LECTURE 10

CLOSED CAPTURE-RECAPTURE

REMOVAL MODELS

CATCH EFFORT MODELS

SELECTIVE REMOVALS

Some Review of Last Lecture

MARK: RABBIT EXAMPLE

Model Selection- We fitted M(t) and M(0).

```
                         Rabbit Analyses for 506

   ------------------------------------------------------------------------
                                          Delta    AICc      Model
 Model                          AICc      AICc    Weight  Likelihood   #Par    Deviance
   ------------------------------------------------------------------------
  {M(t)}                     -536.099     0.00   1.00000     1.0000  3.0000     5.548
 {M(0)}                      -469.416    66.68   0.00000     0.0000  2.0000    74.299
```

Note- How M(t) so much favoured. Lets look at each output.

MARK: RABBIT EXAMPLE

Model Output (Mt)

```
                         Rabbit Analyses for 506
                         Real Function Parameters of {M(t)}
                                                     95% Confidence Interval
Parameter                  Estimate       Standard Error      Lower            Upper
-------------------------  --------------  --------------  --------------  --------------
  1:p                      0.5200943       0.1359513       0.2714729       0.7591460
  2:p                      0.0866824       0.0309946       0.0422018       0.1697371
  3:N                      161.50918       40.414581       115.80591       291.41774
```

Note estimate of N we get from the Lincoln –Peterson.

MARK

INSECT EXAMPLE

Data format –Notepad File

Capture history , No animal gp1(M), gp2(F).

Note; at end of line.

10 63 76;

01 25 37;

11 14 19;

P picivorus Male and Female Data

```
------------------------------------------------------------------------
                     Delta    AICc    Model
Model      AICc      AICc    Weight  Likelihood  #Par    Deviance
------------------------------------------------------------------------
{LP Comb}-1318.987    0.00  0.86021   1.0000  4.0000     12.354
{LP Both}   -1315.353   3.63  0.13979    0.1625  6.0000    11.891
------------------------------------------------------------------------
```

P picivorus Male and Female Data

	{LP Both Sexes}		{LP Comb Sexes}	
Parameter	Estimate	SE	Estimate (SE)	
1:p (M1)	0.37	0.077	0.35	0.049
2:p (M2)	0.18	0.044	0.19	0.030
3:p (F1)	0.34	0.063	0.35	0.049
4:p (F2)	0.20	0.041	0.19	0.030
5:N (M)	210.86	40.54	212.68	29.09
6:N (F)	276.53	45.90	275.38	36.45

Note- 1&3 and 2&4-Lets simplify by putting them equal in the combined analyses. Gains in precision!

The Estimates from Best Model

P Picivorus Male and Female Data
LP Sexes Combined

Parameter	Estimate	St Error
1:p (M)	0.3524099	0.0492986
2:p (F)	0.1946450	0.0303306
3:N (M)	212.68334	29.093079
4:N (F)	275.38463	36.456268

Taxi cab Data: Part of Input File

```
/* Carothers (1973) Scheme A taxicab data, true population = 420 occasions=10 groups=1 */
/*  1  */ 0001000001 1;
/*  2  */ 1000100000 1;
/*  3  */ 0000010000 1;
/*  4  */ 0001001000 1;
/*  5  */ 0000000001 1;
/*  6  */ 1101010000 1;
/*  7  */ 0010000000 1;
/*  8  */ 0101000010 1;
```

There are 283 records-one for each taxi cabs history, note the format used for comments, also this one does not use summary format like the rabbit and insect data.

Taxi Cab Example- PIMS M

M_t PIMS Structure

p 1,2,3,4,5,6,7,8,9,10

c 2,3,4,5,6,7,8,9,10

N 11

Note- In the full model c PIMS 11,12,13,14, 15, 16,17,18,19 with N PIM 20

M_0 PIMS Structure

p 1,1,1,1,1,1,1,1,1,1

c 1,1,1,1,1,1,1,1,1

N 2

M_b

PIMS Structure

p 1111111111

c 222222222

N 3

Summary of Some Output

From CAPTURE (Inside MARK)

- M(0) 368 with standard error 14.4896 (underestimates when there is heterogeneity).
- Model M(h) Suggested for use here from old Model selection Procedure
- Jacknife 471 with standard error 36.32
- Chao 407 with standard error 27.42

From MARK Directly with PIMS

- Model M(0) 368 with standard error 14.4896 (underestimates when there is heterogeneity).
- Can also fit M(0) and M(t) with PIMS.
- Can also fit Finite Mixture approach (for heterogeneity but did not work too well here. Nhat 463 with huge SE of 273.88!) using the "Closed Captures" and then "with Heterogeneity" procedure. Will not insist you know this one in detail.

Summary-Closed Capture-recapture Models

Summary Closed Capture-Recapture Design Issues

Precision Issues

- Need adequate capture probabilities and numbers of samples to estimate standard errors that are small enough (ie. RSE ~ 20% is good level to strive for).
- Look at Tables in Otis et al. (1978).Note that good model selection requires much larger capture probs than just estimation under one (assumed correct) model.
- Full Simulation Study-ideal
- Simpler Approximation: Use Expected Values for guesses of what the data might be like and do analysis on that data using MARK or CAPTURE. The precision (SEs) you get is a fairly good estimate as to what you would get if you ran real data with those parameter values.

Use of Expected Value Method for Precision Evaluation

- Example N=500 Lincoln Petersen Study
- Equal capture probability case N=500, p=0.5 for both periods then n1=250, n2=250, m2=125.

  M(t) Estimate = 498.5 SE = 22.2

  RSE =4%

Summary Closed Capture-Recapture Design Issues

Minimise Model Bias- Satisfy Assumptions

1. **Closure**- Short studies,no mortality, no recruitment, no immigration or emigration. Check with telemetry sometimes?

2. **Equal Catchability**

Heterogeneity-often hard to avoid unless one can use different methods of capture in each sample which is not usually feasible. Rerandomise trap locations each time?

Collect covariate data for Huggins method or to stratify on.

Trap Response- often hard to avoid unless one can use different methods of capture in each sample which is not usually feasible.

Time Variation-try to eliminate so that simpler models can be used.

3. **No Tag Loss** – Obviously avoid, check out in pilot studies. Use double tagging method to estimate tag loss if it is a problem.

Use of Expected Value Method for Model Bias Evaluation

- Example N=500 Lincoln Petersen Study where there is heterogeneity with two groups. Average p=0.5.

  Group 1 250 animals p = 0.9

  Group 2 250 animals p = 0.1.

  n1=250, n2=250, m2=205

  Estimate = 304 Bias = -196

- Equal capture probability case N=500, p=0.5 then n1=250, n2=250, m2=125.

  Estimate =498 Bias ~0.

Use of Expected Value Method for Model Bias Evaluation

Effect of Heterogeneity on LP Estimator (2 Groups N=500)

p = 0.9, 0.1 Bias = -196
p = 0.8, 0.2 Bias = -133
p = 0.7, 0.3 Bias = -70
p = 0.6, 0.4 Bias = -21
p = 0.5, 0.5 Bias = 0

DENSITY ESTIMATION WITH CLOSED CAPTURE-RECAPTURE (14.3)

- Nested Grids (To account for edge effects)
- Trapping Webs (Uses Distance Ideas)

Nested Grids
Fig 14.2

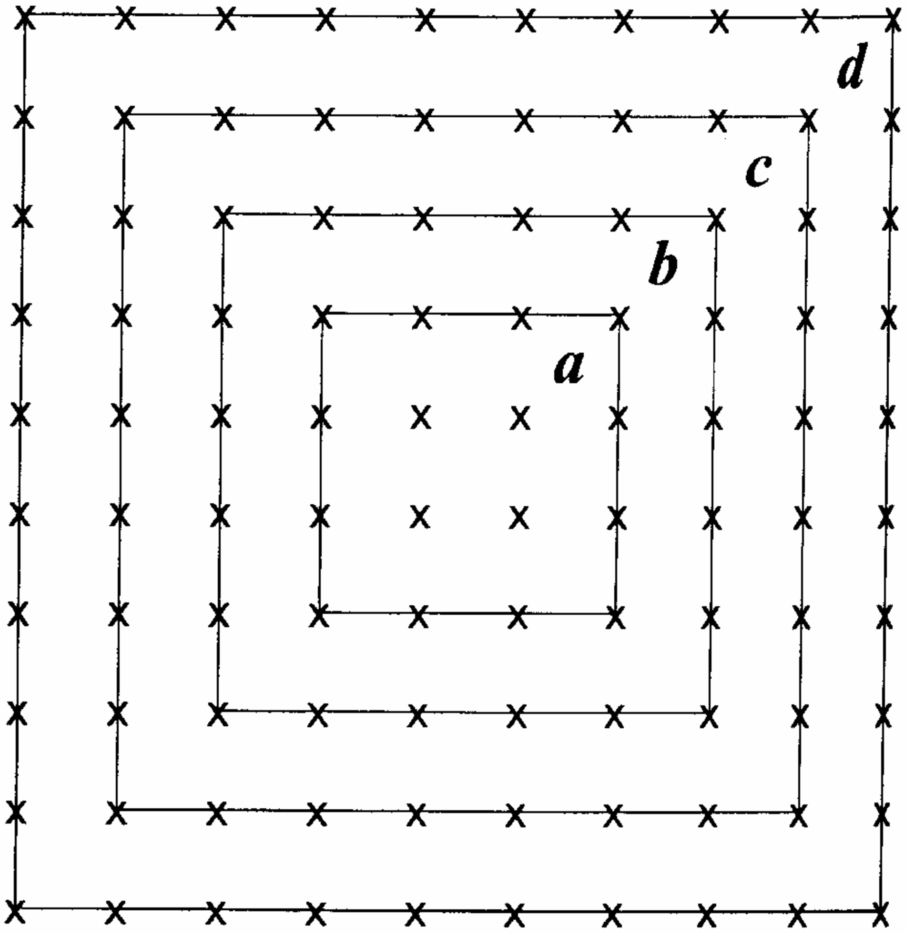


FIGURE 14.2 Nested trapping grids: (a) 4 × 4 grid; (b) 6 × 6 grid; (c) 8 × 8 grid; (d) 10 × 10 grid. After Otis *et al.* (1978).

Trapping Web
Fig 14.3.

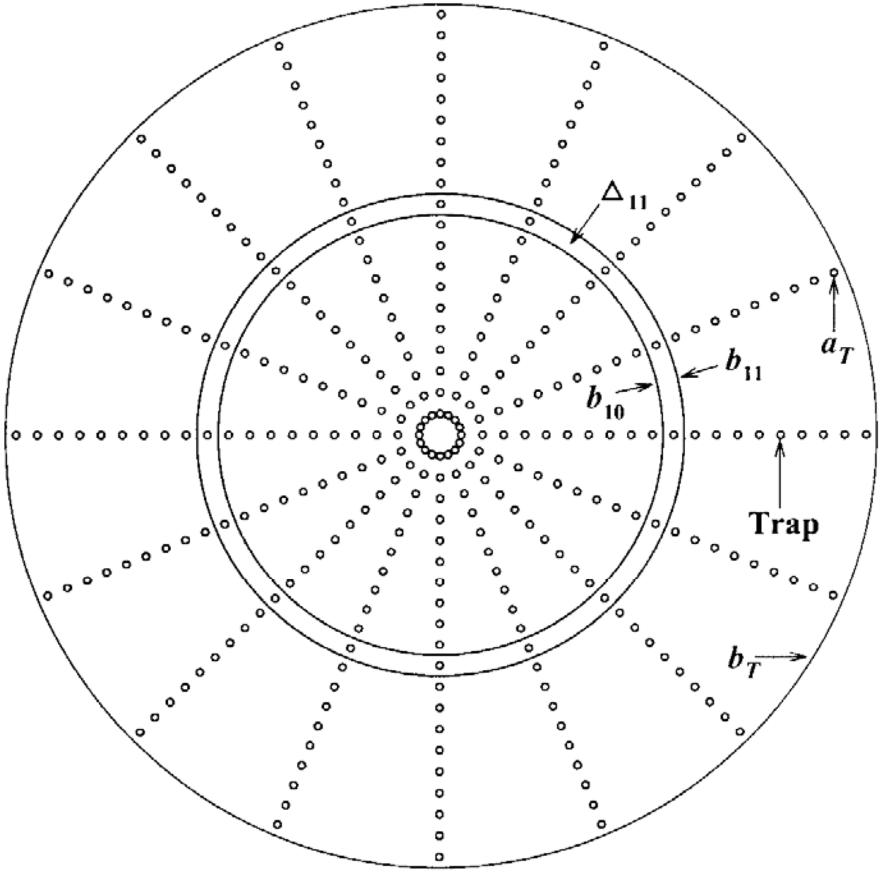


FIGURE 14.3 Schematic diagram of a trapping web with 16 lines, each of total length A_T with $T = 20$ traps per line (after Anderson *et al.*, 1983). Traps are equally spaced along each line. Points equidistant between traps are denoted by b_i, with b_0 representing the center of the web and b_T located just beyond the last trap. Captures in the eleventh ring of traps are assigned to the annulus Δ_{11}, which has area $\pi(b_{11}^2 - b_{10}^2)$. After Anderson *et al.* (1983).

REMOVAL DATA

Non-selective Removals (14.4)

or

Selective Removals

Change-in-ratio(14.5)

Non-selective Removals

Equal Sampling Effort

Controlled studies

- Small mammal trap grids
- Electrofishing in small streams

REMOVAL MODELS

Closed

Unequal Sampling Effort

Uncontrolled Studies

- Commercial fisheries
- Hunter species with control through complete check stations

CATCH EFFORT MODELS

Closed

Closed Population with Constant Effort

1. Two Sample Case:

Example- Maecolaspis flavida –a beetle - removal data from first two sets of sweeps of a net. Each set is four sweeps. Menhinick(1963) Ecology 44, 617-621.

$$\hat{N} = \frac{n_1^2}{(n_1 - n_2)} = \frac{135^2}{135 - 76} = \frac{135^2}{59} = 308.90$$

$$\hat{p} = \frac{(n_1 - n_2)}{n_1} = \frac{135 - 76}{135} = \frac{59}{135} = 0.4370$$

Closed Population with Constant Effort

Example- Maecolaspis flavida –a beetle - removal data from first two sets of sweeps of a net. Each set is four sweeps.Menhinick(1963) Ecology 44, 617-621

$$\mathrm{SE}(\hat{\mathrm{N}}) = \sqrt{\frac{\mathrm{n}_1^2 \mathrm{n}_2^2 (\mathrm{n}_1 + \mathrm{n}_2)}{(\mathrm{n}_1 - \mathrm{n}_2)^4}}$$

$$= \sqrt{\frac{135^2 76^2 (211)}{59^4}} = 42.81$$

Closed Population with Constant Effort

1. Two Sample Case:

Assumptions:

- Closure
- Capture probability (p) is constant over animals
- Capture probability constant over time

Failure: Sometimes if p is low even if the assumptions are valid, the method will fail if $n_1 = n_2$ or $n_1 < n_2$

MARK: Trick to Get this Model Output

Input File

```
 10 135;
 01    76;
```

Running Model

Fix c=0

MARK Output

- Removal Example Mehinick:MARK
- Estimate SE Lower Upper
- ---
- 1:p 0.45 0.0793 0.30 0.60

  2:c 0 Fixed
- 3:N 302.7 39.82 251.6 418.1
- ---
- Note parameter 2:c set to 0.

Closed Population with Constant Effort

2. **Multiple Samples** **(better precision)**

Model **– closed population (N) except for removals**

- constant p all animals, all samples

Data $n_1, n_2, ...n_k$ **removals**

Approaches- Regression Approach First,

Then Use of M_b and M_{bh}.

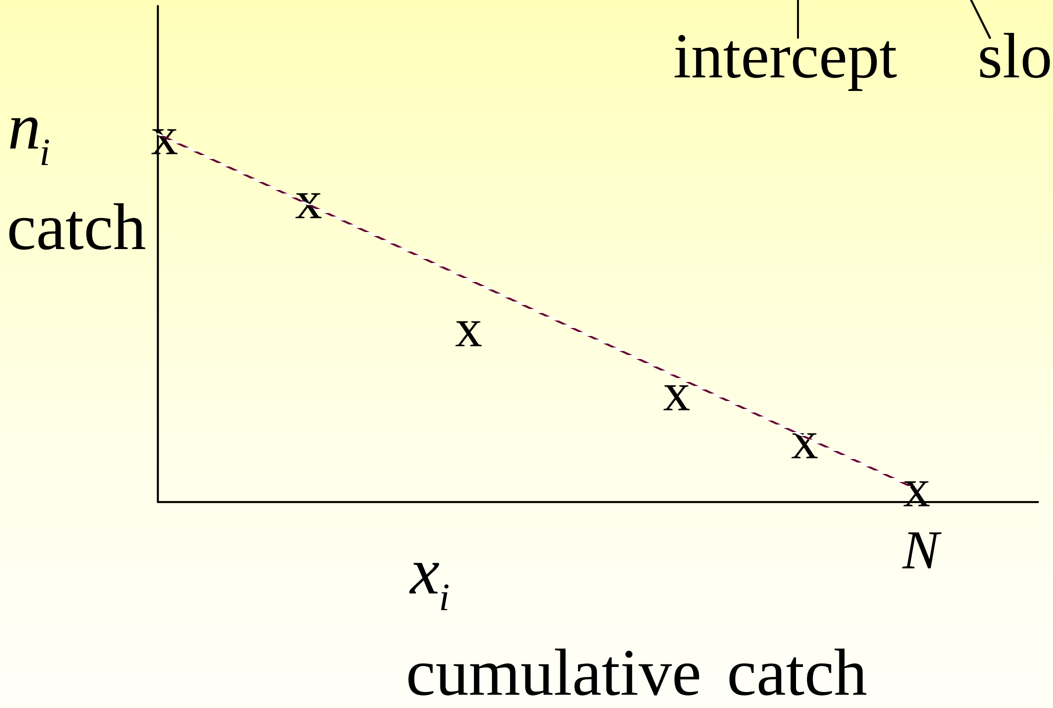
Time	Popn. Size	Observed removals	Expected removals
1	N	n_1	Np
2	$N-n_1$	n_2	$(N-n_1)p$
3	$N-n_1-n_2$	n_3	$(N-n_1-n_2)p$
.	.	.	.
.	.	.	.
i	$N-x_i$	n_i	$(N-x_i)p$

x_i = cumulative catch n_i = catch

Estimation

(a) Regression Model

$$E(n_i) = \underset{\substack{\uparrow \\ \text{intercept}}}{(Np)} - \underset{\substack{\nwarrow \\ \text{slope}}}{p}x_i$$



Estimation

(b) Use Program CAPTURE

(M_b) – Maximum Likelihood

Removal by marking is statistically equivalent to removal physically.

Could use Model $M_{b.}$

CAPTURE (M_{bh}) – Maximum Likelihood

Note: One can extend this removal model to M_{bh} , that is, there is heterogeneity of capture probabilities over animals. However, each animal has constant capture probability over samples.

USE of CAPTURE on the Web

Example of the Removal Models (M(b), M(bh))

```
task read population zippen
7,’Whitefish data’
25,26,15,13,12,13,5
Task population estimate zippen
```

Line 2 -7-is the no. of occassions

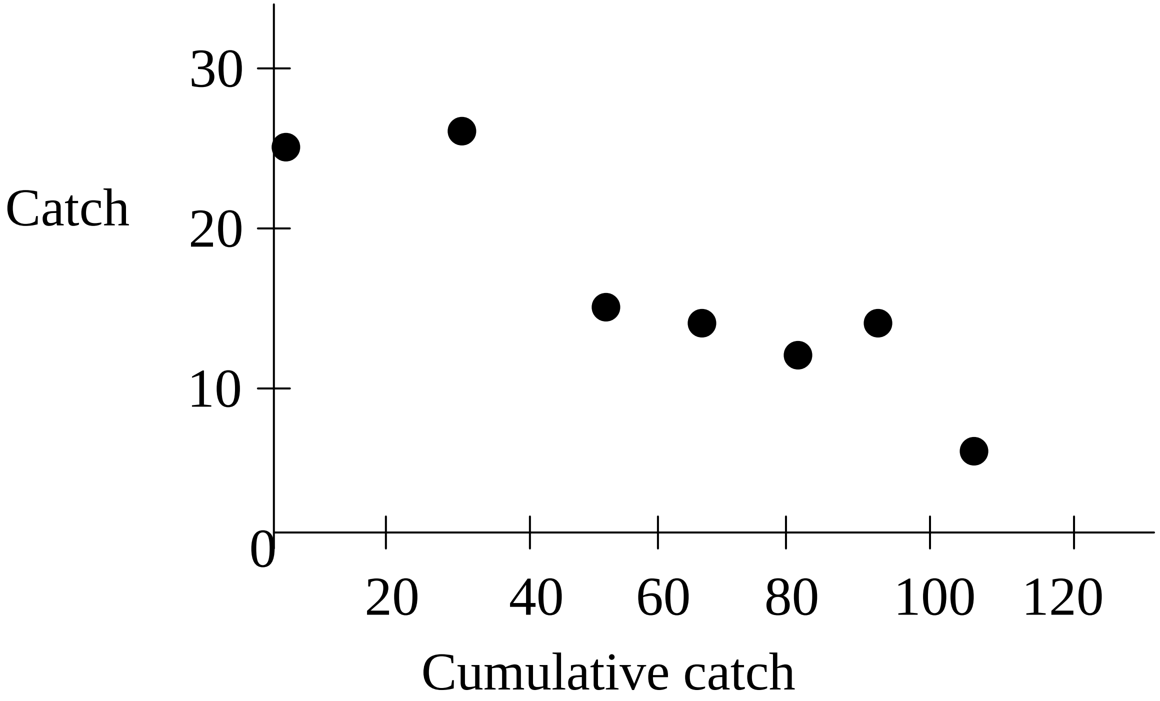
Line 3 - Entries are the no. of removals on each occasion

For model with heterogeneity M(bh) replace zippen with removal

Example: Whitefish (*Coregonus clupeaformis*): Ricker (1958: 150)

A small lake on an island in Lake Nipigon, Ontario was fished by gill nets in an identical manner for 7 successive weeks; the same sizes of nets, positions, and lengths of sets were repeated each week. For Whitefish of fork length 13-14 inches (33-35 cm) the weekly catches and and cumulative catches are given in the table below.

Week (i)	1	2	3	4	5	6	7
Catch (n_i)	25	26	15	13	12	13	5
Cumultive catch (x_i)	0	25	51	66	79	91	104



Plot of catch (n_i) versus cumulative catch (x_i) for a population of Whitefish: data from Ricker (1958).

WHITE FISH -Physical Removal

Ricker (1958) p. 150

	1	2	3	4	5	6	7
Catch	25	26	15	13	12	13	5
Cumulative catch	0	25	51	66	79	91	104

Number removed = 109 **See attached output for details**

M_b $\hat{N} = 138$ $SE(\hat{N}) = 14.7$

M_{bh} $\hat{N} = 138$ $SE(\hat{N}) = 14.7$

NO HETEROGENEITY DETECTED IN THIS EXAMPLE

The regression estimate was $\hat{N} = 142$

Mehinick 10 Period Removal Data

- Removal Data for k=10 were:

  72,63,44,32,31,23,17,18,11,13
- Regression Approach
- Use of MARK or CAPTURE is better (M_b, M_{bh} not shown, You could run it yourself in CAPTURE if you want)

Regression Approach

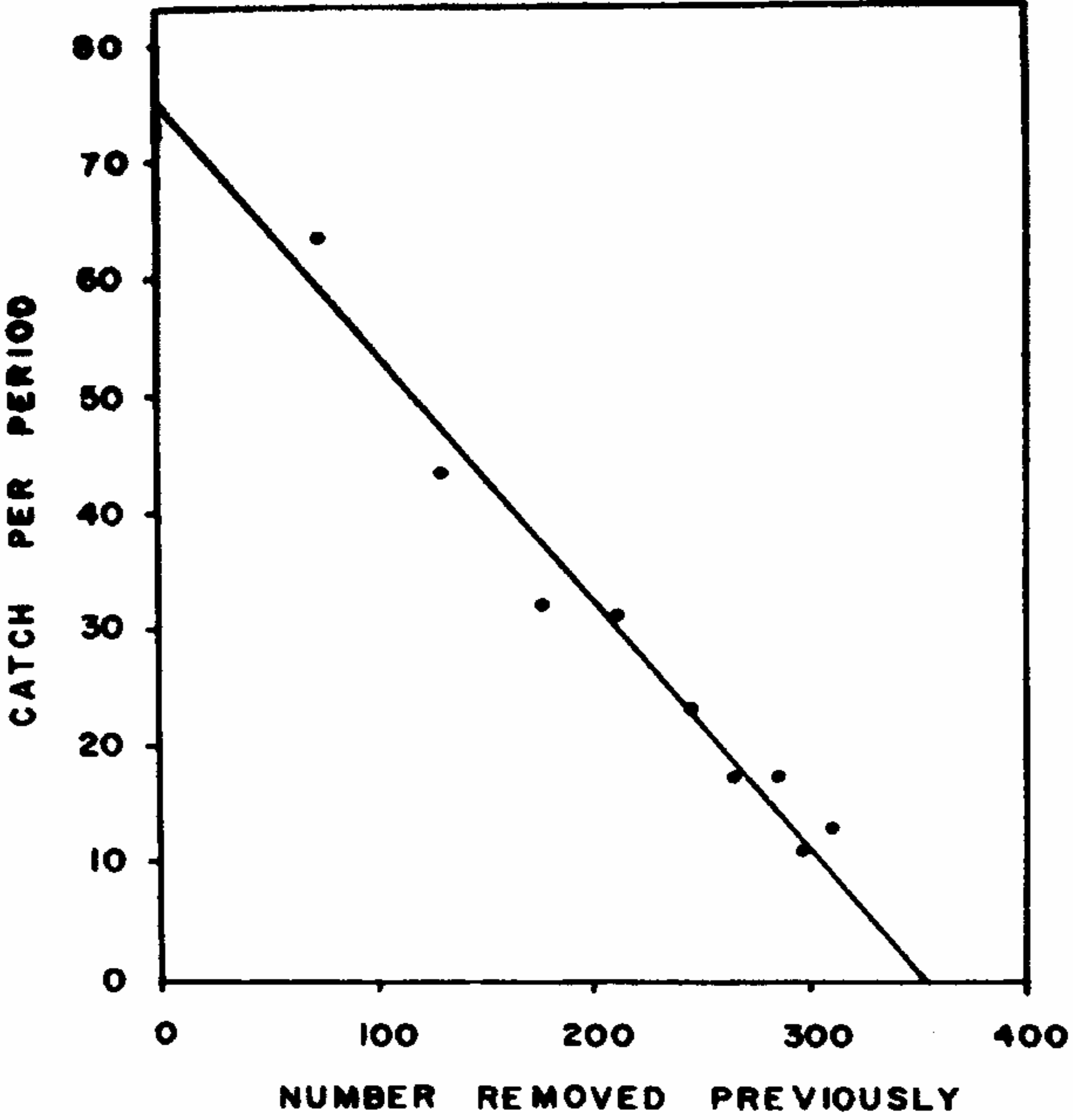


FIG. 1. Progressive decrease in numbers of *Maecolaspis flavida* (Say) caught in successive sweeping periods in a 225 m^2 area of a Sericea lespedeza stand.

$$\tilde{N} = 359$$

Mehinick 10 Period Removal Data

{Model Mb in MARK c fixed at 0}

```
Parameter Estimate SE      Lower          Upper
---------------------------   ---------------   ---------------
1:p        0.1971      0.017    0.1652       0.2334
2:c
3:N          364.1    11.99           346.6    395.2
```

Closed Population (Multiple Samples)

with Variable Effect

Data n_1 $n_2 \ldots\ldots\ldots n_k$ removals

f_1 $f_2 \ldots\ldots\ldots f_k$ effort in each sample

Parameters N initial population size

$$\underset{\substack{\uparrow \\ \text{Probability of capture}}}{p_i} = 1 - e^{-kf_i} \approx \underset{\substack{\uparrow \\ \text{Catch coefficient}}}{kf_i} \quad \text{when k is small}$$

Two parameter Model N, k

Model Assumptions

1. Closed population, except removals
2. All animals, all samples k constant
3. The relationship for p_i holds (i.e., fish caught independently)
4. Information on effort and catch complete from commercial fisheries

Estimation – We can generalize earlier Regular Model

Time	Popn. Size	Observed	Expected
1	N	n_1	Nkf_1
2	$N-n_1$	n_2	$(N- n_1)k\ f_2$
.	.	.	.
.	.	.	.
i	$N- x_i$	n_i	$(N- x_i)k\ f_i$

$$E(n_i / f_i) = Nk - kx_i$$

Linear Relationship

Example: Common Crab Fishery

Example: Blue Crab (*Callinectes sapidus*): Fischler (1965).

- The total catches per week, for 12 weeks, from a commercial-size male crab population are given in following Table.
- Three different kinds of gear were used: trot-lines, crab trawls, and shrimp trawls.
- From the ratios of total catch over total effort for each gear, the relative “fishing powers” of the 3 gears were: 1.00, 1.42, and 1.06
- For example: one crab trawl /day was equivalent to 1.42 trot-lines operating for 1 day.
- These powers were then used to convert the weekly fishing efforts of crab and shrimp trawls into standard units of trot-lines/day.

Example: Blue Crab (*Callinectes sapidus*): continued:

- The assumption of a closed population seems reasonable because:

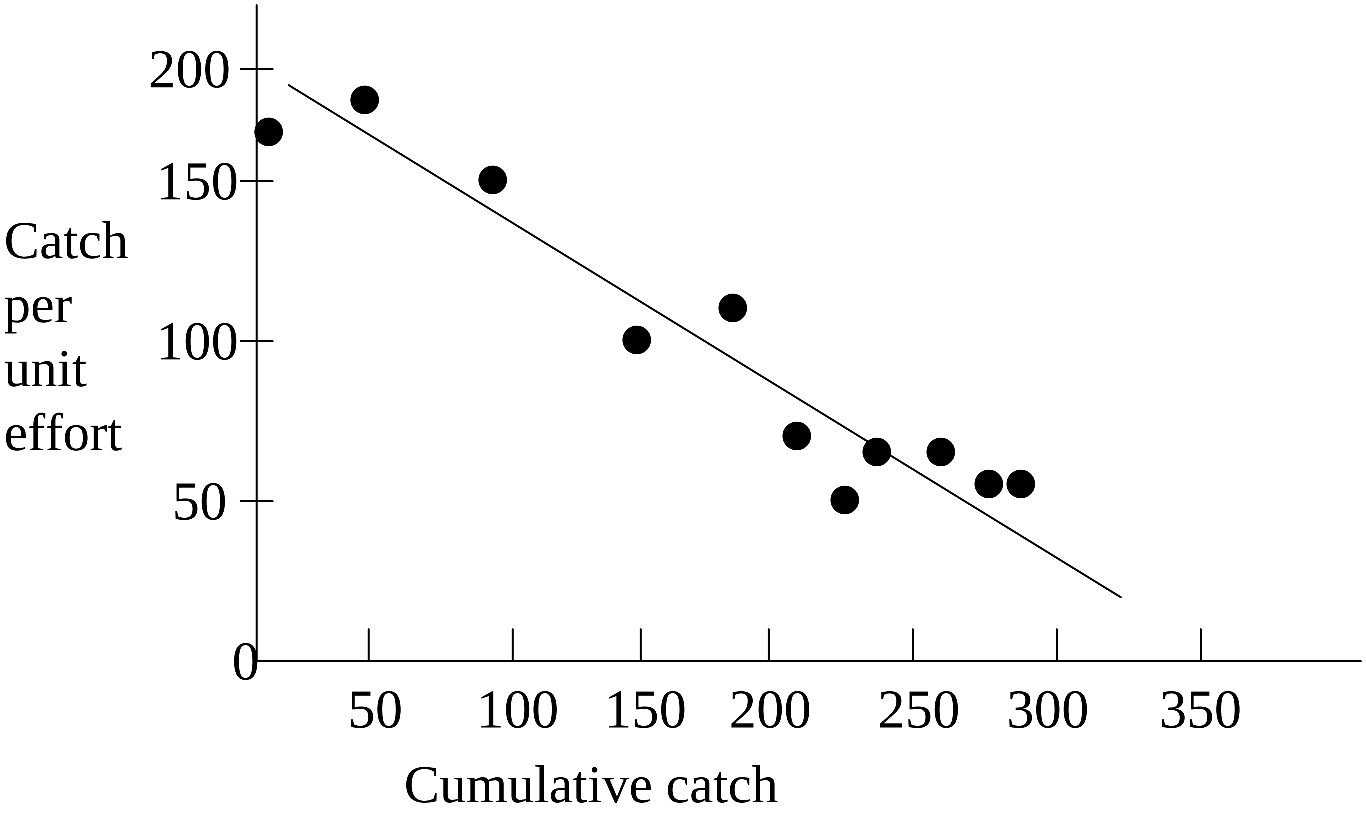
  (i) Natural mortality was negligible.

  (ii) The catches n_i (Table) have been corrected for recruitment from precommercial to commercial size, so that the population under study was the population of commercial-size male crabs at the beginning of the experiment.

  (iii) Only the male population is considered, as tagging studies indicated that commercial-size females were emigrating out of the area while the fishery was operating.

Catch-effort data for a population of commercial-size male crabs from Fischler (1965: Table 11)

i (week)	n_i (lb)	f_i (effort)	y_i ($= n_i/f_i$)	x_i (lb)
1	33 541	194	172.9	0
2	47 326	248	190.8	33 541
3	36 460	243	150.0	80 867
4	33 157	301	110.2	117 327
5	29 207	357	81.8	150 484
6	33 125	352	94.1	179 691
7	14 191	269	52.8	212 816
8	9 503	244	38.9	227 007
9	13 115	256	51.2	236 510
10	13 663	248	55.1	249 625
11	10 865	234	46.4	263 288
12	9 887	227	43.6	274 153



Plot of catch per unit effort (n_i/f_i) versus cumulative catch (x_i) for a population of male crabs: redrawn from Fischler (1965).

Regression $\hat{N} = 330,300$

95% CI (299, 600, 373, 600)

Another Example

Gould, W. R., and Pollock, K. H. (1997). Catch-effort maximum likelihood estimation of population parameters. *Canadian Journal of Fisheries and Aquatic Science*, **54**: 890-897.

I would like you to check this for your self in the text.

TABLE 14.11 Catch, Effort, and Temperature Data for a Commercially Harvested Lobster Population[a]

Period	Catch (n_i)	Effort (f_i)[b]	Temperature (t_i)
1	60,400	33.664	7.9
2	49,500	27.743	7.7
3	28,200	17.254	6.3
4	20,700	14.764	3.5
5	11,900	11.190	3.1
6	15,600	16.263	2.9
7	13,200	14.757	3.1
8	25,400	32.922	3.25[c]
9	29,900	45.519	3.4
10	32,500	43.523	3.6
11	24,700	37.478	4.0
12	27,600	43.367	5.9
13	22,200	37.960	6.1

---

[a] At Port Maitland, Nova Scotia, Canada, 1950–1951; reanalysis of data after Paloheimo (1963), cited in Gould and Paloheimo (1997b).

Pollock

[b] Effort is in thousands of trap hauls.

[c] This value was missing, so we used the average of the two adjoining periods.

TABLE 14.13 Comparison of Parameter Estimates (Standard Errors) for Three Models for a Commercially Harvested Lobster Population[a]

$\hat{N}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$
Effort-plus-temperature model (p_{f+t})			
549,974	−3.94	0.030	0.11
(47,780)	(0.182)	(0.004)	(0.02)
Effort model (p_f)			
472,270	−3.29	0.037	—
(21,840)	(0.108)	(0.0036)	—
Constant probability model ($p_.$)			
716,860	−2.89	—	—
(84,200)	(0.172)	—	—

[a] At Port Maitland, Nova Scotia, Canada, 1950–1951; reanalysis of data after Paloheimo (1963), cited in Gould and Paloheimo (1997b).

SELECTIVE REMOVAL OR CHANGE-IN-RATIO MODELS

Different ages or sexes are removed selectively so the proportions of the ages or sexes change after the removal

Deer with a controlled hunt is a good example:

-Removals selectively made towards males in harvest --

-Removals (harvest) are known.

- Also need an unbiased estimate of the proportion of males both before and after the hunt.

Time 1 Time 2

Sample Removal Sample

$$p_1 = \frac{N_{11}}{N_1} \qquad \rule{10em}{0.4pt} \qquad p_2 = \frac{N_{21}}{N_2}$$

Estimate ↓ Estimate

$$r_{11}, r_{12}$$

$$r_1 = r_{11} + r_{12}$$

Motivation for Estimation Approach

$$p_1 = \frac{N_{11}}{N_1}$$

$$p_2 = \frac{N_{21}}{N_2} = \frac{N_{11} - r_{11}}{N_1 - r_1} = \frac{N_1 p_1 - r_{11}}{N_1 - r_1}$$

Rearrangement gives

$$N_1 = \frac{r_{11} - r_1 p_2}{p_1 - p_2}$$

Theoretical Result

$$N_1 = \frac{r_{11} - r_1 p_2}{p_1 - p_2}$$

Estimation

$$\hat{N}_1 = \frac{r_{11} - r_1 \hat{p}_2}{\hat{p}_1 - \hat{p}_2}$$

$$\hat{N}_1 = \frac{r_{11} - r_1\left(\frac{n_{12}}{n_2}\right)}{\left(\frac{n_{11}}{n_1}\right) - \left(\frac{n_{12}}{n_2}\right)}$$

This is Equation 14.40 p.327

Theoretical Variance for $\hat{N}_1$

$$Var(\hat{N}_1) = \frac{N_1^2 Var(\hat{p}_1) + N_2^2 Var(\hat{p}_2)}{(p_1 - p_2)^2}$$

Note the importance of the difference (p_1 - p_2) to the variance.

There must be a change - in ratio!!!!! or the method wont work at all.

Selective Removal!!!!!!!!!!!!!!!!!

Assumptions:

1. Closed Population (except for the removals).
2. Both types of animals are equally catchable (or sightable) in each of the two samples before and after the removals.
3. The number of removals is exactly known.

Remington Farms Deer Herd Example

Pre Hunt

Post Hunt

$$\hat{p}_1 = 0.0963 \quad \underline{\hspace{6cm}} \quad \hat{p}_2 = 0.0381$$

$$\downarrow$$

$$r_{11} = 56 \text{ Antlered}$$

$$r_{21} = 54 \text{ Antlerless}$$

$$r_1 = 110$$

$$\hat{N}_1 = \frac{56 - 110x0.0381}{0.0963 - 0.0381}$$

$$= 890 \left(\text{total deer}\right)$$

$$\hat{N}_{11} = 86(\text{antlered deer } 890x0.963)$$

$$\hat{N}_{21} = 804(\text{antlerless deer})$$

Note Box 5 next gives the SEs and a summary of the example in a slightly different notation

Box 5. Using the CIR method to estimate population size of antlered and antlerless deer.

Antlered (x-type) and antlerless (y-type) deer were observed during 54 prehunt and 52 posthunt road counts on Remington Farms, Maryland (Conner et al. 1986). One hundred and twenty x-type and 1,126 y-type animals were observed before 56 antlered deer (R_x) and 54 antlerless deer (R_y) were removed by hunters during a 1-week season. After the season, 43 x-type and 1,086 y-type deer were observed. Therefore,

$$\hat{P}_1 = x_1/n_1 = 120/1{,}246 = 0.0963$$

$$\hat{P}_2 = x_2/n_2 = 43/1{,}129 = 0.0381$$

$$\begin{aligned}\hat{N}_1 &= (R_x - R\hat{P}_2)/(\hat{P}_1 - \hat{P}_2)\\ &= \{56 - 110(0.0381)\}/(0.0963 - 0.0381)\\ &= 51.809/0.0582\\ &= 890\ (\widehat{\mathrm{SE}} = 149)\end{aligned}$$

$$\begin{aligned}\hat{X}_1 &= \hat{P}_1\hat{N}_1 = 0.0963(890)\\ &= 86\ (\widehat{\mathrm{SE}} = 14).\end{aligned}$$

In this example both x and y types were removed. Because the y-type (antlerless) animals were probably more observable than the x-type animals, λ was probably >1.0, and the population estimates were likely to be biased high.

Validity of Assumptions in the Example

1. Closed Population (except for the removals). (OK, Fairly short time period, perhaps some migration)
2. Both types of animals are equally catchable (or sightable) in each of the two samples before and after the removals.(Antlerless more sightable than antlered deer and this probably means the estimates are biased high).
3. The number of removals is exactly known.(OK as controlled hunt.)