DESIGN and POWER
of
VEGETATION MONITORING STUDIES
for
THE RIPARIAN ZONE NEAR THE COLORADO RIVER
in
THE GRAND CANYON

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MY PLAN versus REALITY
continued

- I agreed to give a management-oriented version of a technical talk I gave at GCMRC in December.
  - ➔ Interrupting my vacation!
- That talk was about 85% done when late Tuesday night I received a message from Dennis Kubly encouraging me to address a VERY different set of questions.
- NOW: Briefly respond to several of Dennis' questions, then give most of the talk I planned.

QUESTIONS DENNIS ASKED
(Abbreviated versions)

(1) Compare roles of scientists and managers in adaptive management programs?

(2) Prioritizing monitoring and research: compromises resulting from declining budget & conflicting views

(3) Evaluating utility of gathered information what are the measures of worth to managers of information gathered, analyzed, and interpreted by scientists?

(4) Does some information have higher value than other info?

(5) Tradeoffs between sampling designs that allow extrapolation to the entire Grand Canyon and those that do not? When is each most appropriate?

(6) Risk assessment: Potential effects of reduced sampling intensity and consequent lower levels of detection of resource change that are necessitated by funding or logistical limitations?

(7) When should we worry about Type II errors more than Type I errors? How do they differ?

MONITORING IS NOT RESEARCH

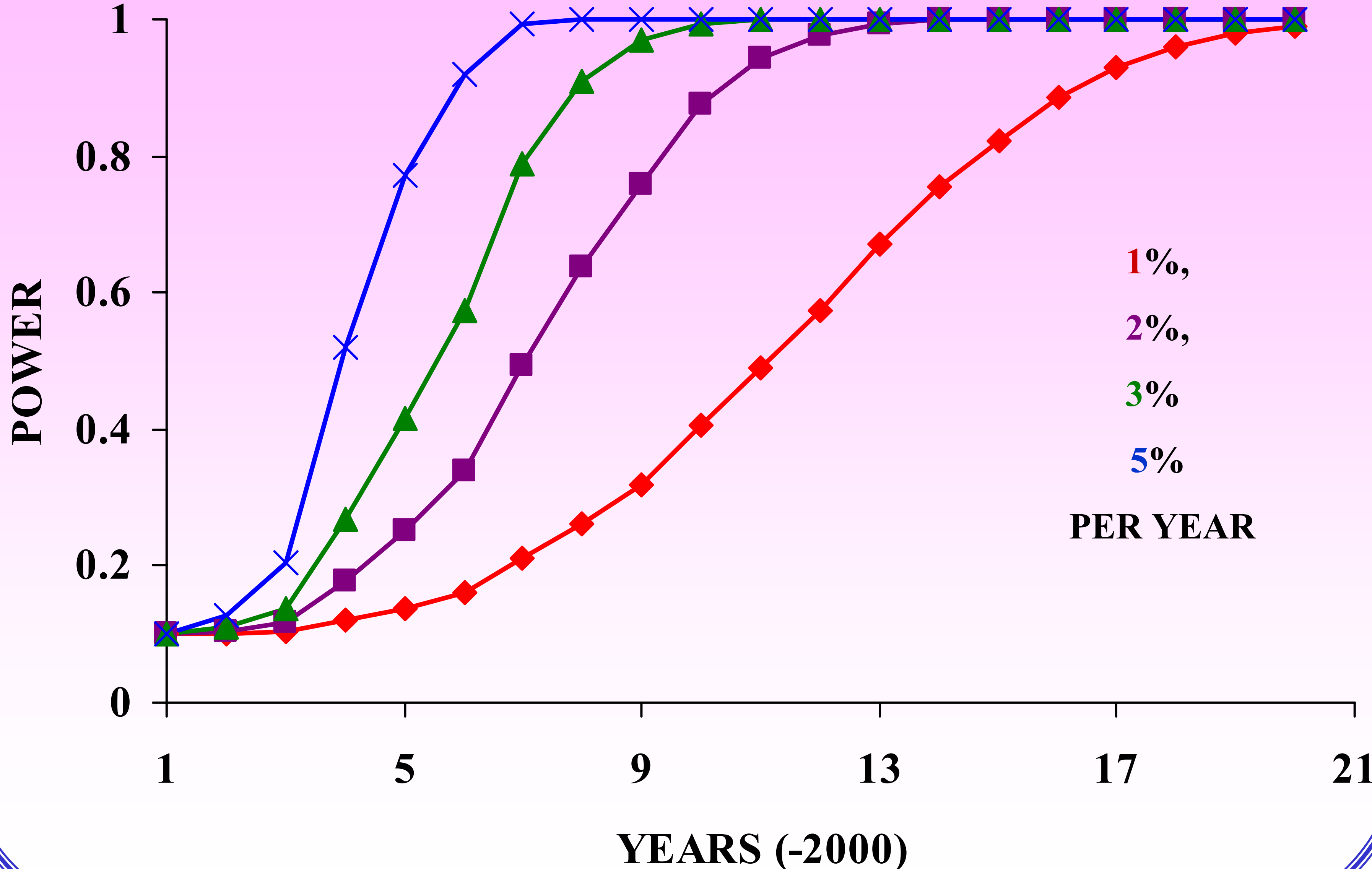
impacts on answers to questions 1 – 4

- **Research concerns how & why things happen.**
  - ➔ **May need to be temporally intensive**
- **Monitoring concerns "What has happened?"**
  - ➔ **Major differences: measures & temporal intensity**
    - ***EX: Mike Kearsley's vegetation index versus detailed stem counts***
- **Adaptive management may require some of both**
  - ➔ **But managers need to look critically at the need for research.**
    - ***Specifically: Its linkage to manageable actions***

QUESTION 5: What are the tradeoffs between sampling designs that allow extrapolation to the entire Grand Canyon and those that do not? When is each most appropriate?

- **When you need to make a statement about an entire area, sample it.**
  - **Biological investigators know far less about where various resources reside than they think they do. All kinds of things turn up where they "aren't suppose to be."**
- **Model development: Targeted site selection is appropriate – even necessary**
  - **Pick gradient of sites which will support estimation of model components.**

POWER TO DETECT TREND IN VEGETATION COVER, ZONE = 15, VARYING % TREND



TODAY'S PATH

- Bit of historical background
- Distribution of sample sites along river
- Inquiry about your stat backgrounds
- Variation and its structure
- Power
  - Responses
  - Zone
- Responses to some questions asked during oral presentation

- How the sample sites were selected
- How the power was calculated

Available Info – Probably not for today

REPORT
from
THE PEER REVIEW PANEL
on

THE TERRESTRIAL COMPONENT

of the
BIOLOGICAL RESOURCES PROGRAM

of
THE GRAND CANYON MONITORING
and
RESEARCH CENTER

THE "BEGINNING" – MARCH, 2000

THE PANEL

PLANT AND ANIMAL INVENTORY
LONG-TERM MONITORING

- **DEFINE THE DOMAIN WHICH BOTH ARE TO COVER**
  - → **PANEL STRONGLY RECOMMENDS THE ENTIRE MAIN-STEM CORRIDOR + RELEVANT SIDE CANYONS**
- **CONDUCT A PROBABILITY SAMPLE OF THAT DOMAIN. PROBABILITY OF POINTS CAN BE VARIED IN MANY PRACTICAL WAYS.**
- **CONDUCT INVENTORY AT THOSE POINTS;**
  - → **PERHAPS SPREAD OUT OVER FOUR YEARS**
    - ***PERHAPS FOUR TIMES WITHIN EACH YEAR***
    - ***COVERING THE ENTIRE CORRIDOR EACH YEAR***

RESULT OF REVIEW PANEL'S SUGGESTIONS

- GCMRC advertised for someone to to conduct vegetation monitoring studies along the lines suggested by the panel.
- Mike Kearsley (NAU) bid on that RFP, and got it.
  - Bid included UNM + HYC
- Mike asked me to help determine and lay out transects running up from the river to the 60 k cfs level.
- Transects laid out June/July, 2001.

A QUESTION

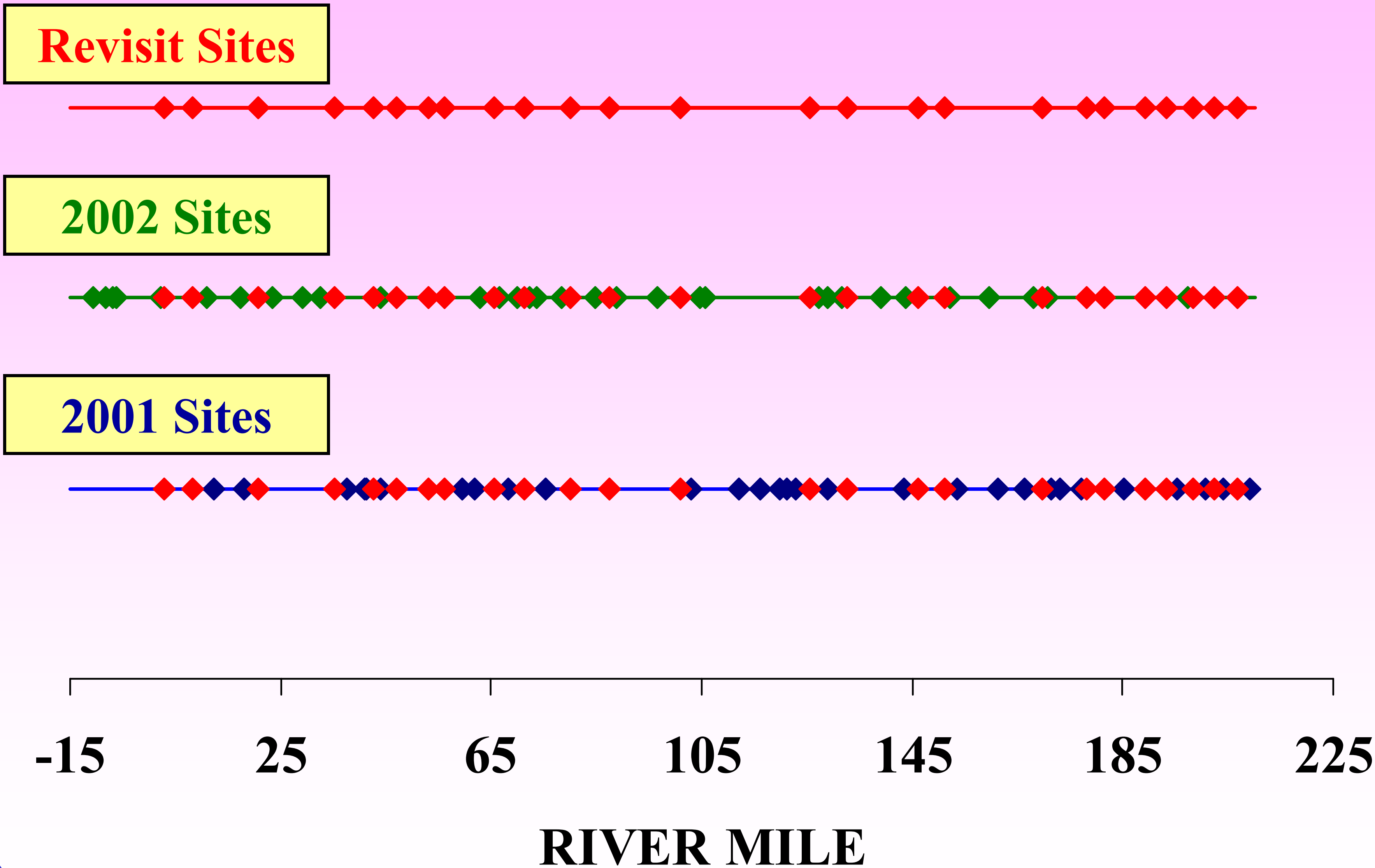
- **QUESTION: "What information did the Peer Review Panel have access to?**
- **RESPONSE:**
  - ➔ **The Panel received about 15 documents, including:**
    - Background information on the process for coordinating and communicating the Adaptive Management Working Group's information needs, along with list of management objectives (MOs) and information needs (INs). 1998. 17 pp.
    - Melis, T., M. Liszewski, B. Gold, L. Stevens, F.M. Gonzales, R. Lambert, L.D. Garrett, W. Vernieu, and B. Ralston. (undated). Draft prospectus for evaluating GCMRC monitoring protocols for the Colorado River ecosystem.
    - Webb, R.H., D.L. Wegner, E.D. Andrews, R.A. Valdez, and D.T. Patten. 1999. Downstream effects of Glen Canyon Dam on the Colorado River in Grand Canyon: A review. In "The controlled flood in Grand Canyon," R.H. Webb, et al., eds. Geophysical Monograph 110, American Geophysical Union, pp. 1-21.

VIEW DOWN TRANSECT AT MILE 12.3

ELEVATION CONTROL POINT FOR TRANSECT AT MILE 12.3


CLIFF AT MILE
135.2
(PARTIAL HEIGHT)

LOCATION OF SITES BY RIVER MILE



“QUICK QUIZ”

- How many of you have taken a statistics course?
  - ➔ HANDS UP!
- Within the last five years?
- Took more stat than was required?
- Remember hearing the word *variance* ?
- Remember how to compute a variance?

WHAT WAS VARIANCE?

- **It was something you could compute that characterized how spread out a set of data was.**
  - ➔ **A small variance meant data was rather compressed, but**
  - ➔ **A large variance mean the data was spread out**
  - ➔ **Next slide illustrates this idea**
- **Detail: variance = (standard deviation)^2**
  - ➔ **σ^2 - unknown value**
  - ➔ **s^2 - its estimate**

MEANS AND STANDARD DEVIATIONS

- **How do means and standard deviations characterize data?**
  - **The range:**
    - ***mean – standard deviation to mean + standard deviation usually contains 60% to 70% of data values (67% for normally distributed data)***
      - **even for very non-normal data**
    - ***Multiply the standard deviation by above 2, and the coverage values increase to 90 to 99% (95% for normal data)***

MEANS AND STANDARD DEVIATIONS

- **Lets use vegetation index to illustrate this**
  - **At 25 kcfs, it has**
    - ***a mean of about 30 ($\mu = 30$)***
    - ***a standard deviation of about 11 ($\sigma = 11$)***
    - ***Illustration is very nonnormal* (*for purposes of illustration only*)**
  - **Second illustration has same mean, smaller standard deviation:**
    - ***$\mu = 30$ and $\sigma = 5.5$***

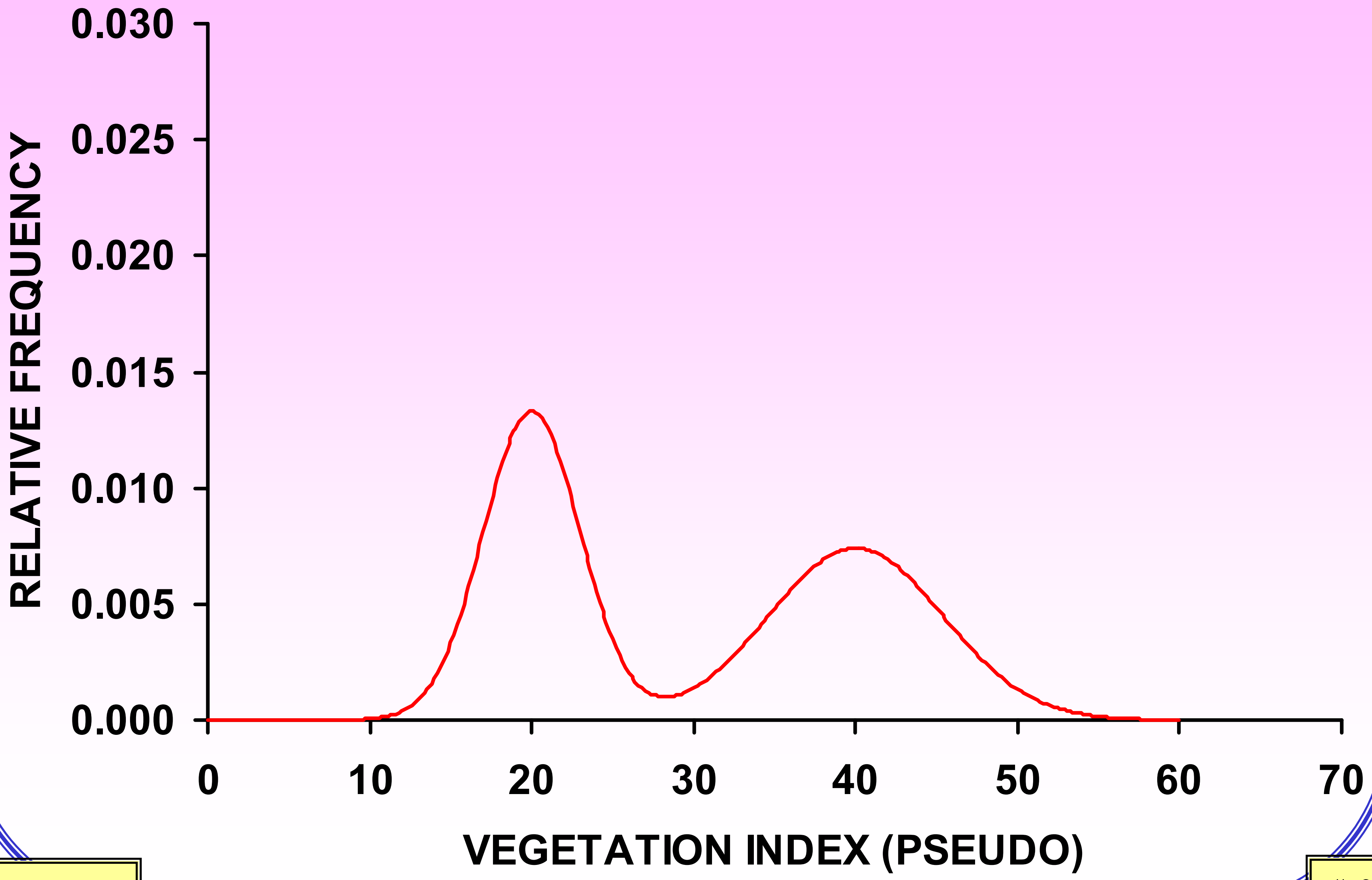

0.030
0.025
0.020
0.015
0.010
0.005
0.000
RELATIVE FREQUENCY
0
10
20
30
40
50
60
70
VEGETATION INDEX (PSEUDO)

ILLUSTRATION $\mu = 30$ & $\sigma = 11$

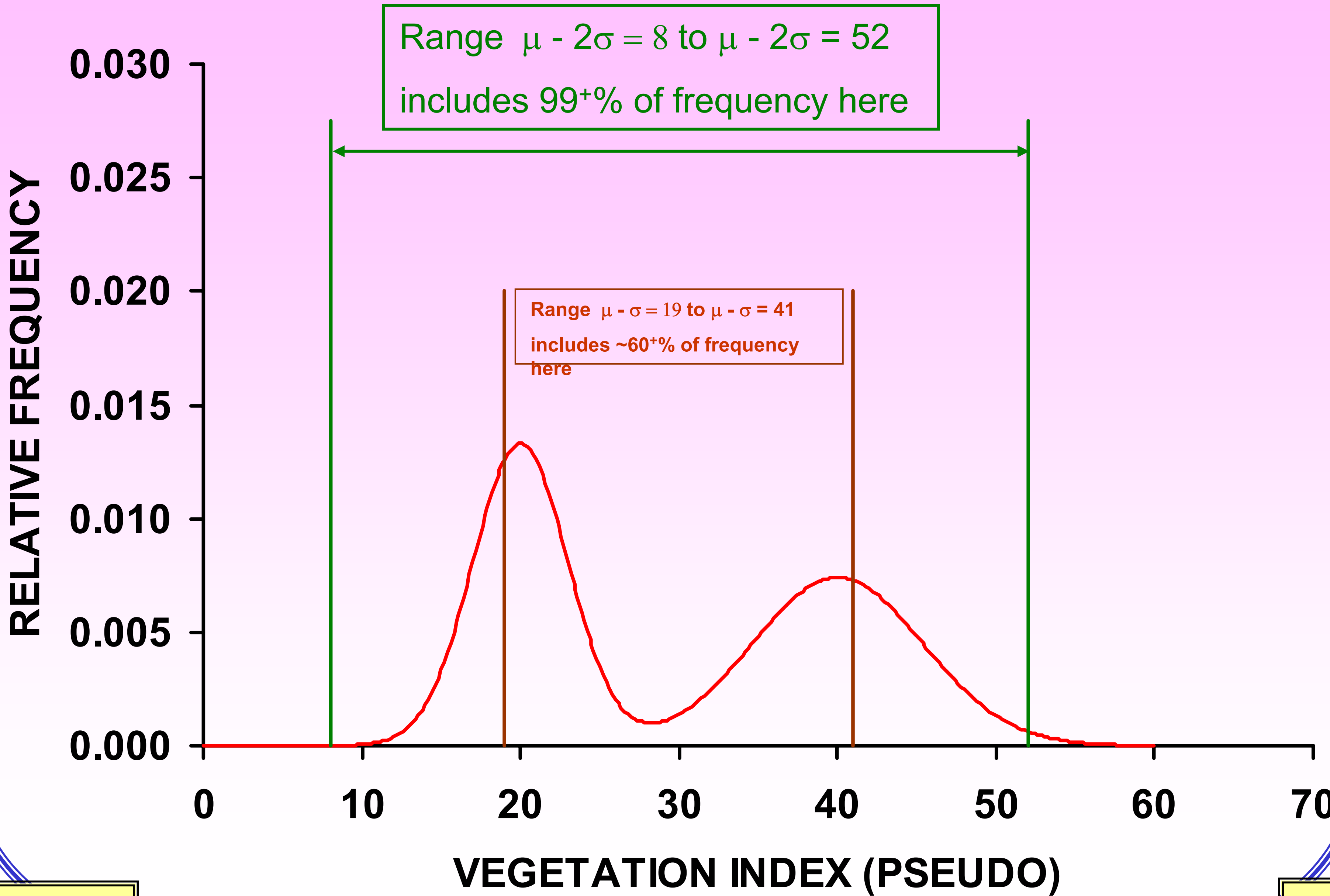


ILLUSTRATION $\mu = 30$ & $\sigma = 5.5$

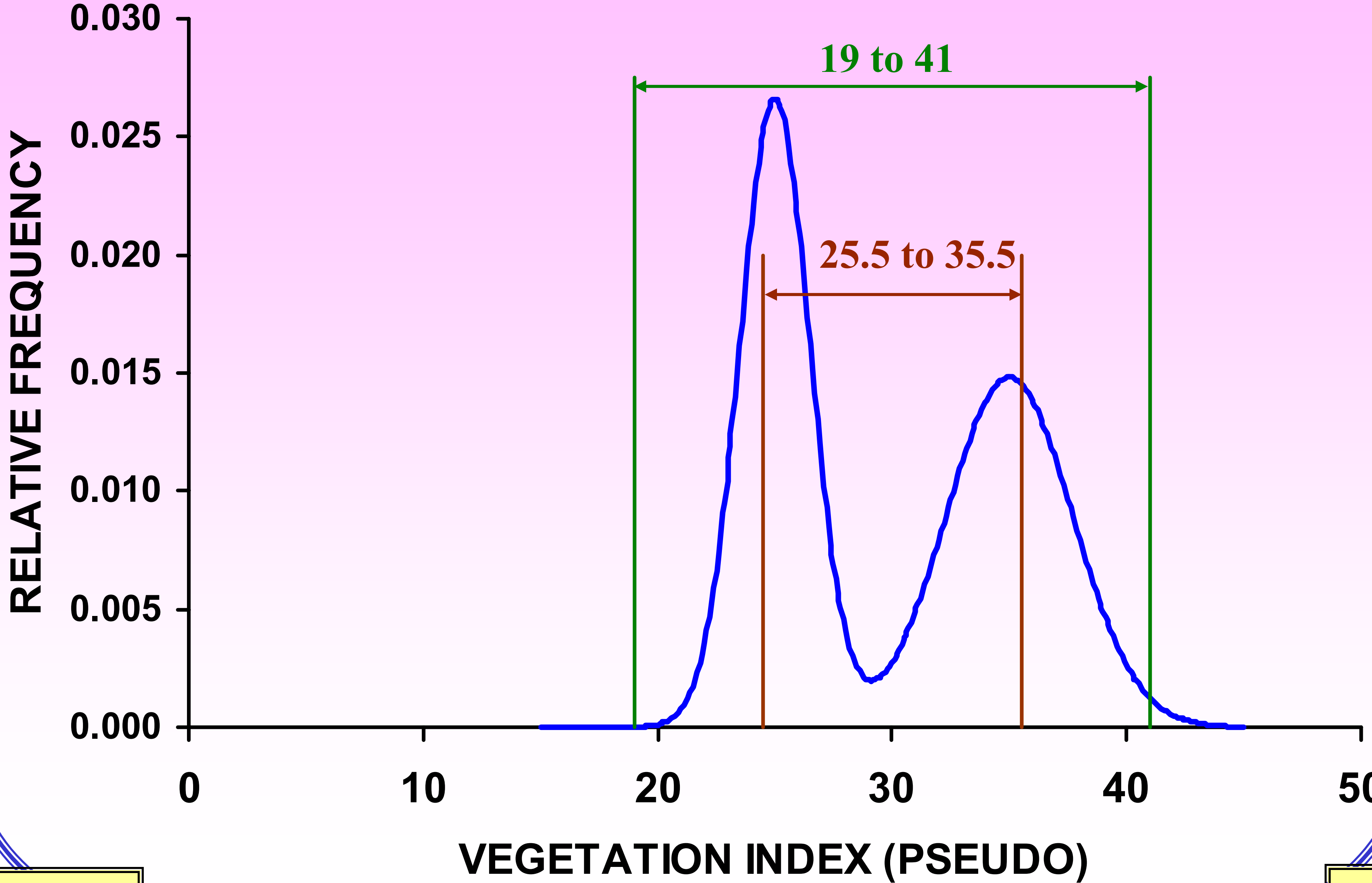
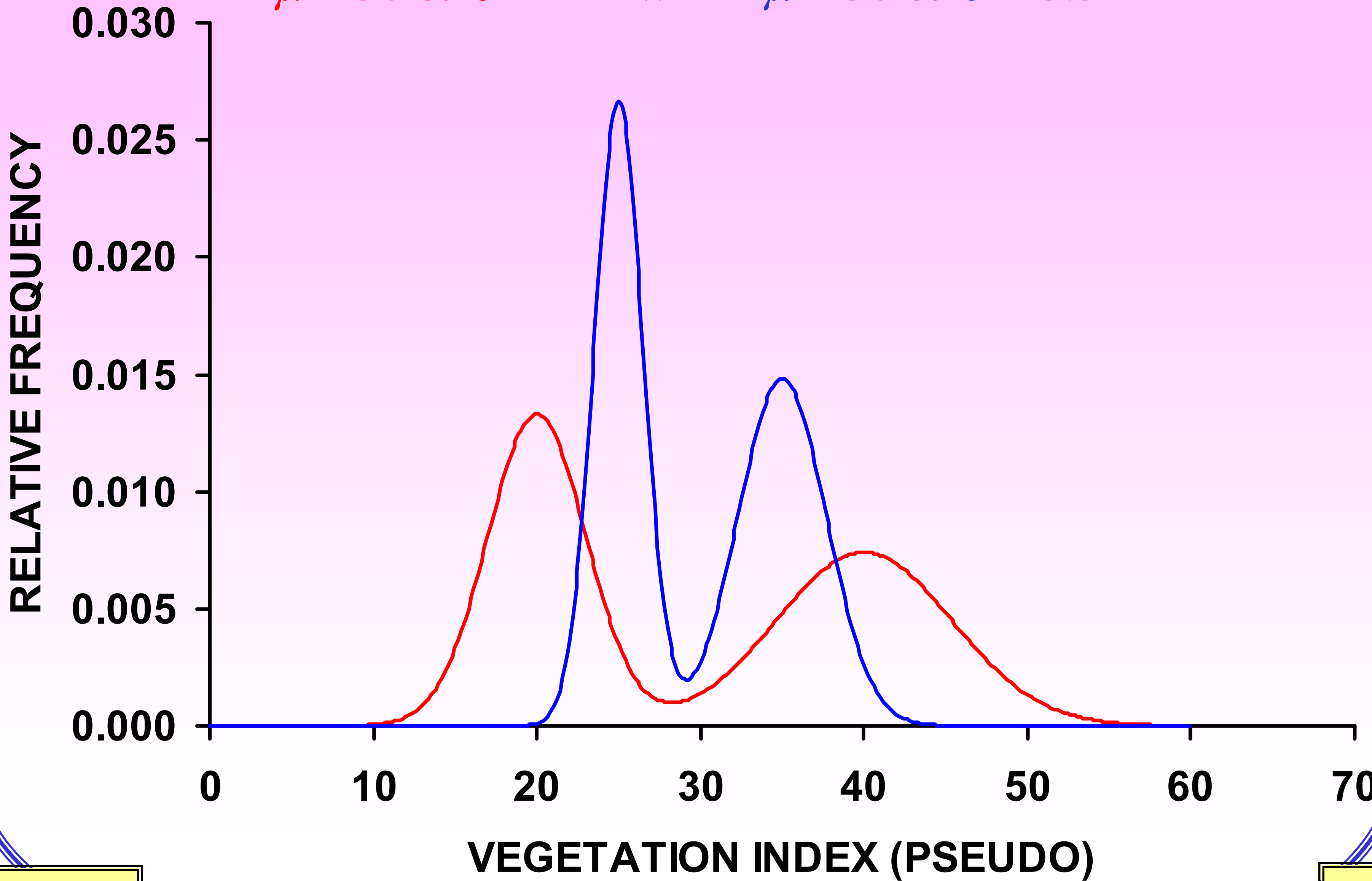


ILLUSTRATION - COMPARISON

$\mu = 30$ & $\sigma = 11$ with $\mu = 30$ & $\sigma = 5.5$



RESPONSE SIZE AND VARIATION

- **Data 2001 & 2002, including revisit sites**
  - *Vegetation cover*
  - *Richness of vegetation species*
  - *Diversity index (H')*
- **Analysis model**
  - *Width (fixed)*
  - *Year (random)*
  - *Station = river mile (random)*
  - *Residual = Year by Station interaction/remainder*

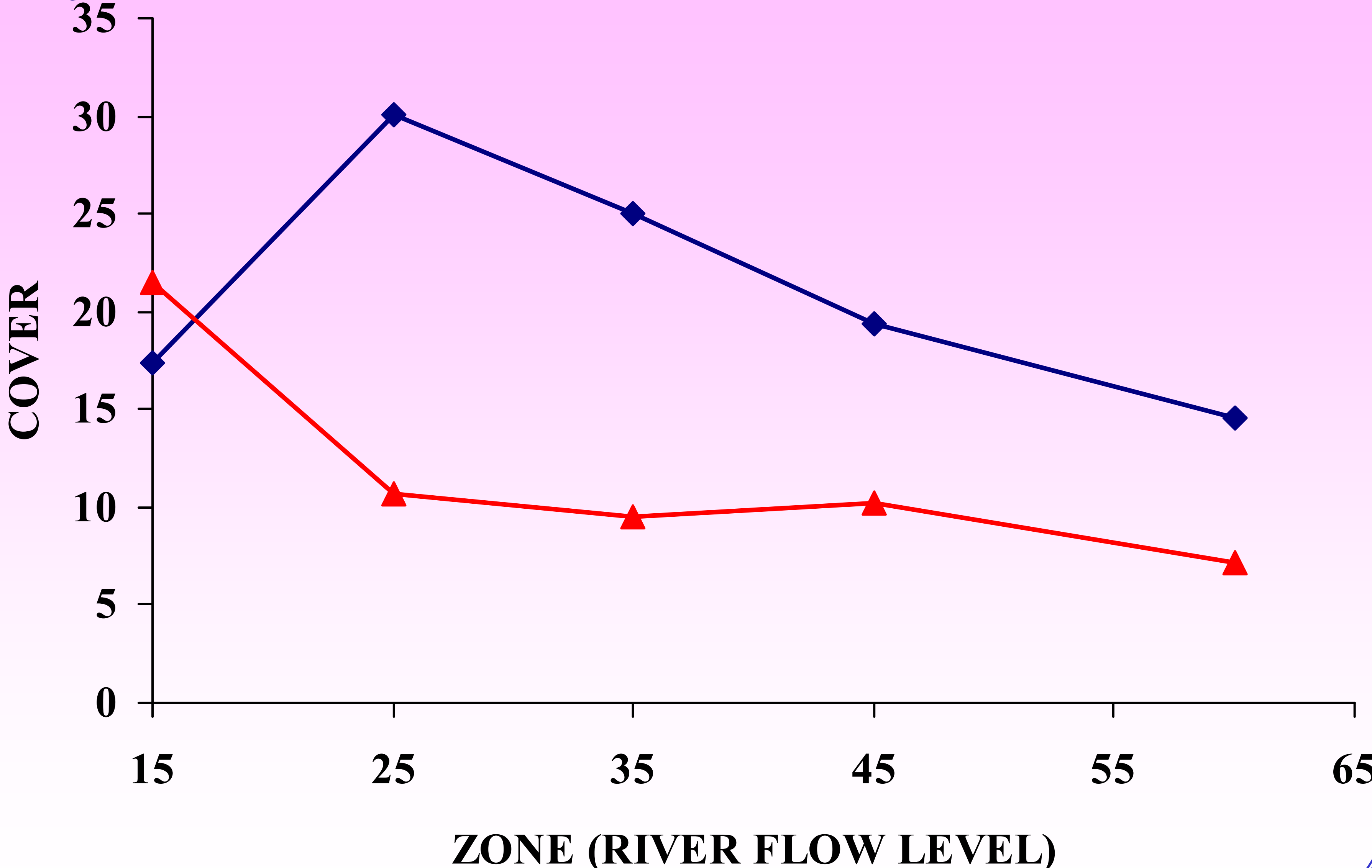
A QUESTION

- **Data 2001 & 2002, including revisit sites**
  - ***Vegetation cover***
  - ***Richness of vegetation species***
  - ***Diversity index (H')***
- **QUESTION: "How were all of the questions of interest to TWG represented in these three variables?"**

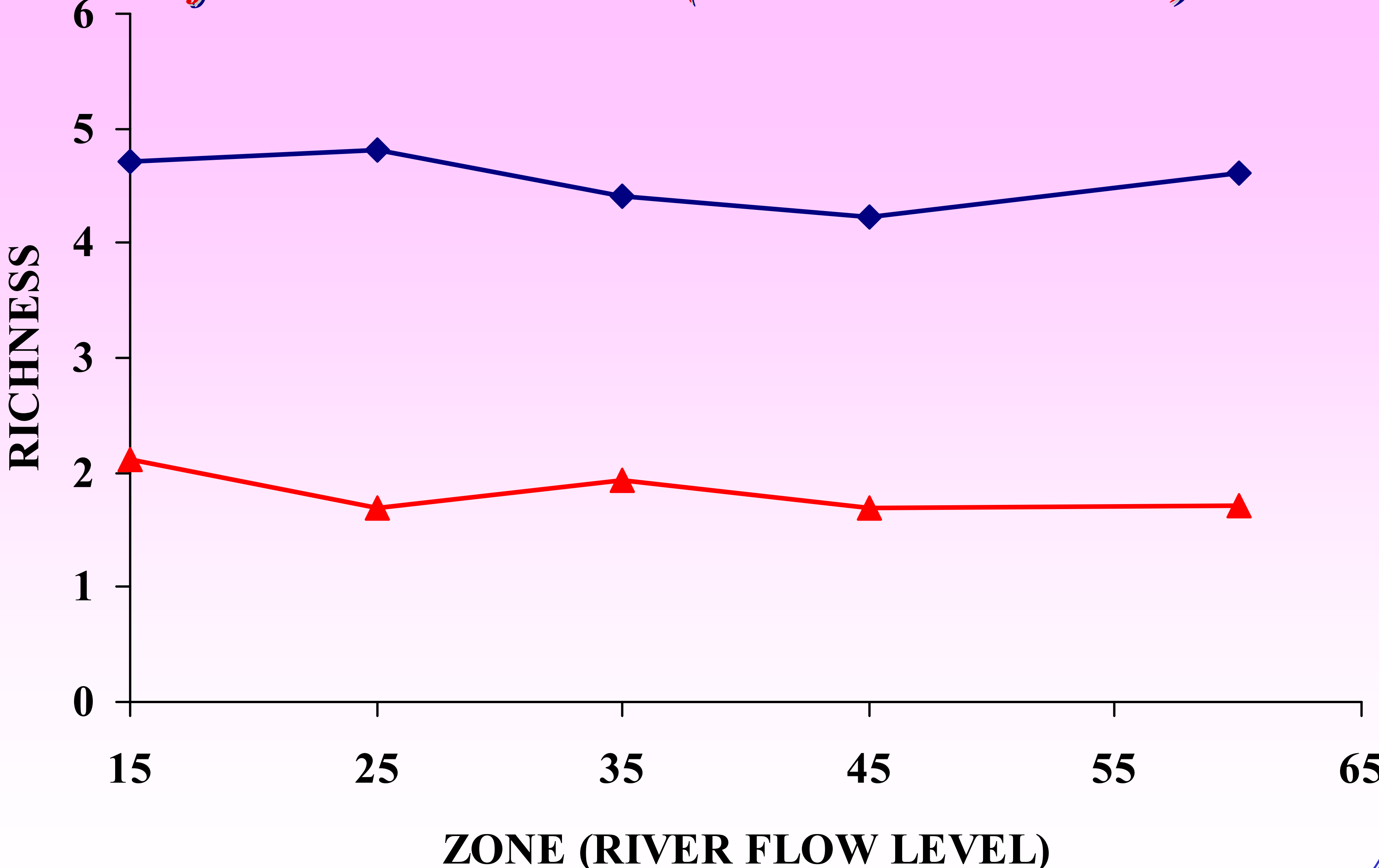
➔ **ANSWER: They weren't. These were available for analysis. Many other variables were evaluated:**

  - ***Insects***
  - ***Birds***
  - ***Reptiles***

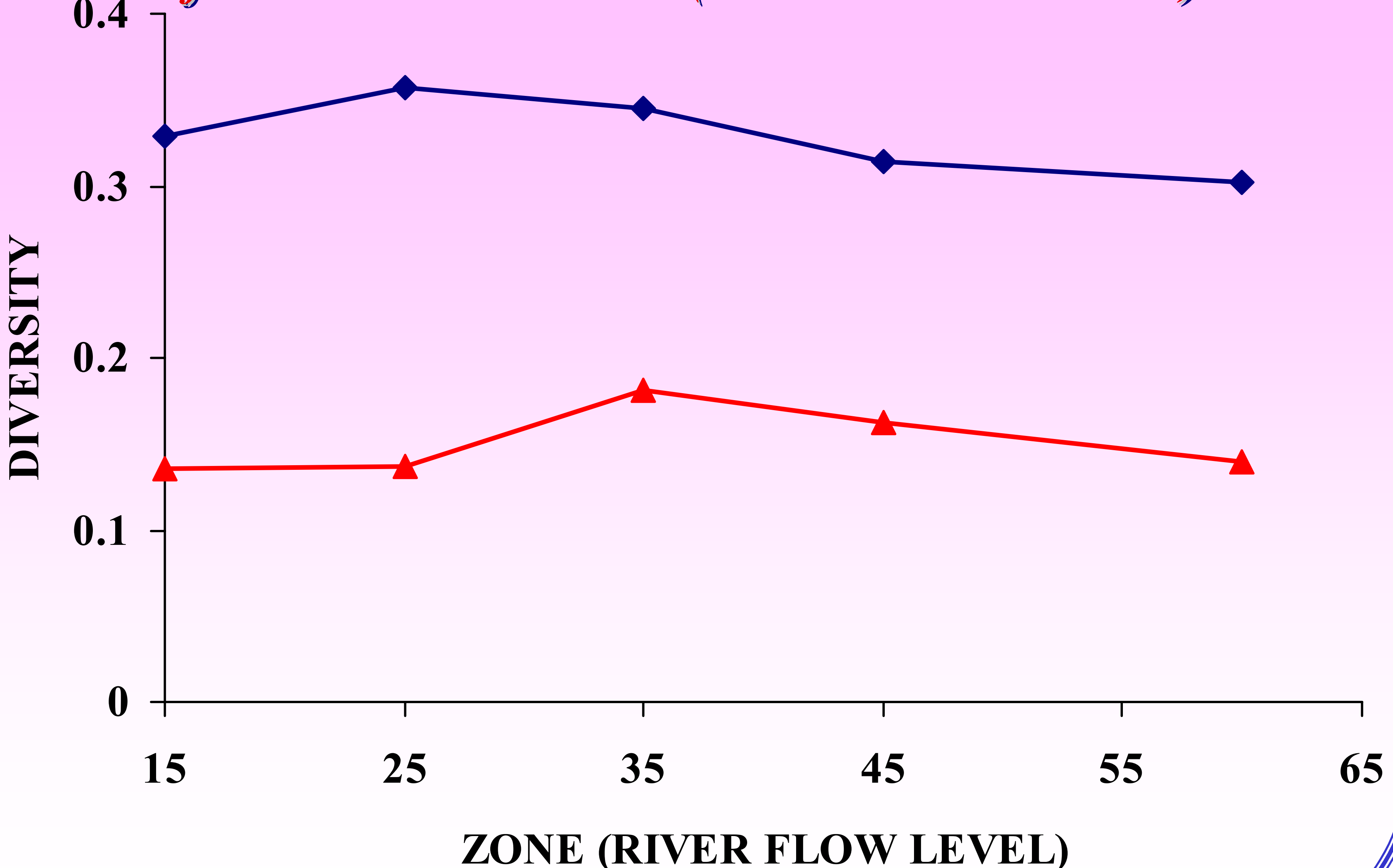
MEAN and STANDARD DEVIATION of VEGETATION COVER vs ZONE (RIVER FLOW LEVEL)



MEAN and STANDARD DEVIATION of RICHNESS vs ZONE (RIVER FLOW LEVEL)



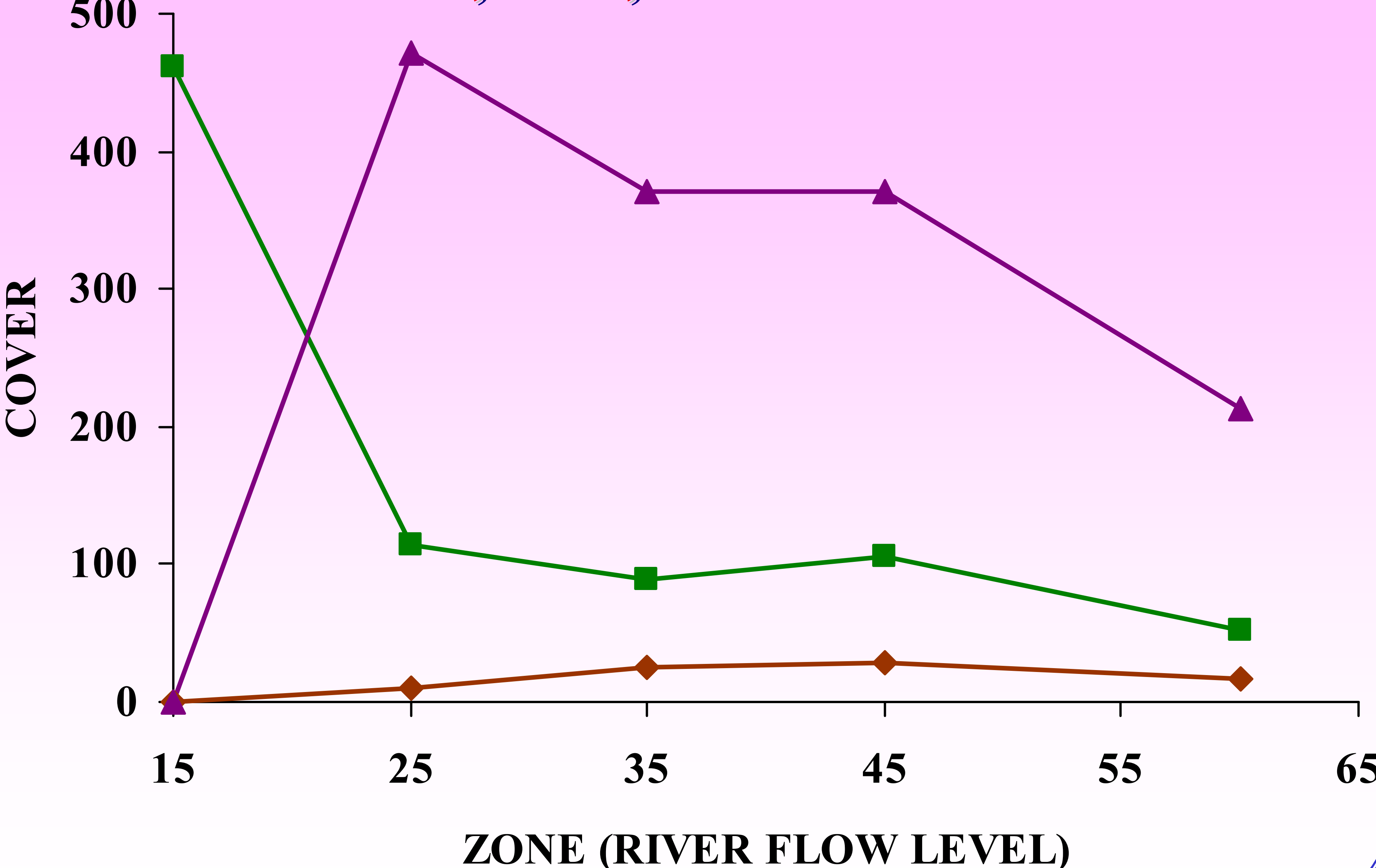
MEAN and STANDARD DEVIATION of DIVERSITY vs ZONE (RIVER FLOW LEVEL)



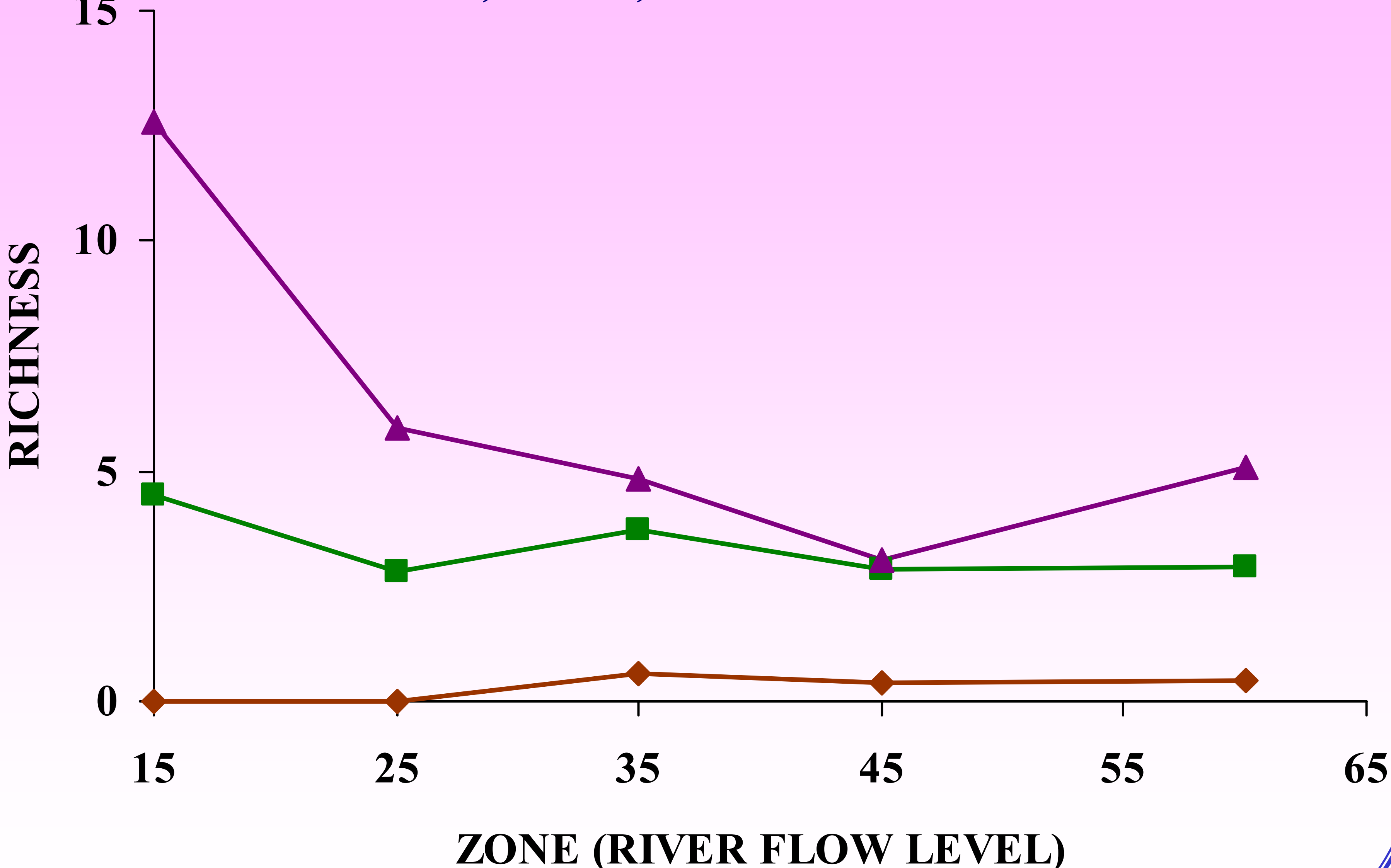
STRUCTURE OF VARIANCE

- **The common formulas for estimating (computing) variance assume UNCORRELATED data.**
- **Reality: This rarely is true.**
  - ➔ **Examples -**
    - ***Data from the same SITE, but different years are correlated***
    - ***Data from the same YEAR, but different years are correlated***
  - ➔ **Total variance = var(site) + var(year) + var(residual)**
- **Subsequent figures show this**

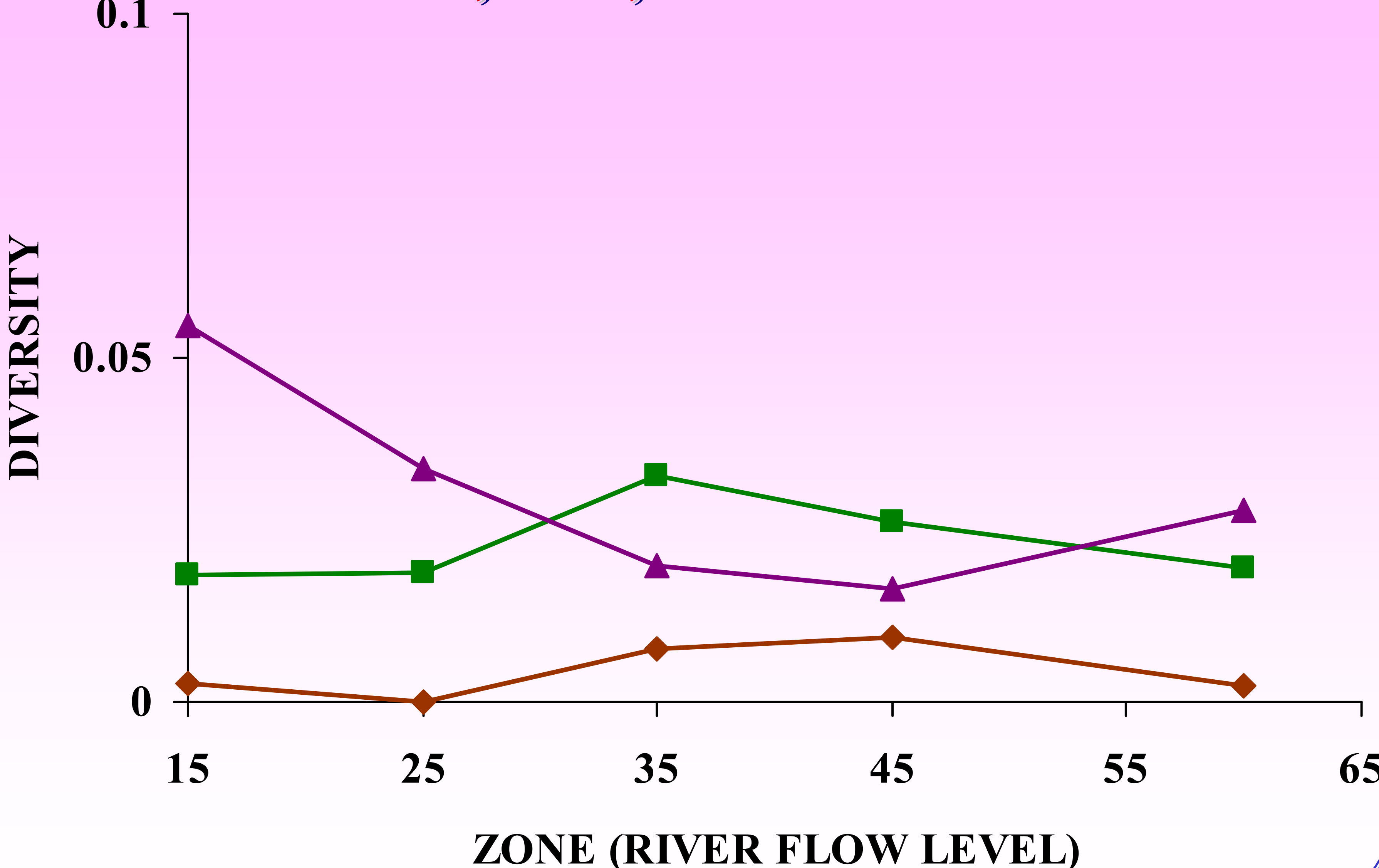
COMPONENTS of VARIANCE of VEGETATION COVER
SITE, YEAR, and RESIDUAL



COMPONENTS of VARIANCE of RICHNESS
SITE, YEAR, and RESIDUAL



COMPONENTS of VARIANCE of DIVERSITY
SITE, YEAR, and RESIDUAL



POWER IS? – to a STATISTICIAN

- **Variation causes uncertainty in making decisions.**
  - **Statistical tests usually are described as**
    - ***Significant (there is a "difference"), or***
    - ***Not significant (there is no difference)***
  - **POWER describes the likelihood of finding significance when an effect really is there.**
    - ***POWER = Prob(correct decision)***
  - **Depends on many things**
    - ***Amount of relevant data ("n")***
    - ***The size of the effect of interest***
    - ***Amount of variance & its structure***

POWER FOR TREND DETECTION

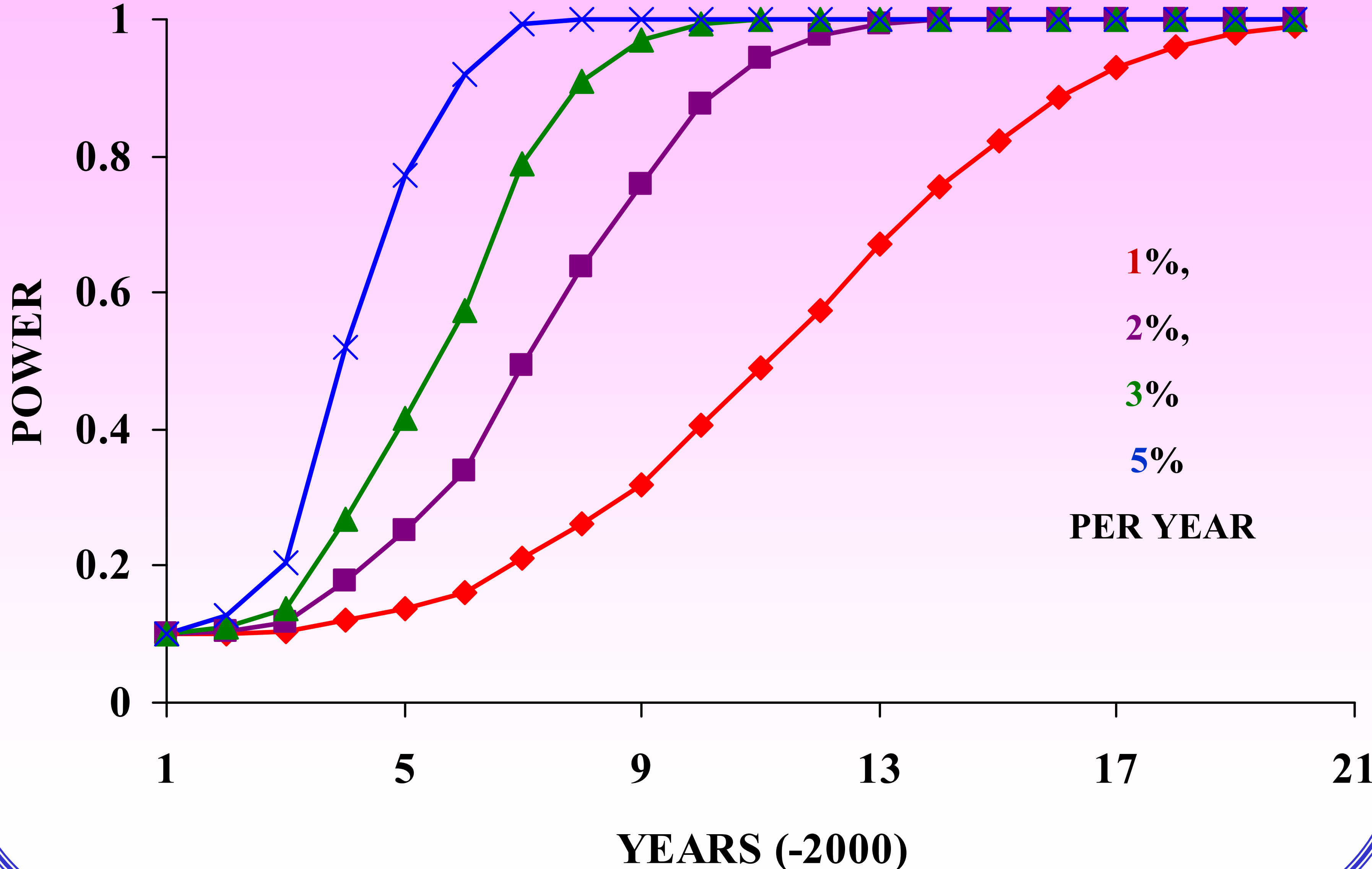
- Trend = generally continuing change in one direction
  - Increasing, or
  - Decreasing
  - Even if it trend curves, it always will display a linear part.
- Revisits to previously visited sites
  - Important to remove the site effect from estimates of trend
  - Some sites need to be revisited annually to reduce the effect of years from what it would otherwise be.

SAMPLE SIZE ASSUMPTIONS FOR POWER

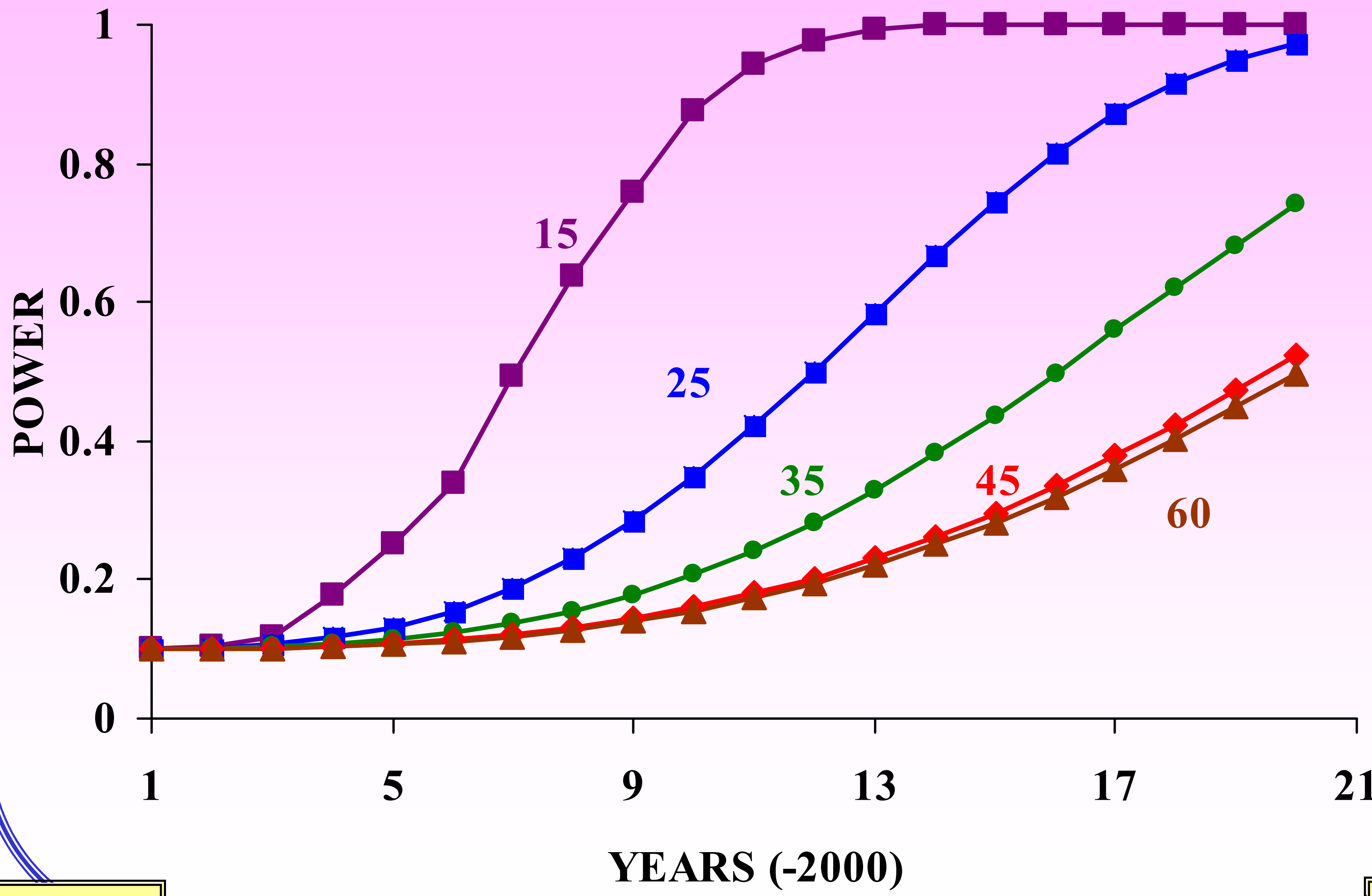
- **25 revisit sites**
  - ➔ **Revisited annually**
- **30 sites to be visited on a three-year rotating cycle**
  - ➔ **“Augmented Rotating Panel Design”**

	TIME PERIOD (ex: YEARS)													
PANEL	1	2	3	4	5	6	7	8	9	10	11	12	13	...
0	X	X	X	X	X	X	X	X	X	X	X	X	X	…
1	X			X			X			X			X	
2		X			X			X			X			…
3			X			X			X			X		

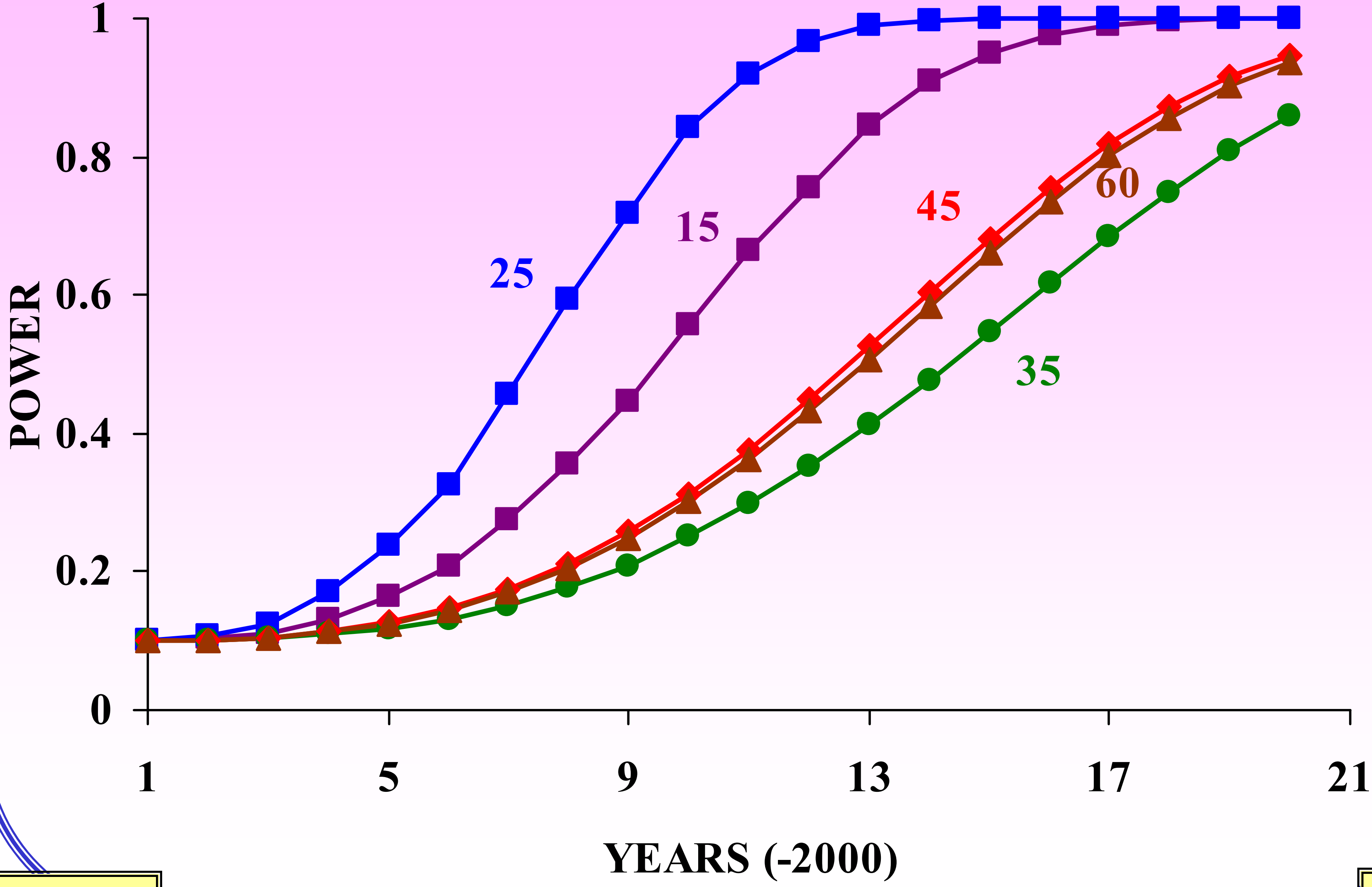
POWER TO DETECT TREND IN VEGETATION COVER, ZONE = 15, VARYING % TREND



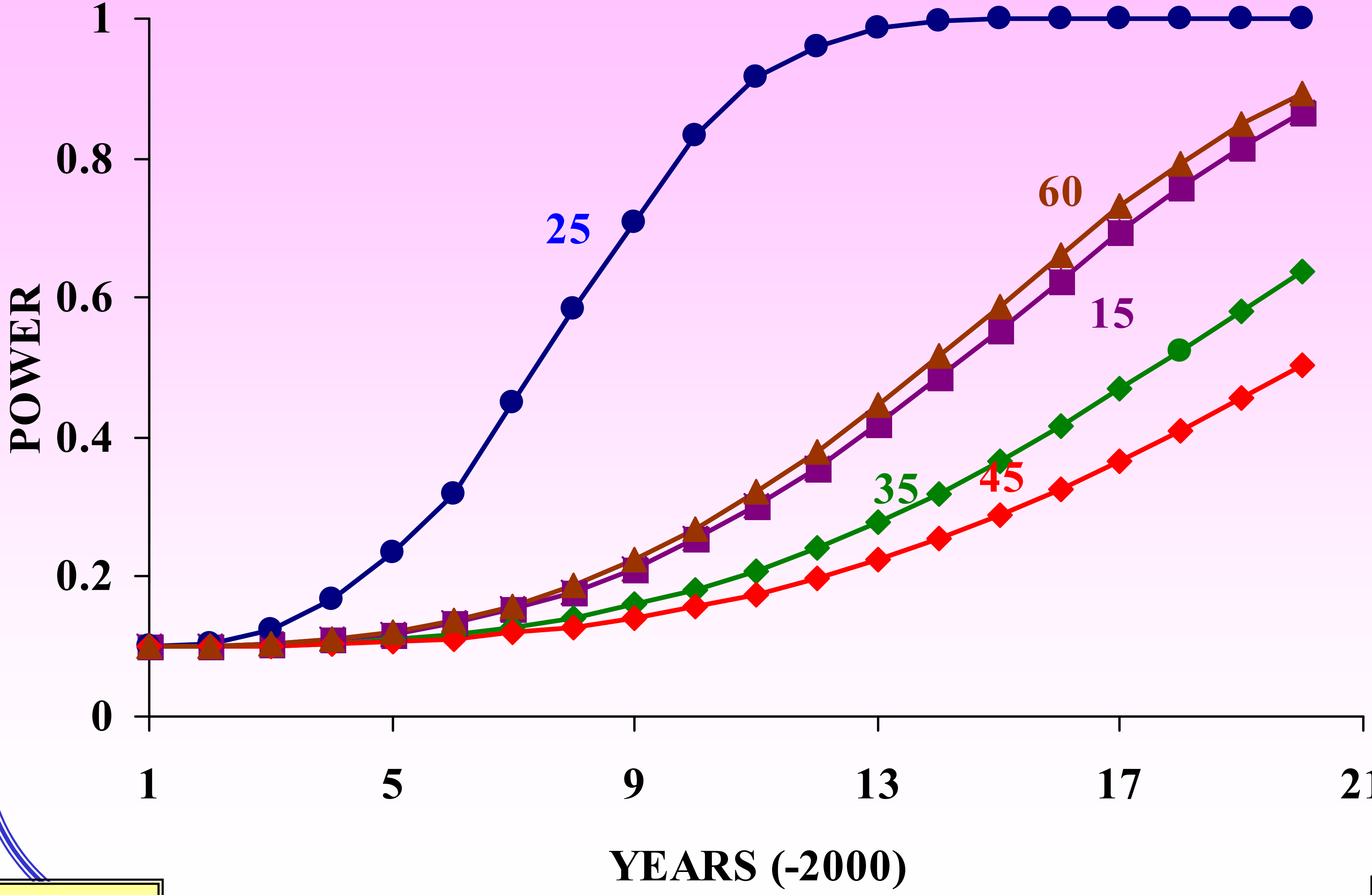
POWER TO DETECT TREND (2%PER YEAR) IN COVER by ZONE



POWER TO DETECT TREND (2% PER YEAR) IN RICHNESS, by ZONE



POWER TO DETECT TREND (2% PER YEAR) IN DIVERSITY INDEX, by ZONE



RESPONSE TO A QUESTION

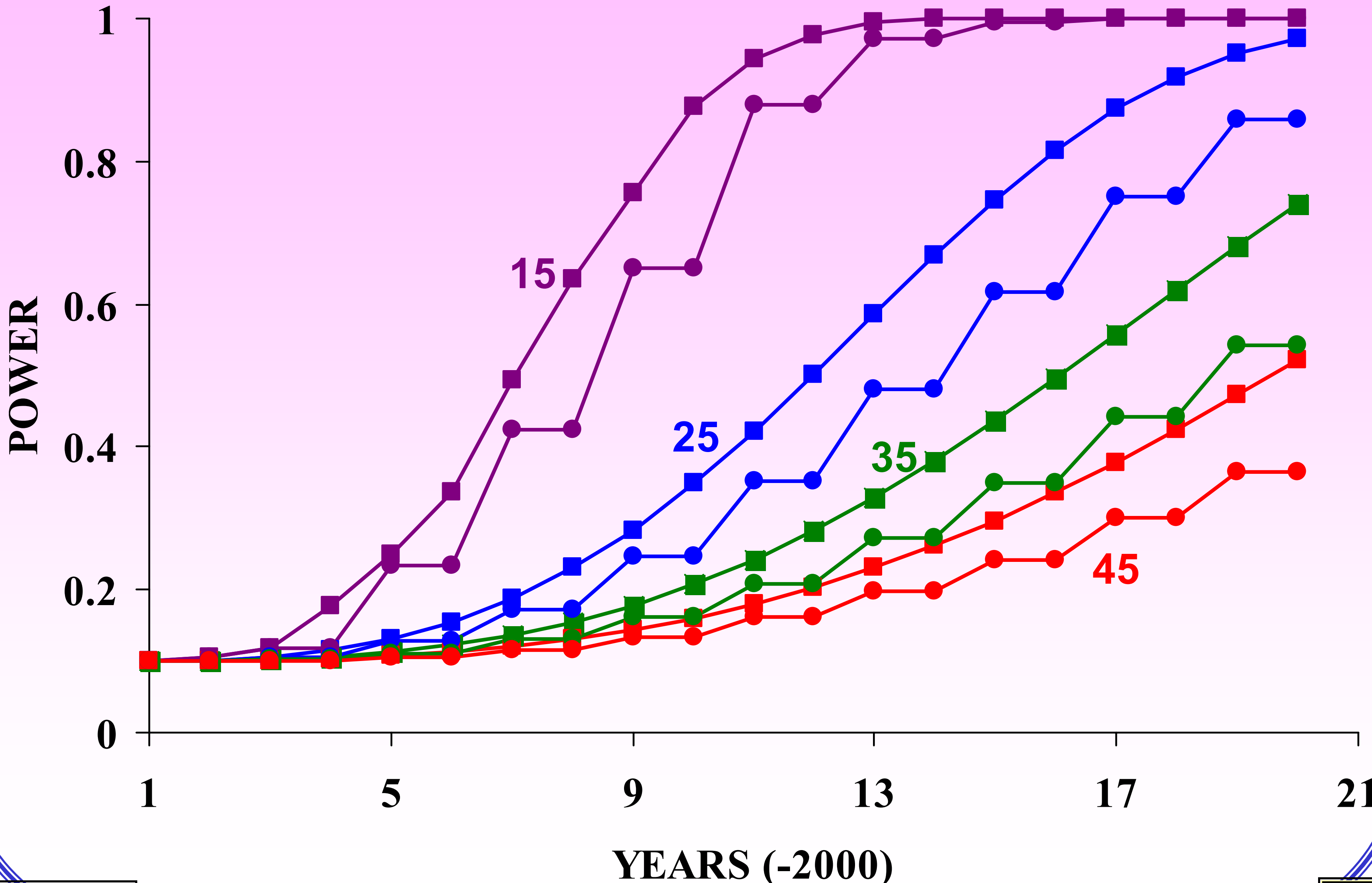
- "What would be the effect of revisiting sites only in alternating years after the first?"
  - ➔ Response 1: My greatest concern would be retaining the skills and knowledge of those doing the evaluations. (Changing personnel would almost certainly change response definitions in subtle, but unrecognized ways.)
  - ➔ Response 2: Power to detect trend would be delayed somewhat. (Actually a bit more than I initially thought!)
  - ➔ This is illustrated in the next two slides.

ALTERNATE REVISIT PLAN and SAAMPLE SIZES ASSUMPTIONS FOR POWER

- 25 revisit sites
  - ➔ Revisited annually, for first three years (as planned), then in alternating years
- 30 sites to be visited on a three-year rotating cycle
  - ➔ A revisit plan with no specific name

	TIME PERIOD (ex: YEARS)													
PANEL	1	2	3	4	5	6	7	8	9	10	11	12	13	...
0	X	X	X		X		X		X		X		X	…
1	X				X						X			
2		X					X						X	…
3			X						X					

POWER TO DETECT TREND (2%PER YEAR) IN COVER by ZONE and REVISIT PLANS: CURRENT = n ; ALTERNATE = l



OBSERVATIONS RELATIVE TO POWER UNDER THE BIANNUAL REVISIT PLAN

- **The loss of power for biannual revisits compared to the augmented serially alternating design has some noteworthy characteristics:**
  - **Power is the order of a quarter to a third for all years less than a decade.**
  - **The time required to get to a given level of power is extended by 3-5 years in the biannual revisit design.**
- **The "years" on the x-axis represents the starting point for ANY comparison**
  - **Power accrues from *accumulating* data, *elapsed* time, and *accumulating* trend**
  - **Detection of moderate trends requires a *commitment* to the continuing acquisition consistent and comparable data.**
  - **These power evaluations DO NOT relate to comparing years 10 to 11, or any specific two years.**
    - ***Neither design "fills up a tank with power" so you can get accurate comparisons regardless of how often you measure vegetation.***

ANOTHER QUESTION

- **Can "Whole Canyon" estimates be obtained from these results and sampling plan?**
- **RESPONSE: YES – with some qualifications:**
  - **For some, but not all, of the responses evaluated.**
    - *Indices like diversity don't combine across sites into overall diversity*
  - **For the whole Canyon below the 60 kcfs level**
    - *and by geologic reach*
    - *More accurate estimates would require quite a bit of GIS work*
      - **Need areas associated with various flow elevations.**

SPATIALLY BALANCED RANDOMIZATION ALONG A LINE

- **Illustrate, rather than explain in general**

- **Consider 16 sites, from which we want a spatially balanced sample of 7.**

SAMPLE	REPRESENTATION
1	0 0 0 0
2	0 0 0 1
3	0 0 1 0
4	0 0 1 1
5	0 1 0 0
6	0 1 0 1
7	0 1 1 0
8	0 1 1 1
9	1 0 0 0
10	1 0 0 1
11	1 0 1 0
12	1 0 1 1
13	1 1 0 0
14	1 1 0 1
15	1 1 1 0
16	1 1 1 1

REAL SITUATION (UNKNOWN TO US!)

SAMPLE	REPRESENTATION	
1	0 0 0 0	
2	0 0 0 1	
3	0 0 1 0	NA
4	0 0 1 1	
5	0 1 0 0	
6	0 1 0 1	
7	0 1 1 0	
8	0 1 1 1	
9	1 0 0 0	NA
10	1 0 0 1	
11	1 0 1 0	
12	1 0 1 1	
13	1 1 0 0	NA
14	1 1 0 1	
15	1 1 1 0	
16	1 1 1 1	

RANDOMIZATIONS - HIERARCHICAL

1	0 0 0 0
2	0 0 0 1
3	0 0 1 0
4	0 0 1 1
5	0 1 0 0
6	0 1 0 1
7	0 1 1 0
8	0 1 1 1
9	1 0 0 0
10	1 0 0 1
11	1 0 1 0
12	1 0 1 1
13	1 1 0 0
14	1 1 0 1
15	1 1 1 0
16	1 1 1 1

TAIL →

9	1 0 0 0
10	1 0 0 1
11	1 0 1 0
12	1 0 1 1
13	1 1 0 0
14	1 1 0 1
15	1 1 1 0
16	1 1 1 1
1	0 0 0 0
2	0 0 0 1
3	0 0 1 0
4	0 0 1 1
5	0 1 0 0
6	0 1 0 1
7	0 1 1 0
8	0 1 1 1

H

→

T

9	1 0 0 0
10	1 0 0 1
11	1 0 1 0
12	1 0 1 1
13	1 1 0 0
14	1 1 0 1
15	1 1 1 0
16	1 1 1 1
5	0 1 0 0
6	0 1 0 1
7	0 1 1 0
8	0 1 1 1
1	0 0 0 0
2	0 0 0 1
3	0 0 1 0
4	0 0 1 1

T

T

→

H

T

11	1 0 1 0
12	1 0 1 1
9	1 0 0 0
10	1 0 0 1
15	1 1 1 0
16	1 1 1 1
13	1 1 0 0
14	1 1 0 1
5	0 1 0 0
6	0 1 0 1
7	0 1 1 0
8	0 1 1 1
3	0 0 1 0
4	0 0 1 1
1	0 0 0 0
2	0 0 0 1

RANDOMIZATIONS - continued

11	1 0 1 0
12	1 0 1 1
9	1 0 0 0
10	1 0 0 1
15	1 1 1 0
16	1 1 1 1
13	1 1 0 0
14	1 1 0 1
5	0 1 0 0
6	0 1 0 1
7	0 1 1 0
8	0 1 1 1
3	0 0 1 0
4	0 0 1 1
1	0 0 0 0
2	0 0 0 1

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12	1 0 1 1
11	1 0 1 0
9	1 0 0 0
10	1 0 0 1
16	1 1 1 1
15	1 1 1 0
14	1 1 0 1
13	1 1 0 0
5	0 1 0 0
6	0 1 0 1
8	0 1 1 1
7	0 1 1 0
4	0 0 1 1
3	0 0 1 0
1	0 0 0 0
2	0 0 0 1

12	1 0 1 1	7/16 = 0.4375
11	1 0 1 0	14/16 = 0.8750
9	1 0 0 0	21/16 = 1.3125
10	1 0 0 1	28/16 = 1.7500
16	1 1 1 1	35/16 = 2.1875
15	1 1 1 0	42/16 = 2.6250
14	1 1 0 1	49/16 = 3.0625
13	1 1 0 0	56/16 = 3.5000
5	0 1 0 0	63/16 = 3.9375
6	0 1 0 1	70/16 = 4.3750
8	0 1 1 1	77/16 = 4.8125
7	0 1 1 0	84/16 = 5.2500
4	0 0 1 1	91/16 = 5.6875
3	0 0 1 0	98/16 = 6.1250
1	0 0 0 0	105/16 = 6.5625
2	0 0 0 1	112/16 = 7.0000

SELECTING THE SAMPLE

12	1 0 1 1	7/16 = 0.4375
11	1 0 1 0	14/16 = 0.8750
9	1 0 0 0	21/16 = 1.3125
10	1 0 0 1	28/16 = 1.7500
16	1 1 1 1	35/16 = 2.1875
15	1 1 1 0	42/16 = 2.6250
14	1 1 0 1	49/16 = 3.0625
13	1 1 0 0	56/16 = 3.5000
5	0 1 0 0	63/16 = 3.9375
6	0 1 0 1	70/16 = 4.3750
8	0 1 1 1	77/16 = 4.8125
7	0 1 1 0	84/16 = 5.2500
4	0 0 1 1	91/16 = 5.6875
3	0 0 1 0	98/16 = 6.1250
1	0 0 0 0	105/16 = 6.5625
2	0 0 0 1	112/16 = 7.0000

0.3
1.3
2.3
3.3
4.3
5.3
6.3

12	1 0 1 1	
11	1 0 1 0	
9	1 0 0 0	NA
10	1 0 0 1	
16	1 1 1 1	
15	1 1 1 0	
14	1 1 0 1	
13	1 1 0 0	NA
5	0 1 0 0	
6	0 1 0 1	
8	0 1 1 1	
7	0 1 1 0	
4	0 0 1 1	
3	0 0 1 0	NA
1	0 0 0 0	
2	0 0 0 1	

ADDING MORE POINTS

- Points will not be usable for a variety of reasons, like no vegetation needs to be measured on solid rock faces.
  - ➔ A process called reverse hierarchical ordering can be used to expand the spatially balanced list with a denser spatially balanced sample. Additional points can be selected from that list in their order of appearance.
  - ➔ I have no simple illustration of that process immediately available. Sorry. See the Stevens & Olsen reference.

EXTENSIONS FOR SPATIALLY BALANCED SAMPLING

- **Cut a stream up into lots of little pieces of the same length**
  - **Do the spatially balanced sampling with the pieces**
    - *Randomly select a specific point in each sampled piece*
    - *We actually used the 702 segments between flow control points*
      - **they had unequal length so these lengths enter into analysis of "whole Canyon" summaries**
    - *Pieces can have different weights in the sampling*
      - **This just stretches/shrinks segment lengths on the sampling line; total length remains the number of points**

EXTENSIONS FOR SPATIALLY BALANCED SAMPLING - II

- This extends to two-dimensional sampling
  - ➔ Effectively represent the coordinates of each small square in a decimal (base 4)
  - ➔ Map the coordinates of the squares onto a sampling line by interspersing the digits in their decimal represenation
  - ➔ Then Proceed as before
- Check at epa.gov/wed/arm   for software

REFERENCE FOR THE SPATIALLY BALANCED SAMPLING METHODOLOGY

- http://www.orst.edu/dept/statistics/epa_program/docs/spatial_balance_imperfect_frame.pdf

A STATISTICAL MODEL

$$Y_{ijk} = S_{ik} + T_j + E_{ijk}$$

where

i INDEXES SITE SETS 1, 2, ... , s

(all sites in a site set have the same revisit pattern)

j INDEXES TIME PERIODS (years in EMAP)

k INDEXES SITES WITHIN A SITE SET 1, 2, ... , n_i

and (uncorrelated):

$$S_{ik} \sim (\mu, \sigma_S^2) \quad T_j \sim (0, \sigma_T^2) \quad E_{ijk} \sim (0, \sigma_E^2)$$

A STATISTICAL MODEL - continued

- **CONSIDER THE ENTIRE TABLE OF THE SITE-SET by TIME-PERIOD MEANS,**
  - → **WITHOUT REGARD TO, AS YET, WHETHER THE DESIGN PRESCRIBES GATHERING DATA IN ANY PARTICULAR CELL**
  - → **ORDERED BY SITE-SET WITHIN TIME PERIOD (column wise)**

$$\overline{\mathbf{Y}} = (\overline{Y}_{11\cdot}, \overline{Y}_{21\cdot}, \text{☹}, \overline{Y}_{s1\cdot}, \overline{Y}_{12\cdot}, \text{☹}\ \overline{Y}_{s2\cdot}, \text{☹}, \overline{Y}_{st\cdot})$$

With this ordering, we get

$$\operatorname{cov}(\overline{Y}_{ij\cdot}, \overline{Y}_{i'j'\cdot}) = \delta_{ii'}\sigma_S^2 \ / n_i + \sigma_T^2 + \delta_{ii'}\delta_{jj'}\sigma_E^2 \ / n_i$$

STATISTICAL MODEL - continued

If we let $\text{cov}(T_1, T_2, \Lambda, T_t) = \Sigma_T = \sigma_T^2 \mathbf{I}_t$, then

$$\text{cov}(\overline{\mathbf{Y}}) = \Phi$$

$$= \sigma_S^2 \mathbf{I}_t \otimes \mathbf{D}^{-1}(n_i) + \Sigma_T \otimes \mathbf{1}_s \mathbf{1}_s' + \sigma_E^2 \mathbf{I}_t \otimes \mathbf{D}^{-1}(n_i)$$

- **NOW LET X DENOTE A REGRESSOR MATRIX CONTAINING A COLUMN OF 1'S AND A COLUMN OF THE NUMBERS OF THE TIME PERIODS. THE SECOND ELEMENT OF**

$$\hat{\beta} = (\mathbf{X}'\Phi^{-1}\mathbf{X})^{-1}\mathbf{X}'\Phi^{-1}\overline{\mathbf{Y}}$$

CONTAINS AN ESTIMATE OF TREND.

STATISTICAL MODEL - continued

- **BUT THIS ESTIMATE OF β CANNOT BE USED BECAUSE IT IS BASED ON VALUES WHICH, BY DESIGN, WILL NOT BE GATHERED.**
- **REDUCE X, Y AND Φ TO X*, Y*, AND Φ*, WHERE THESE REPRESENT THAT SUBSET OF ROWS AND COLUMNS FROM X, Y, AND Φ CORRESPONDING TO WHERE DATA WILL BE GATHERED. THEN**

$$\hat{\beta} = (\mathbf{X}^{*\prime} \Phi^{*-1} \mathbf{X}^{*})^{-1} \mathbf{X}^{*\prime} \Phi^{*-1} \overline{\mathbf{Y}}$$

and $$\operatorname{cov}(\hat{\beta}) = (\mathbf{X}^{*\prime} \Phi^{*-1} \mathbf{X}^{*})^{-1}$$

A STANDARDIZATION

- **NOTE THAT**

$$\text{cov}\,(\bar{Y}_{ij\cdot}, \bar{Y}_{i'j'\cdot}) = \delta_{ii'}\sigma_S^2 / n_i + \sigma_T^2 + \delta_{ii'}\delta_{jj'}\sigma_E^2 / n_i$$

CAN BE REWRITTEN AS

$$\text{cov}\,(\bar{Y}_{ij\cdot}, \bar{Y}_{i'j'\cdot}) = \{\delta_{ii'}(\sigma_S^2 / \sigma_E^2) / n_i + (\sigma_T^2 / \sigma_E^2) + \delta_{ii'}\delta_{jj'}/n_i\}\,\sigma_E^2$$

- **CONSEQUENTLY POWER, <u>*A*</u> MEASURE OF *SENSITIVITY*, CAN BE EXAMINED RELATIVE TO**

$$\sigma_S^2 / \sigma_E^2 \quad \text{and} \quad \sigma_T^2 / \sigma_E^2$$

TOWARD POWER

- ***TREND:*** **CONTINUING, OR MONOTONIC, CHANGE. PRACTICALLY, MONOTONIC TREND CAN BE DETECTED BY LOOKING FOR LINEAR TREND.**
- ***SENSITIVITY*** **(in the title) CAN BE EXPRESSED AS POWER.**
- **WE WILL EVALUATE POWER IN TERMS OF RATIOS OF VARIANCE COMPONENTS AND**

$$\lambda = \beta^0 / \sigma_E, \text{ so approximately, } \hat{\beta} \sim N(\lambda, \sigma^2_{\hat{\beta}})$$

WHERE THIS DENOMINATOR DEPENDS ON THE RATIOS OF VARIANCE COMPONENTS AND THE SAMPLING DESIGN.

POWER REFERENCE

- Urquhart, N. S., S. G. Paulsen and D. P. Larsen. (1998). Monitoring for policy-relevant regional trends over time. *Ecological Applications* **8**: 246 - 257.

TOP OF TRANSECT AT MILE 12.3

MARKING TRANSECT AT MILE 12.3


CLIFF AT MILE 128.0

CLIFF AT MILE 135.2 (FULL HEIGHT)

CLIFF AT MILE 223.5 (FULL SCALE)


CLIFF AT
MILE 223.5
(CROPPED)

MIKE & SCOTT AT THE END!