PRODUCTIVITY OF FLORIDA SPRINGS
NONR 580(02)

First Semi-annual Report to
Biology Division
Office of Naval Research
Progress from June 1, 1952 to January 31, 1953

Howard T. Odum

With sections by John H. Davis, William Sloan,
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31 January 1953
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Chief of Naval Research
Attn: Biology Branch (Code 446)
Department of the Navy
Washington 25, D. C.

Dear Sir:

Herewith please find the first semi-annual report of progress on a project, NONR 580(02), concering "Productivity of Florida Springs."

You will note that work during the first six months has included much exploration of possibilities. I believe that Dr. Odum has made real progress and is now in a position to center down on a more intensive study of the best possibilities among the numerous promising opportunities that he has uncovered.

Respectfully submitted,

W. C. Allee

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Department of Biology

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ABSTRACT

Productivity in the Springs of Florida

Work has begun on studying the factors responsible for productivity in the Florida springs, which are nearly constant temperature, constant chemical, steady state giant laboratories. Progress has been made on five aspects: qualitative description, quantitative description, completion of knowledge of chemical factors, measurement of productivity, development of productivity theory.

Measurement of the primary productivities in Silver Springs and Green Cove Springs by two new methods: the raising of organisms in cages, and the measurement of night day differences in oxygen downstream agree roughly. Production in these springs is greater than previous production figures reported for marine, fresh water, and land areas. Instantaneous measures of production show large variations with season, time of day, and cloud cover. Production estimates range from 11,000 lbs. per acre per year to 70,000 lbs. glucose per acre per year during daylight hours.

Essential stability of the springs environment has been shown with respect to temperature, phosphorus, and plant cover. A correlation of species number with lack of stability has been shown with insects. Quantitative studies have shown very large plant base to pyramids of mass. Correlation of marine invasion with chlorinity has been shown. The essential aspects of pH regulated phosphorus geochemistry in Florida have been outlined. Some theoretical ideas on productivity have been evolved. Mapping of sessile organisms in springs and taxonomic identification of dominants are half completed. Plans for second six months include measurement of herbivore and carnivore production rates and completion of food chain efficiency determinations in Silver Springs as a preparation for subsequent comparisons between springs.

INTRODUCTION

Springs of Florida

By a remarkable circumstance of nature there are many large springs in the vicinity of Gainesville, Florida. These springs have a relatively constant temperature of 71 to 74 degrees F. throughout the year and are all at this temperature. There are many varied types, and all contain aquatic communities in their basins and their outflow channels. Each spring differs from the others by a few factors. Thus there are sodium springs, calcium springs, springs with high and others with low oxygen-reduction potentials, saline springs, soft water springs, and other types. Analyses of many of the major chemical elements in these waters have already been published. *(Ferguson, G. E., Lingham, C. W., Love, S. K., and Vernon, R. O., Springs of Florida, Geological Bulletin No. 31, State of Florida Department of Conservation, Tallahassee, 1947) Oxygen, phosphorus and nitrogen had until recently not been analyzed.

Because of their special properties these springs are collectively a giant constant temperature laboratory. The flow of water of constant quality in the various springs bathes the spring communities with a constant medium in spite of the actions of the community that modify the water. For the first time it is possible to compare whole communities which are maintained under constant conditions that differ by only a few factors.

The spring "runs" provide gradients of conditions in which the patterns of the communities may be related. Because the rate of flow of each run is relatively constant a distance down the run corresponds to a time interval following the first meeting of sunlight and water. Thus the spring run can be used to study rates of productivity. Several of the runs involve a transition from fresh water to sea water of the ocean. The remarkable phenomenon of fresh water fish mingling with salt water fish in fresh water springs provides an opportunity to study the differences between communities exposed to predation of salt water species and similar springs inland having only fresh water fish as predators. Some springs have oxygen gradients. Some have fish populations and some are isolated from such populations.

Thus there exists a marvelous opportunity to study productivity in the ready-made natural laboratory in which whole communities can be studied under controlled conditions. The series of natural experiments that have been set up seem ideal for studying the role of the factors that control productivity.

Purpose and Scope of Investigation

The purpose of this research is to study the basic factors controlling individual, population, and community productivity by an analysis of the unique conditions supplied by outflows from selected constant temperature springs.

The general plan is to establish the qualitative and quantitative structure of contrasting springs, measure the production rates, and determine factors responsible for differences by comparison and experiment.

Funds from ONR, University of Florida, and a small grant ($500) for phosphate work by Florida Geological Survey have provided support of the principle investigator full time in summer, one graduate student and one undergraduate assistant throughout the year, and other students and faculty with field trip expenses.

Personnel and Acknowledgements

This project is a cooperative endeavor. Department head Dr. W. C. Allee has made a significant contribution in planning. Dr. Howard T. Odum has been coordinator and as principal investigator emphasized chemical composition, production rate measurements, and productivity theory. Mr. William Sloan has emphasized the qualitative composition of invertebrate fauna, especially insects, using species-number community analysis. This has been part of his work towards the masters degree. Dr. John H. Davis has investigated the quantitative standing crop of aquatic plants in relation to salinity in coastal spring runs. The Florida Geological Survey has supported Mr. Richard Highton during the summer, 1952, for analysis of phosphorus in these springs and other waters. Dr. A. M. Laessle has developed a herbarium collection of aquatic higher plants from the springs. Essential taxonomic aid has been provided by : Dr. M. J. Westfall, Dr. L. Berner, Mr. John Crenshaw, Mr. Robert Cummings, Dr. C. J. Goin, all of the University of Florida; Dr. H. J. Humm, Oceanographic Institute, Florida State University; and Dr. Horton Hobbs, University of Virginia. Preliminary experiments in springs have been conducted by Mr. Gordon Broadhead, and Mr. David Caldwell, University of Florida.

Special courtesies have been received from Mr. William Ray, Manager, Silver Springs; Mr. Ross Allen and Mr. Wilfred Neil of Ross Allen Reptile Institute; Mr. Elmo Reed, Manager of Homosassa Springs; Mr. Ray Bullard, Manager of Weekiwachee Springs; Mrs. Winifred Dean, Chassahowitzka Springs; and Mr. Harvey, Green Cove Springs.

Procedure

Investigations into the factors controlling productivity can be classified under 5 headings probably in inverse order of importance:

1. Characteristics and stability of non-living environment
2. Qualitative composition of communities
3. Quantitative composition of communities
4. Productivity
5. Productivity theory

During this first half year an effort has been made to obtain results in each of the five divisions. Efforts to develop a methodology for measuring standing state composition and productivity have been restricted to 7 contrasting springs although systematic initial surveys have been made on 40 springs. Since the measurement of production rates is at the heart of the objectives of the project, these studies have been begun even though descriptive qualitative and quantitative aspects of the varied springs are not yet completed. Progress is summarized below under 5 headings.

PROGRESS

1. CHARACTERISTICS AND STABILITY OF NON-LIVING ENVIRONMENT

Phosphorus

To date 125 analyses of phosphorus (inorganic and total) have been made in 33 springs to establish the magnitude, variation, and form of phosphorus in these constantly replenished flow systems. The analyses in springs have been compared with 300 phosphorus analyses from streams, lakes, pools, and estuaries made with financial support of the Florida Geological Survey.

Results so far have established the following patterns of phosphorus distribution:

1. In the large springs with strong flow the phosphorus content is remarkably constant with distance down the run even through heavy plant beds. The data from Silver Springs in table 1 indicate these properties.

2. The phosphorus content of these clear waters is primarily in dissolved inorganic form.

3. The variation of phosphorus content with time is low, indicating that even with minor, biologically active elements, some of the spring environments at least are relatively constant.

4. The dissolved phosphorus in springs although moderate in concentration is available to plants in apparently excess reserve amounts due to the continual outflow of water. In some springs such as Green Cove (table 2) some preliminary evidence shows definite modification of phosphorus content. Highly variable dissolved-phosphorus values were obtained over the wide sluggish lower reaches of Chassahowitzka Springs where the velocity of water relative to plant volume is small.

5. The dissolved phosphorus in springs is relatively small in comparison to very large amounts found in the acid surface streams that flow across phosphatic rich sedimentary rock formations. Solubility properties of phosphorus and pH seem to be regulative. Soft acid surface waters percolating into artesian aquifers become hard and basic and lose the excessive phosphorus concentrations. A complete discussion of this hypothesis with data to support was submitted in report to the Florida Geological Survey (Howard T. Odum with assistance of Richard Highton: Dissolved phosphorus in Florida waters. Report to the Florida Geological Survey, January 22, 1953, tentatively considered for Bull. of Fla. Geol. Survey, 70 pp manuscript). Table 3 includes comparisons pertaining to phosphorus geochemistry.

Table 1
Phosphorus Values in Silver Springs Run

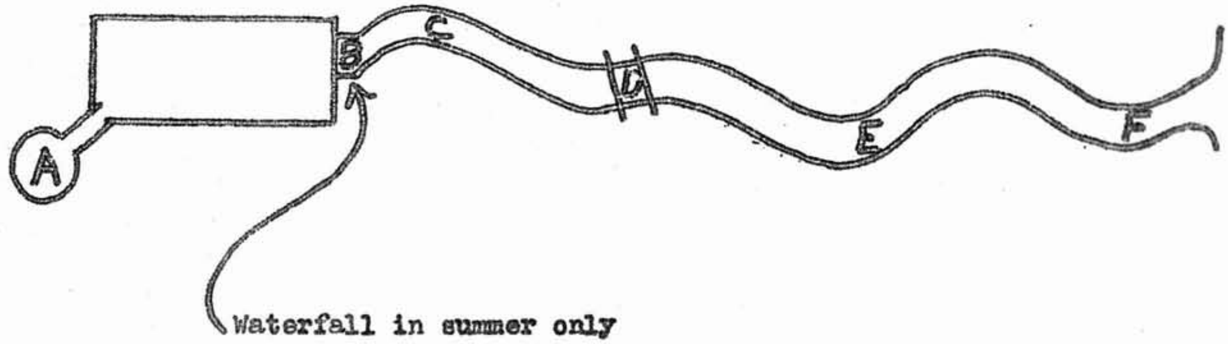
	ppm P	
	Inorg. P	Total P
Aug. 9, 1952; cloudy, 2:30 p.m.		
Boil	.041	.047
1/8 mile	.045	-
½ mile	.045	.047
1 mile	.040	.046
1½ mile	.051	.053
2 mile	.043	.046
2½ miles	.042	.046
3 miles	.041	.041
4 miles	.040	.048
5 miles	.043	.046
Mean	.0431	.0466
Standard Deviation	.00332	.00307
95% of analyses with less error than	15%	13%

(Organic phosphorus: .0035 ppm, 7.5% of total phosphorus.)

July 15, 1952	Boil	-	.045
Aug. 16, 1952	Boil	.036	-
Sept. 3, 1952	Boil	-	.061
June 30, 1952	5 miles down run	.050	.040
June 30, 1952	in littoral *Najas* bed	.025	.027

Table 2 and Figure 1

Chemical and Biological Properties of Green Cove Springs



	A Boil	B Pool Outlet	C Rapids	D Bridge	E Curve	F Curve
SUMMER (1952)						
July 16; clear afternoon:						
Temperature	25.3	26.1	25.9	25.9	26.2	26.7
Oxygen, ppm	0.0	1.6	4.6	4.8	5.5	6.1
Inorg. P, ppm	.022	-	.041	.018	.008	.005
Aug. 10, night series, 10. p.m.:						
Oxygen, ppm	.3	1.4	4.0	3.4	3.4	3.3
Inorg. P, ppm	.005	-	.005	.004	.005	.005
Total P, ppm	.006	.006	.005	.006	.012	.008
Sulfur Bacteria	/-------	-------	-------/			
Vallisneria beds			/-------	-------	-------	-------/
WINTER						
Jan. 27, 1953; clear morning:						
Oxygen, ppm	0.0	1.6	-	2.4	2.6	3.2
CO_2, ppm	.5	-	.6	1.9	1.6	1.1
Temperature	-	-	-	24.6	-	24.4
Jan. 27, 1953, night, 10 p.m.						
Oxygen, ppm	0.0	1.4	2.2	2.1	2.2	2.6
CO_2 ppm	.4	1.4	1.4	1.6	2.8	2.2
Nitrate N, ppm	0.00	-	0.00	.02	.09	.17
Sulfur Bacteria	/-------	-------	-------	-------	-------/	
Vallisneria beds			/- bare spots	-------	-------	-------/

Table 3
Phosphorus in Types of Florida Waters
(# of cases in parentheses)

Water Types	ppm Total P	
	Phosphate district	Other areas
Streams	.876 (18)	.046 (44)
Estuaries	.269 (2)	.044 (21)
Lakes	.290 (8)	.038 (31)
Springs	.061 (5)	.045 (27)

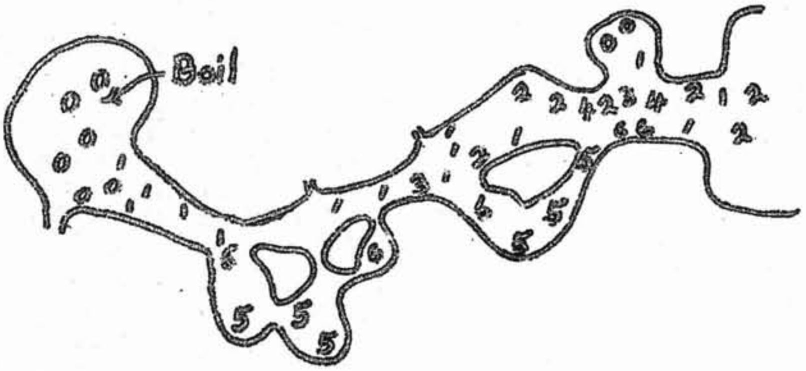
Temperature, Thermistor

Measurements of temperature have been made to verify the essential constancy of the springs environment. In Silver Springs as one passes down the 5 mile run November 13, 1952, with an air temperature of 12 degrees C. the temperatures in Silver River are from the boil down: 23.0, 22.5, 22.8, 22.8, 22.1, 22.1, 22.0. Thus the variation is within a degree even when the air temperature is low for average winter conditions. One June 30 the water beginning at boil temperature of 23.0 increased to 24.0 5 miles down the river. Larger ranges are to be expected in the lower reaches of more sluggish spring runs.

The water temperatures at a time when the air temperature is higher or lower than that of the boil temperature can be used to locate zones of mixing and zones of stagnant water. To make possible rapid mapping of horizontal temperature distribution, a thermistor and bridge apparatus was constructed. Using the thermistor 6 inches deep off the prow of the boat a map of Silver Springs showed the type of pattern in figure 2. Clearly there is continual mixing throughout most of the spring run. A spring such as Silver may serve to determine rates of air-water exchange.

Figure 2
Portion of Silver Springs Run
Aug. 18, 1952 3:00 p.m. cloudy

Temp. = 23.0 + tenths:

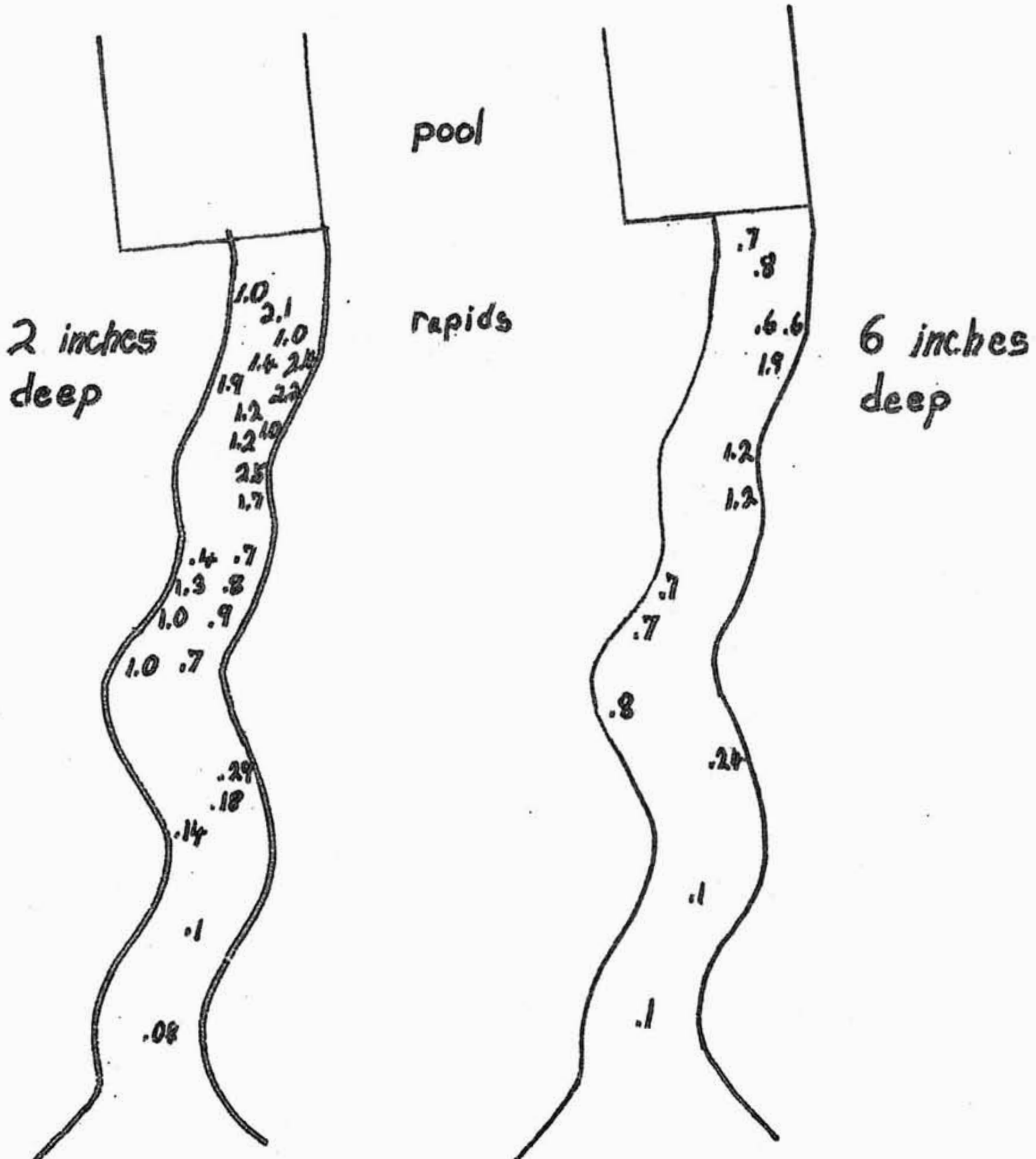


Current

The current structure may be postulated to be relatively constant since the variation in the rate of discharge of the springs is small. Ferguson, Lingham, Love, and Vernon (cited above) show an annual variation in the discharge from Silver Springs of about 20%.

The map in figure 3 was made with a midget current meter in order to get some idea of the patterns of current velocity in horizontal aspect, which may be important in controlling the distribution of organisms.

Figure 3
Current Velocities in Green Cove Springs
Feet per Second
Width Scale exaggerated 3 times



Salinity Gradients

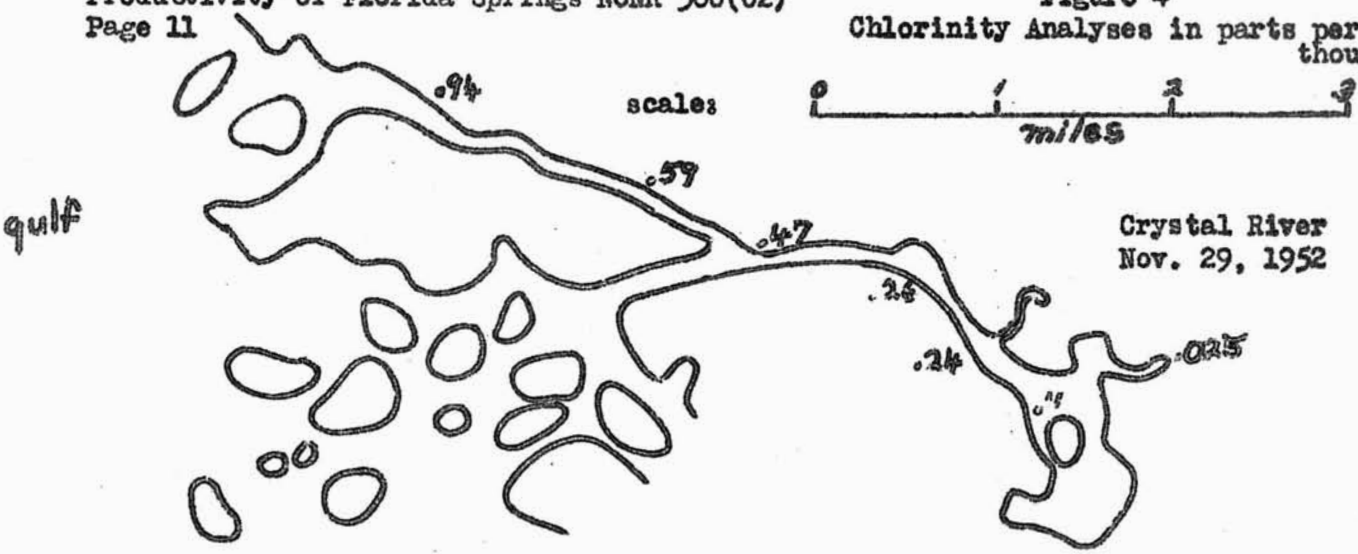
Many of Florida's springs originate in strata which still contain salt possibly left in the pore spaces by the last Pleistocene flooding of lowland areas. These springs are slightly saline, some in the brackish range. The arrangement and pattern of springs and runs are especially adapted to testing effects of salinities on natural aquatic communities in toto.

One group of 4 coastal springs of large size have parallel runs 7-10 miles to the Gulf. These spring complexes are, in order of increasing salinity: Weekiwachee, Chassahowitzka, Homosassa and Crystal River. Initial analyses of the salinities in the runs of these springs are plotted on the map in figure 4. Three boils have salinities logarithmically spaced but with the same calcium concentrations. The runs, as they approach the coast, increase in salinity first due to smaller tributary salty springs and ground waters with gradually increasing salinity, and finally due to tidal waters in the last few miles. A strong distinct tidal wave moves up these narrow runs many miles beyond any salt water of marine origin. The wave affects the pulse of the spring run but does not reverse the flow except at the mouth. The geochemical factors which are in operation have produced gradual salinity gradients which are of much more constant type than the usual sharply fluctuating estuary.

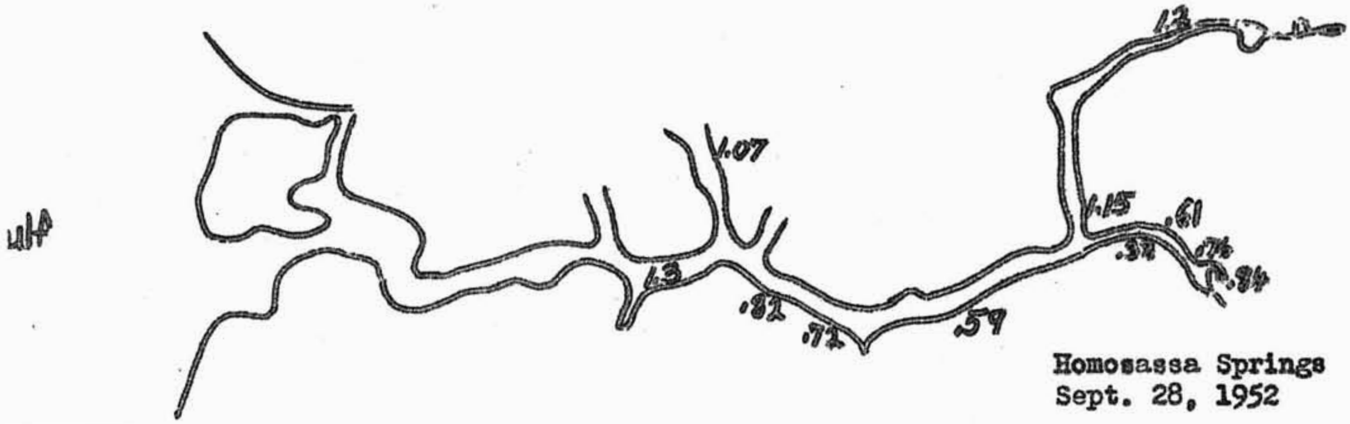
This remarkable natural salinity laboratory has already been the basis of some investigations discussed below: the invasion of marine fish and crabs, the distribution of aquatic plants, the distribution of insect fauna, and comparisons of fauna in stable and changing parts of the same stream.

Further comment on the geochemistry of these springs is included in a paper ready for publication: The Geochemistry of sodium chloride as a factor controlling the invasion of marine fauna into Florida fresh waters. This was presented at American Society of Limnologists and Oceanographers 1952 session at Cornell in September. The essence of the biological aspect follows below:

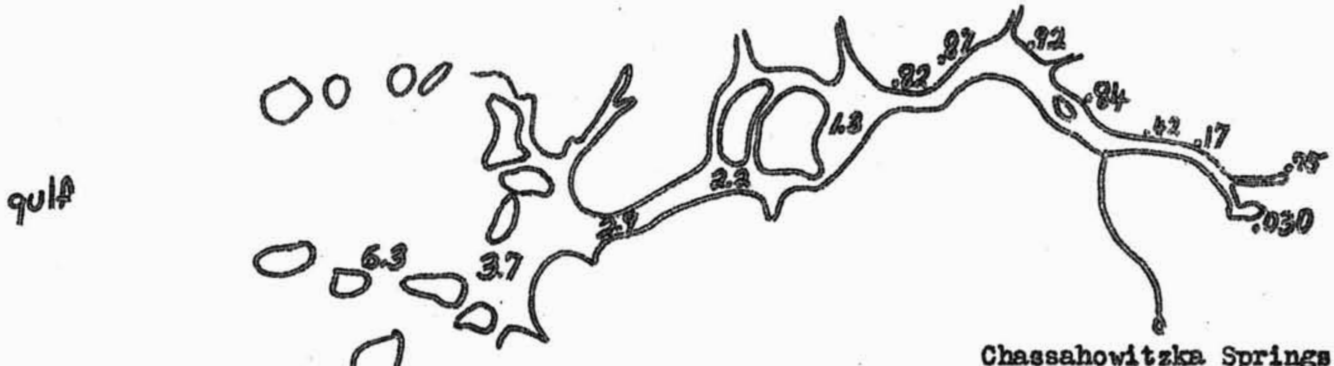
Figure 4
Chlorinity Analyses in parts per thousand



Crystal River
Nov. 29, 1952

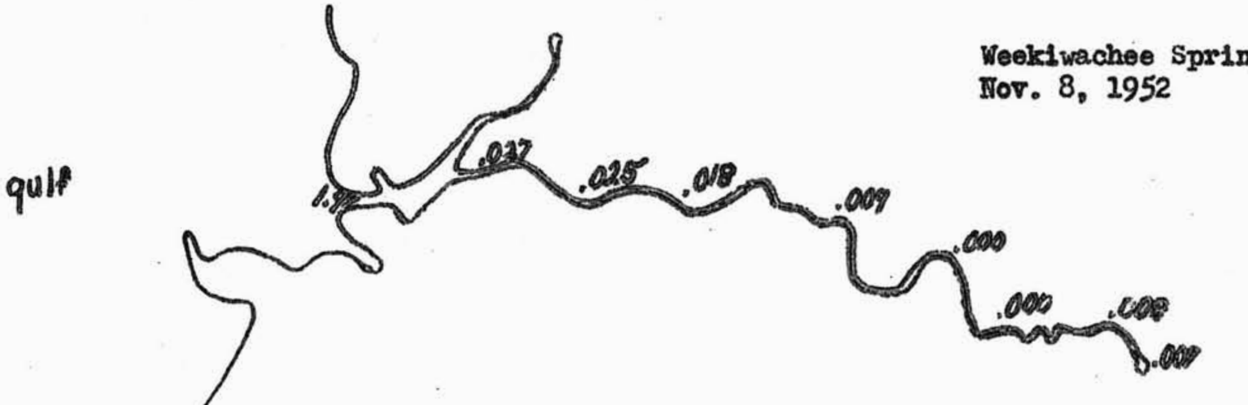


Homosassa Springs
Sept. 28, 1952



Chassahowitzka Springs
Aug. 27, 1952

Weekiwachee Springs
Nov. 8, 1952



2. QUALITATIVE COMPOSITION OF COMMUNITIES

Spatial Distribution Maps

By far the most time has been spent on the initial mapping of the boils of 40 springs using compass and tape. The dominant vegetation has been plotted in position, roughly estimating the extent of plant beds. A typical map is shown in figure 5.

If as discussed below many of the springs represent steady-state environments, the conditions at any fixed place within the community represents relatively constant conditions of current, temperature, nutrient, and predator exposure. Thus horizontal spatial patterns are required in order to compare factors and organisms. The methods for estimating standing states discussed below require a map so that quadrat counts can be multiplied by the area of similar habitat.

One result that has come from this work is an idea of the stability of the vegetational parts of spring communities in Florida. Little Blue Springs, Gilchrist County was mapped a year ago. Visited 5 times since then, the pattern has been essentially the same except for a large bed of floating Najas which comes and goes primarily because of the dislodging by summer swimmers. In gross aspects these communities seem indeed stable systems.

The springs for which initial surveys and maps have been made are: Ichatucknee, Alexander, Beecher, Blue (Gilchrist Co.), Blue (Jackson Co.), Blue (Volusia Co.), Blue (Bronson), Buckhorn, Crystal River, Crystal Springs, Glen Julia, Fanning, Juniper, Lithia, Palma Ceia (dry), Poe, Ponce De Leon (Volusia Co.), Rainbow, River Sink, Rock Spring, Salt, Sanlando, Silver Glen, Sulphur, Warm Salt, Wakulla, Wekiva (Levy Co.), Wekiva (Orange Co.), Welaka, Mud, Silver, Manatee, Orange, Homosassa, Weekiwachee, Chassahowitzka, Bugg, Morrison, Bonita, Green Cove, and Su No Wa. Locations are given in Lingham et al. cited above.

Taxonomic Composition of Dominants

As a basis for all biological studies, the major taxonomic dominants in the springs were collected at the time of the mapping. These cursory samples, representing only several hours collecting each, have been taxonomically divided and the fractions are in process of being identified. The identification of the most abundant species of higher plants, insects, and fishes are essentially completed.

Two striking results are emerging from this phase of the work:

1. The spring communities seem to consist of a few species abundantly represented.

2. Almost every spring differs as to the dominant species even in cases where the chemical analyses of the major elements show essential similarity.

Examples of the living components of spring communities are given in the list in table 4.

Table 4

Examples of the biota of some different types of Florida springs (only a tentative classification)

Warm, Low oxygen, saline, Temp. 87.0, bacteria, diurnal light turbidity variation of peculiar chemical nature, Nitella, Cyprinodon, Tarpon, frogs, blue crabs, requires Rideal-Stewart modification of Winkler method.
Example: Warm Salt Springs, Sarasota County.

Anaerobic, Temp. 75, Sulphur and iron bacteria, blue green algae, midges, heleids, Gambusia, Mollienesia, water clear and initially oxygenless.
Examples Orange, Green Cove, Beecher.

Slightly brackish, half oxygenated, Temp. 75, Vallisneria, Potamogeton pectinatus, marine and freshwater fishes and blue crabs, heavy green algae mats, Paleomonetes, amphipods, water greenish.
Examples: Homosassa, Salt, Chassahowitzka, Silver Glen.

Hard water, medium oxygen content, Temp. 74, clear, Sagittaria, mullet, centrarchids, Paleomonetes, Gammarids, crayfishes.
Example: Silver.

Hard water, higher oxygen, oxygen 5 ppm, Goniobasis snails in profusion, mixed vegetation, Ludwigia, Chara, Najas, etc.
Examples: Blue (Gilchrist), Rock.

Hard water, shadowed (covered at times by back water of turbid river) vegetation almost completely Ceratophyllum.
Example: Morrison Spring.

Hard water, high oxygen West Florida, Temp. 69, Potomogeton, oxygen 7.0 ppm.

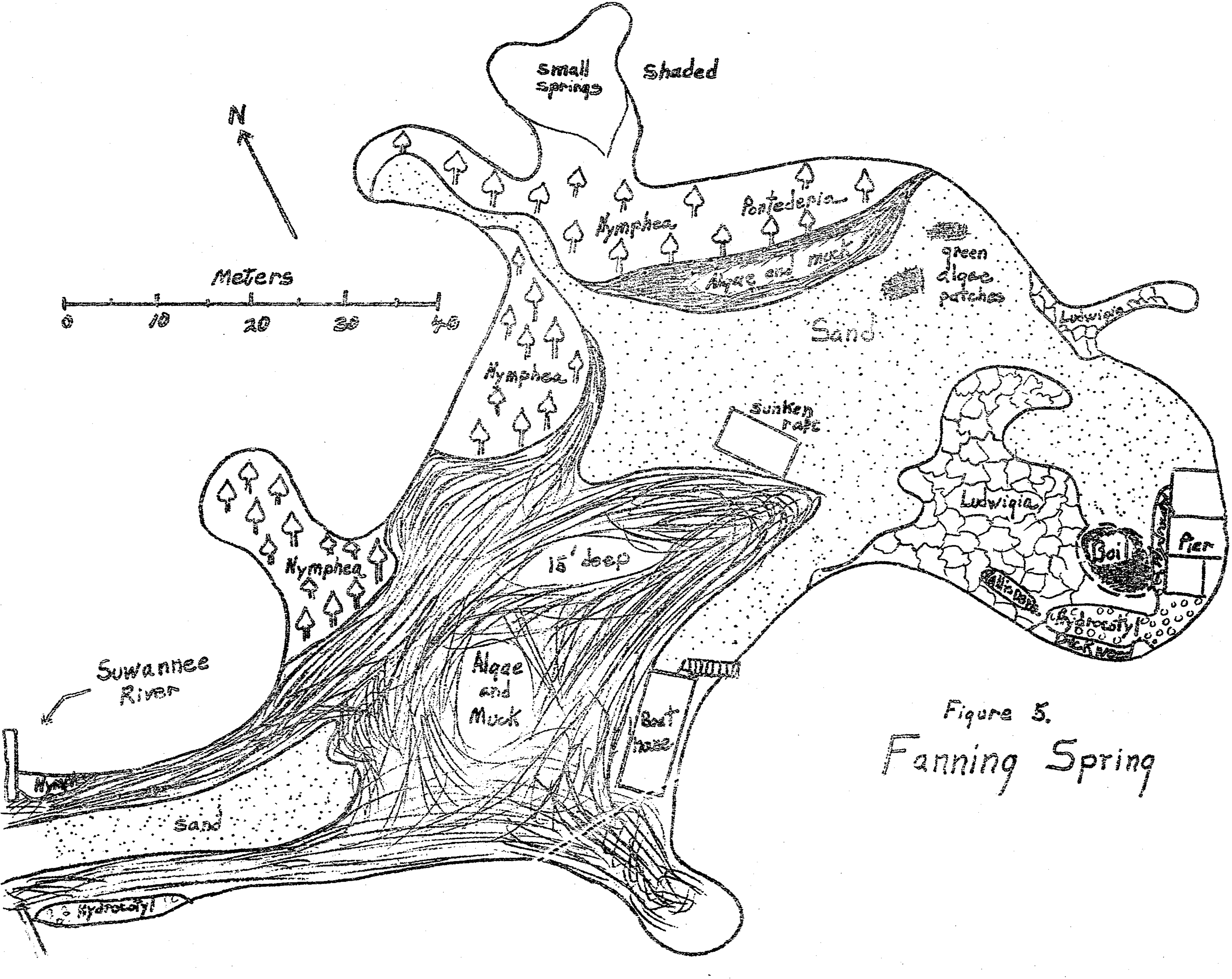


Figure 5.
Fanning Spring

The collections discussed above have suggested the phenomenon observed in pollution where communities have less varied composition but many individuals of each species and where the particular species that is dominant seems to vary radically. Dr. Ruth Patrick has suggested in communication that a stable environment like these springs may possess fewer species than a normal fluctuating environment because there are fewer transitory niches, which in a normal fluctuating environment allow many species to at least maintain a foothold. In both stability or in pollution one has a deviation from the normal fluctuating environment and possibly for this reason fewer species.

As part of work towards a masters degree under the direction of Dr. Lewis Berner, Mr. William Sloan is studying the distribution of insects in relationship to contrasting factors. The following section, written by him, indicates progress to date.

Contrasting Patterns of Insect Distribution
by
William C. Sloan

Berner (1950) observed that the aquatic insect fauna of the upper regions of the Florida springs was scanty and that the population increased a short distance below the boil. This observation was recently substantiated by identification of a series of collections obtained by Dr. H. T. Odum from some 35 springs. One objective of the present study is to explain the paucity of larvae in the boils and their relatively sudden increase below the boils. It is also hoped that some knowledge of the effect of small amounts of chloride on the distribution of aquatic insects will be obtained.

During the fall of 1952, the insect fauna of Silver, Weekiwachee and Homosassa Springs (figure 4) was studied. Collecting stations were established in the boil and runs of each of the three springs, and chlorides (figure 4) and oxygen analyses were made at each station. Collecting apparatus included Needham scraper, dip net, graded wire screen buckets and strainers for larvae and a butterfly net for adults. Adults were taken whenever possible in order to aid in identification of larvae.

Oxygen analyses indicate that, in general, dissolved oxygen content (D.O.) increases with distance down the run. The D.O. in the region of the boils is fairly constant while that of the runs fluctuates from day to night. Table 5 shows the range between day and night in each of the boils. Figure 6 indicates the total number of species collected at stations of varying D.O. in Homosassa Springs. Table 6 compares the total number of species taken in each of the three springs with that of Lake Wauberg, a north Florida lake located in Alachua County. This lake was studied by Mr. Richard Trogdon, then at the University of Florida, in 1933-34 and the data on Lake Wauberg were obtained from his unpublished masters thesis. The species list (table 6) indicates the aquatic insects so far collected from the three springs. It is almost certain that further collecting will increase the list of all three springs, but it seems fairly well established that Homosassa has the most abundant insect fauna, Silver the least, and that Weekiwachee occupies an intermediate position.

Several hypotheses may be advanced to explain the scarcity of aquatic insects in the boils and their increase as the run progresses. As indicated in figure 6, there is a possible correlation between D.O. and distribution of insects. The boil of Homosassa is the only one from which truly aquatic insects have been taken and this has the highest D.O. of the three (see table 5). The fact that even here they are scarce may indicate that there is insufficient food to maintain a larger population. Another factor may be excessive predation. The water of the boils is extremely clear and the vegetation less dense than that below the boils and it seems possible that fish predation in areas of insufficient cover may prevent the establishment of large populations. In addition to D.O., food supply and predation, the number of ecological niches available must be considered. The relatively small number of species present in Silver and Weekiwachee as compared with Homosassa may be explained by the greater number of types of habitats found in Homosassa. Silver and Weekiwachee both have narrow runs, swift currents, and low turbidity for the length of their runs and practically no areas of still water. The run of Homosassa, on the other hand, broadens immediately below the run, the current becomes slower and the turbidity greater. Along the banks, in sheltered areas, the current becomes almost unnoticeable. It is in this type of habitat that the mayfly *Caenis diminuta* and the aquatic Hemiptera *Pelocoris* and *Belostoma*, all predominately pond and lake forms, are found. That the number of species of insects in Homosassa compares favorably with that of a lake may be seen in table 6.

As indicated in figure 4 the chloride content of Homosassa is higher than that of either Silver or Weekiwachee. Even though chlorides are present slightly in excess of 1.0^{o}/oo in many parts of Homosassa run and is thus in the brackish water range, it seems to have little effect on the insect population. It is likely, however, that further collecting will show some forms to be sensitive to even these small amounts.

Methods of sampling quantitatively are being perfected. At the present time, emergence cages are being placed at various points in the runs for the purpose of estimating relative abundance in different habitats.

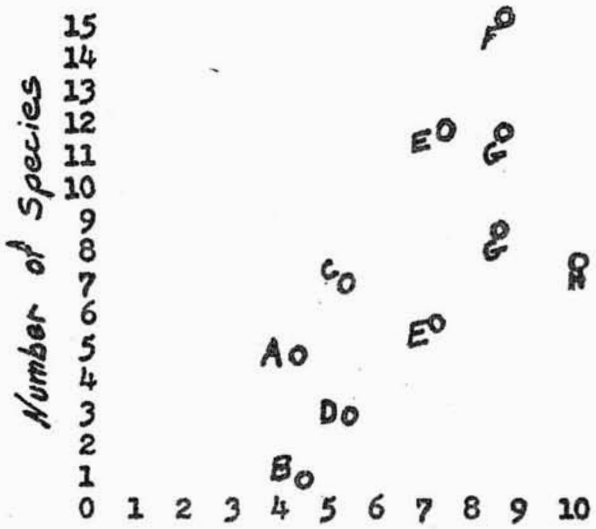
Table 5
Oxygen range in spring boil areas

		Silver	Weekiwachee	Homosassa
O_2	Day	2.9	1.6	5.0
	Night	2.9	2.0	4.3

Figure 6

Distribution of number of species in relation to disvolved oxygen in the spring boils

O_2 in ppm. in boils



O_2 in ppm. Diurnal samples. Each point represents one collection at one station. Number of species indicates the total number taken in one collecting period (1 ½-2 hrs./station). Letters indicate separate or identical stations.

Table 6
Number of species recorded

	Silver	Weekiwachee	Homosassa	Lake Wauberg
Ephemeroptera	1	4	6	2
Odonata				
Anisoptera	A	5	6	16
Zygoptera	5	5	8	7
Hemiptera	5	4	10	8
Coleoptera	6	0	0	6
Trichoptera	1	3	4	1
Lepidoptera	0	1	0	1
Neuroptera	0	0	0	1
Diptera				
Tendipedidae	2*	4*	5*	6
Heleidae	0	A	1	1
Stratiomyidae	0	0	1	1
Tipulidae	0	0	0	6
Tabanidae	0	0	0	1
Culicidae	A	A	2	0
Total	20	26	43	57

A indicates adults observed but no larvae taken.

* the Tendipedidae have only been tentatively identified and may consist of more species than are indicated here.

Table 7
Species List
Silver Springs

- Ephemeroptera
  - *Callibaetis floridanus*
- Trichoptera
  - *Hydroptila* sp.
- Hemiptera
  - *Metrobates anomalus*
  - *M. hesperius*
  - *Trepobates pictus*
  - *Mesovelia mulsanti*
  - *Rhagovelia choreutes*
- Diptera
  - Tendipedidae - species A
  - *Tanytarsus* sp.
- Coleoptera
  - *Copelatus caelatipennis*
  - *C. chevrolati*
  - *Dyneutes carolinus*
  - *D. angustus*
  - *Gyrinus pachysomas*
  - *G. rockinghamensis*
- Odonata
  - Zygoptera
    - *Enallagma* sp.
    - *Anomalagrion hastatum*
    - *Argia* sp.
    - *Ischnura* sp.
    - *Nehalennia* sp.

Weekiwachee Spring

- Ephemeroptera
  - *Tricorythodes albilineatus*
  - *Stenonema exiguum*
  - *Baetis spinosus*
  - *Baetis* sp.
- Trichoptera
  - *Hydroptila* sp.
  - *Cheumatopsyche* sp.
  - Leptoceridae - species A
- Hemiptera
  - *Metrobates hesperius*
  - *Trepobates pictus*
  - *Rhagovelia choreutes*
  - *Hydrometra* sp.
- Diptera
  - Tendipedidae - species A
  - *Tendipes plumosus*
  - *Tanytarsus* sp.
- Odonata
  - Anisoptera
    - *Aphylla williamsoni*
    - *Miathyria marcella*
    - *Erythemis simplicicollis*
    - *Epicordulia regina*
    - *Hetaerina titia*
    - *Gomphus* sp.
  - Zygoptera
    - *Agrion maculatum*
    - *Argia* species A
    - *Argia* species B
    - *Nehalennia* species A
    - *Nehalennia* species B
- Lepidoptera
  - *Elophilus* sp. ?

Homosassa Springs

- Ephemeroptera
  - *Callibaetis floridanus*
  - *Caenis diminuta*
  - *Caenis* sp.
  - *Baetis spinosus*
  - *Baetis* sp.
  - *Tricorythodes albilineatus*
- Trichoptera
  - *Cheumatopsyche* sp.
  - *Oecetis* sp.
  - *Pycnopsyche* sp.
  - *Hydroptila* sp.
- Hemiptera
  - *Pelocoris* sp.
  - *Belostoma luterium*
  - *Mesovelia mulsanti*
- Diptera
  - Tendipedidae - species A
  - " B
  - " C
  - " D
  - " E
  - *Bezzia* sp.
  - *Odontomyia* sp.
  - *Anopheles* sp.
  - *Culex* sp.
- Odonata
  - Anisoptera
    - *Perithemis seminole*
    - *Libellula pulchella*
    - *L. auripennis*
    - *Gomphus* sp.

Homosassa Springs Cont.

Hemiptera (cont.)
Tricorixa sp.
Limnogonus hesione
Trepobates pictus
Metrobates hesperius
Rheumatobates tenuipes
R. rileyi
Ranatra nigra

Odonata (cont.)
Aphylla williamsoni
Aeschninae - species A
Zygoptera
Ischnura ramburi
Ischnura species A
" B
" C
Enallagma sp.
Nehalennia species A
" B.
Argia sp.

Oxygen and the Distribution of Organisms

Oxygen data have been accumulated on 2/3 of the springs listed above in the section on mapping. These analyses have established the general range for the different boils from 0.0 to 8.0 ppm. The oxygen down the run has been highly variable with light conditions, and as discussed in the section on production measures, is the best method devised for estimating primary productivity of the whole spring community.

As discussed above in Mr. Sloan's section, the community properties can be related to the range of oxygen fluctuation as a measure of variability. More directly, the oxygen tolerances of species under ecological conditions of competition and stable state can be inferred from comparisons between boils. Further checking on physiological ability to live at particular oxygen tensions are being investigated by submerging organisms in cages in known waters. One experiment of this type is discussed by Mr. Caldwell below.

The metabolism of the anaerobic springs is especially interting because of the association of iron and sulphur bacteria and blue green algae in a permanent relatively unchanging association. There is thus a steady state natural culture that changes as one goes downstream and as the oxygen increases and the hydrogen sulfide decreases.

The presence of some insect larvae in 0.0 ppm permanent oxygen values in the center of a boiling spring of anaerobic water (on rock outcrops and logs) is especially suggestive. Heleids of small size are found imbedded in knots of blue green algae. It is possible that the oxygen supply of the insects is derived from these algae, at least in the daytime. Thus there is a tiny association that is reduced on the outside but oxidized on the inside— the reverse from the situation within the tissues in organisms.

Ecological Formula for a Species

The presence of cultures of microorganisms in steady state in these flow systems suggests that the idea of an ecological formula for a species is valid. Possibly this old theorem is here practical. Perhaps one can list the conditions in which a species will grow permanently in steady state in natural conditions of competition. The chemical conditions known for anaerobic Green Cove Springs are given in table 2. Other data from **Ferguson** et al (cited above) are: Silica, 15 ppm; Iron, .03; calcium, 28; magnesium, 16; sodium, 2.4; potassium, 1.8; bicarbonate, 100; sulfate, 49; chloride, 5.7; fluoride, .2.

EXPERIMENTS ON THE DISTRIBUTION OF *Gambusia affinis*, *Mollienesia latipinna*, and *Heterandria formosa* DUE TO THEIR HABIT OF GULPING AIR

David K. Caldwell

It has been suggested that *Gambusia affinis*, *Mollienesia latipinna*, and *Heterandria formosa*, all topminnows, can live under anaerobic water conditions due to their habit of gulping air. Beecher Springs, Welaka, an anaerobic spring, contains many of these fish which are continually breaking the surface.

A number of individuals of each species, seined from the spring, were placed in screen wire cages and suspended in Beecher Springs. One cage was suspended so that the fish could gulp air and the others placed at different depths from one inch to three feet below the surface so that the fish could not reach the surface to gulp.

Those which could gulp air lived without apparent distress for the duration of the experiment, 2½ hours. Those which could not reach the surface showed almost immediate signs of distress and were all dead, at all depths, in about twenty minutes.

In order to show that the fish did not have to gulp air as a normal life process, a group of individuals were caged below the surface in oxygenated water further down the run (1.7 ppm O_2). These lived normally without gulping air until the experiment was concluded, in thirty minutes.

This experiment shows that these three species of fish can in reality occur in waters with low oxygen supply which will not support other species which do not gulp air. It is clear that existence in Beecher Springs depends on gulping air. No other fish species were observed.

Peat Formation

A preliminary experiment on decay of wood and leaves was carried out in anaerobic Beecher Springs. The floor of the springs is covered with brown fibrous peat about two feet thick over which flows the very clear, anaerobic, sulfide smelling water. The rate of peat formation under this constant temperature (Temp. 23.0 deg. C.), and constant chemical condition seemed to be worth checking. A hardware cloth cage containing freshly cut, weighed, magnolia sticks and leaves was submerged on June 5, 1952. When reexamined on January 4, 1953, the magnolia wood was found to be essentially unchanged in gross appearance. The appearance indicated so little modification that no analyses were run. The experiment continues. Control samples are stored in the laboratory. Only the submerged leaves had decomposed. Perfectly veined skeletons remained indicating, as might have been expected, that carbohydrate decomposition under anaerobic conditions is slow compared to other fractions of the leaf.

Distribution of Marine Fish and Crabs in the Springs

The phenomenon of the invasion of 15 or more species of marine fishes and the blue crab into Florida fresh waters and particularly springs has been studied as a special project. Chloride maps for Florida's fresh waters have been prepared and the distribution of marine invasion correlated. The manuscript summarizing this phase of the springs work has been prepared for publication (title cited above). The essence of this study is a series of maps of chloride contents in Florida's estuarine and fresh waters, a discussion of chloride geochemistry, a description of the areas which receive the greatest numbers of marine fishes, and a few transplant experiments of blue crabs in the springs. Table 7 summarizes the data on transplantation experiments. The correlation of blue crabs with presence of 25—1000 ppm sodium chloride in springs of constant temperature and the ability to survive longest when transplanted in these springs suggests that inability to reabsorb sodium chloride from low concentrations in the environment is responsible for chloride sensitivity as in experiments by Krogh on the European wool handling crab.

Table 7
Transplantation of Blue Crabs *Callinectes sapidus* in Florida Springs

Crab Source, (Date 1952)	(Date 1952)	Cl PPM	No. of crabs	Spring of Expt.	Ca PPM	T deg. F.	Cl PPM	Days of Survival
Bayport estuary	Feb. 4	3,300.	7	Homosassa	50	75	570	>14
Bayport estuary	Feb. 4	3,300.	5	Chassahowitzka	49	74	53	7-18
Salt Springs	Aug. 7	2,800.	8	Silver	70	73	8	5
Bayport estuary	Feb. 4	3,300.	4	Weekiwachee	49	74	5	1½
Bayport estuary	Feb. 5	3,300.	4	Weekiwachee	49	74	5	1
Chassahowitzka run	Aug. 22	730.	7	Rainbow	21	74	4	2

3. QUANTITATIVE COMPOSITION OF COMMUNITIES (STANDING CROP)

Pyramids of Mass and Number

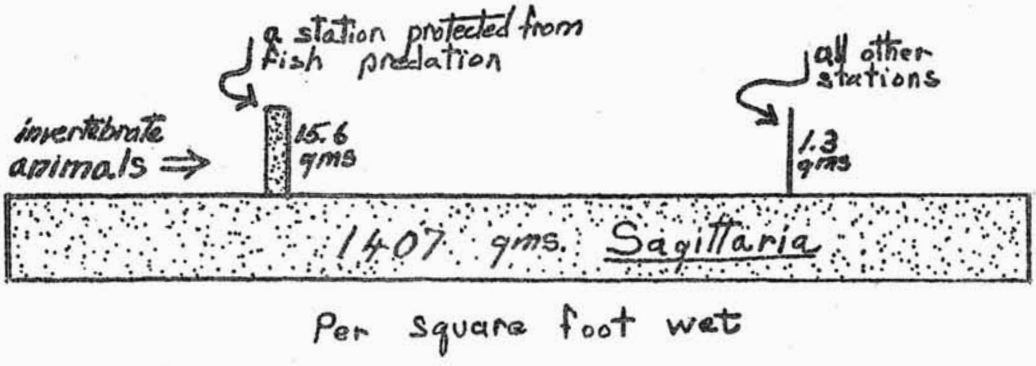
The quantitative description of a natural aquatic community is difficult because each type and size of organism requires a separate means of sampling. It is only the essential stability of the springs that permits one to do one thing one time and come back to finish the job after developing new techniques.

To date initial quantitative sampling has been carried out in the largest spring (Silver) and one of the smaller springs (Green Cove). Whereas the job and the techniques even in these two are incomplete, enough has been done to outline the beginnings of pyramids of mass and number as in figure 7. The steepness of the pyramid is evident. This is suggestive of Dr. Archie Carr's theory of dangling food chains as applied to marine high plant vegetation. Comment on pyramids is discussed below in the theory section.

From these beginnings it seems definite that a valid picture of standing states can be obtained and these compared among springs. The clarity of the waters permits one to census the fishes by eye. Although rough, it is order of magnitude with which one is here at first considering. Start of work on fish tagging is mentioned below by Gordon Broadhead.

Figure 7

Pyramid of Mass in Silver Springs



Methods of quantitative sampling include: planimeter measurement of the areas of each type of association and counts and weights of samples from each association. Sampling procedures under way are as follows: Algae—scrapings from known plant weight; higher plants—by sq. ft. visual cropping under water with face mask; microscopic organisms—scrapings from known plant weight and pouring through plankton net; invertebrate animals—sampling with sq. foot grabs with box sampler; attached microorganism—counts on submerged glass slides which become coated in 3 weeks.

Dry weight equivalents are being obtained for field wet weights.

Special attention has been paid to the aquatic higher plants, their weights, and total tonages in the spring runs. In addition as a base to the food chains and pyramids, this information constitutes interest in itself in relation to physical properties of the springs. Dr. John H. Davis has studied the quantitative variation of the plants in relation to the changing properties down the coastal runs pictured in figure 4. His report follows.

The Weight of Aquatic Vegetation in Four Springs and their Runs of Florida

by
John H. Davis, Jr.

This is a preliminary report of part of the investigation of the biological productivity of plant communities in four Florida spring runs. These are: Crystal, Homosassa, Chassahowitzka, and Weekiwachee, pictured with chlorinites in figure 4. The data in the present report include the weight per unit area of submerged and floating aquatic plants. The waters of the four spring systems flow into the Gulf of Mexico, all of them entering the salt water marsh and littoral zone within three to six miles down stream from their spring heads. Their waters therefore vary from almost no salinity to salinity values that are over half the concentration in the open sea. They all contain hard waters with greater than 144 ppm hardness, and throughout their course the mean water temperatures during the season so far investigated did not vary over 5 degrees centigrade (20.0—25.0).

The chief objective of this part of the investigation was to determine the density of growth of the different plants or groups of plants in terms of weight per unit area and thus arrive at some basis for comparing total plant growth in terms of salinity, turbidity, hardness, and other factors, and some basis for computing productivities when growth rates are established.

The main method employed was directed at first toward estimating the extent of each characteristic type of area of plant growth, and second obtaining representative samples from most of the distinctly different types of areas. The first objective was partly accomplished by inspection of the runs for apparent differences in both density and species composition. Sampling was then made in areas that were most nearly representative. This very selective type of sampling was supplemented by some random sampling in certain parts of these systems so that the sampling was about 70 percent selective and 30 percent random. The latter method is recommended for further investigation. The sampling was accomplished by collecting the attached or floating plants within a one-square-foot iron frame. From these samples both wet (green) condition volumes and oven dry weights were obtained. The green-wet plants collected after draining 1 to 5 minutes were immersed in a large can that had a beaker-like spout and which was filled with water to the spout. The overflow water resulting from the immersion of the sample was measured in cubic centimeters and this volume figure used as the rough wet weight since the specific gravity of water and the plants are similar. Percent water was computed from the wet and dry weights.

The oven dry weights were obtained by first air drying with caution taken to prevent molding and fermentation. Then the samples were oven dried to nearly constant weight at a temperature 100--105 deg. C. The weight values in grams were then used to estimate the pounds per acre in areas for which the samples were representative. A final estimate of the approximate total pounds per acre in the springs and rivers was calculated on the basis of percentages of cover of the plant types as estimated in the field visually through the clear spring waters. The data are combined as a summary in table 8. Similar but incomplete data not included in the table indicate that the lower reaches of these same runs possess higher turbidities, definite marine salt, estuarine fluctuations, and a much smaller density of plants. In the clear offshore marine waters rooted aquatic vegetation again becomes dense in the shallow flats off the Gulf coast.

Plant species constituting the aquatic vegetation were determined in nearly all cases except for identifications of a few algae still pending. Some characteristics of percent water and growth density are summarized in table 9. This table can be used as a basis for wet-dry conversions in further work.

So far, data on chlorinity, oxygen, and phosphorus have been obtained for these runs. Definite correlations between chlorinity and species have been observed as in the correlation of *Potamogeton pectinatus* with chloride values between .100 and 1.0 parts per thousand. Observation of a peculiar zone of depleted chlorides (.000 ppt) among heavy *Chara* beds in Weekiwachee springs is being checked.

The tendency for *Sagittaria* to dominate the low chlorinity waters and for *Vallisneria* to cover the bottoms in the slightly higher chlorinity ranges has been observed. Zones of simultaneous growth of the two species occurred halfway down these runs. These two species are very similar in general growth form. An ideal situation for the study of competition is indicated here.

Table 8

Summary of standing crops of plants in upper non-estuarine parts of 4 coastal spring runs

Spring	# of sq. ft. samples weighed	Range of % coverage	Average Total lbs/acre dry weight	Range of Cl ppT
Weekiwachee Springs (swift current)	16	15%—60%	3,941	.007—.025
Crystal River (wide, sluggish, deep, turbid)	14	30%—70%	2,561	.025—.59
Chassahowitzka Springs (shallow, clear, medium current)	19	25%—70%	4,620	.030—.840
Homosassa Springs (clear, wide, sluggish)	23	15%—70%	4,000	.38—1.3

Table 9

Density, percent water, and dry weights of some aquatic plants in 4 coastal spring runs

Species	# localities sampled	Sq. Ft.	% water	Gms. dry wt. per sq. ft.	
				Mean	Range
Elodea (anacharis)	2	4	85.3	111	86—135
Potamogeton illinoiensis	2	4	84.8	73	43—102
Potamogeton pectinatus	3	6	86.0	114	74—177
Sagittaria lorata	2	4	77.4	105	104—106
Vallisneria neotropicalis	2	4	90.5	59	56—62
Najas sp.	2	3	91.5	85	55—115

The Use of Color Tags in the Study of Fish Populations in Homosassa Springs

by
Gordon C. Broadhead

Homosassa Springs provides an excellent site for the study of marine fish populations because many species of marine fish enter the springs area where submerged observation sites have been erected for tourists, and because the clarity of the water and the narrow limits of the spring area make observation of their movements easy. Casual observation indicates that the large populations of fish in the springs change from day to day both in species and in the numbers of each species present. By marking with colored Peterson fish tags, the movements of the fish can be recorded, the daily populations of fish estimated and the turnover of the fish in the springs also estimated. Tagging will also permit study of the behavior of the tagged fish and estimation of their growth rate if recaptured at a later date.

On December 6, 1952, a preliminary experiment was carried out to test the feasibility of using the colored tags. Nine mullet were caught in the boil of the springs by means of a cast-net. The fish were tagged with large red tags and released into the springs. In future experiments a different color combination will be used for each fish. The following morning five of the nine mullet could be seen swimming in the springs and at one time four of them were observed together in a small school. These fish were observed by the spring attendant for two more days and after that they disappeared and were not seen again.

Although it is impossible to draw any definite conclusions as yet, indications are that the mullet do not remain in the springs any great period of time and that the large daily population is maintained by fish moving in and out of the springs into the much wider run area. The fact that four of the tagged fish were observed in the same small school could indicate that the tagged fish were not randomly distributed throughout the population. Since they were captured one at a time, it is not likely that they were in the same school before tagging.

IV PRODUCTIVITY

Plant Production

The study of the production rates in a community involves the estimation of production rates of each class of organisms in the food chain separately. By trophic levels, there are the primary producers, herbivores, carnivores, secondary carnivores, decomposers. Satisfactory measurement of the production of any of these under natural conditions is difficult and has rarely been accomplished.

To date, attempts to measure production have been directed at measurement of the primary production in situ of the plants in the springs. Most of the effort has been directed at Silver Springs. After some trial and error, some success has been attained by three direct and indirect methods. Silver Springs is almost completely covered with a thick bed of Sagittaria whose growth form is that of eel grass. These heavy plant beds are coated with algae which in places forms heavy mats. Some other plants are found around the edges in relatively insignificant quantities. Measurement of the growth rate of the Sagittaria has been accomplished by the following methods:

a. Growth of wet weighed, transplants in cages,
b. Measurement of downstream drift of plant fragments,
c. Measurement of differences between oxygen content of downstream stations in the day and at night.

a. Cage enclosure method

Measurement of growth of transplants probably produces minimum values since cages shut out some light, exclude turtle herbivores, and in the case of rooted aquatics involve reestablishment of root systems. The direct measurement of plant growth involves two different procedures for two different purposes. In order to measure the production of a community where a study is being made, the species used must be the dominant in the community. Thus in Silver Springs Sagittaria is pulled up, weighed in a cage with a two minute drain, and replanted in the soft organic bottom muds within the 4x6x4 cages in about 3-4 feet of water representing typical bottom conditions. However, a comparison of potential fertility of the spring water also is needed in order directly to compare chemical potentialities of different communities. So a single species should be used in all the springs. For this purpose a floating aquatic such as hyacinth or Pistia should be used so that the type of mud bottom will have no effect. Thus Pistia, a minor natural plant in Silver Springs, is being grown in cages.

The data from direct measurement to date are meager and preliminary but may show that the method will work. Plants of Sagittaria with 1 foot blades had grown to 3 feet length and developed blossoms. The growth of the Sagittaria seemed to be much less than that of the Pistia in the summer, possibly partly due to light differences. The values of productivity obtained by this method in table 10 seem reasonable.

b. Downstream drift method

The second method for measuring productivity involves stretching a gill net across the run 1 mile downstream from the boil. The water by the time it reaches this spot has filtered across a great volume of waving Sagittaria. Now suppose the spring is in a true steady state, and all our evidence suggests that it may be, certainly with respect to Sagittaria since it remains clogged with it all surfaces being covered except the sides of some of the limestone out crops. Then the rate of production should be balanced by the rate of plant loss to the food chain and to drift downstream. Sagittaria, when it breaks loose, floats to the surface. Thus the downstream drift which is large, obvious and continuous is caught in the gill net and later wet and dry weighed. This is done early in the morning so that effects of boats during the day will have least influence on the results. Thus this estimate will be minimum since more would break off during the day. As seen in the data on standing state, the amount of Sagittaria plants is large in proportion to the animals that possibly draw much of their nutrition from algae. If further observations are consistent, it will be concluded that only a small part of the Sagittaria production is drifting downstream. The initial test of the drift measurement gave the figure for Silver Springs in table 10. This drift catching procedure is further discussed in relation to ordinary streams in the theory section.

c. Oxygen gradient method

If the springs are a flow system in which the constant flow of nutritive clear water is mixed at the boil with sunshine to start a biological chain of reaction, then the distance down the run is proportional to the rate of reaction in some chemical kinetic apparatus. Thus this property is the basis for a third measure of plant production in the springs. As water comes out of the springs it possesses a nearly constant oxygen value diurnally and annually as seen in figure 8. Oxygen is added as the large river of water pours downstream due to two actions: diffusion from the air, and photosynthesis associated with production. At the constant temperatures day and night the rate of diffusion will be constant. Thus the difference between the oxygen value down the run in the day and that at night is the difference between photosynthesis and respiration. Thus one has measured the metabolism of the whole community, the size of a small lake, directly and instantaneously. Indeed one can measure instantaneously the production rate during the day versus seasons, cloud cover, etc.

The data in tables 2 and 10 for Silver and Green Cove, and figures 8 and 9, abundantly illustrate that this method indeed is practical. Although incomplete, the data at hand show a large difference between cloudy and sunny days and between winter and summer. This is exciting especially as it permits rapid comparisons of springs and probably can be adapted to streams and rivers and even estuaries if a knowledge of current and simultaneous observations can be made. Certainly, the criticism that communities are too big to work with directly seems circumvented here. Some initial data on other springs suggest similar orders of magnitude. These springs are giant respirometers.

Green Cove Springs as one of the small springs showed (in table 2) an especially striking contrast between: Summer afternoon where trees are such that sun reaches the spring run, summer night where oxygen actually decreases down the run, and winter night and day where the sun does not reach the plants and where because of a removal of plants the production and also the night respiration was decreased indicating the difference between diffusion and respiration in producing the D.O.

If these oxygen data are correct it should be possible to develop check techniques with carbon-dioxide or pH shift of constant alkalinity water. The constancy of the downstream alkalinity has to be proved.

With valid methods of measuring the large dominant aquatic higher plants in most of the springs, attempts are being made now to develop methods of measuring production of algae, animals, etc. Cage measurements can be made on the medium and larger animals, bottle respiration can be resorted to for algae, fish tagging has begun.

Figure 8

Oxygen down Silver River

Clear winter day

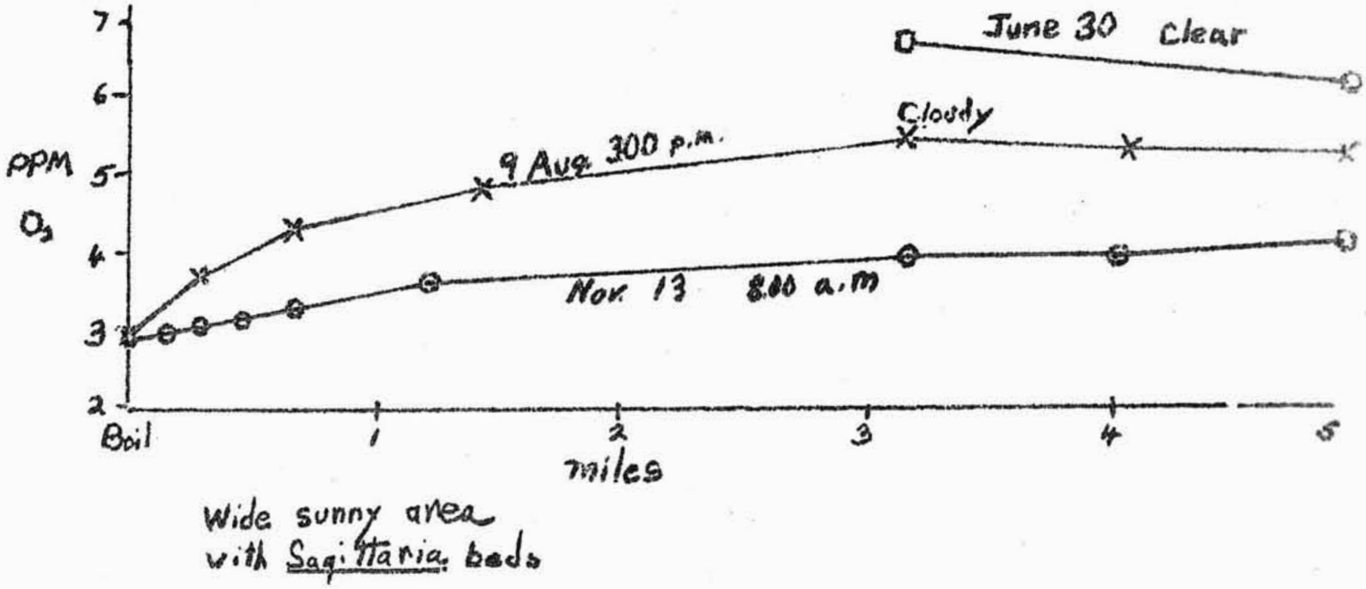
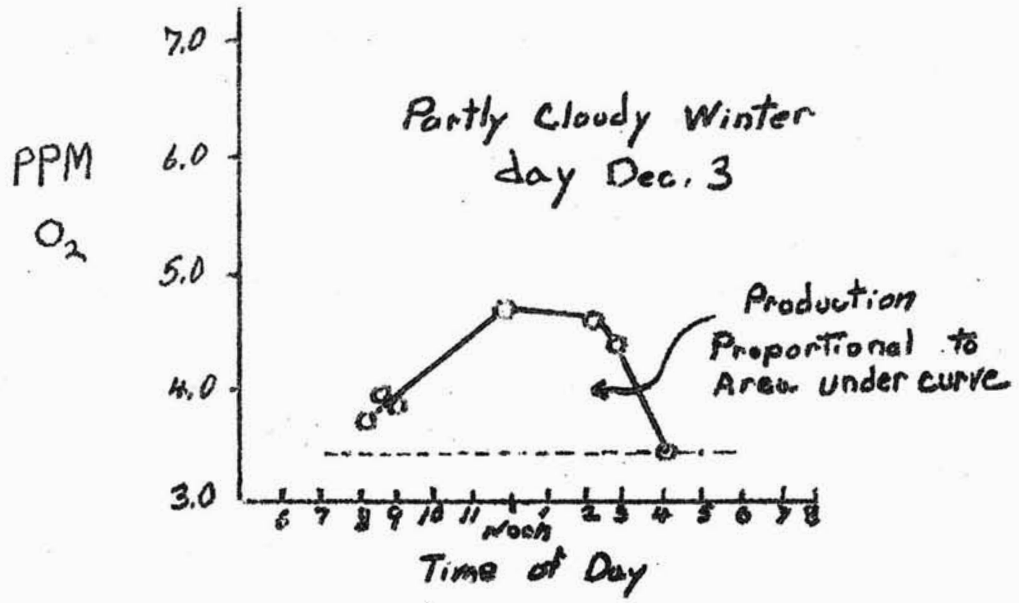


Figure 9

Oxygen at station 1 mile down Silver River



V PRODUCTIVITY THEORY

In the course of a study such as this which involves groping for new procedures, some questions arise that seem to bear on general aspects of the science, such as the following:

Aquatic Stable States

1. Can an ecological aquatic community exist in a stable steady state in which matter and energy flow through the system but standing states quantitatively and qualitatively remain constant? The observations so far suggest that this is possible in a flow system in nature just as in an algal pure culture production machine. It is to be wondered however if a steady state aquatic ecological system can be stablized under matter closed conditions The reason for feeling that it can not be stable is two fold: first, most relatively closed-to-matter systems, like bottle cultures, ponds, and lakes oscillate and fluctuate. Second, in a closed system a limiting nutrient must always give rise by successional and relative depletion to some other limiting nutrient. The stability principle says that all closed systems trend by a natural selection process toward a self-regulated system. The question is: when does a mathematically satisfactory solution exist to stabilized circular transfer of material components through organisms with each component passing at a different yet constant rate. Even more simply and operationally, if placed in sealed bottles and placed in the light how many kinds and types of simple communities will stabilize and how many will oscillate.

Pyramid of Production in Streams

2. In flowing streams of usual type a striking feature is the small standing crop of plants in comparison to small animals and especially fishes. There seems to be an important interpretation other than that there is an autochthonous source of primary food matter. In constructing pyramids of production (not standing crop) for a stream one is interested in production per time such as a year. In this time the fish production is the growth of fish located in one place since they have not left the stream. But for plants and for small animals the production is what has drifted downstream for a whole year as well as that which has passed up the food chain. Thus the standing crop of diatoms drifting down stream from sources in bayous is an infinitely small part of the annual crop which involves the whole years downstream drift. It is probable that such pyramids when constructed will show a more usual wide bottom. In fact, production in rivers may be the easiest of all to measure by catching what drifts down as in springs experiment described above. In the springs, of course, the volume flow is such that initially there is no true plankton.

3. In discussion of food chains, the concept of efficiency of food chain transfer has been a useful operational measure that has helped understand natural ecosystems. However, there is one fuzzy aspect of this concept that needs clarification. It is often pointed out that photosynthetic efficiency is of the order of magnitude of 1% or less but that energy transfers further up the chain are of higher order of magnitudes of 10-20% and under some artificial feeding experiments with fish of 50%. Those interested in increasing natural food resources naturally ask what basic differences there are and whether photosynthesis can't be made to possess a higher efficiency.

It seems that one thing being confused here is the difference between a true efficiency of energy transfer and a food transfer efficiency in which not all of the energy transferred changes state. When a fish eats protein food it may digest and separate amino acids of the proteins and immediately stick them back together to form new tissue. Much of the energy in the amino acids in such a case never changes form. In the case of photosynthesis all of the energy changes form. As discussed below it is suggested that there is a definite thermodynamic reason why efficiencies must be low and why increasing efficiency would cut down total production. When one refers to a 50% food chain transfer efficiency, one is referring to the sum of energetic efficiency for the energy actually changing form in the metabolism and the energy transferred in unmodified chemical molecules.

4. The total energetic output of a living or non-living machine is a product of the rate of inflow of energy and the efficiency of energy utilization. It is suggested here that there are two extremes in living and non-living machines that both produce a zero energetic output per time. One extreme is a machine with a 100% efficiency as in a reversible carnot cycle but an infinitely slow utilization so that the output is zero. The other extreme is an infinitely rapid energy intake and transfer which is so fast that the thermodynamic efficiency is zero and so the total output of this high speed system is again zero for all the energy goes into heat. These two extremes seem to be a necessary result of the second Law of Thermodynamics. If this reasoning is correct (and an actual calculation has been made on a physical system, the Atwoods machine) then there must be an optimum efficiency for the maximum power. If this is the case, then one sees a reason for efficiencies of photosynthesis being what they are. The machines are set to go at the optimum speed to get the best combination of both efficiency and speed. At times, under some ecological conditions, an organism that goes faster and less efficiently may have the edge over one that is slow but efficient. However, if correct, these notions suggest no hope for higher human food production without repeal of the second Law.

Second Six Months:

Having made beginnings in the 5 divisions of the study, the immediate objectives seem clearly outlined: Except for completing identifications, community species-number analysis of coastal runs as part of Mr. Sloan's master's program, and the chemical survey of nitrogen metabolism in the fresh-water springs with the help of an undergraduate assistant, Mr. Hampton, all attention is to be directed to completing the production measurements of all trophic levels in Silver Springs. To complete this and to insure adequate attention to the all important algae, Dr. L. A. Whitford, of North Carolina State, has been engaged to work with us this summer on identification and production. Tentatively, objectives following these are the comparison of productivities between springs using methods which work best in the intensive Silver Springs study.

Measurement of the amount of light diurnally and seasonally that reaches the organisms in these clear water aquatic communities has not yet commenced pending the procurement of a suitable instrument. So far physical and chemical measurements have been made solely for their implications for productivity. A number of splendid problems in physical and chemical limnology and oceanography await future investigation.

Table 10
Primary Production Rates in Springs

Method, Place, Date, Plant	Operationally determined figure	Pounds per acre dry weight (or glucose) per year
1. <u>Cage Enclosure Transplants</u>	% wet weight increase per day:	
Silver Springs:		
<u>Sagittaria</u>		
Aug. 16—Oct. 9	.46%	15,000.
Oct. 9—Nov. 15	.30%	11,600.
<u>Pistia</u>		
Aug. 18—Oct. 9	1.9%	——
2. <u>Downstream Drift of Plant Fragments</u> (production lost from the system)	lbs. wet weight caught per half hour:	
Silver Springs 8:00 a.m. Jan. 14, 1953	8.6 (289 gms dry)	754.
3. <u>Oxygen Gradient Measurement</u> (day minus night)	PPM difference between day and night Oxygen:	
Silver Springs		
Area under curve of figure 9 (winter day, cloudy)	0—1.5	27,700.
Clear day in summer, June 30	0—2.8	77,000.
Green Cove Springs Run Summer day, July 16, clear	2.2	62,600.
Winter day, Jan. 27, clear shaded by trees in winter	.2	4,900.

For comparison: productivities reported for literature in marine, fresh-water and land ranges: 1,200——33,900.