PRNC129

PRNC-129

BIOLOGY AND MEDICINE (T1D-4500)

PUERTO RICO NUCLEAR CENTER

THE RAIN FOREST PROJECT

ANNUAL REPORT

Carl F. Jordan, George E. Drewry

June 1969

OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT

NO. AT (40-1)-1833 FOR U. 5. ATOMIC ENERGY COMMISSION

---Page Break---

Table of Contents

Section II

Part A - Animal Ecology

Part B - Species Diversity

Appendices - Insect Keys

Section IIT

Derivation of Leaf Area Index from

Quality of Light on Forest

Floor.

Nitrogen Fixation by Epiphyllee

at El Verde.

Termites at El Verde: 1968 Recheck

122

123

331

ie

---Page Break---

DIVISION OF RADIOBCOLOGY

TERRESTRIAL ECOLOGY PROGRAM

?THE RAIN FOREST PROJECT

INTRODUCTION

The Rain Forest Project is an ecological study of a tropical rain forest located at an elevation of 1500 feet on the side of El Yunque mountain in eastern Puerto Rico, The study has three objectives: 1) to deie-Fine the effects of gamma radiation on the tropical ecosysten; 2) to stuap fhe cycling of stable and radioactive isotopes through the ecosysten; 3) vo investigate basic biological functions of the ecosystem in order to bettes ?Understand phenomena related to the first two objectives.

?The gamma irradiation study has been completed, and results will be Published in a volume edited by H.T. Odum. Studies of secondary succession in the forest opened up by radiation are continuing. Changes during the first three years of succession are reported here.

This report 1s in three major sections. The first section, by Dr. Carl F. Jordan, concerns the stable and radicactive isotope cycles, ani a portion of the secondary successional work. The second section, by Dr. George E. Drewry, deals with diversity of the successional forest, and animal ecology studies. ?The third section consists of reports by visiting scientists, and a manuscript in press,

it

---Page Break---

SECTION I

ty

carl F, Jordan

?This section deals with stable element cycling, tritium movement in ?the tropical rain forest, and secondary succession following irradiation.

The studies on stable element content of the tropical ecosysten, started by Kline in 1966, ani the stable element flux in the forest begun by Jordan in 1967, were completed during the past year. The results are brought together in section one so that they are amenable to a systens analysis. Because of the extrene complexity of the ecosysten, a systens analysis is necessary to predict such things as, given a certain amount of fallout: how long will it take for the radioactivity to reach equili-briun in the system?; What vill be the levels of radioactivity in each compartment at that time? How long after input vill radioactivity be at a naximm in compartments such as leaves and fruits, hich are bases of food chains?

Also in section one are some of the results of a series of tritiun tracer studies, carried out in conjunction with Dr. Jerry R. Kline of Argonne National Laboratory, and Dr. John Koranda and Mr. John Martin of Lawrence Radiation Laboratory. These studies are of interest, not only

?Decause tritium is a tracer for water, but also because tritium will be a principal product of eny thermonuclear reaction used to excavate a new canal through Central Anerica.

?The secondary successional study vas initiated in the sunner of 1966, one year after radiation of the forest ceased. Results through 1968 con- cerning biomass, gross and net photosynthesis, respiration, and efficiency are presented in this section, Results concerning species diversity ani information are presented in section two.

---Page Break---

PART A - ISOTOPE CYCLES

The movenent of radioactive and stable elenents through an eco- system often is termed "mineral cycling" or "biogeochemical cycling". Both these terms are misleading. "Mineral cycling? is misleading decause to earth scientists, minerals are substances composed of tvo or more elenents, usually having a definite atomic arrangenent. These minerals do not ¢ycle through plants and animals. The tern "biogeo- chemical cycling" also is misleading, because it implies cycling over millions of years whereby an elenent 1s deposited on the ocean bottom, decones sedinentary rock, there is land uplift, erosion, ani then the elenent is again avatisble for cycling through biological systens. The studies at the tropical rain forest at El Verde do not involve this sedimentation, but are concerned only vith the movenent of biologically available material.

The studies involve transfer and storage of stable chemical elements, as well as the radioactive iectopes of some of these elenents. Since stable chemical elements are isotopes, and radioactive elements are radioisotopes, the studies are most accurately called isotope cycling studies.

During the past several years, tracer studies and chemical analyses have been done on many of the compartments ani transfer routes chown in Fig. 1 for the tropical rain forest at El Verde. Within the next year, a mathematical model of Fig. 1 vill be programed for a computer, so that with a given input of fallout of stable or radioactive isotopes, concen- ?tration in any compartment at any time after the input can be computed.

Studies,relevant to the model, that vere completed during the last year by the Terrestrial Ecology Program follow.

?Transfer of Stable Isotopes by Water

Water is a principal means of isotope transfer in the ecosystem, as shown in Fig. 1. Concentration of stable isotopes was measured in the water fluxes given in Table 1, and multiplied times the volume of these water fluxes to give total weight of elenents moved.

Rainfall vas collected in plastic barrels on the top of a tover 12 feet above the top of the canopy. Thrcughfall was collected in sinilar barrels placed on the forest floor. Collars around trees to collect stem flow were nate vith polyvinyl tubing and sealed to the trees. The tubes led to collection barrels, Water moving out of the Litter and through the soil was collected with "Tension-free" lysimeters (C.F. Jordan, Soil Science 105: 81-86). Ruoff water fron the Sonaiora River between storms was taken directly from the river. Runoff water frp the river during storms was collected in plastic bottles placed

---Page Break---

?on

i aTAE

cancer

Fig. 1. Block @lagran shoving major storage

compartments and transfer routes

?in the tropical rain forest.

Table 1. List of vater collectors used for studying rate of elenent

movenent between compartzents.

Fix	Mumber of collectors
Rainfall,	2
?Throughfall	10
Stemflow	ar
Out of litter	18
?Tarough 5 inch soil depth	23
?Tarough 10 inch soil depth	6
Runoff, during storms	2
Runoff, between stoms	4

---Page Break---

on the bank at a level of about one foot higher then the normal river

level. When the river rose, the bottles filled, and when the river receeded, the vater could be collected.

Collections were mate once a week. Weekly vater samples from each separate collector were pooled proportionately to the ancunt of vater collected, For example, 1/500 of the veekly volte of throughfall collector mumber three gave a reasonable sized sample for analysis. Therefore, every weex, 1/500 of the total anount of vater collected in through~fall collector no. three was poured into a plastic bottle labeled "throughfall collector no. three", At the eni of the month, the pooled samples vere analyzed for conductivity with a conductivity meter; ca, k, mg, mn, fe, ani cu by atomic absorption, and na by sodium electrode.? Die t0 various problens, not all the elenents could be analyzed every month.

ALL the concentrations of one group of samples (for example all. the ?throughfall samples) were averaged each month, and the staniard deviation was obtained, While it is desired to give the reader an indication of the variation in? samples, a listing of averages and standard deviations consunes too mich space. ?Therefore, for each group for each month, the standard deviation vas taken as a percentage of the mean concentration. Then the 12 percentages for the year for ca, na, and ng vere each averaged, and are shown in Table 2.

Rain shows a fairly high variation in the caleium samples. This vas probably because the concentrations were near the lower limit of detection. For example, the sane sample could give a concentration of 0.1 ppm the first reading and .2 pn the second, resulting in an average concentration of .15 with a standard deviation of .O71, 47 percent of the mean. Stem flow shows a very highvariation between samples. Last year, Jordan (1968, The Rain Forest Project Annual Report) shoved that larger trees generally have a higher concentration of isotopes, especially trees of the species Dacryodes excelsa. Variation in runoff is lovest, as might be expected, since samples, fare taken in virtually the same spot at the sane tine, while other samples are taken over a wider area.

Concentrations of isotopes in the various water fluxes can indicate certain things about the isotope cycles. Concentrations of ca, na, and mg were compared in water from the A horizon (5 in depth) and B horizon (Zo in, depth), in river runoff during high and low vater levels, and detween the B horizon and river runoff. Average monthly concentrations are shown in Table 3 and, Utilizing analysis of variance (Table 5), no differences can be shown between the A and B horizons, the low and high levels, or between the B horizon and the high water level. However, the ranked sign test showed a difference at the 5 percent level between low water and high water for ca, and ng (Table 6). In this case, the signed rank test might be slightly more sensitive than anova, becasue while there fare moderate month to month variations, the concentration in the low vater ig usually just slightly higher than the high water concentrations. Since sodium ig a more mobile element than ca and mg, it is not surprising that it is not diluted ty rising water, vhereas ca and ng are.

ne

---Page Break---

Table 2. Standard deviation as a percentage of mean concentration.

Percentage

Samples, ca Ya, Me

Rain oT 34 5

Throughfall 45 3T 6

Stenflow 87 ST 9

Out of litter 3h 35 39

Through mineral. soil a 3T 49

Run off ab 9 a

?Table 3. Concentration of elenents in water collected from the A hortzon (5 in. deep) and

?Bhorizon (10 in. deep) of soll in the rain forest near Hl Verde,

Cones sintion

oe

te

ost. 1967 ke 16 ko m6

ers, 1967 ot 8 35 BS a

Dees, 1967 186 6h 58 a

Jan. 1968, oe 68 60 6S

Fer. 1968 a3 89 ws ae La a

mary 1968 Moe wear fe

far, 1968 Lr 6 Th 60 aan Lo

ayy 1968 neo 28 38 2 8

de, 1968 os Bas 0

aay, 1968 ob 06 18 ae 6 9

be) 1968 Cd 2g MS 2 »

Bert, 1968 LL 10 aT 5h

---Page Break---

Lo 60 an sh st oz go6t ?*3d08

ro 90 &9 9s ort ot eget ?SRY

et at ve st 60 ot eget ?Arne

£0 vo gt ae aT ve 996t ?ome

20 60 ot ae oT vt 996t ?Aad

UT ot we sh ge ae g96t (dy

ot at UE ez ez sz 996t ?TH

vt gt ve he ve oe g96t ?a0E

sro 20 on sn at ot gg6t fruee

sto ero ?9 ay at se Ag6t £1990

so sro oe oe ot at 1960 «Aon

20 sto ors on st ore Ag6t °390

xeqvaaay08 soqvaoqan s9y0A equa

?ry__not yore oT wiry AoT

oF

=(sazoqe woangaq) TeAot xoqeA ACT Supp pe (eutoge SUMP) TeAS

soon wiry Burm saKhy exopeIOg aun wAy yoRoeTTOD HOGeM UF SquDLeTS go WoRIeeUS, +

oo

6.

---Page Break---

Table 5

me moet DFS. uemicteimitione mart

sak ws

eer ee Abert te tee

i

i

i

i

peeareareeroarcae

&

an Dk Aer te owe

---Page Break---

Although there is a lower concentration of dissolved ca and mg

when the river is high, the river also carries suspended soil material

when it 1s inflood stage. This soll material represents loss of ca and

ng, but it is probably a loss as a result of erosion of the river-bed, and does not represent material being carried avay from the vicinity of

the roots.

Te fact that there 1s no difference in concentration of elenents in water moving through the soil at the 5 in. level, the 10 in. level, an river mumoff indleates that all the isotopes which are recycled by Plant roots are taken up by the roots before the isotopes reach a five inch depth, This evidence is in agreenent with the hypothesis of Went and Stark (BioScience 18, 1035-1039) who feel that in the tropics, elenents are transferred directly fron litter to roots by mycorhiza,

Total anount of isotopes moved by rain, throughfall, stenflow, out of litter, through mineral sofl (average of A and B horizons) ant runoff (high water only, since that is when the bulk of runoff occurs), were caloulated ty mltiplying isotope concentration in each flux tines volume of the flux. Units are:

(Wolume of flux) (concentration in pm) Quantity of isotope moved

6 v

10° grans of vater

equivalent to 1 3

Z 7

a5 /na/ie) (e/n3) Ke/ta/ve

Total anount of fsotopes moved is given on a weekly basis since collections vere alvays male on the sane day of the week (Von.). Such weekly collections result in some months with four full weeks and some with five full weeks. A month with five Mondays but only 30 days would then have an error of about 14 percent, if there vas a monthly base.

Although in reality the rain falls in discrete storms, it is more practical to calculate results on the basis of a steady continuous drizzle ?throughout the year. ?Then the total moved for each week is a rate function, and the total amount for each month can be calculated by muliiplying rate times the nunber of weeks plus tenths of a week per month

Rainfall is measured above the canopy with a standard U.S, Weather Bureau recording rain guage. Throughfall is measured in 12 collectors on the forest floor, each measuring 5 ft, by 2 in. by 12 in. Jordan (1968,

The Rain Forest Project Annual Report) estinated stem flow to be 18 percent of rainfall, and fzansptration, to be 105 m3/ha/wk. Evaporation from soil surface averages 2.5 m3/ha/wk (Odum and Jordan, A Tropical Rain Forest,

dn press). Water moving through litter equals throughfall plus stenflow minus evaporation from the surface. The same amount of water moves through

---Page Break---

YM/WH/83LYM 30 .W NI TWwsNnive

8

LEAF FALL

----- RAIN

OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

eal =

AWO/W/: 'S3AV31 SWVYS

Fig. 2. Average rates of rainfall and leaf fall at the El Verde site.

---Page Break---

?the mineral soil as out of the litter. Most of the mineral soil lysi-
meters collect more water than the litter layer lysimeters except on
ridge tops, where amounts are roughly equal. This phenomena 1s caused

by the subsurface flow parallel to the sloping soil surfaces describea
by Jordan (1968, The Rain Forest Project Anmal Report). Runoff reaching
?the river is equal to throughfall plus stem flow minus evaporation minus
transpiration,

Centimeters of water flux is quickly converted to m3 water/ha/wk
by the relationship

(cm vater/vk)(100) = m3 /na/wk

Fig. 2 shows n3/ha/wk of rain on a monthly basis for the stuay
period.

Kg/na/wk of isotopes moved by the fluxes on a monthly basis are
given in Tables 7-12 and Figures 3-6. Ca, mg, and na moving out of the
litter follow the trend of rainfall; the more rain, the more loss from
the Litter (compare Figs. 3, 4, and 5 with 2). Input of these isotopes
into the system via rain does not follow the rainfall pattern. Highest
inputs occur around December and January ani are probebly nore closely
associated with the frontal passages that occur at that tine of year than
with total anount of rain.

Gains and losses of isotopes to the ecosystem are calculated by subtracting rate of loss ty runoff from rate of input by rain (Table 13 and Figs. 7 and 8). Largest loss from the system occurred during the heavy rains of May, and gains of na and ca around December occurred as a result of the high inputs during that time. Total yearly difference between input and runoff is presumed to be made up by weathering of parent soil material.

Elenent Concentrations in Ecosystem Compartments

Leaves, wood from trunk, roots, soil, litter, and organte matter in the forest vere sampled to determine stable element concentration in each compartment. Concentration, when miltiplied times biomass of the organic components gives total anount of elements in each compartnent. Biomass of the leaves, trunks, and roots will be calculated from the regressions in Odum (A Tropical Rain Forest, In Press). Biomass of the freshly fallen litter will be taken from the data of the 55 litter col~ lection stations which are sampled monthly. Biomass of the partially decomposed organic material was measured by collecting 300 square meter samples, drying, and weighing them. Average weight was 360 grans per square meter, with one standard deviation of 176. Concentration of elenents in the soil extract will be multiplied times weight of the

upper layer of soil (Table 14).

---Page Break---

????___ afta

ont, 1967 . ap. on

ove, 2967 a oto 16

ees, 1967 8 aah a0 a

san 1968 1 0 19 on

Fea, 1968 5 0.36 0.35 oat

mas, 1968 3 0.9 0.88 a

Aer 1968 8 0.2 1.00 aa 209

ey, 1968 » oat ak on on

ne, 1968 ? 065 099 0.6 7 1.8 000

say, 1968 1 om 0.tT . 6

doa. 1968 3 0.30 1.06 . 0s

Sept. 1968 5 sp 10 02.038 e000 018,

?easly average 8.00 Ae nd 0.35 0.095 1.8L 0.012.000 013

cet. 1961 8 oat Lk ost

or 2961 » 08 16 95

dees, 1961 wo 0.70 1.68 295

an. 1968 » oth 2.03 3

Fe. 1968 8 og 0.5 a0

mar. 1968 3 01 1st 286

nor. 1968 3 om 1st 288 0.

ny, 3968 8 oab 0.8 ato oor

ane, 1968 » 05h 0.53 1.86 035 1.98 005

aay, 1968 » oat 0.33 . 200

tog, 1968 8 onto 0.6 208 009

septa, 1968 9 ob 0,88 1.23 10 00.013 O15

early sverege 1058 OME 2.228 1.5 ah Ligh ook 01S IS

---Page Break---

mae 9.

Bee. 1968 »

mer. 1988 a

pe, 1968 »

May, 1968 a

ae, 1968 2

July, 2968, ry

bea, 1958 6

Bape. 3968 %

easly evereee 08

afte

oom Kom PF

oe 0.30 03

0.5 0.36 2

as 0.30 028

08 ots 055

0s ons 08

06 0.50 08

010 0.00 0g

oak 0.30 er

oak 0.23 1.50 016 0.78

oa 0.08 .

ons .

0.25 Ler .0@

0.29 1.38 0.009 0.18

0.83

1s

ae

282

2.06

1.88

16

136

Lw

6

1.08 sts

29 89

333 3

3.03 aes

ATs aah us

aor 0

1.6 ?

der 139 te

eae 113 0.656

BEREBRE

68

632

Inte cf movement of elements by #ten flow,

or

a

aa

1

1005,
005

ol
or

30

o

---Page Break---

mate 1,

?te of sovenent of elenente through oll ty bulk flow.

ee ceo me oF mre oe

ot 6 es ne)

wer 961 me eae eh

ae. 96t le eat to

San. 3968 08 3.00 es

Fe. 968 8 ovr om ats

ver. 968 Pe ee)

ser. 968 056 ake aa wor

ay 968 » 1m Ae .ne 00

guests eae oe ae 2M cor

ay, 968 ook 1st 0

ag 1968 wos tsa 5

ser, 1968 90.5 Rot om 86 9 ato

Yearly avernge 16.58 0.89 2h 0.360.316 359 008 ast 090

ost. 1967

Yor. 1967

bres, 1967

Jan. 1968

Fe, 1968

Mars, 1968

dor, 1968

ay, 1968

sme, 1968

say, 1968

tog.» 1968

Sept, 1968

?Yearly average

ovat solsble

sale o

1 ot

w 0.96

? ote

a 0.88

» 0.32

5 on

ry 0.6

2 ase

ve ont

6 Ler

6 1.08

0.29

0.83

aat

130

ate

0.08

ae

0.88

2aT

aoe

135

aar

0.4

2b

13+

5

a

3

as

0

0.7 ath

2

2?

0.10.23

0.t0 0.29

ase

2.52

000

BRB

203

008

og

wo

---Page Break---

? RAIN

3] 1 OUT OF LITTER

? THROUGHFALL

STEM FLOW I

=

52

3

z

c

e

OcT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Fig. 3. Average rates of calcium movenent through the ecosystem.

x

=

S

¢

z

<

>

=

°

@

g

OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Fig. 4, Average rates of magnesiun movement through the ecosystem,

---Page Break---

? RAIN

THROUGH FALL

sl eT STEM Flow ?

?1? OUT OF LITTER \

KG of No /HA/WK

OcT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Fig. 5. Average rates of sodium novenent through the ecosysten,

?e? OUT OF LITTER

THROUGHFALL

? pan

4oF\ Stem FLOW A

KG/HA/WK, TOTAL SOLUBLE SALTS

wo AS OND JFMAMJJAS

1967 1968

6. Average rates of movement of total soluble salts

?the ecosysten.

Fig. 6 through

a15-

---Page Break---

Table 13, Met monthly rates of element gain and loss from ecosystem,

detemnined by subtracting rate of loss by runoff from rate

of input ty rain,

oct., 1967 125 +aT +.02

Tov. 1967 -.56 4.16 2h

Dec., 1967 +452 +12 ol

Jan, 1968 2h +436 ?5

Feb. 1968 +08, +01 406

Mar. 1968 -.62 =136 7.25

Apr. 1968 kT +e 216

May, 1968 -LuT 71.33 -5T

June, 1968 12 012 nal

duly, 1968 os 1.08 =.25

?Aug. , 1968 ~ -a +239

Sept., 1968 +001 +256

---Page Break---

KG/HA/WK

OcT NOV DEC JAN FES MAR APR MAY JUN JUL AUG SEP

g. T. Rates of gain and loss of isotopes to and from the ecosystem.

hose

iS

KG HA WK, TOTAL SOLUBLE SALTS

ae

MJJASONDJFMAMJ JAS

1967 1968

Fig. 8, Rates of gain and loss of total soluble salts to

?and fron the ecosysten.

aT

---Page Break---

gVP4 HET = czoryat = £570 x CODES

Hoots 4san0g 30 gu/B = gHo/B x ?TOA

@ o00'HEz = gD OOOOT x "HO H°EE

Hoots aeaHos Jo zi 40d Tos Jo oAST seddn 50 ?toa = at T x wadap a9uraKe

Co ar 3 £50 ez 69 F Hee seats TT

« Lot ¥ 192 equa UOTAVTPEE

or ar F Lao 4 OTE le (su073,

-rpuoo TyO8 poonpat)

SqULE pus sOTTEA

ot ov F 20'r or 60° ¥ 1S*0 co T9Fe'te ?? (suoTaTpUOD TTo8

pezTpTx0) se8pTa

suoyyearosqo ?Ayysu0p suoygearoego Ayyetep ? suoyyeaxosqo ?to

30 ?OH ara Jo ?on rng 30 ?ON ?uadap

emazane oparano aeuroK9

Thor Fo RT TT

?soya some ed Tr08 Jo s926t sadn 30 4uGen pu ?Ty08 Jo eeTareuep ammq pe Yadeq

at stam,

---Page Break---

ALL elenents vere analyzed by atonic absorptii analyzed by atonic absorption spectrophotonetry.

Leaves, wood, roots, organic matter ani fresh litter were prepared for

analysis ty the folloving procedure: er were prepare

1) Put 2 grans of plant material into a 50 ml. beaker.

2) Burn in the furnace at 250°C for 3 to 4 hours.

3) Increase the temperature to 450°C and ash for 12 hours.

4h) Let cool, ada 5 ml. of concentrated HCL and evaporate

to dryness (Don't let boil).

5) Let cool; add 25 ml. of 0.1 HCL and stir.

6) Let sit for 30 minutes.

7) Stir again end filter through Whatman Ho filter paper (Do

not wash filter paper).

8) Run for Co, Cu, Fe, K, Mn.

9) For Ca, Mg, and Sr dilute 1:1 with « solution 2% La; 1000 ppm Ks

?final concentration of La should be 1f and K 500 pa.

10) Divide every $A by scale expansion, if any, and convert to

?absorbance.

11) Prepare a standard curve for absorbance (1) vs concentration

in the samples and multiply by dilution factor, if any.

Hote: Same procedure as above is used for the complete

analysis of organic matter, except for Sr, which has to be analyzed using the method of additions.

Elenents were extracted from the soll for analysis by the following procedure: pe

1) Weigh 2.00 grans of ground,'oven dried soil into a 50 ml. Plastic centrifuge tube.

2) To the soil in the tube, add 15 ml. of 1 N NH,OAe and shake at full speed for 30 nimites.

3) centrifuge at full speed for ten minutes.

4) Decant and save the supernatant.

5) Aid ancther 15 ml, Niy0Ac and shake again at full speed for 15 minutes.

6) Repeat step 3

7) Decant, adding supernatant to the supernatant fron step 4.

8) Repeat steps 5, 6, and 7.

9) Make to a total volune of 50 mi. with 1 W NHyOke.

19) Filter through Whatman 40 filter paper.

1a) Run for Cu, Fe, K, Nn.

2) for Ca and? Mg, dilute 1:1 with a solution 2f La; 1000 pom K to obtain a final concentration of 1 La, and 500 ppm K in the sample.

13) Divide every $ A by scale expansion, if any, and convert

absorbance.

1b) Prepare a standard curve of absorbance (Y) va concentration

(x) with the standards. Determine concentration in the samples and multiply by dilution factor, 1f ary.

---Page Break---

Since available elements in the decomposing organic matter may be important in the elenent cycle, an attempt was made to get an indication of what quantity of elements vere available for inmediate uptake ty plants, as well as total elenents as determined by the combustion technique. There-fore, an extraction procedure for the organic material vas used, similar to the extraction procedure for the scil, It is as follows:

1) Put 4,00 grans of oven dried organic matter into a 50 ml. plastic centrifuge tube.

2) Aad. 20 ml. of 0.1 W MHOAe and shake at full speed for 30 mimes.

3) Centrifuge at full speed for ten minutes,

4) Decant ant save the supernatant.

5) Ald another 20 ml. WijOke and shake again at full speed for 15 minutes,

6) Repeat step 3

1) Decant, adding supernatant to the one fron step 4

8) Repeat steps 5,6 and 7 until the extracting solution (1 ij0ae)?stays clear after shaking.

9) Filter through Whatman ho filter paper.

10) Run for Co, Cu, Fe, K, Mn, Na (dilute, if necessary).

11) For Ca and Mg, dilute 1:1 with a solution 2% Ia, 1000

pm K to obtain a final concentration of 1% fa, and

500 ppa K in the sample.

12) For Sr, use the method of adition, in vhich a standard 1s

faded to the sample; two equal volunes of sample are

@iluted in a 1:1 proportion, one with a known concentration

standard prepared in 26 La, 1000 pom K, ani the other with

Just a solution 2% la, 1000 py K. Compare the absorbance

of the tvo samples using the following proportion.

Goncentration sample Cone, sample + Conc. standard

?Absorbance sample ?sSsorbance of Cemmpie + atantard)

solving the proportion for Conc. sexple,

Asample C standard

Cone. °: (GS Se eee

semple A (sample + standard) - A sanple

13) Divide every $A by the scale expansion, if any, and convert to

absorbance,

14) Prepare a standard curve of absorbance (1) vs concentration (X)

with the standards. Determine concentration in the samples

and multiply by dilution factor,

?The sampling scheme vas designed so that the following statistical

tests could be made:

1, Soil, for difference in sites,

2. Soil, for difference in depth.

3. Tree trunks for difference in species.

---Page Break---

4, Tree trunks for difference in sites.

5. Freshly fallen litter for difference in season.

&. Organic matter for difference in sites.

7. Leaves for difference in presence and absence

of epiphyllas.

8, Leaves for difference caused ty location in

?canopy or understory.

?The exact sampling schene is shovn in Table 15.

Al statistical tests vere made vith the analysis of variance technique, except for the leaves, vhere it was necessary to use a non-parametric sign test.

Results

Leaves with epiphylls contained greater anounts of Co, Ma, Fe, Sr, Ca, and Mg (Table 16). Presumably this 1s because when rain containing these elenents enters the cancpy, the elenents are nore efficiently pound to the leaves when eptphylls are present. Tt 1s not surprising that the eptphyll covered leaves did not contain more K and lia, since these are very mobile elenents and are less Likely to be bound ty the epiphylls. Te ie surprising that Cu shoved no difference, Perhaps there is no sig niftcant input of Cu via rainfall. Pulicoures riparia vas excluded fron ?the tests, because in muy cages it showed tendencles opposite to that of the other species.

?There ie a tendency for understory leaves to be slightly higher in element concentration than canopy leaves, (Table 16), but the dif~ ferences are not great enough nor consistent enough to be statistically

significant.

Averages ani standard deviations of element concentrations in leaves of each category are given in Table 17.

Differences in element concentrations between species are very great in some, but not all, species (Table 18). However, differences fare sufficient for each species to require different treatment in the model. Caleiun differences between three species were checked, and the differences are highly significant (Table 19).

mere vere no differences in six elenent concentrations in Dacryodes between sites, but there were differences in Mn, Mg, and Na. Therefore the sites were checked again for these elements using Manilkara. Magnesium Sinin shovel a difterence, so it was checked again in Sloane, There vas weulterence betveen sites (Table 20). For purposes of the nodel pre-MfousLy discussed, ve can assune no difference between sites.

mere are apparent differences in concentrations of elements in the roots of the various species (Table 21).

---Page Break---

Baectatte a cf sites dentin

Wen arates sat

cs niger 3 omg 2

: 3 . i

8 3 a

e 3 i

5 i

3 : ?se ~ i

5 : : :

5 : : t

3 1 ectyyn cmt 2

3 : : i

3 : t

5 ; 5 : i

to) :

5 :

3 i

5 ?

1

a

"on lage top 3 eg. : og ime s

3 : at 3 ?

C 5 6 S oe : i

aa sites 53 trem auver = top of organo matter an Ler

Poorly drained sot

Te valley vote Legros cles untestory croton gonctati

{

A

i

---Page Break---

Table 16

Reoults of sign tests to test aiff in elenent concentration

ferences in elenent concentration between

eaves with and without epiphylls, Palicourea riparia excluied, ani. be-

?tween canopy and understory leaves.

Element Clean leaves vs. leaves Canopy leaves vs. under-

??sepipyiis ?story leaves

nr level of confidence nr _level of confidence

?that leaves plus that understory

epiphylls are higher leaves are higher

co woh 958 nok -

Ma ww 2 8 yok 5

Fe wo 9% m5 7

cu 2 8 - ak -

x 2 1 uo3 ot

a 2 8 - nos -

sr 2 2 99% nu 3 oH

co 2 2 99% nu 3 oh

Me 2 & 95% no 3 3

* clean leaves are higher in potassium

---Page Break---

?Table 17

Averages and standard deviations of element concentrations in leaves of each category. All values are parts per million.

Dacryodes excelsa

canopy

clean leaves (n = 3)

co Mn Fe

M6etioT 33942 setie

cu K Na

2.M6 $1.02 1137 + 679 1482 + 190

sr ca %

8.2 £1.d1 3321 + 64h 1067 + 105

Dacryodes excelsa

understory

lean leaves (n = 4)

co Ma Fe

2,90 + 2.22 2.95+79 89 +16

cu K Ta

5.15 + 2.87 ? e7ho + 615 17074773,

sr ca %

6.45 $2.54 3713 + 693 Iae3Te

Dacryodes excelsa

ccancry

leaves + eptphylis (n = 3)

co Ye Fe

5.02 + 2.21 381+ 181 102 + 36

ou Kc Na

2,66 + .lh 981 + 283 1700 + 368

Br ca Me

10.2 + 1.8 4529 + 833. 1222 + 205

Dacryotes excelsa

understory

leaves + epiphylls (n = k)

co Yo Fe

4.39 43.34 NBT + 1N6 120+ 26

ou K ma,

2.72 + .26 1209 + 189 1529 + 6a

sr ca %

12.8 + 2.96 5173 41534 1320 + 232

2h

---Page Break---

eS

Continued Table 17

ee

Yantlkara bidentate

canopy

clean Leaves (n = 2)

co Ye Fe

Toh+0.22 33412 she 9

ou x ma

4.95 $0.64 2656 +12 315k + 364

se ca Ne

22.6 $16.1 4991 $582 2019 + 3m.

Maniikara bidentate

understory

clean leaves (n = 4)

0 Ma Fe

4,78 42.84 32413 136+ 8b

ou K Na

8.00 + 2.59 3663 + 1099 haB5 + 2116

sr ca Ne

30.7 $ 13.1 6651 + 2047 3080 + 506

Mantikara bidentata

canory

leaves + epiptyiis (n = 2)

co os Fe

8.254+0.36 Moree 8429

ou x Ma

Tho + L9T 18a HIB 3263 472

sr ca, Me

38.5 + 10.5 6496 th53 2647 ¥2TO

Vanilkara bidentate

understory

leaves + epiphyils (n= h)

co Ma Fe

4.96 $3.bh 0456 253 + AT

cu K Ya

1.85 + 0b 1359 + 323 3828 + 2589

se ca Xe

Mae + 13.5 8070 + 1690 3539 + 502

25+

---Page Break---

Continued Table 17

Sloanes berterts

canopy

clean leaves (n = 2)

co Ma Fe

4.394132 M5 heh os Th

ou K Ta

9.10 $6.50 2224 +922 510 + 180

Sr ca %e

16.4 + 9.4 5698 43069 2008 + 608

Sloonea berteriana

understory

clean leaves (n = 5)

co Ym Fe

4.70 43.29 1Sh+ 85 TT + 38

ou K ta

10.22 + 3.k 28h + 607 685 + 197

sr Ca %

25.38 + 4.65 4587 + 797 1596 + 152

Sloonea berteriana

conory

leaves + epiphylis (n = 1)

co Yn Fe

5.2 nn 123

cu x Na

43 ant ate

sr ca Xe

MT eo 2678

Sloanes berteriana

understory

leaves + epiptylis (n = 4)

co Xa Fe

5.354595 2554121 139 +29

ou K Na

5.32 + 1.50 1979 + 359 1135 + 22h

Sr ca Me

24.0 + 4.95 THB + B43 2039 + 185

---Page Break---

Contimiea Table 17

Palicoures riparia

clean leaves (n= 5)

co ry Fe

7.32 £3.24 1Tht 93 he iy

cu K Ya

13.96 £3.78 4596 + 954 2202 #1062

Sr ca Me

U8 ¢ 32 1092T + 983 5300 + 523

Croton poeetlantius

clean leaves (n = 1)

co Mn Fe

2.87 828 8

ou K No

8.8 5250 6130

sr ca ¥%e

st eet Hoel

Palicourea riparia

leaves + epiphylis (n = 5)

Co. Yn Fe

7.32 £2.95 ll+ 68 277 + 126

ou K Na,

18,98 418.25 3171 41228 5344 41012

sr ca, Me

aah + 53, 10368 sukgh 5239 + 803

Groton poectianthus,

leaves + epiphylis (n = 1)

co Mn Fe

3.37 1204 a

cu x Ma

6.0 3202 8025

sr ca Me

68 8586 eB

-21-

---Page Break---

??_

Continued Table 17

©

115

w.2

Sr

23.7

Buterpe globosa

lean leaves (nel)

Ya Fe

305 23

x Yo

4387 926

ca %

wt20 2958

Buterpe globose

leaves + epiphylls (n=1)

© Me re

4.87 06 22h

ou x me

12.5 2665 315

sr ca %

19.6 3981 ?687

Table 18

SS

?Averages ant standard deviations of concestrations of elesents in tree trunks

POPE R RE

5.62

wo

29

178

258

3.38

ats has,

ah ale

m3

na 188

31st

a8

wah 33

48

25

3.36

as

ast

90

m & 2 =

33 £388 3.502 200 29 tL 5502

AB tr BT Tt 39 rw Leos art

uss hae we:

sete ase wet

ca wot

art ba 15

1.80 + 0.50 83 +

wt ee 6

set we ao

20

oh

2.98

6

aus

aa

cc

---Page Break---

Table 19

Results of analysis of variance to test differences in concentrations

?of calcium in wood, between ape!

han, /dence. F Level of stant

Tested _?Shecten Element «of Patio? «ratio fleant Atterences

Spectes ?De-De ca 1/38 3h.o 9.8

Mao ca 1/38 12.0 9.58

. De-Sb ca 8 06 9

Table 20

Reoulte of analysis of variance to teat aifferences in concentrations

?of elements in yoo! between sites.

mm./tence, PF Level of stgntfi~

tested Gpecten © Elenent? «of Prratio? ratio cant difference sites be ca bas wer a

. De x aps 158 -

0 be c 4As 1.88 e

. De % aps 1.80 9.56

. be Br aps ua a

. De % As 6.22 9.58

. be re aps 1.8 5

0 be ca eho 0.00 o

. be Ma ans 2.62 sof

. me a aps 1.53 -

. Ys % aps abe sot

. % Ma aAs 0.62 -

. > 6 4s ade S

---Page Break---

Differences in elenent concentration in the soil extract vere teste, between the five well drained sites, and all six sites including the poorly drained site. Differences between sites occurred only in Mn and K (Table 22) for the soil 0-2 inches deep, but these differences occurred within the vei; drained sites, and not necessarily between the vell and poorly drained sel]. However, with soil fron the 5-7 inch level, differences between the well and poorly drained soil existed for Mn, Ca, Mg, and Sr (Table 22). Since aifterences increase with depth, differences are likely to be caused by differences in parent material,

There are differences in element concentration between the 0-2 and 5-T inch level for Mn, Ca, Mg, Na, and K, Tron, Cu, and Sr appear to be equally distributed in the soil down to the 7 inch depth (Table 22),

Average and standard deviations of concentrations of element in soil extracts are given in Table 23.

Concentrations of exchangeable and total elements in the organic ma~ kerfal are given in Table 2h. In the extractable elements, there 1s @ fa aenence between sites only in Mh and Na, and for the total elements, in Ma and Co. There is a strong difference between total and extractable elements for all but Sr (Table 25), Seasonal differences in freshly fallen litter exist only for Na and Ma

(Table 26). Exceptionally high sodiim concentrations occur Aurice theo

wuary collection. This coincides with high sodium input to the ecosystes

Yee rain during Jan, Manganese is low in the litter in the May collection,

Yearly averages of elenents in the litter are given in Table Of.

Table 21

?Average and etanacd dviatces of concentrations of element tn rote,

SME 1ss sot Gah sah we As tas om tom

m ert at Agee serine am: n wt Oi oem

See ts mes ke norss barat ast an és nye

ce tas gas m8 + sah hk + oes am

% wht mo Tet me st th est ae oy wy

? ht we mrt met Mt OS met at se

500 tA GTB £16 ce tet TA 22.08 12 t 600 835 ¢ any

x GL t 6 ws tw st Et OT ems Ty les To

? M6 tig abt Ts et homes mt er He

---Page Break---

Table 22

Results of analysis of variance to test soll differences

?between sites and depths.

Depth, un. /aencn. Level of signifi.

Tested inches Element _F ratio cant difference:

all sites 0-2 Mn 5/18 2.64 90%

5 well drained sites 0-8 Ya ins 3.08 958

?all sites 0-2 ca 5a 1.01 -

non 0-8 Me 58 2.09 -

nos 0-2 Fe 5s 1.88 =

B 0-2 ou 5/8 1.00 :

" o-2 Sr 581.55 5

" 0-8 Xa ip 0.55 =

as 0-2 K 5s 3.28 958

5 well drained sites one K As 3:38 95%

all sites 5-1 Ma 5182. 90%

5 well drained sites 5-1 Ma ns 1.60 E

all sites 5-1 ca 5fie 22h 8

5 well drained sites 5-1 ca ins 0.92 :

?all sites 5-7 My sib 3.96 oth

5 well drained sites 5-7 Mg is 1.37 5

all sites 5-1 Fe sb 8.67 oot

5 well drained sites 5-1 Fe ins 9:16 59%

all sites 5-7 cu 5/18 0.50 =

all sit 5-1 Sr 5B 3.05 958

5 well drained sites 5-1 sr ins 0150 fs

all sites 5-1 ia ya ong :

all sites 5-1 K sng 0.9 a

Ma a6 00 99%

ca Ue +23, 91%

" Mg 1/6 75, 99%

Q Fe 3/6 35 es

o ca ane 25 :

G Sr ase 32 :

G Ta ifs 6 90%

" « afu6 50 9%

Be

---Page Break---

Table 23,

oo

i

Fre evaes

?Averages and standart deviations of

ou

x

%

Re

oo

%

se

me

Table 24

Se

concentrations of elenente tn organic

?aatter on top of soll,

Pacts per miiton

29

a

°

?8 determined by to sethote,

Sree

Mi\OAe extraction

2.85 + 1.60

2+

at x

aa t 30.2

amo + gh

em sats

30.9 t Bb

wet 5

32

3m ¢ as

mot we

ht x

wart bs

nak 2 ono

9.68 fa

wee

E

25.6

25+

ast

aie

30.3

n.6.

16.5

x

105

a6oe

32

a

&

1.29

3.06

o&

out

as

---Page Break---

?Table 25

Results of analysis of variance to test differences between sites, and between

snalytical methods, for organie matter on top of soll.

tun. /denom, F Level of signifi-

Tested Blement _F ratio" ratio cant difference

All sites, extractable elements

BRE OTR Re

elements

SERESTE Re

orennnns

A

8

gw

HOTEL

e

* ? sr 2/38

2? R38888

---Page Break---

Table 26

So

Renults of analysts of variasce to test atfterences in soothly

?concentration of elenente tn freshly fallen Litters

Ma/aenoe. oP Level of

estea Rest P'iatio? ratio gaan alge

Month (San. 5 Mars, May July,

Sept, Wov.5 ca sh 0.50 -

sone ee = . Ar .

wee ee = on 4

e+e» « a s a .

sone ee o . a .

Month (Jan., Mars, Suny, Hoy.) ne 3/6 2.32 -

rar x = a .

hoe ee Ss . oO -

she m . ser 98

oo

Table 27

?averages an stantant deviations of concentrations

?of elesenta in freshly fallen litters

esest Parts per mtition

© 8.52 ¢ 6.10

a Mbt oot

% mt

o 5.72

© 30

m 05

or os

ce sick

% 2200

ots

*

Ne

ag

asse

33

---Page Break---

ne

ak

1b.

TRANSFER AND STORAGE FUNCTIONS FOR STABLE AND RADIOACTIVE ISOTOPES IN ?THE TROPICAL RAIN FOREST ECOSYSTEM

Input of isotope into system by rainfall 1s a function of volune of rainfall tines concentration of isotope in rain.

Isotope movenent by throughfall is a function of volune of through= fall times concentration of tsotope in throughfall.

Isotope movenent by stem flow is a function of volume of stem flow ?times concentration of isotope in stem flow.

Isotope movenent ty leaf fall is a function of biomass of leaf fall times concentration of isotopes is undecomposed litter.

Isotope movenent from litter to soil is a function of volune of water leaving the litter times concentration of isotope in that water.

Isotope movement through the eoil is a function of volume of soil water times concentration of isotope in soil water.

Isotope loss through runoff is a function of volune of runoff times concentration of isotope in runoff.

Loss of isotope through sediment movenent is a function of the volune of water during flood stage tines concentration of sediment tines concentration of isotope in sediment.

?Turnover time of isotope in canopy is the biomass of the canopy tine: ?the concentration of the isotope in the canopy divided by the loss rate from the canopy.

?Turnover time of isotope in the understory is the biomass of the understory times the concentration of the isotope in the understory divided by the loss rate from the understory.

Tumover tine of isotope in the litter is the biomass of the litter

?times the concentration of the isotope in the litter, divided by

the lose rate fron the litter.

Increase of isotope in bionass of canopy is a function of the rate of

?canopy increase tines concentration of isotope in the canopy.

Increase of isotope in bionass of stem is a function of the rate of

stem increase times concentration of isotope in the stem.

Increase of isotope in biomass of roots is a function of the rate

of root increase times concentration of isotope in the roots,

?Transfer rate from epiphyllae to leaves determined by tracer experiment.

35+

---Page Break---

16. ?Transfer rate from canopy to root through phloen determined by tracer

experiment.

A. Transfer to roots calculated ty subtracting loss fron ecosystem from

total movenent into litter.

Influence of Species, Site, Canopy Position, and Fpiphylls

on Fallout Distribution

To construct @ model which will predict pathways, rates, and turn-over tines of stable and radioactive Jeotopes in the tropical rain forest ccosysten, it is necessary to understand inputs to the system. Fallout, of course, is an inportant input. Once fallout is carried into the eco. syeten ty rain, a variety of factors night influence its subsequent behavior, Tes eaetty tests the importance of four of these factors: species, site, dgoatton of leaves in canopy or understory; presence or absence of epipiyila on leaves.

?The sanpling plan vas to take one sanple of leaves heavily covered Sir sPiptyliae, ant one sample devoid of epiphyllae trom the topsscst at te sitet? on fron the botton-nost understory leaves of three spectes gf five sites. In addition, clean and epiphyllae-covered leaves ves ec

Ae was difficult to find and reach all the desired samples at all tre sites, Tore sangegited samples vere obtained (Table 28). ?yo aiditional srectes were sampled at sixth site for additional comparison (Table 26),

Samples vere oved-dried, and counted in bulk by gamma scintillation gpectronetry. Data vere corrected ty computer solution of similtaneons equations. Comparisons between sites, species, canopy position, and pres~ ?ence or absence of epiphylls vere made using 137Cs, Lice ana 95a,

First, averages of 137cs, Mice, and 952r were calculated for the caiWy tnd understory, for clean ani epiphyil covered leaves, ty, egesin and site (Tables 29-31), Then differences were tested by analysis of vayainee Scchmiquee for apectes, attes, clean vs. epiptyll coven, aed ranegy

Pomitterstory (Table 32).. Ditterences at the of error level or nae

found between species for 1370s and llilice on clean understory leaves, and

Cresent species for all isotopes on epiplyll covered understory tees

(ieble 5). Since tables 2,3 and k show that average levele or fence on

Feltcourea riparia are most different fron the rest, species tn tre wdc

Har? He Gin eteed for alfferencen, this tine without, Pultosnres siea-

Hig, Mo dttference between other speciés vas evitent. The eee ee

Gifference between species in the canopy,

Ivo differences between sites, out of the 12 tested (table 32), vere

significant. Tis is not enough to'state that there are difference) bene

sites.

---Page Break---

Table 28, Actual sampling schene for deteraining fallout atstribution.

Montara Slonnea *Palicouren Buterpe _Croton

Bidentata berterfana ?iperia globose poecflantius

canopy + eptptyll x x

Sitel understory clean x

understory +

eptptylt x x x

canopy clean x x x

canopy + epiptyl x x =

Site 2 unerstory clean x

unlerstory +

epipty x

canopy clean

canopy + epiptyl.

Site 3. tlerstory clean

understory +

epiptyi x x x

ccanory clean

canopy + eptpty2L

Site § understory clean x x x x

understory *

epiphylt x x x x

canopy clean

canopy, + eptptyli

Site 5 understory clean x x x x

unlerstory +

epiphyt

understory clean gq

Site 6 unterstory +

epiptyl. x

swnderstory epectes

-3T-

---Page Break---

Je 2. Tnt}ynce of species, site, canny postion an eptptylia

mee on ?7'Cs distribution, Average values are picocuries per

ee.

Unteratory

Tiean leaves Teaves plus epipiyils

en Heats __Teaves plus epiphylis

" 1 et. deviation "

Site 1 3 3.03 2.02 2

Site 3 2 Mor 2:59 2

Site & 3 3:8 0.22 3

site 5 3 B59 1.30 3

Dacryodes excelsa w 3.62 2.9 4

Manflkare bidentate = 3.73 0:90 4

Slonnea berterfana = 33.88 on 2

Fulicourea riparia = 55.65 159 5

Canopy

Site 2 2 2.62 0.67 3 b.80 0.48

Site 2 3 3.03 0.55 3 123

Bite 3 i 36 + 2 wT :

Dacryodes excelen 3 3.50 0.35 3 kage 0.50

Mantikara bidentate 1 © 218h 2 2 3:5 0.92

Sloanea berterians = 22.37, 0.32 2 kt 0.80

---Page Break---

Tuble 30. Infhugnce of species, atte, canony position ant epiptylis

en 1iMGe"ataertbuticn. ?Average vues are ploocurien Der eran,

underat

Teaves plus epipiyiis

" x deviation 1 st, deviation

Bite 1 3 2.38 1.26 2 6.46

Site 3 2 2154 2125 2 W10

site & 3 LIS 0.08 3 wat

Bite 5 3 0.63 0:86 3 49

Dacrycdes excelsa ath 1.72 » Beta

Yaniikera bidentate 1:09 0162 4 465

Bloanea berterians = 3 a5 0.8T 2 4gT

Falicoures riparia 5 6.59 3.26 5 15.88

canopy

site 1 2 2.92 ak 3 5.99 LAS

Site 2 3 21h6 2:70 3 619 6205

Site 3 L 8.06 + i ea :

Dacryodes excelsa 3 5.19 aT 3 8.19 4.23

Wantizara bidentate 1 ag 0:86 2 an 3119

Sloanea berterians = 2 ore : 2 5.78 2136

---Page Break---

?table 32

site 1

Site 2

Site 3

Decryodes excelen

Sloanes berteriain

oor

oe.

of opectes, site, canopy position ant eptptylis

?Metribution:

iean eaves

x

Beas ERaT

RSE

Unters

Lat, deviation

0.

3

0,

°.

0.

0:

9,

0:

BEER

BbSE

Teaves

mx

2 1

2 0.92

3 1:05

3 Lot

Bake

wong

2 ot

5 kB

3 Las

3 0196

L139

3 Lp

2 166

2 0.68

?average values are picocuries per

ius pips

1 et, deviation

---Page Break---

?Tile 52, Femulte of analvaia of variance to detemine algntficance of differences in fallout,

(SR _ ier ee Degg eterno

syectes ?Understory clean Dey8o,Majop,Pr 3.338 5.10" 2h ape

a

Ten eae 8 va

m9 eee oe e

a ee

TrogaE? aaeme aseokA on

seiee Campy, cies tem TD ve

ee

TE meta

os tetay, cnn begs she an

we haart oe sie

site Cancry, clean Dein, 1.20 2.31 2.6 3

Bee cone Pyle ?De Mn, Bb o.2h 0.16 1.29 of

CLean-eptphyll Canopy Dein, Sb 1b. 6e4 2.5 2.83 ya

Ceara taaeeiny eR! AY the ve

cumyotervioy Cleese OSh th as

cumvmtentey ian iglla eka Oa ns

= atgnteteant at 5f level

+ = wtgniticant at 24 level

aha

---Page Break---

Table 33. Average values of fallout within and

where no significant aifferences ext:

lean Leaves,

between compartnents

st.

NK 1 etadeviation » &

122 sites ana

toecfggs except Pr,

fer Ge. 2337 as 25.30

Fulicomen riparia,

for 137s 5 5.65 1.59 5 7.82

Wa sites and

cpeclepe exmeyt Pr

for hk, ie 1.65 1.27 na 4.50

Pullcopren riparia

for se 5 6.59 3.26 5 15.88

2 sites and gpectes,

except Pr for Ber" 220.58 0.08 nou

Palicomea riperta,

for ir 5 15h 0.98 458

canepy

man ottes,

fpeles furs 6 ga 0.68 1 kst

san sites,

species for lWige 6 3.54 2.83 647

m2 sttes, aan

species for 952r 6 0.79 0.65 T 1.31

le-

underst

Se eet ____ a a ST

2 stedevtatice

La

1B

1.6

hag

ob

2.78

0.81

38

0.61

---Page Break---

There are strong aisteren

me erences tetveen clean and eptphyll cover

leaves in the unerstony, for ail destopes, and for USPS Ue eee

Differences betve

?en canopy and understory vere not signtficen

Hine (1967, P-R.M.C. Aamual Repore) peported differences teereen eato

and understory leaves for 137Co, with the understory leaves higher. Ppl

plyll covered teaves in the understory shoved a higher burien than those

pas eenonva Cieble 33), but the difference is not significant. Perhaps

Fences vere obscured because 1370s levels were lover ty a factor o

about 4 from the time at which Kline took his samples. Sr ye tac *

Averages values of fallout within and betveen conpactnents vhere x0

significant differences existed are tumarize! In Table 3300

TRITIUM MOVEMENT THROUGH A TROPICAL RAIN FOREST ECOSYSTEM

Movenent of tritiun through ecosystem 1s of interest for two reasons:

1) Tritium is a tracer for water, and thus aids in water balance studies of the ecosysten, especially in transpiration stulies. 2) Tritium is a major by-product of thermo-nuclear reactions, and could contaminate the environ~ nent as a result of both peaceful and military uses of thernomclear pover.

A series of experinents were undertaken to determine rates at which tritium moves through a tropical ecosystem, and the proportion of tritiun that 1s immobilized and thus becnes 0 long-term radiation hazard in the ecosystem. The experiments vere done in cooperative vith Dr. Jerry Kline, ?Argonne National Laboratory, ana Dr. John Koranta and Mr. John Yartin of Lawrence Radiation Laboratory.

?The first experinent involved applying tritiated water to 2 0.9h sq. meter plot ty simulated rainfall, ani collecting runoff water beneath the Litter and at a depth of five inches, Results vere published in Science 160, 550-551, and the 1968 Terrestrial Ecology Annual Report.

The second experiment consisted of injecting two Dacryodes excelsa and one Sloanea berteriana vith a pulse of tritium, and determining the length of time 1t took for the pulse to reach the canopy, the residence half time of tritium in the free vater, ani the anount of tritium bound

in the leaves by photosynthesis.

?The third experiment vas called a micro-systens experiment because

it wos an attempt to measure tritium movement through all portions of a

micro-ecosystem, a plot of 3.7 square meters in the middle of the tropical

rain forest.

?me fourth experiment was a combination of a milti-isotope experi

ment anda pulsed tritium experiment. The objectives vere: 1) to deter-

mine if certain gamma emitting isotopes which are similar to mutrient

---Page Break---

2) to deter.

shout @ variety

moves unifornly

rr xylem.

elenents move through trees at the cane rate as tritiun.

nine the variation in tritiun movenent through tree throug!

of meteorological conditions. 3) to determine if tritium

throughout the sten, or if it is concentrated in the oute:

The fifth experinent was to detemine tritiun uptake, residence half tine, and tritium bound by photosynthesis in a secondary successional tropical tain forest.

The sixth experiment consisted of injecting a tree with tritium and one gama enitter by using & procedure whereby the transpiration streas of the plant vas not interrupted, as a check on the other tree injection experiments where the transpiration strean vas interrupted.

?The first tree injection experiment was reported ty Dr. Jerzy Kline at the 1969 meetings of the American Nuclear Society. Folloving 19 an abstract of the paper.

Measurenent of Water Behavior in Tropical Trees Using Tritiated Water

Abstract

JR, Kitne!, John Martin?, cari Jortan3, John Koranda?

Water utilization by plants in one of the most widespread process: in Biology, Ecologists seek more detailed information on water relation ships in terrestrial ecosystems as part of a general quest for deeper unler= standing of their functional processes. Modern nuclear technology adde urgency to the acquisition of knowledge on the functions of water in the environment since both peaceful and military miclear operations could contaminate biological systens with tritiun as a major by-product of themo-

nuclear reactions.

Despite this need for information, there is little detailed quantitative data available. The Rain Forest Project of the Fuerto Rico Mvclear Center and the Ecology Group of the Biouedical Division of the Lawrense Radiation Laboratory, Livermore, Ca. have cooperatively initiated a serie: of experinents on this problen using tritiated water as a tracer. ?The fisst

experinent in the series is reported here.

The objective of the initial experinent was to determine the response of several tropical rain forest trees to the injection of a pulse of tritiated water. Secondary objectives included monitoring of air ourrounding the experimental site and of involved personnel to establish appropriate safeguards in the execution of such experinents.

lyomerly with PRIC, now with Argonne National Laboratory.

2 Laboratory, Livermore, Ca.

?Lavrence Radiation? ry, "i

Puerto Rico luclear Center, Rio Piedras, Puerto Rico,

hha

---Page Break---

Tmree tropical trees representing two spectes vere injected with tritiated vater through holes bored inthe tranke neer ground levels The novenent of the labeled vater was monitored by saxpling leaves from a. tover nich had been previously erected nearby. leaf samples vere collected, at first several tines daily; and later, once daily, and sealed in plastic bags and frozen prior to analysis, Samples were analyzed by extracting tismue Vater in a specially designed high vacuum freeze drying apparatus, ant then counting the water by standard Liquid seintiliation technlques-

The pulse of tritium reached a peak in all leaves approximately five days folloving injection, after which concentrations of the isotope deelined. ?The time required for the isotope to reach the crown of the trees vas not dependent on the height of the tree. ?The sane time was required for a tree seven neters tall as for tvo about twenty meters tall. ?Tritium did not pass through the trees in a symetrical pulse. After the peak was reached, tritium concentrations died away exponentially vith half residence times ranging fron approximately two to eight days. The largest differences in tritium residence times were found between species, suggesting that they have dif-ferent adaptations for water use even though they occupy essentially the sane environment. The dieavay curves shoved several erratically spaced peaks and valleys during the course of the experiment. This was suggested to be due to exchange of leaf tissue water with uncontaminated rain water without corresponding exchange in the xylem elements of the tree.

It vas concluded from this experiment that: (1) Tritiated vater is a safe powerful tool for the detailed assessment of water use by plants in the Tiel. (2) Tritiated water persistsin tropical trees with appreciable residence times even though large amounts of rainfall occurs in the rain forest. (3) Rains bearing tritium will probably cause leaf tissue voter to become labeled innediately due to the exchange of water on leaf surfaces. (h) The persistence of tritium in an entize forest may be longer than that shown by single tree experinents due to possible recycling of tritium which nay be exchanged at leaf surfaces and carried to the rooting zone of plants

ty rainfall.

MICRO-SYSTOS EXPERIMENT

Because an ecosystem, when studied as a whole, often shows properties different than, or not apparent in, the sum of all its ports, ?an attempt vas made to study movenent of tritium through all portions

of an ecosystem at one time.

MeTHODS

230 em by 160 om was outlined with string. One

and soil water collectors ("Zero-Tension

81-86) were installed. Each

A plot of ground,

side of the plot was cut avay,

Iysineters", Jordan 1968, Soil Science 105,

hs.

---Page Break---

lysimeter collected water fron a 2h sg, inch area, ?vo lyeineters vere installed beneath the litter, two at a depth of 5 inches, two at 10 inches, and two at 15 inches. The bulk density of the soil from the surface dovn to about 10 inches averages 0.57, at which point there ie a region where the bulk density changes quite rapidly to a value of approxinately 1.02,

Leaves for analysis for free and bound water vere picked from three trees groving inside the plot. They vere a Dacryodes excelsa, 2.31 inches basal Slaneter, Microphilous gareinifolta, 2-06 inches basal diascter eg Mantikara bidentata, 1.Uh inches basal diameter. Transpiration water vas collected fron two other smaller trees, a Palicourea riparia, 0.56 inches Dasal dianeter, and a Manilkara bidentata, 0.72 inches basal dianeter, by the following method: ?A plastic bag was put over a bunch of leaves stili on the tree; a floodlight vas shone on the leaves to increase transpiration;

air was pumped out of the bag and through a condensing tube submerged in 4a dry ice-alcohol mixture, and then back into the bag. About 2 ml. of water collected in the condensing tube in a half hour.

Free water was extracted from the picked leaves by freeze and dry methods using high vacuum apparatus.

Cores of wood were taken from the buttresses of two large trees Whose roots extended into the plot. The trees vere Buchenavia capitate, 17.75 inches d.b.h., and Tetragastris balsamifera, 8.93 inches @-b-h~ Free vater was extracted from the wood with the freeze dry apparatus,

Water vapor was collected at 8 points immediately surrounding the Plot, at 8 points about 3 meters distant fron the plot, and at b, 100, fand 175 cm above the plot. At the 3 meter points, the water was collected in the following manner: An aluminum tube 1 1/2 inches in diameter and about 11/2 feet long was inserted in an ordinary wide-mouth thermos bot= tle so that one end of the tube extended about 6 inches out of the bottle. One cup of liquid nitrogen was poured into the bottom of the thermos. Water vapor condensed and froze on the protruding portion of the aluninun tube. When the liquid nitrogen boiled avay, the ice melted and the water ran into the bottle where it could be collected. For the other points, water vapor was collected as follows: Rubber tubing vas extended from the collection points to a condensation tube in the sane manner as for transpiration water. Air and water vapor vere punped into the tube, the vater vapor condensed, and was later collected.

The following method vas used for applying tritium to the plot. Fifty millicuries of tritium vere diluted into 4 litere of water? the water was siphoned through a polyvinyl tube and ordinary shower head, and applied evenly to the plot. Before the actual application, test runs were made to practice uniform application.

Water vapor samples were collected 15, 8, 165 and 240 minutes, 2 days ani 6 days after opplication. Leaf, wood and vater sanples vere collected daily for a week, and weekly thereafter.

---Page Break---

Rainfall vas measured above ti

ae he canopy with a standard U.S. Weather Bureau recording rain guage, and below the canopy vith two 5 ft. x 2 in.

x12 in. trough type rain guages. Wet a

Zeagured on every perren gusges. et and dry bulb tesperatures were

Water samples were analyzed by

e zed by standard liquid scintillation tech- niques. Known standards vere incluted vith the samples and results vere converted to decompositions per minute.

EVAPORATION OF TRITIUM FROM THE SOIL

The water vapor from the collectors on the ground surrounding the plot shoved decreasing specific activity with distance avay from the plot. On the afternoon following the tritium application, specific activity decreased with distance most slowly on the uphill side of the plot, most rapidly on the downslope side, ani intermediately on the North and South sides (Table 3). This indicates a slight upslope vind vas bloving during the afternoon, Other ground collectors at greater distances shoved the sane trend as that shovn in Table 1.

To calculate the quantity of tritiun lost through evaporation from the soil, the collections from 4 cm, 100 cm and 175 em above the plot were used. Procedures for calculations vere as follows. No decay correc- Sse ere) waa] Uecence az] ie] =sia2iy=37)ee0 half Life of tritium (12 years).

Specific activity of the vater vapor vas plotted as a function of distance above the plot, for each sampling time (Fig. 9). Specific activity of the vater vapor at ground level imedtately after application was taken to be the sane as the specific activity of the solution applied (50 mei in b liters equals 11x10! dpm in 4000 mi. equats 2.75x107 apm/m1). Attenpts vere made to fit a curve to the points by using least square fit toa quatratic (Y= ax° + tx +c) and least squares fit to a parabolic (x= ax), but nefther resulting equation yielded a line that fit the data catiefactorily. Therefore, specific activity of water vapor at

ground level at tines after application vas estinated ty extrapolation

Of the curves of Fig. 1 (Table 35), using a flexicurve.

Specific activity of water vapor at ground level, (Table 35) vas

then plotted ac a function of tine after application, using three dif-

ferent tine scales (Figs. 10, ll,and 12).

Average specific activity for each given tine period vas then taken

from Figs. 10, 11 and 12 (Table 36).

?aun and Jordan (1969) estimated evaporation from the soil to be

36 g/m2/aay. If evaporation occurs only during the deytine, the average

is 3e/ne/nr, during the daylight hours. Since the tritiun plot was 3.68

qe

---Page Break---

?ibie 34, Spectete activity of vater vapor collected arount the tritim plot folloving application, shectete activity,

sa

veh a Fe yy

zeit a nt a

atte a.sine® oo a, ara

aero? ? 2.0505 g.otmact 6, sisao asta? gas

32 cx, domatege (Bat) 6asact 6.390% 2201) area air

6c Sout abn ? shuo? ? egeaot ?rasuch aan? ate

ce. wow pot G.rimao® ? s.68ai05§?a.s3n0a.etmaoS 55303 algae?

wom st 6.18 ea? bac, aT wr

wet dea? kar asucd 162 " n

Table 35. Specitic activity of tritiated water at sotl surface as dete

ty extrapolation of curves.

Date cific activi fa

55 22ehs, 2.15 x aot ®

SAS 33:50 1.0 x 106

5S 15:15 5.0 x 10°

s/s 16:30 4.0 x 105

SAT 16:00 1.2 x10

sa 15:00 ko x13

+ calculated

---Page Break---

?? 99, 208

& 4

pw TATUM/AM WATER \APOR

a

STANCE ABOVE GrowNO (eM)

Fig. 9. Specific activity of tritium in the water vapor above the

@xperinental plot as a function of distance sbove the plot.

3

&

5s

?eM TmITMA/ ML WATER VAPOR

a

?re (ours)

Fig. 10, Specific activity of tritiua in the vater vapor at grouni

?evel as a function of hours since tritiun application,

lg.

---Page Break---

aren vapon

a3

aa

a.

Te (oars)

Fig. 11, Specific activity of tritium in the water vapor of

?at ground level ac a fumetion of days since

?tritium application.

ot

gc}

j

eft

a et

:

2 i

ee,

Fig. 12, Specific activity of tritium in the water vapor at

ground level as a function of months since

?tritiun application,

50

---Page Break---

60" jot x Lot

Tex0,

oot 0 por ce 06 e/L = Th

oes oo =e pores ot/9 - t6/5

3 ct ore 5'08t core s't o/s - ?2/$

£96 0 OT * 2°05 got x re B/S

ous 0 sot x 9°25 got x ort v/s

£6 10 sot x E19 errs 7

9°96 eo {ox ents eoree?g ers

8°S6 ot got * 2°Tt got x Se et/s

ons er gurce goux ort an/s

626 os got x 4°65 got * Se o/s

vile ee got ¥ Lon got ELE co:gt-00tt st/s

9% MH got x o'r got ¥ 0'% 00:11-00:9T sys

So on GOT * $6 ot Sth (00:9T-0025T s/s

on v9 got ¥9°9 got x09 00:5t-c0r4t sus

899 wit got ¥ Let got XLT cotyt-ooret sys

ts ats got S*S OT X OT oorer-of:2t st/s

PeqeIOMONS ? paTAONGAS ? PSS FoI AT TEE war TE

gusosod 1303 dp e203 wtb Te}0ypayutodeaa jug AaTATRO? OpTOadg

eaTaUTRIM] Jo quaDTAT Jo ugDIOr

uoTwesoeas pre

?ord 9ug woxz zaqua posvraTz3 30

?sonmo waxy pouTateyep #8 sousans Tyo 4 zaqeA poqeTaTTa JO AYTATIOB OTTOOMS ?gC

TABS

51s

---Page Break---

b fle activity ¢

n2, 11,04 mi/nr evaporated from the entire plot. Spec ater

fa given tine period (Table 36) vas multiplied tines length of tine perio,

times 11 mi/tr to give total dpm evaporated during the time period. ?Tots,

tritiun evaporated vas 10.7107 dpm, or .09 percent of the total tritim

applied.

Fifty one percent of the total evaporation took place during the

Ee ese at rea pear on Seas

Movement of Tritium Through the Soil and Trees

Specific activity of tritium in the soil water at each depth vas plotted as a function of time since application. It is immediately apparent that there are at least two residence half-times of tritium at each depth. Individual points of specific activity vs. time are shown in Fig. 13 to illustrate how clear the break is between the two release rates of tritium, When a least squares straight line regression is calculated for each release rate, the first residence half time in the litter is 1.7 days, and the second is 30 days. ?The first release rate is approximately equal to that predicted by Odum and Bloom (1969, in press) based on total free vater in each ecosystem compartment, and rate of movement of water between compartments. Therefore, it may be safe to assume that this release rate represents total free water turnover in the litter.

The second release rate, however, vas not predicted by Odum and Bloom. A hypothesis to explain the second release rate is based on the Presence of a thin film of water which surrounds individual soil particles, soil algae, and decomposing organic matter. This water is called hygro-scopic water. It is bound to the individual particles, and water molecules in this film are not freely exchangeable with the pool of free water. Sone exchange does occur however. As the pulse of high specific activity moves through the litter and soil, some of the tritiated water in the free water Pool undoubtedly exchanges with the hygroscopic water. After the peak of specific activity passes downward and the specific activity in the free water becones lover than that of the hygroscopic vater, tritium diffuses outward, the rate of diffusion being governed in part by the amount of bound tritium and the difference in specific activity in the hygroscopic vater and the free water.

Further evidence for this hypothesis is shom in Fig. 1h, where folloving period of heavy rainfall, specific activity drops sapily, due to the high dilution of the tritium aiffusing out trom the tyeroscopic

shell, and then jumps up again during a relatively dry spell, when the out-diffusing tritiun is less diluted.

Specific activity as a function of tine, for each of the four depths

sompled, is shown in Fig. 15, The buildup of specific activity at the 10

and 15 inch depths is clear, as the peak of specific activity noves dewn-

ward and broadens. After outward diffusion of tritiated water fren the

---Page Break---

a

Fig. 13. Specific activity of tritiu: in the water leaving the

Litter layer as a fiction of tine since

?tritium application,

id]

« |

e

ie log,

3 1.

i

"| .

; j

oe

et ee

spite ctety of ran he te ee

ne

Fig. 1h.

---Page Break---

hygroscopic shell begins, one half residence time at the 5 inch depth

: at the 10 ant 15 depth it is 32 days. The differences

in salt tines between the aifferent ecll depthe coud be explained Oy ait-

inch depth, the clay particles are

ferences in soil structure. At the 5 inch depth,

well segregated (bulk density is 0.57) and therefore the reservoir of

bound tritium is not as large as at the lower depths, where there are

more clay particles per unit volume (bulk density is 1.02).

Me release rate of tritiun after 165 days (Nov. 1) should change again for the 5 inch depth. ?Theoretically, the specific activity at sy depth cannot be lover than that in the soll above, because if it starts to get lover, invart diffusion of tritiated water into the hygroscopie shell begins, as the vater from above moves down, thus ineredsing the

specific activity again.

When specific activity 1s plotted as a function of depth on a given day, mich less scatter appears in the data pointe (Pig. 16). When a sertes of these functions 1s plotted on a single graph, a ploture enecges of the movenent through the soil of the peak of maximum specific activits (Fig. 17). The pattern is vave-1ike, moving donvarl through the soils gradually decreasing in vave height.

Specific activity as a function of time for soil water at the 5 inch depth is compared for tvo experiments in Fig. 18, In the experiment initiated on Feb. 1h, 1967, (Kline and Jordan, 1968), the tritium has « appatence time similar to that of the micro-systens experiment. A big Gifference, hovever, occurs in the initial few days of the experiment 7a, ihe earlier experiment, specific activity increased during the first see ays) whereas in the nicro-systens experiment, maximum speci fie Seharaty Cocurred the first day. The difference can be explained by the gaiy o-aPattern following tritium application, In the earlier experinent, gnly 0,24 inches of rain fell during the first 2 days following isthe

The pattern of tritium movement through the trees 1s influenced by

the pattern of novenent through the soil. Since tritin hase tens

residence tine in the litter and soil, the roots of trees are enced to

tritiated vater for a relatively long tine. Specific activity orn stion

in the transpiration vater 1s affected by several factors: 1) Sightititson

of roots with depth in the soil 2) Specific activity of inter iet

depth 3) Water vapor deficit of the air, which affects rate et wetce ter

is pulled through the plant h) Light, witch indizectly controls tesroeh,

ration through regulation of stonatal openings. 5) Proportion of reste

Which are in the contaminated plot (not applicable, of course, Sa 2 ohve=

She

---Page Break---

Dew TmTUM ML SOL WATER,

3580

Fig. 15. Specific activity of tritium in the soll water at four

depths as a function of time.

a,

Es

3

(pw TATUM /ML SOK WATER.ON 5/23/68,

oS

DDSTANCE BELOW SOL SURFACE (NCHES)

specific activity of tritius in the soil water as a

Fig. 16.

6 eight days after tritiun application,

fimetion of depth,

---Page Break---

?oars. snce

Fig. 17. Specific activity of tritium in the sotl water as a

function of depth, at intervals following

?tritium application,

oS oso

?we (ons)

Fig. 18. Specific activity of tritium in the soi1 vater at

?the five inch depth as @ function of tine since

tritium application, for tvo experiments,

---Page Break---

spreal fallout situation). As a reou these factors, data points

of speciftc activity of ?titttun in leat ora woot mer aa furotion of

time show much scatter, after the initial buildup. If a least squares

regression of DPM on time is performed, residence half times range from

25 to 50 days. However, if data points are averaged together (weekly

averages for the first month, then monthly averages), a dle-avay curve

appears that follows the trend of specific activity in soil (compare Figs. 19, 20 and 13). Sivisy in the Uivtes ee

In the roots of the larger trees, yet another phenomena sens to

be involved (Fig, 21). The fret litte peat nay sebrecent water taken out of the Litter by rootlets in that layer, vile the second, more dif- fuse peak, may represent vater taken up by rootlets deeper in the soil.

A comparison of the prediction of specific activity of tritium in ecosystem compartments based on total water content only, and experimental results of the micro-systems experiment are shown in Fig, 22, Because

of the hypothesized diffusion of tritium into and out of the hygroscopic shells, residence half time in the tropical rain forest ecosystem is increased ty a factor of five to ten.

Novenent of 13Tcs, Sp, sr, ana in through Canopy Trees

Movenent of gama emitters through large trees vas measured in two vays. (1) A portable rate-neter with a G-M tube was connected by a co- axial cable to a portable scaler that was carried to the area of injected trees. The G-M tube was fastened to a pole in such a vay that the tube could be held flush against the tree without the field assistant getting closer than 8 feet from the radioactive tree. As the field assistant Placed the tube against the tree from the adjacent tover, the operator determined gross counts per minute with the scaler. (2)?Various parts of the tree vere collected periodically, oven dried, and counted for 100

nimites ine 400 channel gemma analyzer. When more than one isotope was

present ina sample, it was necessary to solve simultaneous equations to

quantify each isotope in the sample.

A tree of the species Mataybs domingensis, 31 on. a.b.h. and 52 ft.

high vas Injected with .46 fllicurles of 17Cesiun on sept. 18, 1968.

Table 37 shows the portable scaler readings. At the base of the tree

there vas an increase in activity for seven days, followed by a gradual

decrease. ?This downward movément is confimed by Table 38 which shows

the wood at the base of the tree to be somevhat radioactive, and the bark

to be very radioactive 20 days after the injection. The high level of

activity 1 ft, above the injection hole 20 days after injection (Table 38)

and the low level between holes indicates very little translocation laterally

across the xylem cella as compared with longitudinal movenent. Portable

scaler counts between the injection holes, ani st an injection hole (Table 37)

show a gradual decline in activity, indicating a movenent of the 137Cs

avey from the injection holes. The activity rose to a maximum at six feet,

---Page Break---

Ir PALicouREA pIPARA

2 WIROPHOLIS. GARCNIFOLIA

3 DACRYODES EXCELSA

&

5,

a

5.

PM TRITIOM/ML FREE WATER IN LEAVES

3085

302015080

TIME (OAYS)

Fig. 19. Specific activity of tritium in the free water of leaves

of three species, as a function of tine since

initiation of the expertent.

cy

I+ MADeLKARA OOENTATA, 14 NOB

2+ MANSUXARA BOENTATA,O7 IN OBH

a

[DPM TRITIUM /ML FREE WATER IW LEAVES

?Te. (oars)

Fig. 20, Specific activity of tritiun in the free water of leaves of two trees of the same species, as a function of time since initiation of the experinent.

---Page Break---

TETRAWOGASTI BALsAMrERe

ge PRA canta

iy

z

Sd

E

z0

380 35s Tho

we (oars)

Fig. 21. Specific activity of tritiun in the free water of

root buttresses of two trees as a function of time

Since initiation of the experiment.

DICTED FoR LITTER

A. ResuLTs Fon LITTER

Bs PreDeTeD rows

ys RESULTS FOR SOL.

is PrevETED FoR W000

Gj yt ResuLrs FOR? WOOD,

PReDeTED rom "Leaves

(+ RESULTS FOR? LEAVES

PM TRITUM/ML WATER

a

a a)

Time (oars)

Expe: idence time in the

Fig. 22. vrimental results of tritium res:

Ss coat compared to predicted residence tines,

59°

---Page Break---

Table 37

Days stace

acer retgs on ataghe diene

Sots ver aise

Between tnsestion Ab tnseetion

pote ?Tnjettioe nase of tre Tole fle 6. s,s te, tere

sme oo 18 10,049 est

shy 25 rose 2,595 at 8

slo Pc)

sit 8 ? asa wf

sie oo 1,620 oT ow

sys 86 15,718 % 6 »

es ow 3.987 =f ho

whos a 10,013 w 6 & ow

we om 10,902 mo @

rset a 9,6 a a

wp se 4x0 nak wm @

wes 0 an 5 we

ewe ry 1 awe ~ 8 8 om

?ante 38. Movement of Soe trough Yatayba dotngensts

Diya since injection

Sample > oT . ae

Activtty in plcocurtes per exes Any vetght

? om oe ke

on owe

SI oy me

wpa, oe ?

caeek |S som

ark, base of tree 170,388 was G20,

---Page Break---

three days following the injection; a maximm at 21 ft., seven days afters and a maximum at 35 and 42 ft. 20 days after. Table 38 shows that the leading edge of the pulse of activity reached the leaves sometime between ?the 20th and the 37th day. ?The relatively stable level of activity after ?the 37th day could indicate that a steady rate of Input to the leaves had ccourred, and that cesium was being leached from the leaves at the sane rate it was being supplied to the leaves. By 132 days, there vas a fairly uniform distribution of the cesium throughout the tree, with the exception of the bark near the base.

A tree of the species Dacryodes excelse, 51 cm, a.b.h, and 60 ft,

high vas injected vith 17,69 miliicurtes of Sémb, 0.19 nillicuries of 85sr, and 0.34 millicuries of "My on Sept. 18, }968. Interpretation, of the portable scaler data (Table 39) is more difficult than for the 13cesiun Injected tree because of the presence of three isotopes, and their relatively short half lives. Nevertheless, the sane trends as in the Natayba can be detected (Table 37). The peak of the dovnvard moving pulse occurs at the pase of the tree about 7 days after injection, and activity at the level

of the injection holes gradually declines, The peak passes the 6 ft. level on the 5th day, and the 21 ft. level and above at about 3 weeks.

Tables 40, 41, and 42, show downward movement of all three 1sotepes, presunably in the phloem vhich vas included in the bark samples, with CORD shoving the fastest movenent. At 132 days after injection, [Rb was still increasing in the leaves (Table io), Data for day 132 indicates that the peak of upward moving [6m is somewhere between 20 ft. above the injection hole and the twigs in the canopy.

During Jan., 1969, a large increage in fallout in the EL Verde area resulted in an obscuration of ®%sr and Nn data after the T5th day. | However, it is clear that both isotopes had only reached approximately 2h ft. (20 tt. above injection holes) ty the 75th day.

£11 isotopes not only moved dovnvard in the trees, they also moved cut of the roots into the Litter and soil (Table,3). All isotopes vere found in litter and mineral soil samples except 86%, which was found only in the litter. As a check to see that the isotopes actually were transferred out of the tree, all organic matter was separated (by agitation and Flotation) from mineral sol} and the mineral soi only checked for activity. All tsotopes except CR vere present.

?A curious phenomena occurred on Dec. 2, the 75th day. In the portable scaler readings on Matayba domingensis (Teble 37), the values at the injec tien hole level and above all declined, then increased again on the 132 day. Table 38, which shove the results of the gamma analysis, indicates the sane thing. fortable sealer reatinge on Dacryodes excelse at, the injection Level (Table 39) show the same trend, as well as Table TO for . No explanation is apparent for this phenomena.

---Page Break---

Table 39

Portable scaler renting on Dcryoten excelem

ickgrows ie 30 om

Comte per stmt

nee EIA nee pee PEE SEE on, ee, ten,

ar) ws ome se ?

ony ox 00 eter 2

oO =

ofa 3 ah ?9,807 Ba we 6

sla 8 we 8x6 seaie ey

wes a ah ass 6 » »

west a fe eo

ar) eae are mu 6 & fw

ry 5,6 angus o sw

whs ot Ave ype mw 6 6 ow

bie ? sino to m 8 8 8

safe 3 7 2,286 3,327 2 3 aT

vet owe @ Li 6 momo ow oe

?ate No, sovenent of Sm enroigh Bacryotes exselan

?igs since tnjection

> ase

ne

Activity in plooeuries per gran dry veteht

en 3,386 r0j@9 25,285

hos 65,6

19,90, 2267 hee

ake 9,70 13,7

eng 25,839 hejtos

6,450 ot datectabte

---Page Break---

Table M1, vovenent of sr through Dacryodes excelsa

Days since injection

Semple © 2 B

Jotivity in pleccuries per gran, ary weight

Leaves _ 6.0 2.0,

tee 23.6

Wood, 20 ft. above

?ijeation hole ea

Wood, 1 ft, above hole ? 0.0

Wood, base of tree 0.0 22

Berk, ase of tree 3,385

Table 42, Movenent of hin through Dacryotes excelsa

Days since injection

Sanple 2 B

Activity in pleocurtes per gran, ary weight

Leaves 19 16.9

?es wT

Wood, 20 ft. above

?thjection hole wT 68.1

Wood, 1 ft. above

Anjection hole 5h

Wood, base of tree 0.0 erg

Dex, dase of tren 0.0 8,020.0

---Page Break---

° ° 1 ° ° gg

1 2 wat ° ° ye

w 8 a a © 339

et 9 zz 0st este "yee

{PTAR Axp mad sod soEMaoaTd UF AYTATIOV

?FaPOTTRG oxy WER ws TET es | HUNT || STIR uy eMonoer

a5 § Faquo Troe ToxouT sa S tog sag txoaaT Tage TTOR 4g 6 aoa

WORT

sqzete 4005 $t exe TASER we TOT

?wuosa0ofuy e809 Feqs0 Sfp 96 Troe Pi ZeraTT UT AATATIOY ?fy orauy

---Page Break---

PART B - SECONDARY SUCCESSION IN THE IRRADIATED AREA

METHODS

Description of Site

The study area is located near El Verde, in the Luquilio Experimental Forest of eastern Puerto Rico. ?he site is at an elevation of 1500 feet, in a forest described as Tabomuco type (Wadsworth 1951). ?Annual rainfall is epproxinately 240 on. per year, vith more than 10 om. every month. ?The terrain consists of a series of sharply sloping ridges and ravines, Average height of the forest top is 65 feet.

The studles of early succession vere mate in the area affected ty gama radistion. In 1966, the area surrounding the source location, out to about 15 meters, was virtually barren of canopy leaves (Figs. 1, 2). By August 1966, canopy dieback haa ceased (Table 1).

There are two distinct soil types in the irradiated area, one reddish yellow (7.5 YR/6/8) (Munsell 1954) and associated with the ridges, and another dark brown (10 YR/l/3) and associated with the ravines. Richanis (1957) states that the reddish-yellow color of the soil formed under conditions of unimpeded drainage in the tropics is due to the abundance of iron oxides, vhile non-peaty swamp soils often have a grey or ?brown color, and occur under conditions of superebundance of water and poor aeration. For convenience, the reddish-yellow soil will be called ?oxidized? soil, and the brown soil "reduced",

Soll color was used to delimit boundaries of two communities within the irradiated area.

Studies in a later stage of succession were made in the forest surrounding the irradiated area. To simplify discussion, the surrounding forest will be called the "mature" forest, even though it contains some successional species, and the irradiated area will be called the "successional" area.

Gria

To facilitate measurenent of vegetation in the irradiated area, a grid-work of nylon line vas laid out in one meter squares, 26 meters on each side, with the center of the gridwork coinciding with the source location. On the four cardinal exis, a strip of squares two meters vide vas run cut to 30 meters fron the source.

~65-

---Page Break---

n the center of the pie

the source during ii

LEAF AREA INDEX

DISTANCE FROM CENTER

Fig. 2. Leaf area index of the irrad

Leaves directly at the center are

?la racemiflora which were pi ,

?*~radiation by the plug above

66-

---Page Break---

Sampling

Neasurenents of all the plants within the 676 square meter grid vere aie in the fall of 1966, 1967, and 1968. In 1966 and 1967, measurements were made of basal dianeter, diameter at 30 om., and of height, of all plants vith single stens, including niividual gprouts. Since 1t vas later determined that basal diameter alone was an adequate predictor of biomass (see next section), basal dianeter only was measured in 1968, For plants with stilt roots such as Cecropia peltata, basal dianeter measurenents vere made above the roots. Basal dieters were measured to the nearest 1/126. of an inch with micrometer calipers. a

For ground cover species such as grasses, sedges, and Desmodiun, percent cover of each square meter was estimated, and then percent of total possible density within areas covered was estimated.

Leaf Fall

Square meter leaf fall collection baskets had been placed throughout the site during the radiation experinent (Odum In Press). Leaf fall during the period following radiation vas high in the area surrounding the source due to die-back of the canopy. After August, 1966, there was no further neasurable dieback of the canopy (Table 1) and therefore, presumably, no leaf fall in the irradiated area due to canopy die-back.? From June, 1966, 14s nonths after cessation of radiation, through March, 1968, the 10 collec- ton baskets within the area where canopy die-back hai occurred yielded a relatively constant amount of leaves, except during the perio? of May through July, when the amount increased, as does leaf fall throughout the forest (Kline and Jordan, 1967 and 1968 Annual Reports). Average leaf fall during the post die-back period was 0.63 g/n@/day.

Leaf fall in the mature forest was taken from Odum and Jordan (In Press).

Biomass of Successional Vegetation

Ten individuals of each of 15 common successional species, ranging in dianeter fron 1/8 inch to two inches, were taken fron other successional, sites in the vicinity of the study? area.

The sbove ground portions of the plants were clipped off, and the roots vere carefully extracted from the soil, The entire plant vas then dried and veighed.

Correlation coefficients were made betveen heights, diameters, and Weights (Table 2). Since basal diameter and height were closely correla-ted there was little to be gained by using height in addition to basal Gimeter as q predictor of biomass. Because basal dianeter ani laneter at

---Page Break---

Table 1, Average leaf area indexes of canopy leaves measured from

0 to 30 meters fron source Jocation in irradiated area,

Date Leaf Area Index

Aug. 1966 2.20

Feb. 1967 2.10

?Aug. 1967 2.21

Feb. 1968 2.25

Aug. 1968 2.19

Table 2 . Correlation coefficients of measurements of successional plants.

x x Correlation coeffictent

dasal dianeter veight ST

basal aianeter height 98

height veight 9h

height weight (adjusted for dia.- .2h

wt. correlation)

basal dianeter @ianeter, 30 cm.

99,

---Page Break---

30 em. were almost perfectly correlated, nothing could have been gained dy vsing both as predictors of weight. ?Therefore, basal dieneter alone yas used to predict biomass.

Regression of biomass on basal diameter for all 15 species were tested for differences by covariance analysis. There was no detectable difference in slopes and y intercepts in the regressions. Therefore, all 150 individuals were used to calculate a single regression. The regression line was curved on linear paper, so the most general equation for a curved line ($y = ax^2 + bx + c$) was derived from the data. The equation is:

$$Y= .0289x^2 - .2525x - 13.4557$$

where Y equals biomass in grams of dry weight, and X equals basal diameter in 1/128 of an inch.

Due to lack of perfect correlation, diameter values less than 3/16 of an inch give negative values for bionass. All plants less than this dianeter vere arbitrarily given a veight of one gran in the calculations of total ecosystem biomass.

Equations for Phytolacca icosandra, a comon successional species with an unusual shape, and for all sprouts (above ground portions only) Nere derived in a cinilar manner. For grasses and sedges, and Desmodium Jrocubens, bionass vas determined ty digging wp 10 individual square eters of cach type, and regressing biomass on the quantity (% coverage) x (faensity). onass was directly proportional to this quantity.

Regressions were programed into a desk-top computer, and total tions Gf evecy plant. or every a in the cave of grass etc.) was computed, Total biomass of various categories (as shown in the results section) was then obtained ty adding together all plants in the appropriate category.

Bionass of Mature Forest

To calculate the bionass of mature forest trees, the equations of Ogawa et al. (1965) vere used. These equations vere based on measurenents made in-scuchern Thailand, in stands which, from their description, closely resembled the forest of this study. Calculations were made for trees in every 2-inch dianeter size class, from 4 to 26 inches, dianeter breast height. Biomass of trees in each size class was then multiplied times number of trees in each size class per hectare. Tree density data is from Dr. Frank Wadsworth, Director of the Institute of Tropical Forestry, who has transect information from over 20 years of observation in the area, Finally, biomass/sizeclass/nectare for each size class was added together to give total bionass/hectare.

---Page Break---

Net Photosynthesis (Assimilation)

Net photosynthesis in the successional area was determined ?by sub-fracting total blonass of standing crop of one year from that of the next. Bionass of successional vegetation in 1965 was assumed to be zero.

Net photosynthesis for the mature forest was determined as follows. Total bionass/hectare vas determined as described in the section "Biomass of mature forest", using 4 in., 6 in., 8 in., etc. as the dianeters for calculating biomass in each size class. Change in dianeter per size class Was measured on 19h trees fron July 1, 1966 through Dec.1, 1967. Each tree Was fitted with an alunimun tape that expanded as the tree grew. The tapes Were marked with a vernier scale. Change in dieneter/size class/ year was Computed. Total biomass of the forest was again calculated, but this tine the diameters used for each size class determination were the original Gisneters plus average change in dtaneters of each class tree per year. For example, in the 4 inch class trees, the new diameter was i inches plus average yearly disneter increase of 4 inch trees.

Diameter growth was measured only on dicotyledonous trees, while density data included palm trees, Therefore, if rate of biomass increase in palms is different from rate of bionass increase in other species, an error was introduced. It is not known if the rates differ.

Respiration

lest respiration of successional vegetation was determined during night tine hours only, using the folloving technique, A plastic bes wea inverted over the leaves to be studied; the bottom of the bes was soft

open. Air was slowly pumped from 92 feet above ground (to ensure a source of air with a stable CO> content) through a plastic tube into the top of

the bag. A relay evitched attached to a tiner set for 15 nite treme ds directed air into an infra-red CO analyzer, alternately tron the etatne

air source, and fron the bottom of the bag.? Differences in CO, concerteation between source ani bag were converted into grans of carbon ressireajee ieee area/nour. (Lugo, in press, describes calculations),

Total leaf respiration (7.L.R,) for the successional ecosysten vas

calculated by the equation:

$$TLR. = ax + ty$$

where = 1, vhen leaf area index = or) 1

leaf area index, when leaf aréa index < 1

= (leaf area index) - 1

= respiration rate of top leaves

= respiration rate of bottom leaves

Skewes

---Page Break---

Gross Photosynthesis

Gross photosynthesis was calcul ror the su: 01 a

ogee ated for the successional area ty

GP.

?biomass + leaf fall + leaf respiration + root respiration.

Biomass and leaf fall vere converted into carbon ty multiplying tines

0.44 (carbon = Hf OG, 205). nko conven Wy mltignyins

Gross photosynthesis of the mature forest was calculated ty adding enange in bionass to total forest respiration (Odum and Jordan, In Press).

Solar Radiation

Solar radiation above the canopy was measured vith an Epply pyrano-neter from April 1967 through Jan. 1968. Data was recorded on Fustrak ?tape, and daily records vere integrated with a compensating polar planimeter,

Leaf Area Index

leaf area index is an index of the quantity of vegetation. An index of three, for example, indicates that there are three square meters of leaf surface for every square meter of soil surface.

leaf area index of vegetation less than 6 ft, high was determined by dropping a plumb bob on a string directly over each corner of the grid, ?and counting the munber of leaves touching the string. Leaf area index of vegetation greater than 6 ft. was determined as follovs: A mirror with a hairline cross in the center was mounted at 45 degrees on one end of a level; on the other end was mounted a peep sight. When the device was level, a vertical line of sight was obtained, and the muiber of sprays of leaves through vhich the Line of sight passed was counted. It was assumed that a spray of leaves averaged one leaf in thickness.

Leaf area index of the mature forest was derived fron the infra-red/

red light ratio on the forest floor (Jordan, In this volume), Leaf area index is proportional to the light ratio.

Chlorophyll Content

Chlorophyll A content of leaves was taken from results of 773 deter- minations which constituted part of another study (Cintrén, In Press),

---Page Break---

Total chlorophyll (Cy) in the successional ecosysten was calculates ty the equation

Ch = axt ty

and for the mature forest b the equation

cy = arts

where

= 1, when lea? area index = or) 1

= leaf area index, ven leat a¥ea Index < 1

(ear area index) ~ 1

chloroplyl1 concentration of sun leaves, successional plante

chloroplyll concentration of shale leaves, successional plants

chloroptyl1 concentration of sun leaves, trees in mature forest

chloropiyi1 concentration of shade leaves, trees in nature forest

BHdKoee

"Equivalent" Age of the Nature Forest

To plot long term changes in ecosysten funetions vith succession, it was necessary to establish an age for the forest surrounding the irfa~ diated area. the forest, however, had been affected in the past by hurri- canes, and come selective logging, with the result that it 1s an uneven aged stand, Therefore, an ?equivalent? age was determined by dividing the biomass of the mature forest (22,853 g/m? fron Table 3) by the average of the four values of assinilation/year (Table 5). The equivalent age of the forest in 1966 vas? 59 years.

RESULTS,

Standing Crops

?Total standing crop increased every year fron early succession up through the 60-year-old forest (Table 3, Fig. 3). Standing crop was greater on the oxidized soil of the irradiated site than on the reduced oil (Table 4, Fig. 3). Sprouts played a decreasingly important part during succession (tabie 4).

Me 1x most comon species in the mature forest, in decreasing onler of importance, are Buterpe globosa, Croton poseLiantina, Dacsyeles eecetss, Gecropia peltata, Sloanen berteriann, ant Wenttias nitian (eee et). Gecropia 1s a secondary successional species, vite the Teet proaee seeks Gfneercepable of germinating beneath a closed canopy, ant thus can te called "climax" species. The standing crop of the five most important clinax

?T2-

---Page Break---

5,

?ON oxinzeED

BIOMASS, GRAMS /M?

CLIMAX SPECIES

r 3 10 30100

TIME (YEARS)

Fig. 3. Change in biomass of plant

material during succession.

?ble 3. total standing crops (Dionase) of vegetation in the trrailated ares ant the surrounding forest.

Ea, SE ee

: eo ue om

: = 8 ® ne pa

» ae saciee

e aan

---Page Break---

Table 4. Percentage of standing crop contributed by vegetation in vartous

categories.

Years fron

start of

secondary

succession

1 19.00 130.57 58.67 0.12

2 10.80 123.69 66.66 0.39

3 12.32 227.54 63.30 0.61

59 36.88

?ible 5. et shotouyntheets (aeetntiation) in the irredtated area and mature forest,

ehe2/any

?Sraanse HE aay

i te ee

Years fron start rota. ive camon Total, _?Pive comen Total ?Five coma

cof seconsary susceseton vegetation slink species vegetation clin species vegetation cline Hest

a ae 0.291 0.683 0.0008 0.252 o.oo

e 326 2.616 aah 0.0073 0.638 0.0032

3 oe 3.86 0.800 0.0095 o.35e ote

9 186 3.23 asst ute 0.585 one

The

---Page Break---

species was mich lover than that of other species during early years of succession, but these climax apecies had a rate of increase much greater than the average of all vegetation (Table 5, Fig. 3)-

During succession, percentage of total bionass of sprouts decreased, percentage of climax species increased, ani percentage on each of the two soil types remained constant (Table 4, Pig. 4).

Net. Photosynthesis

?Total net photosynthesis for the ecosysten vent up to maximum value of 0.634 gC/m?/day only two years after succession began (Table 5, Fig. 5). From the second through the 59th year, total net photosynthesis showed neither a distinct increasing nor decreasing trend.

Net photosynthesis of the five most common climax species increased vy a factor of 537 times from the firet through the 59th year (Table 5).

Respiration

?There is very little difference in respiration rate between leaves in the sane position in different species (Table 6). Only Cecropia peltata has a decidely higher respiration rate. Mich greater differences occurred between leaves toward the top of the plant ani leaves toward the bottom of the plant, with the top leaves having a greater respiration rate.

No clear aifferences occurred in rate of soll respiration between the mature forest and the secondary successional area (Table 7). The

see mete Se Sespiration in the mature forest on Feb. 1h, 1968 may have been iSleca ty an unusually dry condition on the floor of the mature forest. Setween Feb. 5 ani Feb. 1i, no moisture vas collected in 12 belov-canopy pain fall collectors (Jordan 1968), while about 1/10 of an inch fell in

the open.

Soil respiration consists of the respiration of microorganisms decon-posing fallen leaves and plant parts, and root respiration. Total soil respiration of the secondary successional ecosystem could not have been equal to that of the mature forest, since the mature forest contained bout 22 times as mich biomass as the successional site. High soil respi-ation in the successional area is probably due to decomposition of dead ?and fallen trees which were killed by radiation, plus roots of these trees which were at least partly living, as evidenced ty the presence of sprout:

Therefore, to calculate total respiration of the successional ecosysten, root respiration of the successional plants was taken to be 37% of the total respiration of the ecosystem, because in the mature forest, root respiration was 37% of total ecosystem respiration (Odun and Jordan In Press).

?15+

---Page Break---

JOvASS ON OXDIZED SOL

158 ON REDICED SOL

?CLIMAX. SPECIES

PERCENT OF AVERAGE StANOING CROP,

3 380

17

Te (YEARS)

Fig. lb. Contribution tovard total bionass contributed by

various categories of plants during succession,

109)

cross

"OF puoTosyntHess

S

??Respinanion

GRAMS CARBON /W?/DAY

Net pnotosynrHesis

r 3 30

TIME (YEARS)

Fig. 5. Change in net photosynthesis, gross photosynthesis,

?and respiration during succession,

?16

---Page Break---

oe

?able 6 . Reeptration of teaves in the trradinted ares

ae ind

Paychotrta pertertana 0.0096

Rultooures riparia 0.0196

bene paste 0.0136

Diayeoneng: sorstctont 0.028

cecropin peltata 0.0383

Pemetion procumbens o.aass

?ystotria bertertane 0.0009

uttoouren riparia 0.0093

?Bbehate paluuan 0.0062

Pigyeogana orstotont 0.0061

average top o.019 A560

verage etter o.oo AEB

?ble 7, Sola respiration in the irradiated area ant the mature forest.

rams, carvan reepirea/e?

sure forest,

(ulated sol. 06 008 Sr

ware forest

retuced soll a oT 038

?oxlated soll

lof grace covered 22 ory

rratiates area,

xtatzed soll,

fo grace cove? 20 otto

ryudiated area,

Fefuced sot,

Soy arace cover oO mss

ee

---Page Break---

Limb respiration was not measured in the successional vegetation, Hovever, when leaves were covered with a plastic bag for respiration measurements, the bag covered the twig on which the leaves were growing except for Cecropia peltata, and thus respiration due to small limbs were included in the leaf respiration data. In the case of Cecropia peltata, ?there were no limbs on the young trees, All leaves originated from the main stem,

?Trunk respiration and animal respiration were not measured in the successional area. In the mature forest, trunks contributed 1.7% and aninals 0.7$ total ecosystem respiration (Odum and Jordan, In Press). Respiration due to trunks and animals in the successional area vas cal-culated by taking the sane percentage of total ecosystem respiration as ves found for the mature forest.

Ecosystem respiration increases during succession (Table 8), The least squares line of regression of respiration on years since start of succession is shown in Fig.

Gross Photosynthesis

Gross photosynthesis was calculated by adding change in biomass to total respiration (Table 8). ?The least squares line of regression of gross photosynthesis on years since start of succession and the regression Line Gerenpiration on years converge with passage of tine during succes~ sion (Fig. 4).

Ratio of gross photosynthesis to respiration decreases with time during succession (Table 8),

Leaf Area Index ani Chlorophyl1

Leaf area index increased rapidly during the first years of succes- sion (Table 9, Fig. 6). After only three years, leaf area index in the suc cessional area was greater than half of the leaf area iniex of the mature forest.

Chlorophyll content is slightly higher in shade leaves than in sun

leaves, ani higher in the leaves of the mature forest than in these or whe successional vegetation (Table 10).

Chlorophyll content of the ecosystem increased more rapidly than lea

area index, because of the proportion of shade leaves and nature leaves imreases with succession (Table 9, Fig. 6).

~18-

---Page Break---

8. Reeptration ant

le 8. Reap rose photonmtbeate in the muses an mature forest.

a 2M MH 06 kts aya Le

2 oe Bot kam 19

3 a a a a a aas

2 NTT Gor 398 8k 8388.98 aos

?rineiuded with leat respiration

?Table 9. Leaf area index and chlorophyll content of forest during succession, Years fron start teat area Total chloroptyy A

of secontary succession inter in ecosysten a/=?

1.0 6 1206

1.5 1.64 ish

2.0 2.90 +883

2.5 3.26 1.006

3.0 3.53 1.098

0 6.60 2.745

---Page Break---

\

CHLOROPHYLL

wo

CHLOROPHYLL, GRAMS/M®

LEAF AREA INDEX

TIME YEARS

Fig. 6. Changes in leaf area index and amount

of chlorophyll during succession,

re

?Teble 10, Chloreptyll A content of Leaves (tron Cistaén In Press).

Ieee ee

grans/a? of teat aren

tee alae ae ae

Se ES ae 236 35

ious ?

Eeeelina ops

Seoropta pettate sn

Slows berteriana

Euterpe glstose.

Santieare bifereata

Decrrates tok 388 sas

Brenoter exeiee

SRE

a

33h

---Page Break---

Solar Radiation

me average total solar radiation duris B 1

yeriol April 1967 through January 1968 vas 206.6 cay ee tan wink

Pie standard deviation of 69.9. This 1s 2.066 x 10° eal/n®/aay

fone gran Of glucove yields 3730 calories (\itlson ant Loomis, 1962), en 2.005 x 10? calories would yield 553 grins glucose /at/any? at 100k efficiency.

Efficiencies and Taxes

Trophic level efficiency, vhich 1s defined as the ratio of gross piotoaynthesis to total light (Lindemann in Odum, 1957) increases during Fucceasion (Table 11, Fig. 7). Total light te the total sunlight oa Szagured ty an Epply pyranoneter, and converted to grans of glucose/a?/ day by taking one gram to be equivalent to 3730 calories. Gross photo~ gythesis also was converted to grans of glucose /a?/aay.

?issue growth efficiency, which can be defined as the ratio of assimilation to gross photosynthesis, decreases during succession (Table 11,

Fig. 7).

Property tax (Olson, 196l), taken here as the ratio of respiration in grams of organic matter/n@/year to standing crop in grans/n®/decreases during succession (Table 11, Fig. 7).

Comparison of Functions

A-conparison of several of the fimetions, as they change with suc cession, is shown in Fig. 8. Especially striking is that several functions er ee tatocrnthesis, leaf area index) approach a macimn just a few

Joss eter stack ch guesession. Divereity Will be considered in the next section,

Correlation

Species whose seeds are carried by wind or aninals might be expected to have a random distribution shortly after germination in a cleared area, With a perfectly random distribution, the correlation coefficient between any two species 1s necessarily zero, because random distribution implies there are no positive or negative correlations between species. As succe: sion proceeds and competition increases, some species which are better adapted to ene mice habitat (group A, for example) will crovd out other Species vhich are less well adapted (group B). In another habitat, the situation coula be reversed. All pairs of species within group A vill be Positively correlated, vhile pairs, one from each group, vill be negatively correlated.

---Page Break---

$65 fo" glo" On" eH 6

sort sev oto" ?9s ?

gut see" oto" 2" 2

see eet 200°0 sere t

T TOUTS ITT Tip] a BOOSTS WERET Wo aasSoTS-ERSPUOSS FS

Arsedosz you onssy, §??tonoy oTudons © ?a ogudeoqoud sear

aavys toqze exeax,

woysss00ns Supp Saxey PUB BOTOURTOTSFE ?Tr sTauE

---Page Break---

PROPERTY TAX

TISSUE GROWTH

EFFICIENCY

i

S

TAX PERCENT)

r 30 3500

?TIME (YEARS)

Fig. T. Changes in various types of efficiencies

?during succession.

Fig. 8. Comparison of trenis of varlous

?Tunctions during succession.

?83+

---Page Break---

Part of this study vas to determine how correlation between species of plants changes with succession in the tropical rain forest.

As described previously, all the plants within a 676 n° grid vere tallied according to the quairat into which they fall. The sane vas done in a nearby area of the mature forest. Correlation coefficients between pairs of species vere determined by counting the mmber of each species in every quairat, and then determining the correlation coefficient. For exemple, the input data into the correlation coefficient calculation for positively correlated species might be as follovs: quadrat 1, species X, 5 individuals, species Y, h individuals; quadrat 2, species X, 2 individuals, species Y, 1 individual, etc. For negatively correlated species, ?the data might be: quadrat 1, species X, 8 individuals, species Y, 0 individuals; quadrat 2, species X, 1 individual, species Y, 12 individuals, etc. In the successional area where the grass fcnanthus pallens was very comion, 1t vas given a valve of one if present, regardless of its coverage of the quadrat.

Correlation coefficients depend on the size of the quadrate (Grieg Snith, 1962). Therefore, several size quairats were used. One square meter quadrats vere too small, even for the successional area, Too nary quadrats occurred vith zero of both members of each pair. For the successional erea, four contiguous square meter quaarats vere used to make one size quairat, and 16 contiguous quadrats were used to make a larger size, four meters on a side. In the successional area, quadrats larger than 16 square meters could have included two or more single-species clusters of plants, and thus could have shown positive correlation whereas negative correlation actually existed. Therefore, 16 n° vas the maximum quadrat size in the successional area, For the mature forest, quadrat sizes of 16 nm? and 64 m@ were used. Quadrats smaller than 16 m2 resulted in too many zeros, and quadrats larger than 6h n® presented the cane problem 2s quadrats larger than 16 n? in the successional area.

Correlation coefficients vere determined for all possible combinations of the nine most important species (according to biomass) in each area. This anounted to 36 correlation coefficients for each quadrat size for each area. Correlations for the successional area vere taken from the 1966 data.

Coefficients were calculated with the ald of a desk top computer.

Apparently there is no increase or decrease in correlation in the area studied (Tables12 and 13), 8h

---Page Break---

Table 12. Correlation coeftictents betveen species in the successional area, 1966.

Far

Tangeiatons cost tctene

To. Spectes_x Spectes ¥ ihm? quadeate 6 quadrats

2 Paychotrie bertertane Lénocierm doningensis «0.02.05

2 ? ?Tabebuia palliga 0.19 0129

3 . : Tenanthus? pallens ont oor

geen picate ole

3 : eee ese 033 ok

é " Palicourea rij -0.08 0.16

1 : 0 Digymopanax morototons 0. 0.28

a Parergniony oe fer

wctgra dewingenate ??Bbebuie pitts 085

20 " Tcnanthud pallens 0106 0:31

a " = Zecropia peltata 0.03 0.38

i i . Alchornia latifolis 0.15 0.18

: Falicourea riparia 0.03 0.01

Fs a. 66 igemearmettont ?002 ?aca

a " . Gasearia bicolor 0,06 0.05,

12 taterute pansan See ee 0.03

y =e Gecropta eltata e100 blot

18 " . ?Archornia latifolia 0.01 0.15

® so Rees ee 00318103

2 nS = Etim ?Ook O08

a "os Saeeaste Bicsler 2 lee

2 onantius pallens Seen pices 30 0.08

5 = oink

ak . . 0.01 0.07

25 . 0.05, (0.10

26 " 0.03 noice

2 ceoropte peltata on

28 0.01, 0.15,

29 " " 0.27 0.37

30 " " 0.55 0.65

31 «= Alchornea latifolia 0.47 0.38

2° . 0.35 0.64

3 patteogren ripest oer Oke

3 coures riparia oor ol

5 GR ES Gasearfa Biostar oor 8

38 piaymopanex norototont Gauss Hester og Os

Average of 36 patra, 011 signs changed to plus o.to.ak 0,2240.21

---Page Break---

Table13. Correlation coefficients between species in the mature forest.

Far Carrgintion coef Figient

To, Species x Species ¥ 2énequadrats ?Ghnéguadrate

2 Dacryodes excetse Ruterpe globose 0.01

2 Menigies sxcgiee Wniikars bidentate Soa

3 an Higenia seahiit 70:33

a . : Fallcoures riparte

5 ee Deypetes glauca

é . : domingensis

1 oo Sloanea berterians

8 ae Groton pocet lantinis

9 Buterpe globose Hanitkare bidentate

0 70135

a : * 0.05

2 oo: -or2h

Fr 4 Bat 1

i c G ont one

a5 G 5 0.07 0.33,

36 Manttxara bidentate 0.02 0.09

ye cols. ?0.46

B 5 : 0.39 0.39

ay : G 0.07 0.06

2» 5 5 0116 1

a a a Groton porctlanthus 70126 70.38

22 Bugenta stants riparia 0.09 0:38

B eee Drypetes glauca 0:38 0.35

2b G 9 Einoolera demincensta ore 0.57

25 o G Slomnea_ berteriana 0122 0.03

26 G G Groton poectlanthus 0:20 over

21 Pallcouren riperte Drypetes glauca 0.22 03

23 ee Sloanen bertertana o:ah o.5L

2a . . ?Groton ?poeeilanthus 0:06 0.88

30 . a Einociera demingensis 22 ?0.24

Bl Deypetes glauca Tinosiers deningensis 0. 0.79

32 Sioanes berteriane -0110 2.9

33 " " ?poecilanthus 70:30 ~2

3% Linoctera domtngensis _?-?Bloanea Derteriana cole -2.01

3 Groton poeciianthia ?0.27 -0.9

36 Stomnea bertertang Groton poectianthus 0.05 we

Average of 36 patrs, all signs changed to plus 0.16 $0.12 0.36 ¢ 0.19

---Page Break---

SECTION Ir

by

George E, Drewy

In section two, current animal ecology etudies including tracer

work, end territoriality and other work with amphibians are reported.

Also in this section a new approach to species diversity is developed, and applied to plant diversity in the radiation recovery area, and to insects in the surrounding forest.

Insect keys constructed in the past year are also presented as an appendix .

---Page Break---

PART A - ANIMAL ECOLOGY

Work begun earlier on tvo animal ecology projects was continued dy visiting investigators. Both studies involve termites, which are among the most important insects of the rain forest animal commmity. One study includes a census of individuals and relative metabolic rates of each caste in the termite nest by measurenent in a microrespironeter. ?The other study, reported by Dr. E. McMahan in section three, is a follow-up of radiation effects on nest survival and includes some interes- ?ing experiments on vorker behavior and direct responses to ganma radiation.

Staff efforts continue to include studies of isotope tracers, insect diversity, and amphibian ecology. Isotope studies vere enlarged to include uptake and bicelimination of tritiun in the form of HTO, Tritiated vater sprayed at ground level vas absorbed by direct contact and respiration in insects, snails, frogs and lizards. No uptake was exhibited by insects, frogs or lizards subsequent to 36 hours after treatment. Snails contimued to show uptake as long as 72 hours after treatment when collected after crossing contaninated litter surface.

A method for live testing snails consisted of teasing them back into their shells at which tine they released 1 toh ml. of urine. Urine samples exhibited approximately the sane count rate as tissue fluids obtained by dissection. Biological half life of tritiun in snails was very short, just under 2h hours.

?Tracer and bicelimination studies of Zine 65 in a natural population of the snail Caracolus caracolla moved into the second year, vith resolution of some of the mysteries of the first year. Area of home range was found to te a function of age, increasing until the second year after puberty and decreasing after that. Adult size, previously demonstrated to be independent of hone range area, is likewise independent of age, shell growth ceasing at maturity. Present estimate of life span in this species is up to 18 years, with sexual maturity not developing until 8 years of age. On the basis of last year's growth these eatimates appear to be within 2 years of the true values.

Insect diversity studies involved research on methods of obtaining and expressing diversity measurenents as well as the slow, continuing labor of separating and identifying the species of sone of the poorly known groups. In some of these groups the recorded fauna for the whole island has been as mich as quadrupled in this study alone. Comparisons are being made between diversities obtained vith various trapping methods such as sticky traps, pitfall traps, light traps and Malaise (flight) traps. Attractant traps such as light traps avoid the distorting effects of irregular natural concentrations or foci, but impose their om artis ficial focus on the distribution. The effect of natural focl le linai- nated in this comparison as giving a curvature to the nomally Linear relationship between nunber of species and log minber of inliWivels,

---Page Break---

Progress in the study of amphibian ecology has moved into an

area of collaboration with tvo graduate students at the University of Texas. With James P. Bogart, who finished a doctoral thesis on the evolution of anurans in the fanily Bufonidae and in the process accu- mulated considerable data for the family Leptodactylidae, a cooperative ?study on Puerto Rican Leptodactylide is vell advanced. Karyotypic analysis of 11 of the 12 species of this family in the Luguillo National Forest is completed and forms the basis for a set of hypotheses about insular trends in the evolution of the family and the role of ecological specialization in their evolution. A joint publication in which ana~ lytical data is presented by Bogart, and ecological data by Drewry, is to be the result of this study, Preliminary information indicates that several of the speciation events giving rise to separate genetic lines may have been due to ecological separation vithin the geographical limits of the island, and not to separate migrations from elsewhere. A list of chromosome counts fron species of this family is given as Table I.

Of particular taxonomic interest is the rediscovery after several years of Eleutherodactylus unicolor Stegner and the discovery of its call,

its habitat and methods for collecting it, and the fact, revealed ty its karyotype, that it may not belong in the genus at all, but to the genus Syrrophus.

The second collaboration is with William Martin, who is finishing fa doctoral thesis on the biophysics and mechanics of vocalization in anurans. Some of the hypotheses tested and supported ty his research were originally proposed by Drevry, and others grew out of a long period of correspondence, so that the basic model is considered a joint achieve-nent and is in early manuscript stages, Data on rain forest species is ?to be included in this publication.

Possible ecological role of the call of male eleutherodactylia

frogs as a population spacing device is presently being studied. Mate attraction as one primary role is ell documented, tut recent observa~

tions of increased calling activity after introduction of tape recorder ploybacks or natural inigrations of calling males suggest additional

functions. Agonistic behavior tovard calling intruders imediately after

their calis has also been observed. Tape recording equipment and additional

electronic cireuitry to create a "responsive" artificial competitor are

nov on order. If quantitative behavioral responses are obtained, options

designed into the equiment can control the timing and acoustic charac

teristics of the competing call, providing data of ecologi v0)

?arlstlen of the comartin P ing data of ecological, evolutionary,

---Page Break---

?Table 1

chromosome counts of Puerto Rican leptodactylid frogs.

Diplota Chromosome Count

Leptodactylus albilabris 22

Bleutherodactylus unicolor 30

E, portoricensis 26

E, antdliensis 26

brtttont 26

E. wightmamnae 6

E, rlotmonat 30

E, snetdse 26

E. hedriki 26

E, Locustus 26

ak

E. gryllus

---Page Break---

PART B - SPECIES DIVERSrry

Introduction and Methods

Most methods devised to numerically describe population structure 4n ecological communities have been extensions of cre or the other of ?two basic approaches. The earliest, ani still most common, approach rests on an assumption that there 4@ an unterlying mathematical rela tdonsh{p that governs the complex ratio of mmters of intividuale of various species to one another. Very iittle has been published of cau- ative factors that might generate such a relationship, although 1t has been repeatedly observed that opecies siniiar enough to be included in a sample collected by a single method are alnost never equally abundant, ani that real samples never seem large enough to include all of the species know to exist in even a relatively homogeneous ares. Willians (196K) has brought together a large amount of the evidence for the existence of such a relationship, and has proposed sone sophisticated methods for utilizing this assumption. Although the methods are sonevhat difficult to apply and require use of a set of computer generated nonographs, he has carried then to sone remarkable lengths, and even proposes a model for the rate of species formation over the earth as a vhole based on these methods.

The mathematical relationship most commonly assumed to exist between organisns of a single habitat 1s an exponential one, that the mmber of species ina given sample is sone function of the logarithm of the number of individuals in it, The simplest function would be a fixed ratio between ?these parameters (Odum 1953) and the iniex of diversity would be species

er decade of sample size. A statenent of species per thousand individuals or per any other fixed mimber) taken in conjunction vith this assumption would provide sufficient information to extrapolate in either direction,

to expected opecies mmber for any sample size. Although widely used, this method of description has only occasionally been validated by the total distribution of mmbers in a field sample, and the validating graph has normally been constructed by counting spectes in a few subsamples of various sizes or by noting accumlated individuals each tine a new species is encountered in a random sorting of the sample. Both tally methois require a randonizing procedures for sorting and recording, and neither uses as information the relative munbers of each species present, Willians has pointed out that assumption cf a linear relationship between species munber ani log number of inilviduals violates mathenatieal reality, Decause zero species must involve zero individuals, while zero does not occur on a logaritimie scale, which is infinite in both directions. le substitutesthe mathematically valid log series curve, which is defined dy a parancter calle 0G, ani whose graph in semi-log plot 1 linear for large muibers and curves to the intersection of one and one. He claims validity for this relationship in many stande of vegetation ant for light trap collections of lepidopterous insects, but has used the above mentioned methods of validation, with their limitations.

le

---Page Break---

Willians also suggests that when collections are expanied to Anelude organions from more than one habitat type the relationship shifts fron a log series to a log normal series, in vhich the logarithm of species mmber is linearly related to the logarithm of munber of individuals. MacArthur and Wilson (1967) have utilized this assumption Im a recent book on the theory of island biogeography. Again their

validating data is a widely scattered series of points, although it Sens clear that the relationship holds in a general way.

alef (1957) has introduced a new (to biologists) measurenent of syecies diversidy that does not rest on prior assumptions of rela~ tionship between species and individual numbers, but has the disadvantage of not describing community structure beyond diversity. This is actually a fanily of measurenents derived from formal information theory as used in communications engineering, ant has been subsequently utilized ty Plelou (1966a and b), Lloyd and Ghelard; (1964), Lloyd et al (1968), Dickman (1969), and others. Information content of an individual in the sense of species diversity is not all of the information possessed, ?wut rather that required to distinguish it from the other species of the sample, i.e. possession of feathers is sufficient information to separate a sample of two chickens and a cat, but mst be supplemented if the sample also contains turkeys.

?vo equations are available for calculating diversity in tems of mean information content per individual, known as Brillouin's measure and Shannon's measure. Both are given in several forns by Lloyd et al. (2968). Shannon's measure estimates the diversity of an unlimited population composed of a known mumber of species or classes from the proportions of each in a sample and is largely inapplicable to biological diversity where the total mmber of species obtainable is almost never known or present in a single sample. This measure will not be discussed further here. Brillouin's neasure is:

H =-2. (1ogj9 N! - E logy nt!)

where H is mean diversity or information content per individual, ¢ is @ scale factor to convert to any number base desired (binary bits are often used in information theory where ¢ = 3.321928), N is total individuals in the sample and ni are mmbers of individuals of each species. This measure gives only the sample diversity and does not extrapolate to a larger population unless the population has the sane structure as the sample. At this point the discussion has come full circle and focuses on the problem of structure.

Many biologists have attempted to describe the structure of com

munities with graphs of relative abundance or relative frequency or

with various arbitrary abundance classes, but apparently have not attempted

to relate these to species diversity. In this research an effort has

been nade to relate all of the measures of structure and diversity in

the simplest possible vay. If species of a sample are ranked in orler

of decreasing representation a curve can be dravn connecting the muber

?92.

---Page Break---

of tnatviduais of each,

of plivasuaie of cach. Eeoause of the iange sange of catesony sist

the level of the rarer species, Resorusien con be Inroved ty plotting

ere foectee, ?Resolution cen be inproved ty siete

amor of {titvidinis on a log" seaie, ?Figure 1 hea soh's pisty sole

on Ceigianting tfasr mtntee se 2 eisatias

Recovery area, labelled cumastive speios tereee teense

would gormaly be, vlewea with te eft eige nt ition tote hat the

taro, so species represented ty one igeiviou ore

ance se cere ae en ae eter eaean a reseseree Loney

; eaateneasttaataenae

intomation avaliable in the suxple ant Mes doe sewuined acateptions

to be made about structure. the curve can be inverted by aivisine X

Ee Gotat munber of inifviduaie inthe saaree, tor eee menney of ta viduals in each species. The curve so formed is labelled cumulative species versus log N/n and can also be called a reciprocal frequency Gurve or a composite ratio curve, Ie retaina the slopes of the relative Shimlance curve beomase divioion to sigevrarcaliy muberactive en 8 106 Scale, but aifers from the relative abunience cuore tn thaty given {int Uae composite ratio of species ceion courtant ar rexpleteiee 12 Increased, each point on the relative abuntance curve moves to the Hert as sonpie eize increases vile the conpostee ratio cae Only Eide points at the upper ents, Points an this curve representing epectes say be real ap a ratio, 20:12:15 or aa ene pact in 20) 12) 15 et The SSuposite ratio curve in this focn te ainitery but mot iaentiesly to'8 Sisbeaity inten curve developed ty classianl evneds or to Wiiiiéa?® log etse Ciera tie wager Thave head goiahs vhaeh eercesente © single Siaclen in the composite setio, also repreosnte total species fd 10s srtcied dtyintais Bo vill be dwed'ea trance petnt an ony eiverslty TOaet SOSA Sache nay date potrt normally used ah WiNldan's ale mete, Teporeant to gote; horerery tutte break near 10g 1.5 cee coe site Butte curve le fot a concession to nsthenatical reality in the comport reese eserty of the vegetation, separating a Group Of but epresents 9 reer e cee natio elope from a group of rarer apecies chante pects Te niopes Busha. break has characterized most, raving quite a afferent, o0Pe- ommnities stulied ant hae inveresting

and predictable properties of its own.

?The mathematical relationship between the composite ratio curve and the diversity index curve generated by ary method is a rigorous exercise in probability theory and has been substituted here ty an empirical correlation method covering the range of curves and slopes encountered in this study (some are not linear at any point), An exanple of the theoretical complexity is provided by the fact that the probability that a single species vhose frequency is one yart in one hundred vill de missing from a randon sample of one hundred is its pro- bability of absence ina sample of one (.99) raised to the 100th pover (approxinately 36%). The probability that it will be absent, but re~ placed by a still rarer species, involves all of their probabilities Jaa manser almost too complex for computation. Comon sense iniicates that for even a single sample there is not one but an indefinite fanily of diversity index curves depending on the order of sorting ani recording {ndividuals, and that there is a maximm likelihood curve having the highest provebility of occurrence that will best represent this furily.

---Page Break---

Such a curve should run approximately parallel to the composite inex Gurve, alvaye to the left of it (randomly varying individua> ciovey care cneeey® SOa'ne convergent with it because it is subject to the aaa eroteaines cs the log series curve at lov munber. Tt mst Pe caer acined that no theoretical reasona exist for Linearity of {ties gymhasized that 20 Chaposite ratio curves in ary type of Graph. Sent log plots are merely a representational convenience.

?the empirical method of comparing these tvo types Of CRETES

consie ns CPrarecting easily sampled populations of known composite

consisted oF oncom and extrene types of populations encountered i

ratio for the meonao not ineiude all theoretical curves, sone of which

BREAST aeviate from the conclusions reached. For exanpies £9 the

cereus yy aiverse population, each of vhose menbers 1s & ai Stereo?

seerets ine diversity Antex 10 0 log series vhose OC ie tnrini ty

while the composite ratio is a vert! whatever sample size

ieal line at

fe chosen. The other extreme is an inde:

sinite population of one

se etees diversity index 1s a straight Line at one, oc ie tere, ene

?at whatever 9%

composite ratio is a single point ample size is chosen.

ereettsoite ratios chosen for this experiment ranged from 10 to 500

Jhecies per thousand individuals and vere either straight, broken, oF

see ee onsly curving upward in semi-log plot. "Collections! were made

continvrnaion munbers table whose digits were ?identified? in groupe

or three by assignnent of mumber groups fron 000 to 999 to relative

frequency categories dictated by the composite ratio. Diversity index

eae rece only evaluated to 100 individuals because of the constraint

SPetinite mumber of species per 1000 rather than the natural situation

OF on indefinite mumber of species of progressively lover frequencies, Sistetbution of data points in large mmbers of series of 100 indivi-duals confirmed the comon sense expectation; the curves followed a

fog ceries at low mnbers shifting to a curve similar to the composite wekie curve past 10 individuals. Distributions appeared to be normal

gn the species per fixed mmber of individuals exis, for vhich the mean $e an adequate measure of central teniency, while on the log individuals per fixed muber of species axis distributions resembled the Poisson Bistribution and the median wes taken as the best measure of central tendency. Convergence of the curves predicted from the necessity that

the diversity index curve pass through the upper point of a realistic composite ratio curve was supported in curves having a straight segnent from at most 50 to 1000; the curve straighted and passed through log individuals at the sane nunber of species as the composite index curve

had at log 100 individuals; when extended it passed log 640 individuals

at the species level of log 1000 individuals in the other curve and also intersected the upper point of the composite ratio curve, which is always above the line of the curve itself, A maximum likelihood diversity index curve consistent with these observations is given in figure 1. If such

?a maximum likelihood curve contimues to be supported by theoretical and/or empirical evidence it provides a method of stating the slope of a linear seguent of the diversity index curve above 100 individuals in terns of the slope of the composite ratio curve (it will be 1.0280 times the slope of the composite ratio curve or log 640-log 60) and for extrapolating

the munber of species in any fixed sample size such as 1000 believed

?9h

---Page Break---

Cr)

A Cumulative species

vs log

?~

B. Diversity index

?maximum,

likely hood,

curve C. Cumulative

species vs

N

9

10 20 40

tog

Fig. 1. Graph showing inter-relationship between relative

Runtesbe (curve A) composite ratio (curve C) and the

seetatoted marimm Likelihood curve of traditional

Weereity index methods (curve B). Semilog plot is

fon representational convenience ani does not reflect

asamptions about species inter-relationships.

aot?

30!

th

20

10?

---Page Break---

fo tie on the linear portion of the composite ratio curve. Species

Per thousand 1s approximately the intersection of the composite ratio

Gurve with log 1000 plus .2 tines the C.R. curve slope (10g 1000-10g

0 times log 64O-1og 60 or .1926x1.0280 = .2). Basing the standard Reaourenent of species per thousand on the slope of the composite ratio curve, rather than on the munber of species collected in a sample of 1000 individuals, hao already proved to be a valuable strengthening Of the foundation for this useful measurerent. When notified that the number of rare epecies in a certain collection vas theoretically inade~ quate, one collector vac reninded that a small group of very rare species hhad been put aside for detailed identification and forgotten, The re~ lative taxononic abilities of several collectors have siso been evaluated by thie method and the evidence obtained has been consisted with other evidence available. Extrapolation of such measuresents as species per thousand upward beyond the Limits of the sample has for far been confined to communities having Linear composite ratio curves, but dovnvard extra~ polation along non linear diversity curves agreeing in shape to the Composite ratio and passing the log 640 and 60 points has given realistic

estinates.

Information theory measurements have proved difficult to relate in fa simple way to the above measurements of diversity. Independence of sample size has been found ina very few cases where the composite ratio curve vas linear and the usual group of comuon species exhibiting © @ifferent elope vas absent. Mormally Brillouin's measurement is very sensitive to sample size, making our necessarily differing samples aifficult to compare. In addition, the output measurement is subtractive rather than multiplicative and scaling to a comparable sample size must be done on the input data before computation. This scaling is most readily accomplished by computer manipulation of the data, Log factorials are most easily handled in tabular form (Lloyd et. al. 1968) but fortunately an alternative exists in the form of Sterling's approximatior

Log nt = (n+ 0.5) log n - 0,43h2gKKB2 n + 0.39909

which can be written into a computer progran. For rigorous accuracy, 1ogarithns should be taken to six places but it vas determined that the uncertainty in Brillouin's H of four random subsamples of 100 square meter plots from a sample of 676 square meter plots outweighed by at least an order of magnitude the error in H occasioned by using four place logarithns, so

these were used. Five programs have been written for computing this neasurenent on the Olivetti Underwood Programa 101 desk top computer.

The first tvo are alternate prograns yielding total information content

in bits, H in mean bits per individual ani N, the total number of individuals. ?One is for unskilled operators, requiring only the entry of

species nunber (n) for each species but is much slower owing to the calculation of log n, which it prints for each entry. ?The other accepts n ani log n in pairs and runs at approximately 50% entry time and 50% computing tine for a skilled operator. The remaining prograns differ only in stored constants and scale data downward to 1000, 500 or 100 individuals distributed accord- ing to the composite ratio curve. They require entry of N, log N and

nand log n for each species in pairs. By utilizing Sterling's approxi-

---Page Break---

nation they calculate log n ! on a continuum rather than as diserete vnole numbers and thus avoid rounding errors. Species are entered fron comonest to rarest ant reatout is autonatic when N/m for an entry 18 less than 1.5 (log n ! for single individuals is zero and does not contribute to the index). Prograns and constants for this computer are stored on magnetic menory carts ani entered ty passing the card through a reader. Copies of these programs are available to anyone on request. Equations have been rewritten and constants consolidated to minimize nenory space. The entire menory capacity 1s utilized in each progran.

Processing of data has been consistent and diversity measurenents are now availoble for several communities of plants and aninals. These include a cemi-log plot of composite ratio, called the CR plot, the

slope of linear portions of the CR curve in species per decade, designated A slope for abundant species and B slope for rare species vhen two Linear slopes are present, an estinate of species per hundred, per five hundred and per thousand tased on the slope of the CR curve (sonetines Involving extrapolation upvani, if the CR curve is linear), Brillouin's

H and information content of the sample in bits per individual and binary bits respectively, ani scaled H an information content for samples scaled dovmvard to 100, $00 ana 1000 individuals where appropriate designated F,o9» #500» Hoo and Int./100, Int./500 and Inf. /1000.

Of these measurements the CR plot has proven most informative to the experienced evaluator. It opens the way to further research by pointing out real discontinuities in ratio between abundant and rare species that are smoothed over or concealed ty the random fluctuations of traditional diversity index plots. Species per fixed mumber of indi-viduals, particularly per thousand, which form an easily remembered diversity statement can be rapidly and reliably estimated from CR plots and arduous randomizing procedures are unnecessary. The only danger seens to lie in its apparent ability to conceal the combination of certain unrelated types of commmities (it readily reveals others) and ?the consequent possibility of publishing diversity figures that are meaningful only for the unnatural combination. A non linear CR plot immediately reveals the fallacy of applying linear diversity index methods and can be used to expose such inappropriate applications in past research, It is hoped that both the advantages and limitations of information theory measurements vill be realized by the bulk of vorkers in this field and that uncritical and inappropriate application and resulting false conclusions can be avoided.

CR plots in the renaining portions of this manuscript will be pre sented with log N/n on the ordinate and cumulative species on the ebeteca, This 1s done deliberately to avoid confusion with traditional species diversity curves.

---Page Break---

?The Development of Plant Community etructure

Plant succession following a dose of gamma irradiation that either killed old vegetation outright or greatly reduced its ability to compete illustrates well gome of the trends in the development of communities, A grid measuring 676 cquare meters has been mapped in detail each year Deginning one year after the 1965 period of irradiation,

?Taken as a vhole, the vegetation had reached its maximum level of mean information content vithin a year after irradiation, Hf decreasing from 4.922 bite per individual in 1966 to 4.889 in 1967. At the sane time the species per thousand increased from 6 to 76, an increase of more than 5 percent in this measurement of diversity. The apparent dis-crepancy ie explained ty the CR plots in figure 2 (data points are omitted in this and the folloving plots. All are very similar to fig. 1 in fit),

?The diversity changes reflected in H occurred in the A slope or abundant species group, while species per thousand responded primarily to large increases in the number of rare or B slope species. Breaks in the composite ratio curve delineate 17 abundant species in 1966, having a total of 4,002 individuals, and only 10 species in 1967, the nunber of individuals

fH is calculated for the abundant species only

?At the same time the mmber

increasing to 5,133.

?the drop in diversity is from 3.62h to 3.097.

of rare species was extended from 79 to 109, and while rare individuals increased 1,24 to 3,090, diversity meacured ty H increased from 5.147 to 5.439 on these species alone. The B slope increased from 33.28 species

per decade to 41.1h while the A slope decreased from 19.90 to 11.46. Thus only the CR plot tells the whole story. The dimensionless indexes appear to contradict one another until their bias is revealed, Three trends are noteworthy: a rapid and early increase in both mumbers and diversity of

abundant species, which seem to be vell adapted to the situation; a subsequent reduction in mumber of abundant species with further increase in number of their individuals; and a slover increase of species ani individuals of rare species bringing the total species count to a maximm. 1968 data on total vegetation is still being processed but the numbers of both species and individuals declined as individuals grew and space became a limiting factor. Overall species diversity has probably increased as intraspecific competion eliminates individuals of conmon species more rapidly than those of rare species, but the exact effects on H and species per thousand can not be predicted.

Data processing is complete for tree species, and CR plots for trees originating from seed after the radiation treatment are given in figure 3- In this figure the 3 graphs on the left are for seedlings in 1966, 1967, ant 1968 respectively, while the two right hand graphs are for saplings nore than 4.5 feet tall for 1967 and 1968. Only Cecropia peltate saplings exceeded this height in 1966, so no ratio was obtained. The composite ratio of seedlings in 1966 is different from any of the other curves shown and reflects the effects of open, vell lighted ground for germination. The A portion of the curve includes 20 species ana the fast growing species ha not yet gained the numerical advantage they enjoyed in the next two years. ?The slope and H of the A curve were the highest measured for any A trees, being 11.38 species per decade and 3.639 bits per individual, respectively

---Page Break---

aE

Fig. 2. Composite ratio curves for total vegetation in a radiation

?cles data points cited.

ar

30000}

23

25

6

<ase

Kase

21109) 1966 1967 ast suse

" i968 1967

mr) s 6 8

Oo 2400 20400 2040020 400

Species

Fig. 3. Composite ratio curves of seedlings (4.5 ft.

?Hecovery area one ani tvo yearo after irradiation. Ordinate

?and absoisea have been reversed fron figure one and spe-

20,

Das

1968

2040

tall)

and saplings (> b,5 ft. tall) of tree species one, two

fan three years after trraiiation. Slopes given? to

nearest whole munber. Scale of species axis

shorter than figure 2.

---Page Break---

The B curve is not well differentiated and contains only 20 species. Species per thousand at 35 is the lowest registered for seedlings. Combination of this curve with the curves for non-tree plants, sprouts, old trees and saplings obliterated all traces of the break in the CR curve, (see Fig. 2) one of the few cases in vhich this happened.

?The ceedling trend in 1967 was similar to that in the total vegetation but more pronounded. Six species produced more seedlings than 20 had possessed the year before. The H measurement for the A segnent dropped more than a vhole unit to 2.!13 and the slope Likevise decreased to 8.0h species per decade. The B segnent increased even more than the A segnent decreased, with an increase from 20 to 95 species, 37 to 1,588 individuals, and 3.377 to 4.748 in average information content of the segment. Overall diversity thus increased species per thousand from 35 to 47, H fron 3.732 to 4,071 and the scaled Hoo9 from 3.67 to 3.977. Seedling changes in 1968 represented the sane diversity trends to a mich enaller degree, except for the A segment, which changed very little. The mumber of abundant species renained the sane, about 1 percent of the individuals moved into the sapling category or died (mostly the former), raising H fron 2.413 to 2.ts, ?The B segment lost two species ani 10 percent of its individuals, but this was a net increase in diversity of 8 percent in elope ant 2 percent in H. Overall diversity rose by 6 percent in spectes per thousand to 50.5 and ty 2 percent in H and Ho90, Perhaps it is purely coincidental that these values all correspond very closely to those found in climax trees in this general type of terrain and soil, but it is very intersting that seedling trees, consisting of & lange percentage of successional species that will be replaced in the mature canopy by other species, should in three years time establich euch @ mature comunity structure. ?Of eourge, if species versus area vere under consideration, the seedling diversity vould appear to be enormous, but it would seem that species versus individuals 1s the more appropriave neasure of diversity vhen communities of very different individesl size are being compared, It will be interesting to see vhether the large reductions necessary in species and individuals for this 676 square meters to be occupied again by mature forest can be accomplished vitheut dietwsb. ing the diversity structure, or if osciliations are inevitable, Sapiine changes in the first three years have involved clover but steady inerecces in all of the diversity parameters. Species increased from one the gonna year to 16 the third year to 2l the thind, Individuals increased free I? to 557 to 707. Extrapolated species per thousanl vere 1, 2), ant 3h has gone from zero to 2,923 to 3.196, Slope A has been 0, 5?ani 6; shite slope B was 0, 15.02 and 19.54. ?The only probable overshoot eo far lean number of A segnent species which went to 10 in 1968. Tate category would appear to be at a diversity stage sonevhat similar to that of the evenings before the first measurenents vere mate in 1966, so atversity overseer and subsequent correction are probably to be anticipated anoe the eoeron species. There appears to be Little conpetition among saplines ce thin time.

The area of this study has been divided ty Dr. Carl Jordan into two soil types, well and poorly drained. Vegetation from these two types tas processed separately before being conbined into the categories alrealy aic-

---Page Break---

cussed, and although a great deal of labor vas involved, trends in the two were so similar as to varrant little discussion here. Development aid proceed more rapidly in well drained soil and it seemed always at amore advanced stage. Although several individual species showed strong preferences for one or the other type of soil, any slight differences in diversity parameters vere averaged rather than additive when the two were combined. In distinction to different habitats to be discussed below, ?these seemed to be complenentary parts of the saxe habitat fron a diversity viewpoint, One difference that was amazing in its consistent repe- ?tition vas the munber and corresponding slope of A segment species. ?These were alvays more mmerous and diverse in vell drained soil, In vhat 1s taken as mature ratio, ie, climax vegetation, old radiation center vegetation and 1966, 1967 seedlings the A slope species munbered 9 to 11 vith a slope near the sane value in vell drained soil and about 6 in poorly Grained soil, averaging 8 in combination. This phenonenon appeared identical in manifestation with the sun-adapted abundant species of recovery vegetation and the entirely different dominants of mature forest. ?The explanation seems to be that fever species are well adapted to the anerobic soils of poorly drained areas, so that the competitive advantage these few have is greater. Figure 4 illustrates this phenomenon. Teble 1 shows sone of the stronger individual soll preferences. ?These were computed by multiplying by @ scale factor to correct for inequality of soil areas, substracting less preferred from preferred ani dividing ty the sun. No preference would be zero percent, while 50 percent indicates that three fourths of the individuals are found in the preferred soil.

?fo discuss trends in the development of rain forest community structure after irradiation, the often stated rule that successional Communities develop higher diversity in early stages than they will exhibit at maturity (Oium 1959) seens to require qualification. ?The SEttint seeno to be very true for the nore abundant species, which

sree tebe the ones best adapted for vapid germination and growth and Shien will always be collected and identified in quantitative studies. These species will also bear the brint cf competition during the inevi- Bile cererowding ao individuals grow, hovever, ant competition may be Tent tierce at the intraspecific level, with the result that formerly Couton species may recede tovard rarity without aisappesring more rapidly than lees well adapted epecies are completely eliminated, all of vhich would dictate gradual increases of diversity in species yer individual. Eonething of the sort seens to have happened here, because at no tine has there been a reduction n total diversity anong plants in comparable size Categories. This generalization does not hold st all if species per unit area taken as a measure of diversity, for the growth process itself dic- tates that a large percentage in early colonists can not survive to reach tree size ant selective forces favoring rarer species vould have to be many times stronger than they apparently are to overcome this elimination

process. Thus the generally held belief that diversity in terms of inii-

Mituale do the sane as diversity in tems of area mst be strongly restric

tea to situations in which size and/or density are equivalent. ~

---Page Break---

ings in well and poorly drained coils.

(A) well drained (B) poorly drained.

Comparision of composite ratios for 1967 tree

Seeali

Fig. 4.

?Table 1

Abesbtebemniecd

asaepganacennos,

' i

ae

---Page Break---

In summary, the seedling by

population of this recovery area was able

in three years to produce a diversity structure comparable to that of sae ee nen erat in every way except species per unit area, In that regard it achieved a species density that can only be reduced vith the passage of time. In addition tvo general classes of abundance that characterized the composite ratio of every vegetational unit studied were manifested very early in the succession, These classes exhibit, within thenselves, a renarksble exponential relationship between species ani individuals having a characteristic slope, and the differences in slope and information content between classes increased with tine to a plateau level. Overall tree species diversity in this successional vegetation

Fach ©Tevel rear 92 pees per tonal ibivadiae Wy the tte

Several studies have aimed at discovering community structure and diversity of lover montane rain forest in Puerto Rico. Snith (in press) studied preirradiation diversity in the El Verde site ty conventional diversity index methods and arrived at a figure of approximately 48 species per thousand individuals for the mature forest. In a later

study involving transects into different habitats, he obtained 60 species per thousand. The present techniques were applied to a sample of 116 trees in 676 square meters of the control center sampled especially for the purpose and yielded a composite ratio having an A slope of 8 epectes per decade, extrapolating to 50 species per thousand individuals (figure 5). In an attempt to avoid extrapolation, a sample of 2000 trees was nade ina 10 meter wide transect encircling the irradiated area at a Gistance of 160 meters. One thousand trees were taken on well drained soil and the transect was lengthened by spiralling to include 1000 trees on poorly drained soil. The composite ratio for poorly drained soil had the expected shape and reduced A segnent, but had 53 species and a B slope Gniteating 58 species per thousand, while the vell drained soil sample had ?an unexpected shape with three segnents, had 55 species and would require 62 for the usual synnetry (figure 5).

?As the more or less linear transect haa been taken in order, the trees were divided into groups of ten and a search made for frequency correlations of certain species in neighboring groups. The data under {his treatment fell into three groups having high internal correlation and lov correlation with other groups. One group was dominated by Croton

poccilanthus, a tree of ravines ani flate that is rare on ridges and

Flopes and vas raze in the other two groups. A second group vas, dominated

by Buterpe globosa, vhich vas also a doninant in the Croton group but ad

a comple of species almost absent from the other groups, including Wyreia

Gefiexa, Trichilia pallida ani Ixora ferrea, The habitat of this group

Sensi 4o be gentle slopes having mostly soils of high moisture content,

seemot easily separated into vell and poorly drained categories. The

Thina group vas dominated by Sloanea berteriana and seened to be a ridge

top ani steep slope flora but included also a river bank flora having

Siveinetive species which vas impossible to separate with this technique,

---Page Break---

empos re 6

e ratio curves obtained for nature forest. (A)

M16, dave nevers in ruitation control center (B) 1000 trees groving

im poorly drained (reduced) sctis (?) 1000 trees from red oF

Fellow (presumbiy well drained soils).

Fig. 6, Further breakiow of figure 5C into three apparent tree assoctae

?tons which correlate with toposraply. Lower curve characterizes

flat areas and is dominated by Croton poecilanthus, Mildie

curve includes steer slopes ond river bank ani fo doninas

ted by Sloanes berterians, Upper curve includes gentle

slopes with Hiterpe globosa and Dacryoies excelen

fs doninants but has Trichtlia pallida gnt igre

gia deflexn as exclusive subdoninants,

---Page Break---

When processed separately all three of the groups had higher

diversities than expected, but the unique third segent proved to be a phenomenon of the Myreia ~ Trichtlia group (upper curve in figure 6).

Me A segment of this group has only three species; Buterpe globosa

at 1 part in 5, Dacryodes excelsa at 1 part in 10, and Myreia deflexa

at 1 part in 18.? Almost all of the remaining tree species found in

any forest habitat occurred as rare species among the 360 individuals sampled and very rare species were inatequate in mmber. ?The only other place such composite ratio was encountered was in post radiation sprouts to be discussed belov. Explanation is very hypothetical at

this point but may involve a sublethal environmental stress such as strong seasonal fluctuation in moisture content. Specialist species, such as those.in the chronically poorly drained soils, could be dis-couraged by temporal physical diversity of the environment from exerting strong competitive presoures, leaving the habitat relatively open for sub-optinal, subsistence utilization by any comer. Such a situation could lead to development cf a coniition of maximn diversity and may have, to the extent that the diversity limits of a small island land

mass are being reached. The composite ratio for this habitat would apparently allow for a species per thousand diversity of about 70,

which approaches that recorded in continental rain forests, and it te doubtful that so mary sufficiently unspecialized species are available.

Jn analogous situation existe in the himan economic situation of Puerto Rico, where an infusion of foreign capital has acted to depress competition. Aggressive entrepeneura are able to anass fortunes and there sens to remain plenty, yet many specialized occupational niches remain mysteviously open or are filled by relatively non-aggressive immigrants; the explanation being that the husan technological diversity of the, island, developed under conditions of stronger competition, is inadequate to fill the niches as rapidly as they vould be filled in a larger area having a broaier economic base. If applicable, the hypothesis may further indicate that maxim diversity, although not to be expected under conditions of strong environnental stress, may appear under conditions that are not conducive to the most rapid utilization of resources, as these promote keen competition and stress of biological origin. Chronte or recur-

rent sublethal stress could therefore be the key to maximum diversity.

Community Destruction

only tvo categories of plants seened to show diversity effects attributable directly to the radiation stress. They were the plants that survived until the postradiation measurements were taken, and a subcategory, those that sprouted and began regrowth after custaining visible damage. ALL plants in the sompled area had chown visible aenage cy 1967. Fron the standpoint of the composite ratio the plants maintained an orderly retreat (figure 7). Individuals decreased. fren 82h in 1966 to 386 in 1967, the mmber of species from 5h te lo, eeteapolated species per thousand from 51 to Wk, and H fron 3.821 to?3.4Si

Te number of species in the A segnent decreased from 8 to 5 enl'ite.?

---Page Break---

oe

aa aa a ar

Figure 7, Composite ratios of old vegetation surviving

?from before irradiation until 1966 and 1967, one

and tyo years respectively.

=r

Figure 8, Composite ratio curves of sprouts populations

one ani tvo years after irradiation,

---Page Break---

A slope from 9.5 to 5.3, while a comparable decrease occurred in the

B slope, from 20.25 to 22.55. Thus, although individual species differed in radiosensitivity, the decreases were distributed throughout the composite ratio, in contrast to the development pattern, in which diversity changes in the common species vere not synchronous with those anong rarer species. Processing is not complete in 1968 old vegetation, but the overall trend continued without major discrepancy.

Sprouts from old vegetation vere placed in a separate category from the parent plant, hich renainea in the group just discussed, Although sprouts have taken a respectable position in the commmity of recovery vegetation, and have increased in nunbers and diversity, they did exhibit fan unusual composite ratio during the first year that may represent a reaction to the radiation stress (figure 8). Separation of the usual B segnent into two separate linear segnents having different slopes vas observed earlier in vhat appeared to be a community of natural occurrence. Here the explanatory hypothesis has a nore tangible fom, Renoval of the canopy created conditions conducive to rapid grovth, and undanaged neris- tematic tissue near or below the ground surface, vhere rock and slope shielding had reduced radiation dosage, fount itself with a strong compe- titive aivantage over seedlings ty virtue of possessing extensive and relatively undamaged root systens and food reserves. Spacing of the old plants reduced competition between sprouts to a very mininal level. The

Controlling factors for diversity therefore decane the diversity of old plants, the diversity of meristenatic tissue near the ground anong then, The rate at vhich this tissue could be stimiated into growth, the radia tion dose received and the relative radiosensitivity of each. Meristen diversity may be the factor most responsible for the fact that sprouts

hai a lover diversity than ola vegetation as the sprout lists are very Sintlar to the olf vegetation lists but lack certain of the species complete- ly. The 1966 anomaly in composite ratio, on the other hand, seems to be puttly a function of sprouting rate, as several rarer species did not join the sprout community until 1967. Other factors may have also operated

to cnocth out the anomaly, conpetition vith the fastest growing saplings probably intensified and the inroads of disease ani insect predators Increased the rarity of some species. The B slope ultinately achieved was the one predicted by the more diverse of the two B segments of 1966.

Animal Diversity

?Aninal diversity studies have lagged behind the stuiies of vegeta- tion because fauna are more poorly known than the flora, sompling nethois are more biased due to motility and secretiveness of the organisms, and fever investigators have studied the question of diversity in this area, In particular, the problem of mobility becones almost insurmountable in sone groups. ?Turner (in press) discussed problens he encountered in attempting to assess vertebrate populations ani how greater nobility in one lizard species made data obtained for it incompatible with data

---Page Break---

gathered for a more sedentary menber of the same genus. The census data for birds gathered ty Recher (1964, 1965, in MacArthur and Wilson 1968) is good in many respects, but nunbers were obtained on both sexes of some species, only males of others, and others were observed but could not be counted, Insectivorous birds are rare in the resident Populations but the pattern is complicated ty massive seasonal influxes of migrants, particularly insectivorous warblers of numerous species. Wiegert (in press) made population determinations of soil and litter microarthropods but could not carry separations to the species level in sone groups.

Continuing efforts have been made over the past three years to achieve sufficient familiarity vith the insect fama for meaningful diversity estimates to be made. To this end keys have been written separating distinguishable species designated by code letters. When sufficient material is accumlated in a family group, the group is sent first to the U.S. National Museum under an agreement with Dr. William Anderson, and, if the miseun specialists reconmend, it is forvanied to a recognized specialist for the group. Of some 30 fani-

Lies sent so far, none has failed to contain some undescribed species, and some have contained more unknown than knovn forms. A sample key written for tne Dolichopodise is included as an appendix to this report. This is a Dipteran family for which determinations have just been made by Dr. Harold Robinson of the U.S, National Museun, For diversity purpose, all Dolichopodids are assigned a letter and the abbreviation Dol. Other abbreviations are explained at the beginning of the key. Insect collections have been made using sticky traps, malaise flight ?traps and Light traps. Composite ratio plots have nov been made for significant mumbers of insects collected in single 24 hour periods. Mumerous other collections have been made and are in various stages of sorting; some are waiting on taxonomic vork for only @ very small percentage of rare species in difficult groups.

?A sample of 6,377 insects was taken in 31 small mosquito type Light traps on the night of Sept. 24, 1965. Total diversity calculations have been made on these insects, 5,769 of which were Diptera with 98 species, 268 Lepidoptera with 60 species, 145 Homoptera vith 26 species, 79 Trichoptera with 13 species, 62 Coleoptera with 16 species, 42 Psocop- tera with 9 species, 35 Heniptera vith 9 species, 32 lymenoptera with 7 species and 13 Neuroptera with 9 species. All CR plots with the ex- ception of Lepidoptera vere smooth curves with no clearly discernible seuents such as were characteristic of vegetation. Lepidortera exhibited a sharp break beyond the fifth species but tended to curve a {ittie beyond the break (see figure 9). Samples of other families are also presented in figure 9, vith Trichoptera the least diverse and

Coleoptera nore diverse. ?Such curvature makes Ha very inadequete

measure because of its high sensitivity to sample size. Scaled H seems

fo be the only Information neasurenent giving valid conparisons between

groups, although no routine scaling procedure for senples less than 100

fas used. Crude extrapolations for H 100 vere made on Trichoptera ant

Coleoptera, yielding 100 of 1.6 and 2.8 respectively. 100 for Homop-

---Page Break---

Fig. 9. Composite ratio curves for insect families taken in

Light traps Sept. 24, 1965. (A) Trichoptera (B) Cole-

coptera (C) Lepidoptera.

Fig. 10, Composite ratio curves for total insects taken in (A)

Hsgni trope Sept. 24, 1965. (B) malaise flight trap Yar,

gut rgb. nate scale on apecies axie is very different

?hon previown curves,

---Page Break---

tera was 3.5, for Lepidoptera 3.9, for Diptera 4.2 and for total insects 4.3. As no insect family can be said to forma community in the sense the word was used for plants, perhaps only the total insects (figure 10) should be compared to plants, "An estimate of species per thousand by the maximum 1ikelihood method is/125, while #1000 = 5.108, both much higher ?than in any community of plants measured.

Malaise trap insects exhibited similar patterns but the largest Sample in 24 hours was 199 insects of 120 species (figure 10). #100 of ?this sample was the sane as in the light trap at 4.3, but curvature was much stronger as is suggested by the fact that almost as many species were obtained in 200 individuals as the estimated species per thousand from the light trap. A very crude estimate of species per thousand vould fall between 200 and 300 and suggests that the light trap is more selective ?than the flight trap, which uses no bait but depends on the tendency cf flying insects when encountering an obstacle to veer upward. When one considers that this trap is almost limited to flying insects and is inmune to mary of them as evidenced by sticky trap collections we see that total insect diversity mst be very high with a truly unbiased and random sample of 1000 insects containing perhaps 500 species,

Conclusions and Discussion

From the standpoint of diversity methods we have concluded that each method mentioned makes a valuable contribution to our understanding of community structure and diversity, ani that there are pitfalls in the uneritical applications of any of them. In particular, linear methods such as William's log series or a falsely assumed constancy of Brillouin's H measurenent vith increasing sample size can be misapplied. Actual plotting of a diversity index curve can give warning of nonlinearities at high nunber levels and the even more easily computed composite ratio provides a view of total sample composition, giving a solid foundation to whichever diversity index is chosen.

Details of community structure noted are a break in composite ratio of most plant communities which is not a mathematical artifact and which Givides the community into a group of conmon species with lower divereity and rare species of higher diversity, an occasional second break farther? out which sets off a group of the rarest species having lover diversity than the intermediate species also thus formed, and the absence of such breaks in trap samples of insects of most groups. It is probably innap-propriate to call trap samples of insects or their taxonomic subgroups communities, or to compare them in any rigorous way to communities of macroscopic vegetation, When more knowledge of the ecological role and trophic levels of the particular insects 1s gained it may be possible to assign species to commmities. An example is the fact that sone phorid flies, a group dominating sticky trap collections, are scavengers and some are known to be insect parasites, These are menbers of the same con munity only in the sense that vines and mishrooms anong the plants are,

---Page Break---

and diversity of this scope has not yet been measured in the plants. It is even possible that the continuous curvature in the composite ratiog of the insects 49 the result of single breaks at different

points in many combined commmity curves, but thie unlikely in view

of qurvatare 1 such groupes as Trichoptera, which are ecologically

very narrov, A more probable explanation is that the insects collected are aiults, and many, if not most, species fron breeding aggegrations of varying density ani dimensions, There is thus a potential non Linearity in the distribution of each species ani random sountings should yield many valleys and few peaks, ?The combined sample of mary iniependent species should therefore show the sane trend. In addition to possible selective attraction of light traps, thie phenonenon

might provide additional reason to expect less ratio curvature and diversity, as an attractant should tend to shift several distribution peaks into register and sample the tops of all.

Tt was hypothesized that ananalous double-breaking vegetation CR curves could be due to the effects of reduced competition combined with some sort of linit on the mumber of species able to take advantage of this. In post-radiation sprouts the lack of competition was clear and the limit was suggested to be the rate at which species could sprout. This anomaly disappeared in the second post radiation year. A similar anonaly was found in nature vegetation in certain so!l types apparently intermediate between vell and poorly drained ani containing ?a complex of medium to rare trees species alnost absent elsewhere. Reduced competition vas inferred from the comparative absence of abundant specialized species, and the limit on rare species was suggested to be the island's lack of sufficiently unspecialized species able to grow there.

In the development of plant conmunity structure, abundant species were found to overshoot the ultimate levels of diversity very early and return more slowly to the mature levels. Rare species were found to slowly increase to the mature levels with no overshoot yet observed.

Total species diversity as species per thousand was found to be more sensitive to changes in rare species, but Brillouin's I did not show @iversity overshoot in tree species only. ?The latter measurement followed the common species in overshoot and correction when total vegetation including herbs and vines was considered. Seedlings of tree species considered as a class established mature levels of diversity

in every paraneter by the third year, and served to point up the fact that species per fixed mumber of iniividuals is a very different measure~nent from species per unit area unless individual size is strictly

?couparable,

Reduction of diversity in vegetation showing radiation damage dia

occur, but the reduction was orderly in that disruption of the composite

ratio did not occur as plants died.

In projected diversity studies it is desireable to follow radiation

recovery vith annual surveys for several more years. The sapling class

of new trees seems to be duplicating in slow motion diversity events that

---Page Break---

Dezrmes ino malty tnt seating cats for snd seetin._fore

sey aa Wet tte ana uae eet ame,

fs ogetes alt ai eeesitns Bene tre aes

Soose Bete ee oR cee ah re Erte

Sent cee Sr cea of Some Sie ena,

tunes ano ae a ele

ee acne ots aceasta Marr eek

Sic eeeliy ay fort cme tant SSS eta

See ence enter ey tie tee et

soa eet lo

References

Brillouin, L., 1956. Sefence and infornation theory. Acadenie

?Press.

Loyd, M., J-H Zar, ani JR. Karr, 1968, On the calculation of

?Informational-theoretical measures of diversity. An,

Midland Naturalist 19:257-272.

Mackrthur, ReH., H. Recher, and M. Cody, 1966. On the relation

?fetween habitat eelection ani Species diversity. An.

Maturalist, 100: 319-327.

Machrthur, R.H., and 2.0, Wilson, 1967. The theory of Island

?Biogecgraphy. Princeton University Press.

Margalef, R., 1957. Ia teoria de 1a infornacién en ecologta.
?Mem: R. Academy Sci. y Artes, Barcelona, 32: 373-449.
(Transition, 1959. Information theory in ecology.
General Systems 3:36-71).

MoMahan, E.A, and N. Ferguson, in press. Diversity of micro-
arthropods after irradiation. A tropical rainforest,
E.?, Odum, ed.

Odum, E.P., 1959. Fundanentals of ecology, second edition.
WB, Saunders Company.

Pielou, E.C., 1966. The measurement of diversity in different
types of biological collections. J. Theoret. Biol.
1321321.

Recher, H., 1964, 1965. Census of birds at the El Verde site.
?Anmal reports, Terrestrial Ecology I, P.R.N.C.

Wiegert, R.G., in press. Effects of ionizing radiation on
leaf fall, decomposition, and the litter microarthro-
pods of a Puerto Rican montane rain forest. A tropical
pain forest. H.T. Odum, ed.

Willians, C.B., 1964, Patterns in the Balance of Nature and

Related Problems in Quantitative Ecology. Academic

Press.

12+

---Page Break---

?Appendix A

to Dolichopodsdas of the Rain Forest at HL Verde by George Dr

ot at HL Verde ty George Drewy

(Gientittentions ty taroia Tobinwon, UeSy National Suseus). abbreviations

a: A ~ anterior, P- posterior, ?D = dorsnis V - ventral, Tl ~ protbia,

Ws mesotibia, 1 netavibin, ? m

Wing veins efter Curran (Worth Anerican Diptera, Second edition, Henry

artpp, Pb.)

21 Fourth vein with a widely divergent fork; all metallic flies

more than 3 mm. long .

1! Fourth vein without a fork

2 Scutellm with 4 strong bristles (Condylostyius)

2 Soutellim with only 2 strong bristles (Scien)

3. Wings ploturea ...,

3* Wings clear .

4 Wing pattern Atstinets PY bristles of TL elongate. C, pLlosus (Loe¥)

Do

4" Wing pattern indistinct; AD bristles of Tl elongate.

c. aiffusus Wied . & sesteseees DOL AR

5 AD and AY bristles of 12 greatly elongated; 2 long PY bristles on

.C. prutnosus (Cog.) «. perms seeeere DOLW

5" j2 bristles normal; no PV bristles on TL. C.

Dol

(Van Duzee) ....

6 Gap between tips of third and fourth veins mch vider than diane-

ter of tibiae; all coxse yellov; bristles and wing veins yellowish.

8. sp. near bellinanus (Van Duzee) «

6+ ?Titra? and fourth veino almost meeting ai

meter of tibiee; wing veins dark .....

7 Pleura light in color (except a small anterior spot); tvo stripes

on each abdominal tergite. 8. dorsalis Loew

T? Pleura a dark metallic color

8 Meso and metacoxne dark in color «s++++++ peer co 6)

8' Metacoxae yellow, mesocoxae slightly darker; sclerotized portion of

first abdominal tergite two narrow Wedges joinded ty a thin line. 5.

sp. near wnicinetus (Van Duzee) ssssereeersereeerasereee Dol Q

9 Sclerotized portion of firat abdominal tergite divided into two

separate thin slivers; second tergite with triangular posterior

?and having an anterior lobe. S. sp. not identified .... Dol X

9* An undivided bend on first tergite, which may have on anterior ?

notch

ae peaees seeee 10

---Page Break---

10 Three medium ~ sized bristles on each side of first abdominal seg-

ment, an anterior notch in band; all antennal segnente dark. S.

sp. near inaequalis (Van Duzee) « + Ee Dol D

10" A single very large bristle on each side of first abdominal

segment, no notch in band; antennal seguents yellowish, Lx

especially first. Probably 8. innequalis (Van Duzee) «+++

11 Pronotun mostly bare of fine hairs, those present confined to

strips in front of bristle rows; color alvays metallic .. ah

11! Front of pronotun with mmerous scattered fine hairs; 9

metallic

12 Fourth vein bent strongly forvard beyond posterior crossvein ..

12" No trong bend in fourth vein, may be curved «eeeeeeseeee

13 Posterior ezocevein almost perpendicular to fourth vein; legs

esse Dol

yellow. Sareonius lineatus (Ald.) ...+ peers

reveii oblique to fourth vein; legs dark

a3

1s Fourth vein ending near ving tip. Tachytrechus sp. Dol FP

24" Fourth vein ending well before wing tip. Plagionewus|

tatus Loew sss... 3 RS renssa + Bon

15, Front of pronotu yellow « %

15* Front of pronotun metallic?. B

26 Sixth (anal) vein present; a large, round green spot in frontot

scutelium, Nourigonte signifer Ald. .. Dol k

Tt

16" Sixth vein absent: thorax wholly yellow. Xanthina

17 72 with a comb of ventral bristles, having in afdition long hairs

in the male; posterior half of postscutellun and postnotun yellow

EDs soeee 60

17! T2 without ventral bristles; postecutellum dark and a thin dark

line down postnotun. X. sp. » oon

18 Fosterior crossvein would intersect thind vein if extended forvard

by its ovm length; bristles yellowish; very small, Thrypticua 19

18! Fosterior crossvein too short to intersect third vein if extended

forward by its own length; bristles dark . seeeeeees B

19 Coxae and femora dark ...

19' Coxae and fenora yellow .

20 Wing veins yellowish; a minute AD bristle about one fifth of way

down 12, I. 5p. seeseseee = seeeseees Dol I

20' Wing veins dark; a normal AD bristle about one third of way down

Dol

2, %. fraterculus (Wheeler) .

21 Basal abdominal tergite yellow... abdominalis (Say)

21" Basal abdominal tergite dark .

1h

---Page Break---

ge Basal ebaominal sternites yellov.. setoous il, Robinson «

2. pasal ebdominal sternites dark, . ap. undeseribed .

ob Slender elongate flies vith vings about 3 tines as long as vides

third antennal segnent triangular with aristee on basal half of

upper edge; a ventral bristle on 12, Symycmus +25

gy Wot exactly as above ., +2

Basal metatarsal segment about as long as second segment; 3 prea

© Meal AD bristles on 72, S. sp. Ps Dol

Basal metatarsal segment shorter

apical AD bristles on 12 .,

x

26 Pleura light in color; 2 AD bristles on 13, 8. sp. sees Dol BB

26! Pleura dark in color; only 1 AD bristle on 13 (disregard dorsal bristles).S. sp. .

2 Four strong bristles on end of male sbdonen; face of male usually

wides Zenales difficult to separete so all can start here.

fo strong bristies on end of male abdonenj face narrow, eyes of

ales alnost touching below antennse, Chrysotus «+...

er"

+35

seers 29

32

28 Front coxae yellow .

28" Front coxae dark 05

29 A strong ventral aristae on 12, 12 also vith 2 AD and 2 PD pre-

apical bristles; legs yellow with a distal dark band on metafencra,

2, dimtdtatus Ald. + Dol 88

29" Tio strong ventral br: 30

92} nostly small speck

30 Avistae of male apical on a slender neck, pleura dark; wing tip

Dehind long axis of wing; female unknown. D, flavipes Ald. ..

3L Wot as above, Chrysotus females ...++-,

- contiguus Ald. ...44e. Dol R

32, Hyes contiguous above base of antennae.

32! Byes not contiguous above antennae ..

33 A medion AD bristle on 72 about half way between upper AD and epex

of leg, but median D or PD of Tl, if present, is mich smaller than

basal D of TM; thira segnent of antennae little higher in lateral view

Second segnent; basal metatarsal segment of males with a strong

gg: Yenttal bristle; large species over 2.5 mm long «+ +++++.

3' Median AD bristle of T2 absent, or mich closer to upper AD than to

®pex, or a median D or PD present on Tl that is as long as upper

>. Crysotus females .

+ 3h

---Page Break---

3h Median AD of 72 more than half as long as upper AD. ?Third vein of

males not strongly arched. D. sp. . ++. Dol DD

3M" Median AD of 72 less than half as long as upper AD, ?Third vein of

males strongly arched. D. simplex ...

35, Ab least front coxae yellov; small species less than 3 mm long «+

35° ALL coxse dark; size variable .+++eve,

36 Distance between tips of second and third veins little more than

@istance between tips of third and fourth; fenora solid yellow;

only one ell developed preaptcal bristle on 72, C. sp. seseeeees Dol C

36" Distance between tips of second and third veins almost twice that

detween third and fourth . paseceneesens

37 Pleura, legs, and antennae yellow; very small flies 1-2 m. long;

?third antennal semuent of male vith slender processes above and

velow aristae. C. sp. + ae

31" Pleura and antennse dark; usually with some dark shading on

fenora pacon

38 A small PD bristle opposite or basal to upper AD on T2.

36" Any PD bristle on 72 distal to upper AD; profenora usually not

shaded vith dark color

39 Sone dark shading on all femora; all seguents of antennae dark; T3

of male shorter than first metatarsal segnent, that of fenale

normal. C, brevitibia Van Duzee sssesssessseeeeers +

39' All fenora yellow; second antennal segment yellow, third darks

of male normal, C, mexicams H, Robinson ..,.

40 A median AD bristle on 72 and 73, although minute in males;

@ark bands on fenora variable but usually strong on mesofemora of

males. C, flavohirtus Van Duzee eseeeea

40! Upper AD only noticable bristle on T2 and 13; dark distal band on

netafemora only. G. sp. «

41 At least basal three fourths of all femora dark sesesees 2

41! Metafenora solid black, others yellow vith slight dark shaiing in

female, heavy shading in male; third antennal segnent of male

spearhead - like vith a long tapering point; aristae apical. ¢.

excavata Van Dusee

42 Third antennalsegnent disc ~ shaped, its height in lateral view

nore than tvice that of second segent; median AD bristle on 12,

4f present, mich closer to basal AD than to 12 apex; medium sized,

all longer than 2 mm. ooo tocsersseeses

hg! Height of third antennal segnent littie more than that of? second,

median AD of 2, if present, midvay between upper AD and 2 apex.

43. At least front tibiae yellov ..., seseeseeae

43! ALL tibiae black; median AD bristle of 12 developed but almost

rather than AD; second metatarsal of male shorter than third. C, sp.

near excisus Ald. wes Dol ce

---Page Break---

4h Only basal AD of T2 well differentiated from hairs -

ut Tree AD bristles differentiates on 12, the uppermost @

dasal to the usual basal AD; metatibies of males brovn; aristac Of |

males not recessed but females very sintiar to C. proxims, C. sp. Dol JJ

45 Aristae of male recessed in a deep notch, those of fenale slightly

a0; basal netatarsal segnent of male lacking a ventral bristle.

. proximus Ald. .

us: Hate of hale not recess

netatarsal segment of mile; fenale not discovered but possibly

Andistinguishable fron 0, proximus. C. spinipes Van Duzee

6 Median AD bristle of 12, if developed, less than half as long as

basal AD; small species mostly less than 2 mn. long .., eee MT

46" Median AD bristle of 12 almost as long as basal AD; very similar

to Diaphorus species DD and GG but distinguished by a median D to

PD bristle on Tl that is as long as basal D; males lack a ventral

bristle on basal metatarsal seguent, C. sp. se-ses eres Dol W

WT Wings dusky, veins dark; tibiae of males dark, females lights

femora dark but with little metallic sheen; basal AD of 12 present

in both sexes seeeeeeeeee

Ay" Wings clear, veins yellowish; pleura ani fenora with bright green

metallic sheen; male abdomen vith viclet reflections; [2 of male

Lacking bristles. C, humilis Parent seeee Dol FP

48 Basal metatarsal segment longer than next segment; 13 dark on

?asal one fifth in female; third semnent of male antennse rounded

in front and somevhat bean-shaped in lateral view. C. sp.

near niger Ald. ea Dol Tr

gt Basal aetatarsal segnant no longer than next segent; 15 of

fenale all light; third segnent of male antennae triangular ?

?end pointed; aristae barely subapical. C. sp.

-t-

---Page Break---

Appendix B

Key to Muscidae (sensus lotus) of the Rain Forest at El Verde (Anthonyiidae gna Muscidae) vy George Devry (sone identifications provided and all checkea by Silverio Medina, U.S. Departnent of Agriculture, University Experimental Station, Rio Piedras).

Abbreviations sane as in Appendix A.

1 Lower calypter rounded posteriorly and dorsally. Anthyomyiidae..... 2

1! Lover calypter broad, scuevhat flattened posteriorly and triangular dorsally (Muscidae). Aristae bare. Synthestonyia mdiseta

Van der Walp s..+ eae = Mus A

2 Sixth vein very short, seventh curved outward so that it vould

intersect sixth only short distance beyond end of latter.

Subfamily. Fanniinae ... od i

2 Not as above .

3 A small preapical AD bristle on TM; palpt broad, flat and yellow;

+ Anth U

tibiae yellow, fenora black. Probably Euryouma sp.....++

3" No preepical AD on Tl; pmipi cylintrical ent black; heel

bristles all shorter than third antemal segment; color shiny

Diack overall. Fannia sp.

4 Less than two presutural doreocentral bristle:

Coenosiinse

4' Oo presutural a:

5, One pate of presutural dorsocentral tristles .+++e+ees+e+0 6

5+ Dorsocentral bristles not differentiated fron thoracte halva}

profenora black, meso and netafencra yellow. Atherigona exelsa

Thomson + +.+++ Sissesesesesesee vererersee Anth W

6, wo pairs of posteutural dorsoventral bristles. Bithorachaeta 1

6! Miree pairs of posteutural dorsocentral bristles. Necleniopsis si. 6

1. Legs yellov. B, leucoprocta (Wiedemann) ....+. nth F

(Coquillett) .....

T! Legs black. 3.

8 Apical scutellar bristles more than three fourths as long as

subbasals .

8! Apical scutellars less than three fourths length of subbasals

9 One pair of postoutural TA (intralar) bristles; procoxae yello 10

9" wo pairs of postsutural IA bristles; procoxae yellow or black

10 Palpi and third segment of antennae yellow (males presently

10? ?Third antennal segment dark below aristae; palpi dark with some

Light shading; female with distal fifth of all fenora darkened,

three preapical bristles on ?3 (AD, D, AD), distal AD on apteal

eighth of 133 male with an additional PD bristle on 13 basal to

the other 3. N, rex Curran

---Page Break---

ul Two lerge median anterior bristles on mesofemur; proboscis

Light yellov; fenale with posterior side of profenora dark,

others banded distally, sone 73 bristles as N. rex but situated

more basally so distal AD on apical third. undesoribed

near Ne rex, on 5 sieve Anth G

tit One large median anterior bristie on mesofemury proboscis

bromj fenale with all femora yellov; sane 13 bristles as

ex but Gistal AD on apleat fourth, Mop. undescribed neat

- tees Anth

12 Procoxse gray or black and sane color as adjacent mesopleura.....+. 13

jp! Procoxae yellow and much lighter than adjacent mesopleura

13 A preapical AV bristle on 13 .. Beeeerserses

13' Wo preapical AV on 3 (the usual AD, D, AD present); no longi

tudinal stripes on thorax. N. sp.undederibed near ditiportus.. Anth J

1% Four preapical %3 bristles (AD, AV, D, AD); indtetinct longi

tudinal stripes on thorax; tibise black; median parafrontal

bristles reclinate, N. ditiportus Snyder.seseesereeeseee

1! Five preapical ?% bristles, a PD almost even with basal AD;

distinct longitulinal stripes on thorax; tibiae brown;

nedian parafrontals cruciate, N. sp, undescribed near ditiportus Anth K

15. Wo preapical AV bristles on 73 sesseseresees:

15" A cnall AV near median AD of 73; paipi yellow; third antennal

segment dark with a prominent yellow band basally (nale unknown);

fenora of fenale yellow with posterior of profenora shaded black,

others banded distally with black. N. op. undescribed near N.

Aiscolorisexus .

ee 16

+ Anth

36 Thira antennal segnent darks 3 preapical 13 bristles (AD, D, AD);

legs of female black, those of male yellow with black tarsi.

discolorisexs Snyder « paenereeeee

16' ?Third antennal segnent yellov female with # preapical 13

bristies (AD, D, 2D, AD); 13 of male vith munerous long,

bristly hairs, 'N. colvaiata Snyder (probebly a synonym of W,

nedine Snyder) .

LT Fenora, all coxae and palpi dark, tibiae light ...

LT" Fenora, coxae and palpl yellow se+++eee

19

18 one patr of postoutural TA (intralar) Briatles} median para

frontal bristles cruciate; 3 preapical bristles on 13 (AD, D, AD).

fale trknow. 'N. ebintemir Styler seecesssesssenee 2 hnth 0

18" to pair of ?tsutural IA bristles; median parafrontals ??

reelinatey ?preaploal 3 bristles (AD, A, TD, D, AD, PD).

Ty maldonadel Sryeer. peecst neces aes + Ante N

19 Stignatal and propleural bristles duplicated (It snall bristles

near base of front coxse); tibiae of males fairly straight e

---Page Break---

19' Only 2 small bristles above base of front coxae; tibiae of

known males bowed considerably and enlarged distally; third antennal segment dark . Ee 22

20 Third antennal segment clear, light yellow cose aL.

20' Third antennal sequent brown vith yellov area aljacent to base

of arista; males with long hairlike bristles on tibiae, 1A and

2D on 72, a basal PD, AD patr then FD, D, AD, on 73; sides of

male abdomen shiny vith few setulae, two postoutural TA on at

east sone opecinens, one in listed for holotype. MH. srleplacta

Snyder. co Anth 4

21 One pair posteutural intralar bristles; male with 1A and 3D

bristles on 12, numerous curly hairs on 73 and dorsum of basal

metatarsal segnent; posterior hairs of oral margin yellow in

fenale. N. sp. undescribed ..... + Anth R

21! Two pair postusutural intralar bristies; both sexes with 1A

and 1D on 72, AD, D, and AD on 73; posterior hairs of oral margin black?in female, N, neoflavipes Snyder « a Anth P

22 An AV bristle on 73; otherwise intermediate between next two

species. N. sp. undescribed or possibly hybrid sees AnthW

22! Wo AV on 13. pcaeenee iene

23 Males with one A to AD bristle on 72, merous posterior T2

hairs and bristles, abdominal setulae sparse and abdomen shiny;

fenale vith all hairs on oral margin black, one posterior bristle

on 2, N, micans Snyder

23' Males with munerous, long curly A and P bristles on 72, abdo-

minal setulae normal; fenale vith posterior hairs of oral

margin light, two posterior bristles on 2, N. crassicrumus

Snyder .

2k Fourth vein curving forvand at end toward convergence with

third or small species less than 4 m,long

eh* Fourth vein parallel or divergent with third at end

?than I mm. long; Aristae long-plumose. Subfamily Phaontinae

25 Aristae long-plunose; middle thoracic stripe light in colors

third vein with a tuft of setulae at base. Subfamily Mydaeinae

25! Aristae short-plumose to bare; middle thoracic stripe dark in

color} no setulae on third vein. Subfamily Linnophorinae .

26 Aristae alnost bare; color a dirty blue-gray with indistinct darker pattern; small species less than 5 mm. long. Gynnodia

26' Aristae short-plumose; color pattern fairly atetinct when dry, fa clear denarkation on mesopleura between a smooth, dark anterior half and a silvery pollinose posterior half; large species mostly longer than 5 mm, Limnophora .

7 Fifth vein reaching margin of wing; 3.5-5 mm. long. G. sp...

---Page Break---

eq! Fifth vein stopping short of wing margin; 2.5-3.5 mm. long & sp. . Anth JZ

28 ?vo posterior preapical bristles on 72; first posteutural

dorsocentral bristle much longer than second.l. sp. «

28' Only one posterior preapical [2 bristle; first two po

sutural dorsocentrals similar in size and considerably

shorter than last two, L. ap. .

29 Third vein setulos

three sternopleural bristles. Scenetes

oardint Malloch ..... seeessceeees Anth FF

29! Third vein bare; two stemopleural bristles, Phacni

preapical bristles on Tl; 1 AV, 2 AD and 1D on 13.

Wo.

P. 8p,

30 Posterior crossvein almost twice as long as segnent of fifth

vein distal to it; first postautural dorsocentral bristle

slightly longer than second; hhumeri;and seutellun black.

Nyospila obsolete (Brauer and Bergenstann)

30! Posterior crossvein little longer than segnent of fifth vein

distal to it, first postsutural dorzocentral much shorter

than second; ?tuner! yellow, scutellum red posteriorly. Heo:

museina farri (Dutch?

Notes: Key expanded in part from Snyder, F.M. 1957. Puerto

Rican Neodexiopsis (Diptera Muscidae: Coenosinnae)

J. Agr. Univ. of Puerto Rico M1: 207-229. His charac-

ters involving intraler bristles and distal mesofenoral bristles did not hold for all specinens of N, crispiseta and N. micans examined. Species identified as N. calva-lata on basis of wing shape were more like medinai in all Tess exact characters ani cast doubt on specific distinc~ ?tion.

---Page Break---

SECTION IIT

Section three consists of a manuscript submitted for publication wy Dr. Carl F. Jordan, and two reports by visiting sctentists who were supported by the Terrestrial Ecology Progran.

?itrogen Fixation by Epiphyllae at EL Verde" was prepared by Dr. Joe A. Einisten, of the University of Georgia, ani his graduate student, M.A, Harrelson. Dr. Einisten spent two weeks during the sumer of 1968 at the Ei Verde site, to initiate the project, and Mr, Harrelson spent two months on site completing the work.

Dr, Elizabeth McMahan of the University of North Carolina has

?een visiting the Fl Verde site yearly since the termination of radia-

tion, to measure long term changes in termite populations as a result

of radiation. Her report for the 1968 check is included.

1007 // agove canopy

3

FOREST FLOOR

SPECTRAL INTENSITY (MICROWATTS /CM2/my)

°

400 600 800 1000

WAVELENGTH (mp)

Fig. 1. Intensity of radiation vs, wavelength, measured above

?the canopy at noon on Nov, 16, 1967, and measured

?on the forest floor a few minutes later.

122+

---Page Break---

DERIVATION OF LEAF AREA INDEX FROM QUALITY OF LIGHT ON FOREST FLOOR

By

Carl F, Jordan

Introduetion

Beosysten studies such as those of productivity and chemical elenent cycling require measurenents of the quantity of leaves in fhe canopy. This quantity ie often expressed as leaf area index, {hat 46, area of lea? per areaof ground. In herbaceous communities, it can be determined directly by clipping (Monsi and Saeki, 1953), jut forest measurenents are nore difficult to make. In order to Getinate leaf area intex throughout a large area of tropical rain forest, Odum, Copeland, and Brown (1963) measured leaf area intex dizectiy in 10 locations, correlated it with optical density measured {ith silicon solar cells, ani then nade optical density determinations Ynroughout the forest.

?There are two disadvantages in using optical density determined by solar cells as a measure of leaf area index. One is practical, in ?that it is inconvenient in a field survey to have one cell above the canopy and the other in the investigator's hand, both of vhich must Ye read simultaneously, or nearly so. The second is theoretical, in that solar cells respond to light over a broad band of the spectrum Incluiing infra-red vhereas extinction of light is due primarily to chlorophyll vhich absorbs light in a relatively narrow band, Much of the light recorded ty a solar cell on the forest floor is due to Scattered Light of vavelengthe other than the chlorophyll absorption dani. The quantity of this scattered light could be influenced ty shape, orientation, and spacing of canopy leaves.

?This paper presents an indirect method of measuring leaf area index. ?Tae method may be superior to the optical density method.

Theory

Intensity of red light reaching the canopy is slightly greater

than that of near infra-red, but on the forest floor, the relative

intensity of the infra-red is many tines greater (Fig. 1; Federer

?ani Tanner, 1966). This is due to the selective absorption of radia~

tion by leaf pignents. The more leaves that are present, the greater

WEL be the aleference An red and infra-red radiation at? the forest

oor.

?The intensities of infra-red and red light can be expressed as

a ratio, and this ratio can be calibrated with leaf area intex measured

183+

---Page Break---

@irectly at several points ina forest. Leaf area index throughout

the entire forest can then be derived from ratios measured at the

forest floor.

To maximize the ratio as leaf area iniex increases, the ratio

should be detween light at 600 and 675 millimicrons. Absorption of

Light by the canopy is at a maximm at 675 millinierons, and trans-

mission has a maximm at 600 millinierons (Fig. 1).

Since absorption of light 1s greatest at 675 millinicrons,

scattering of light at this wavelength vill be less than at most

other vavelengths. The less scattering, the less the ratio is influenced by the angles and spacing of leaves, and hence, the nore reliable the correlation of ratio and leaf area index. ?Hovever, even at 675 millinicrons there probably is sone light ?scattering.

To mininize this scattering, ratios should be measured only in direct sunlight, and vhen the sun is high overhead. At 800 millimterons, it is not clear hov much of the transmission through the canopy is due to scattering of light, and how mich is due to absorption and re-emission ty leaves. Here again, hovever, scattering 1s probably at aninimm in direct sunlight, and vith the sun overhead.

To use the ratio ac a measure of leaf area index within the forest, the ratio mist be constant above the canopy. Figure 2 shows ?that although quantities of light vary during midday hours of sunny days, the ratio 800/675 remains almost constant. The ratio is also independent of tine of year (Table 1). The slight variations could be caused ty human and instrumental factors. In any case, the varia~ ?tions are mimite compared to changes due to the light pasding through ?the canopy.

Since chlorophyll content per unit leaf area varies between species, the correlation between the ratio and leaf area index will be valid only in the forest type where the calibration was accomplished. However, a correlation between ratio ani chlorophyll concentration per square meter of forest floor could be valid for many vegetation types. With such a correlation, if mg. of chlorophyll per square meter of leaf area vere determined for a given vegetation type, leaf area index

could easily be derived by dividing chlorophyll concentration per

square meter of forest floor ty concentration per square neter of

leaf area.

---Page Break---

120)

a

£

BI00 nano 4o7 2

s os 2

2 80 §

g 8

5 8

2° 7 | 3

iS o

#40 ?800

1000 1200, 14001600

TIME

Fig. 2.

Absolute intensity of light at wavelengths 600

?and 675 millimicrons during the day, and

ratio between these intensities.

sanle 1, ito of Mght of wavelength 60 at 5 wtitatorsee

a

me Ramer ceatige Amat Me

ne 961 5 om 0.3

er, 6 : ca

ee 5967 ; one

de 36,961 a ar

ee 9,60 6 on

say 5, 96 1 ew

fet 25,961 5 ?

sent a8, 96 2 oa to

cuts 8, 961 : one

sor 1960 s ee 4 000

a ob om oe

vay 2, 2988 ? cm + 00

ay 3, 3968 . oo 2 08

ses eth $0.05

–

---Page Break---

Methods ani Results

Leaf area index was measured at three locations in the Luqutllo Experinental Forest near El Verde, Puerto Rico, by the folloving method, Scaffold type towers vere erected to a height equal to the top of the canopy, and vith a minimum disturbance to the forest. A string with @ weight on the end was thrown out from the top of each tower 16 tines in such a way as to hock over a twig and then fall straight to the ground, ond the number of leaves which each string touched was recorded,

Veaf area index at each site as taken to be the average munber or leaves touched by the string on each throv. Leaf area inter at a fourth site ina ravine was taken to be 2.2, the value Oitm, Copelaniy oni

Bro (1963) determined for that site by clipping ani measuring leaves,

Light readings at each location were made with a spectroradio-
eter manufactured by Instrument Specialties Co. he first vavelenath
yas disled in and a light intensity reading vas token. Innediately,
?the second wavelength vas dialed, and a second reading taken, The
process took about 15 seconds. Since the ratio method proposed here
assunes that both readings are mate simultaneously, the first wave-
length was dialed in @ second time to assure that the intensity had
not changed while the second reading was being made. On clear, cumy
days, there was no measureable change.

?The spectroradioneter was calibrated with a spectral standard
amp supplied by Instrument Specialties Co. All readings vere corrected
to absolute values, and the 600/675 ratio was calculated in the office

some time after the field measurements were nade.

Results of the correlation are given in Table 2 and Figure 3.

?The equation for the regression line in Fig. 3 18

Fa. (1) log ¥ = 0.3813 + 0.0989x

where Y is the ratio of Light at the wavelengths 800 and 675 milli-
microns, and X equels leaf area index. Using a value of 310 ng. chlo-
rophyll A per square meter of leaf area for this forest (Oiun, Copeland,

and Brown, 1963), the relation shown in Fig. 4 was derived. The

equation here is

Eq. (2)

where Y again is the ratio, and X is mg. chlorophyll A per square

neter of forest floor.

Equation 1 is probably not valid for values of leaf area index

less than one, since it ie known from Table 1 that with a lea? area

index of zero, the ratio is 0.78.

it scattering were not a factor, Fig. 4 could be used to

determined snloropiyll ?A concentration in any forested area, and from

og ¥ = 0.3813 + 0,0002908%

---Page Break---

Table 2.

Data for correlation between leaf area index and Light ratio.

Also, leaf area index determination for entire forest.

site

Slope

Slope

Ridge

Ravine

?Total for

forest

eat aren Average Light Ho, of readings Date of

index ratio, 600/675 m taken readings

6.68 10.51 16 tag. 15, 1968

6 dug. 19 1968

5.60 88h 4 May 2, 1968

4 uly 23, 1968

30 Aug. 15, 1968

10 fori 2h, 1968

8.60 w.3t % fort 24

8 Suly i, 1968

2.28 3.98 32 hug. 22, 1968

nak April 24, 1968

eee 0 133 Ney 2, 1968

130 July 26, 1968

% Value taken from Odum, Copeland ani Brown, 1963.

---Page Break---

g

3

RATIO, 800/675

os

2. 4 6 8 0

LEAF AREA INDEX

Fig. 3. Ratio of light intensities at 800 and 675 milli-

?microns measured on the forest floor, as a

function of leaf area index.

g

3

RATIO, 800/675

S.

1000 2000 5 3000

MGM CHLOROPHYLL "A'/M? FOREST

Fig. 4, Relation between ratio of light intensities at 800 ant 675 millimicrons measured on the forest floor, and milligrans of chlorophyll A per square meter of the forest,

---Page Break---

this, leaf area index could be derived, as previously deseribed. Since the calibration vas male ina brood leered forest with the canopy top at about 65 feet, and very little shrub vegetation, the closer another forest resenbles this structure, the more applicable this relation will be.

Light readings were done in a systematic manner, ani values were recorded regardless of whether a light speck fell on the meter, or whether a limb was in a direct line between the sun and the meter. As a result, individual ratios taken at a given site varied greatly, ?tut the averages (Table 2) were almost perfectly correlated with leaf area index (Fig. 3).

Average leaf area iniex for the entire forest as determined dy Light ratios measured every 5 feet along three 600 foot transects vas 6.6 (Table 2). Odum, Copeland, and Brow (1963) determined an average value of 6.4 for the sane forest by optical density means.

Light ratios were always higher at the calibration sites during early morning and late afternoon hours, and any tine during winter months. The higher ratios were a result of relatively less light at 675 millimicrons, at the forest floor. This could result from the chlorophyll of the forest not being saturated at these times. Only Guring noon hours, during the summer, was it possible to get repeatable results. This suggests that trees of the forest have evolved 50 that their chlorophyll content is such that only during periods of maxim insolation is there no excess capability of chlorophyll for absorbing red light.

If this is true, this means that actual determinations of leaf area iniex of a forest, by the ratio method, must be done under the sane solar conditions as those vhich exist during calibration, ani that this 16 best accomplished during the noon hours during sumer months, north of the equator. It also means that if Fig. is used for other forests, it mist be assumed that these forests have chloro-

plyll contents adapted to the maximm light levels hich exist at

?their location, probably a safe assumption for mature forests.

Cloudy skies are not suitable for using the ratio method of

determining leaf area index for two reasons. First, the thickness

of the clod cover could change without the observer on the forest

floor being evare of a change in incoming light intensity. Secondly,

Vith relatively more diffuse light entering the forest under cloudy

conditions, there 1s more light scattering, and consequently the

calibration is less reliable.

?A spectroradioneter is not necessary in order to use the ratio

method, Any of many types of light meters can be used in combination

Vith narrow band pass filters for wavelengths of 675 and 800 millinicrons,

The only requirenent is that the meter be caltbrated so that field

readings can be converted into absolute light ehergies,

---Page Break---

Literature Cited

Federer, C.A., and C.B, Tanner. 1966. Spectral

distribution of light in the forest.

Boology 47: 555-560.

Monsi, M., and T. Saeki. 1953. Uber den licht-

?faktor in den pflanzengesellschaften

und seine bedeutung fur die stoffpro-

duktion. Jap. Jour. Bot. 14: 22-52.

Odum, H.T., B,J, Copeland, and R,Z. Brown. 1963.

Direct and optical assay of leaf mass

of the lover montane rain forest of

Puerto Rico. Proceedings of the

National Academy of Sciences 49: ka9-h3h.

---Page Break---

NITROGEN FIXATION BY EPIPHYLLAE AT EL VERDE

J.-A. Hamisten* and M.A, Harrelson?*

Apatract

Acetylene reduction techniques with gas chromatography have

pen used to denonstrate that epiphytic plants on leaves could fix

Rtmospheric nitrogen. ?These experiments confim earlier 1N tests

?ith the sane organisms. Leaves with intact mixed epiphyllae

?tions both on the tree and in flasks have been shown to reduce Bertylene to ethylene. Mixed epiphyllae populations scraped from Jeaves produced more ethylene than scraped leaves. Mixed bacteria

fations from leaves vere shown to reduce acetylene. Three genera bf blue-green algae isolated from leaves were found to have the abi- Sity to fix nitrogen as evidenced by the acetylene reduction teste.

Introduction

Root nodule experinents by Edmisten show that the generally accepted nethods of nitrogen entering the tropical rain forest ecosystem at El Verde vere not sufficient for the existing grovth Sates. Eamisten (1968) suggested that epiphyliae might be contri- buting factors in the nitrogen cycle, Kline and Eanisten (1968), in 15N experiments, reported on a high rate of N-fixation by mixed epiptyliae on Citrus leaves and shoved that some of the fixed 1N tas transferred to leaves. The mixed epiphyllae included bacteria, algee, fungi, lichens, and livervorts.

To explore this idea, the acetylene reduction technique (stewart, 1966) vas used on whole leaves, scraped leaves, and bacte- Hal end blue-green algee cultures isolated from leaves. This tech- nique involves the fact that the same enzyme complex which converts nitrogen to reduced usable forms will also reduce acetylene to etiylene. It was generally expected that certain bacteria and blue-green algae were responsible for the nitrogen fixation.

Seven genera of plants, representing shrubs and trees, were

tested. These are shown in Table 1.

department of Botany, University of Georgia, Athens, Georgia.

Department of Biology, Gardner-Webb College, Boiling Springs, N.C.

---Page Break---

?TABLE 1

ee

Plants from El Verde Forest Used in Acetylene Tests

Genus Growth Habit Miche

Citrus small understory tree escaped

Groton slender canopy tree climax

Dacryodes large spreading canopy tree climax

Euterpe medium palm follows streans

Manitkare large canopy tree climax

Peychotria small understory shrub successional

Sloanea large canopy tree climax

Materials and Methods

?Two basic methods were used in preparing specimens for testing. For testing of whole leaves with epiphyllse on trees, plastic bags were sealed around the leaves at the twig with plastic tape. A piece of plastic tape about two inches long vas used as a reinforcement for hypodermic needle insertion during gas exchange. After completion of gas exchange, a omaller piece of tape was used to seal the needle hole.

After securing the bag in place around the lest, air vas with: aravn by mouth vacuum through a plastic tube and kypolemic needle, The bag vas then filled with a mixture of 226 On, -OUk COp, and 17,95% Argon. The bag vas again evacuated and refilled vith the same mixture to insure the elimination of nitrogen. Acetylene vas aided to account for one-tenth of the volume of the bag. After varied exposure tines, ranging from 1 to 6 days, the leaf in the sealed bag was clipped from the twig and taken to the laboratory for testing with .C. techniques for the presence of ethylene.

For testing organi sns isolated from leaves, and leaves with epiphyllae removed from trees, Erlenmeyer flasks of suitable size were used. Rubber serun stoppers were used to seal the flasks while allowing the replacement of gases through hypodermic needles. Flasks were flushed (an inlet for flushing gases and an outlet for escaping air) by about 10 volumes of the Op, CO and Argon mixture. Acetylene

was added to make up one-tenth of the flask volume.

---Page Break---

For isolating the various organiens suspected of fixing nitrogen, sterile disposable gloves ani sterile scissors vere used to detach and place leaves in sterile flasks. ?The leaves vere taken to the field lab Ghere the isolations were done.

Whole leaves vere placed in Erlenmeyer flasks in media specific for either algae or bacteria. Agitation vas used to free the organisns fron the leaf surface, Transfers were made to suitable media.

Bacteria were grown in Ruinen's Medium (1965) at pli T and pH 1.5.

?Aigee vere grom in gol] extract media for flush growth, then to

yefree media (Rutnen, 1965) for testing.

Fungi vere isolated by cutting strips of leaves 3x20 mi and placing them on Martin's Rose Bengal Mediun, sotl-extract medium, and ¥-8 juice medium. ?Transfers were made to N-free medium for testing.

?The surface of leaves vas scraped to get a mixture of Lchens ani Liverworts. ?These vere tested as fresh materials and not cultured.

After adding acetylene, cultures were tested on a gas chromatograph for conversion of acetylene to ethylene.

Controls were run on the gas chromatograph with pure acetylene, pure ethylene, air and the flushing gas mixture.

?The total mmber of cultures prepared for testing by gas chromatography were as follow

Whole leaves on trees...

Whole leaves in flasks ....

Whole leaves in flasks, scraped clean

Epiphyllae in Flasks, from scraped

leaves 5

Bacterial cultures ..

?Algal cultures

Fungal cultures

Results and Discussion

Positive results vere obtained for epiphyllee as follows:

1. bacteria grom in culture, 2. blue-green algae grown in culture,

31 vnole leaves with epiptyliae intact, 4. epiphyllae scraped from

leaves.

me bacteria tested for figure 1 vere isolated from the older leaves of an understory paln Euterpe globosa. ?The presence of these

and other nitrogen fixing bacteria on leaves has been reported by

-133-

---Page Break---

Pylten (1965) when Bet Jerinckia, Azotobacter and Hhizobiun were aata

to have increased total nitrogen in, on, and around leaves of bean

and coffee grown in culture.

Figure 2 shows a very efficient conversion of acetylene by epi-

Hiyliae on old Citrus leaves ina flask. Citrus leaves with epiptylise

xemoved (figure 3) show less converaion of acetylene than those im

Stgure 2. The epiphyllae scraped from the leaves in figure 3 show

00d conversion of acetylene to ethylene (figure 4)

A comparison of figures 2, 3, and 1ed us to believe that most,

Of the organions vith nitrogen fixing ability are found in or on the

Visible epiphyliae which consist mainly of livervorts and lichens,

of livervorts and lichens taken fron leaves

Microscopic exanination

have shown that blue-green algae are often enbedded in both these

organisms. One of the spectes of Nostoc used in later acetylene teste

of pure cultures was isolated fron livervorts. Although the usual algal partner of an epiphyllous lichen is a green alga, blue-greens are often found also in tunor-like growths called cephalodia. ?The fact that the leaf scraped clean of visible epiphyllae still shoved ability to reduce acetylene (figure 3) may be explained by the fact that Azoto. dacter could be isolated from it,

Figure 5 shows good conversion of acetylene by older Mantlkara Jeaves vith epiptyllse ina flask, while figure 6 shows very high gonversion to ethylene by epiphyllae scraped from older Mant kara leaves like those in figure 5.

The data shown in figures 5 and 6 reconfirm the concept established in the experiment shown by figures 2, 3 and h and indicate that the nitrogen fixing ability of epiphyliae is not host specific. ?The sane species of lichens and liverworts have been identified fron a wide variety of leaves from Feru, Panama, and Colombia as vell as Puerto Rico,

Plastic bags on trees (figures 7 and 8) shoved redue-
tion of acetylene to ettylene as determined in earlier 23M expectaena by Binisten and Kline (1968). The acetylene reduction teste represented by figures 7 and 8 were performed on leaves of the sane grasereeit tee that was used in the prelininary 15% test as well as on Scenes teas climax species, Mantikara. In the Hi test, it vas found thet eoiakel= jag Seraped from leaves, ad 104 of thetr total n{trogen as 15M veLsh had been taken up fron }np during the 48 hour exposure period end incorporated into organte form. Host Citrus leaves from which enipkyl=

lace had been scraped and washed had If of their total nitresen or eke

stable isotope 15", When considered together, these experiments indicate

that epiphyllae have the ability to fix atmossherie nitrosen ena that

some of the fixed nitrogen is transferred to the host leaf within a 48.

hour period.

Since blue-green algae have long been known to fix atmospheric

nitrcgen, it was not surprising to find 4 genera on leaves that shoved

conversion of acetylene to ethylene. Figures 9 and 10 show the actual

Leaves in

---Page Break---

ane Patt

Fig. 7. Scale drawing of gas chrosatograph tracings

to show conversion of acetylene to ethylene by

a Citrus leaf ina plastic bag on the tree,

besa a

ao Pe Het

actin 0 to Pomme

Fig. 8. Scale draving of gas chromatograph tracings

?to show conversion of acetylene to ethylene

by a Yanilkara leaf in a plastic bag on tree.

---Page Break---

ee we

Fig. 9. Gas chromatograph tracings to show conversion

OF acetylene to ethylene by blue-green algae.

Fig. 10. Gas chromatograph tracings to sho convertion

of acetylene to ethylene by blue-green algae.

---Page Break---

tracings of the gas chromatograph for the four blue-green algae Nostoc, Scytonena, Anabaena snd Calothrix fron leaves at El Verde. The blue-green algae used in the tests illustrated by figures

9 and 10 were isolated from Citrus leaves taken from the El Verde forest and vere grown in Chu's nitrogen-free media. ?They were transferred with sterile technique four times before being tested for the ability to fix nitrogen in order to help assure their being

in pare culture.

Conclusions and Implications

Mixed populations of leaf epiphytes have been shown by two separate methods to have the ability to fix atmospheric nitrogen. The principal organians thought to be responsible for the fixation have been shown to be various blue-green algae and free-living aerobic bacteria which live in and on leaf lichens and livervorts as well as on the bare leaf during early stages of successional coverage of a nev leat.

Although this study vas not designed to be quantitative but rather qualitative, preliminary calculations based on the areas below the ethylene and acetylene peaks of figures 1 through 10 indicate that the rates of nitrogen fixation would range between .05 Kg/acre/day to +15 Ke/acre/day.

?The biomass of epiphyllae in tropical rain forests has not been established, but the presence of heavy populations of epiphyllae has been noted on leaves of all symusia of the El Verde forest except the exposed leaves of the upper canopy. When one realizes that there are Detween 5 and 15 acres of leaves over each acre of ground in El Vere, ?the potential nitrogen input by epiphyllae becomes an important factor to be considered in the nitrogen budget of any moist tropical forest.

The results of these experiments suggest a new way of adding nitrogen fertilizers to crop plants. It would appear feasible to isolate and grow blue-green algae and bacteria from leaves and select the ones with high ability to live on leaves and fix atmospheric nitrogen. Such knovn "fixers" could be sprayed on crops such as Citrus, pineapple or sugar cane in irrigation water with certain chemicals aided to facilitate the adhesion of micro-organisns to leaves.

If man could effectively copy this synbiosis on his crop plants,

the nitrogen fixed would become available to the crop plants directly through the leaves and from leachate in rain and irrigation water.

Finally, this experiment has denonstrated that the quick, inexpensive acetylene reduction test for the ability to fix nitrogen is a

feliable tool as shown by the independent 1°N experiment. Tue acetylene

-1ho=

---Page Break---

reduction test was also performed

rformed on vell-nodulated, henoglobin-

containing root masses fron six species of legumes fron El Verde

with strongly positive results. The six vere Inga vera, Inga lau-

zing, Andira inemis, Neorudalphia volubilis, Omosia krugii ant a

Successional species of Desmodium

A series of acetylene reduction tests should be perfomed to

quantitatively establish the rates and extent of all nitrogen fixation

in the El Verde forest ana thus establish a nitrogen budget for a

tropical rain forest. Puerto Rico Nuclear Center should support

studies in which various nitrogen fixing epiphylle are grom on

citrus, pineapple and sugar cane with their crop yields and nitrogen

contents compared to untreated control crops.

References

Bimisten, Joe A., and Jerry R. Kline. 1968. Nitrogen fixation by epiphyliae in: The Rain Forest Project Annual Report. Puerto Rico Nuclear Center, University of Puerto Rico.

Ruinen, Jakcba. 1965. The Phyllosphere TIT, Nitrogen fixation in the phyllosphere. Plant and Soil MUI, No. 3, p. 375-393.

Stewart, W.D.P., G.P, Fitzgerald, and R.. Burris. 1967. In Situ studies on Np fixation using the acetylene reduction technique. Proceedings of the National Acadeny of Science, Oct. 1967, pp.

2071-2078.

a1

---Page Break---

?TTERMETES AT EL VERDE: 1968 RECHBCK

Elizabeth A. McMahan

University of North Carolina

Chapel Hill, North Carolina

P. Murphy and R. Wiegert made preliminary surveys of Nasutitemes costalis nests at 1 Verde, beginning in 1965, and Wiegert's subsequent studies have been concerned mainly vith their metabolism. Me-Mahan continued and expanded the curvey stuies, making a complete census of nest condition and tunnel occupancy during the sumers of 196, 1967, and 1968, The chief aim of the studies vas to examine the effects of the 92-day (Spring 1965) exposure of a gamma source (13%Cs) in the Radiation Center.

Methods

costalis nests vithin 8 m of point zero in the Radiation Center and in the South Contro Center has been mapped originally by Wiegert, with later additions by McMahan. At each survey period the areas vere scoured for new nests, and each old nest was examined to see if it was still active.

A tunnel survey was also made each sumer. Every tree (dead or alive) of one-inch dianeter or greater within 30 m of point zero in the Radiation, South Control, and North Cut Centers was carefully examined for evidence of termite tunnels. If a tunnel vas found it was checked for occupancy and by which species (Usually N. costalis or Parviternes discolor; once Glyptotemes was found inside a stub on vhich vere P. discolor tune:

Results

Nests

In the summer of 1966 there were 11 active Nasutitermes nests in the Radiation Center, 11 in the S. Control Center, and an undetermined number in the N. Cut Center (none within 30 m of point zero in the latter).

By duly 1967 five of the Radiation Center nests haa been abandonea (14,15,19,20,21), while only one (7) was newly empty in the 8. Control Center. That year a new nest (26) was found at about 26 m from point zero in the Control Center.

At the 1968 survey (July 9-21) nest 18 in the Radiation Center

had been abandoned and nest 12 was barely active - only two soldiers were ever seen to emerge to investigate disturbance of the nest surface.

---Page Break---

But two more nests were found to be abandoned aloo in the 8. Control Center: Nests 2 and 9. Anew nest (27) vas found in the witation Center, only about 8 m NNE (behind the big Cyrilla tree) from point zero. Figure 1 shows the position and states of nests in the two centers in July 1968,

?Nnnels

?The 1966 and 1967 studies had shown that about 106 of the trees in the Centers had tunnels or tunnel fregnent on them. This was also true for 1968. Table 1 gives the percentages of tunnél ocoupancy for the three years. Tt shovs that in 1966 the percentage of occupied tunnels in the Radiation Center was much less than that for the tvo

se Costes Tani int te] parcennes| acta Saceeseel
1967.

?The 1968 survey shoved for the first time that reinvasion of Radiation Center by termites had begun. The new Nasutitemed nest in this center has already been mentioned, and the occupied tunnels were probably, in large part, fron this nest. While the percentage of occupancy was till not as great as in the Control Centers, the proba-Dility seems good that ty 1969 it will more nearly equal them.

TABLE 1

ee

Percentage of Tunnel Occupancy for the Three Centers

ee

Radiation 8. Control A, Cut

Year Center Center Center

xs 12 51. 38

Ber 8 hs ty

1968 23.6 ?AT 42.6

---Page Break---

Discussion

Taree years after removal of the ganna source from the Radiation Genter, effects of the irradiation in terms of nest abandonment by Nasutitermes costalis seem to be still appearing. Twice as many nests in this center as in the Control Center vere abandoned in 1968. The Unusual amount of nest abandonment may be attributable to sterilization of reproductives and the consequent lack of normal colony growth which would offset natural attrition.

It seens surprising that three years vere required for evidence of refaunation of the irradiated area, and this evidence of reinvasion vas contributed solely by N. costalis, Nasutitemes-occupied tunnels are naturally more nunerous tn the vicinity of nests (Parvitermes dis-golor constructs no discrete nests), and the new nest in the Radiation Genter probably explains the increase. The lack of increase in P discolor occupancy of tunnels to more nearly approxinate the Parvitermes densities of the Control Centers may reflect the slowness of termite refaunation of an irradiated area,

---Page Break---