OPTIMIZATION IN FISHERIES MANAGEMENT

Case of Sea Scallops

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OUTLINE

1. Formulation of the optimization problem: objectives, decision variables, constraints
2. Optimization technique.
3. Examples for Georges Bank Scallops.

OPTIMIZATION PROBLEM FORMULATION

* **Maximize** Total fishing yield = f(x: decision variables)

* **Subject to:**

  1. Sustainability:

     $F_{avg} <= F_{Target}$

     or $B > B_{Threshold}$ (deterministic)

     or $P(B < B_{Threshold}) < \alpha_1$ (stochastic)

  2. Variability in annual yields $< \alpha_2$

  3. Bycatch

* **Decision variables** (x):

  1. Fishing factor F_{it} for sub-area (i) in year (t)

  2. How to partition scallop fishing ground into management sub-areas

α_1, α_2 are threshold values.

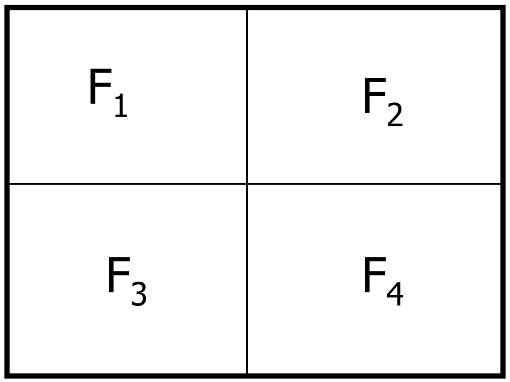
DECISION VARIABLES

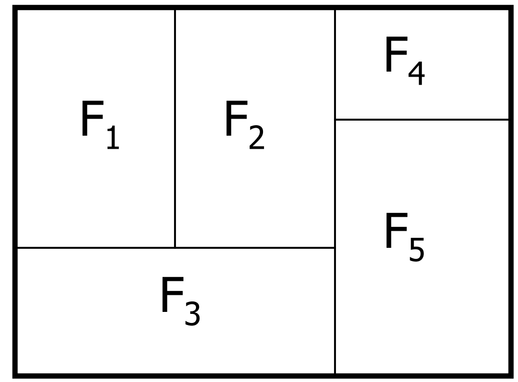
We consider two types of decision variables:

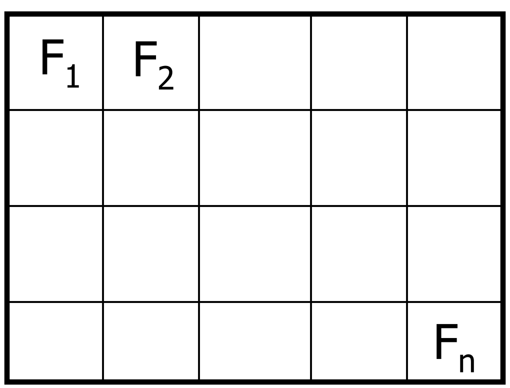
1. How to partition fishing ground into management sub-areas
   (non-numerical decision variables)
2. Fishing mortalities F_{it} for sub-area (i) in year (t)

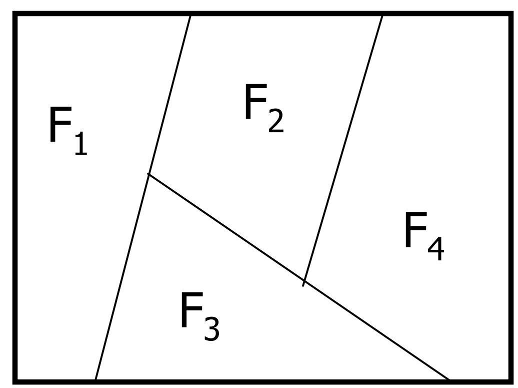
- Rotation options could also be optimized when we set some specific $F_{it} = 0$
- The number of sub-areas should be decided by managers since there is trade off between simplicity for management and economical profit.
- Fishing capacity restrictions (DAS) or Landing restrictions (TAC) could be derived from fishing mortalities.
- Gear restrictions (Ring size) could also be added into the model.

Examples of area partition



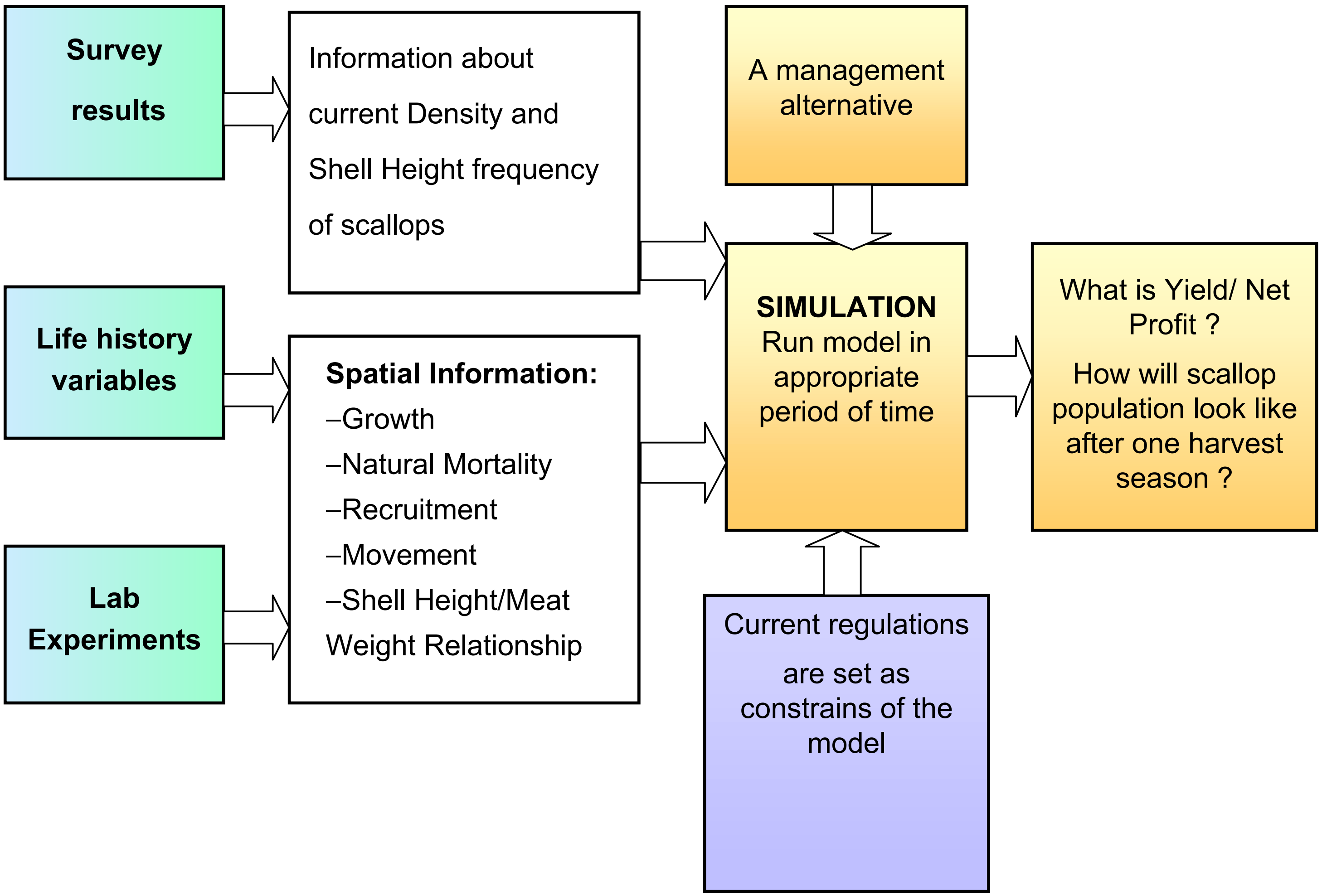






Simulation Model

Answers to “WHAT – IF” questions



Optimization using simulation

A hybrid approach, combines simulation modeling to optimization technique:

- Simulation returns performance measure (objective function value) for any given scenario.
- Optimization technique provides search process to find the optimum management policy

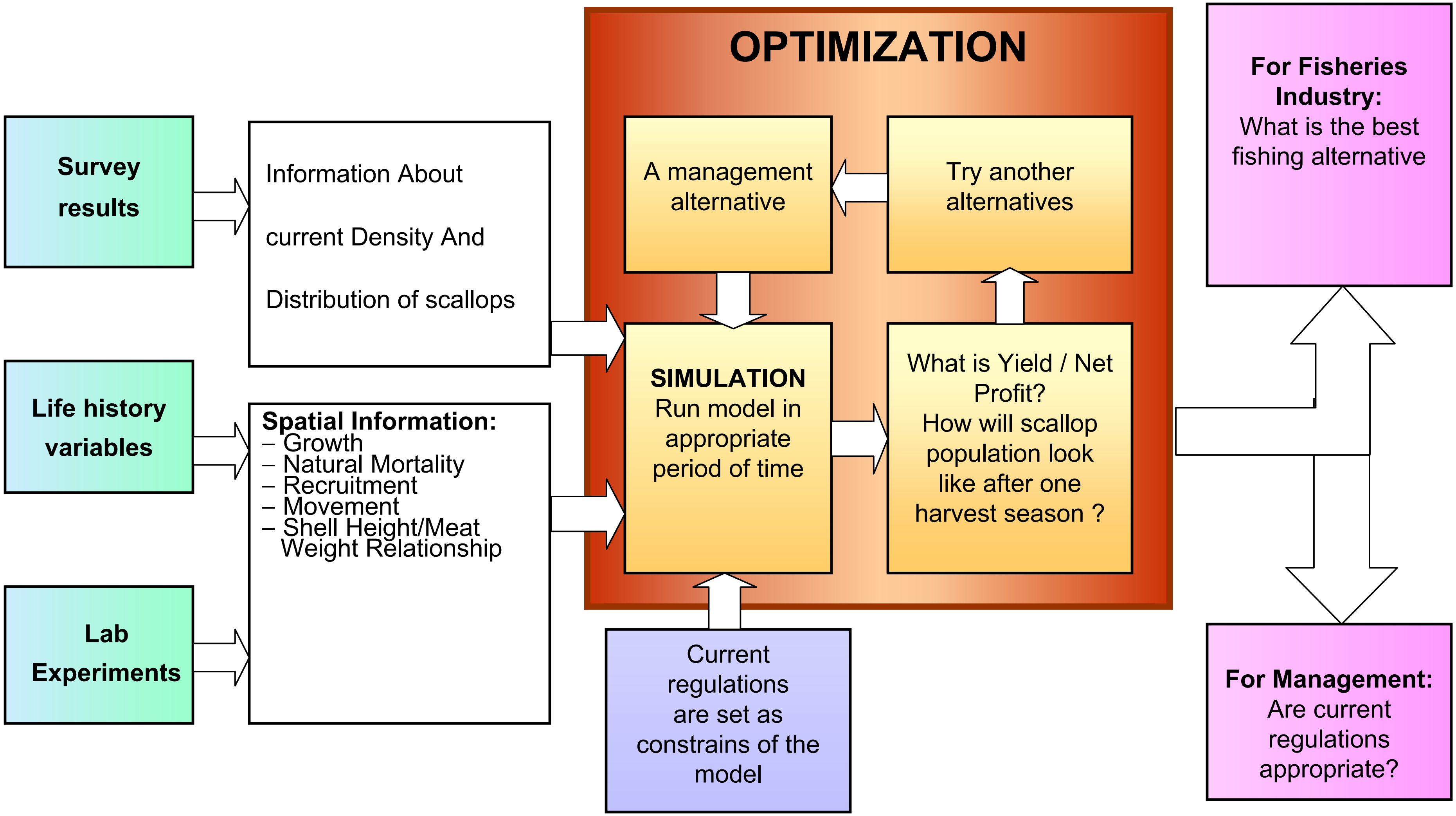
Optimization using simulation

Advantages of using simulation in optimization:

- Complexity of the system being modeled does not significantly affect the performance of the optimization process. Optimization is independent of Simulation
- For stochastic systems, the variance of the response is controllable by various output analysis techniques.
- Where structural or policy optimization of systems are considered, simulation provides an advantage that is often not possible in classical optimization procedures.

Optimization program

Answers to "WHAT – TO – DO" questions



Optimization technique

For optimization technique, we use Genetic Algorithms:

Genetic Algorithm is a class of stochastic search techniques inspired by natural evolution. Decision variables are encoded as genomes. Optima searching processes take place with selection, recombination (crossover) and mutation operators

Genetic Algorithms

Main idea of Genetic Algorithms stems from Darwin’s evolutionary theory. Genetic Algorithms always maintain a population of coded solutions (called genomes). By applying appropriate operators of selection, reproduction, and crossover between two individuals, we could create better and better generations.

Genetic Algorithms

Major advantages of Genetic Algorithms:

- Require no knowledge of gradient information about the response surface.
- Do not become trapped at local optima.
- Allow to handle non-quantitative variables.

Part 3: Examples

Three scenarios have been tested:

1. F = 0.2 everywhere.
2. One rotation option: close 3 years, open 2 years.
3. Optimize both the area breakdown and F.

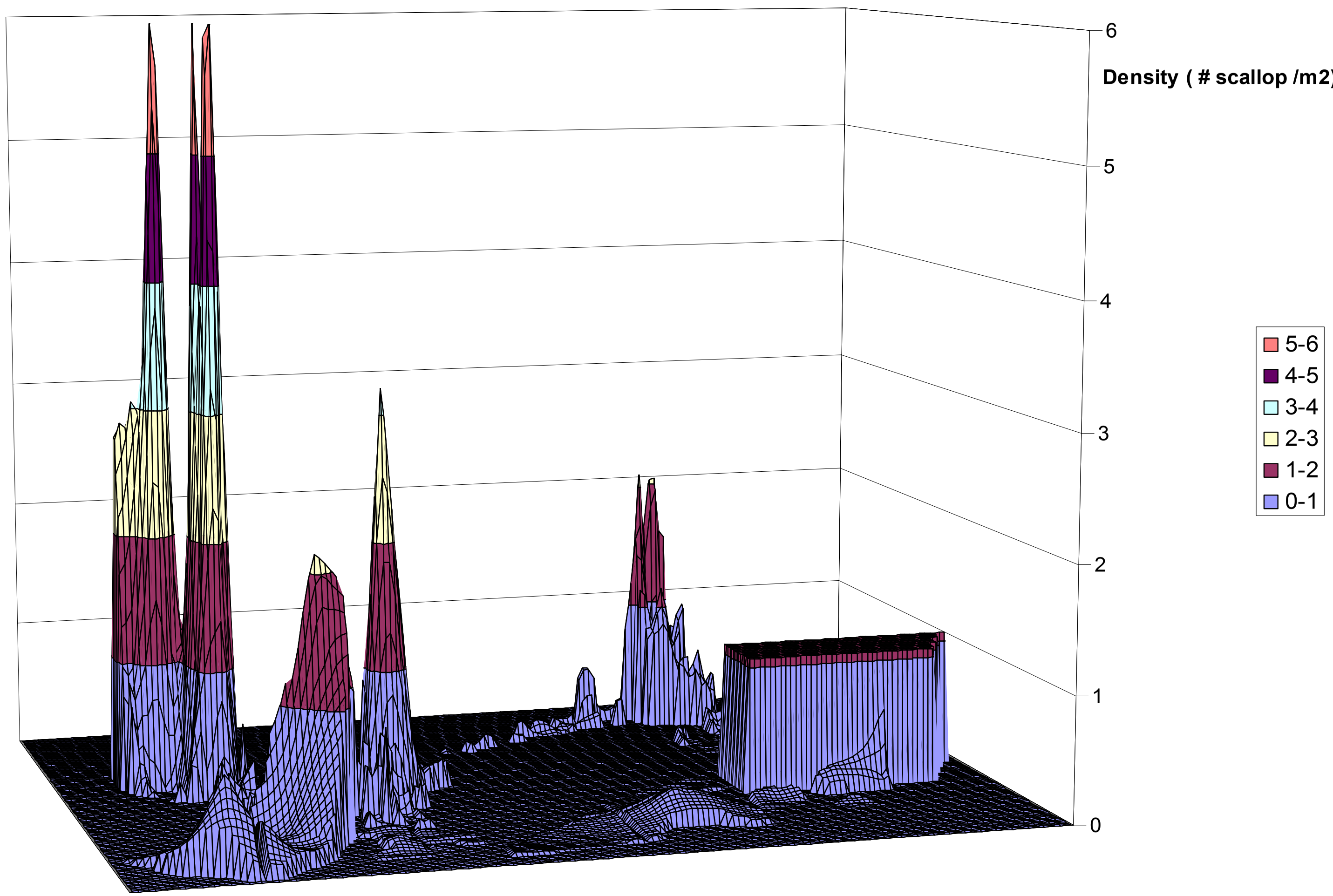
Input data

Input data for simulation and optimization program are from:

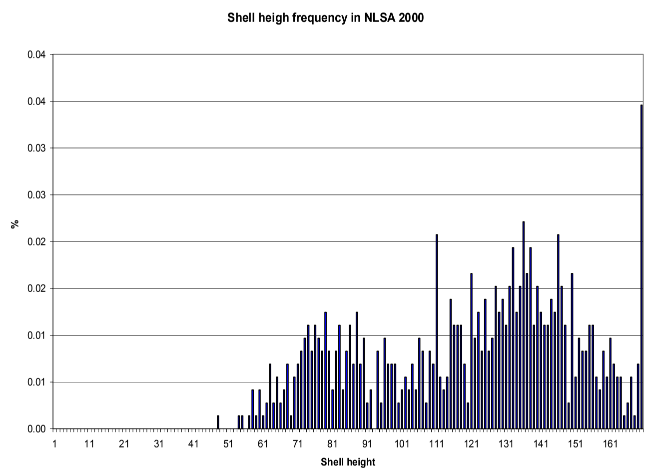
- 1999 and 2000 SMAST video surveys.
- Preliminary data of 2001 SMAST video survey.
- 2001 SMAST tagging experiment.
- 2000 NMFS dredge survey.

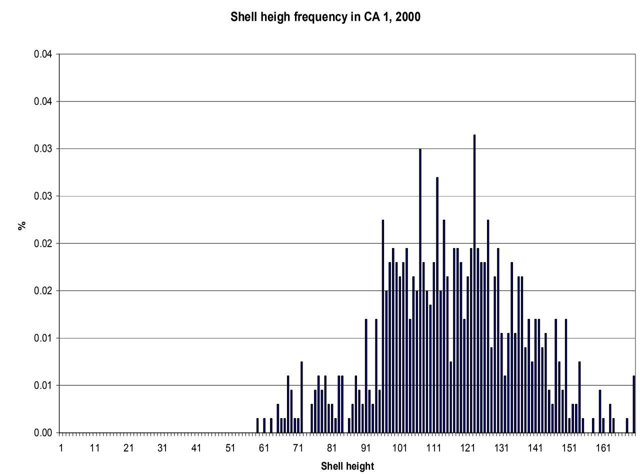
Density distribution

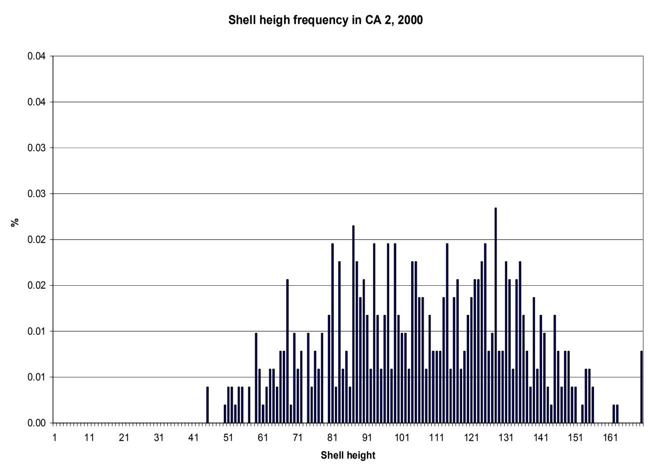
Georges Bank scallop density distribution

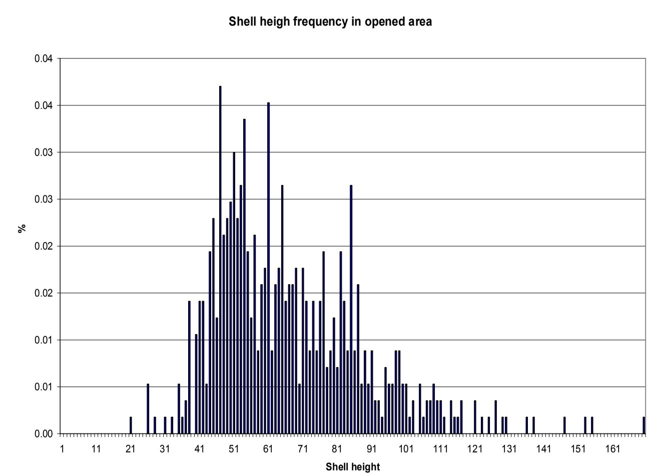


Shell height frequency









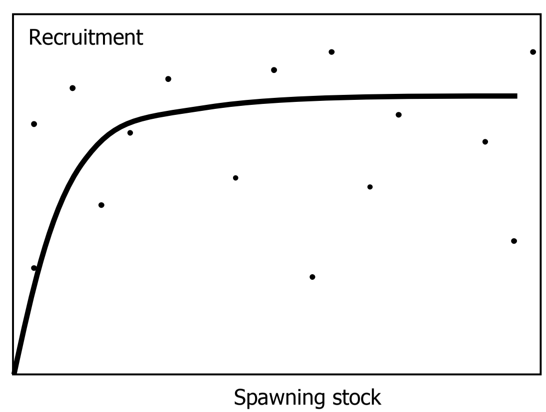
Recruitment hypothesis

Very important for long-term planning (10^+ years)

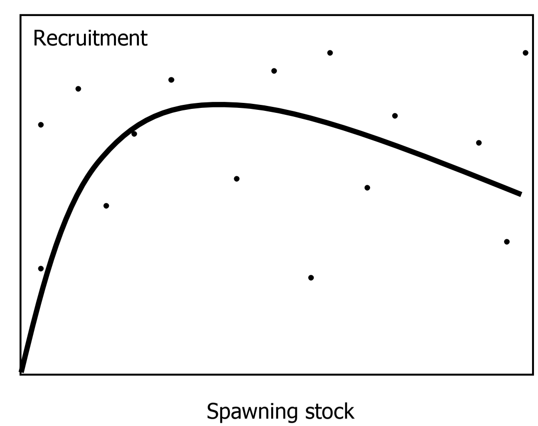
More work needs to be done on this subject. We are very careful in applying recruitment models. Following examples are tested in two cases: without recruitment or with Ricker recruitment model

RECRUITMENT AS A RANDOM PROCESS INDEPENDENT OF SPAWNING STOCK

BEVERTON-HOLT RECRUITMENT MODEL



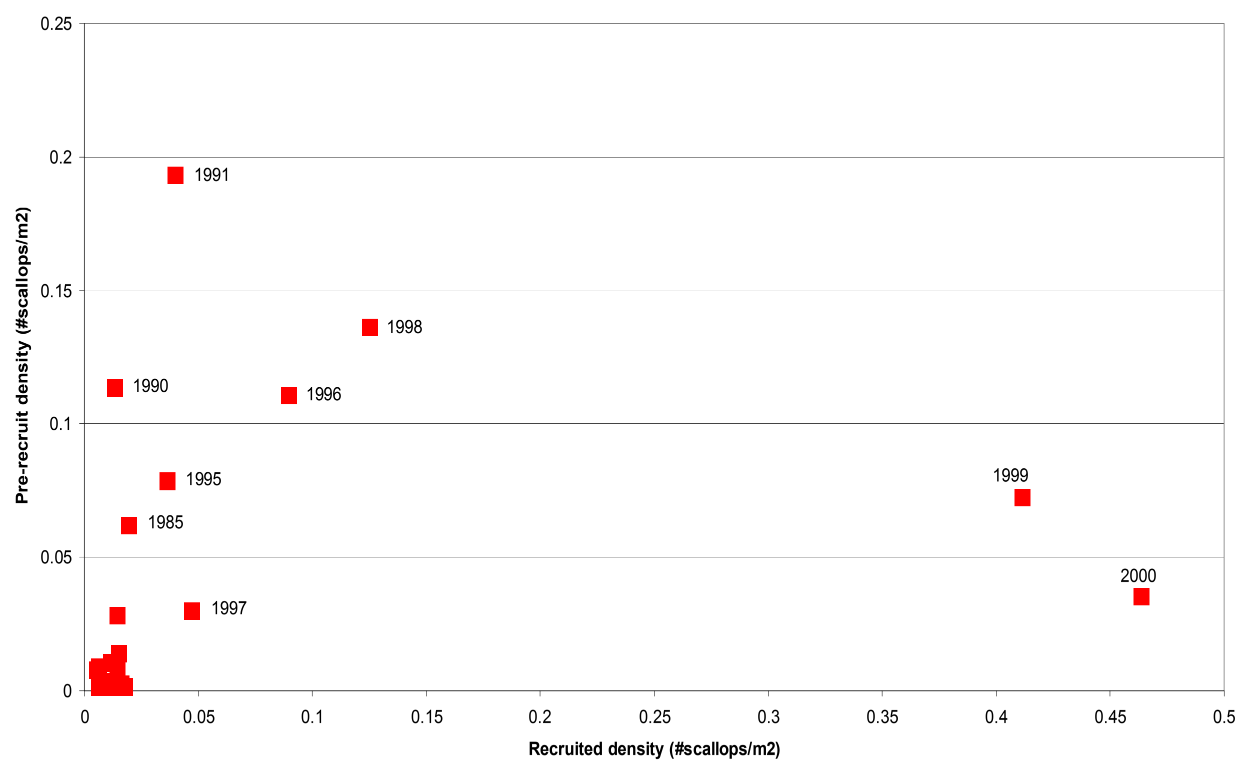
RICKER RECRUITMENT MODEL



Recruitment hypothesis

Ricker recruitment model is selected after observing recruitments in Nantucket Lightship Area since 1979-2000. Recruitment models for other areas are being studied.

Recruitment in Nantucket Lightship Area 1979 -2000



Scenario 1: F = 0.2

	Year 1	Year 2	Year 3	Year 4	Year 5
Area 1	0	0	0	0	0
Area 2	3178	3942	4,056	3,770	3,278
Area 3	0259	321	330	307	267
Area 4	210	260	268	249	216
Area 5	173	214	221	205	178
Area 6	61	76	78	73	63
Area 7	100	124	128	119	103
Area 8	3	3	4	3	3
Area 9	91	82	70	57	46
Area 10	1342	1,213	1,037	853	683
Area 11	0	0	0	0	0
Area 12	2247	1,959	1,642	1,335	1,059
Area 13	1334	1,164	976	793	629
Area 14	3707	3,459	3,031	2,538	2,056
Area 15	1178	1,099	963	806	653
Total	**13,883**	**13,918**	**12,805**	**11,110**	**9238**

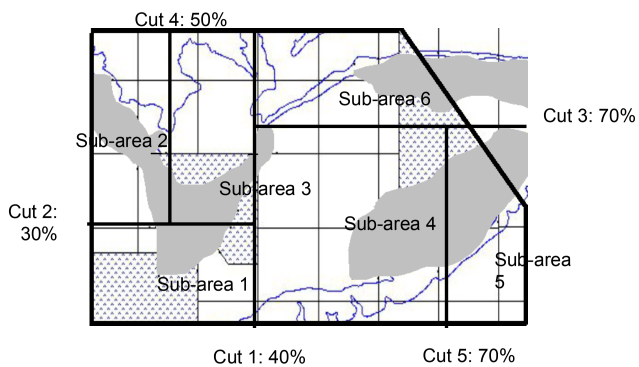
Total yield = 60,953 MT / 5 year

Scenario 2: Close 3 years - Open 2 years

	Year 1	Year 2	Year 3	Year 4	Year 5
Area 1	0	0	0	0	0
Area 2	0	0	13,069	8,991	0
Area 3	0	0	0	1,208	777
Area 4	0	0	863	594	0
Area 5	0	566	431	0	0
Area 6	134	124	0	0	0
Area 7	0	0	0	468	301
Area 8	0	0	11	8	0
Area 9	0	218	138	0	0
Area 10	2,920	1,955	0	0	0
Area 11	0	0	0	0	0
Area 12	0	0	5,332	3,211	0
Area 13	0	3,093	1,921	0	0
Area 14	8,066	5,577	0	0	0
Area 15	0	2,922	1,896	0	0
Total	**11,120**	**14,455**	**23,662**	**14,479**	**1079**

Total yield = 64,793 MT / 5 year

Scenario 3: Optimize sub-areas and F_{it}



	Year 1	Year 2	Year 3	Year 4	Year 5
Area 1	7,401	3,503	1,033	0	952
Area 2	0	2,166	3,110	5,833	4,365
Area 3	2,190	1,750	2,661	1,760	617
Area 4	917	1,168	863	3,294	2,969
Area 5	1,206	2,708	5,750	1,969	2,146
Area 6	1,070	2528	972	1,255	1,253
Total	**12,584**	**13823**	**14,389**	**14,111**	**12,302**

Total yield = 67,209 MT / 5 year

Scenario 1: F = 0.2 with recruitment

	Year 1	Year 2	Year 3	Year 4	Year 5
Area 1	0	0	0	0	0
Area 2	3,299	4,189	4,429	4,272	3,914
Area 3	327	540	741	919	1,064
Area 4	259	404	524	619	687
Area 5	226	402	595	782	944
Area 6	79	134	188	237	279
Area 7	118	173	217	252	278
Area 8	3	6	10	14	18
Area 9	109	122	133	141	148
Area 10	1,442	1,441	1,407	1,356	1,307
Area 11	0	0	0	0	0
Area 12	2,361	2,216	2,062	1,920	1,801
Area 13	1,622	1,814	1,997	2,161	2,295
Area 14	3,711	3,473	3,072	2,638	2,254
Area 15	1,274	1,317	1,317	1,293	1,264
Total	**14,833**	**16,238**	**16,696**	**16,608**	**16,260**

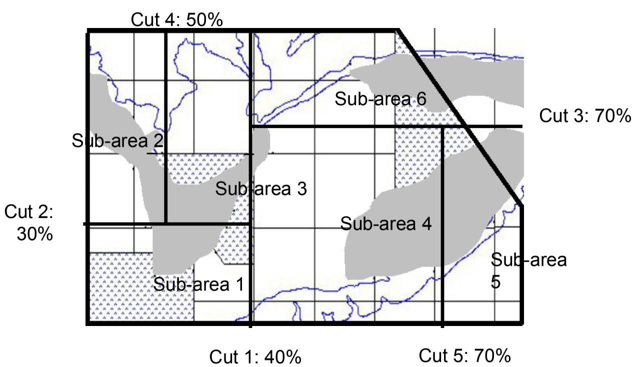
Total yield = 80,634 MT / 5 year

Scenario 2: Rotation with recruitment

	Year 1	Year 2	Year 3	Year 4	Year 5
Area 1	0	0	0	0	0
Area 2	0	11,006	8,637	0	0
Area 3	0	0	2,150	1,939	0
Area 4	0	0	0	1,998	1,567
Area 5	492	689	0	0	0
Area 6	0	340	363	0	0
Area 7	0	0	655	551	0
Area 8	0	0	0	50	44
Area 9	238	211	0	0	0
Area 10	0	3,750	2,731	0	0
Area 11	0	0	0	0	0
Area 12	0	0	0	6,706	4,432
Area 13	3,535	3,128	0	0	0
Area 14	0	9,214	6,062	0	0
Area 15	0	0	3,970	2,835	0
Total	**4,265**	**28,340**	**24,568**	**14,080**	**6,043**

Total yield = 77,296 MT / 5 year

Scenario 3: Optimize with recruitment



	Year 1	Year 2	Year 3	Year 4	Year 5
Area 1	5,639	6,641	2,987	2,355	0
Area 2	3,278	2,976	3,762	3,005	6,041
Area 3	1,036	4,289	2,111	3,883	2,572
Area 4	1,124	1,241	1,034	1,202	2,931
Area 5	5,025	0	8,397	5,051	4,001
Area 6	2,310	2,527	0	1,449	1,142
Total	**18,412**	**17,674**	**18,292**	**16,946**	**16,687**

Total yield = 88,011 MT / 5 year

THANK YOU