FISH 621
Estimation of Fish Abundance:
11: CPUE GLM(M)s

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Updated Homework Timing

- Working around Spring Break
  - Emailed homework schedule (incorrect)

Thanks Ben R!

Homework Assignment Schedule

Name	Assign Date	Due Date
Homework 1	Thursday, January 27	Friday, February 11
Homework 2	Thursday, February 17	Friday, March 4
Homework 3	Thursday, March 17	Friday, April 4
Homework 4	Thursday, April 7	Friday, April 22

← *Change*

  - Finalized homework schedule

Homework Assignment Schedule

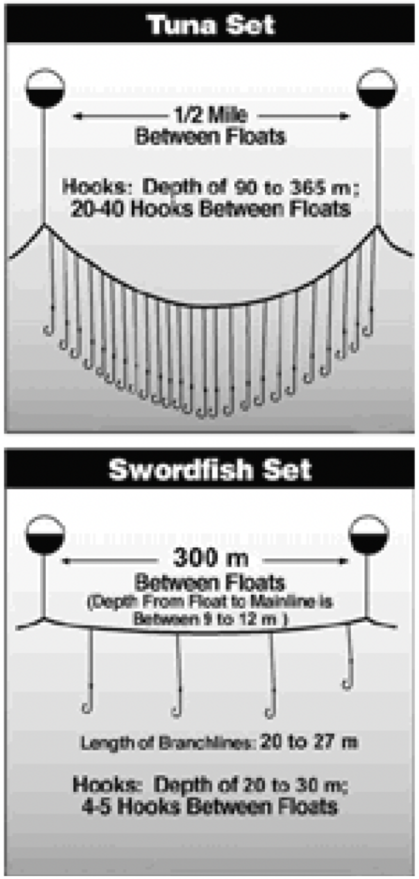
Name	Assign Date	Due Date
Homework 1	Thursday, January 27	Friday, February 11
Homework 2	Thursday, February 17	Friday, March 4
Homework 3	Thursday, March 17	Friday, April 1
Homework 4	Thursday, April 7	Friday, April 22

← *Change*

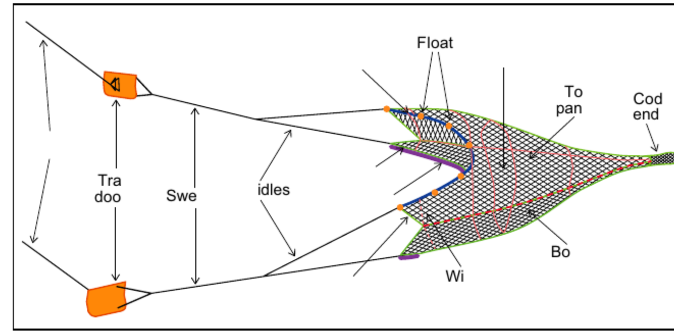
What is CPUE Data?

- Catch per unit effort
  - CPUE is a ratio commonly used to eliminate
    - Temporal and regional trends in simple estimates of fish stock abundance
- Catch
  - May be in units of abundance or biomass
    - Distinction is ***VERY*** important!
    - 10,000 x 1kg (age-2 fish) vs. 1,000 x 10kg (age-7+ fish)
- Effort
  - Usually refers to the time a uniformly designed and employed piece of fishing gear
    - Is deployed in the water
    - ***Not all gear is uniform!***
  - Commonly in units of time or effective gear, or a combination
    - Number of hooks
    - Length of net
    - Net-hours
    - Hook-hours
    - Trawl-hours
    - Trip duration (days)

FIGURE 11.2
Diagram of pelagic longline gear (National Marine Fisheries Service).

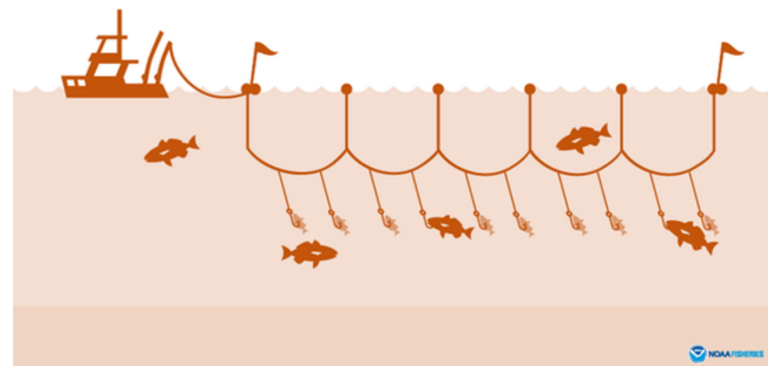


Fishing Effort ($\boldsymbol{E}$)



R. White

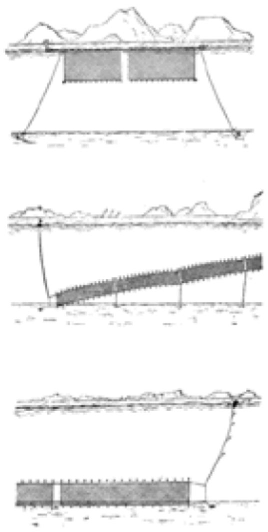
- Quantified in many different ways
  - At the seasonal level (fishery-dependent)
    - Number of vessels
    - Number of fishers
    - Amount of time
    - Number of pot lifts
  - At the haul or event level
    - Area swept (km^2)
    - Number of hooks
    - Number of hook-hours (hooks x hours fished)
    - Gillnet fathom-hours (net length x fishing time)



CPUE Index

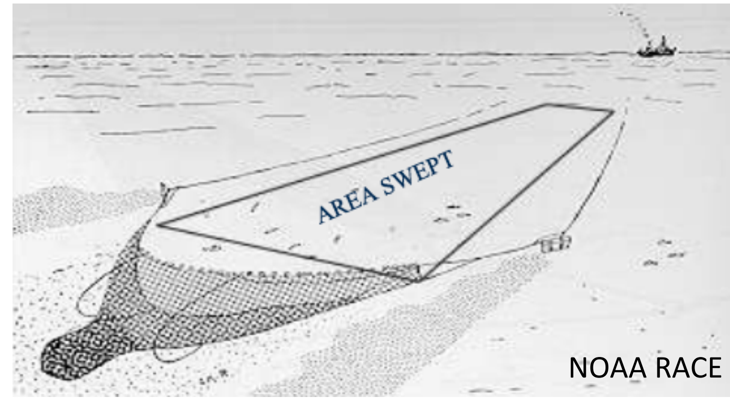
- Many aspects of the fishery or stocks(s) can be monitored utilizing CPUE analysis, including:
  - Trends in overall fishery catch rates
  - Catch rates of target versus bycatch species
  - Catch rates in specific depth strata
    - Seasons or subregions
  - Catch rates of size classes and sexes
    - and catch rates of specific vessels or types of vessels/gears
- CPUE is a much ***more powerful*** tool than catch data alone
  - ***Total annual catch doesn't account for intensity of fishing!!!***
  - A ***decline*** in CPUE over a time period is usually a good indication that stocks are declining
  - However, many factors can influence CPUE trends
    - Advancements in fishing gear
    - Improvements in fishing abilities of captains and crews
    - Changes in fishing grounds, current patterns or weather
- Interpretation of CPUE data must be undertaken with knowledge of such potentially confounding factors
  - How has effective effort changed over time?

FIGURE 11.1
Three variations in the placement and design of gillnet fishing gear. The net floats and anchors are all visible (NOAA).



Catch-per-Unit-Effort (CPUE)

- CPUE Notation
  - E
    - Fishing effort over a time period t
  - $U = \frac{C}{E}$
    - Catch-per-unit-effort
  - q
    - Catchability coefficient
  - a
    - Amount of area fished by the gear
  - A
    - Amount of area occupied by the population
  - $D = \frac{N}{A}$
    - The population density (numbers per unit area)



Catch Per Unit Effort:

$$\text{Catch Per Unit Effort (CPUE)} = \frac{\text{Catch (weight or numbers)}}{\text{(Net Width) (Distance Fished)}}$$

"area swept"

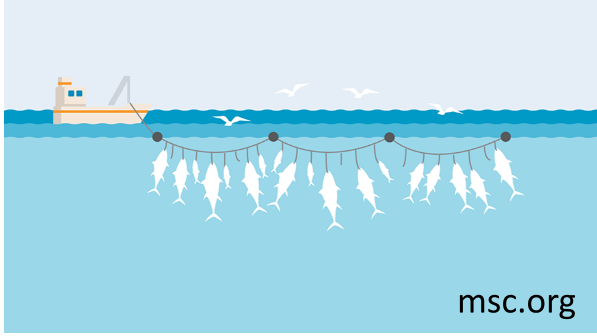
CPUE Index Basic Calculations

- Use of CPUE as an index of abundance is based on fundamental relationship
  - $C_t = qE_tN_t$
    - $Catch_t = (catchability)(Effort_t)(Abundance_t)$
  - $cpue_t = U_t = \frac{C_t}{E_t} = qN_t$
    - $Catch_t/(Effort_t) = (catchability)(Abundance_t)$
- Based on this we can make the assumption that CPUE is proportional to abundance or biomass
  - $cpue_t \propto N_t$
    - If, and only if, q is ***constant across time!***
- Note:
  - Units of biomass or abundance are applicable
    - For $Catch_t$ and $Abundance_t$

Interpretation of CPUE

- Assume that each unit of fishing effort operates
  - Independently and additively
- Catchability coefficient q
  - Has units of: $(effort\ units)^{-1}$
  - i.e. $(km^2)^{-1}$, $(hooks)^{-1}$, $(hooks \times hours)^{-1}$
- Even if q is ***not*** known
  - CPUE can still be used as an ***relative*** index of abundance over time
    - ***Proportional*** changes in CPUE (U) are equal to ***proportional*** changes in abundance (N)
- If q is ***known***
  - Then average abundance can be estimated by U/q
    - Providing an ***absolute*** index of abundance: $\widehat{\overline{N}} = \frac{U}{q}$

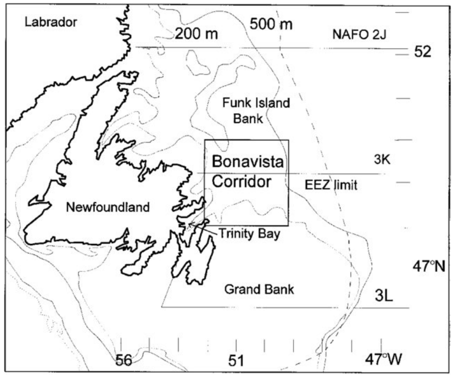
Types of CPUE



- Fishery-dependent ***catch rate*** data
  - Low cost to collect
    - Fish tickets at time of sale + index of effort (trip duration)
  - Historically one of the most commonly used
  - Requires standardization
    - Not all effort is created equal
  - ***Likely*** allocates effort proportional to abundance!
  - Problematic!
    - Atlantic Cod collapse
- Fishery-independent ***survey*** data
  - Collected in a standardized format
    - Consistent gear specifications
    - Follows a sample design to minimize bias and maximize precision
  - Survey design can ensure effort is consistent
    - And therefore q is constant across time
  - Does ***not*** allocate effort proportional to abundance!

A Word of Caution

- A word of caution about fishery-dependent CPUE
  - IT CAN, AND HAS, LED FISHERIES ASSESSMENT AND MANAGEMENT ASTRAY!
    - See Northern Cod (Newfoundland)
- However, the methods we describe are equally applicable
  - To fishery-independent CPUE calculations
    - From standardized survey designs
    - Where all representative habitats are sampled
- Marginal (low abundance) habitats
  - Are asymmetrically informative
    - Regarding population trends

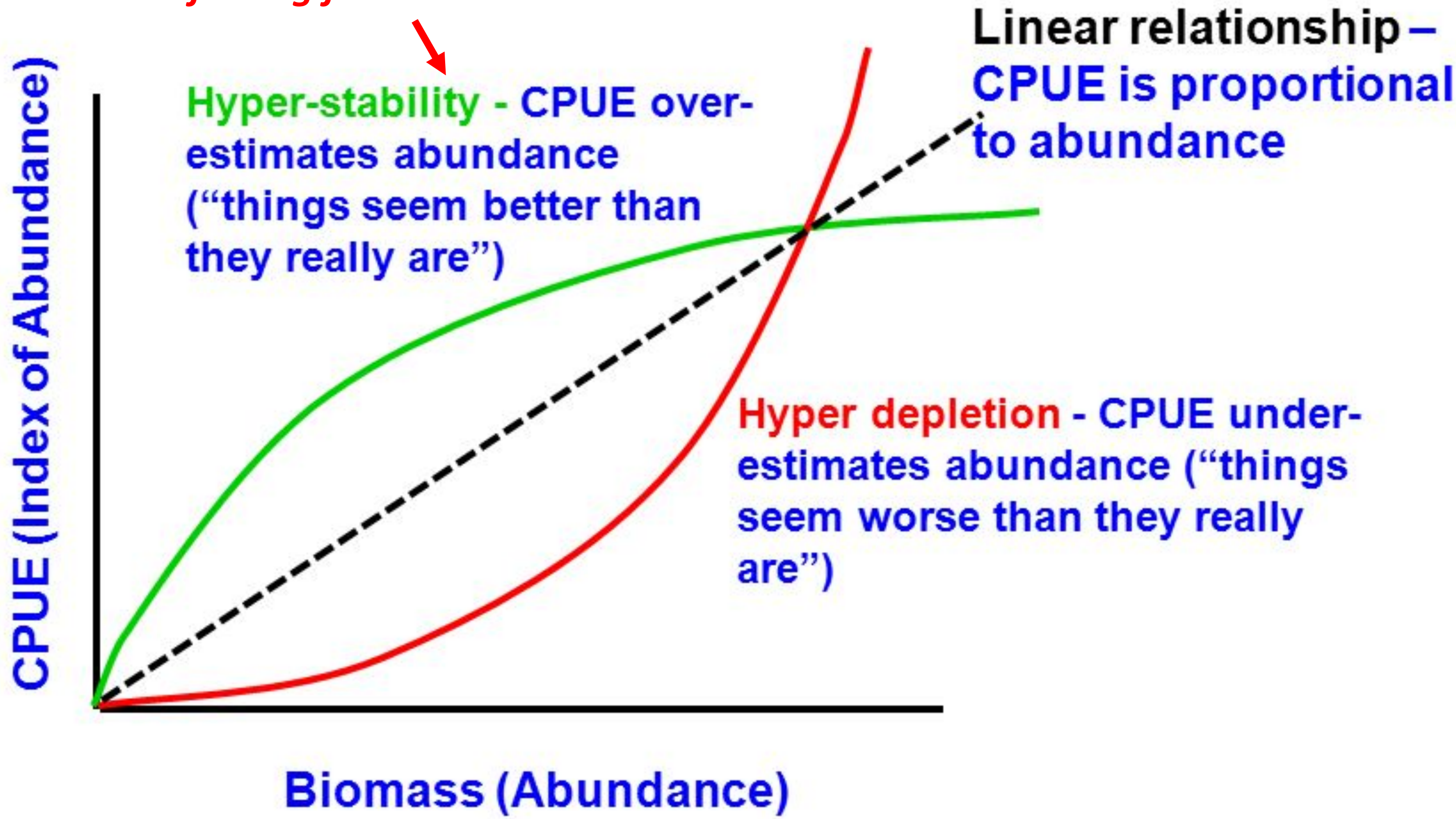


Rose and Kulka (1999): "Misinterpretations of elevated catch-per-unit-effort (CPUE) in the northern cod (Gadus morhua) fishery contributed to overestimations of stock size, inflated quotas, and unsustainable fishing mortality in the 1980s and early 1990s."

Hyperstability/Hyperdepletion

Fishermen are good at finding fish!

Ideal situation



[Cecilia Johnston]()

Impact of Time-varying $\boldsymbol{q}$

- $cpue_t = U_t = \frac{C_t}{E_t} = qN_t$
  - $Catch_t/(Effort_t) = (catchability)(Abundance_t)$
    - $N_t = \frac{U_t}{q}$
- Increasing trend in q (effort creep)
  - CPUE index will be biased high
    - $N_{est} > N_{true}$
- Decreasing trend in q
  - CPUE index will be biased low
    - $N_{est} < N_{true}$

Factors Causing Time-varying q

- Efficiency of the fleet
  - Catchability often ***increases*** over time
    - As efficiency of the fleet increases
    - New technology: “effort creep"
- Targeting by a fleet
  - q greatly affected when a fleet changes targeting
    - From one species to another
    - Perhaps driven by market demand (price)
- Dynamics of the population or fleet
  - Aggregation = hyperstability
    - If effort tracks catch rate (fishery-dependent data)
  - Search time for a fleet may change over time
    - Greater search time = lower q
  - Spatial expansion of the fleet
    - q remains high despite near-home depletion
    - Space must be considered
- Walters (2003)
  - Must make some assumption about what catch rates would have been in spatial strata
    - Have not yet been, or are no longer, fished

ICES Journal of Marine Science, 63: 1373–1385 (2006)
doi:10.1016/j.icesjms.2006.05.008

Available o

Interpreting catch per unit effort data to assess the status of individual stocks and communities

Mark N. Maunder, John R. Sibert, Alain Fonteneau, John Hampton, Pierre Kleiber, and Shelton J. Harley

Maunder, M. N., Sibert, J. R. Fonteneau, A., Hampton, J., Kleiber, P., and Harley, S. J. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. – ICES Journal of Marine Science, 63: 1373–1385.

RAPID COMMUNICATION / COMMUNICATION RAPIDE

Folly and fantasy in the analysis of spatial catch rate data

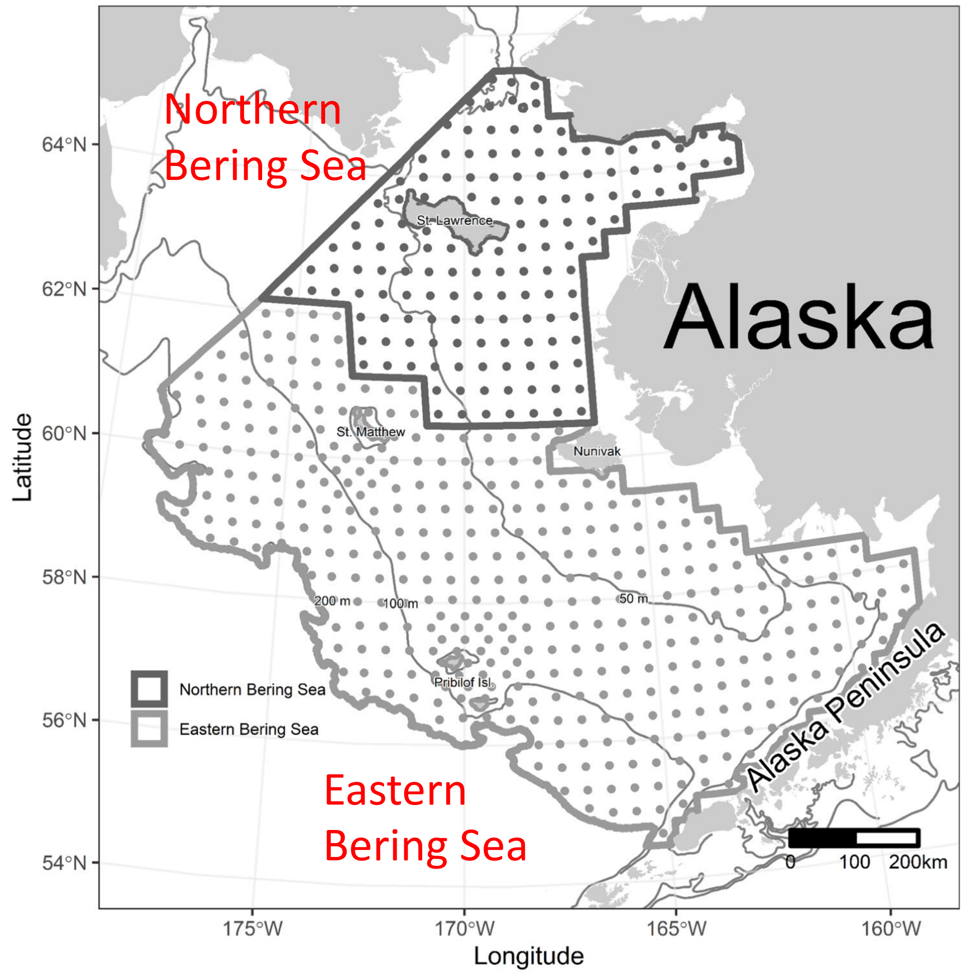
Carl Walters

CJFAS 2003

Abstract: Spatial catch per effort data can provide useful indices of population trends provided that they are averaged so as to correct for effects of changes in the distribution of fishing activity. Simple, nonspatial ratio estimates should not be used in such analyses. The averaging for any time period must necessarily make some assumptions about what catch rates would have been in spatial strata that had not yet, or were no longer, being fished. Ignoring the unfished strata (averaging only over the areas that were fished) amounts to assuming that they behaved the same as the fished strata and can lead to severe hyperdepletion in abundance indices for fisheries that developed progressively over large regions.

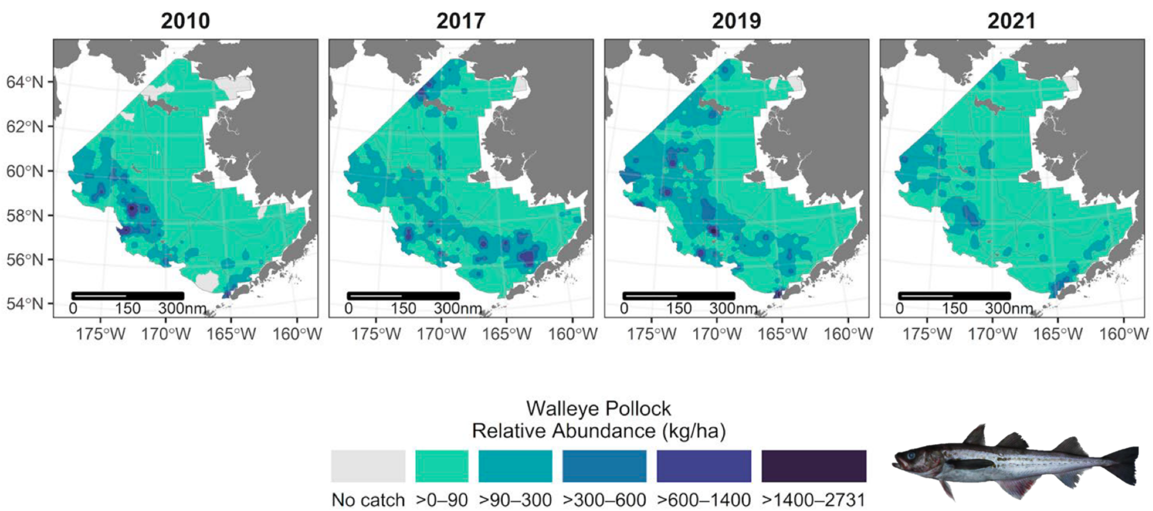
Groundfish: Changing Distribution

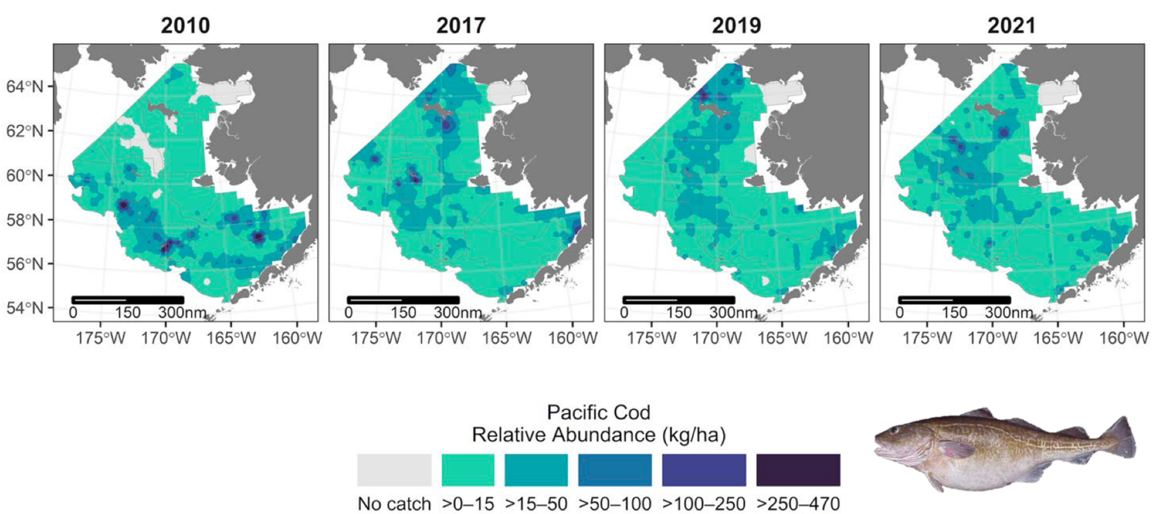
- NMFS Bottom Trawl Survey
  - Index of abundance
  - Critical size and age information
  - Early 1980's +
- Northern Bering Sea
  - 2010, 2017, 2019, 2021+



Map: NOAA-AFSC RACE Program

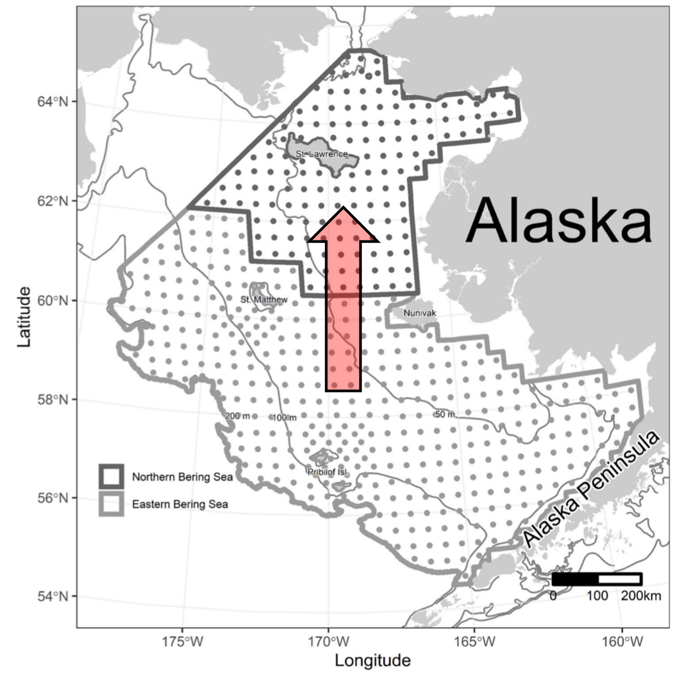
Groundfish: Changing Distribution





$$Index_t = qB_t$$

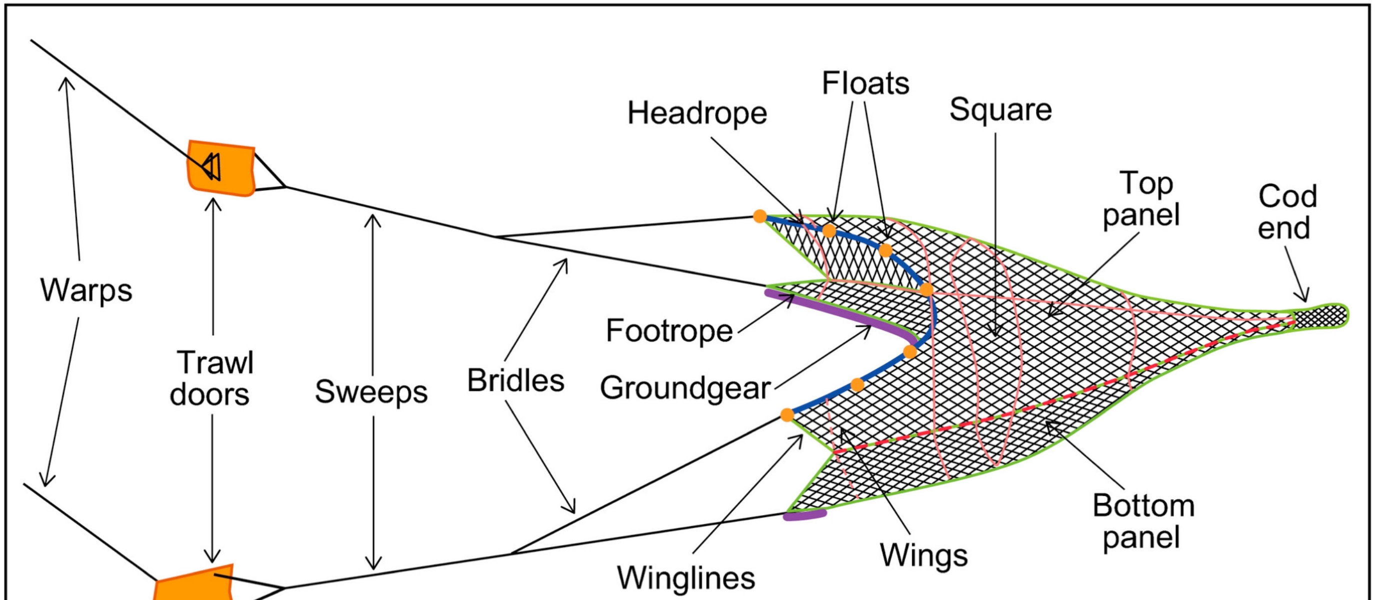
Declining q = **Underestimate** B_t



Figures: NOAA-AFSC RACE Program November 2021 GPT Meeting

Anatomy of a Trawl

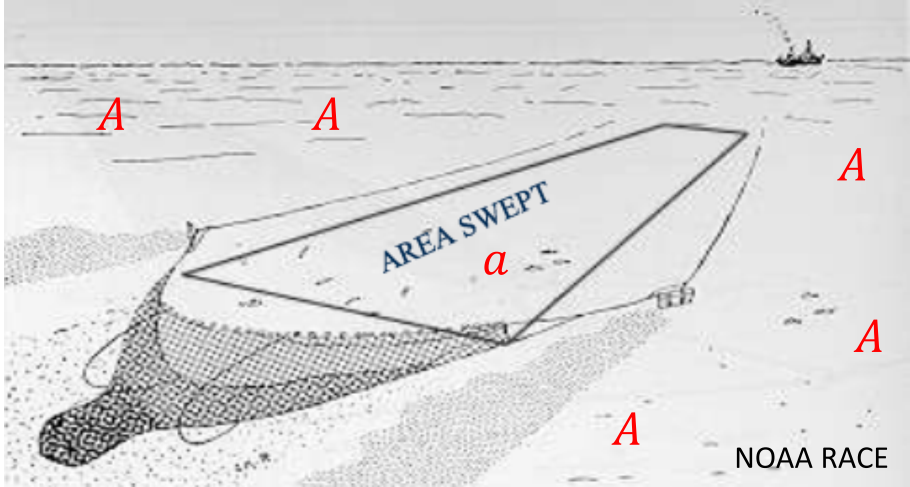
- Trawl net is a conical bag with a wide mouth
  - Otter boards ensure horizontal opening
  - Floats and weights ensure vertical opening
- "Codend" is the tail end of the gear where fish are collected
- Mean catch (weight or numbers)
  - Divided by unit of effort provides index of stock abundance
    - Can be converted to absolute measure of biomass using "area swept" method



McConnaughey et al. (2019)

CPUE: Area Sampled (swept)

- If the amount of effective fishing area
  - Can be determined for a particular gear type
    - Then the abundance can be estimated by projecting the catch in the sample area (a)
    - To the total area occupied by the population (A)
  - $\bar{N} = \frac{A}{a}C$
    - Paloheimo and Dickie (1964), Gulland (1983)
- The density (or concentration), D, of fish in an area
  - Is number of fish, per unit area
    - $D = {}^{\bar{N}}/_{A}$
- If we assume that fishing area
  - Is proportional to fishing effort
    - $a = q'E$
  - Then …
    - $U = q'D$



CPUE: Regional Considerations

- Comparison of CPUE among regions
  - Requires we consider the amount of fishing area
    - Covered (sampled) by fishing effort (Quinn et al. 1982)
- If a ***small*** fishing area had the same CPUE as a ***large*** fishing area
  - The ***concentration*** of fish in both areas is equal
    - But their ***abundances*** differ greatly (i.e. ***higher*** in large area)
- CPUE in a region (r) is proportional to population density
  - $U_r = q\frac{\overline{N_r}}{A_r} = qD_r$

Density

Area

Catchability (effort)$^{-1}$

CPUE: Regional Considerations

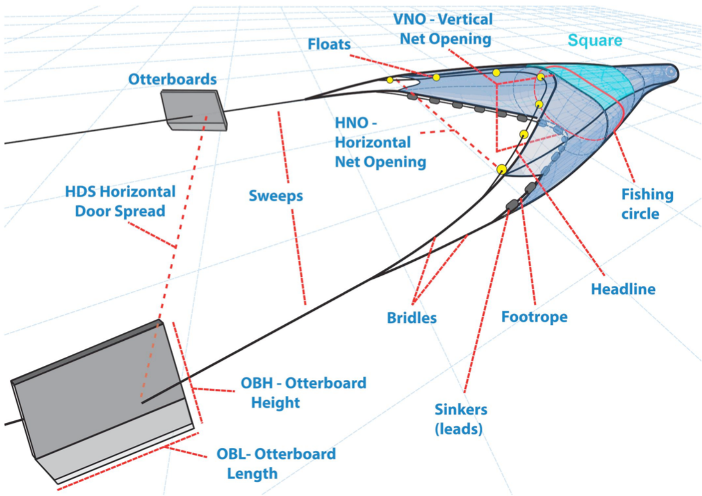
- Density for the entire population
  - Combination of regional densities, weighted by habitat area
    - $\bar{N} = \sum_r \overline{N_r} = \sum_r A_r D_r$
    - $D = \frac{\bar{N}}{A} = \frac{\sum_r \overline{N_r}}{\sum_r A_r} = \sum_r \frac{A_r D_r}{A}$
- CPUE for the population should also be weighted by habitat area
  - $U_A = \sum_r \frac{A_r}{A} U_r$
    - Area-weighted CPUE, reflects abundance at the population scale
- Overall CPUE, weighted by relative effort
  - Only viable if effort is proportional to area
    - $U_E = \frac{\sum_r C_r}{\sum_r E_r} = \frac{C}{E} = \sum_r \left(\frac{E_r}{E}\right) U_r$

Conventional Area-swept Estimator

- Weight of catch in each haul divided by area swept
  - To get standardized index per haul
  - $CPUE_{i,j} = Biomass_{i,j}/area_{i,j}$
    - For each station j , within stratum i
    - Where m_i is the number of successfully trawled stations, within a stratum i
- CPUE by stratum
  - $CPUE_i = \frac{\sum_{j=1}^{m_i} CPUE_{i,j}}{m_i}$
- Area-weighted average CPUE (across the entire survey area)
  - Summarized across strata
  - $CPUE_T = \frac{\sum_{i=1}^{n} CPUE_i \times A_i}{A_T}$
    - A_i is the area of each stratum i
    - A_T is the total survey area
    - n is the total number of strata

Conventional Area-swept Estimator

- If exact position is not available from GPS (lat, lon)
  - Distance covered in an hour can be calculated from
  - $D = \sqrt{VS^2 + CS^2 + 2 * VS * CS * Cos(dirV - dirC)}$
    - D = distance in nautical miles
    - VS = velocity of vessel (knots = nm/hr)
    - CS = velocity of current (knots)
    - $dirV$ = course of vessel (degrees)
    - $dirC$ = direction of current (degrees)



Sala et al. (2019)

Regional CPUE: Pacific Halibut

- 1980: Southeast Alaska and British Columbia
  - Catch
    - lbs
  - Effort
    - Skate: 1800’ of groundline with 100 equally-spaced hooks
  - CPUE
    - lbs/skate
- $U_A = \sum_r \frac{A_r}{A} U_r$

Region	Ur	Ar	CPUE	% CPUE
Southeast Alaska	82	45,000	35.5	47.8%
British Columbia	68.4	59,000	38.8	52.2%
	(lbs/skate)	km^2	74.3	

CPUE Standardization

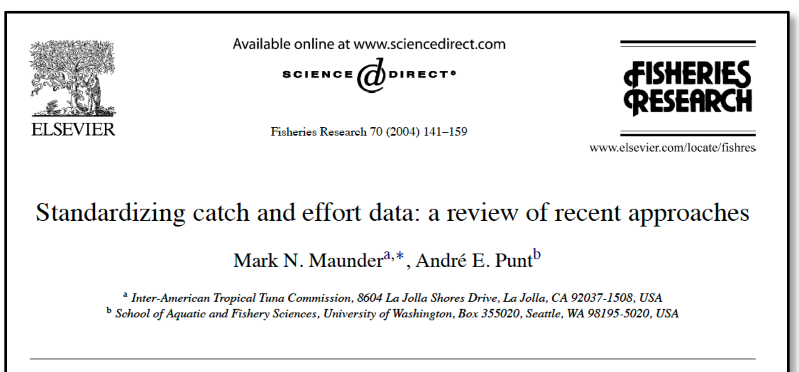
- Comparison of component groups
  - To standardize fishing differences
- Olsen and Laevatsu (1983)
  - ***32 factors*** affecting longline CPUE
    - Hook-spacing, hook size, line depth, bait, ect.
- Gulland (1983), Hilborn and Walters (1992)
  - Vessel tonnage, mesh size, quality of electronics
- Standardization Approaches
  - Direct experimentation
    - Fish different gear types in same area, compare CPUE
  - Comparison of CPUE among years (within areas)
    - Calculation of fishing power coefficients

CPUE Standardization

- Fishing power coefficients
  - P_i, for gear type (i)
  - $P_i = U_i / U_s;\ U_s = U_i / P_i$
    - U_s: CPUE from a standard (reference) gear type
  - Effective fishing effort for each gear type
    - $\widetilde{E}_i = P_i E_i$
  - Total effective effort
    - $\tilde{E} = \sum \widetilde{E}_i$
- Current example
  - NMFS Shelikof Strait Pollock Acoustic Trawl Survey
    - Paired sampling with “old” (AWT) and “new” (LFS) nets

CPUE Standardization Among Years

- $ln(U) = ln(U_r) + \sum_i \sum_j X_{ij}\, ln(P_{ij}) + \epsilon$
  - i is a factor affecting catchability (i.e. area fished)
    - j is a level of that factor (i.e. Area-1, Area-2)
  - $\epsilon \sim Normal(0, \sigma^2)$
  - $U = U_r \prod_i \prod_j P_{ij}{}^{X_{ij}}\, e^{\epsilon}$
- In practice catchability ratios will always be defined relative to
  - Reference level for each factor, and a reference year
- Multiple regression
  - Standardizing across regions, tonnage, gear size
    - $ln(CPUE) \sim factor(year) + factor(region) + tonnage + size$



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Standardizing catch and effort data: a review of recent approaches

Mark N. Maunder[a,*], André E. Punt[b]

[a] Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Drive, La Jolla, CA 92037-1508, USA
[b] School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020, USA

Hastie et al. (2001)

$$g(\mu_i) = \mu + \sum_{j=1}^{p} f_j(\mathbf{x}_i)$$

Non-linear effects:

- Depth
- Seasonal patterns

CPUE: Non-linear Models

- In practice catchability (q) may not be constant
  - Due to gear competition (or cooperation), and spatial and temporal effects (Rothschild 1977)
- Generalized relationship (Bannerot and Austin 1983)
  - $C = qE^{\alpha+1}N^{\beta+1}$
  - $U = \left(qE^{\alpha}N^{\beta}\right)N$
- Quinn and Collie (1990)
  - Walleye pollock CPUE ~ biomass
    - Square root relationship ($\beta = -0.5$)

Design-based Estimators: Stratified Random Sampling

Unit i of stratum h

- Goal
  - Within each stratum
    - Units are as similar as possible
- y_{hi} is the variable of interest
  - Associated with the ith unit of stratum h
    - Strata: $h = 1 \dots, L$
- N_h is the ***total*** number of units in stratum h
  - Total number of units in the population
    - $N = \sum_{h=1}^{L} N_h = 400$
- n_h is the number of sampled units in stratum h
  - Total sample size
    - $n = \sum_{h=1}^{L} n_h = 40$

$h = 1$ $h = 2$

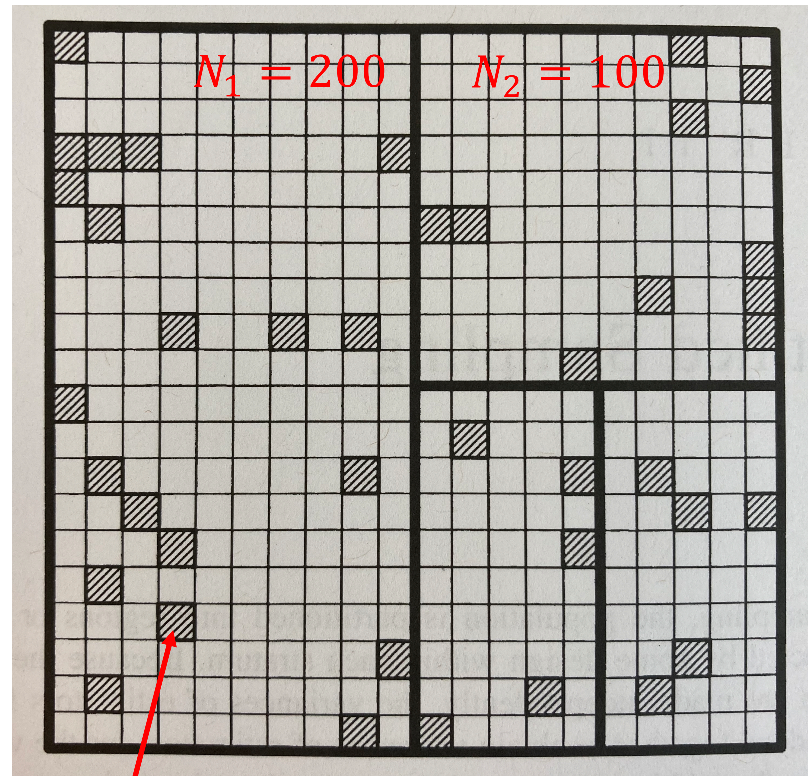


Figure 11.1. Stratified random sample.

y_{hi}

$N_3 = N_4 = 50$

Design-based Estimators: Stratified Random Sampling

- Total of y-values in stratum h
  - $\tau_h = \sum_{i=1}^{N_h} y_{hi}$
- Mean for the stratum
  - $\mu_h = \tau_h / N_h$
- Population total
  - $\tau = \sum_{h=1}^{L} \tau_h$
- Overall population mean
  - $\mu = \tau / N$

This is UNKNOWN!

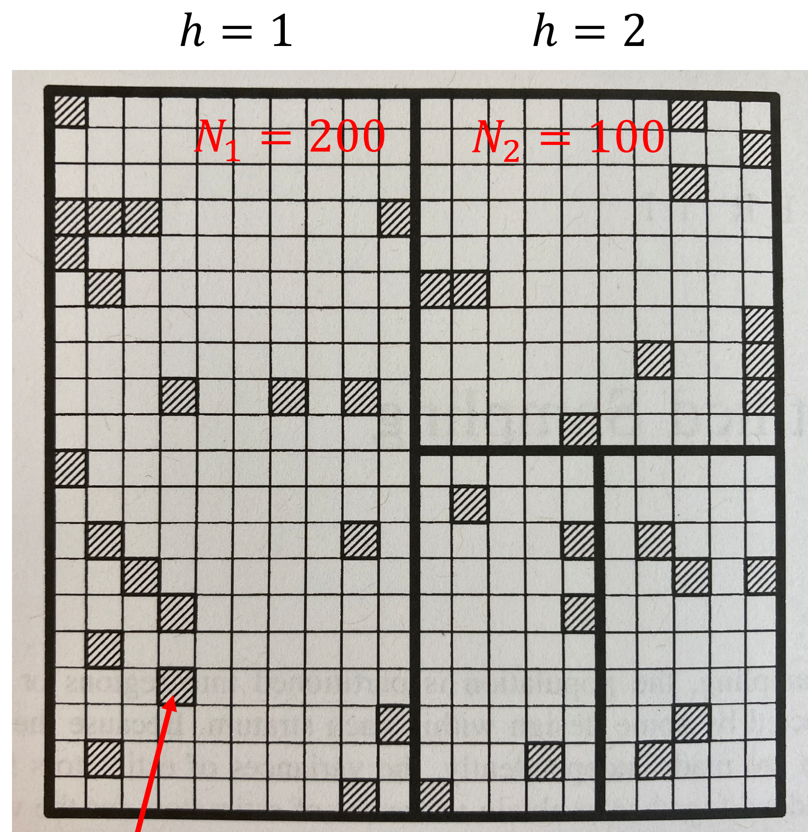


Figure 11.1. Stratified random sample.

Design-based Estimators: Stratified Random Sampling

Unit i of stratum h

- Unbiased estimator of stratum ***total***
  - $\hat{\tau}_h = N_h \bar{y}_h$
- Sample mean for stratum h
  - $\bar{y}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} y_{hi}$
- Unbiased estimate of population total
  - $\hat{\tau}_{st} = \sum_{h=1}^{L} N_h \bar{y}_h$
- Unbiased estimate for variance of the total
  - $\widehat{var}(\hat{\tau}_{st}) = \sum_{h=1}^{L} N_h (N_h - n_h) \frac{s_h^2}{n_h}$
  - Where, the sample variance for stratum h is:
    - $s_h^2 = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2$

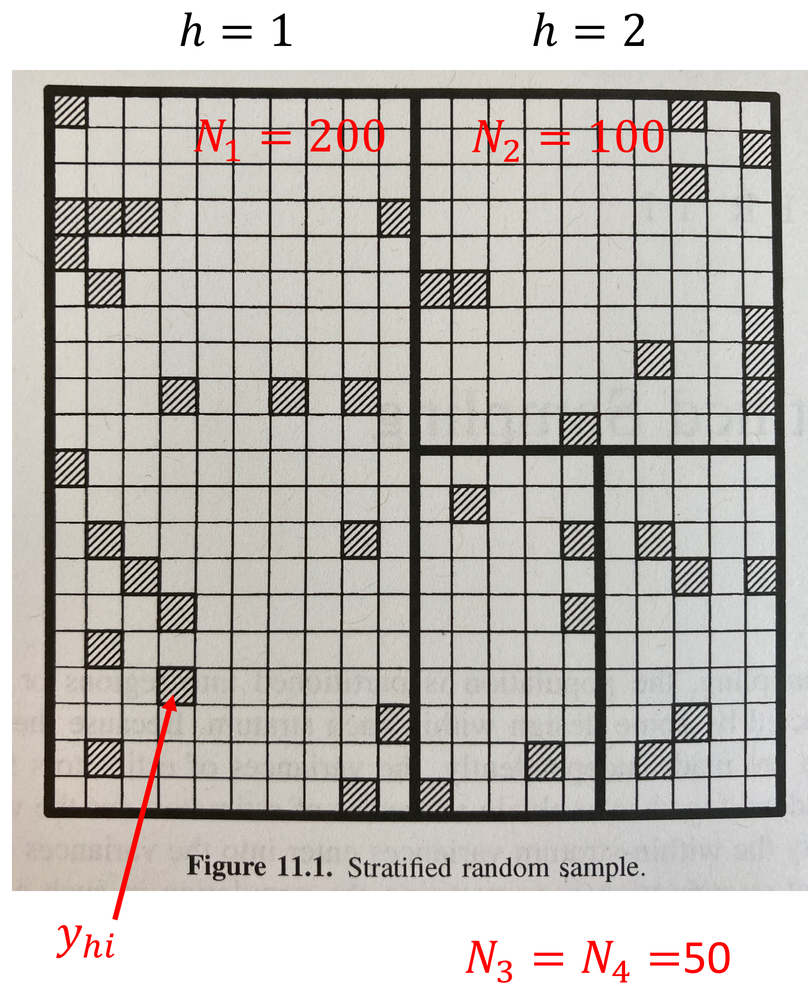


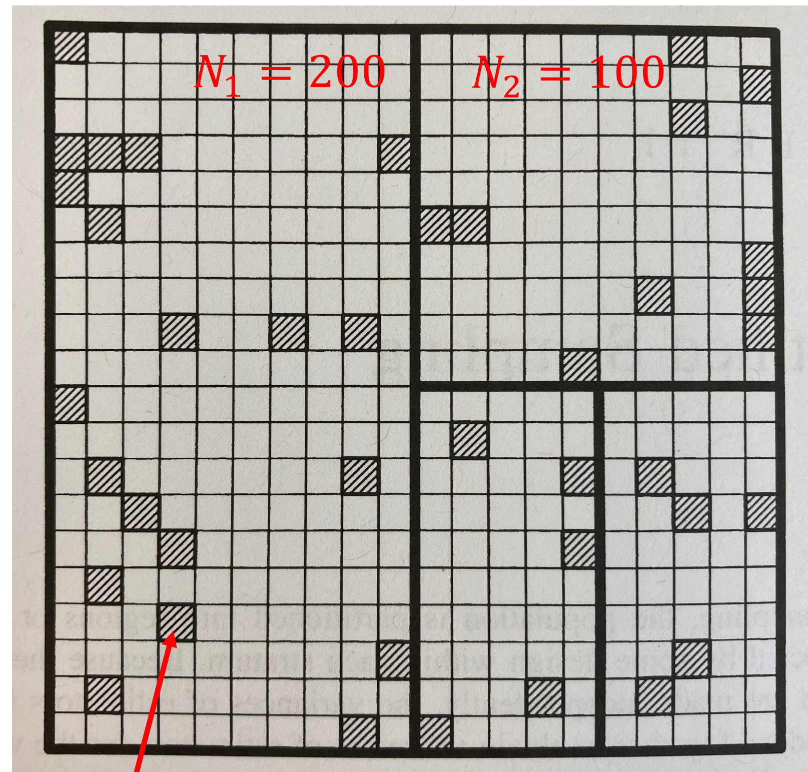
Figure 11.1. Stratified random sample.

Design-based Estimators: Stratified Random Sampling

Unit i of stratum h

- Unbiased estimate of population mean μ
  - $\hat{\mu}_{st} = \bar{y}_{st} = \frac{1}{N}\sum_{h=1}^{L} N_h \bar{y}_h$
- Sample mean for stratum h
  - $\bar{y}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} y_{hi}$
- Unbiased estimate for the variance of the estimate of the population mean
  - $\widehat{var}(\hat{\mu}_{st}) = \widehat{var}(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{N_h}{N}\right)^2\left(\frac{N_h - n_h}{N_h}\right)\left(\frac{s_h^2}{n_h}\right)$
    - $s_h^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h}(y_{hi} - \bar{y}_h)^2$

$h = 1$ $h = 2$



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y_{hi}

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