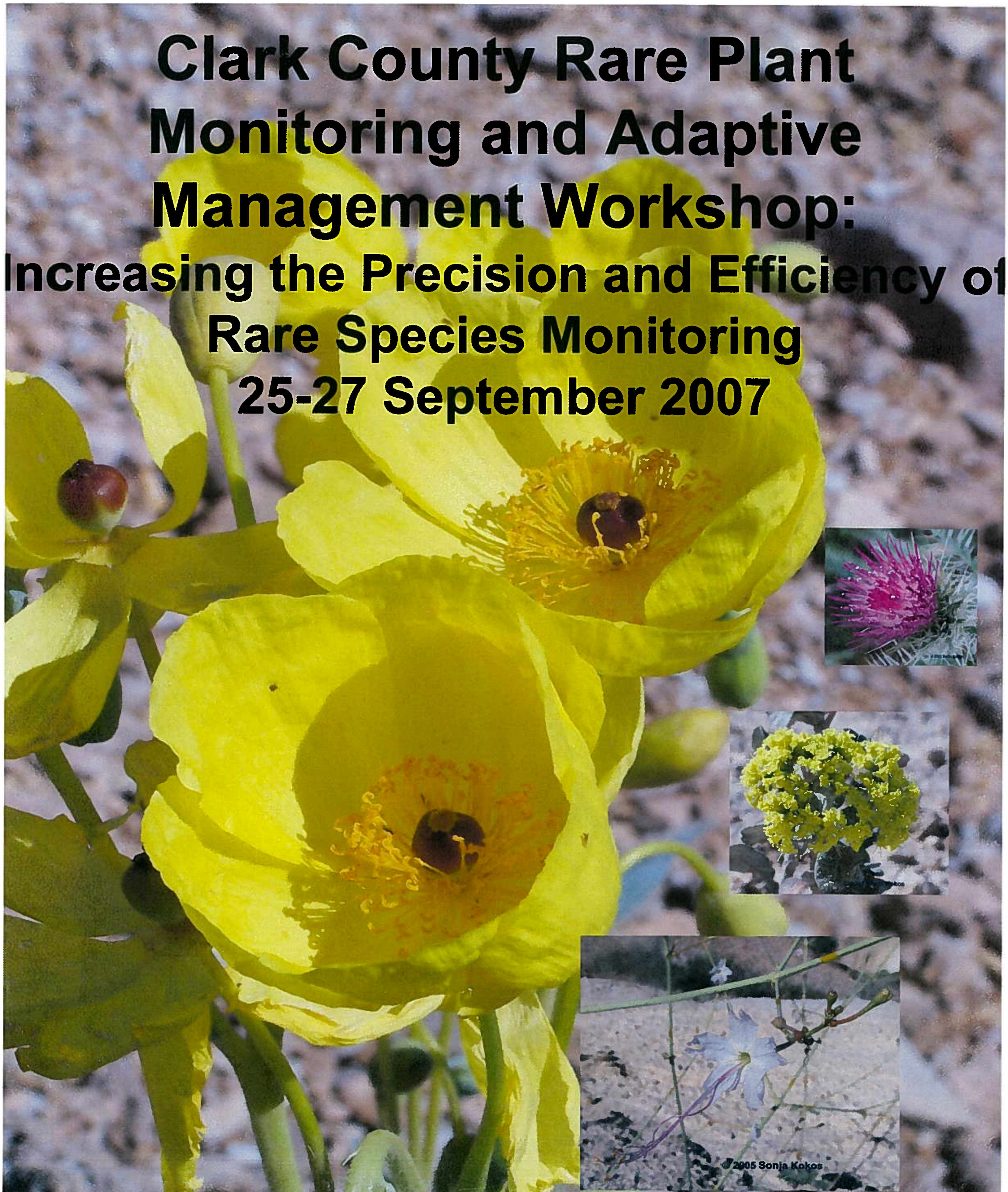
Clark County Rare Plant Monitoring and Adaptive Management Workshop:

Increasing the Precision and Efficiency of Rare Species Monitoring

25-27 September 2007



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Workshop Objectives:

- Empower participants to improve their quantitative observations of natural plant populations through:
  - Developing focused monitoring and sampling objectives
  - Using ecological models to understand the ecology of target species
  - Using a framework to strengthen monitoring and management
  - Developing precise and efficient sampling designs
  - Knowing the reliability of population estimates
  - Understanding the precision of different sampling methods
- Provide opportunity to improve monitoring protocols for a species or a project you are working on
- Provide guidance on how to incorporate the concept of adaptive management into monitoring projects

Tuesday, 25 September 2007

An Introduction to Rare Species Monitoring, Adaptive Management, and a Framework for Monitoring

9:00 am	Welcome, Workshop Objectives and Agenda, Introduction of Participants
9:30	Introduction to Rare Species Monitoring and Monitoring in an Adaptive Management Context
10:30	Break
10:45	A Framework for Monitoring Rare Species: • Objective-based Management and Monitoring • A model of monitoring, management and adaptive management • Desired Ecological Conditions • Ecological Models • Types and Selecting Indicators to Monitor
12:00 noon	Lunch
1:00 pm	A Framework for Monitoring T&E Species (continued)
2:00	Exercise: Refining Ecological Models and Drafting Monitoring Objectives
3:00	Break
3:30	Peer Review and Discussion of Ecological Models and Monitoring Objectives
4:30	Sampling Objectives and Preparation for the Sampling Design Session
5:00	Adjourn

Wednesday, 26 September 2007

The Statistical and Sampling Design Basis of Rare Species Monitoring

An Overview of Sampling Design

8:30 am	An Overview of Sampling Design: Definition, Terms, Concepts, Statistics
9:45	Break
10:00	An Overview of Sampling Design Non-sampling and Sampling Errors, Precision, Power

Five Sampling Design Decisions

10:30	Population of Interest (Sampling Frame) *Discussion: Population of Interest in Projects*
11:15	Appropriate Sample Unit and Sample Unit Size and Shape *Exercise: Selecting Sample Unit*
12:00 noon	Lunch
1:00 pm	*Discussion: Selection of Sample Unit Size and Shape*
1:30	Spatial Allocation of Sample Units *Discussion: Spatial Allocation of Sample Units in Projects*
3:00	Break
3:30	Temporal Allocation of Sample Units *Discussion: Temporal Allocation of Sample Units in Projects*
4:00	Number of Sampling Units *Exercise: Determining Sample Size*
4:30	Sampling Design Decisions and the Biology of Species
5:00	Adjourn

Thursday, 27 September 2007

Sampling Design, Methods and Monitoring Protocols: Approaches and Methods at Ash Meadows National Wildlife Refuge

9:00 am	Field Presentation: Review and Discussion of Sampling Design and Methods for some Rare Ash Meadow Plant Species
11:30	Field Exercise: Developing a Sampling Design and Method for a Selected Species
12:00 noon	Working Lunch: Discussion of Monitoring Protocols
1:30	Photographic Monitoring
2:15	Adaptive Management Revisited
2:30	Reflection on what has been learned, Wrap-up and Discuss Next Steps
3:00	Adjourn

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Introduction to T&E Species Monitoring and Adaptive Management

Rob Sutter, Regional Scientist
Southern US Conservation Region, The Nature Conservancy

Clark County, NV Rare Plant Monitoring and Adaptive Management Workshop

25-27 September 2007

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Session Objectives

- Summarize the **ecological concepts** and social context that influence the current approach to conservation and adaptive management
- Define **adaptive management** and discuss its characteristics and how it is successfully implemented
- Define **ecological monitoring**, discuss four types of monitoring, differentiate status and effectiveness monitoring, identify how research relates to monitoring, and discuss how monitoring is incorporated into adaptive management
- Discuss what makes monitoring **effective and efficient**
- Discuss the **challenges** to accomplishing the status and effectiveness monitoring

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How Does One Conserve Species, Communities and Ecological Systems?

Ecological Concepts

- Biological and Ecosystem Diversity
- Ecological Processes
- Spatial and Temporal Scales
- Viability and Integrity
- Complexity
- Human Impact/Human Context
- Uncertainty

Sources of Uncertainty

- Ecological Uncertainty
- Environmental Stochasticity
- Partial Observability
- Partial Controllability

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“All uncertainty is fruitful so long as it is empowered by the wish to understand”

-- *Antonio Machado*

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Adaptive Management

an approach that recognizes the **inherent complexity and uncertainty** in managing natural resources and **structures management into a learning process** that **maximizes management success and reduces uncertainty**.

- Management in the **context of uncertainty**.
- The process of linking ecological management within a **learning framework**, that adapts to the gain of information.
- An **iterative process** of planning, management, monitoring, evaluation and adjusting management.

Adaptive Management

- More than just the management and monitoring with feedback
- The successful implementation of adaptive management requires:
  - a thoughtful approach to the development and implementation of management actions
  - a well designed process of monitoring the effects of management
  - an institutional structure that allows for adaptive action and active learning

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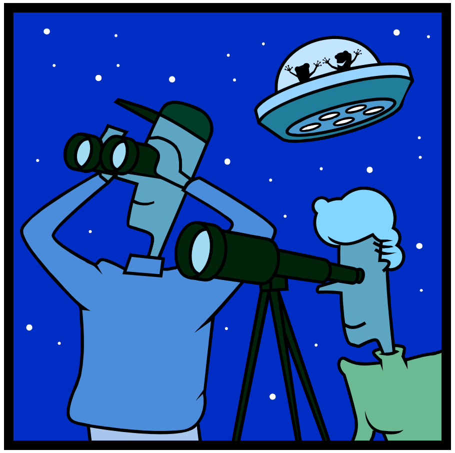
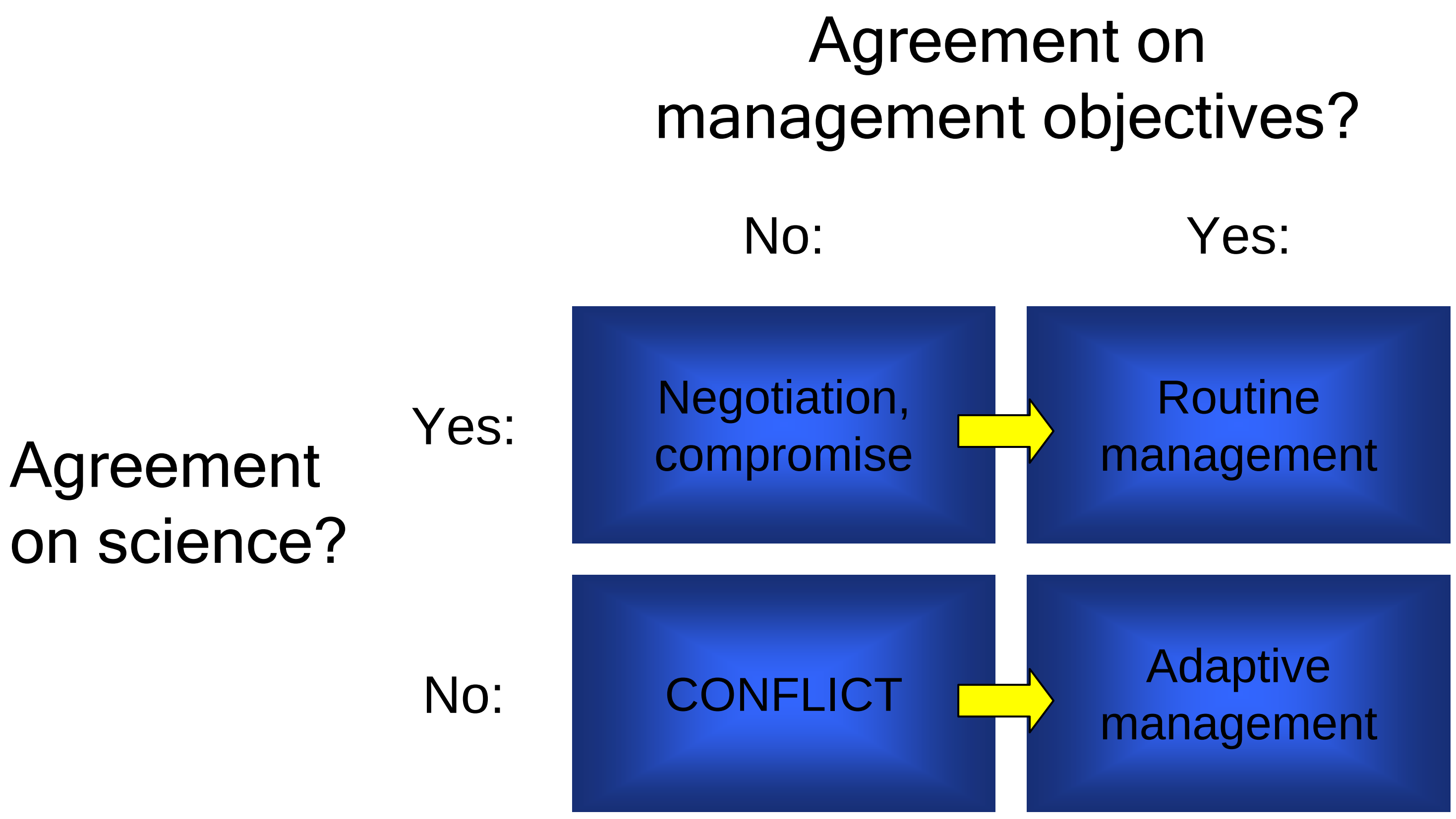
Controversy and Paralysis in Decision Making: Why does it exist?

- Failure to separate ***disagreements about objectives*** from ***uncertainty about science***
- Don’t know current state of the resource
- Reluctant to make transparent predictions about management



Controversy in Resource Management:

Negotiate objectives first, resolve uncertainty through management



from Lee (1993)

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Why is Adaptive Management a Misunderstood Concept?

- Simple interpretation: “a willingness to change” or “flexible management”
  “… means try something initially, then try something else if that fails.”
  - **Adaptive management is a guided, formal decision making process**
- Complex interpretation: research using an experimental design to determine cause and effect
  - **Adaptive management focuses on the appropriate means to assess and refine management outcomes.**
- Complex explanations that do not resolve management questions
  - **Adaptive management is only as complex as the population, species or system being managed, and it can range from simple to complex.**

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Keys to a Successful Adaptive Management Program

- Approach
  - develops clear, explicit management goals
    - developed at the right scale, with the right people (partners, stakeholders)
  - approaches management as an experiment, using hypotheses to test predictions and assumptions (models)
  - prioritizes actions through an explicit (not arbitrary) process
- Leadership
  - develops focused objectives
  - provides funding and skilled personnel
- Institutional Structure
  - supports sequential decision making
  - supports integration (programs, projects) and communication
  - supports a learning culture, that allows the questioning of the way management is done

"You can observe a lot by watching"

Yogi Berra

- Ecological Monitoring:

  the process of acquiring information over time

  - to assess status and detect change/trend of populations, communities and ecological systems
  - **for the purpose of evaluating management and conservation actions**
  - **to learn (reduce uncertainty) about the species/system**
  - **to guide future management, monitoring and research**
- Monitoring is the "cornerstone" of adaptive management

The Case for Monitoring

Monitoring enables us to:

- Show **trends** in target, biodiversity & threat status
  - related to desired ecological conditions and the effects of disturbances
  - and, when linked with other locations, an assessment of status and trends of global biodiversity
- Determine the **effectiveness** of conservation actions and provide the basis for adaptive management
- Demonstrate **efficiency** of our conservation actions and investments
- Reduce the **uncertainty** of conservation actions
- Provide **insights** in the biology and ecology of targets and **focus** internal and external scientific research

Types of Monitoring – USFS

- Implementation Monitoring
- Status Monitoring
- Effectiveness Monitoring
- Validation Monitoring (Ecological Research)

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Types of Monitoring

- Implementation Monitoring
  - determine if a planned activity was accomplished
  - asks: Did we do what we said we would do?
- Status Monitoring
  - determine the current status of a population, species, ecosystem
  - asks: Is the current status acceptable?
- Effectiveness Monitoring
  - determine if a specific activity/strategy achieved stated objectives
  - asks: Did it work? Is it working?
- Validation Monitoring (Ecological Research)
  - determine if assumptions and models are correct
  - questions form the basis of research needs

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Status versus Effectiveness Monitoring

Status Monitoring

- Objective: assess the current condition of a target, threat or conservation management
- Does not explicitly link management actions and target condition
  - provides an assessment of current condition
  - tracks the cumulative impact of all conservation actions and confounding factors
- Data can be qualitative or quantitative
- Provides a measure of overall success and an early warning of change

Status versus Effectiveness Monitoring

Effectiveness Monitoring

- Objective: determine whether one or more conservation actions are having the intended impact on the target or threat
- Continuum of ability to discern the causal relationship between the conservation action and the response of the target or threat
  - Observational Study: qualitative or quantitative assessment of the relationship of the action and the impact on the target or threat
  - Experimental Study: more rigorous with an experimental design, controls, replication of treatments and collection of additional variables
- Most appropriate monitoring for adaptive management

Two Important Points

- Confusing Means with the Ends
  - Implementation versus Outcomes
- Monitoring: along a continuum of inference strength
  - Status: current condition
  - Effectiveness: response to management
  - Validation: focus on stronger statistical inference and predictive models and generalizations
  - Differences along continuum:
    - Focus on implementation of management
    - Replication of treatment(s) and presence and replication of controls
    - Resources required

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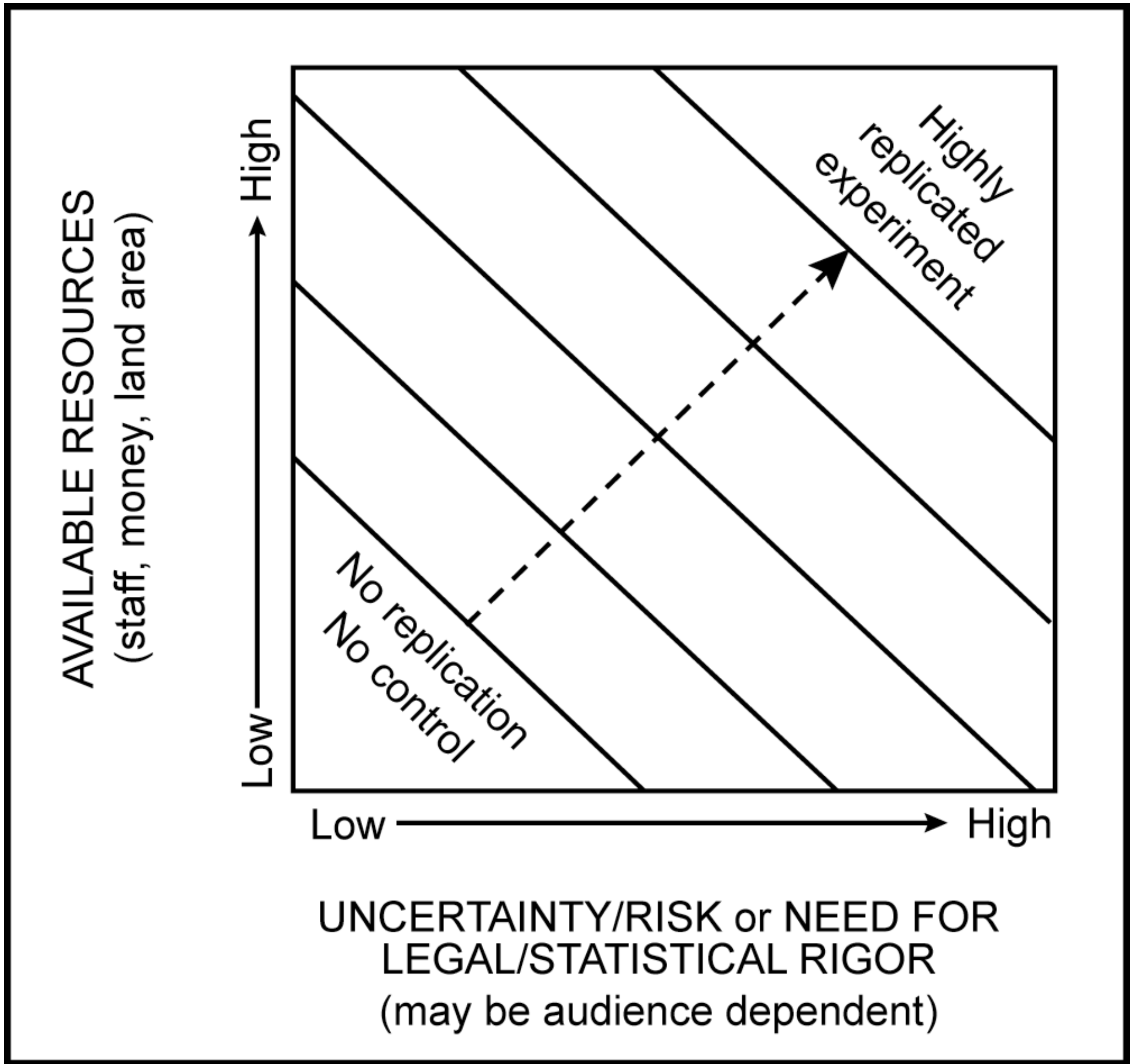
What Type of Monitoring is Appropriate?



What Makes Monitoring Effective?

- Clear Management/Monitoring Priorities
- Sound Biological Understanding
- Clear Management and Sampling Objectives
- Appropriate Level of Monitoring and Acceptable Level of Precision
- Efficient and Precise Sampling Design and Method
- Monitoring Projects that are:
  - Long-term Enough to Capture Natural Processes and Response to Management
  - Repeatable
  - Efficient

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What Makes Monitoring Challenging?

Summary

Why should you implement an adaptive management and monitoring program for your project?

- to conserve the resource and maximize the success of the management actions
- to learn and reduce uncertainty
- to efficiently use resources
- to meet standards and regulations
- to be a leader and set an example for others within and outside your agency

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A Framework for Monitoring Rare Species

Objective-based Monitoring

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Session Objectives

- Discuss the **value of objective-based management and monitoring**
- Summarize the **six components** of monitoring objectives
- Define the **two categories** of status monitoring objectives
- Discuss the use of **Desired Ecological Conditions** and **Ecological Models** in the development of monitoring objectives
- Identify the different types of **indicators** used for status and effectiveness measures
- Identify criteria for **selecting indicators**
- Present the concept of a **sampling objective** for each of the two categories of monitoring objectives

Objective-based Management and Monitoring: Values for Conservation

- Focus and sharpen thinking about the desired state or condition of the resource
- Describe to others the desired condition of the resource, provides the basis for understanding and collaboration
- Determines the conservation actions that will be implemented
- Provides direction for the appropriate type of monitoring and the basis for evaluating management success
- Identifies resource needs

Components of a Monitoring Objective

- Target – the population/species or community/habitat that is the focus of monitoring and/or management
- Location – the specific location where monitoring and/or management is taking place (management unit, subpopulation)
- Desired Ecological Condition - a monitoring threshold or management benchmark or endpoint
- Condition or Management Assessment
  - Status – range of threats or management assessed by monitoring
  - Effectiveness – specific management or threat abatement actions chosen to get to desired ecological condition assessed by monitoring
- Timeframe
  - Status: when condition will be assessed for next steps
  - Effectiveness: when the management action will have its impact
- Indicators – what will be measured to assess status or effectiveness

Identifiers
of a Monitoring Objective

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Management Components of a Monitoring Objective

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Monitoring Components of a Monitoring Objective

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Examples

- Status: Maintain the density of species x in the – conservation area at a mean greater than 5 plants per $10m^2$ and an occurrence rate of greater than 40% in $10m^2$ sample units between 2007 and 2010.
- Effectiveness: Determine the effectiveness of voluntary exclusion (agreement, notification, signage) of vehicles from the – conservation unit over the next 3 years (2008 to 2011) comparing density, mortality and recruitment of species x and the cover of vehicle impacts before and after the voluntary exclusion and between – conservation unit and the reference site in – conservation unit.

Types of
Status Monitoring Objectives

- Target/Threshold Management Objective
  - an estimate of a parameter or combination of parameters in a population, such as population size, density, reproduction, demographic structure, to assess overall condition and viability
- Change/Trend Management Objective
  - an estimate of change in a parameter or combination of parameters in a population over time
  - best when insufficient information exists to describe a status/threshold, condition is less important than trend

Types of Status Monitoring Objectives

- Target/Threshold Monitoring Objective
  - Maintain the mean density and spatial extent of species x in the dune habitat at Eglin AFB
  - Increase the mean density of a selected species in dune habitat at Eglin AFB to 20 plants/m2 by 2005
  - Decrease the mean cover of a specific invasive species in Unit A at Eglin AFB to less than 5% by 2005
- Change/Trend Monitoring Objective
  - Increase the mean density of a selected species in dune habitat at Eglin AFB by 20% by 2005
  - Decrease the mean cover of a specific invasive species in Unit A at Eglin AFB by 50% by 2005

Discussion of Monitoring Objectives

Management Components of a Monitoring Objective

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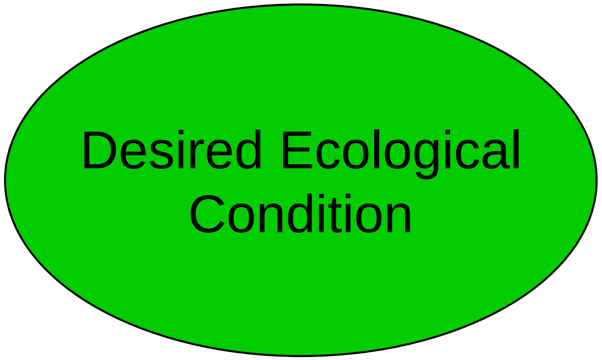
Monitoring and Management Framework

Monitoring and Management Framework



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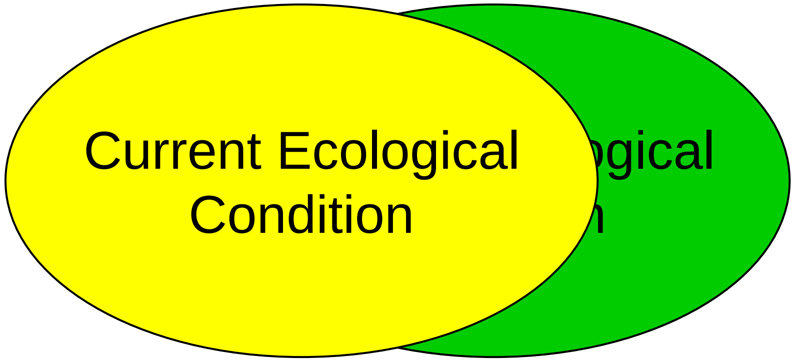

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Monitoring and Management Framework

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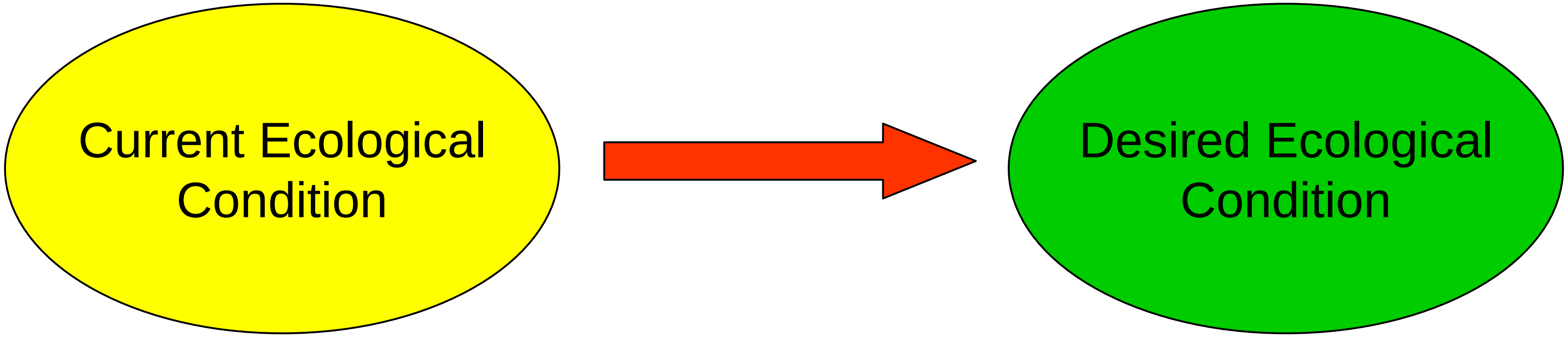
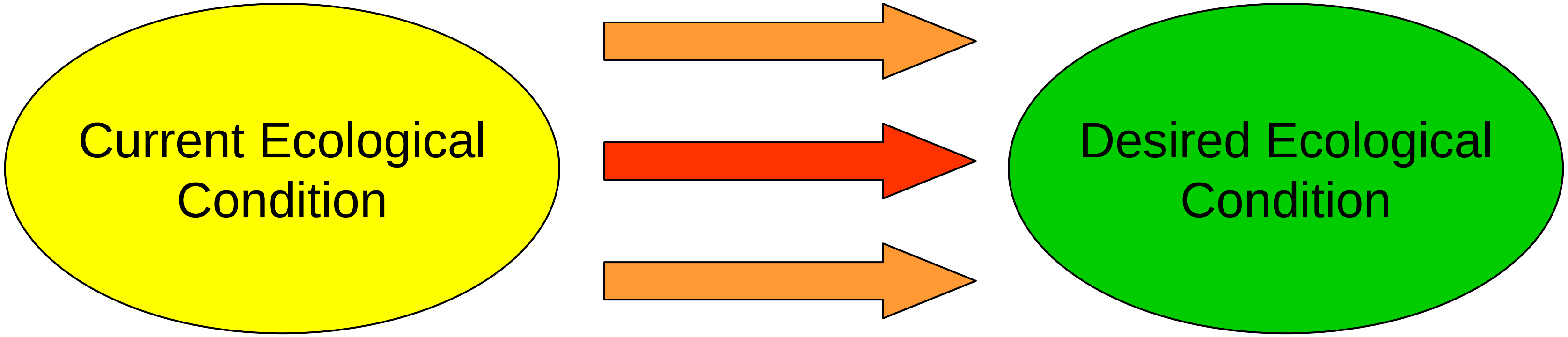


Management/Restoration
Hypotheses

Monitoring and Management Framework



Management/Restoration Hypotheses

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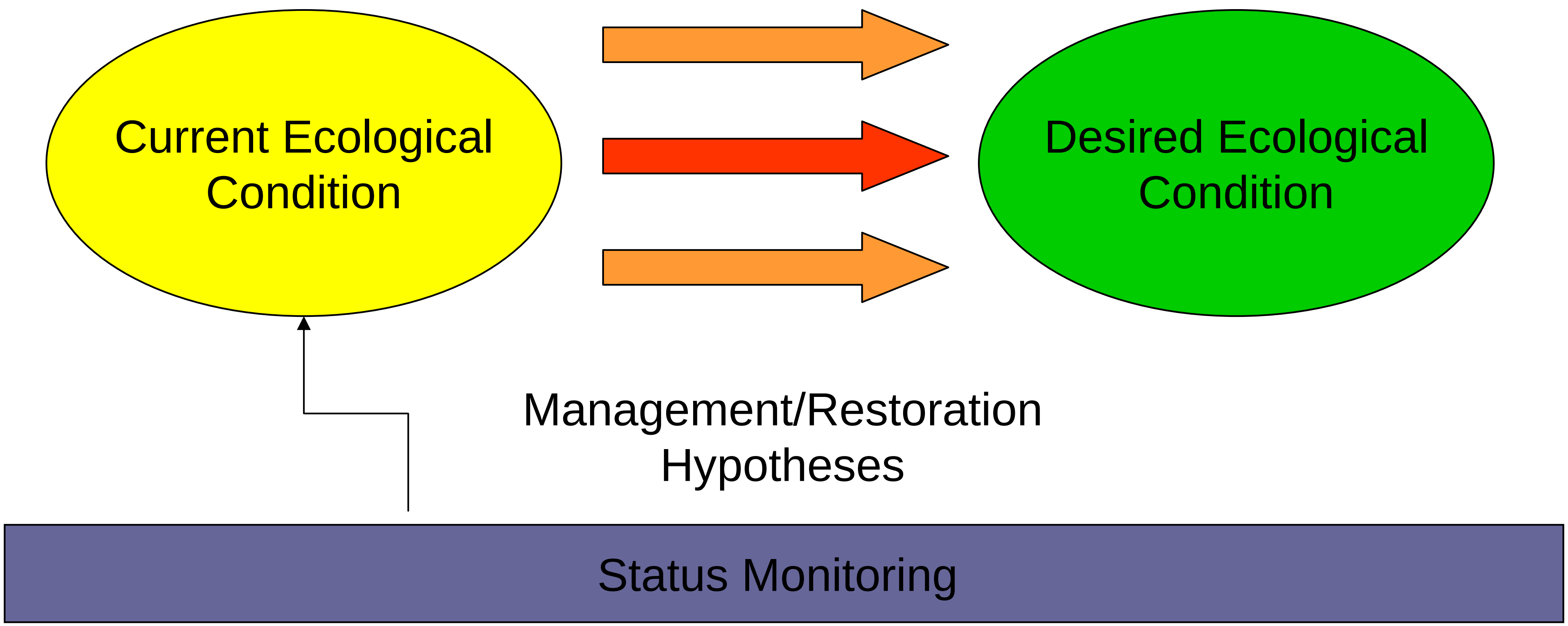

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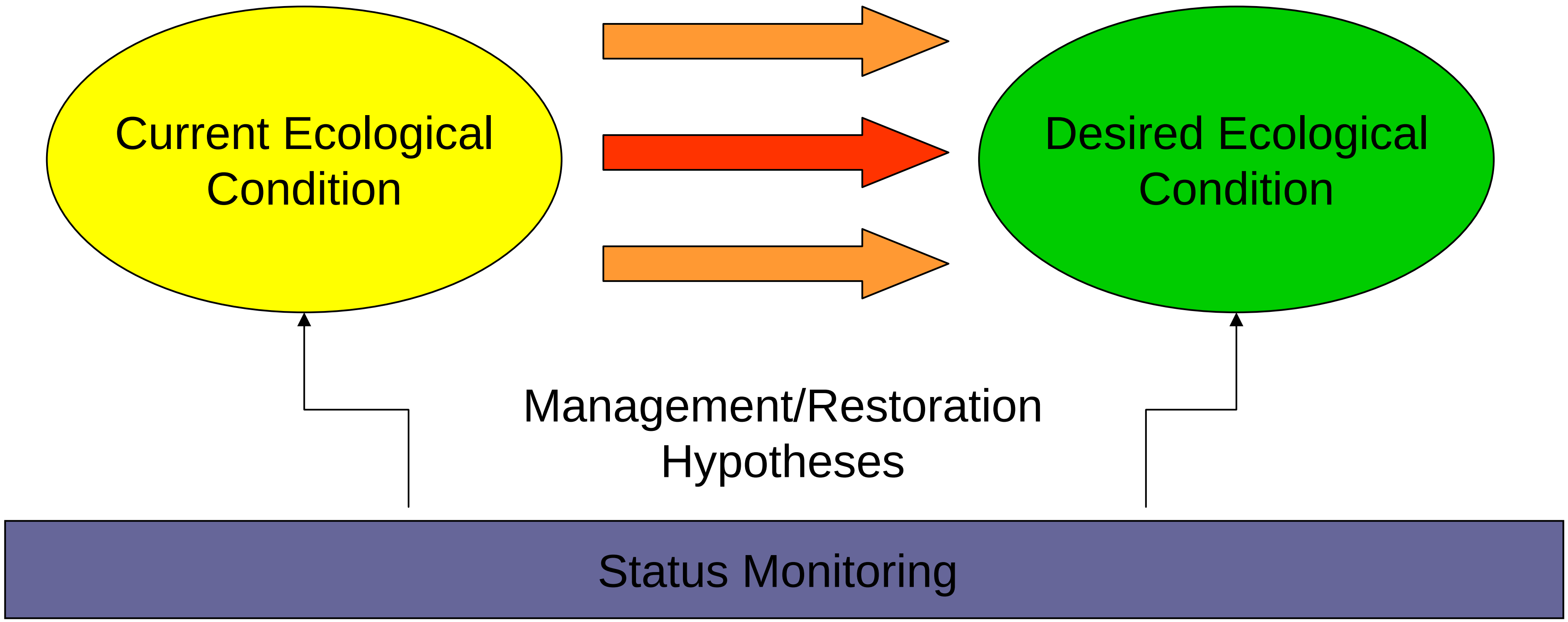

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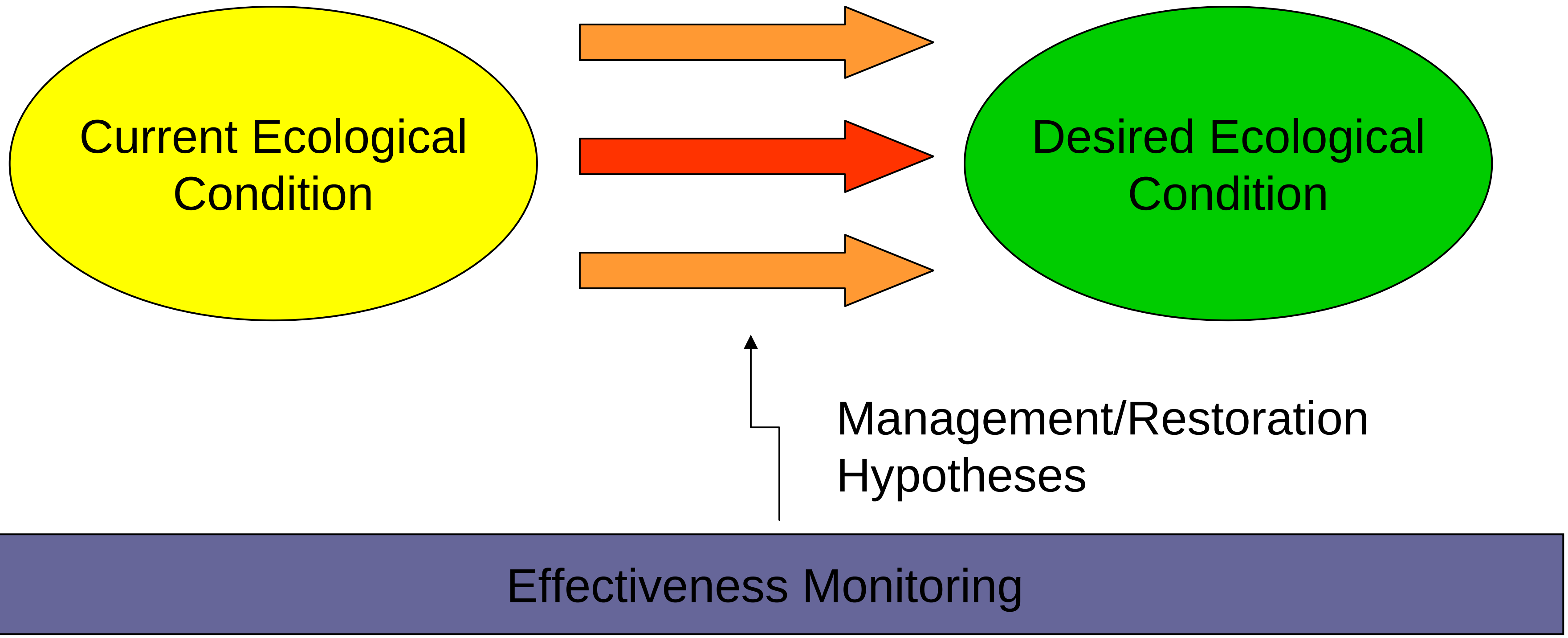

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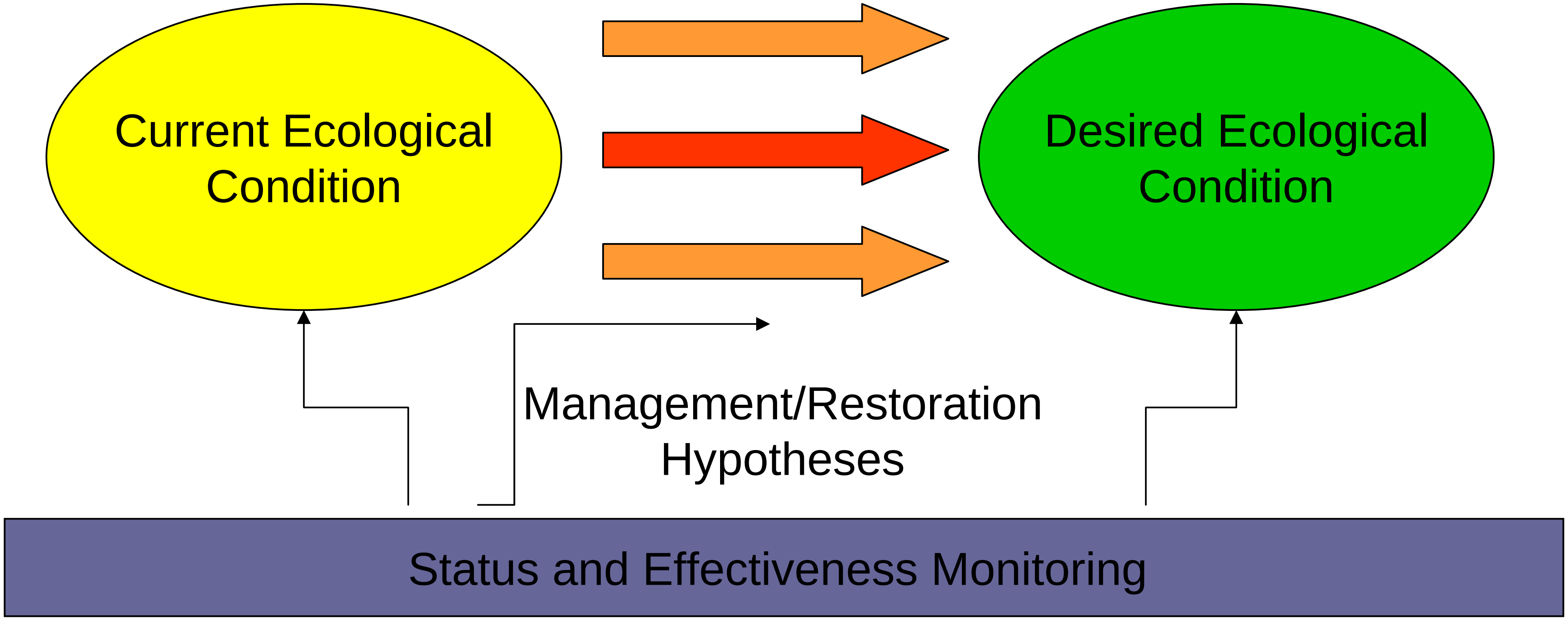
Monitoring and Management Framework



Management Components of a Monitoring Objective

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Desired Ecological Conditions

- **A range of ecological conditions preferred** for a population, community or ecological system, **attainable** within the human context over a selected period of time, used to guide management, restoration and land use.

Described by Key Ecological Attributes:

- **Critical components** of a target's life history, community interactions, habitat, ecological processes and landscape context

Two Types of Desired Ecological Conditions

- Condition-based
  - Management or restoration to a pre-defined state
    - Theoretically (PVA – need greater than 100 plants)
    - Empirically (compared to most pristine sites or current condition)
  - Assumption that we can determine an appropriate pre-defined state
- Process-based
  - Maintenance, management or restoration of the processes that allows for a viable population/system
  - Assumption that just restoring ecological processes will result in a viable population/system

Cladonia perforata

- Size and Condition: in current and restored subpopulations maintain density between 5 and 20 plants per m^2 and presence between 30 and 50% of the area, with a total population size greater than 5000 individuals
- Function (Ecological Processes): maintain natural coastal dune dynamics, reduce unnatural disturbance (fence subpopulations in areas with human and military disturbance)
- Spatial Extent and Configuration: maintain and restore 5 populations along the 30 miles of barrier island, with each population spanning a range of dune elevations and backdune habitat

Longleaf Pine Sandhill

- Structure: Longleaf Pine DBH distribution, densities and BA; Understory Oak DBH distribution and density
- Composition: species richness, abundance measures of Graminoids, Legumes, Woody Vines, Woody Species, Invertebrates, Herps, Birds
- Function (Ecological Processes): fire frequency and intensity and light gap formation
- Spatial Extent and Configuration: natural fire blocks or fire blocks approaching 10,000 acres, and a spatial configuration that minimizes edge

Process-based Desired Future Conditions

- Florida Bog Frog, Okaloosa Darter
  - protect watersheds, threat abatement
- Atlantic White Cedar/Baygall
  - assume natural processes will conserve it, allow fire to enter these systems, maintain hydrology
- Riverine Aquatic
  - protect water quality/quantity, habitat quality

Sources for Developing Desired Ecological Conditions

- Existing Plans and Documents
- Ecological Models and Expert Opinion
- Reference Populations or Sites
- Contemporary Analogs
- Historic Written Accounts, Photographs, Plot Data
- Pollen and Macrofossil Records
  - use all with caution: assumptions and bias, unknown historic events, problems with extrapolation

Start somewhere, successive approximation of an accurate management objective

Types of Ecological Models

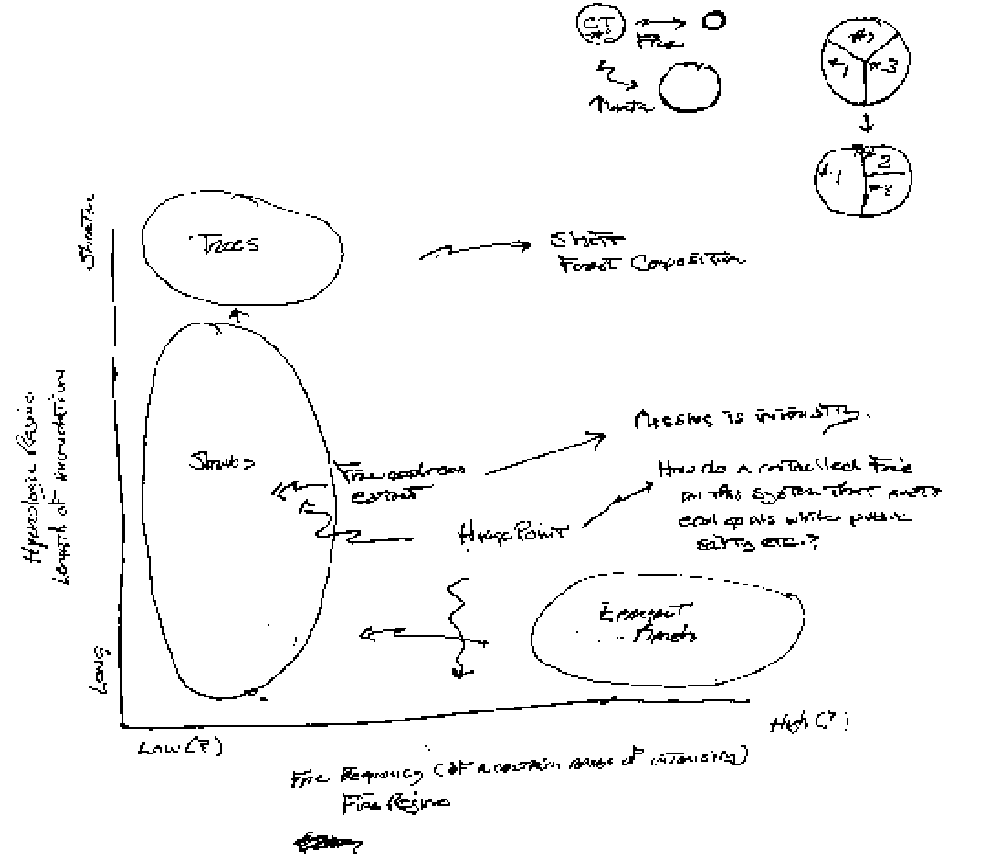
- Heuristic (Conceptual) Models
  - Illustrates the understanding of system behavior
  - Underlies all management/restoration, what varies is the degree to which the model is articulated and communicated
- Statistical (Quantitative) Models
- Simulation (Predictive) Models

Conceptual Ecological Models

- Conceptual or Heuristic Models include
  - schematic diagrams that illustrate the working understanding of system behavior
  - components of the model are states and processes
- Can evolve into other models:
  - Statistical and Simulation Models
- "The most useful and strategic approach is to start with an initial model – no matter how crude – and use its formulation, parameterization and uncertainty to marshal field studies that will build and refine the model most efficiently." Dean Urban

The Best Models …

- Framed in terms of attributes that might be measured in real systems
  - Speaks directly to field data
- Multi-dimensional
  - Multiple attributes
- Allows comparison between a managed or degraded system in terms of ecological similarity (integrity) with some reference condition



Uncertainties:

What range of fire intensities alter structure & composition?

Is length of inundation the right metric for Hydrologic Regime?

Is Intensity more important than timing?

Is drawdown a tool to eliminate ...?

Can increased length of inundation extend benefits of fire (inhibit shrubs)?

What is relationship between emergent marsh, floating mat & open water?

Develop ... alternative hypotheses.

How to use Model?

Document the DATA

Id. DATA gaps

Agencies – action, ...

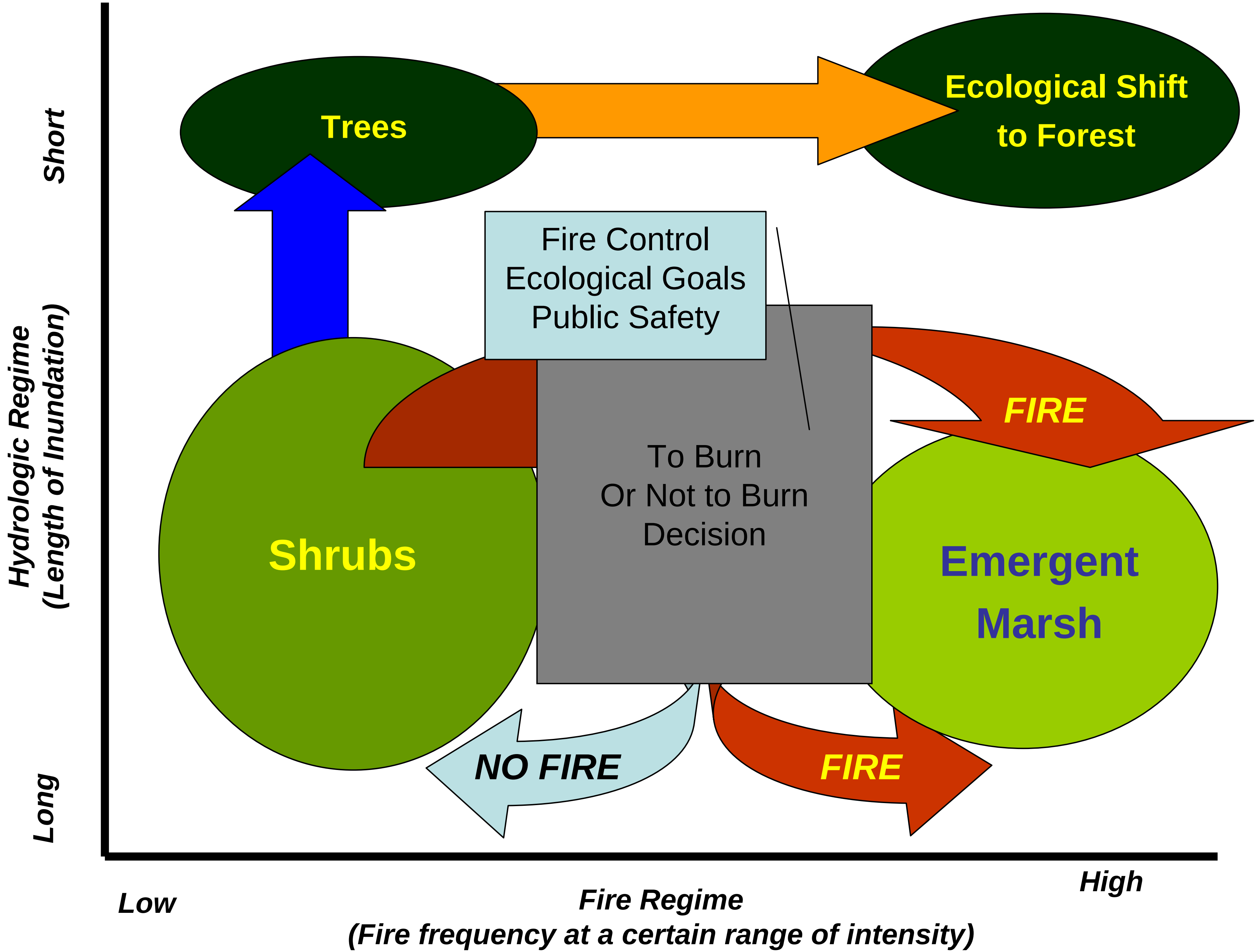
hypotheses – Diff. Interpretation

(...) – ... open water ...

– lose public support

– limit spatial extent?

... – ... goals


Trees
Ecological Shift
to Forest
Fire Control
Ecological Goals
Public Safety
To Burn
Or Not to Burn
Decision
Shrubs
Emergent
Marsh
FIRE
NO FIRE
FIRE
Short
Long
Hydrologic Regime
(Length of Inundation)
Low
High
Fire Regime
(Fire frequency at a certain range of intensity)

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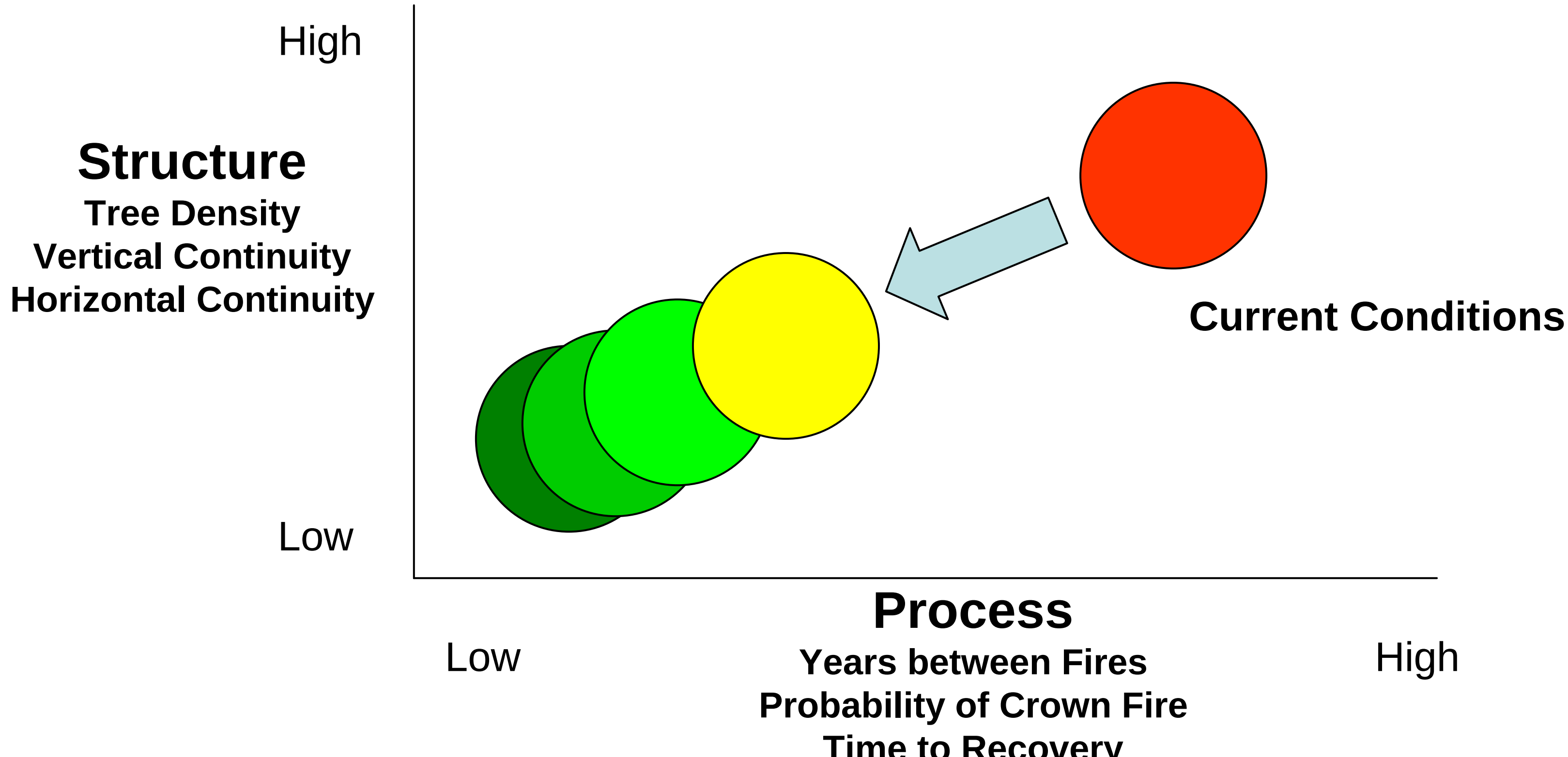
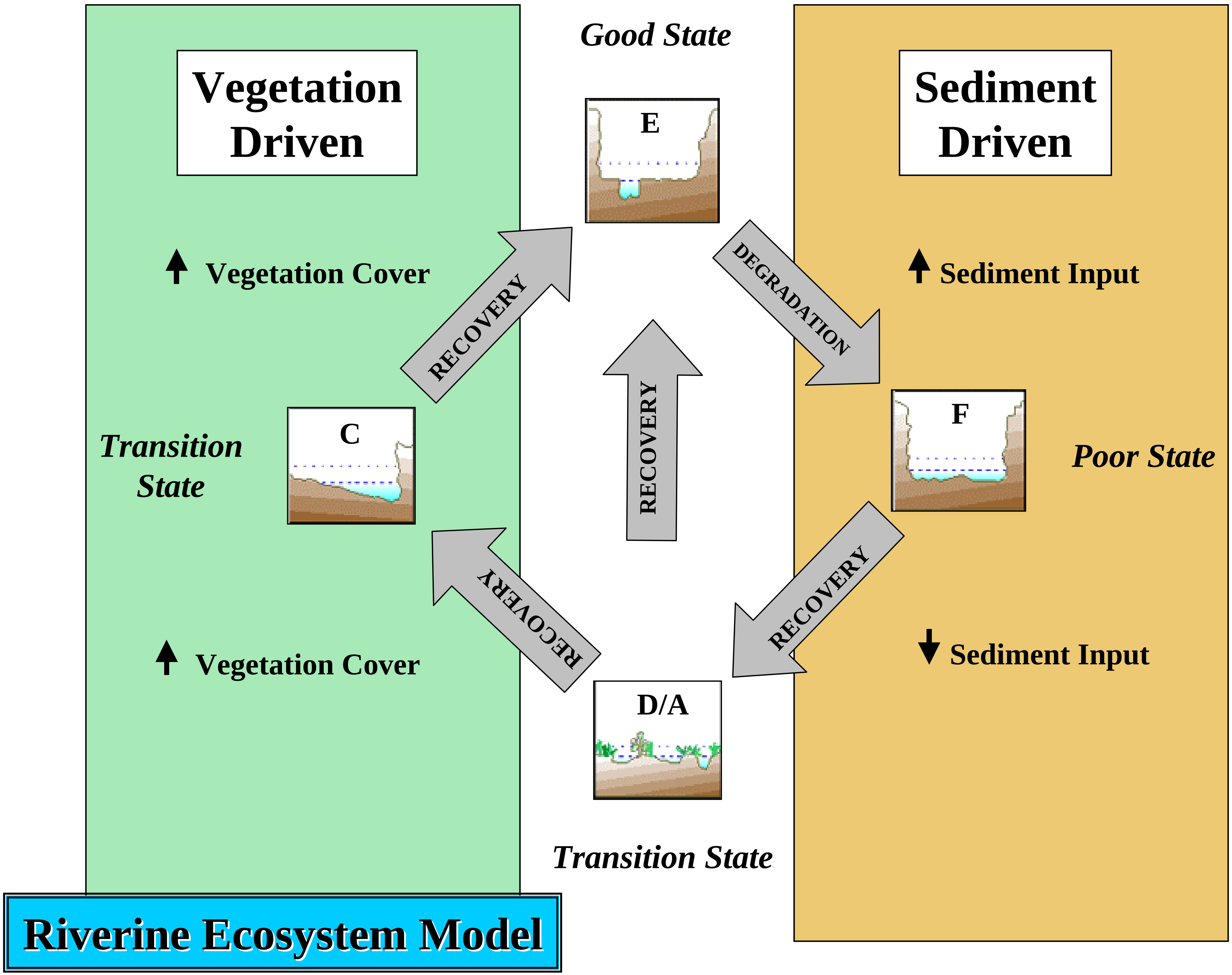
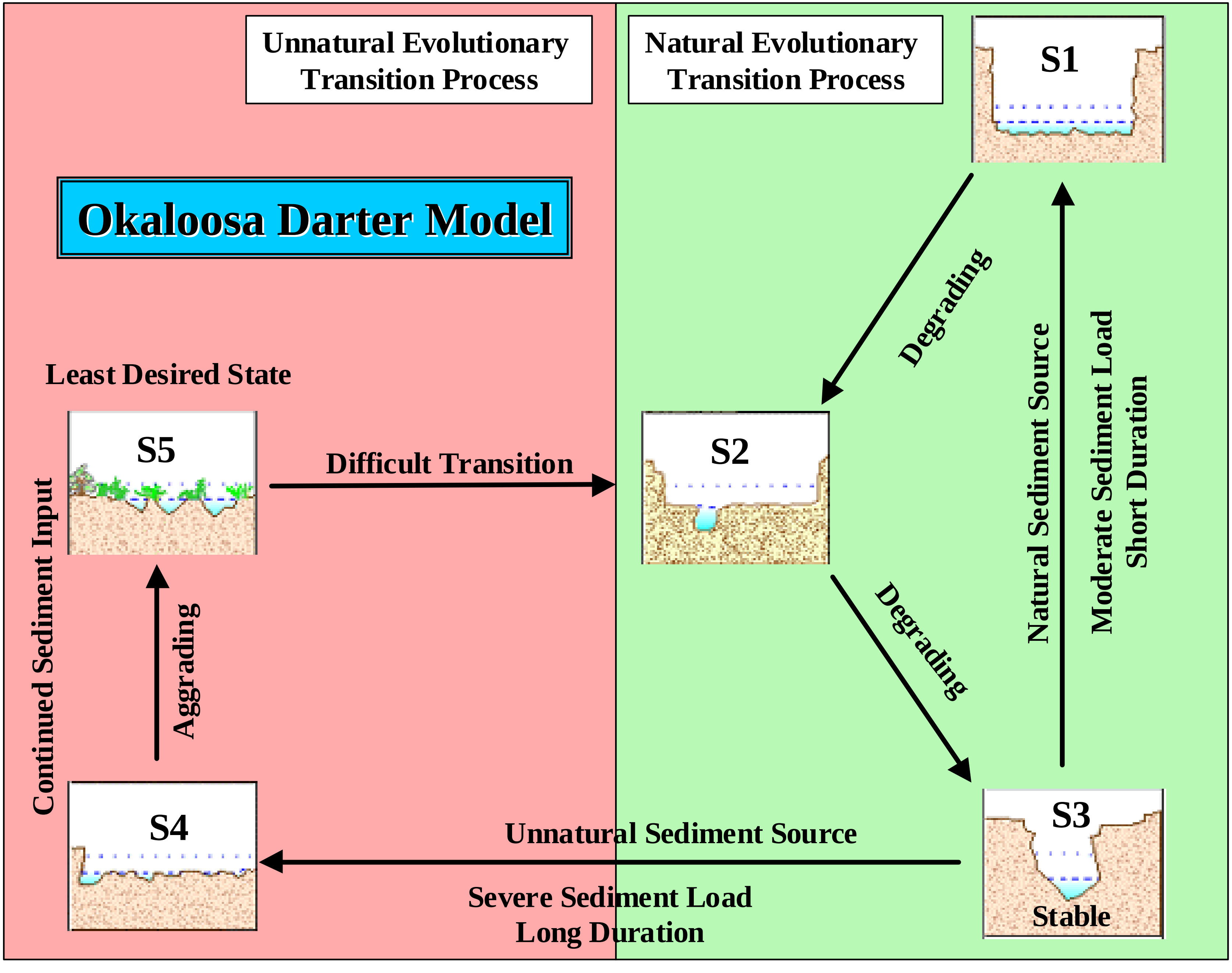
Conceptual Model of Ponderosa Pine Forests (Allen et al. 2002)



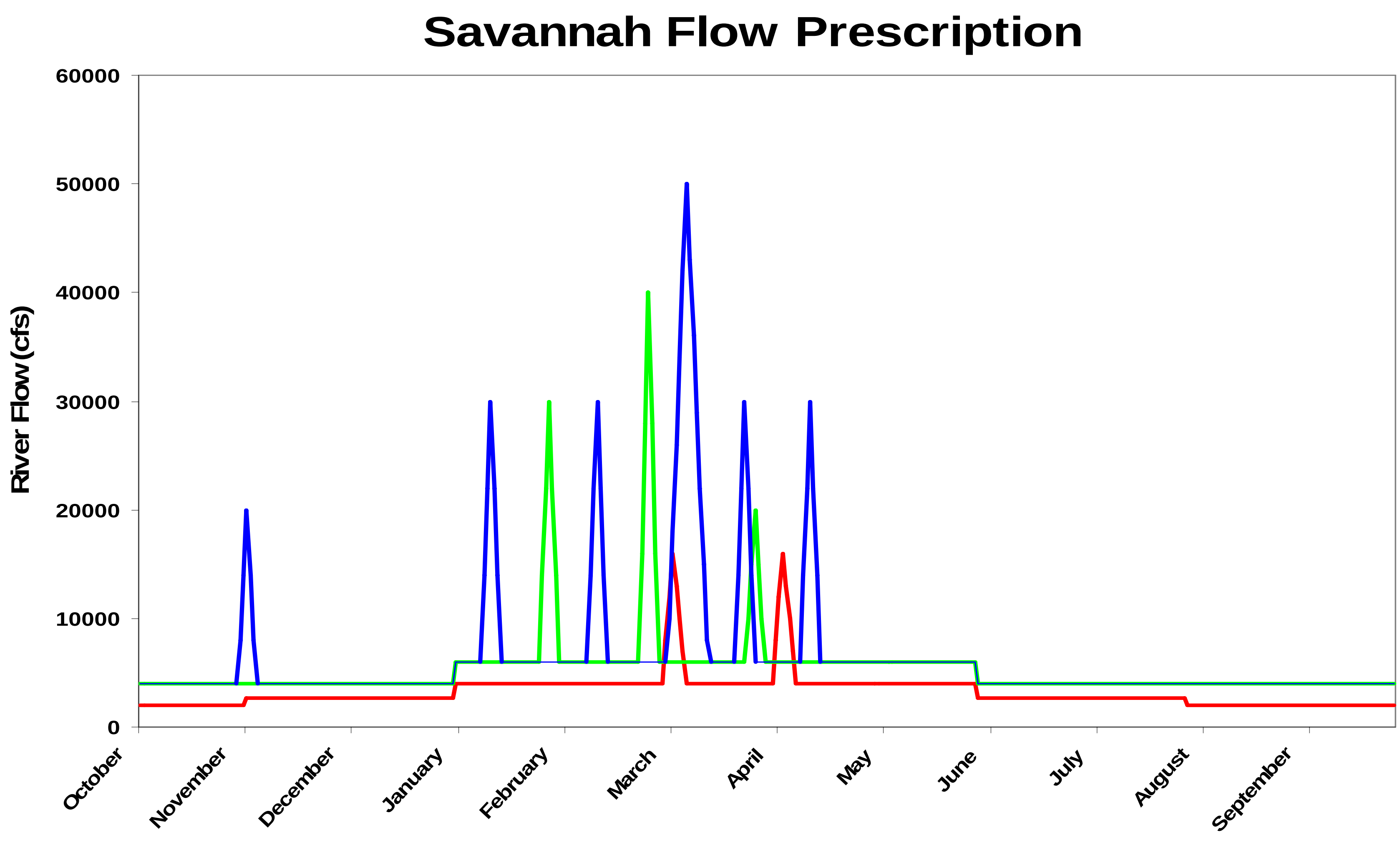


Good State
Vegetation Driven
Sediment Driven
E
Vegetation Cover
Sediment Input
RECOVERY
DEGRADATION
RECOVERY
F
Transition State
C
Poor State
RECOVERY
RECOVERY
Vegetation Cover
Sediment Input
D/A
Transition State
Riverine Ecosystem Model



Unnatural Evolutionary Transition Process
Natural Evolutionary Transition Process
Okaloosa Darter Model
S1
Degrading
Natural Sediment Source
Moderate Sediment Load
Short Duration
Least Desired State
S5
Difficult Transition
S2
Degrading
Continued Sediment Input
Aggrading
S4
S3
Unnatural Sediment Source
Severe Sediment Load
Long Duration
Stable

Desired Ecological Condition for Flow for the Lower Savannah River



Management Components of a Monitoring Objective

- Target – the population/species or community/habitat that is the focus of monitoring and/or management
- Location – the specific location where monitoring and/or management is taking place (management unit, subpopulation)
- Desired Ecological Condition - a monitoring threshold or management benchmark or endpoint
- Condition or Management Assessment
  - Status – range of threats or management assessed by monitoring
  - Effectiveness – specific management or threat abatement actions chosen to get to desired ecological condition assessed by monitoring
- Timeframe
  - Status: when condition will be assessed for next steps
  - Effectiveness: when the management action will have its impact
- Attributes – what will be measured to assess status or effectiveness

Conservation and Management Actions

- Conservation and Management Actions are the **HOW** you get to the desired ecological conditions
- Need to consider the starting conditions
  - Threat abatement
  - Restoration phase versus Management/Maintenance phase
  - Multiple tools
- Also need to consider:
  - Public response, perception
  - Logistics of implementation
  - Resources required
- Management is a **Hypothesis**

Timeframe

- Time is an ecological process
- It has taken decades (centuries) to get to this degraded state
  - It may take decades to return it to a desired state
  - Structure and function will be regained before composition
- Emphases the need for a durable management and monitoring plan

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Discussion of Ecological Models, Desired Ecological Conditions Management Components of the Monitoring Objective

Monitoring Components of a Monitoring Objective

- Target – the population/species or community/habitat that is the focus of monitoring and/or management
- Location – the specific location where monitoring and/or management is taking place (management unit, subpopulation)
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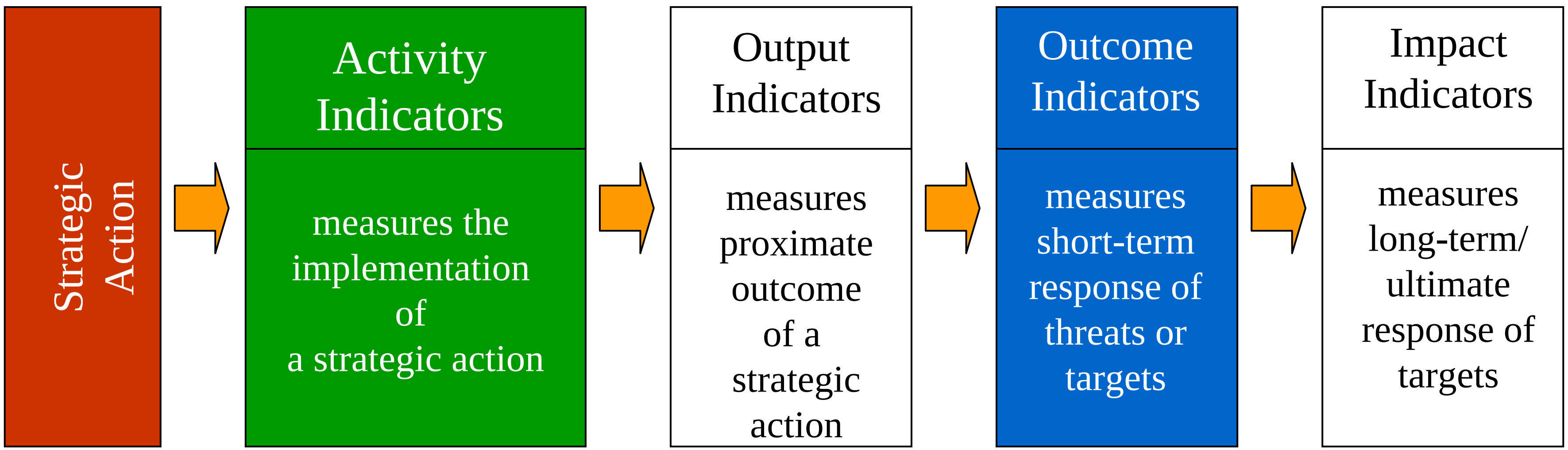
- Timeframe
  - Status: when condition will be assessed for next steps
  - Effectiveness: when the management action will have its impact
- Indicators – what will be measured to assess status or effectiveness

The Difficulties of Selecting Indicators

- The word: indicator, attribute, metric, variable
- Multi-dimensional Nature of Indicators
  - Conservation Activity >>> Impact on the Target
  - Direct and Indirect Indicators
  - Temporal Indicators
    - Leading and lagging indicators

Types of Indicators



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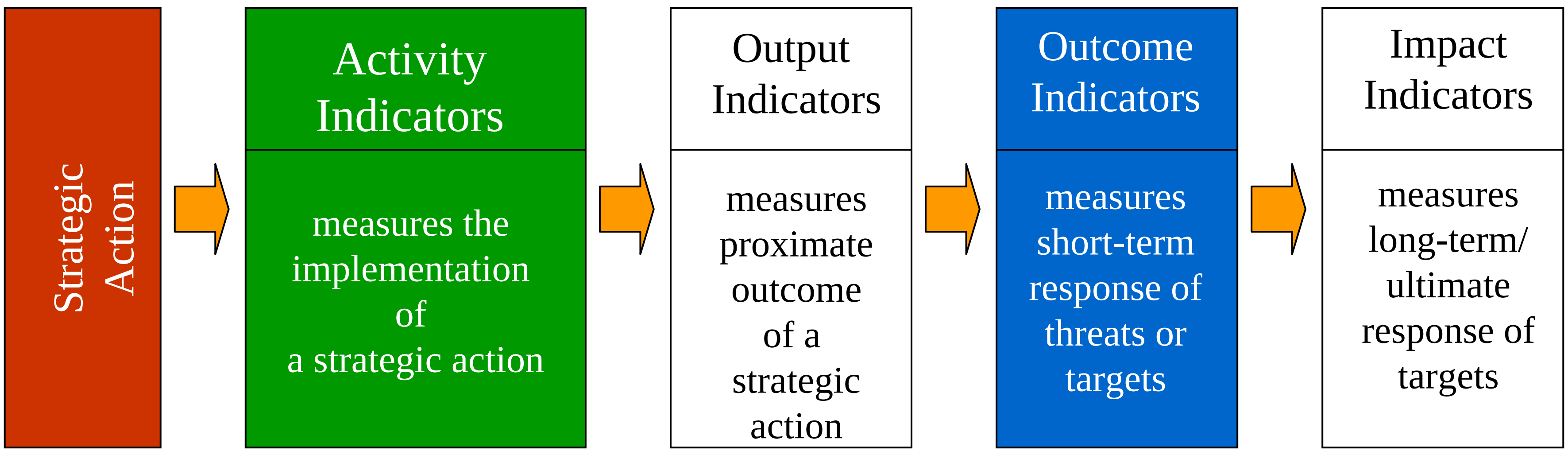
Types of Indicators



Example: Longleaf Pine Ecosystem

Prescribed Fire Implemented

Fire Effects

Structural Response

Species Richness Target Species

Types of Indicators

Strategic Action → **Activity Indicators**: measures the implementation of a strategic action → **Output Indicators**: measures proximate outcome of a strategic action → **Outcome Indicators**: measures short-term response of threats or targets → **Impact Indicators**: measures long-term/ ultimate response of targets

Example: Longleaf Pine Ecosystem

Activity	Output	Outcome	Impact
Prescribed Fire Implemented	Fire Effects	Structural Response	Species Richness Target Species

Public Concern   Conservation Concern

Selecting Indicators

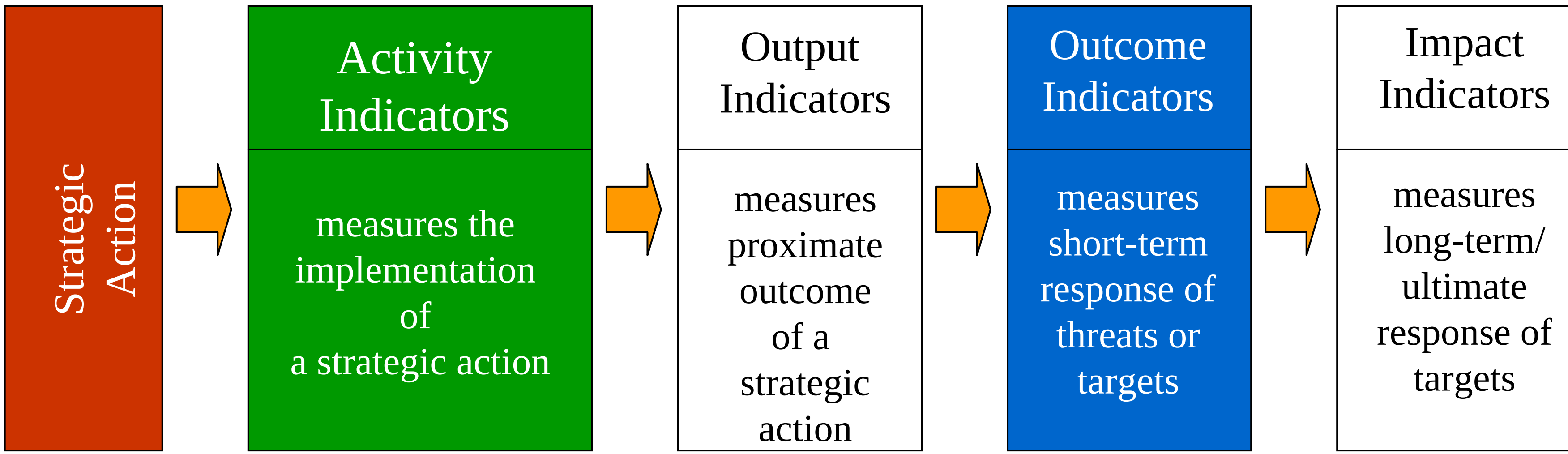
How closely are the indicators related to the targets?

- Indicators directly related to changes in the target
  - Species: population size, fecundity
  - Systems: composition, structure

- Indicators hypothesized to be related to changes in the target (proxies)
  - Species: community structure, fire history, water quality, indicator species
  - Systems: community structure, fire history

- Indicators that reflect land use, land management and/or threat abatement
  - Land Use: urban, forest cover
  - Land Management: acres burned, sediment control
  - Land Protection: protected acres

Types of Indicators



Example: Longleaf Pine Ecosystem

	Activity	Output	Outcome	Impact
	Prescribed Fire	Fire Effects	Structural	Species Richness
Direct			Response	Target Species
Indirect			Remote Sensing	Structure Indicator Species

What Indicators Best Assess Progress Towards the Desired Ecological Condition?

Criteria:

- **Sensitive to stresses of the system.** The most useful indicators displays high sensitivity change or to a particular stress or management action, with a known, predictable, low variability response
- **Anticipatory and predict changes** that can be averted by management actions
- **Easily measured** both in time and instrumentation
- **Span multiple spatial and ecological scales:** Abundance/ Demographic Condition, Habitat/Ecological Processes, and Landscape Context
- **Relatively few in number**
- **Meaningful to managers; Appropriate for scientists**

Challenges Selecting Measures and Indicators

- Understanding and Identifying the **different types of Measures and Indicators**
- Identifying the appropriate **Direct and Indirect Indicators** and understanding the **assumptions** associated with indirect indicators
- Selecting a **minimal set of indicators** for each strategy, target or threat
- **Integration of indicators** across all effectiveness and status measures
- Developing appropriate **monitoring protocols** for each indicator
- Incorporation of **frequency and timing** into monitoring

Exercise:
Drafting a Monitoring Objective

For a Selected Species

- Target – the population/species or community/habitat that is the focus of monitoring and/or management
- Location – the specific location where monitoring and/or management is taking place (management unit, subpopulation)
- Desired Ecological Condition - a monitoring threshold or management benchmark or endpoint
- Condition or Management Assessment
  - Status – range of threats or management assessed by monitoring
  - Effectiveness – specific management or threat abatement actions chosen to get to desired ecological condition assessed by monitoring
- Timeframe
  - Status: when condition will be assessed for next steps
  - Effectiveness: when the management action will have its impact
- Attributes – what will be measured to assess status or effectiveness

Write either as a Status or Trend Monitoring Objective

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Discussion

- What difficulties did you have completing the management objective?
  - Difference between Status and Trend Objective
  - Lack of information for Desired Ecological Condition
  - Unsure of which attributes should be selected
- What information would you like to have and where would you get that information?
- How does the Desired Ecological Condition and management objective focus monitoring efforts?
- What barriers exist in your agency/situation to developing management objectives?

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Sampling Objectives

How precise will the data be?

What amount of change can be detected?

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Sampling Objective

- Companion to a monitoring objective whenever monitoring includes sampling procedures
  - Sampling: assessing a portion of a population or ecological system with the intent of making inferences to the whole population or system
- A sampling objective sets a specific goal for the measurement of the target/threshold or change/trend value identified in the monitoring objective

What are Precision and Power?

- Precision: statistical term for the closeness of repeated measurements to one another
  - A measure of the variability of your data
- Power: statistical term that relates the risk of failing to detect a true change
- Goal:
  - minimize the variability of your data to better detect crossing a threshold or a trend
  - minimize the risk of failing to detect a change

Sampling Objective Components

- For **Target/Threshold** Monitoring Objectives:
  - Confidence Level
  - Confidence Interval
- For **Trend/Change** Monitoring Objectives:
  - Power
  - Minimal Detectable Change
  - False Change Error Rate

How do you Increase Precision and Power?

- For **Status/Threshold** Monitoring Objectives:

$$SE = s / \sqrt{n}$$

SE = Standard Error
s = standard deviation
n = sample size

- For **Trend/Change** Monitoring Objectives:

Power = a function of (s, n, MDC, α)

MDC = minimal detectable change
α = false-change error rate

Sampling Objective Components

- For **Status/Threshold** Monitoring Objectives:

We want to be 95% confident (CL) that estimates are within +/- 25% (CI) of the estimated true mean

- For **Trend/Change** Monitoring Objectives:

We want to be 90% sure (Power) of detecting a 20% change (MDC) in density and willing to accept a 1 in 10 chance that it didn't take place (FC)

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Overview of Sampling Design

Statistical Terms and Concepts

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Session Objectives

- Understand what **sampling design** is and why it is essential in monitoring and adaptive management
- Learn the definitions of **population, sampling unit, sample**
- Define a **standard deviation and standard error**
- Define **accuracy and precision**
- Calculate a 95% **confidence interval**

Example of a Failed Monitoring Project

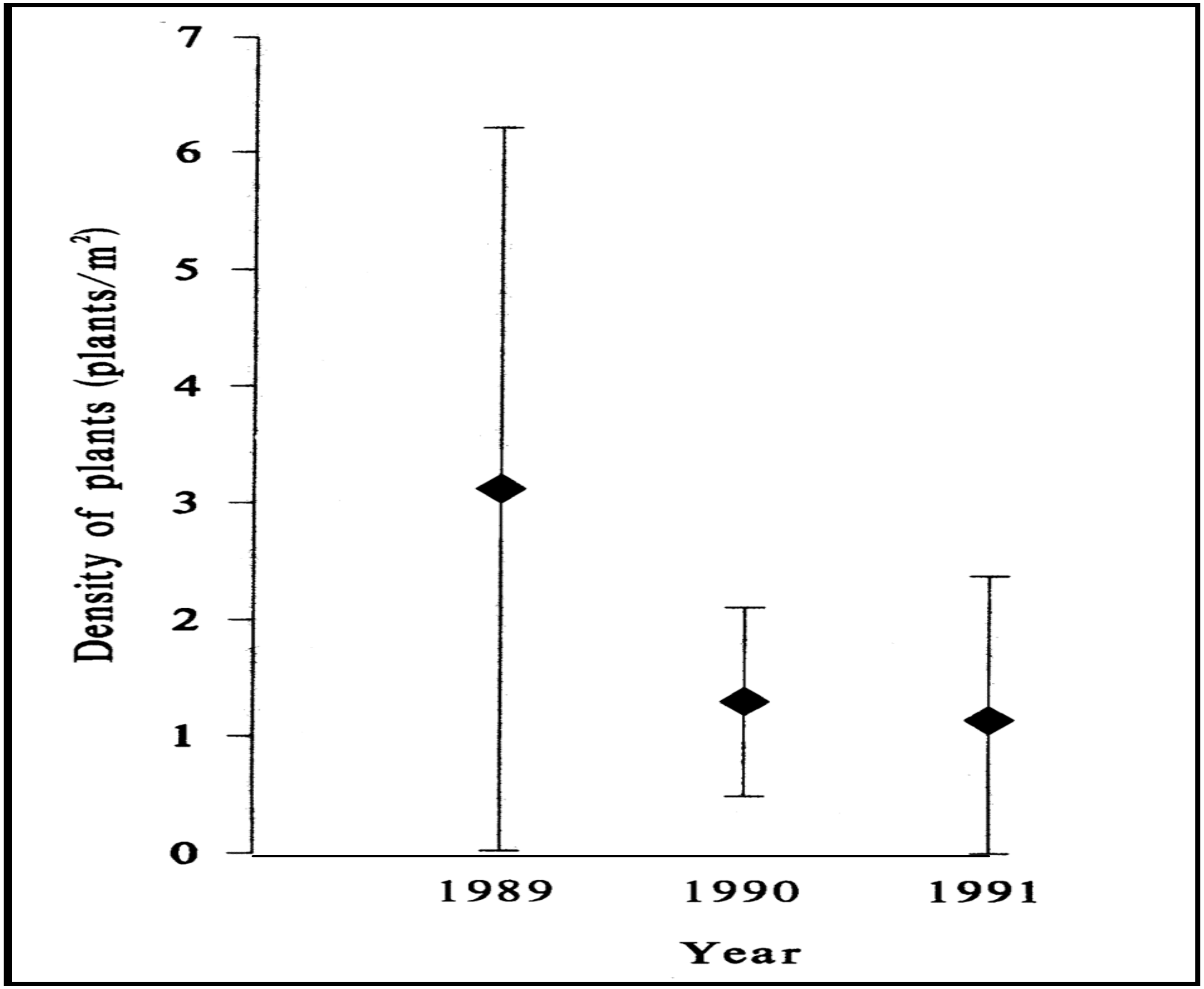

Figure 1. Density of *Lomatium cookii* in Macroplot 2 at the Agate Desert, 1989-91. Bars represent 95% confidence intervals. *Lomatium cookii* were counted in 50 1m^2 plots each year.

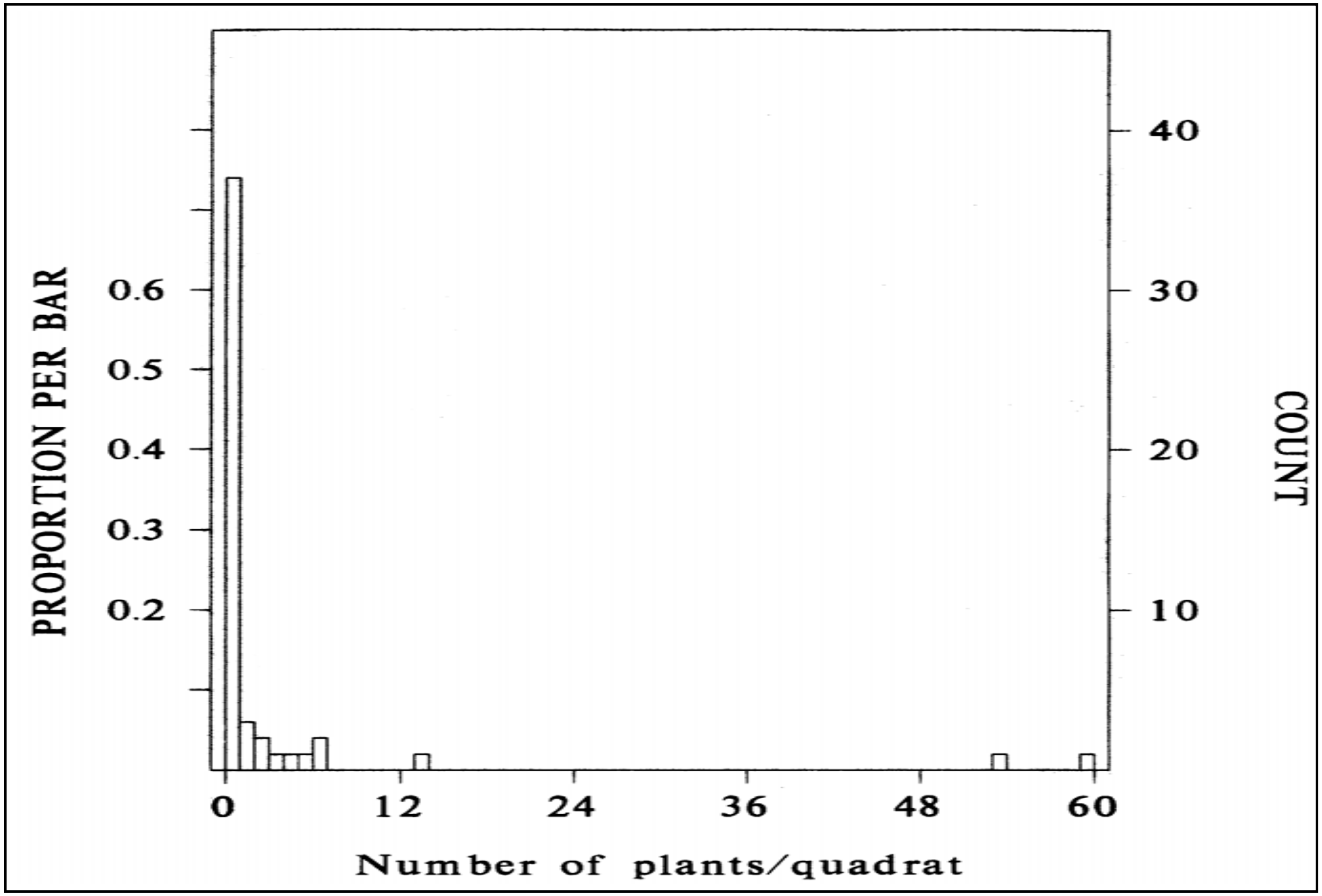

Figure 2. Frequency histogram of number of *Lomatium cookii* plants per $1m^2$ quadrant in macroplot 2 at the Agate Desert in 1989. (n=50 quadrants; sum=156 plants; mean # plants/ quadrat=3.12; sd=11.17; 37 quadrats with no plants; 13 with plants; 3-1 plant, 2-2 plants, and 1 quadrat with each of the following counts: 3, 4, 5, 13, 53, 59).

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Sampling

- Sampling is the process of selecting a part of something with the intent of showing the quality, style or nature of the whole.
- Monitoring does not always include sampling
- Sampling
  - When counting/measuring everything is not practical
  - Can yield better results than a total count by increasing the accuracy of the data

Sampling Design

A plan of sampling that minimizes data variability and maximizes the detection of change.

- Precision: describes the closeness of repeated measurements (of the same quantity) to one another
- Repeatability: ability of measurements to be repeated over time with limiting errors related to taking the measurements
- Efficiency: ability of making the measurements easily and quickly, durability of project

No "Best" Sampling Design

- Sampling designs must be tailored to fit specific objectives and ecological conditions.
- "… the decision-making process in sampling must be viewed as a flexible exercise, dictated not by generalized recommendations but by specific objectives; there is no panacea in ecological sampling."

Population, Sampling Units and Sample

- Population of Interest/Statistical Population/Sampling Frame: the complete set of individual objects about which you want to make inferences and can be sampled
- Sample Units: the individual objects that collectively make up a statistical population, e.g. individual plants, quadrats, transects, etc.
- Sample: part of a statistical population; a selected subset of the total possible number of sampling units

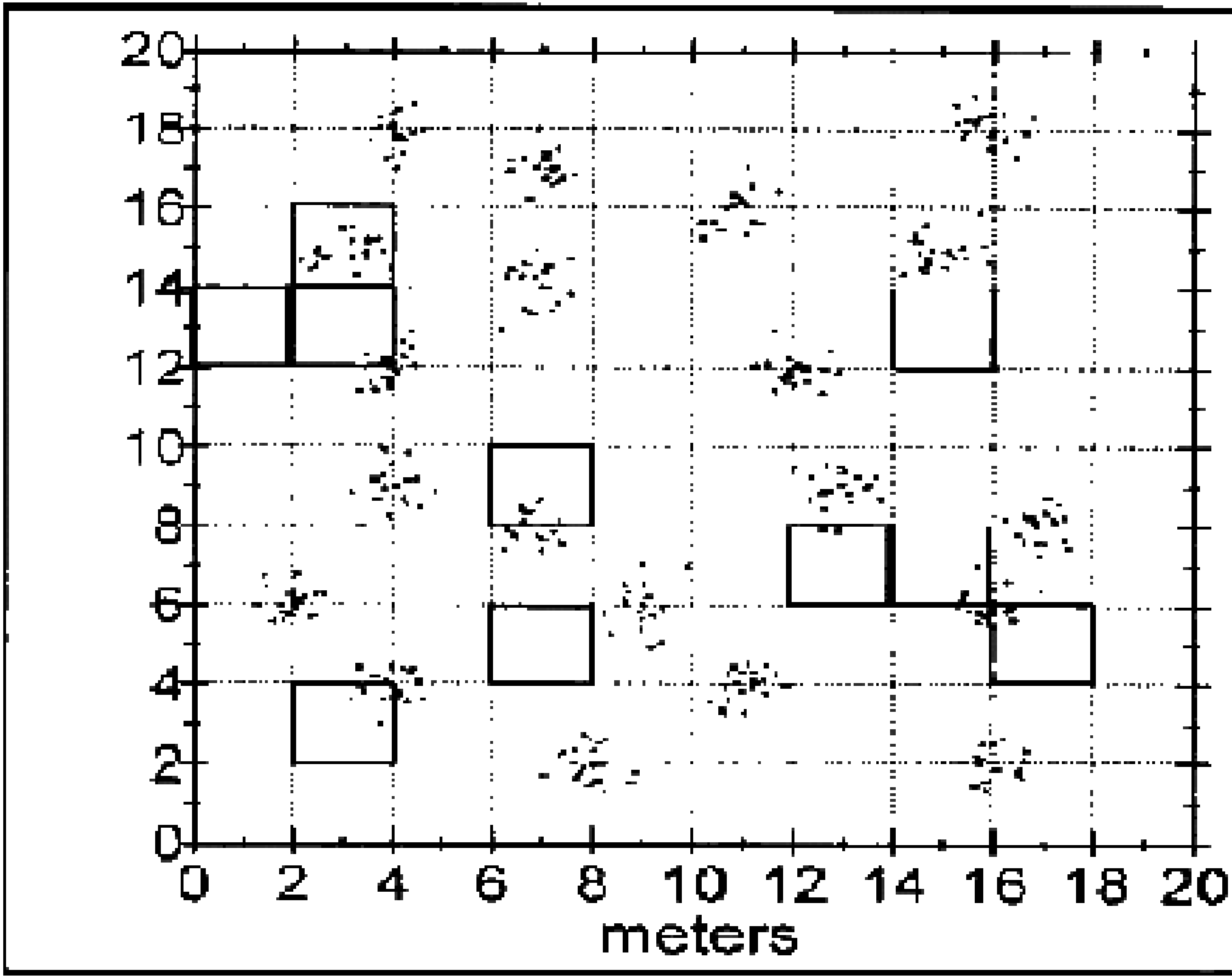


Figure 3A. A random arrangement of 2m x 2m quadrats positioned within a 400-plant population.

Population Parameters

- Descriptive measures which characterize the population and are assumed to be fixed by unknown quantities that change only if the population changes.
  - True population mean (μ)
  - True population standard deviation (σ)
    - Measure of how similar all individual observations are to the overall mean
    - Most common measure of variability

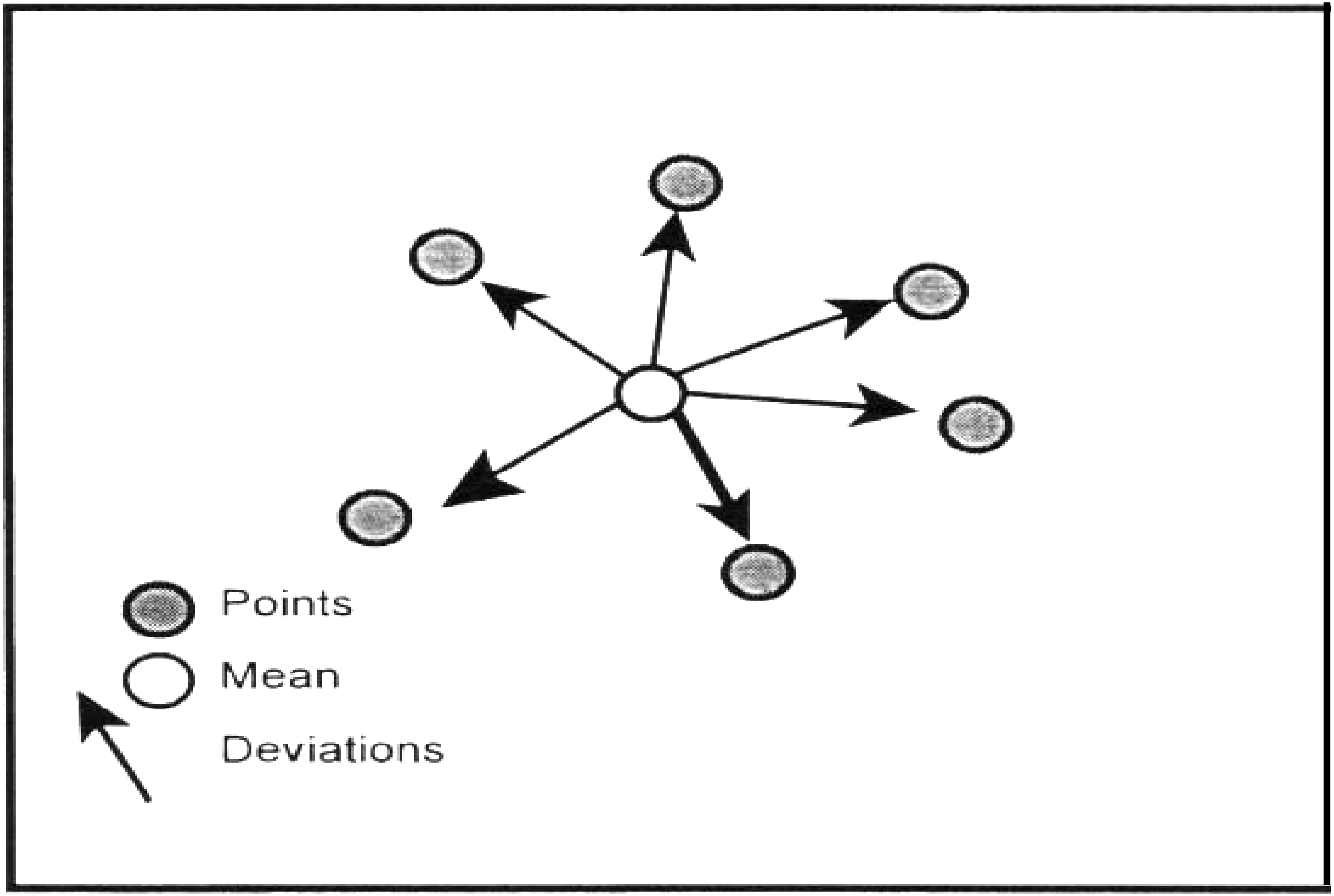


Figure 4. The standard deviation is a kind of average distance between the observations and the mean of all the observations.

Sample Statistics

- Descriptive measures that are estimates of the population parameters
  - Sample mean (x)
  - Sample standard deviation (s or SD)
    - Measure of how similar each individual observation is to the sample mean

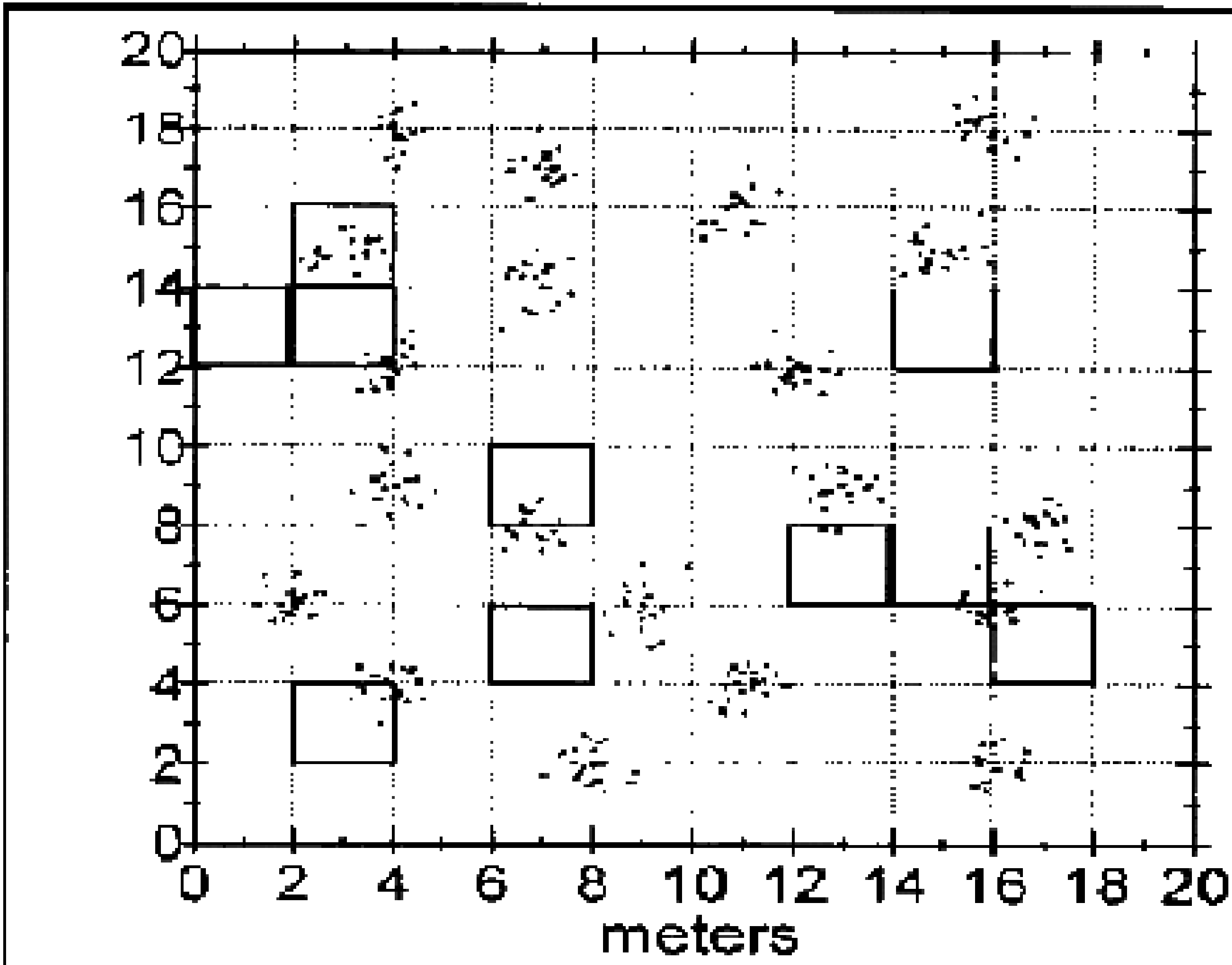


Figure 3A. A random arrangement of 2m x 2m quadrats positioned within a 400-plant population.

Sample information		
Coordinates		# of plants
X	Y	
2	2	4
6	4	0
16	4	3
12	6	2
14	6	5
6	8	10
0	12	0
2	12	6
14	12	0
2	14	20

Population parameters

Tot. pop. size: 400 plants

Mean # plants/quadrat:

$\mu = 4$

Standard deviation:

$\sigma = 5.005$

Sample statistics (n=10)

Mean # plants/quadrat

$\bar{x} = 5.0$

Standard deviation:

$s = 6.146$

Population estimate

Est. pop. size = 500 plants

95% CI = ± 361 plants

Figure 3B. Population parameters and sample statistics for the 400-plant population in **Figure 3A.**

Accuracy and Precision

- Accuracy: the closeness of a measured or computed value to its true value
- Precision: statistical term for the closeness of repeated measurements to one another -- a measure of the variability of your data
  - Dependent on the:
    - variability of the underlying population
    - variability of the sampling data
    - sample size (number of sample units)

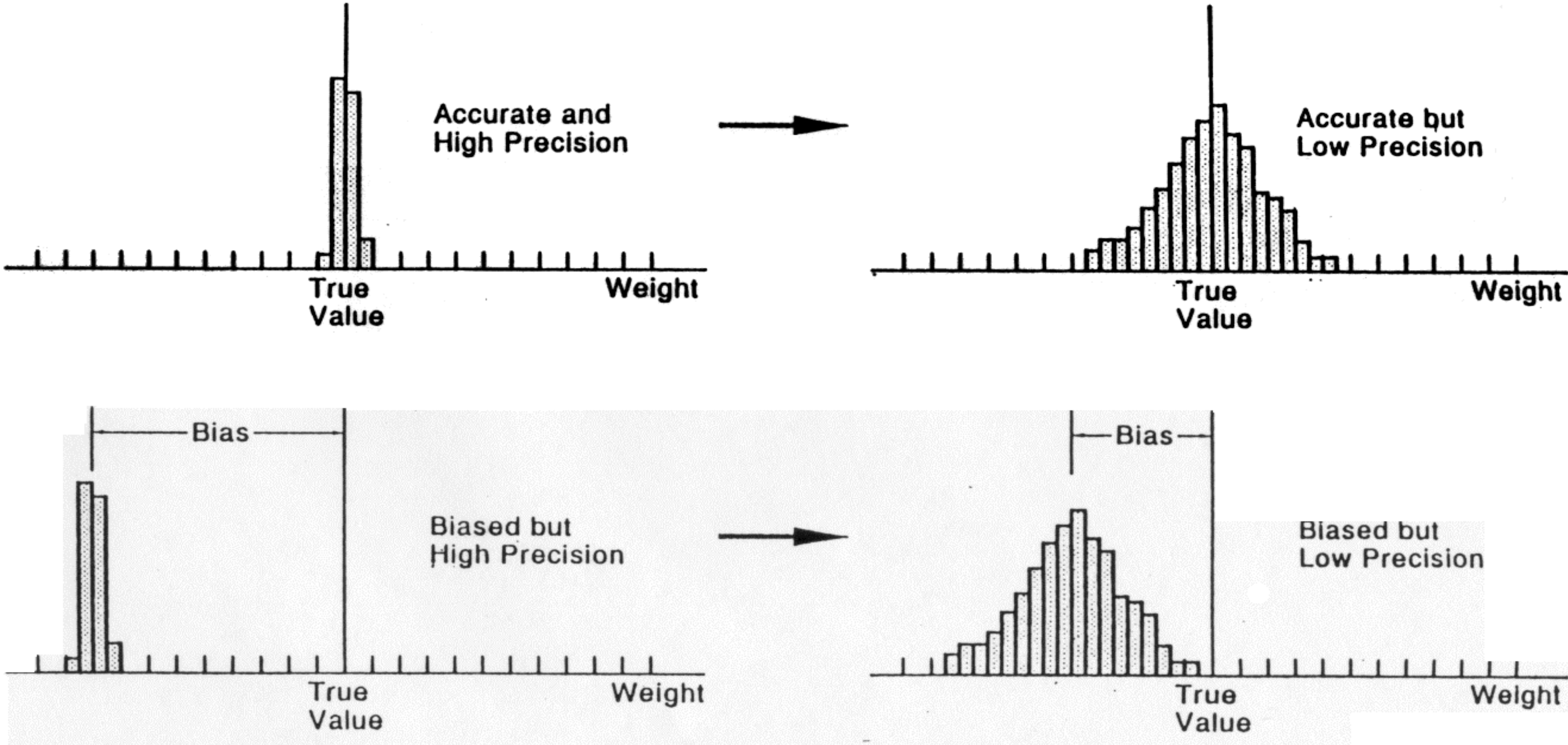
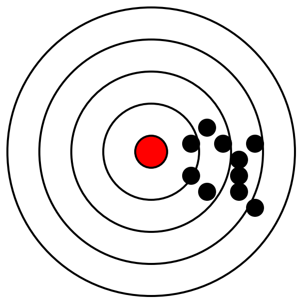


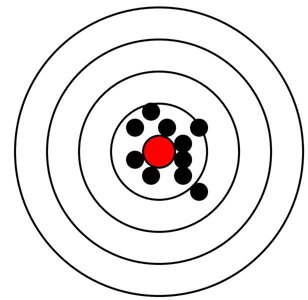
Figure 5. An illustration of accuracy and precision in ecological measurements. In each case, a series of repeated measurements are taken on a single item, e.g. weight of a single fish specimen. From Krebs, C.J. 1989. Ecological Monitoring. Harper Collins, New York.

Estimation

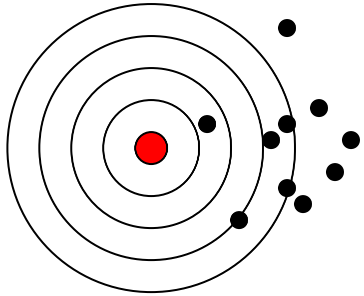
Precise but biased



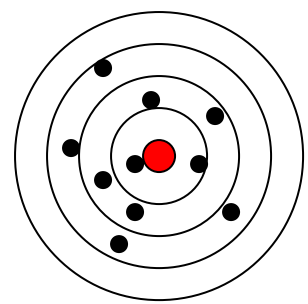
Unbiased and precise



Biased but not precise

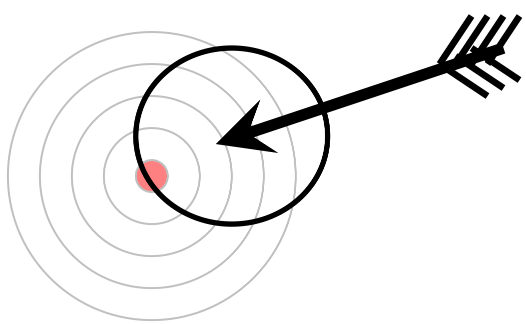


Unbiased and not precise



Estimation

- *Statistical estimation is like shooting a single arrow at an invisible target and inferring the location of the bull's eye based on where the arrow lands.*



Measures of Precision

- Standard Deviation (s)
  - Measure of how similar each individual observation is to the sample mean (same units as measured)
  - S, σ (n-1) on calculator
- Standard Error (SE)
  - A standard deviation of all possible mean values
  - $SE = s / \sqrt{n}$
  - Sampling Design = reducing the standard error
- Confidence Interval (CI)
  - An estimate of precision around a sample mean that specifics the likelihood that the interval includes the true value
  - CI (1/2 width) = (SE) (t-value)
  - Two components
    - Confidence Interval Width (+/- 15 plants)
    - Confidence Level (90%)

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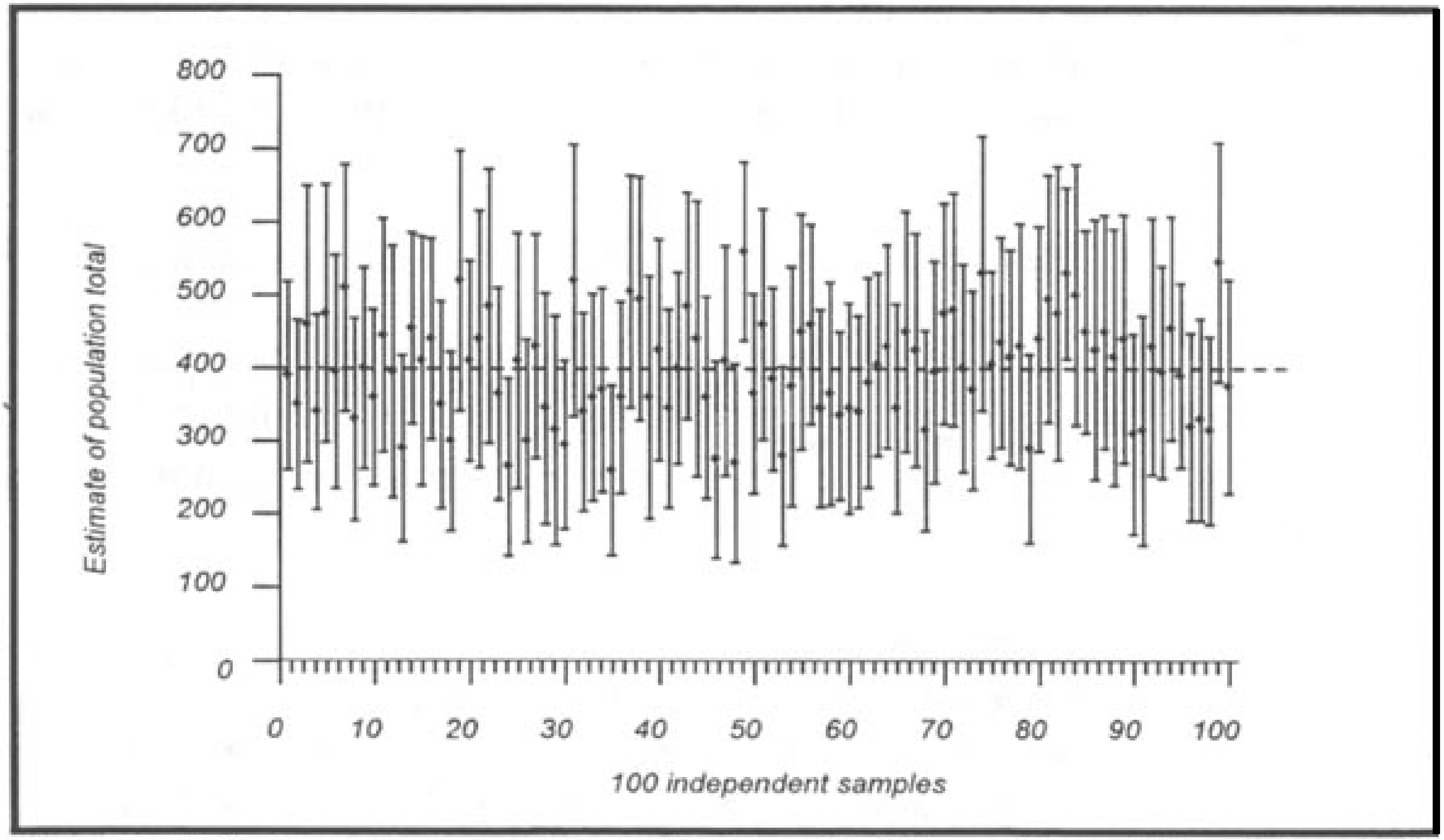

Figure 7. 100 independent population estimates with 95% confidence intervals from 400-plant populations.

Figure 6A. Different confidence intervals for the 10 2m x 2m quadrat design.

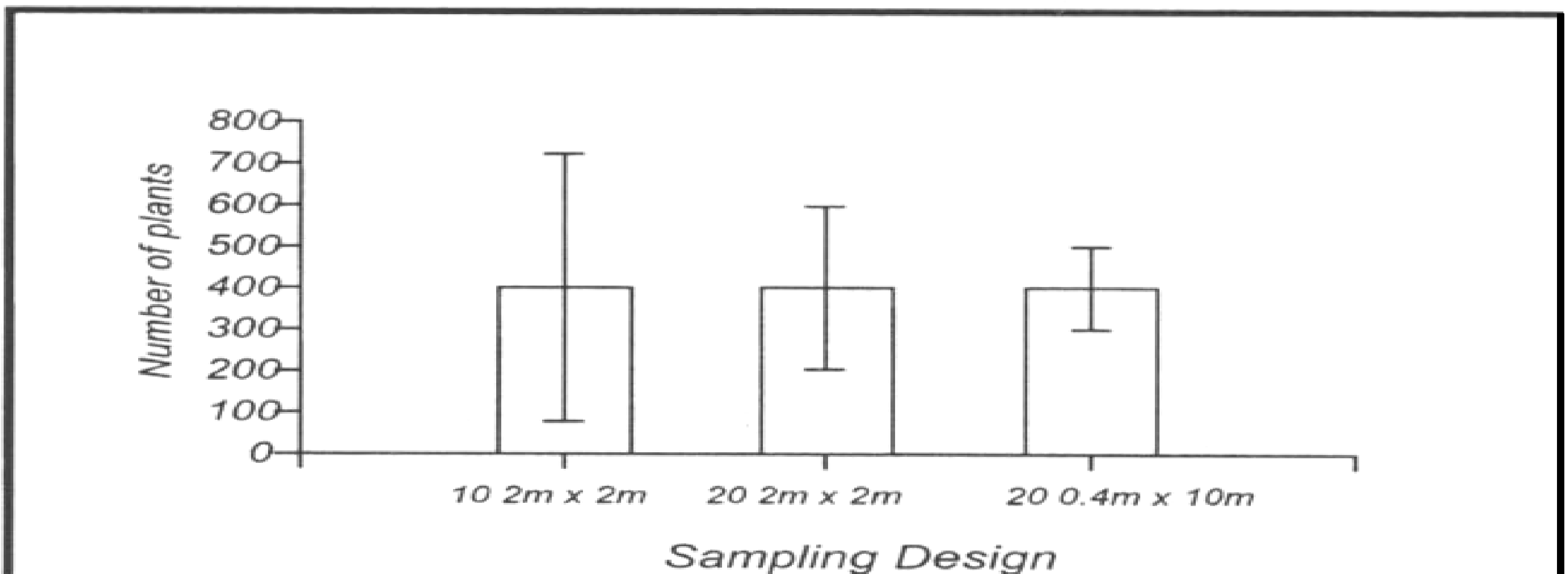

Figure 6B. 95% confidence levels for 3 different sampling designs.

Finite vs. Infinite Populations

- Sampling and statistical analyses assume an infinite population
  - Very large statistical population
  - Use of points or transects, dimensionless in one or both dimensions
- In our work: Finite Populations
  - Smaller statistical population
  - Use quadrats: finite number of locations
  - End up sampling a great percentage of the population
- Rewarded: Finite Population Correction Factor
  - Good: fewer sampling units

Exercise:
Calculating Confidence Intervals

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Five Sampling Design Decisions

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Sampling Design (Survey Design)

A plan of sampling that minimizes data variability and maximizes the detection of change.

- Precision: describes the closeness of repeated measurements (of the same quantity) to one another
- Repeatability: ability of measurements to be repeated over time with limited nonsampling error
- Efficiency: ability of making the measurements easily and quickly, durability of project

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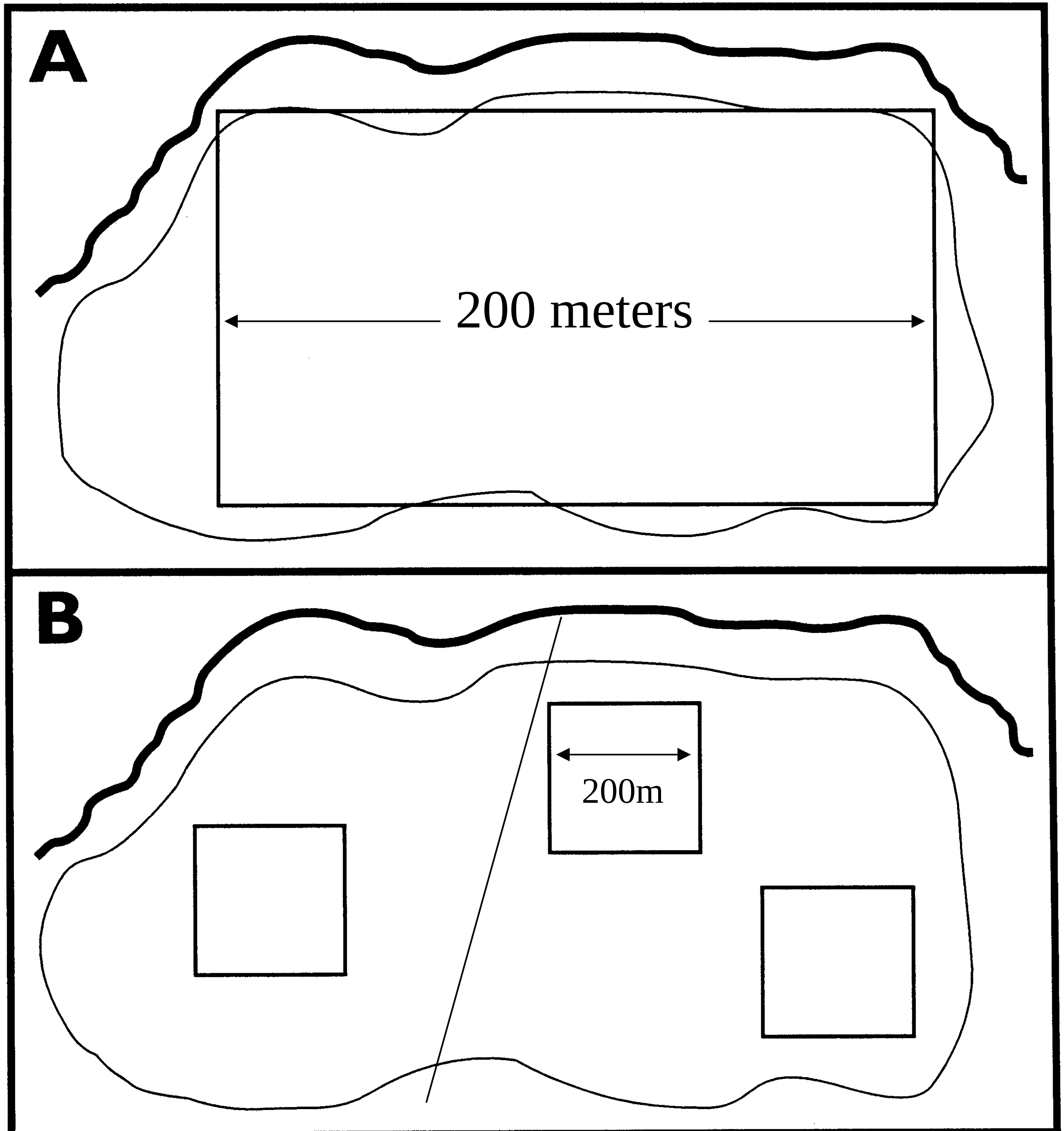
5 Sampling Design Decisions

1. What is the population of interest?
2. What is the appropriate sample unit and the appropriate sample unit size and shape?
3. What is the spatial allocation of sample units?
4. What is the temporal allocation of sample units? (How often should the sampling units be sampled? Should the sampling unit positions be permanent or temporary?)
5. How many sample units should be included in the sample?

1. What is the Population of Interest?

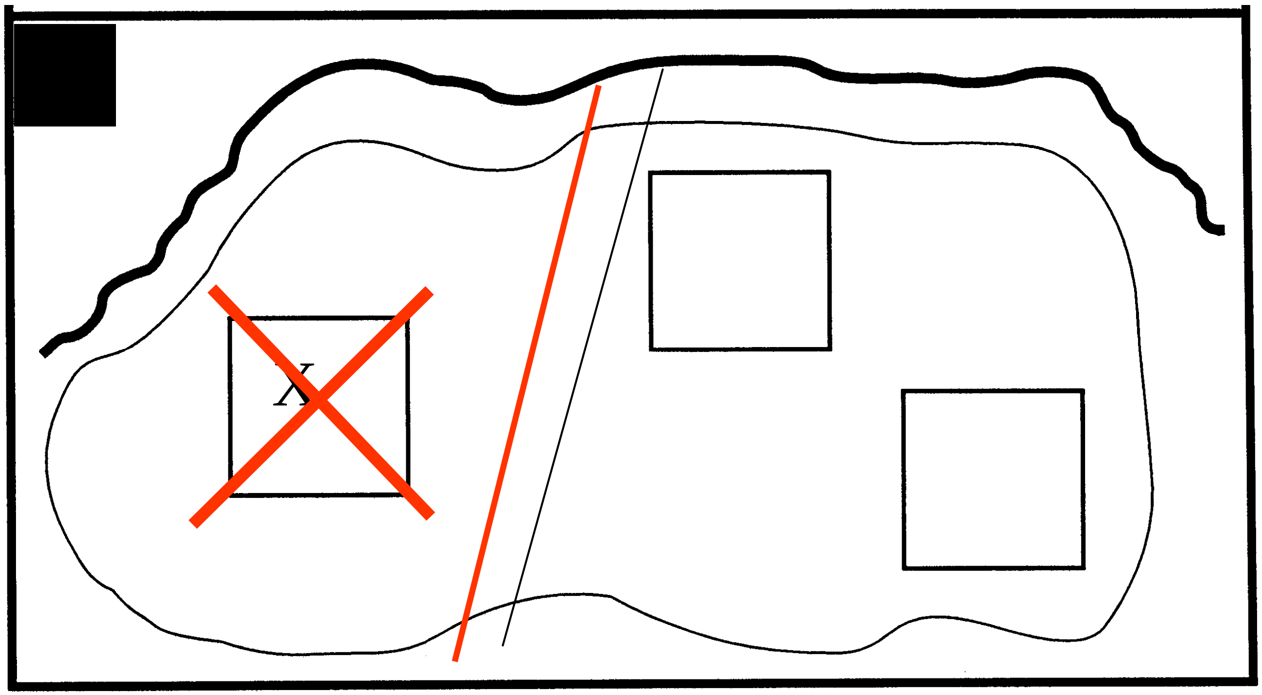
- Biological population
  - all individuals within a specified area at a particular period in time that are assumed to be biologically (reproductively/ demographically) interrelated
- The statistical, or "target" population
  - the portion of the biological population that is of interest and can be sampled to estimate parameters for the whole target population
- The sampled, or "index" population
  - the portion of the target population that is selected to represent the whole population
  - represents a biased and untestable estimate of parameters for a larger population



What are the population boundaries like?

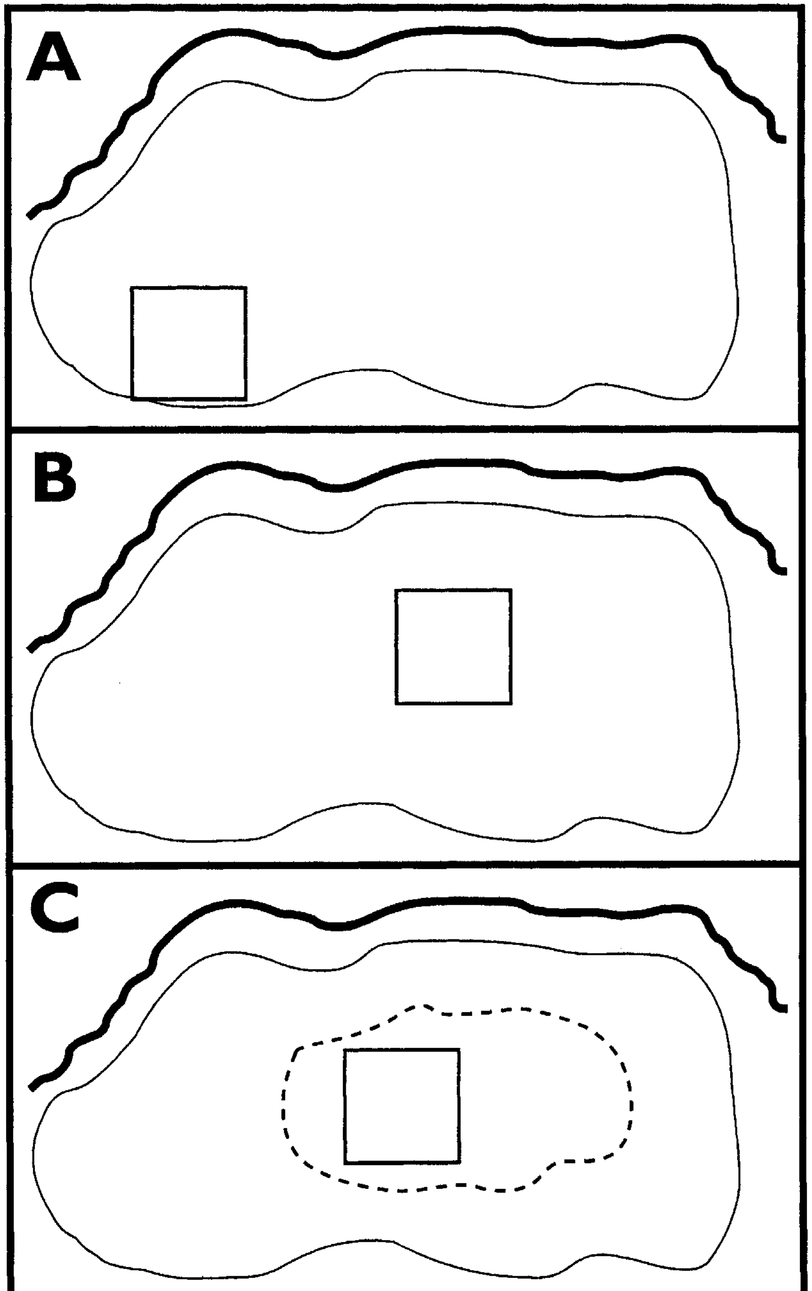
How large is your target population?

Positioning of macroplots (rectangles or squares) within irregularly shaped target populations (thin lines).



Can you sample all of the biological population?

Positioning of macroplots (rectangles or squares) within irregularly shaped biological population (thin lines).

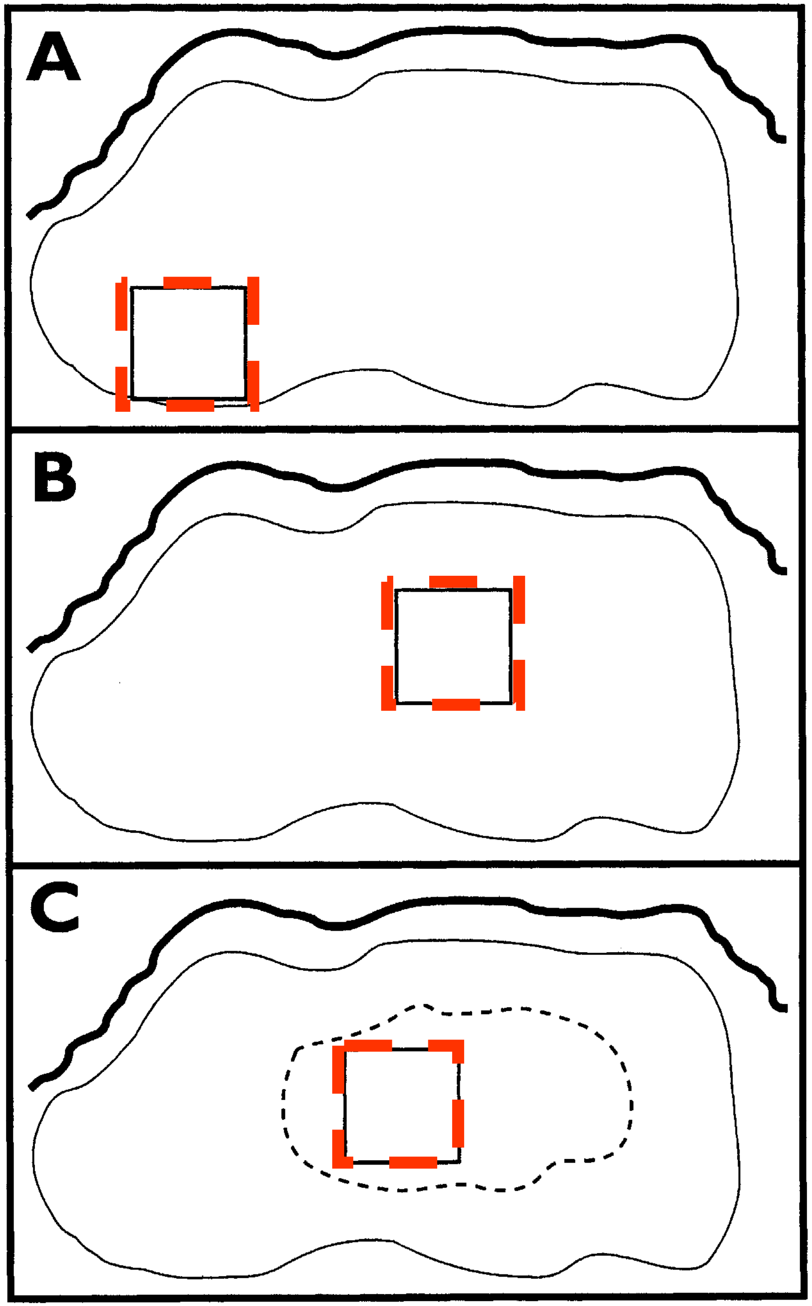


Index Population

In each case, a single square macroplot has been placed in the target population.

If only one macroplot is used, the sampled population is MUCH smaller than the target population.

In C, subjective placement is in a "representative" area, illustrated by the dotted line (defines new, smaller, index population).



What is the extent of your inference space?

In A, B and C, the inference space only extends to the sampled population – because the sampling design lacks replication.

What is the Population of Interest? Examples

- Biological population
  - All individuals (community/species) within the open wetland defined by the road, Cold Prong Creek and the upland forest at mile marker 247 along the Blue Ridge Parkway.
- The statistical, or “target” population
  - All individuals (community/species) within the open wetland on NPS ownership defined by the road, Cold Prong Creek and the upland forest at mile marker 247 along the Blue Ridge Parkway.
- The sampled, or “index” population
  - All individuals (community/species) with a macroplot established in the wettest section of the open wetland defined by the road, Cold Prong Creek and the upland forest at mile marker 247 along the Blue Ridge Parkway, this area was selected to represent the whole wetland area.

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What is the Population of Interest?

- Think about the concept of population of interest and how it pertains to your project.
- Discussion

2. Appropriate Sample Unit

Sample Units

- Individuals
- Quadrats (macroplots)
- Lines (transects)
- Points
- Distance (plotless)

Depends on the Attribute

- Density
- Cover
- Frequency
- Biomass
- Individual Attributes

Size and Shape of the Sample Unit

Exercise: Estimate the population size with the sampling objective: 95% confident (CL) that estimates are within +/- 30% (CI) of the estimated true mean

- map of the population
- given a specific plot size
- you will randomly pick locations (set up 10 minutes) and sample the population (15 minutes)
    - random numbers table, data sheet, instruction sheet
- calculate confidence intervals based on your data

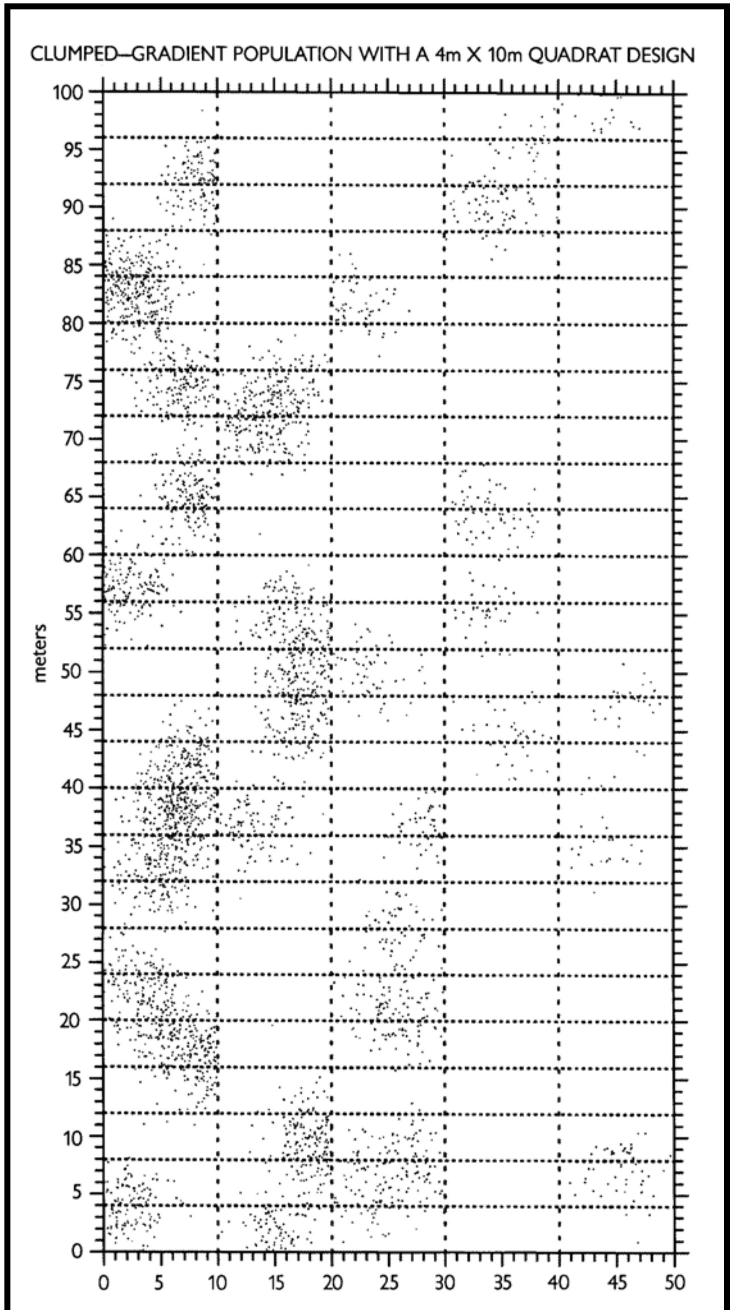

Figure 12. Clumped-gradient population with a 4m x 10m quadrat design.

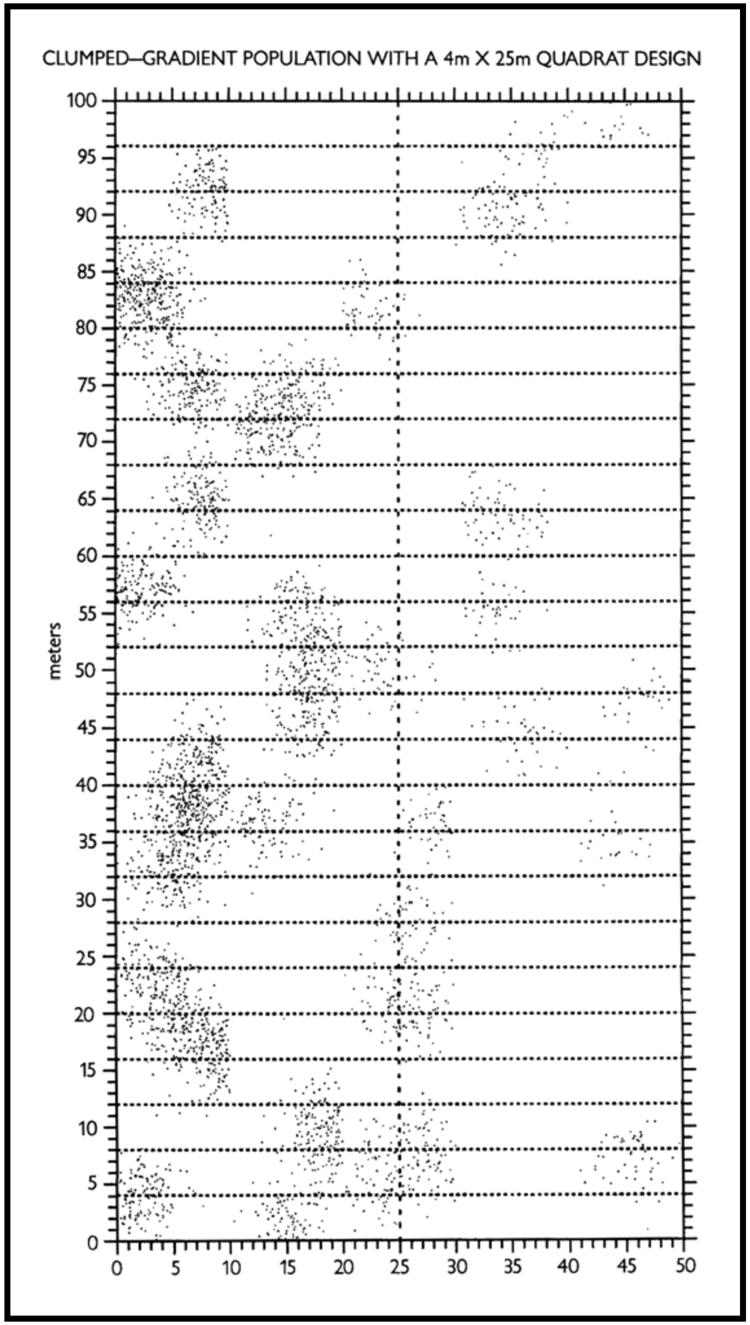

Figure 13. Clumped-gradient population with a 4m x 25m quadrat design.

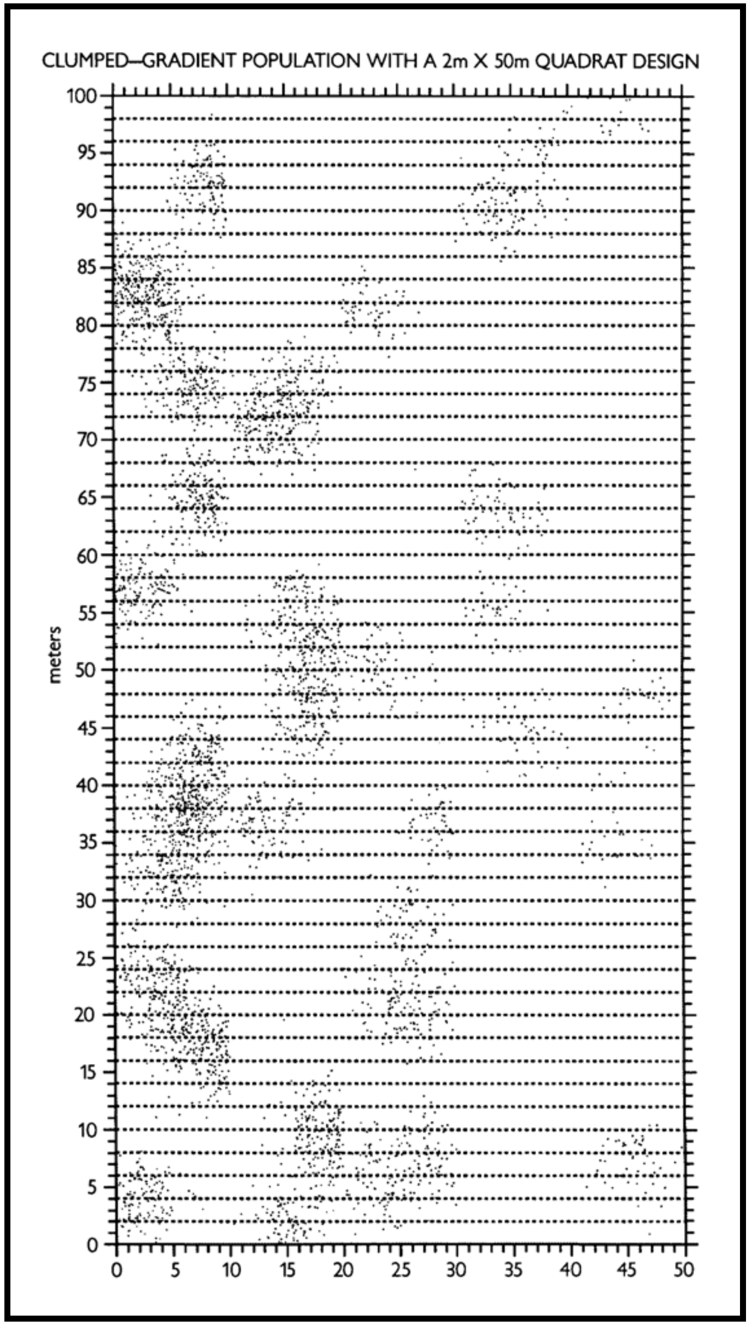

Figure 14. Clumped-gradient population with a 2m x 50m quadrat design.

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Exercise and Discussion of Exercise

Size and Shape of the Sampling Unit

- Larger square or longer rectangular sampling units usually better balance precision and efficiency
  - More precise because they capture the variability of the population within rather than among sample units.
  - More efficient because fewer sampling units mean:
    - less time traveling to and finding a sampling location
    - less set-up time, fewer markers to prepare and carry
    - and perhaps less measurement and processing time
- Small sampling units have equal or better precision
  - In regular, random, highly clumped populations
  - Could be less efficient if high cost of more sampling units

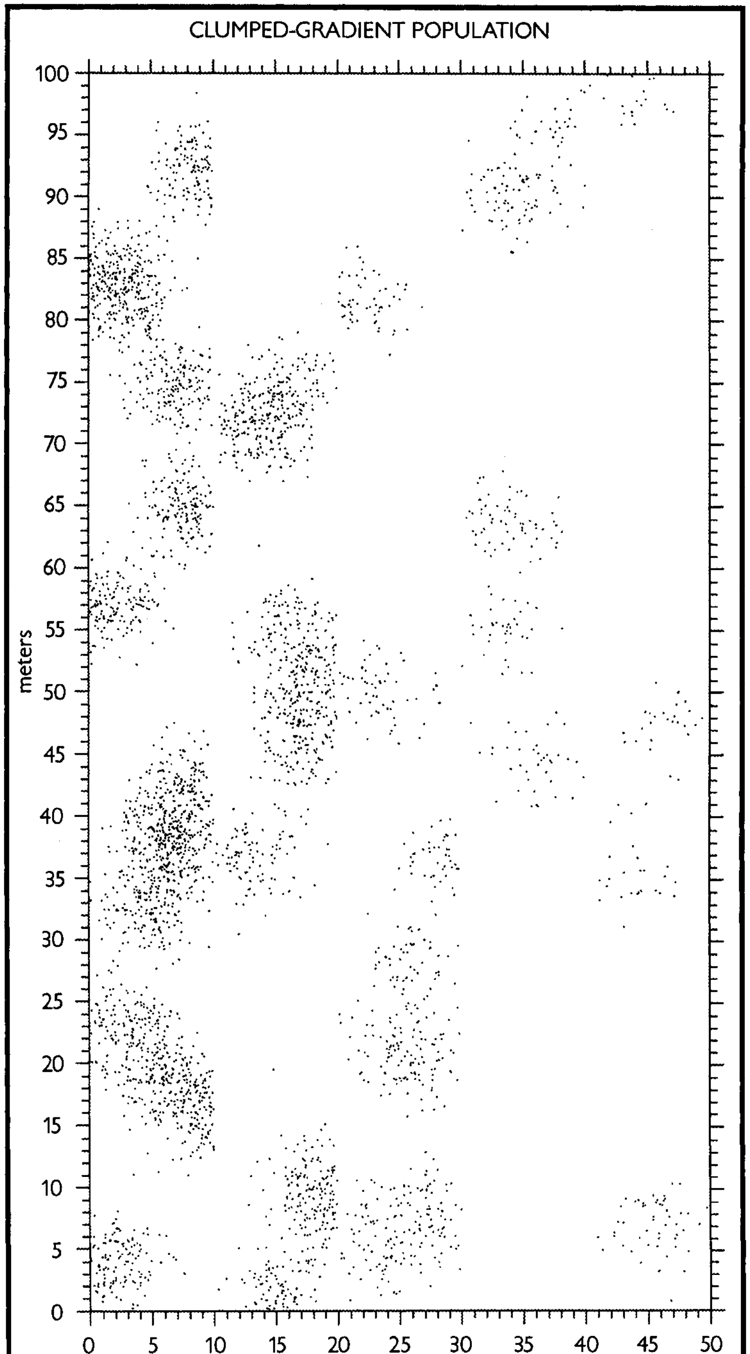


Figure 3. A "clumped-gradient population" clumped in distribution and responding to a gradient that runs from left to right, along the x-axis.

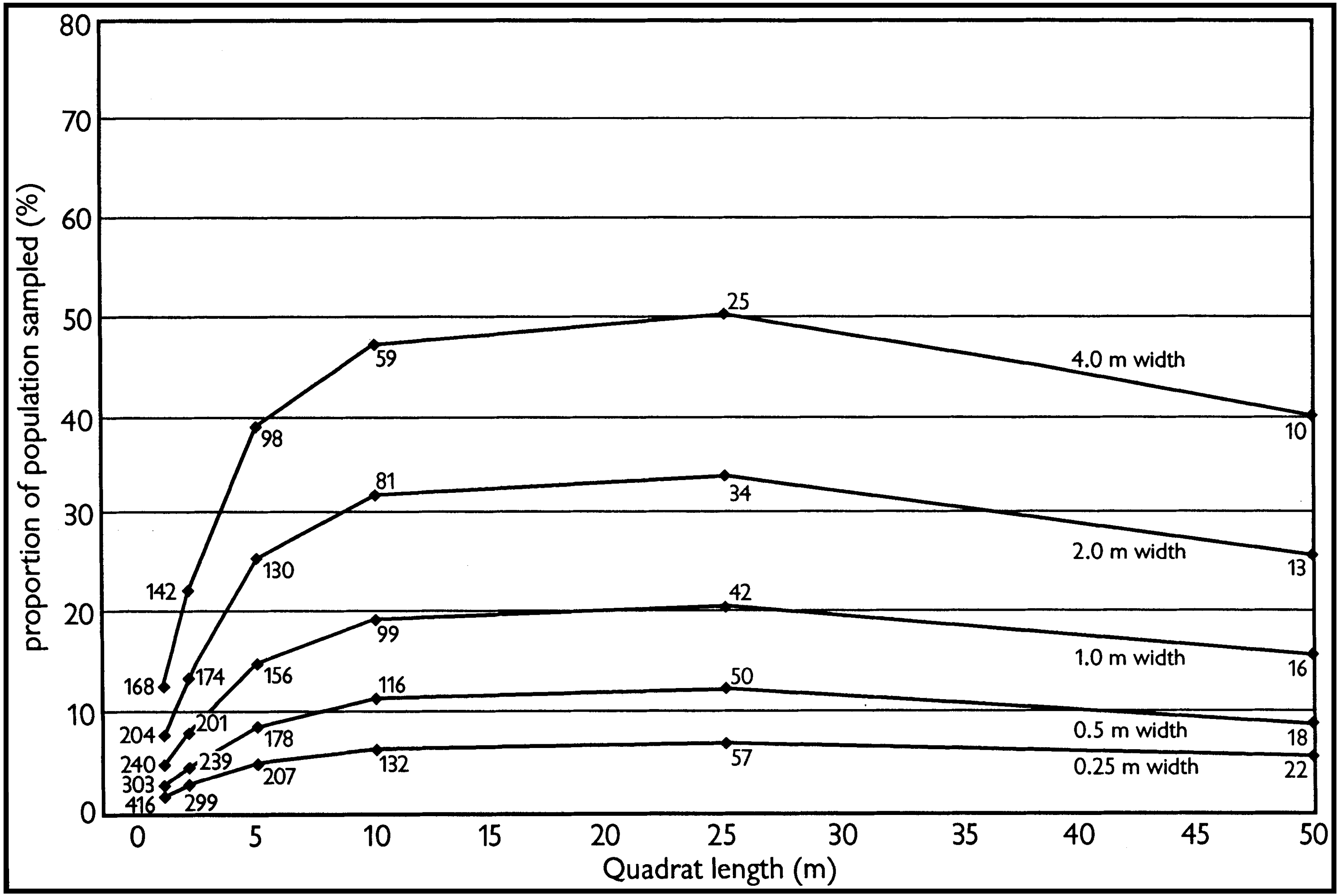


Figure 4. A comparison of 30 sampling designs for the clumped-gradient population. Each design achieves the same precision level. The number of quadrats to sample are indicated by the numbers next to the data points. Quadrats are oriented along the 50 m axis (with the gradient).

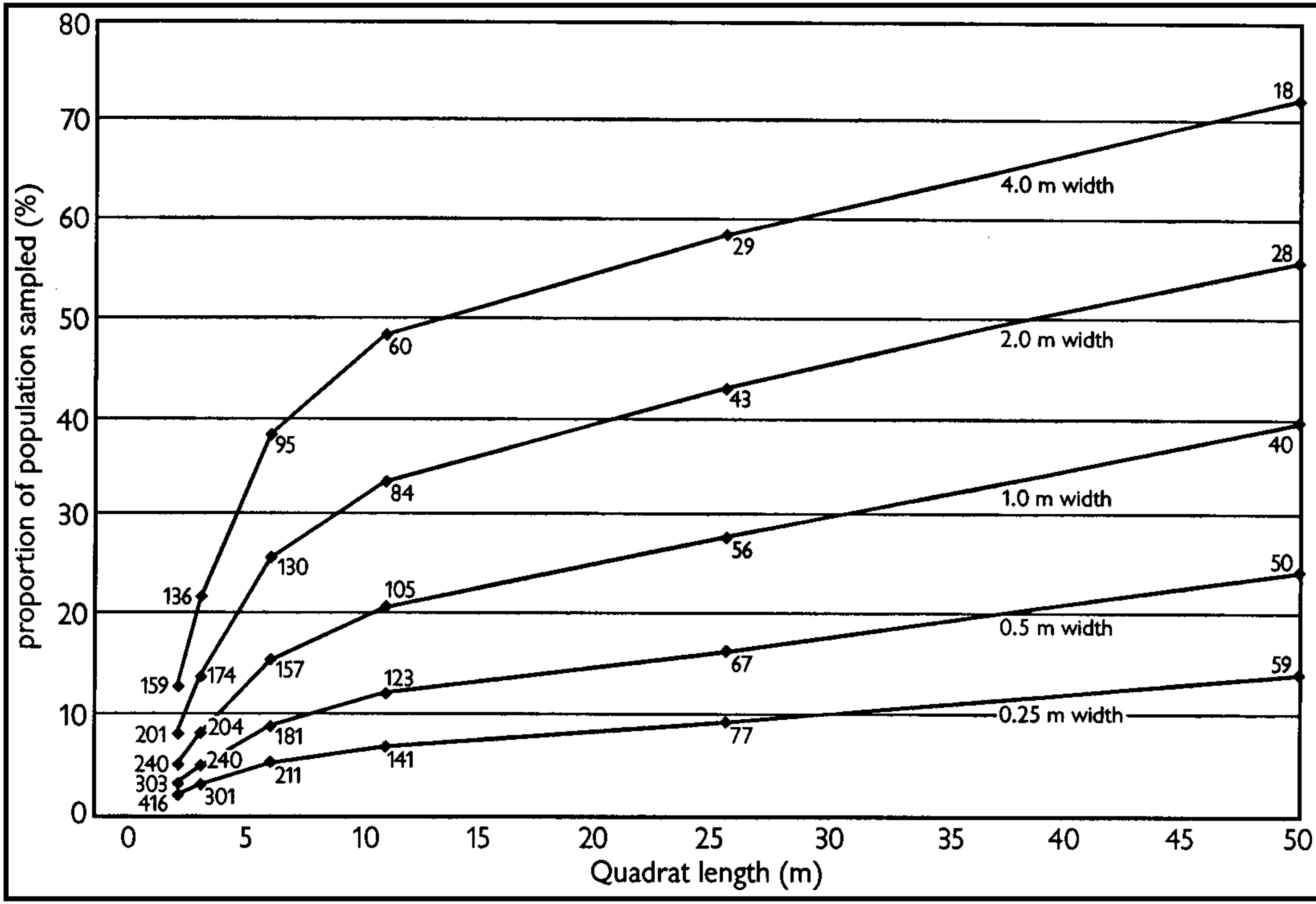


Figure 5. Comparison of 30 sampling designs for the clumped-gradient population. Each design achieves the sample precision level. The number of quadrats to sample is represented by the numbers next to the data points. The quadrats are oriented along the 100 m axis (against the gradient).

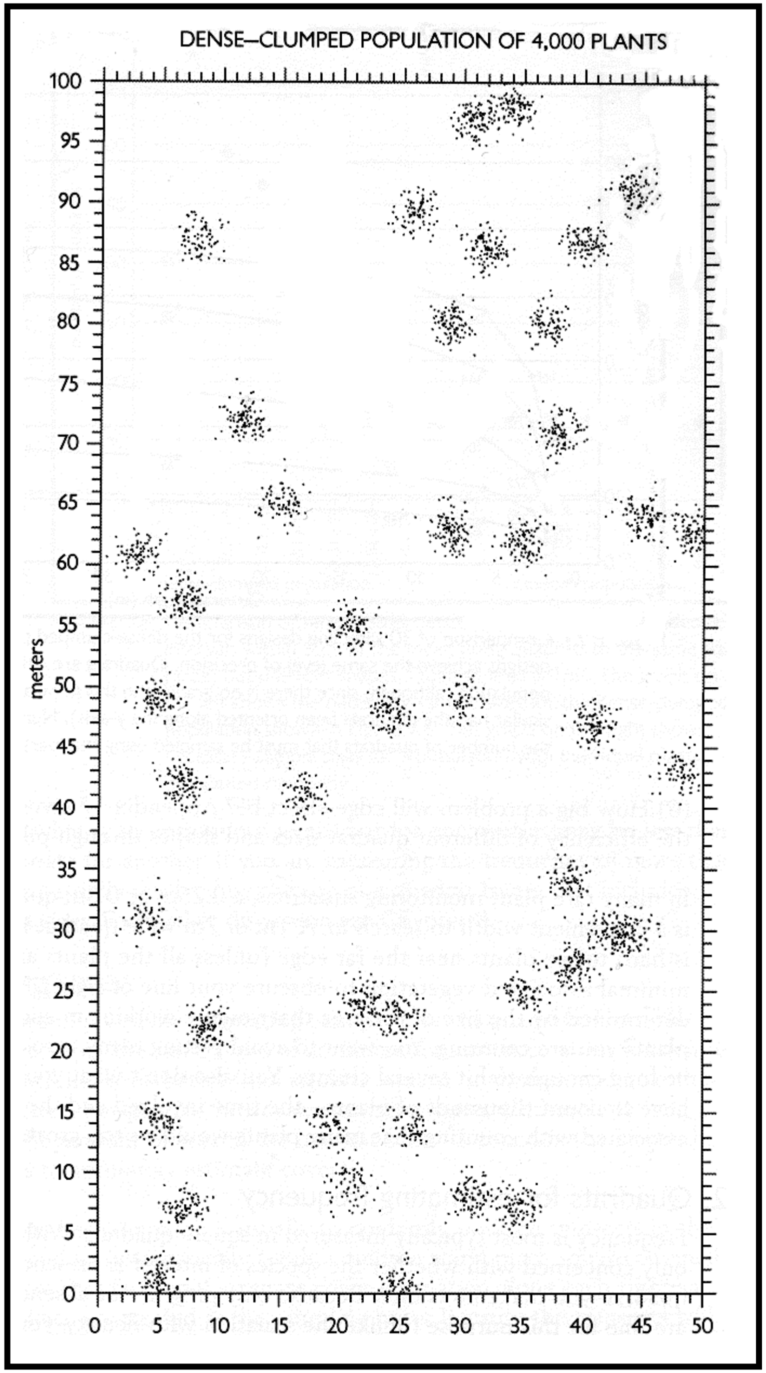


Figure 6. A dense-clumped population of 4,000 plants.

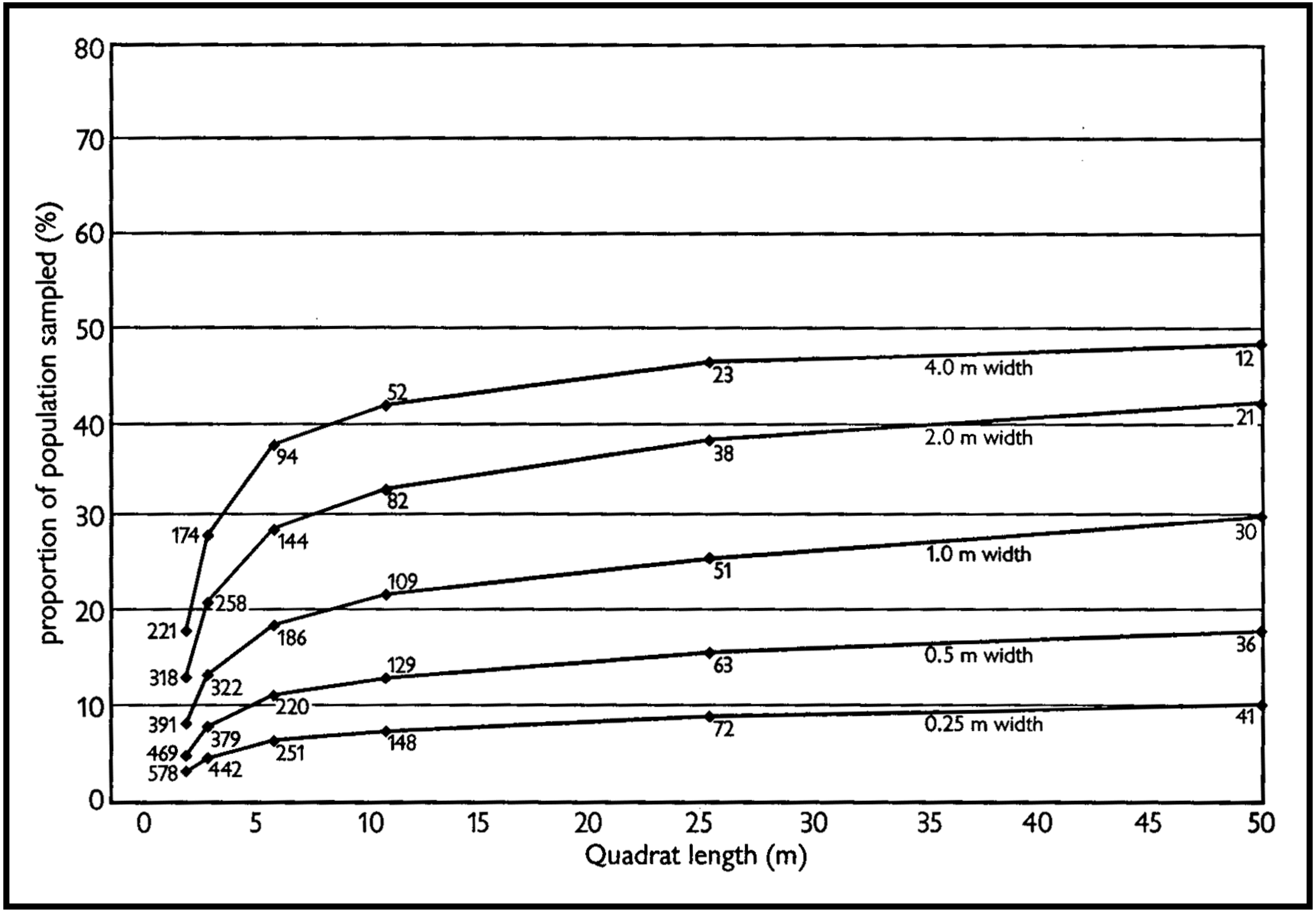


Figure 7. Comparison of 30 sampling designs for the dense-clumped population in Figure 6.

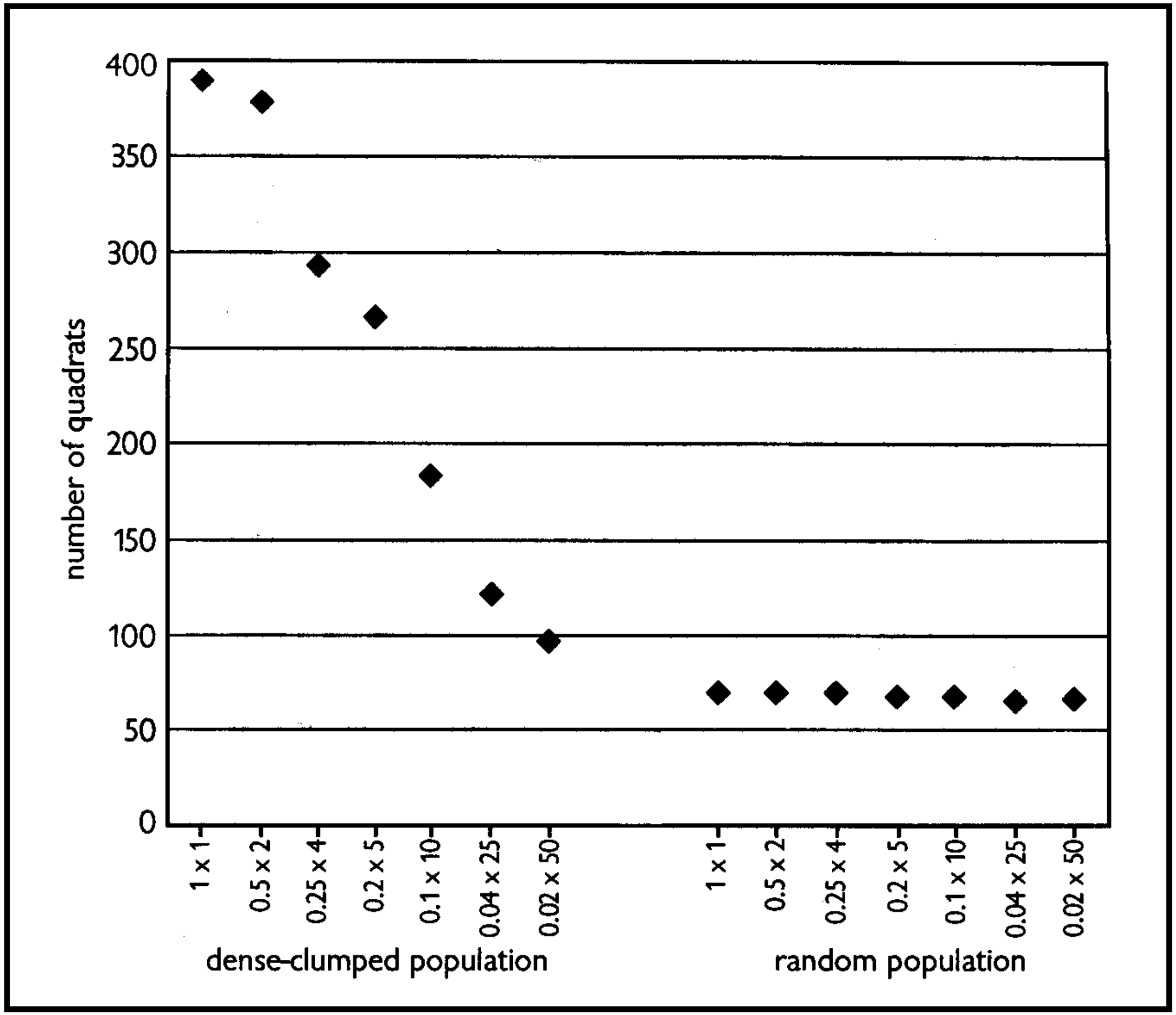


Figure 8. A comparison of the necessary sample sizes for different quadrat sizes that are all the same size but different shape. The graph on the left shows the necessary sample sizes for the dense-clumped population in Figure 6. The graph on the right shows the necessary sample sizes for a randomly distributed population also with 4,000 plants.

Site: ______________________ Date: __________ Page _____ of ____

Observer: ______________________ Total quadrat length: __________ Segment length: ______

Total quadrat width: ____________ Width of left side: ________ Width of right side: __________

Plot #	Segment #	Plant counts			Plot #	Segment #	Plant counts		
		Left	Right	Total			Left	Right	Total

Figure 9. A sample field data sheet to use to collect pilot study data

Long Transects, Large Quadrats or Small Quadrats

- Long Transects
  - better for populations with distinct gradients
    - placed across the gradient for population questions (placed along the gradient for gradient questions)
- Large Quadrats
  - captures variability better if patchiness occurs at scales smaller than the quadrat size
- Small Quadrats
  - better in regular, random or highly clumped populations

Size and Shape of the Sample Unit

- Larger square or longer rectangular sampling units usually better balance precision and efficiency
  - More precise because they capture the variability of the population within rather than among sample units.
  - More efficient because fewer sampling units mean:
    - less time traveling to and finding a sampling location
    - less set-up time, fewer markers to prepare and carry
    - and perhaps less measurement and processing time
- Small sampling units have equal or better precision
  - In regular, random, highly clumped populations
  - Could be less efficient because more sampling units needed

BUT…..

Other Considerations Concerning the Size and Shape of Sample Units

Size of Individuals

Density/Abundance of Individuals

Edge Effects

Ease in Sampling

Investigator Impact

3. Spatial Allocation of Sample Units

- An anonymous early ecologist: “The most important decision an ecologist makes is where to stop the car.”

Positioning Sample Units

- Three characteristics:
  - Random Placement – Each sample unit has the same probability of being selected
  - Good Interspersion – Better representation of the target population
  - Independence – Selection of one sample unit is not tied to another

- Why Random?
  - Allows statistical inferences to be made to the target population
  - Eliminates bias

Positioning Sample Units

- Ways to position sample units:
  - Simple Random Sampling (Grid Cell)
  - Stratified Random Sampling
  - Systematic Sampling with a Random Start
  - Restricted Random Sampling
  - Two-stage/Multi-stage Sampling
  - Cluster Sampling
  - Adaptive Sampling
  - Double Sampling
  - Other Ways to Sample Individuals

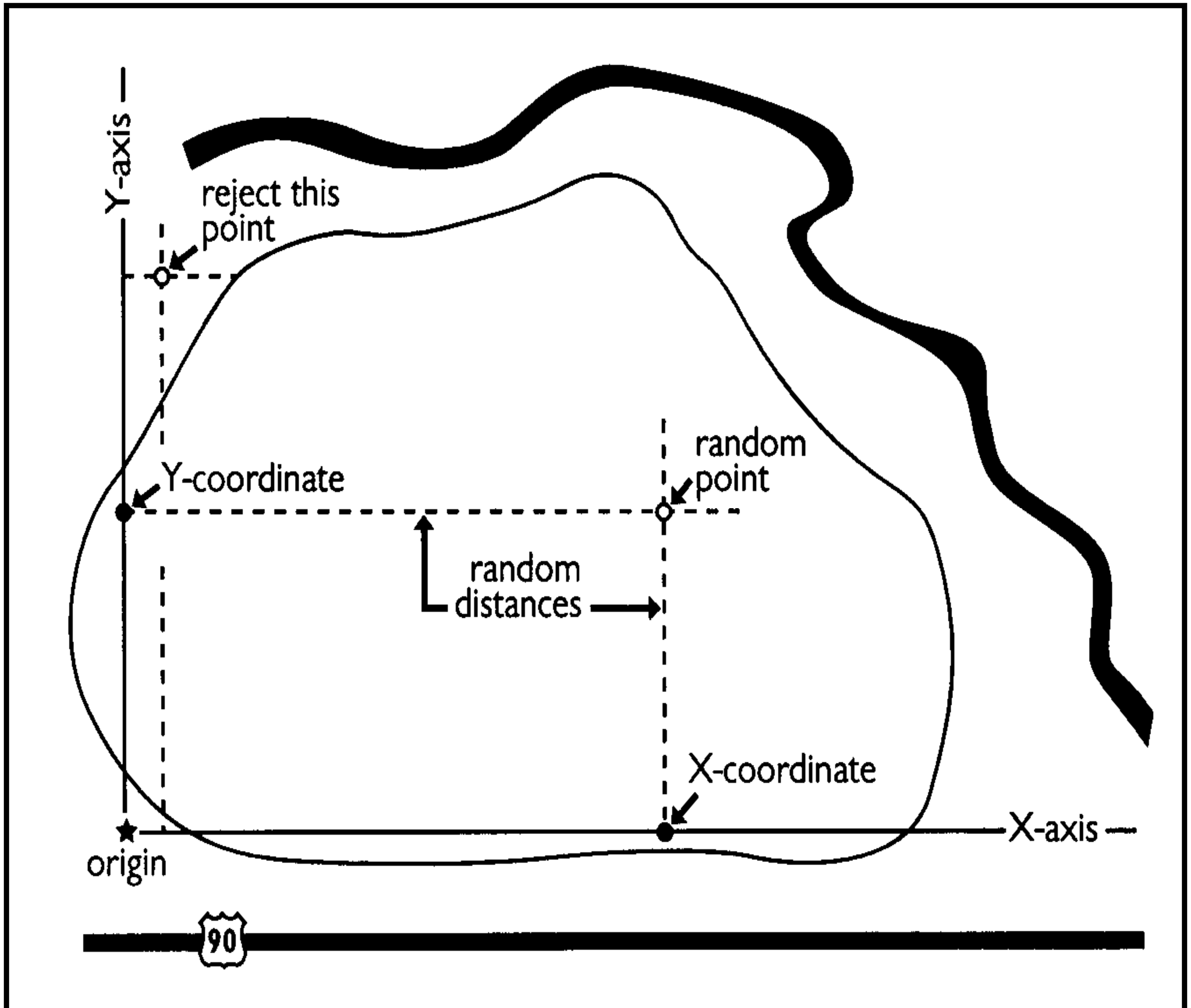


Figure 11. The simple random coordinate method.

Simple Random Sampling

Advantages

- conceptually simple
- easiest formulas

Disadvantages

- locating plots can be problematic in large areas
- difficulties locating rectangular plots – edges and overlap
- interspersion can be poor
- poor precision in populations with heterogeneous or clumped distributions

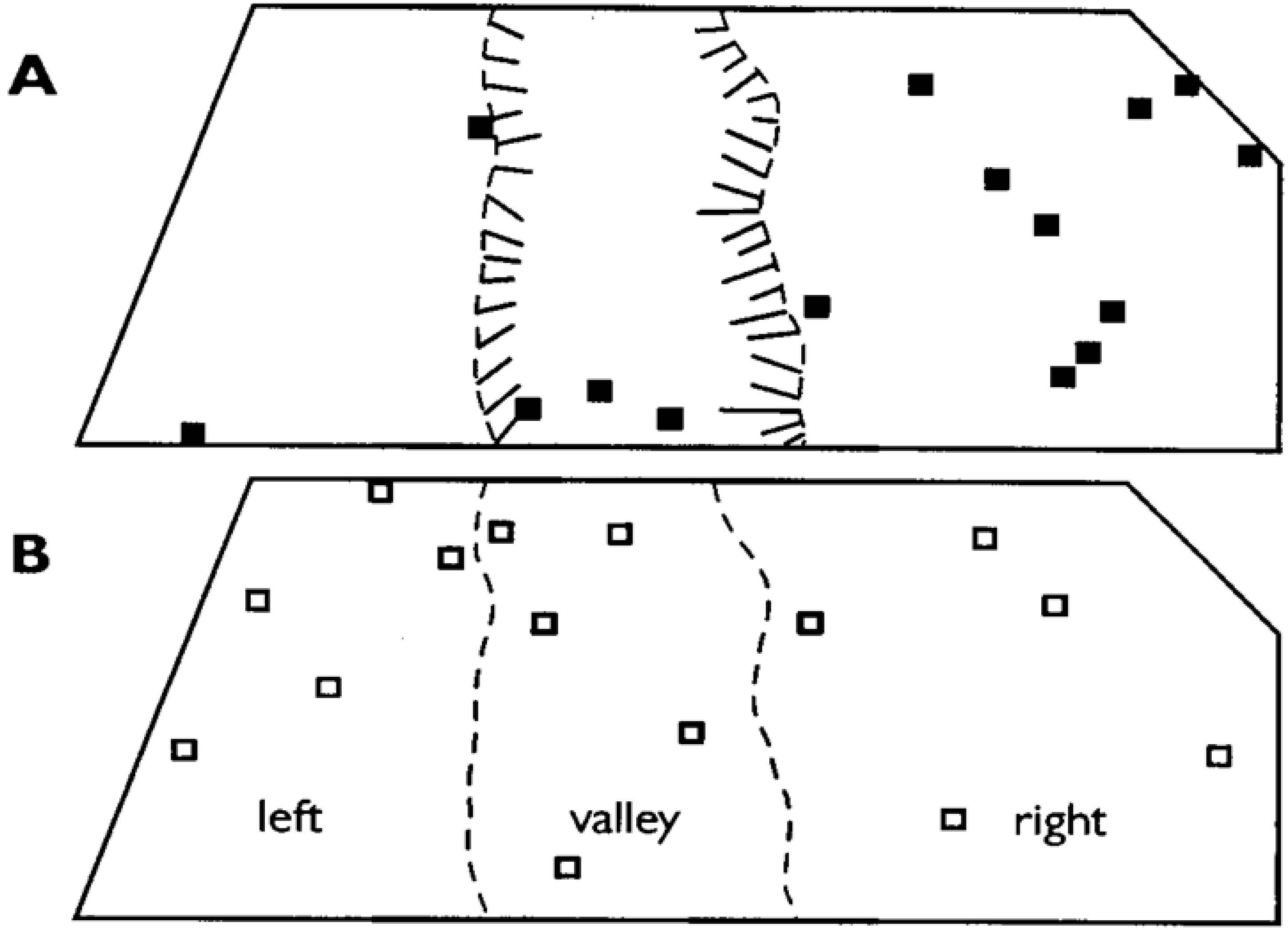
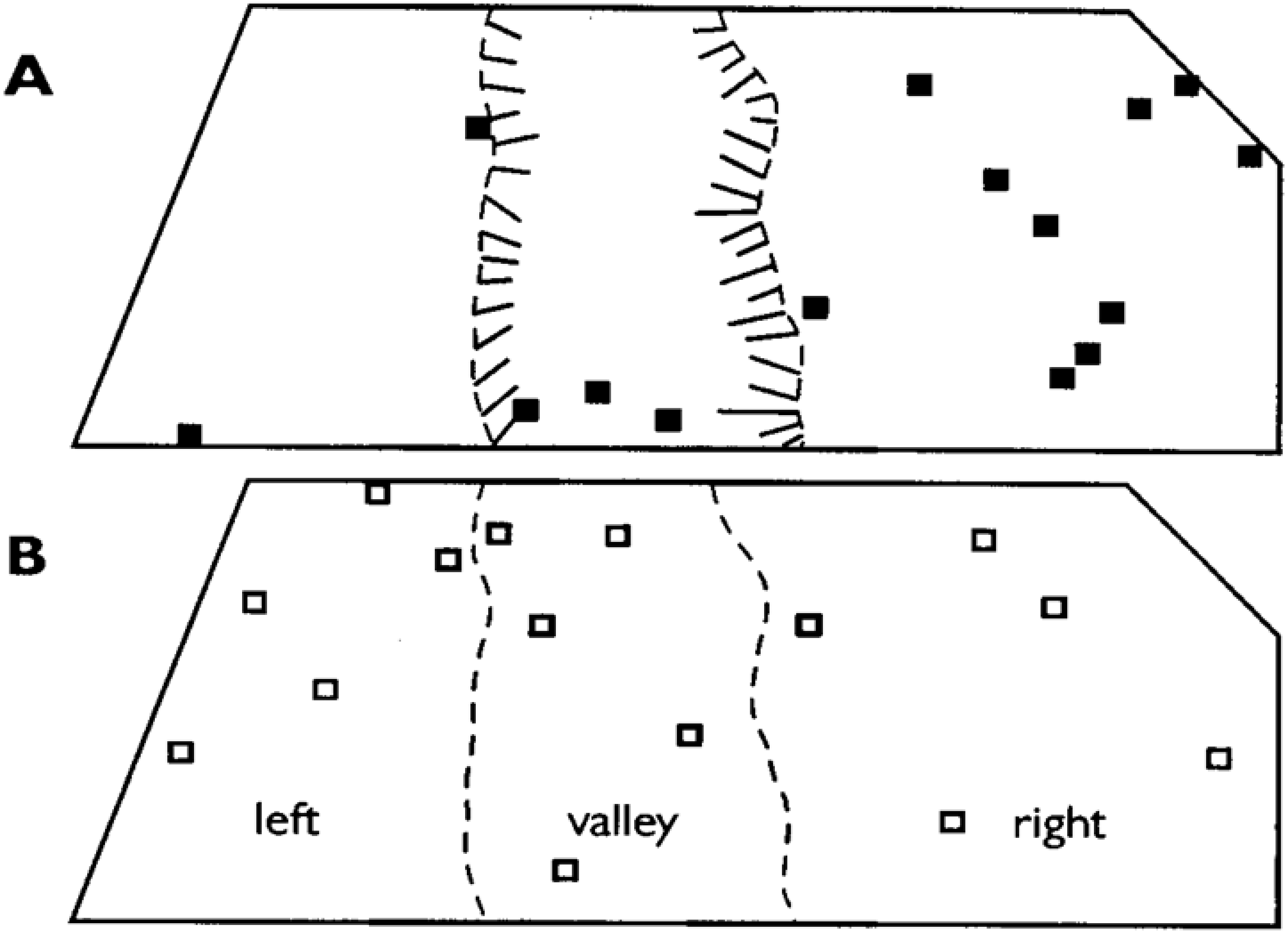


Figure 17. A comparison of the placement of sampling units on a diagrammatic nature reserve, with a valley running through it. (A) shows a simple random sample resulting in 10 quadrats placed on the right plateau, three in the valley, and only two on the left plateau. (B) Shows a stratified random sampling design where quadrats were distributed equally in each of the three strata.



How are the strata defined?

How are the SUs allocated to each strata?

Strata and Allocation

- Strata defined on habitat or ecological characteristics that are less likely to change over time.
  - landscape position, soil type, hydrology
- Sample units allocated:
  - equally
  - proportion to the size of the strata
  - relative to the current and expected variability of selected attributes

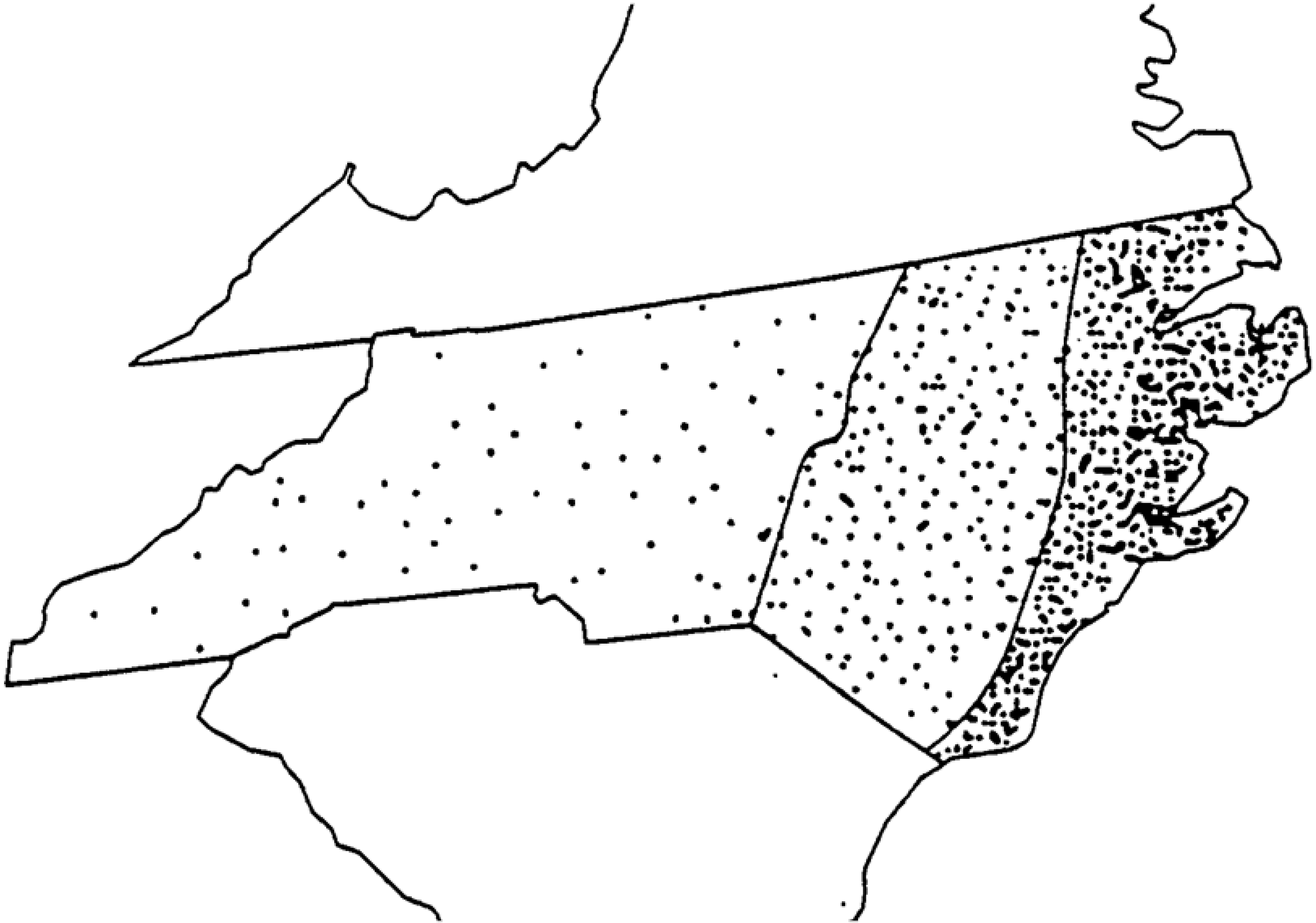


Figure 18. A stratified random sampling scheme. From the National Wetlands Inventory, 1991.

Stratified Random Sampling

Advantages

- useful in larger geographic areas when the attribute of interest responds differently to clearly defined habitat features
- strata relatively homogeneous

Disadvantages

- interspersion can be poor in each strata
- relatively poor precision in populations with clumped distributions

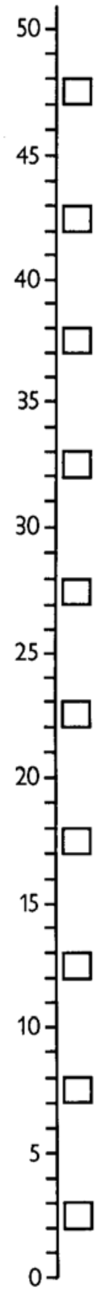


Figure 20. An example of systematic sampling with a random start. Ten 1m^2 quadrants are placed at 5m intervals along a 50m transect.

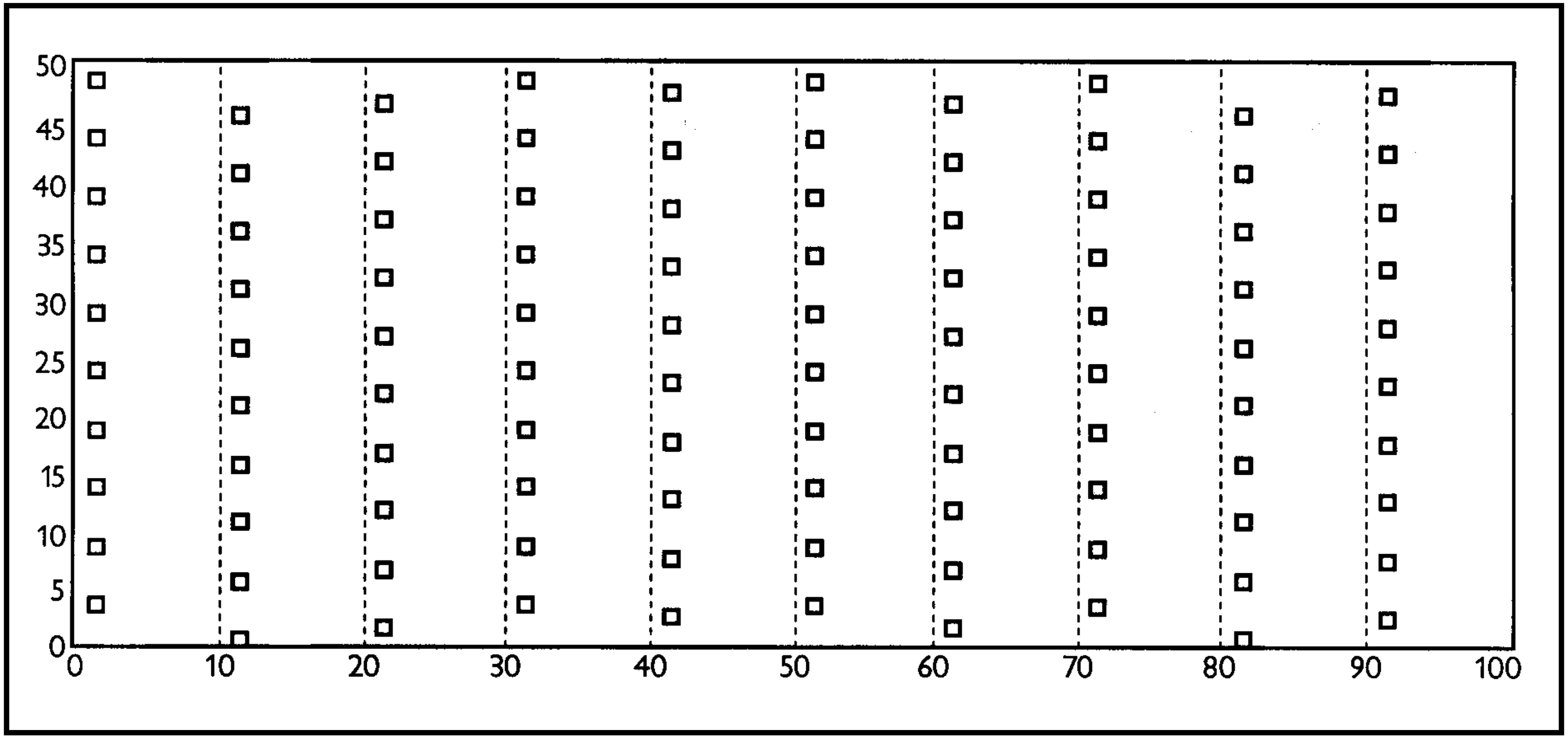


Figure 21. The placement of quadrats along a transect as an example of systematic sampling with a random start. To be considered a random sampling method, the starting point for the placement of sampling units must be selected randomly.

Systematic Sampling with Random Start

Strengths		Weaknesses	
+	Results in more precise estimates than simple random sampling when sampling clumped distributions.	–	Undesirable if sampling unit placement intersects some environmental pattern. Data analysis, particularly standard errors, cannot reveal such patterns and will be wrong.
+	Allows for even sampling across an area.	–	Sampling designs to estimate density can lead to questionable results.

Figure 22 lists the strengths and weaknesses of systematic sampling.

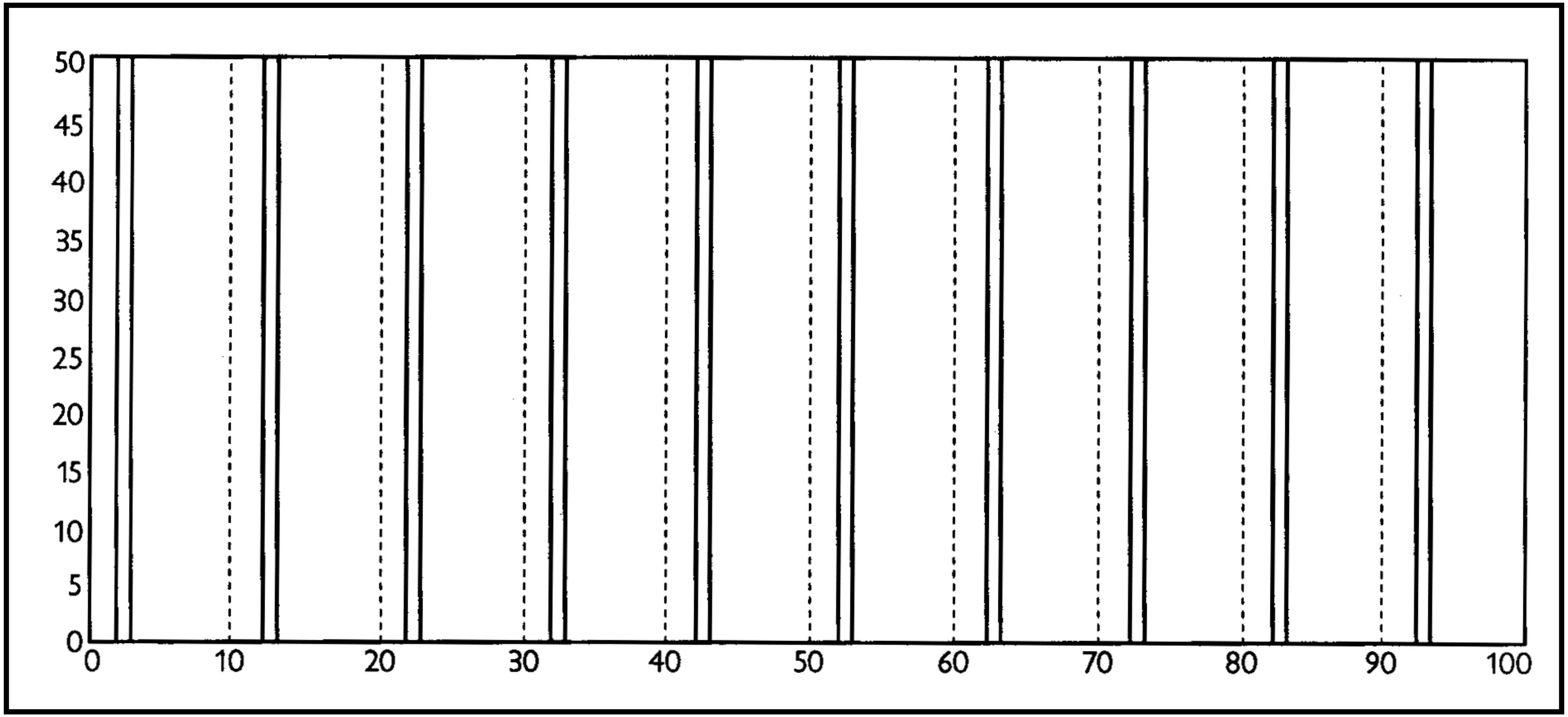


Figure 23. Ten 1m x 50m quadrats systematically positioned with a random starting point at the 3m position and quadrats positioned every 10m after that. Since the position of all quadrats is fixed once the first quadrat is positioned, there are only 10 possible samples to choose from.

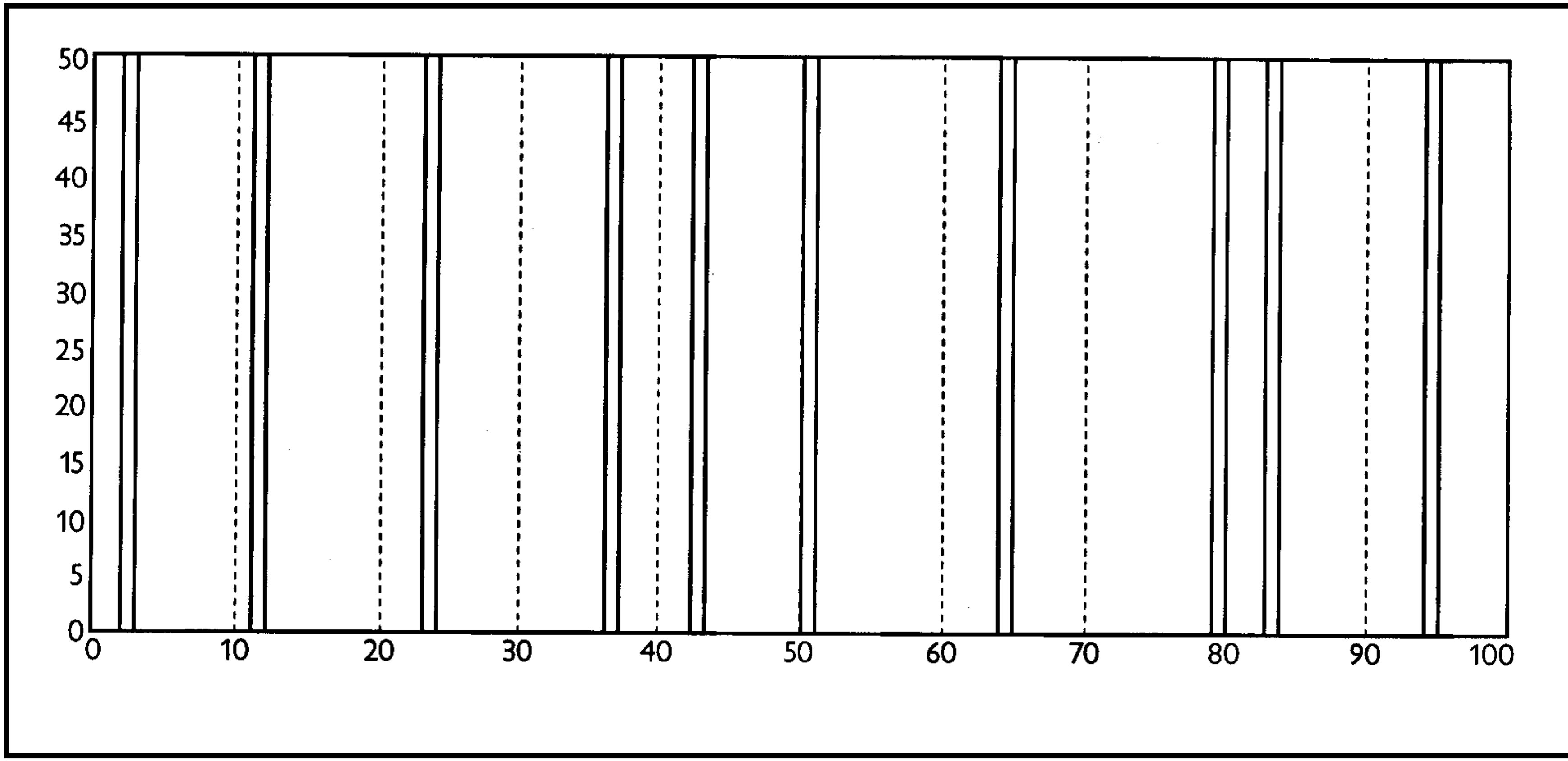


Figure 24. Using a random sampling technique, as illustrated above, will result in better interspersion of quadrats in the population compared to quadrat placement using simple random sampling.

Restricted Random Sampling

Strengths	Weaknesses
+ Results in good interspersion of sampling units throughout the target population.	– Requires more complex formulas to calculate means and standard errors than simple random sampling
+ Is more robust than systematic sampling because sampling designs don't severely constrain the number of possible samples (Salzer, in prep)	

Figure 25. Strengths and weaknesses of restricted random sampling.

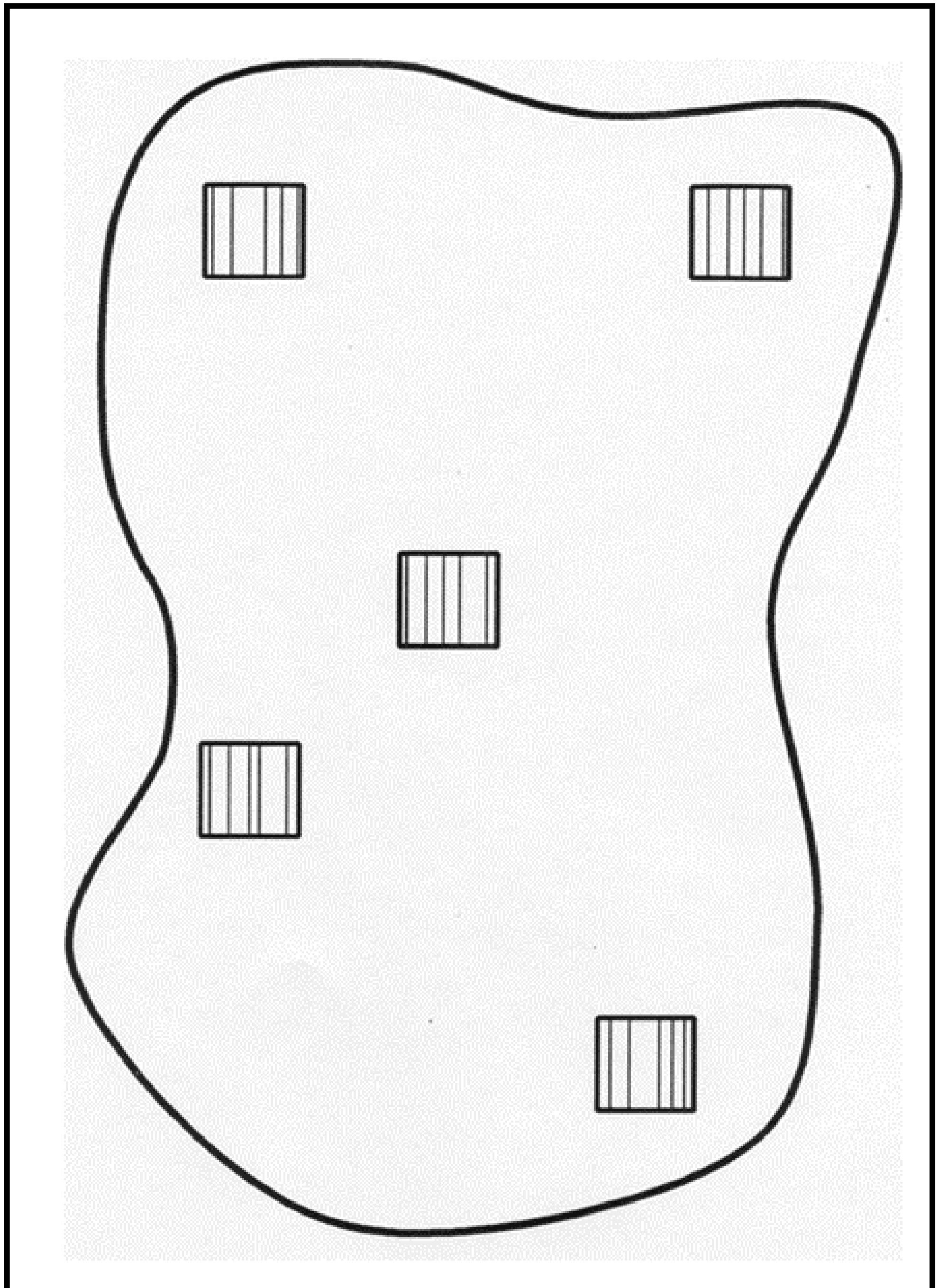


Figure 26. An example of two stage sampling for the line intercept method. Five macroplots are randomly positioned in the population. Five lines are then positioned within each macroplot.

Two-stage/Multi-stage Sampling

Advantages

- useful in estimating attributes associated with individuals
- useful in estimating attributes in large areas
  - less travel time, less expensive

Disadvantages

- complicated formulas dealing with the variability associated with each stage of sampling
- the two stages result in lower precision (but greater efficiency)

Cluster Sampling

- When selecting individual elements of interest are difficult because of their clustered distribution, then groups or clusters are randomly selected.
- Most efficient when clusters are similar to one another.

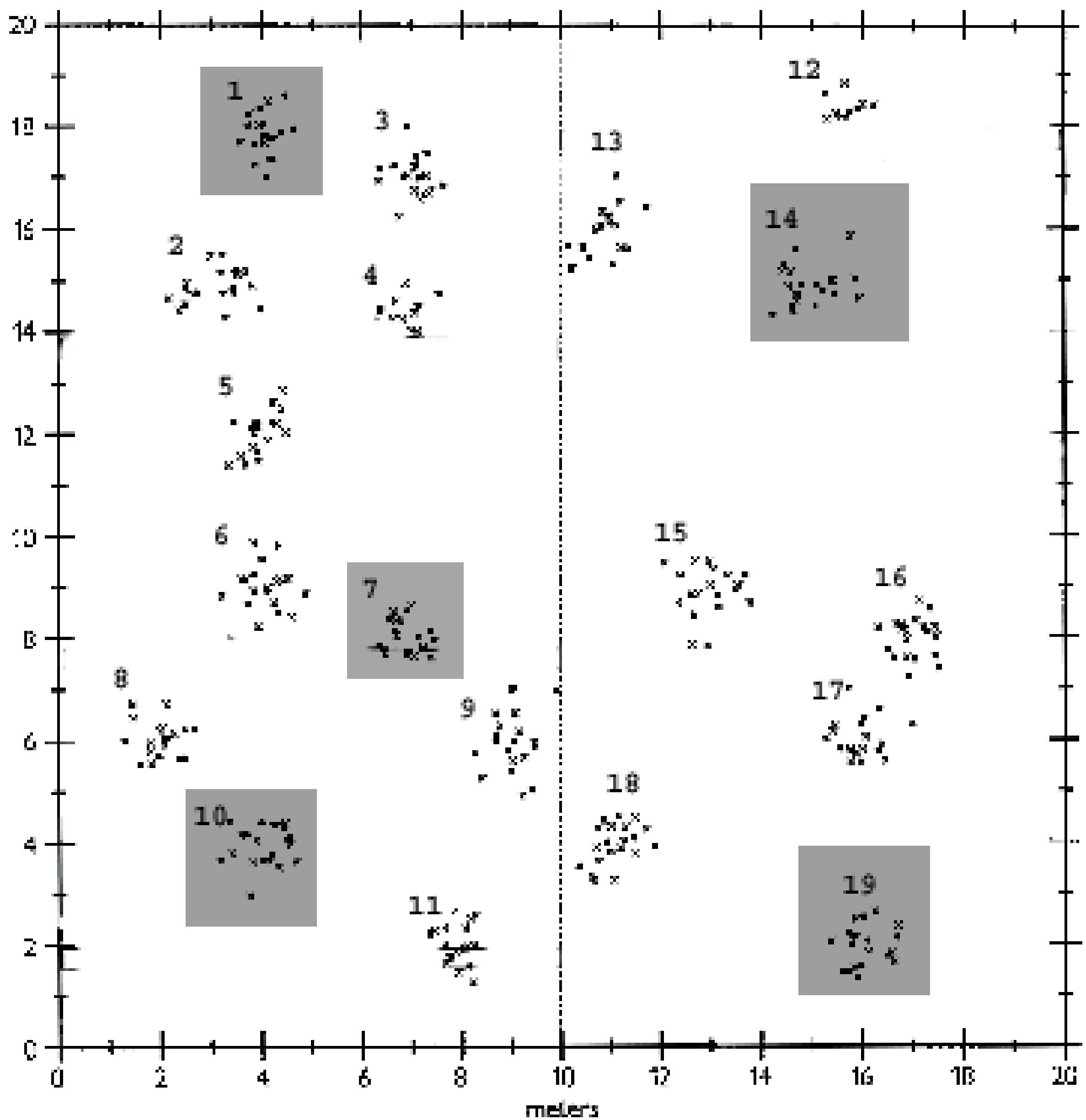


Figure 28. An example of cluster sampling to estimate the mean height of plants in a population. Five clusters are randomly selected in the population and the heights of all plants within these quadrats are measured. From Elzinga, et al. (1998).

Adaptive Sampling

- A sampling design to address species with small-scale patchy populations
  - common spatial distribution for rare species
- Focus sampling effort in areas where the target species occurs or has a higher density

  Theoretically:
  - more precise estimates
  - more efficient

Double Sampling

- Estimation of a variable at two levels of sampling intensity and precision
  - a complete count is made in the subsample - more difficult and expensive, but more precise
  - an incomplete count is made in the larger sample or the whole population using a method that is relatively easy or inexpensive, but less precise
  - precision depends on how well the variable estimated in the incomplete count correlates with the variable measured in the complete count
  - can be used to estimate detectability

Double Sampling

- Example:
  - aerial surveys for large mammals, with a ground count as the subsample
  - mussel surveys, with destructive sampling in a subset of quadrats to assess detectability
- Assumptions of Double Sampling
  - complete count is accurate
  - population closed between application of both counts
  - complete and incomplete counts independent

Sampling Individuals

- Plot-based methods
  - density, cover, frequency
  - individual characteristics: two-stage, cluster, double
- Individuals as sampling units
  - count all individuals, select random sample
  - systematic random sample
    - estimate size of total population
    - estimate sample size needed and sample every *n*th individual
  - nearest individuals to a random point - bias
  - wandering-quarter distance (plotless) method

Spatial Allocation of Sample Units

- Discussion of your experience, insights and questions about the spatial allocation of sample units

4. Temporal Allocation of Sample Units

- Are the sample units permanent, temporary or a combination of permanent and temporary?
- What is the frequency of sampling?

Permanent or Temporary Sample Units?

- Permanent Sample Unit Advantages:
  - easier to detect change
  - fewer sample units
- Permanent Sample Unit Disadvantages:
  - markers: expensive, prep, carry to site
  - markers: susceptible to loss or damage
  - relocating markers time consuming
  - investigator impact
  - impact on wildlife

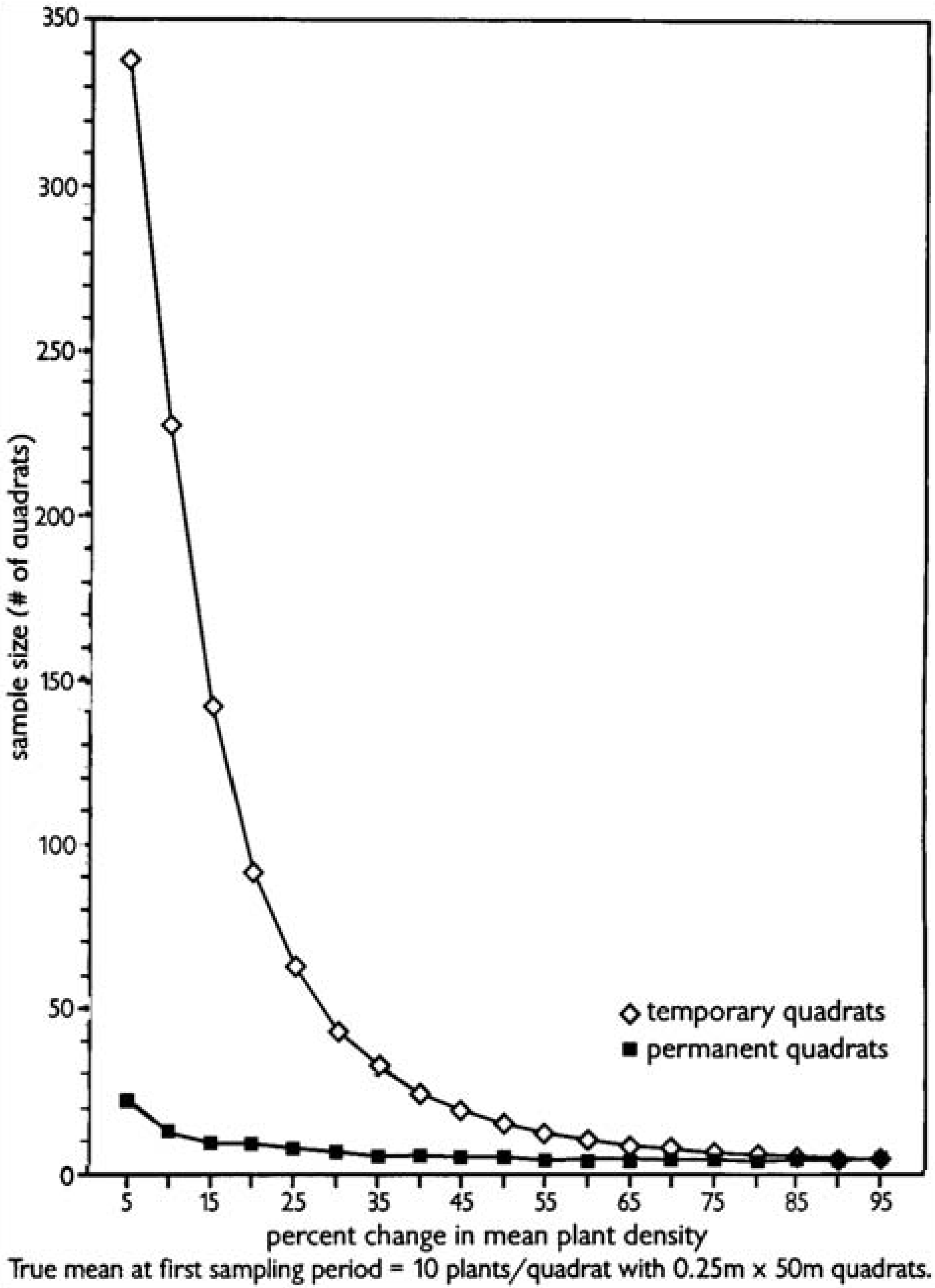


Figure 32. A comparison of necessary sample sizes to detect different degrees of population decline from an artificial clumped population of 4,000 plants. All changes are due to mortality of the original population without any recruitment of new plants.

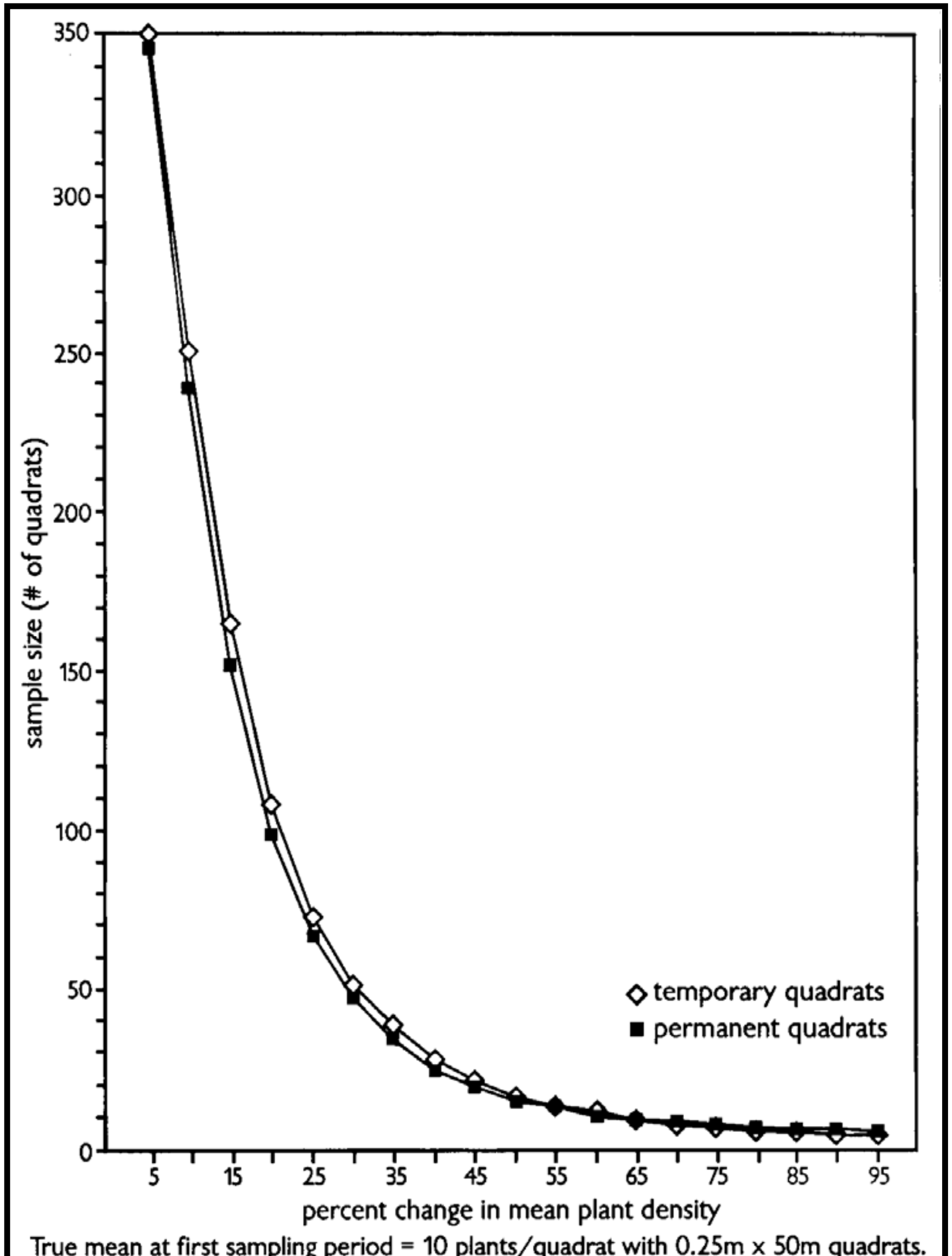


Figure 33. A comparison of necessary sample sizes to detect different degrees of population decline from an artificial clumped population of 4,000 plants. All of the population changes are due to 100% mortality of the original population with various levels of recruitment.

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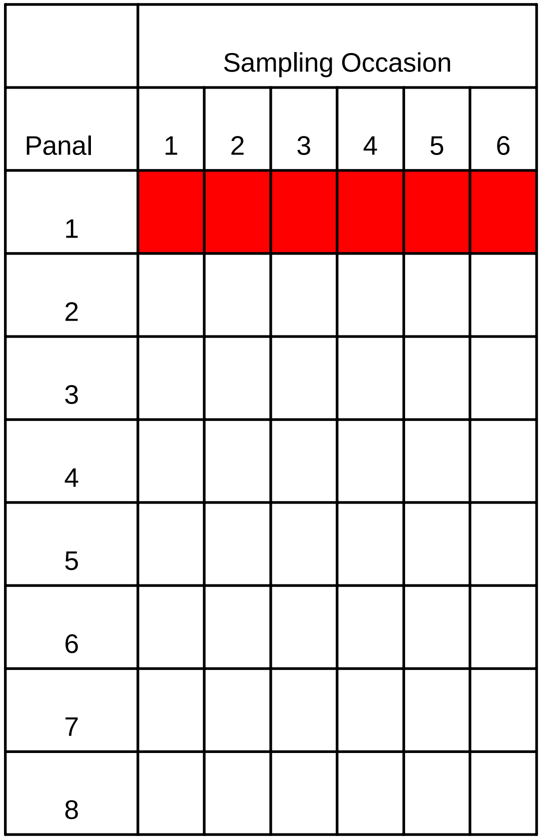
Statistical and Sampling Design Issues with Permanent Sample Units

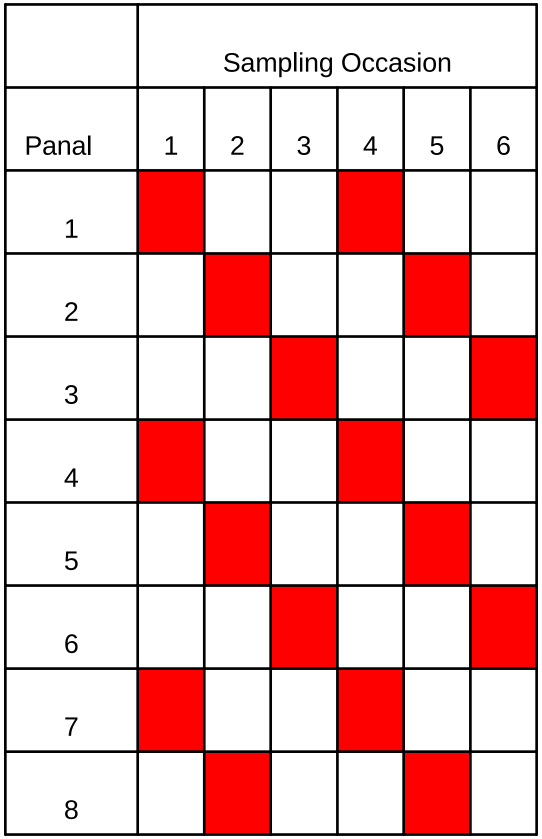
- Sample Size Equations
- Autocorrelation
  - statistical tests that assess autocorrelation
- All populations change distribution and condition with time (changes in population parameters), thus
  - permanently marked plants or plots will lose their precision over time
  - changes in statistical characteristics of the population
    - normality
    - homogeneity of variances

Major Temporal Designs

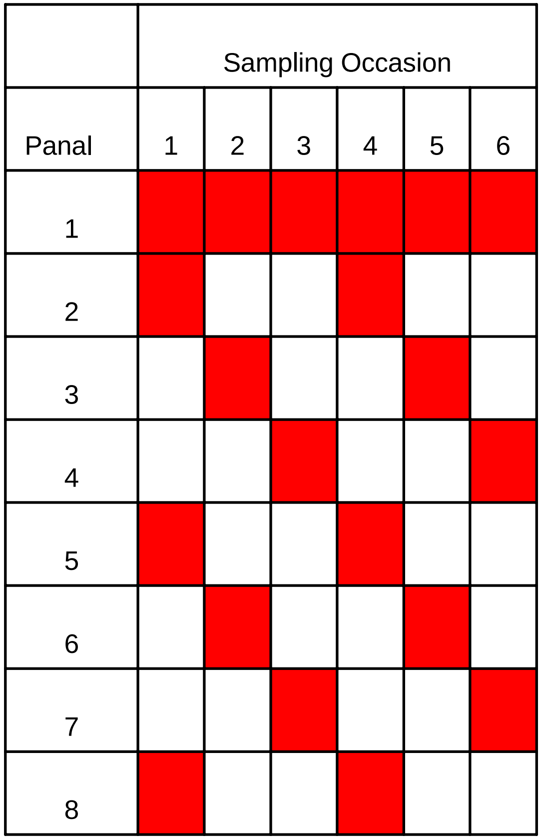
Complete Revisit



Repeating Panel



Split Panel



Partial Replacement

- Solution: partial replacement of sampling units over time, a certain percentage each sampling time.
- Example:
  - sampling each individual or sample unit for at least 2 years
  - every year replacing some of the sample units with new, randomly selected ones.
  - Expanding on the example in Figure 17 (under stratified sampling), the 15 quadrats in (b) are sampled in years 1 and 2, with a new set of 15 quadrats added in year 2 that will be sampled in year 3, and 15 new quadrates added in year 3 that will be sample in year 4, and so on.
- Increased intensity of sampling; but greater reliability in the data

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Frequency of Sampling

- Is once a year enough?
- Is every year necessary?
  - Several sequential years to assess status or trends
    - then choose the appropriate frequency for assessing status or detecting change
- Is the same intensity of sampling needed at every sampling time?
  - Baseline Sampling - usually more intensive data collection in first year
  - Baseline intensity can be redone at an appropriate frequency
  - Less intensity monitoring designed for intervening years
- Dependent on:
  - time frame of change
  - trade-off between cost and the value of the data

Temporal Allocation of Sample Units

- Discussion of your experience, insights and questions about the temporal allocation of sample units

5. Number of Sampling Units

Considerations:

- Management objectives
- Variation in actual measurements (pilot data)
- Assumptions of (many) sample size equations:
  - randomly located plots, normally distributed data
- Decisions to use permanent or temporary sampling units
- Whether you are sampling from an infinite population
- Precision increases with sample size, but not proportionately

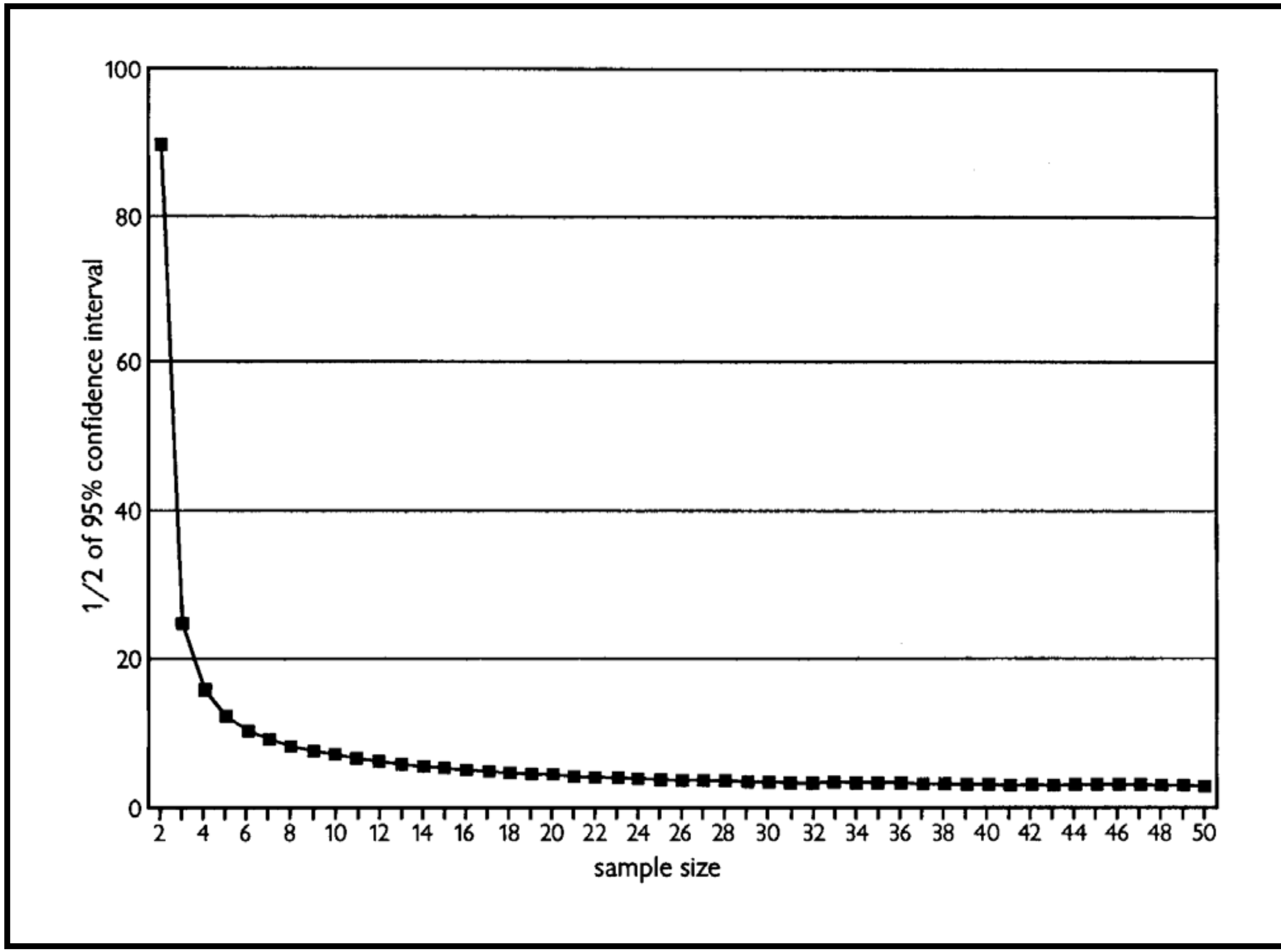


Figure 34. The influence of sample size on level of precision, using a t-distribution with a constant standard of deviation (sd = 10).

Table 1. Quick reference table for the sample size equations in Appendix II.

Equation	Abundance Measure	Objective Type	Temp/ Perm SU	Conf. Int. /Statistics	Information Needed[1]	Correction Needed[2]
1	Density, cover, etc.	Thresh	--	CI	s, CL, CW, Threshold	K/H, FPC
2	Density, cover, etc.	Thresh	--	Stat	s, α, β, MDC, Threshold	FPC(2)
3	Density, cover, etc.	Change	Temp	CI	s, CL, CW, MDC	K/H, FPC
4	Density, cover, etc.	Change	Temp	Stat	s, α, β, MDC	FPC(2)
5	Density, cover, etc.	Change	Perm	CI	s_{diff}, CL, CW, MDC, corr	K/H, FPC
6	Density, cover, etc.	Change	Perm	Stat	s_{diff}, α, β, MDC, corr	FPC(2)
7	Frequency	Thresh	--	CI	p, CL, CW, Threshold	FPC
8	Frequency	Change	Temp	Stat	p, α, β, MDC	FPC(2)

Finite vs. Infinite Populations

- Sampling and statistical analyses assume an infinite population
  - Very large statistical population
  - Use of points or transects, dimensionless in one or both dimensions
- In our work: Finite Populations
  - Smaller statistical population
  - Use quadrats: finite number of locations
  - End up sampling a great percentage of the population
- Rewarded: Finite Population Correction Factor
  - Good: fewer sampling units

Pilot Study

- Trial run of the sampling design provides three critical things:
  - estimates of standard deviation for sample size formulas
  - exposes design problems
  - assesses feasibility

Good: pilot study becomes 1st year data

Bad: redesign

Sample Size Exercise

- Review 3 Common Sample Size Equations
- Exercise using two of the Sample Size Equations, working in teams of 2

Summary

- Sampling Design is dependent on:
  - the question being asked (management objective - status versus effectiveness)
  - the attributes being measured (management objective)
  - the desired precision (sampling objective)
  - the characteristics of the organism
  - the resources available for the project (time, money, personnel)

EXERCISE S2: CALCULATING CONFIDENCE INTERVALS

Exercise Objectives

At the end of this exercise, participants will be able to:

- **calculate a 95% confidence interval using data obtained from a random sample**

Introduction

You want to know the average height of participants in a past monitoring workshop. There isn't enough time to measure all participants so you will need to estimate the true height of all participants by taking a random sample.

You want a measure of precision around your height estimate. So, you want to calculate a 95% confidence interval around your estimate.

Materials Needed

To complete the exercise, you will be provided with the following materials:

- **A cup that contains little slips of paper. Each slip of paper contains the height of one of the participants in the workshop. The height has been converted to a decimal number (e.g., 5' 6" = 5.5).**
- **A hand calculator capable of calculating means and standard deviations. You may use your own calculator if it can perform these function.**
- **A table of t-values (included in your workshop binder).**

Instructions and Exercise

1. **Thoroughly shake the cup.**
2. **Remove 5 pieces of paper.**
3. **Using your hand calculator, calculate the mean and the standard deviation for the five height measurements that you have sampled.**
4. **Calculate the standard error of the mean:** $SE = \frac{s}{\sqrt{n}}$
5. **Find the correct coefficient from the t-table for a 95% confidence interval given your sample size of 5.**

EXERCISE S2: CALCULATING CONFIDENCE INTERVALS

To obtain t-distribution coefficients for calculating confidence intervals:

- **Subtract 1 from your sample size (i.e., n-1) to obtain the correct degrees of freedom (*df*).**
- **Find the correct degrees of freedom number in the left most column of the table (*df*).**
- **Find the appropriate α column for the desired confidence level. For 95% confidence, use α = 0.05.**

6. Multiply your standard error by the t-table coefficient to obtain your 95% confidence interval width.

$$CI_{\frac{1}{2}width} = (t)(SE)$$

$$FPC_{CI} = \sqrt{\frac{N-n}{N}}$$

Where: N = total # of participants, n = sample size

7. Since your sample of 5 is more than 5% of the entire population (23 participants), you should apply the Finite Population Correction (FPC) factor to your confidence interval width.

Critical t-values for several levels of confidence (for 2-sided confidence intervals).				
degrees of freedom	**80%**	**90%**	**95%**	**99%**
1	3.078	6.314	12.706	63.656
2	1.886	2.920	4.303	9.925
3	1.638	2.353	3.182	5.841
4	1.533	2.132	2.776	4.604
5	1.476	2.015	2.571	4.032
6	1.440	1.943	2.447	3.707
7	1.415	1.895	2.365	3.499
8	1.397	1.860	2.306	3.355
9	1.383	1.833	2.262	3.250
10	1.372	1.812	2.228	3.169
11	1.363	1.796	2.201	3.106
12	1.356	1.782	2.179	3.055
13	1.350	1.771	2.160	3.012
14	1.345	1.761	2.145	2.977
15	1.341	1.753	2.131	2.947
16	1.337	1.746	2.120	2.921
17	1.333	1.740	2.110	2.898
18	1.330	1.734	2.101	2.878
19	1.328	1.729	2.093	2.861
20	1.325	1.725	2.086	2.845
21	1.323	1.721	2.080	2.831
22	1.321	1.717	2.074	2.819
23	1.319	1.714	2.069	2.807
24	1.318	1.711	2.064	2.797
25	1.316	1.708	2.060	2.787
26	1.315	1.706	2.056	2.779
27	1.314	1.703	2.052	2.771
28	1.313	1.701	2.048	2.763
29	1.311	1.699	2.045	2.756
30	1.310	1.697	2.042	2.750
35	1.306	1.690	2.030	2.724
40	1.303	1.684	2.021	2.704
45	1.301	1.679	2.014	2.690
50	1.299	1.676	2.009	2.678
100	1.290	1.660	1.984	2.626
200	1.286	1.653	1.972	2.601
500	1.283	1.648	1.965	2.586
∞ = Infinity	1.282	1.645	1.960	2.576

ANSWERS TO EXERCISE S2

Full data set			
Name	Feet	Inches	Height
Martha	5	7	5.58
Bob	6	3	6.25
John	6	0	6
Dan	6	0	6
Mike	5	10	5.83
Charley	5	9	5.75
Lucy	5	4	5.33
Peggy	5	4	5.33
Jim	5	8	5.67
Tracey	5	7	5.58
Ron	5	8	5.67
Dea	5	2	5.17
Mike	5	10	5.83
Cam	5	1	5.08
Mary Ann	5	6	5.5
Kevin	5	9	5.75
Carolyn	5	6	5.5
Linda	5	2	5.17
Cindy	5	8	5.67
Barb	5	4	5.33
Marcy	5	8	5.67
Marilyn	5	5	5.42
Jeff	6	2	6.17
		Mean	5.620
Standard deviation			0.312

Example of calculations for a random sample of 5 individuals

Sample data		**Sample statistics**	
John	**6.00**	**n:**	**5**
Dan	**6.00**	**Mean:**	**5.648**
Mike	**5.83**	**S:**	**0.420**
Cam	**5.08**		
Barb	**5.33**		

Calculate standard error:

$$SE = \frac{s}{\sqrt{n}}$$

Where: SE = standard error
s = standard deviation
n = sample size

Find correct *t*-value from table:

1. **Find correct confidence level column:**
   For a 95% confidence interval use the column labeled "α(2): 0.05".

2. **Subtract 1 from sample size (i.e., n-1) to obtain the correct degrees of freedom (*df*). *df* = 5-1 = 4**

3. **Find *df* =4 row in left-most column and look under α(2): 0.05 to obtain the correct *t*-value: 2.776**

Calculate the 95% confidence interval width:
Multiply the SE x *t*-value to get CI width:
CI width = 0.188 x 2.776 = 0.522

Apply the Finite Population Correction (FPC) since you have sampled more than 5% of the entire population:

$$FPC_{CI} = \sqrt{\frac{N-n}{N}}$$

Where N = total # of possible sampling units (23).

Multiply the CI width by the FPC_{CI} to obtain the corrected CI width: Corrected CI width = 0.522 x 0.885 = 0.462

Mean and 95% confidence interval = 5.648 ± 0.462

Non-sampling and Sampling Errors

- Non-sampling error: error that occurs because the sampling design is incorrectly applied
  - Biased sample unit selection
  - Inappropriate sampling techniques
  - Sloppy field work
  - Transcription error
  - Inconsistent species identification

  Statistics assume this error = 0
    - cannot be measured

- Sampling error: difference between sample-based estimate and true population, inherent in sampling and observing organisms
  (can be measured)
- the inevitable result of sampling from a larger population despite correct implementation of the design

  Statistics are designed to help you understand and control this error

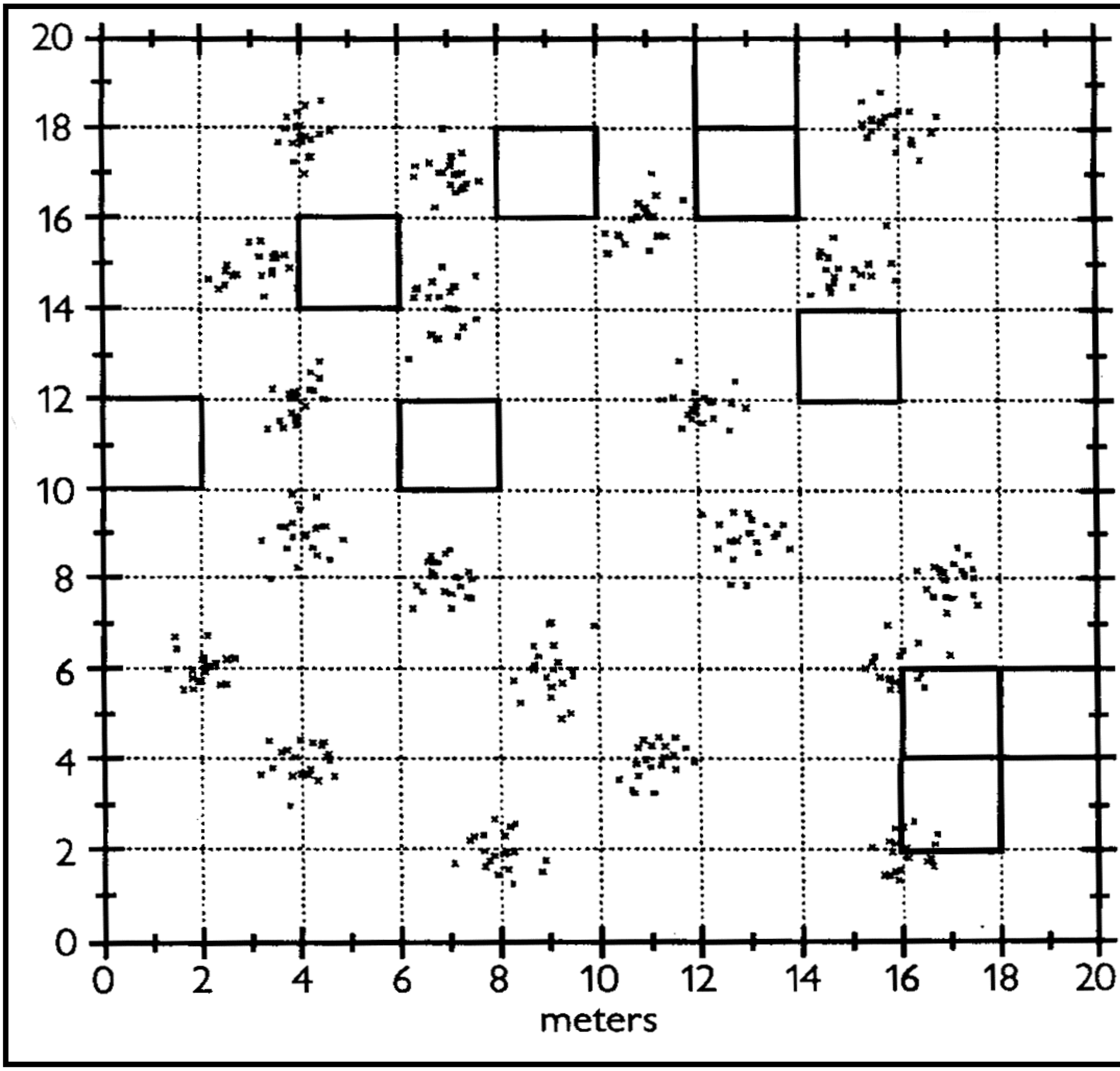


Figure 8A. A random arrangement of 2m x 2m quadrats positioned within a 400-plant population. Note that in figure **8D**, the population estimate = 960 plants. From Elzinga, et al. (1998).

Sample information		
Coordinates		# of plants
X	Y	
16	2	5
16	4	3
18	4	0
0	10	0
6	10	0
14	12	0
4	14	0
8	16	0
12	16	0
12	18	0

Population parameters

Tot. pop. size: 400 plants

Mean # plants/quadrat: $\mu = 4$

Standard deviation: $\sigma = 5.005$

Sample statistics (n=10)

Mean # plants/quadrat:

$\bar{x} = 0.8$

Standard deviation:

$s = 1.75$

Population estimate

Est. pop. size = 80 plants

95% CI = ± 119 plants

Figure 8B. Population parameters and sample statistics for the 400-plant population in **Figure 8A.**

Confidence Interval: > 0 - 199

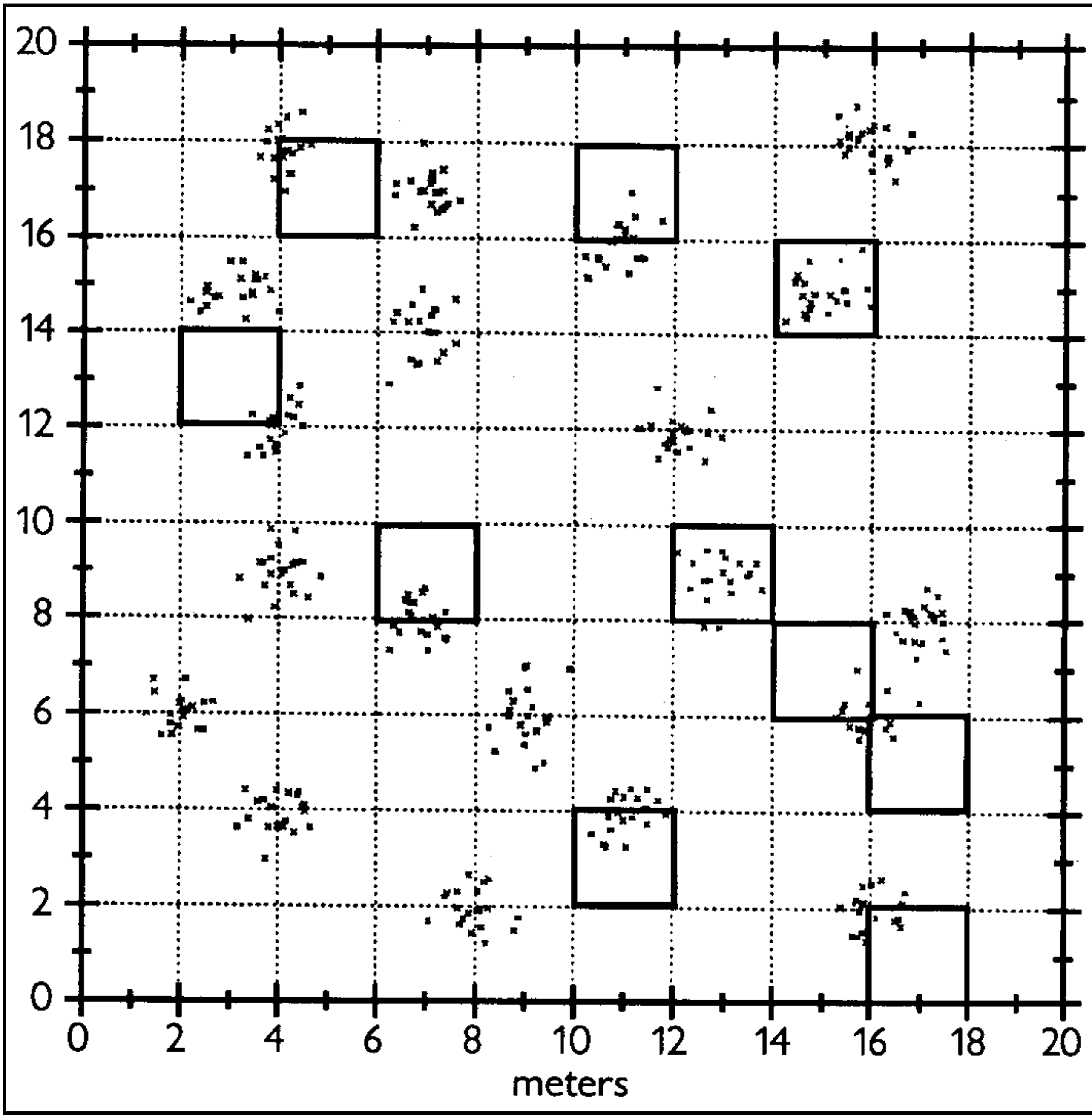


Figure 8C. A random arrangement of 2m x 2m quadrats positioned within a 400-plant population. Note that in **Figure 8A**, the population estimate =80 plants. From Elzinga, et al. (1998).

Sample information		
Coordinates		# of plants
X	Y	
16	0	5
10	2	11
16	4	3
14	6	5
6	8	10
12	8	18
2	12	6
14	14	20
4	16	9
10	16	9

Population parameters

Tot. pop. size: 400 plants

Mean # plants/quadrat: $\mu = 4$

Standard deviation: $\sigma = 5.005$

Sample statistics (n=10)

Mean # plants/quadrat:

$\bar{x} = 9.6$

Standard deviation:

$s = 5.58$

Population estimate

Est. pop. size = 960 plants

95% CI = ± 379 plants

Figure 8D. Population parameters and sample statistics for the 400-plant population in **Figure 8C.**

Confidence Interval: 581-1339

Sampling Distribution

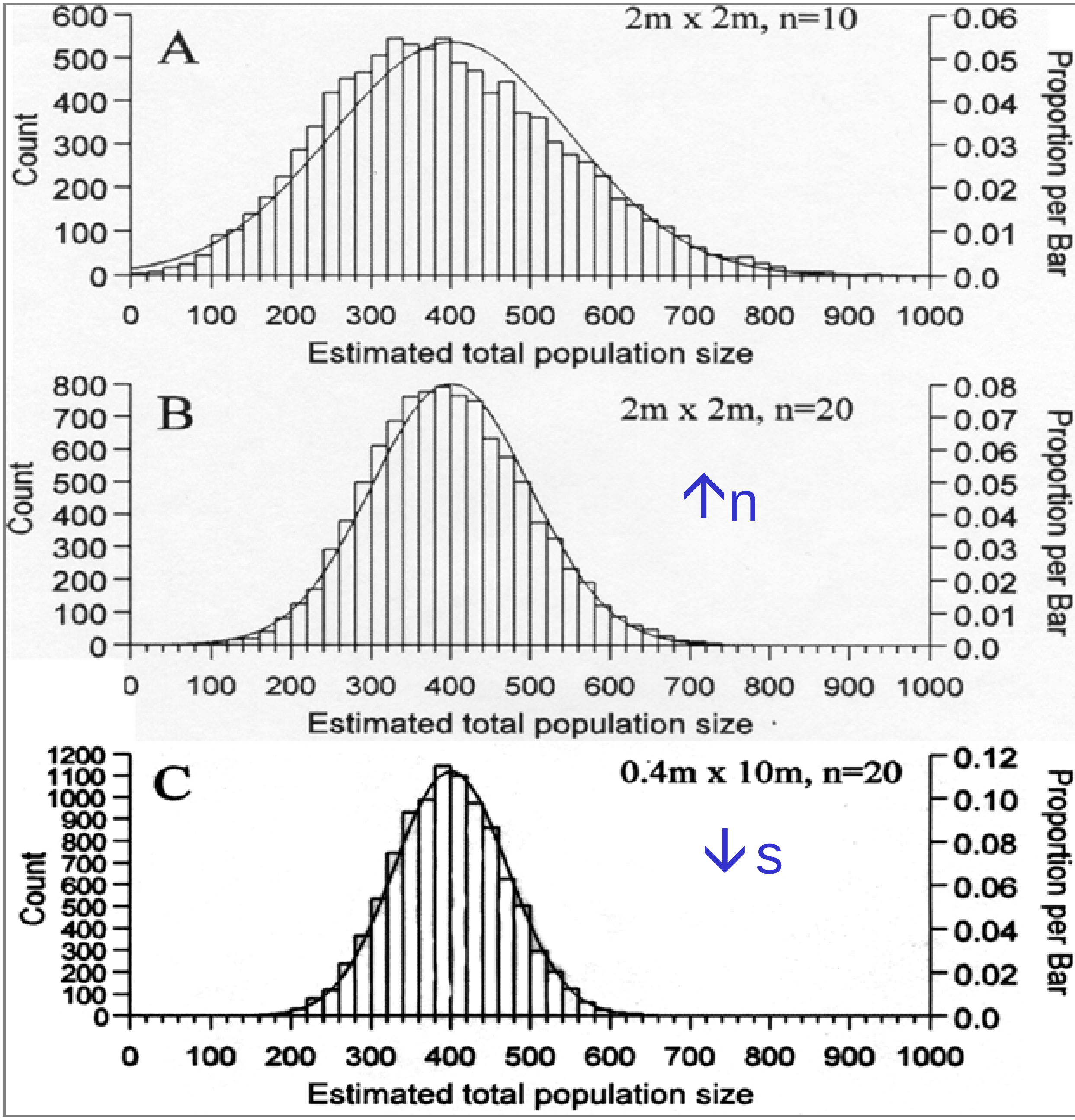


Figure 9. A distribution of population size estimates from 10,000 separate random samples from a 400-plant population. The curved line shows the normal distribution bell-curve fit around the overall mean of the distribution. (A) shows the sampling distribution when 10 2m x 2m quadrants were used. (B) shows the sampling distribution when 20 2m x 2m quadrants were used. (C) shows the sampling distribution when 20 0.4m x 10m quadrants were used.

Improving the sampling design will reduce the standard error:

$$s / \sqrt{n}$$

which reduces the width of the sampling distribution.

Types of Sampling Error

	No change has taken place	There has been a real change
Monitoring system detects a change	False-change Error (Type I) α	No Error (Power) $1-\beta$
Monitoring system detects no change	No Error $(1-\alpha)$	Missed-change Error (Type II) β

Figure 10. Monitoring for change: possible errors

False change error → taking action unnecessarily

Missed change error → failing to take a necessary action

Power = (1 – Missed change error rate)

$$\text{Power} = f\,(s, n, \text{MDC}, \alpha)$$

Increase Power by:

- s – standard deviation
- n – number of sample units
- MDC – minimum detectable change
- α – false-change error rate

$$n = f\,(s, \text{Power}, \text{MDC}, \alpha)$$

Sampling Design

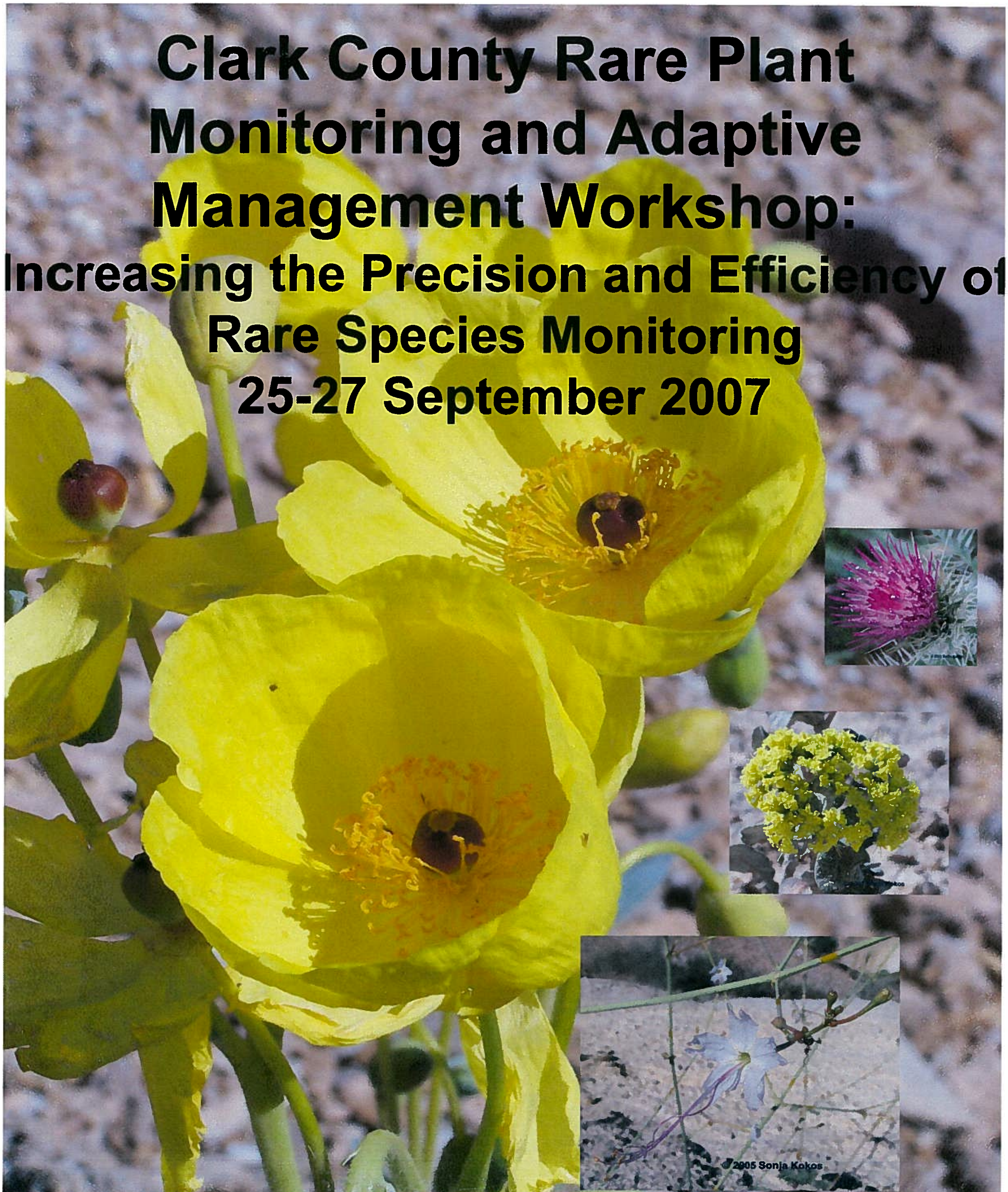
A plan of sampling that minimizes data variability and maximizes the detection of change.

- Precision: describes the closeness of repeated measurements (of the same quantity) to one another
  - sampling errors: difference between sample-based estimate and true population, inherent in sampling and observing organisms
    (can be measured)
  - nonsampling errors: result of biased selection, inappropriate techniques, sloppy field work, transcription errors
    (cannot be measured)
- Repeatability: ability of measurements to be repeated over time with limited nonsampling error
- Efficiency: ability of making the measurements easily and quickly, durability of project

Clark County Rare Plant Monitoring and Adaptive Management Workshop:

Increasing the Precision and Efficiency of Rare Species Monitoring

25-27 September 2007



The Nature Conservancy
Protecting nature. Preserving life.

PHOTOGRAPHIC MONITORING

Session Objectives

At the end of this session, participants will be able to:

- explain the differences between three types of land-based photographic monitoring: photopoints, photoplots, and repeat photography.
- list the equipment necessary for photographic monitoring.
- describe the techniques for taking photopoints and photoplots.
- list the information required for documenting photopoints and photoplots so that they can be repeated in the future.

Introduction

photographic monitoring: a qualitative to semi-quantitative method using repeatedly taken photographs of the same area to visually document changes in the appearance and condition of populations, vegetation, and landscapes.

Photographic monitoring is proving to be an extremely valuable technique to:

- detect changes in vegetation structure and composition.
- gain insights into the effects and dynamics of geomorphic processes (dune systems, debris flows).
- measure the effects of trampling, grazing, and erosion.

Specifically, photographic monitoring can quantify the rate, nature, and direction in change of observed features and allows an evaluation of the underlying causes of the perceived changes. It can provide qualitative data on sites, and quantitative data on cover, frequency, and density.

When used in conjunction with other monitoring methods, it can strengthen and visually illustrate interpretations and conclusions. The insights gained from photographic monitoring can be used to develop ecological models of systems that can be tested with more quantitative methods.

Photographic monitoring is an elegant way to convey complex information to a range of audiences, including the public, elected officials and colleagues.

Photographic monitoring is efficient, both in cost and time, aesthetically unobtrusive, permanent, and able to address multiple objectives. It is an especially valuable monitoring technique when resources and expertise are limited and in baseline studies, when it is not clear what parameters should be measured and when to measure them. The archiving of photographic information is inexpensive.

Three Types of Photographic Monitoring

Generally, there are three types of photographic monitoring: *photopoints*, *photoplots*, and *repeat photography.*

photopoints: repeated photographs of a landscape area.

photoplots: repeated photographs of a plot located at or near ground level.

repeat photography: the science of locating and reoccupying the exact camera position of a previous photographer.

NOTE: This workshop focuses on land-based photomonitoring methods. While not discussed here, a fourth type of photographic monitoring, aerial photography, is useful for detecting land-cover changes over time.

Equipment

There are five key equipment considerations to photomonitoring:

- camera equipment
- film
- tripod
- cable release
- range pole

Each is discussed in detail below. **Figure 1** provides a more comprehensive list of recommended equipment.

Camera equipment.

35 mm cameras: We recommend either a quality 35 mm camera with either a 35 mm (for wide angle shots) or a 50 mm macro lens (for normal shots). A 35 mm lens is better than a 28 mm lens, and a 50 mm macro lens is better than a regular 50 mm lens because both have less peripheral aberration. Zoom lenses are not recommended since it is hard to repeat exact focal length.

Higher quality camera bodies have strong bodies and better seals, thus are better for the rigor of the field. Useful options include: a film dating mechanism, an auto-wind unit, and a weather-proof carrying bag.

NOTE: Some photographic monitoring references recommend large format cameras (2.25, 4x5) rather than 35 mm. They are better from a purely technical viewpoint, however they are expensive and difficult to obtain making them inappropriate for our agencies.

Digital Cameras:

Image resolution is dependent on what the image will be used for, whether presentations or prints. It is best to record images at higher resolutions. Most current cameras have a choice of image resolution. One weakness of the majority of moderately priced digital cameras is that they all come with zoom lens, which can result in a loss of precision when repeating photopoints.

Digital Videos:

Easy to take and distribute. Greatest limitation is the memory of computers. Five minutes of video is equal to 1 GB. Costs for equipment is also high, ranging to $10,000 for the camera and appropriate computer.

Film. For archival purposes, either black and white prints on Kodak T-Max 100 film or Kodachrome slides are best. Color slides are the choice for most current biological projects. The color in Kodachrome slides (E-13 processing) has proven to be stable for at least 50 years.

The ASA of the film should be the lowest possible under the range of conditions at the site being studied. Below are useful rules of thumb:

- for sites with extensive sun, 25 or 50 ASA is appropriate.
- for sites where you might have substantial cloud, a faster film of 100 ASA is better.

Films faster than 100 ASA are increasingly grainy and result in lower resolution slides.

Tripod. A tripod is essential for repeating shots at the same location and height above the ground, using slower films and slower f-stops for greater depth of field, and greater stability while focusing. A tripod can also help take photos from a set height, no matter the height of the person taking the photograph.

Cable release. A cable release for the camera reduces the chance of movement when the exposure is made.

Range pole. A pole with clearly marked units to measure the height of vegetation and to provide a scale in the photographs.

Photographic Monitoring Equipment Checklist

✓ Photographic Monitoring Record Form	✓ Lens tissue
✓ Monument stakes (PVC, conduit, rebar)	✓ Film
✓ Tape	✓ Tripod
✓ Compass	✓ Cable release
✓ Map of vicinity (largest scale possible)	✓ Range pole
✓ Camera and lens	

Figure 1. Equipment Checklist for photographic monitoring projects.

Management Objective and Sampling Design Issues

As with any monitoring project, there needs to be a clear, concise, and complete monitoring objective that answers the following questions:

- What is the population being monitored?
- Specifically, what is being measured? What is expected to change?
- What frequency of measurement is needed to detect this change?
- What sampling universe will inferences be made to?
- What are the acceptable missed change and false change error rates and the desired minimum detectable change? (For quantitative monitoring.)

All the sampling design issues discussed in earlier sections are appropriate for photographic monitoring:

- random placement of photopoints and photoplots.
- permanent vs. temporary plots.
- number of photographic sampling units.

The Permanently Marked Point

For photopoints and photoplots, the location from which the photograph is taken needs to be permanently marked using either a permanent stake or marker or a location along a permanently marked baseline.

NOTE: When establishing a permanently marked baseline either use a steel tape or, if using fiberglass tapes that can stretch up to 3 cm per 50 m, establish permanent points every 10-20 m along the baseline to improve accuracy.

The locations of permanent plots should be mapped on the data sheets (see **Data and Data Forms** below). To assist in relocating, especially when permanent markers disappear, triangulate all permanent points and the end points of baselines to other reference markers or witness trees.

NOTE: Reference markers or witness trees need to be relatively permanent themselves.

The 360 Degree Photopoint

The Brevard County Environmentally Endangered Lands Program (EEL) has developed one of the best 360 Degree (panoramic) monitoring programs for habitat restoration. They establish fixed photopoints and mark them with a permanent steel rod base, in which a staff with the camera attachment can be placed. They use a software called VRWorx2.1 to combine the photos into a continuous 360 degree image and stitched together over time into a Quicktime VR movie. Total costs, including the camera, is about $1000.

The EEL Program has a pdf of how to construct the base and staff, take the photos and process the images. Contact the EEL Program for more information: Raymond Mojica at the Brevard County Environmentally Endangered Lands Program.

Data and Data Forms

The data taken and the information that should be on data forms fall under two categories: location data and photopoint data.

Location data includes:

- political and administrative units
- geographic location
- written description of photopoint
- written description of reference points including bearing and distance to reference points and range pole
- a general map of the photopoint, reference points, location of range pole, and features in the immediate area

Photopoint data includes:

- date of photograph
- bearing
- height of camera
- vertical angle
- lens

- film ASA
- slide number
- notes on weather conditions
- name of photographer(s)

Figures 2 and **3** are samples of Photopoint and Photoplot Monitoring Record Forms, respectively. **Figure 4** is an example of a Photoplot Data form.

Archiving Photographic Monitoring Data

The data sheets and images must be archived in a safe and accessible location. Information about the project should be distributed in several locations, so the project is not lost from the land managing agency. It is probably appropriate to publish information to let others outside of the agency know of the project. While these comments are true for all monitoring data, it may be especially true for photographic monitoring with possible resampling intervals over 25 to 100 years!

35mm Images:

Slides and photographs should be stored in an environmentally safe storage area that is:

- dark: UV light, sunlight, and fluorescent light breakdown slides.
- cool: no warmer than 70° F.
- low relative humidity: between 25 - 50%.

Storage locations can be metal file or storage cabinets or archival storage boxes made of acid-free paper. Wood storage facilities should not be used as wood maintains higher humidity and may emit fumes that damage the film.

Slides should be stored in archival quality holders for protection in handling and from dust. This includes plastics of the following types: low density polyethylene, cast polypropylene, and extruded polypropylene. These holders should hold the slides/photographs tight enough so they don't slip out in the file cabinet or in the field.

Making duplicates of slides or photos is recommended for any long-term project. Duplicates of slides are usually made on an Ektachrome-type film, thus will not last as long as the Kodachrome originals. We suggest that the Ektachrome duplicates be used for projection (light and projection does less damage to Ektachrome than Kodachrome) and for use in the field and that the Kodachrome originals be archived.

Digital Images:

Download images immediately and store in several formats (hard drive, cds). The archival nature of digital media is not good as 35mm slides! It is unknown how well digital media will store data over decades, so a continual updating of the archival media is needed.

Distribution of Photographic Monitoring Data

Email/Mail Distribution: Obviously the use of digital photography has greatly enhanced the distribution of the images.

Presentations

Movies

Web Sites

Take Home Message: get the information distributed!

Establishing Photopoints

The monitoring objective is generally to document the condition of a landscape area. Important considerations for successful photopoint monitoring are the:

- establishment of a permanent point.
- vertical angle of the camera maintained at 90^0.
- use of a range pole.
- position of the sun (either directly behind or above).

PHOTOPOINT MONITORING RECORD FORM

Project:

Initial Take Information:

Camera Point Number: Location:

Date: Retake Frequency:

Camera Point Description -- Describe access, location of permanent point, surrounding area, include sketch map.

Reference Point Descriptions: **Sketch Map below:**

Reference Point 1

Description:

Marking:

Bearing: , m. to camera point

Reference Point 2

Description:

Marking:

Bearing: , m. to camera point

Reference Point 3

Description:

Marking:

Bearing: , m. to camera point

Photographic Information:

Photographer:

Camera: Lens: Filter: Film: ASA:

Time: Weather:

	View 1	View 2	View 3	View 4
Camera Height:				
Vertical Angle: +/-				
Bearing:				
F-Stop & Speed:				
Range Pole Bearing & Distance:				

Notes:

PHOTOPLOT MONITORING RECORD FORM

Project:

Initial Take Information:

Photoplot Number(s):

Photoplot or Transect Location:

Date:

Retake Frequency:

Photoplot or Transect Description -- Describe access, location of permanent points, surrounding area, include sketch map.

Reference Point Descriptions:

Sketch Map below:

Reference Point 1

Description:

Marking:

Bearing: , m. to camera point

Reference Point 2

Description:

Marking:

Bearing: , m. to camera point

Reference Point 3

Description:

Figure 3. Sample Photoplot Monitoring Record Form.

PHOTOPLOT DATAFORM

Site:

Photographer: Date: Page of

Lens: Filter: Film (ASA):

Time: Weather:

Slide #	Photoplot #	Camera Ht (m)	Vertical Angle[1]	F-stop	Speed	Focus dist[2]	Notes

[1]Enter angle as departure from horizontal if other than -90°.

[2]Enter distance in meters if other than infinity.

Figure 4. Sample Photoplot Data form.

Establishing Photoplots

Figure 5 compares the strengths and weaknesses of using photoplots. While the monitoring objective can be qualitative, photoplots are most useful for quantitative assessment of cover or density. The analysis for cover can be done by projecting the slide on or overlaying the photograph with a grid and counting the hits at each grid intersection.

The prerequisites for quantitative photoplots include:

- short-statured vegetation: usually less than .5 m.
- identifiable species of interest in the photograph or slide.
- sufficient plot size: .5m x .5m at most; small enough to be photographed by people of different heights.

	Strengths		Weaknesses
+	Result is a precise measure of cover or density (at least of visible adult plants) that is sensitive to small changes in abundance	–	Can be difficult to relocate plots
+	Data is quick to collect reducing field time and investigator impact	–	Can be difficult to retake of photos with the same camera angle
+	Is more flexible in the timing of analysis	–	No guarantee of sufficient lighting to identify the species of interest
		–	Tendency exists not to analyze the data during the field season, eliminating the ability to return to the site to get missing data

Figure 5. Strengths & weaknesses of using photoplots.

Repeat Photography

Repeat photography is replicating the unwritten, the science (perhaps art) of locating and reoccupying the exact camera position of a previous photographer, matching camera equipment, time of day for correct shadows, and the use of filters to highlight or subdue important subjects (Webb 1996). As such, a specific monitoring objective may not be clearly defined.

NOTE: Photopoints and photoplots should not become repeat photography in the sense that it is used here. Photopoints and photoplots should have adequately archived information so that repeating the photographs is relatively easy.

Locating the exact position of a previous photographer requires the use of a photogrammatic tool called *parallax*. Repeat photographs should be taken at the same time of year and same time of day to match shadows and lighting.

parallax: the adjustment of camera location and height by lining up foreground and background objects on either side of the photographic view.

Previously taken photographs are rarely representative of the landscape. There is some inherent bias to all previous photography, including the specific goals of the photographer (only photographing a particular feature or attractive scenes) and photographing from well-traveled routes where human impacts are comparatively great. Interpretation of repeat photography requires that one carefully assesses the bias of previous photos.

Interpretation of Monitoring Data

Use statistical procedures, which allow us to distinguish between an ecological "signal" and natural variation, to:

- Estimate parameters
- Compare a sample to a threshold value
- Compare two or more independent samples
- Compare two or more related samples
- Correctly interpret the results of a monitoring study

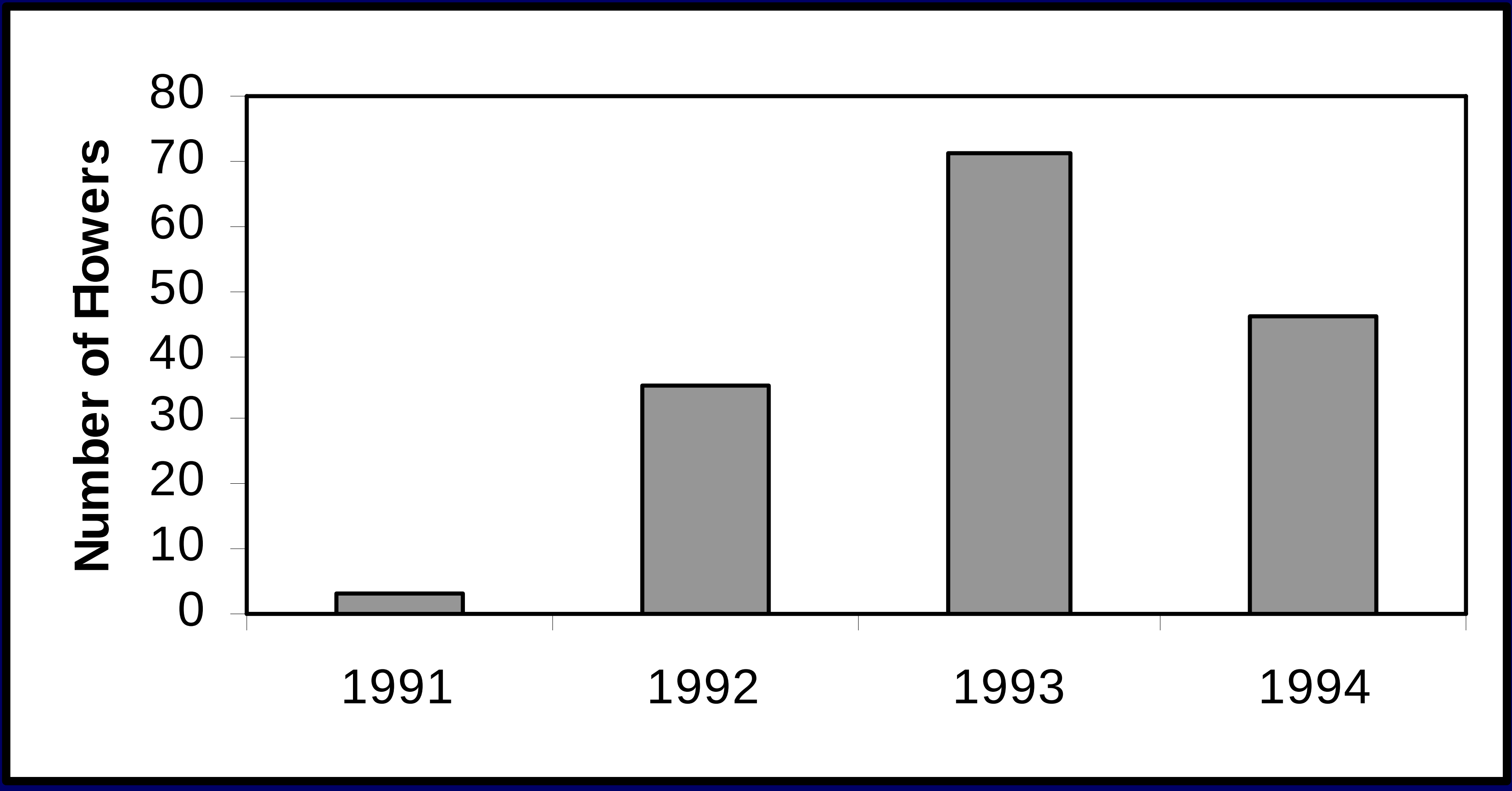


Figure 1. Flower abundance of *Sarracenia jonesii* at McClure's Bog, 1991-1994.

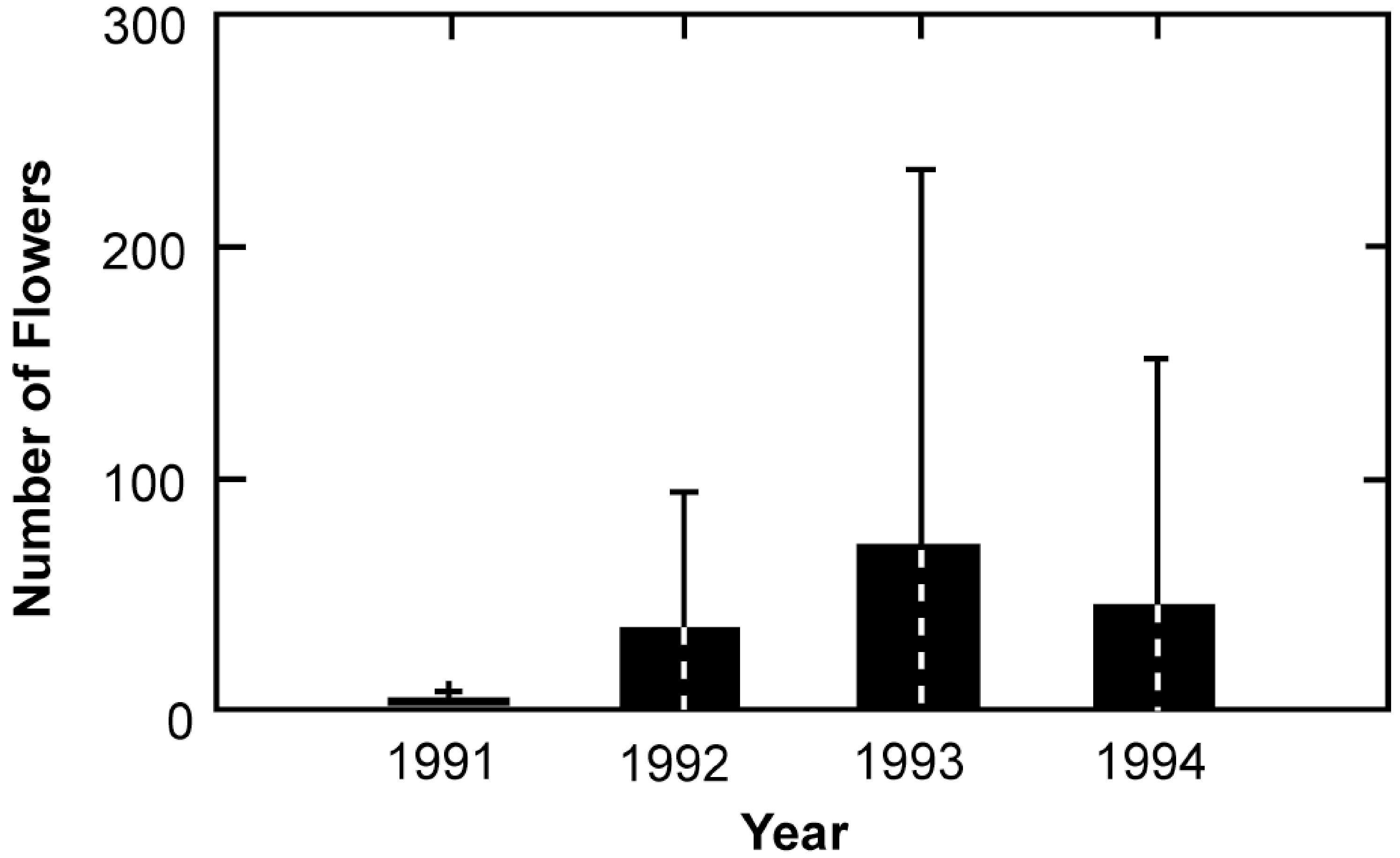


Figure 2. Flower abundance of *Sarracenia jonesii* at McClure's Bog, 1991-1994. Data presented with 95% confidence intervals.

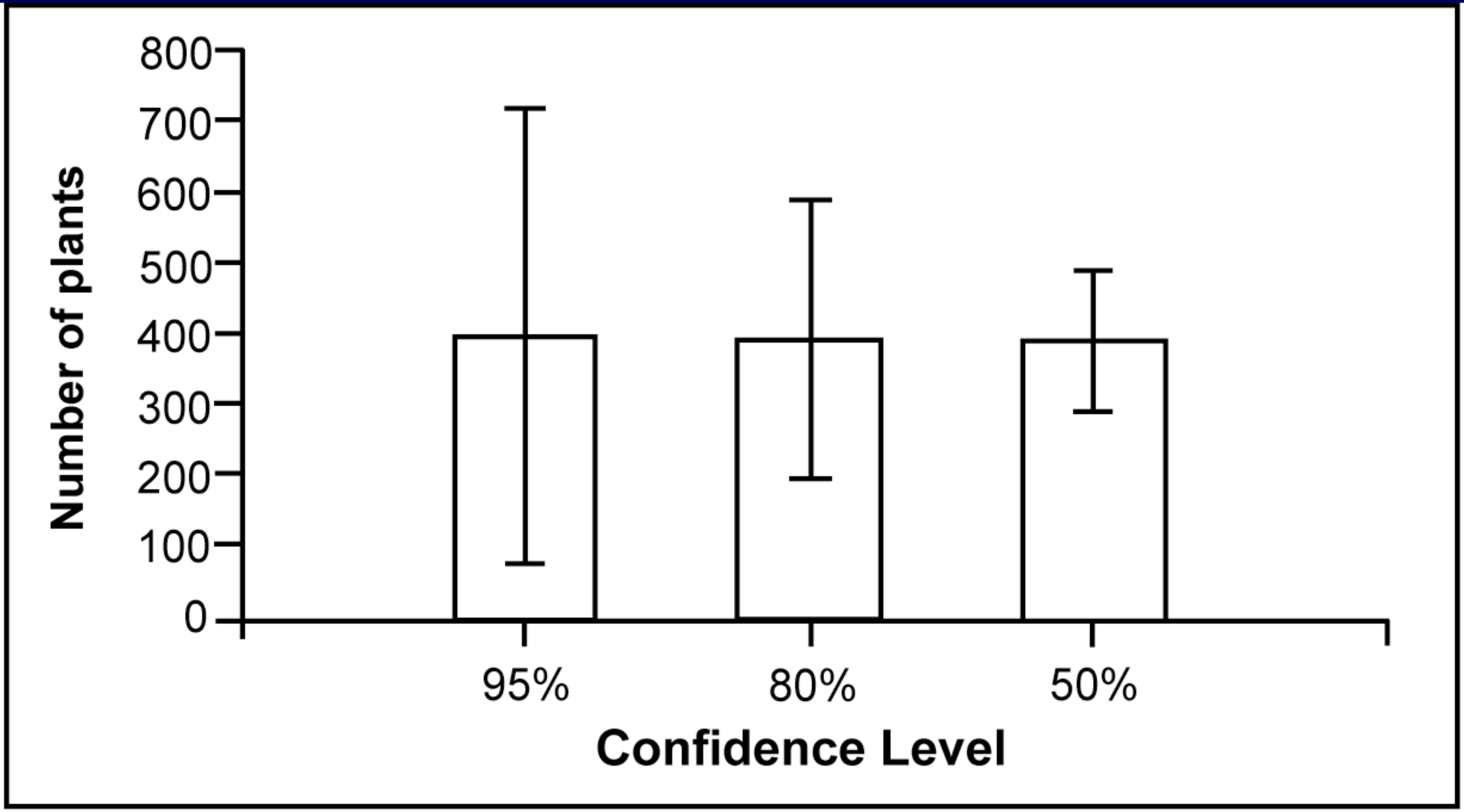


Figure 3. Comparison of confidence intervals and confidence levels for different sampling designs from the 400-plant population. Three different confidence levels (95%, 80%, 50%) are shown for the same data set based upon sampling 10 2m x 2m quadrats.

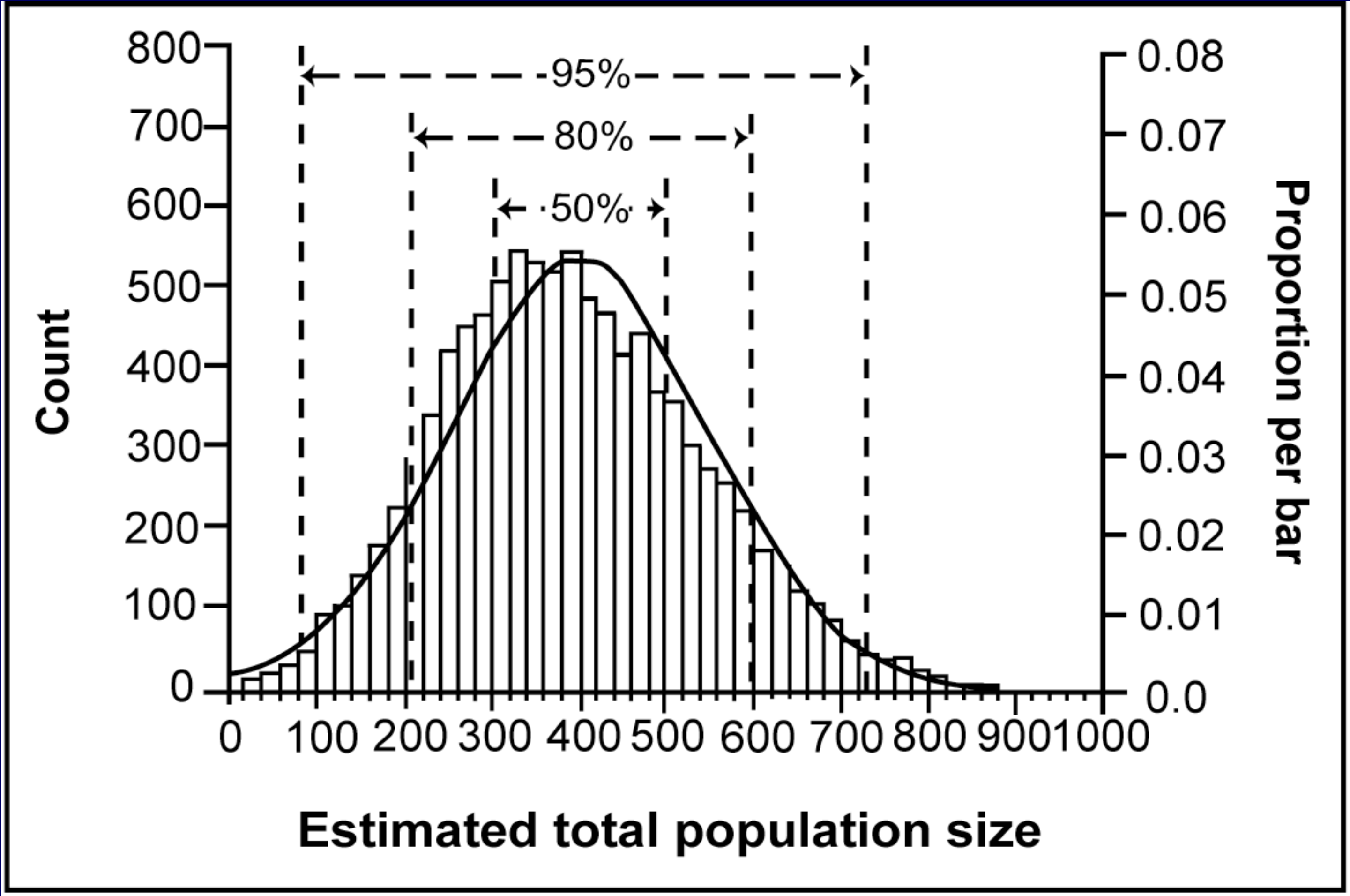


Figure 4. Sampling distributions from sampling the 400-plant population 10,000 times with samples of 10 2m x 2m quadrats. This figure shows the 95%, 80%, and 50% confidence intervals around the true population size of 400 plants.

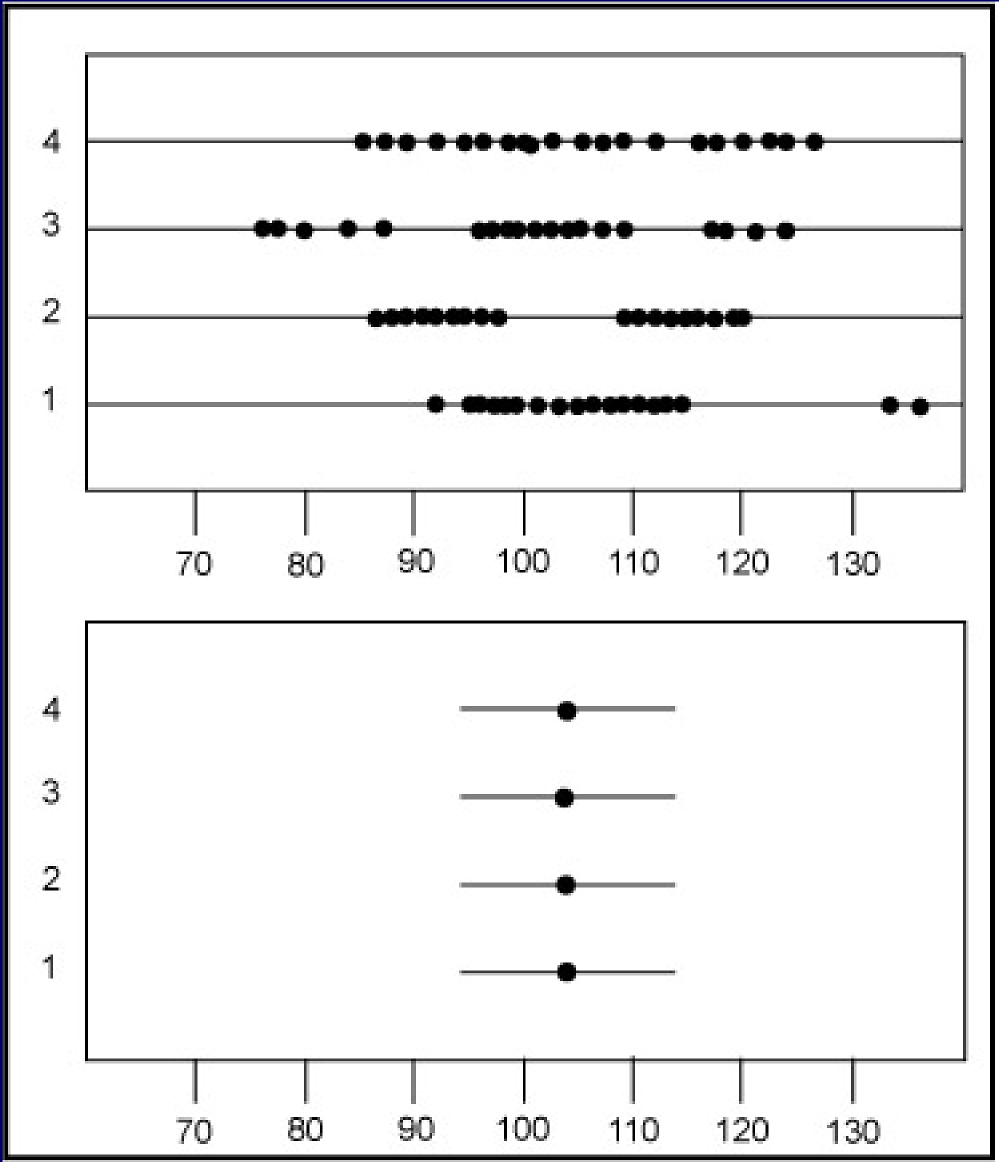


Figure 5. Illustration a failure of means and sample standard errors. Four sets of data are graphed with their means and standard errors. The four distributions have the same number of observations, the same means and the same standard deviations, but the distributions are very different.

Use Confidence Intervals to:

- Compare a sample mean to a threshold by seeing whether the C.I. intercepts the threshold
- Compare 2 independent (temporary S.U.) samples by
  - seeing whether their C.I.s overlap
  - seeing if the C.I. of the difference between the samples intercepts 0
- Compare 2 non-independent (permanent S.U.) samples by seeing if the C.I. of the difference between each pair of the samples intercepts 0

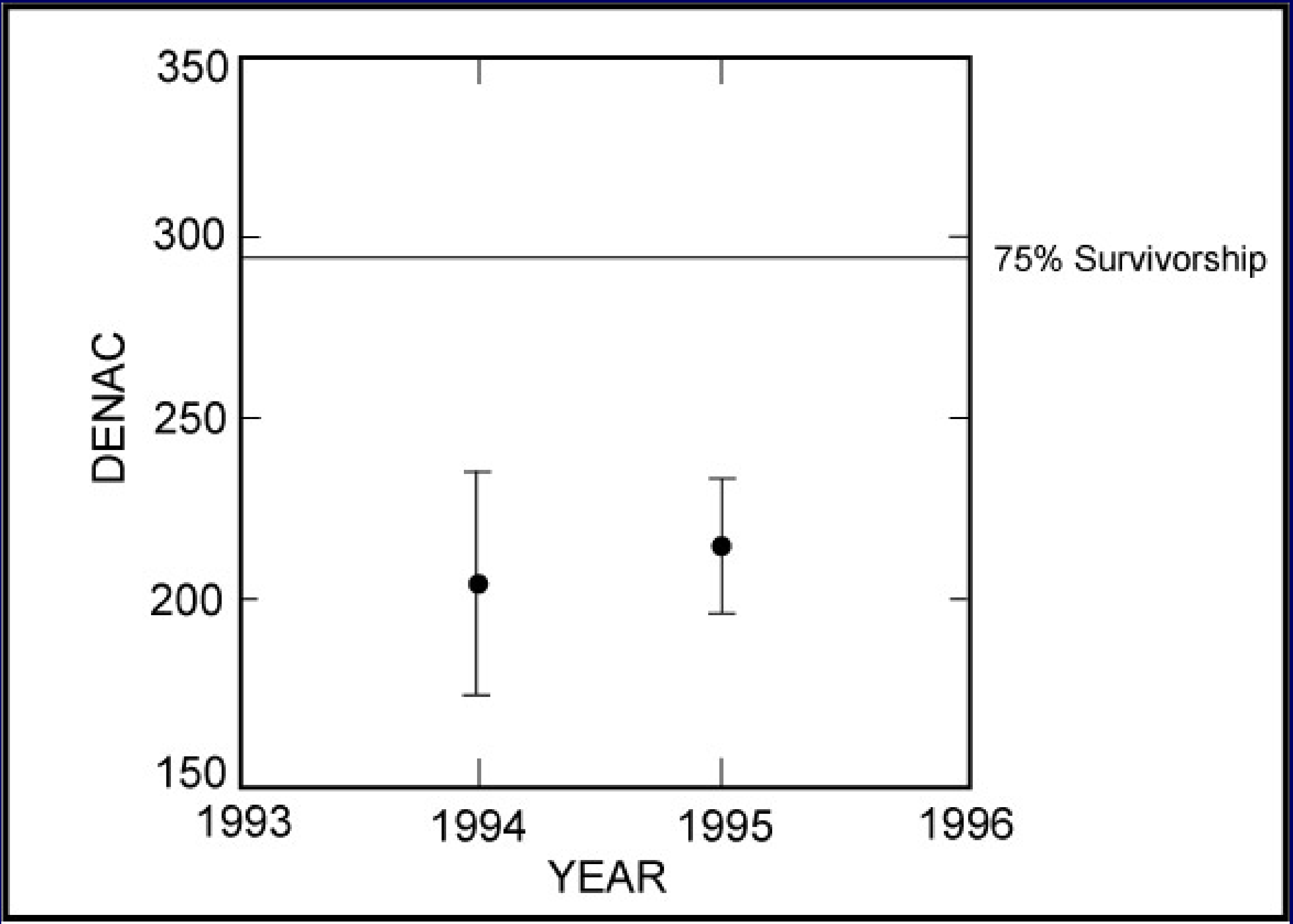


Figure 6. Survivorship of planted seedlings, Robbins Tract (90% CI)

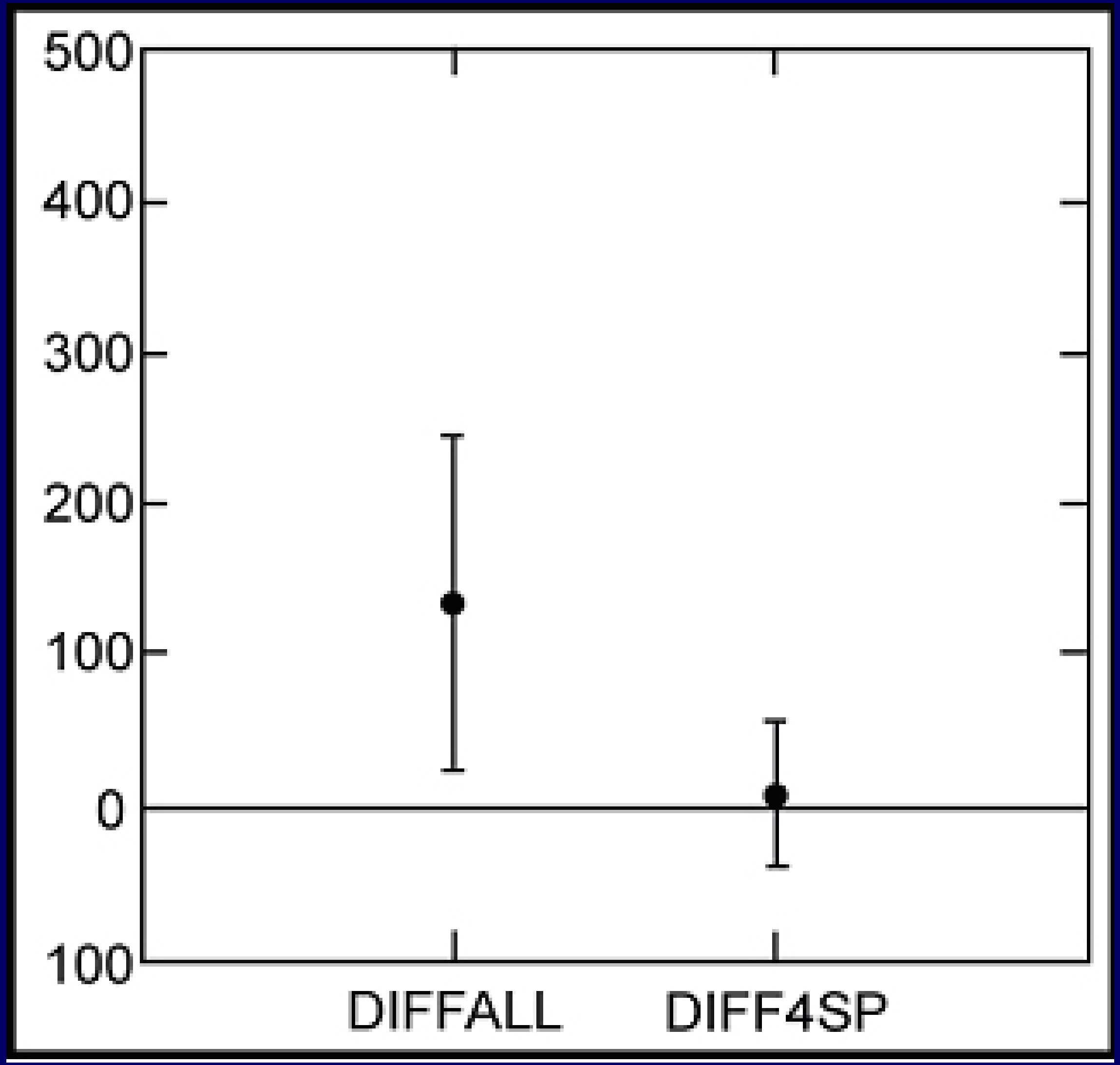


Figure 7. Mean and 95% CI for change in stem density. Robbins Tract, 1994-1995.

Use Confidence Intervals to:

- Compare a sample mean to a threshold by seeing whether the C.I. intercepts the threshold
- Compare 2 independent (temporary S.U.) samples by
  - seeing whether their C.I.s overlap
  - seeing if the C.I. of the difference between the samples intercepts 0
- Compare 2 non-independent (permanent S.U.) samples by seeing if the C.I. of the difference between each pair of the samples intercepts 0

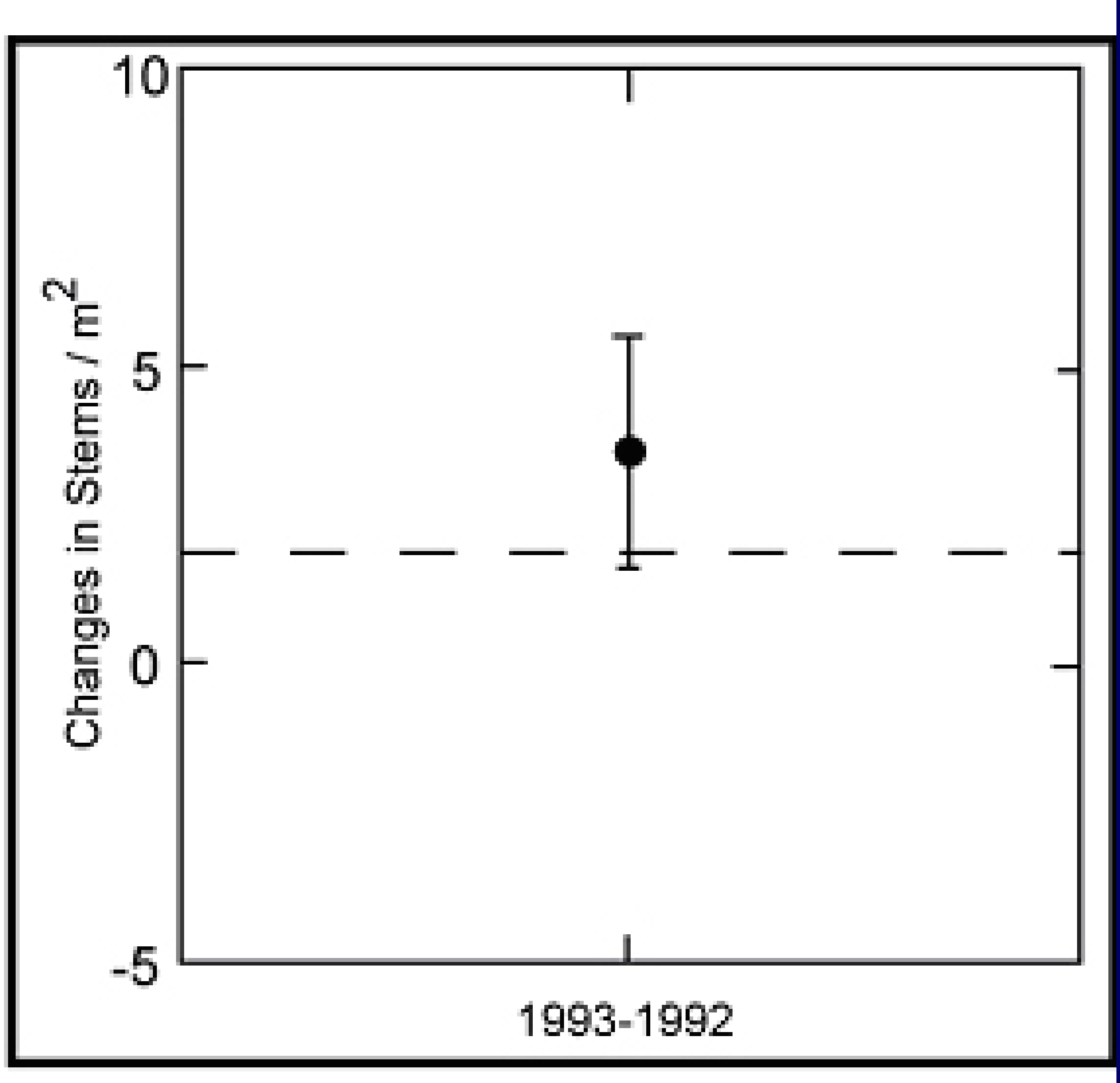


Figure 8. Mean and 90% CI for change in stems / m^2 for *Bigelowia nuttallii*, 1992-1993.

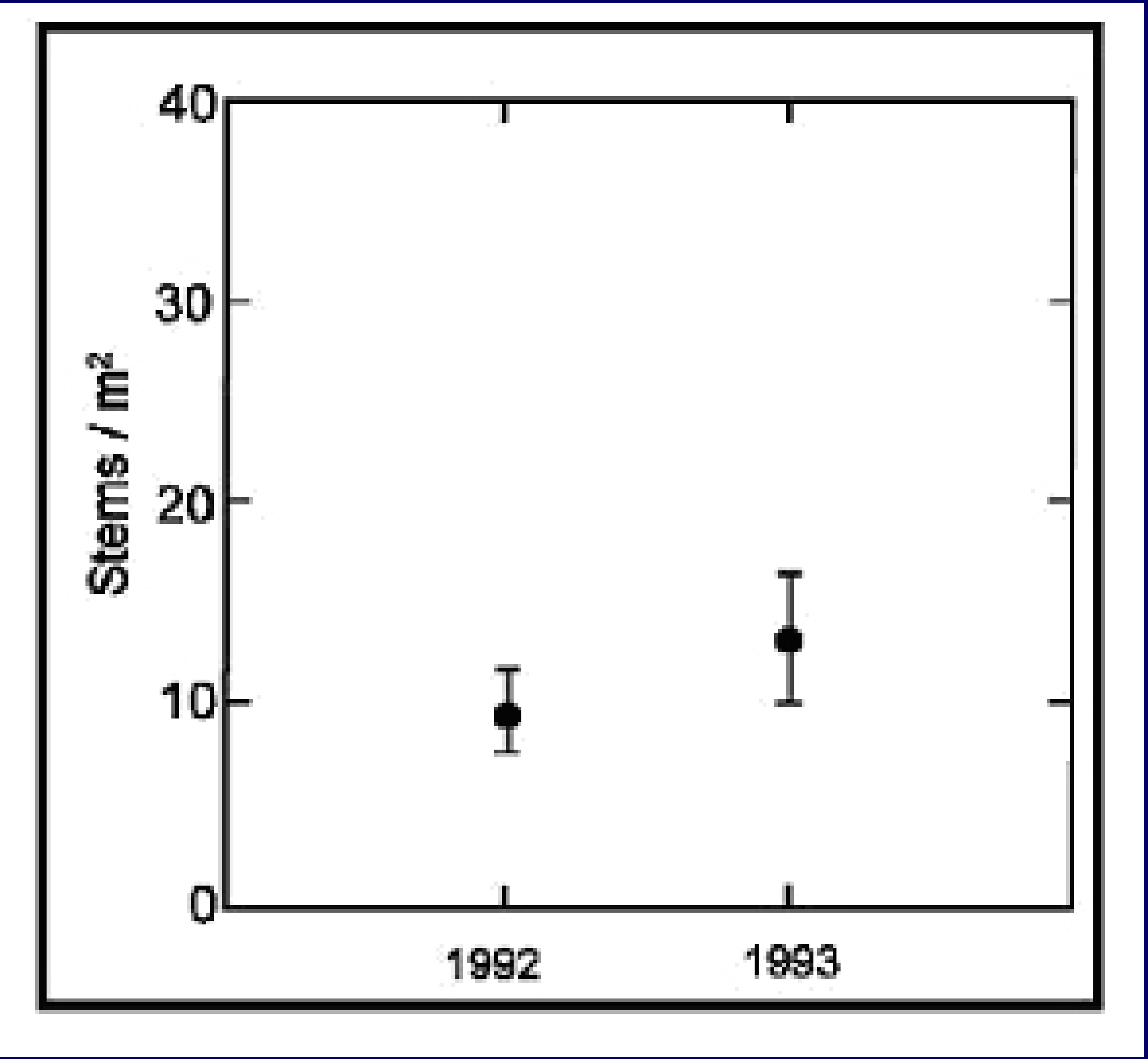


Figure 9. Mean and 90% CI for stems / m^2 by year, *Bigelowia nuttallii,* 1992-1993 if plots were temporary.

Assumptions for Confidence Intervals

- Random sampling
- Independent samples – use difference between years for permanent plots
- Variances of compared datasets are equal (not frequency) – larger variance is > 3x the smaller variance
- Normal distribution (not frequency) – transform data if not normal

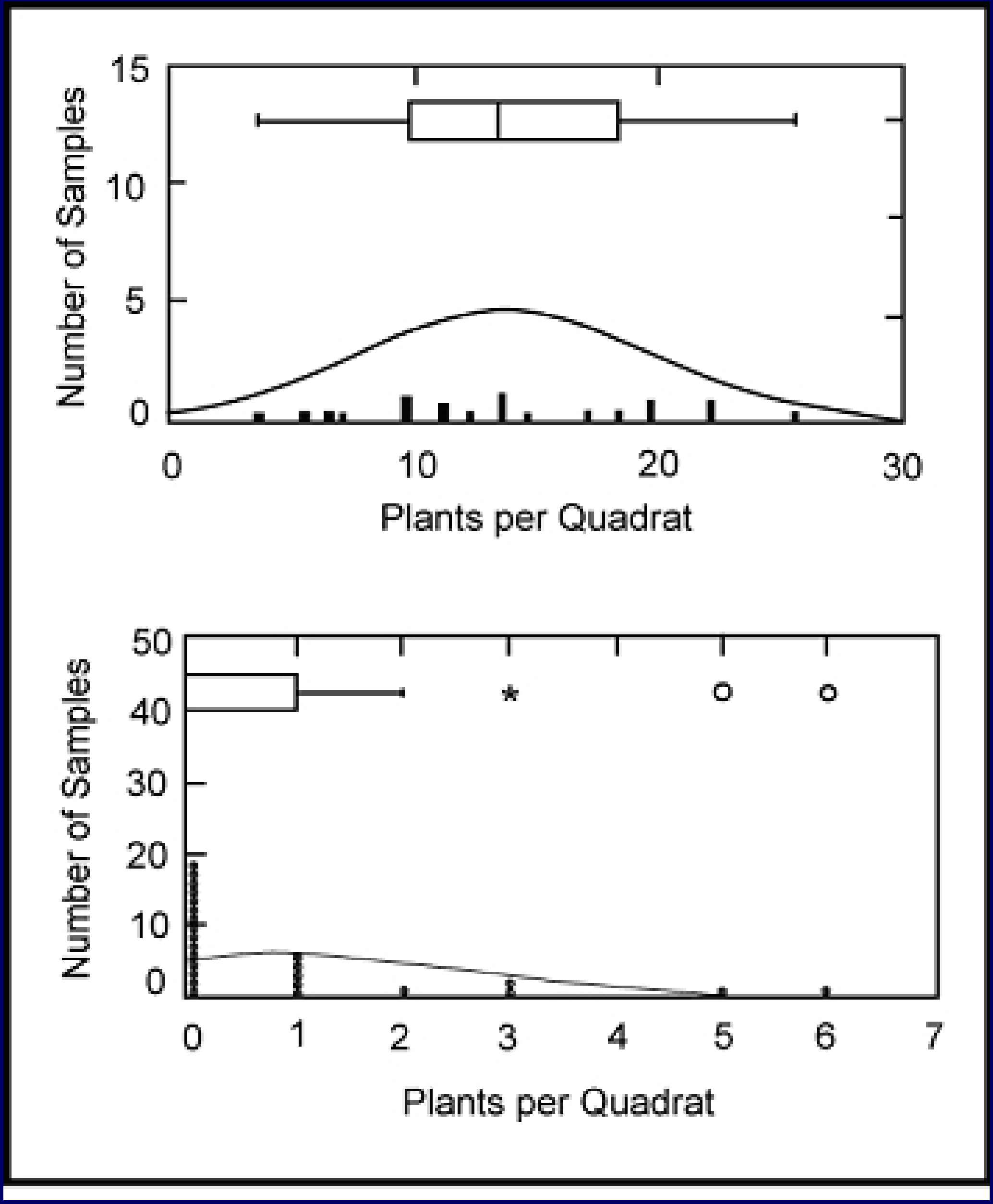


Figure 10. Box plots and dit plots. For each graph, the box plot is the upper graphic, the dit plot is the lower.

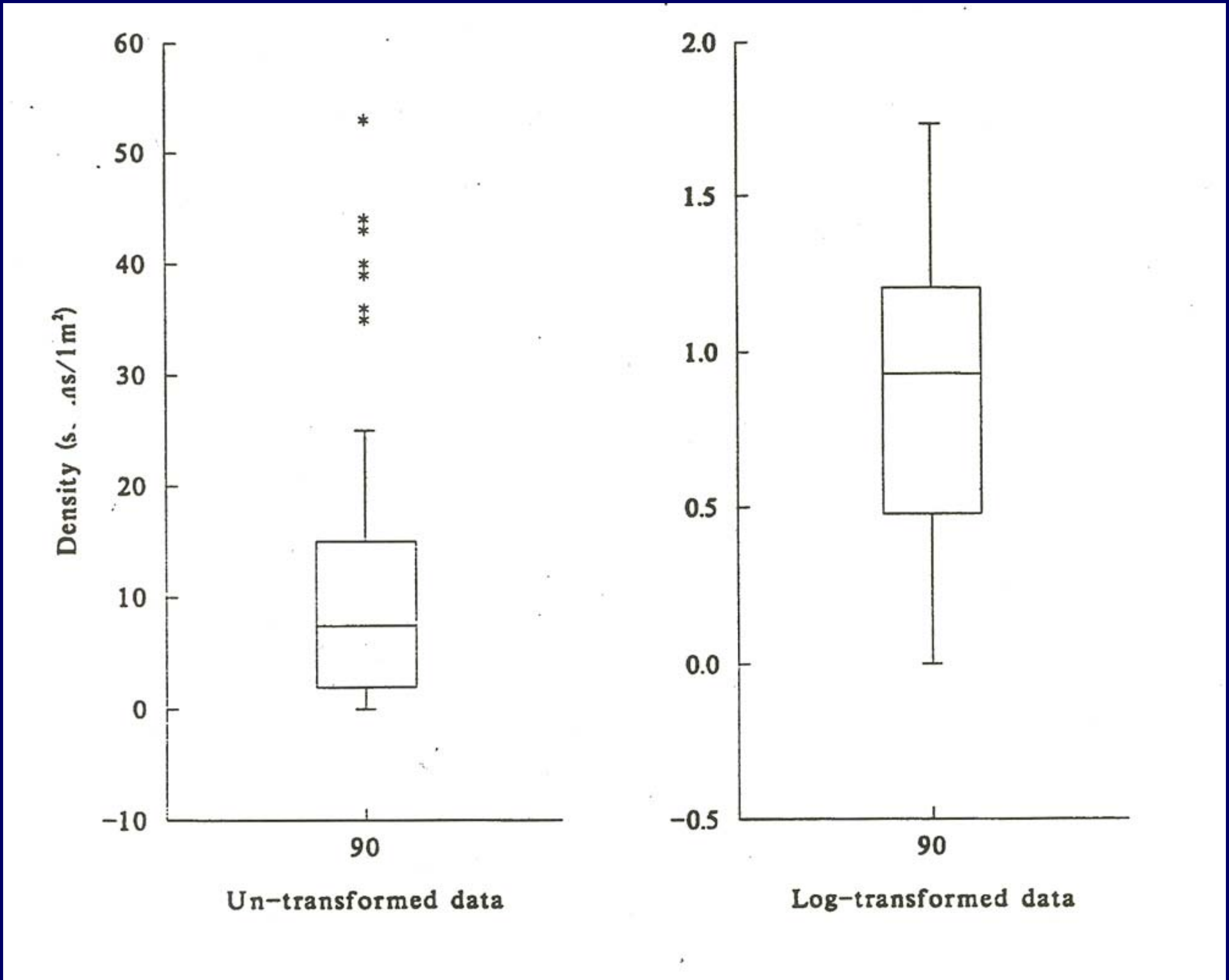


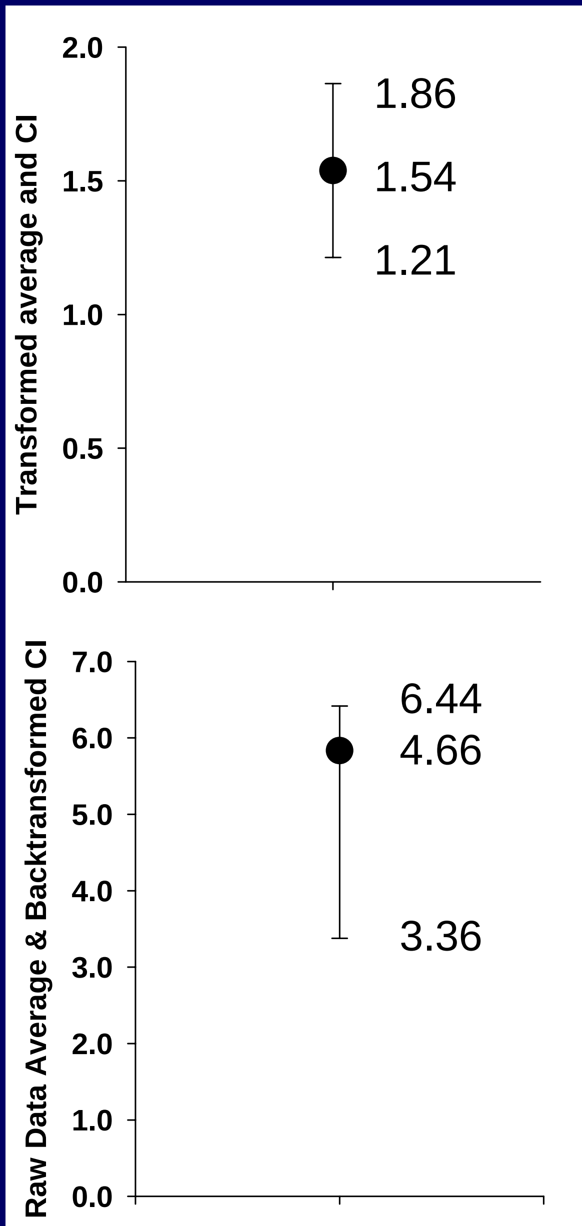
Figure 11. Results of a log-transformation on the density data for ANOD. 1990 Penacle research plots B Control.

Common transformations:

Continuous data – ln(x)

Count data - √x

Percent data – arcsin √x



Graph of transformed average graphed with Confidence Interval (*t*-value for 95% CI, n=20 (19 degrees of freedom) = 2.093.) 1.538 ± 0.325101

Graph of raw data average with back-transformed interval (take exponential of interval tails) New CI = 3.364 -6.443. Note uneven tails.

Figure 12. Example of back-transforming data.

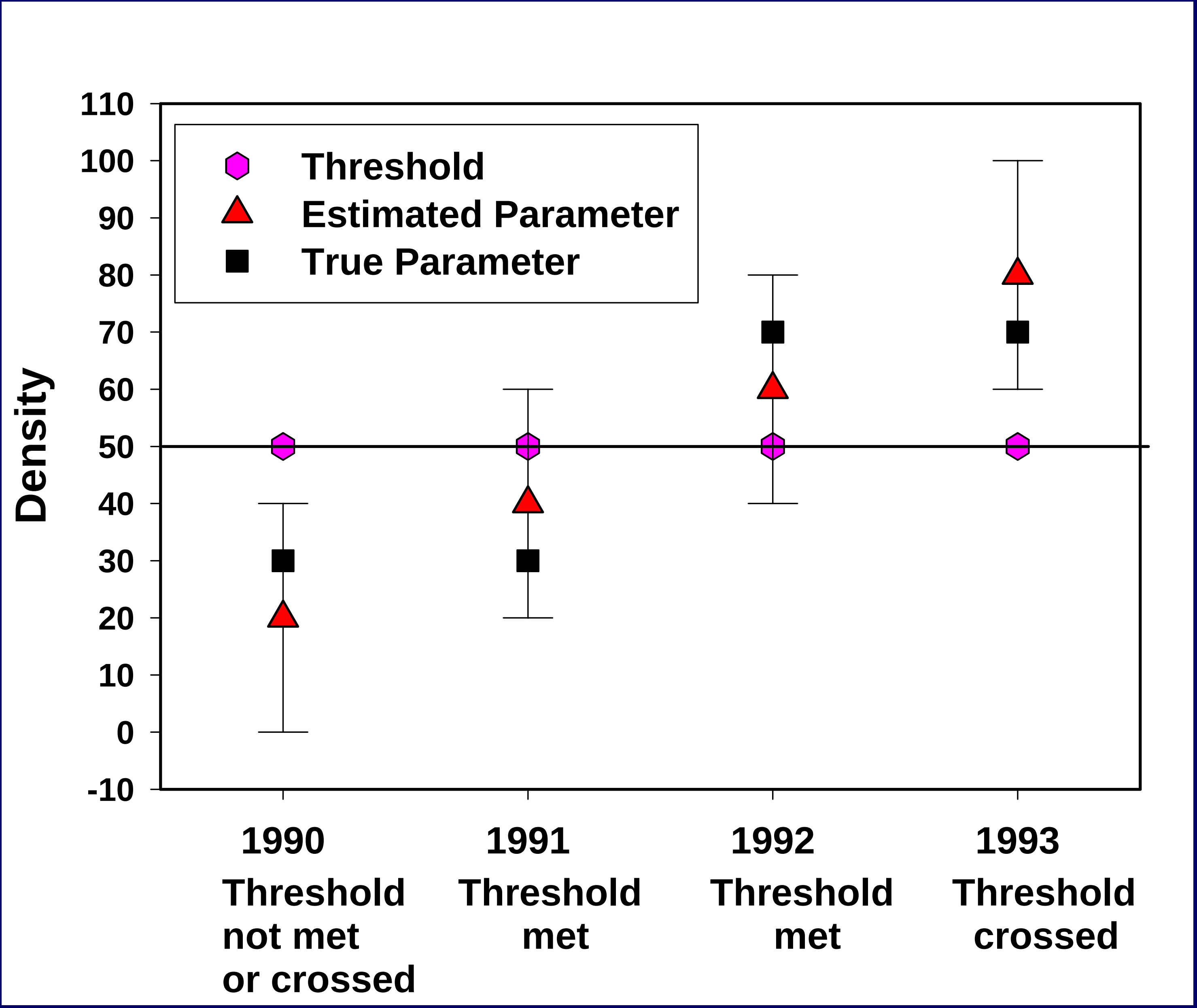


Figure 13. Modified from Mori, S., undated. Monitoring, considerations for study design. USFS PSW Berkley.

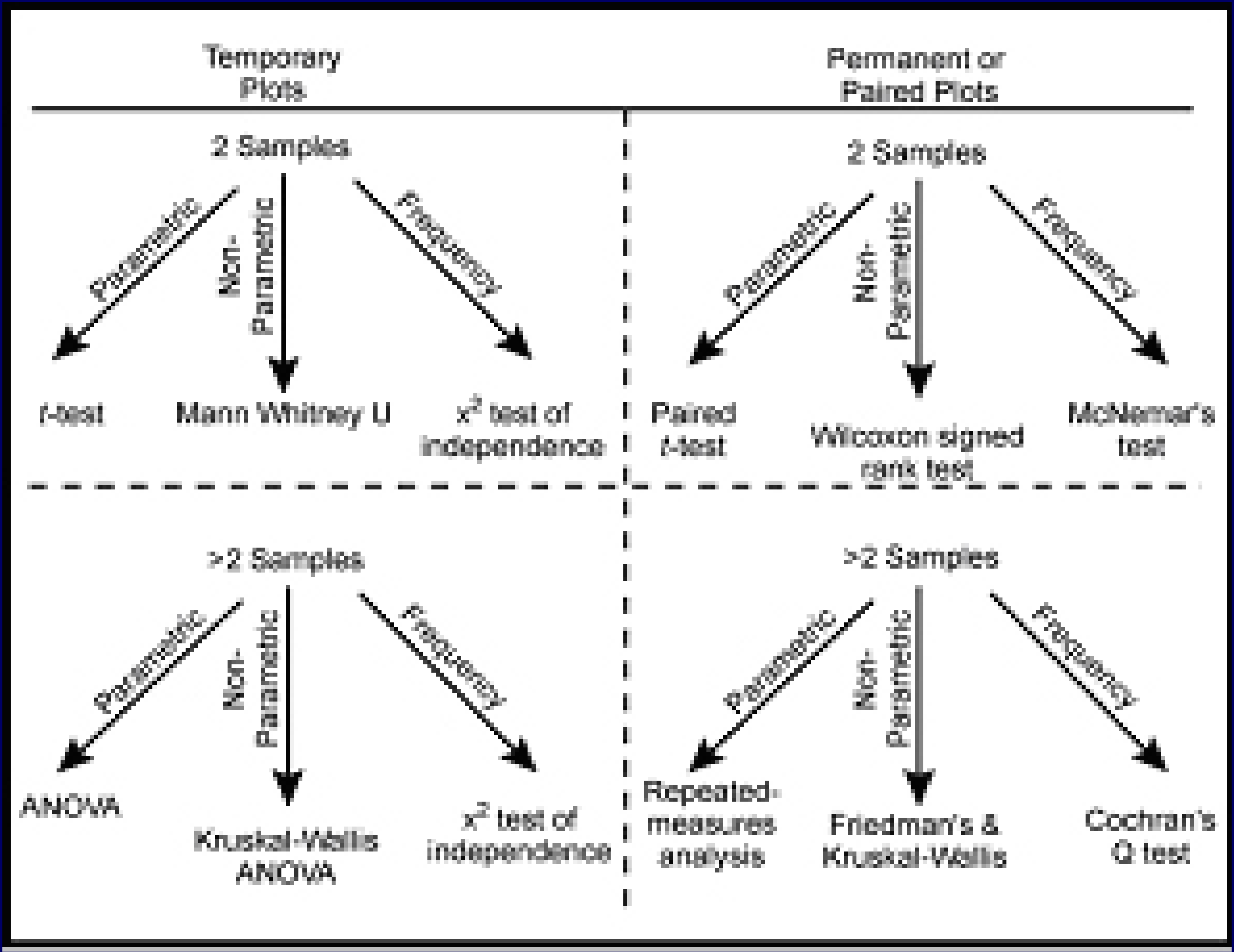


Figure 14. How do you decide which statistical test to use?

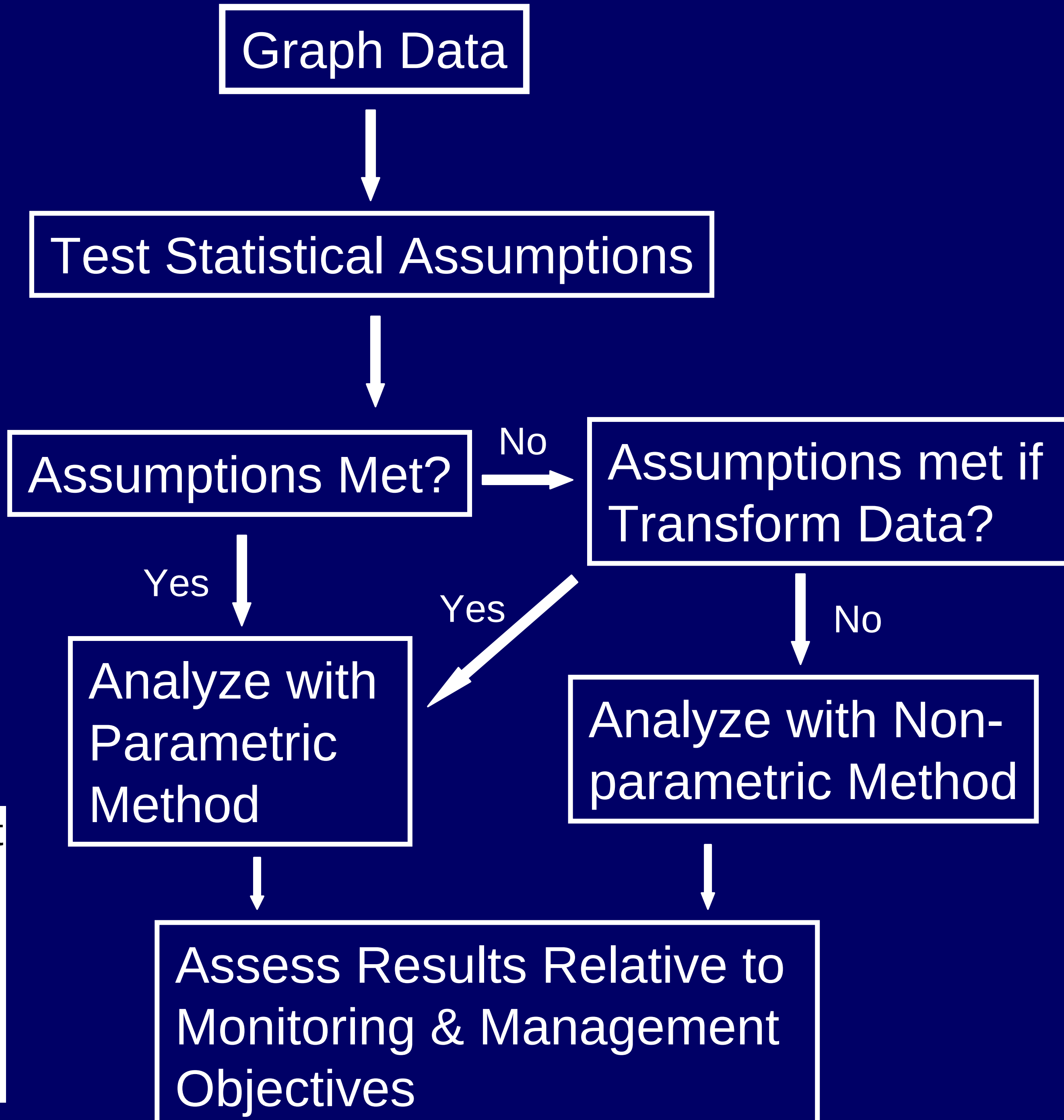


Figure 15. Important steps in analyzing monitoring data that we have covered except for bottom box.

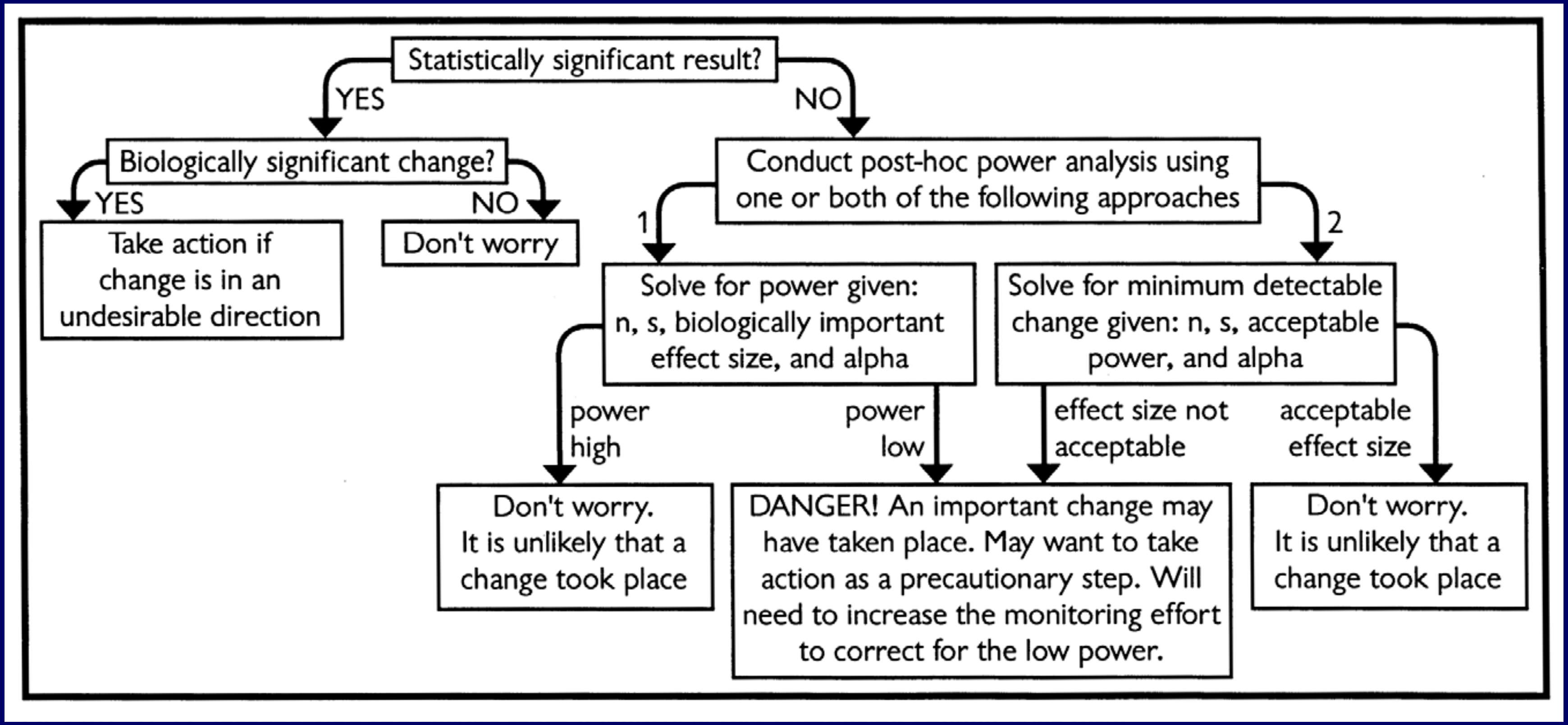


Figure 16. Interpreting results from a statistical test comparing change over time.

Ex. D2: Interpreting Monitoring Results for Detecting Change Over Time

Target	***Polygonella myriophylla***
Management Objective	**Maintain stable or increasing foliar cover of *P. myriophylla* at Saddle Blanket Lakes Preserve, allowing a decrease of no more than 25% cover from 1991 to 1994.**
Sampling Objective	**Be 90% sure of detecting a 25% change in cover from 1991 to 1994 with a 1 in 10 chance of a false-change error.**

N	Observed Change	Test results (p)	MDC	Conclusion & Action: Important Change?	Real Change	Errors
20	-26	0.0001	23.6		-30	
20	-23	0.032	23.6		0	
10	-12	0.146	34.2		0	
10	-10	0.222	34.2		-26	
20	-3	0.600	23.6		0	
50	-8	0.036	14.8		-5	

Target	***Polygonella myriophylla***
Management Objective	**Maintain stable or increasing foliar cover of *P. myriophylla* at Saddle Blanket Lakes Preserve, allowing a decrease of no more than 25% cover from 1991 to 1994.**
Sampling Objective	**Be 90% sure of detecting a 25% change in cover from 1991 to 1994 with a 1 in 10 chance of a false-change error.**

N	Observed Change	Test results (p)	MDC	Conclusion & Action: Important Change?	Real Change	Errors
20	-26	0.0001	23.6	Yes, action taken	-30	no errors
20	-23	0.032	23.6		0	
10	-12	0.146	34.2		0	
10	-10	0.222	34.2		-26	
20	-3	0.600	23.6		0	
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10	**-12**	**0.146**	**34.2**		**0**	
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10	**-10**	**0.222**	**34.2**		**-26**	
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10	**-10**	**0.222**	**34.2**	**No change, low power, preventative action.**	**-26**	**Missed change error.**
20	**-3**	**0.600**	**23.6**		**0**	
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10	-10	0.222	34.2	No change, low power, preventative action.	-26	Missed change error.
20	-3	0.600	23.6	No change, high power, no action	0	No errors.
50	**-8**	**0.036**	**14.8**	**Unimportant change, high power, reduce sampling?**	**-5**	**No errors.**