyzed.

b Other aspects of the biota which should be considered are the aquatic plants. In lakes and ponds floating and rooted plants should be enumerated and identified. The collection of plankton (rivers and lakes) should be taken in order to determine the degree of bloom, which in itself may cause fish kills because of diurnal DO levels.

c Both aquatic plants and macro-invertebrates may be preserved in a 5% formalin solution.

4 Bioassay

Static bioassay techniques as outlined in Standard Methods may be effectively used to determine acute toxicity of wastes as well as receiving waters.

a In situ using live boxes

b Mobile bioassay laboratory

c Samples returned to Central Lab for toxicity tests

V DETAILED EXAMINATION OF SOURCE OF POLLUTION

A Seven general categories under which causes of kills can be grouped are.

1 Industrial waste discharges

2 Waste discharges from municipal sewerage systems

3 Water treatment plant discharges

4 Agriculture and related activities

5 Temporary activities

6 Accidental spills of oil and other hazardous substances

7 Natural causes

B Industrial Waste Discharges

1 Upon locating the outfall source, collect a sample immediately if possible at the point where the wastes leave the company property.

2 Make an in-plant inspection if possible.

a Contact the plant manager or person in charge

b Request a brief tour of the facilities

c Obtain general information concerning the products manufactured; raw materials, manufacturing process, quantities, sources, and characteristics of wastes, and waste treatment facilities if any. Possibly the company may be able to supply a flow diagram or brochure of the plant operations.

d Request specific information concerning the plant operation immediately prior to the start of the kill.

C Waste discharges from a municipal or domestic type sewerage system

1 Discharges from this source may be domestic sewage and industrial wastes combined with domestic sewage. These wastes may be subjected to treatment of a municipal treatment plant or may be discharged directly, untreated to a stream

2 Generally, the municipality or owner of the sewerage system is held responsible for any discharge in such a system, consequently, after collecting samples, the owner or a representative of the owner of the sewerage system should be contacted. This may be a sewage treatment plant operator, city engineer, public works supervisor, a subdivision developer, etc.

a Obtain information about the operation of the system.

b If the cause of the kill was the result of an industrial waste discharge to a municipal sewer and thence to a stream, information should be obtained from a municipal official about the industry and the problem An inspection of the industrial plant may be desirable. Generally, this should be done only in cooperation with a municipal official.

D Agriculture and Related Activities

1 Pollution capable of causing fish kills may result from such agricultural operations as crop dusting and spraying fertilizer applications, and manure or other organic material discharges to a stream.

2 Generally, kills related to these factors will be associated with high rains and runoff.

3 The source or type of pollution may be difficult or impossible to locate exactly. It may involve a large area. Talking to local residents may help pinpoint the specific problem area. Runoff from fields, drainage ditches, and small streams leading to the kill area are possible sampling places which may be used to trace the cause

E Temporary Activities

1 Causes of kills may result from such temporary or intermittent activities as mosquito spraying, construction activities involving chemicals, oils, or other toxic

substances, and weed spraying with herbicide containing materials toxic to fish such as arsenic.

2 As with agricultural activities, tracing the cause of these kills is difficult and may require extensive sampling.

3 Accidental spills from ruptured tank cars, pipelines, etc., and dike collapse of industrial ponds are frequently sources of fish kills.

F Possible Natural Causes of Fish Kills

1 Types of natural causes

a Oxygen depletion due to ice and snow cover on surface waters

b Oxygen depletion at night because of plant respiration or at anytime during the day because of natural occurring organics in the water

c Abrupt temperature changes

d Epidemic and endemic diseases, parasites, and other natural occurring biological causes

e Lake water inversion during vernal or autumnal turnover which results in toxic material or oxygen-free water being brought to the surface

f Interval seiche movement in which a toxic or low DO hypolimnion flows up into a bay or bayou for a limited period of time, and later returns to normal level

2 Fish kills in rivers below high dams immediately following the opening of a gate permitting hypolimnionic water to flow down the stream (as in TVA region)

VI CASE HISTORY

A The Lower Mississippi Endrin kill is an excellent example of the investigation of a major fish kill Bartsch and Ingram give the following summary (See Table 1)

TABLE 1

ELEMENTS OF INVESTIGATIONS

I Examination of usual environmental factors

II Elimination of parasites, bacterial or viral diseases and botulism as causes of mortalities*

III Considerations of toxic substances Examination and prognostication of symptoms of dying fish Autopsy, including·

- Haematocrits and white cell counts
- Kidney tissue study
- Brain tissue assay for organic phosphorus insecticide
- Tissue analysis for 19 potentially toxic metals
- Gas chromatographic analysis of tissues, including blood, for chlorinated hydrocarbon insecticides

IV Explorations for toxic substances

- Bioassay with Mississippi River water
- Bioassay with extracts from river bottom mud
- Bioassay with tissue extracts from fish dying in river water and bottom mud extracts
- Bioassay with endrin to compare symptoms and tissue extract analyses with those of dying fish in all bioassays

V Intensive chemical analysis for pesticides in the natural environment, experimental environment, river fish, and experimental animals

VI Surveillance of surface waters for geographic range and intensity of pesticide contamination

VII Correlation and interrelation of findings

* The investigator should be aware of the fact that apparently healthy fish may be harboring pathogenic bacteria in their bloodstreams (see Bullock and Snieszko) Thus there may be several factors involved in fish mortalities all of which may obscure the primary cause or causes

The investigation was designed to consider and eliminate potential fish kill possibilities that were not involved and come to a point focus on the real cause. It was found that the massive kills were not caused by disease, heavy metals, organic phosphorus compounds, lack of dissolved oxygen or unsuitable pH. Blood of dying river fish was found to have concentrations of endrin equal to or greater than laboratory fish killed with this pesticide, while living fish had lesser concentrations. Symptoms of both groups of dying fish were identical. It was concluded from all data obtained that these fish kills were caused by endrin poisoning.

B Recent investigations in Tennessee have shown that the leaking of small amounts of very toxic chemicals from spent pesticide-containing barrels used as floats for piers and diving rafts in lakes and reservoirs can produce extensive fish kills. The particular compound used to control slime growth in manufacturing processes, contained two primary chemicals in solution (phenylmercuric acetate and 2, 4, 6-trichlorophenol) The former compound which breaks down to form diphenylmercury was found to be more toxic to aquatic life than the latter.

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11 Muncy, Robert J. Observations on the Factors Involved with Fish Mortality as the Result of Dinoflagellate "Bloom" in a Freshwater Lake. Proc. 17th Ann. Conf. Southeastern Assoc. of Game & Fish Commissioners. pp. 218-222.

This outline was prepared by Jack Geckler, Research Aquatic Biologist, Fish Toxicology Activities, EPA, Newtown, OH 45244

Project Personnel Contacted

a. Name ____________________

b. Means of Contact ____________________

c. Date & Time ______________

1. Reporting source

   a. Agency ____________________

      (1) Address ____________________

      (2) Phone (s) ____________________

   b. Individual ____________________

      (1) Address ____________________

      (2) Phone ____________________

      (3) Fish Kill Network __________ yes __________ no

   c. Other Contacts ____________________

      (1) Address ____________________

      (2) Phone ____________________

      (3) Fish Kill Network __________ yes __________ no

2 Data furnished by reporting source

   a. Location of Kill ____________________

   b Dates of Kill ______________ Dying last observed ______________

   c. Kinds of organisms ____________________

   d. Approximate number killed ____________________

   e. Cause of kill (if known) ____________________

   f. Suspected causative sources ____________________

   g. Measures taken ____________________

   h. Other Agencies contacted ____________________

      (1) Date and Time ____________________

3. Action requested

   a. Field investigations ____________________

   b. Laboratory analysis ____________________

4. Assistance to Project

   a. Provided by ____________________

   b Personnel ____________________

   c. Equipment ____________________

   d. Transportation facilities ____________________