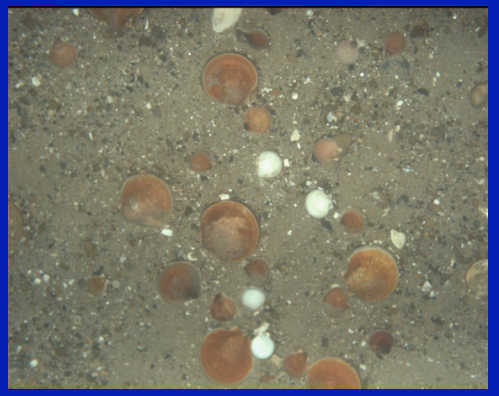
Sea Scallop Surveys in the 21st Century: Could Advanced Optical Technologies ultimately replace the dredge-based survey?



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2. Northeast Fisheries Science Center, Woods Hole, MA
3. Woods Hole Oceanographic Institution, Woods Hole, MA

Talk Organization

- I. Background information - Atlantic Sea Scallops (Biology, the fishery, management)
- II. Dredge Surveys and Optical Surveys
  - What are they?
  - What information do they provide?
- III. How do dredge and optical surveys compare - A calibration experiment
- IV.Address question “Could optical surveys replace the traditional dredge survey?”
- V. Future research

Part I. Atlantic Sea Scallop Background

Placopecten magellanicus (Atlantic sea scallop)

From: http://seagrant.gso.uri.edu/research/georges_bank/Species_List/Pectinidae.htm

Atlantic Sea Scallop - Biology (*Placopecten magellanicus*)

Atlantic Sea Scallop

Dvora Hart: http://www.nefsc.noaa.gov/sos/spsyn/iv/scallop/

- Found in NW Atlantic (Newfoundland to N.Carolina)
- Filter Feeders
- Main Habitat: Sand and gravel bottoms
- Ideal temperature < 17 C
- Size: Typically < 17 cm (6.7 in); Depth: 25 - 200 m depending on location
- Life span: Up to 20 years.

Atlantic Sea Scallops - Fishery

New Bedford Style Dredge;
Photo by Laura Oremland

- One of most valuable fisheries in U.S.
- Ex-vessel value in 2007: > ~$385 M
- Primary U.S. Fishing areas include Gulf of Maine, Georges Bank, Mid-Atlantic
- Harvesting begins at age 4-5
- Fishery year around
- Primarily harvested by New Bedford Style Dredge

Sea Scallops and the Law

- Magnuson-Stevens Reauthorization Act of 2006 (MSRA)
  - Mandates management measures that:
    - (1) Prevent overfishing while achieving optimum yield from each U.S. (commercial) fishery
    - (2) Be based on the best scientific information available
    - (3) Minimize costs and duplication where practicable
  - In addition, MSRA reaffirms support for Cooperative Research

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What this means for scallops:

1. Monitor scallop populations (e.g., abundance, size)
2. Provide best available science to support scallop fishery management

The Importance of Scallop Size to Management

- Shell Height Distance in mm between the umbo and shell margin
- Important in stock assessments and fishery management
  - Scallops hard to age (false age annuli), size important
  - Biological reference points, fishing gear
- Size frequencies can indicate overfishing

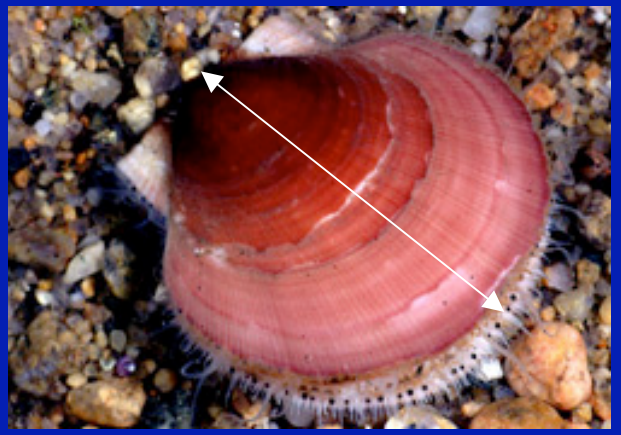


Photo from:

http://www.mbl.edu/marine_org/marine_org.php?func=reveal&myID=D165

Management Measures

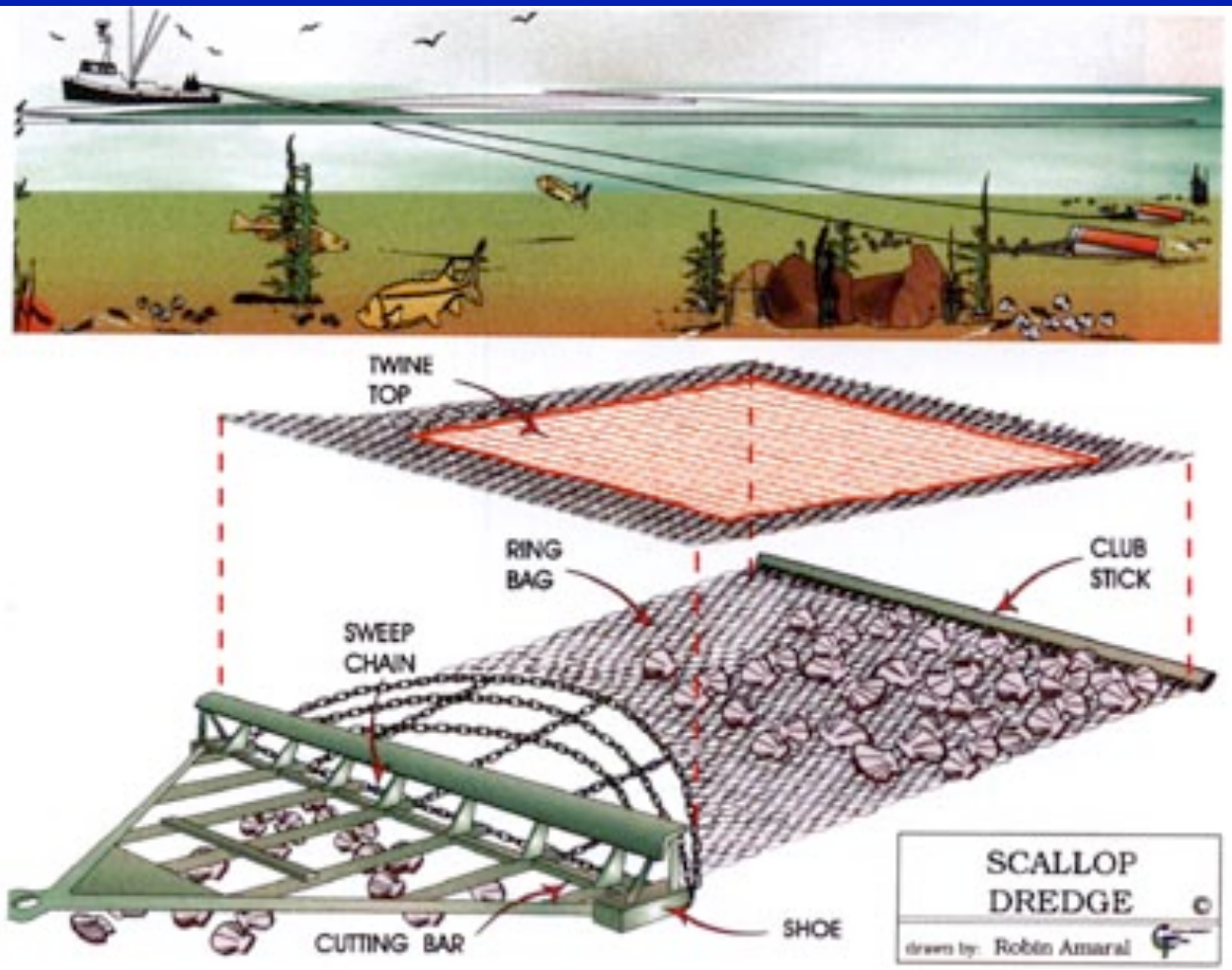
- Gear Size Restrictions (scallop dredge ring size)
- Fishing Effort Limitations (# permits, DAS, Max crew size)
- Closed and rotational fishing areas

Part II. Sea Scallop Surveys: Dredge and Optical Methods

- Dredge Surveys
- Optical Surveys
  - Habcam
  - SMAST

New Bedford Dredge

SMOLOWITZ FIGURE 2 (page 48) The New Bedford style scallop dredge, with top removed for illustration. Drawing by Robin Amaral.



New Bedford Dredge:

Photo from: http://www.fishingnj.org/diascall.htm

Dredge Survey

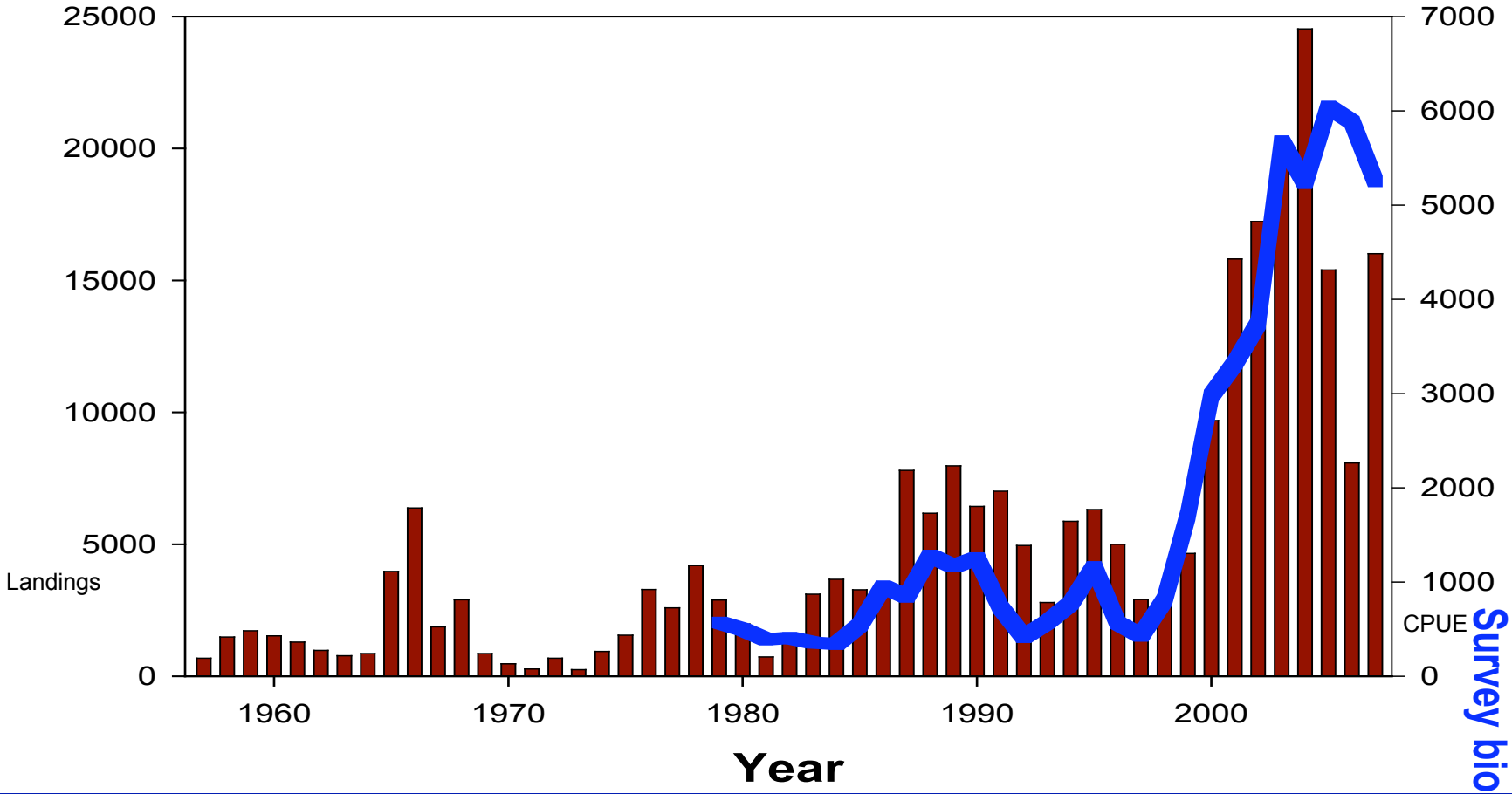
- Conducted aboard R/V Sharp
- Former boat, Albatross, was recently retired from the scallop survey
- Conducted annually since late 1970s

R/V Hugh R. Sharp

Photo: Dvora Hart

Dredge Survey tow analysis

The NEFSC sea scallop survey has been conducted annually since 1979. The survey index is closely related to commercial landings and CPUE.



Optical Survey Options

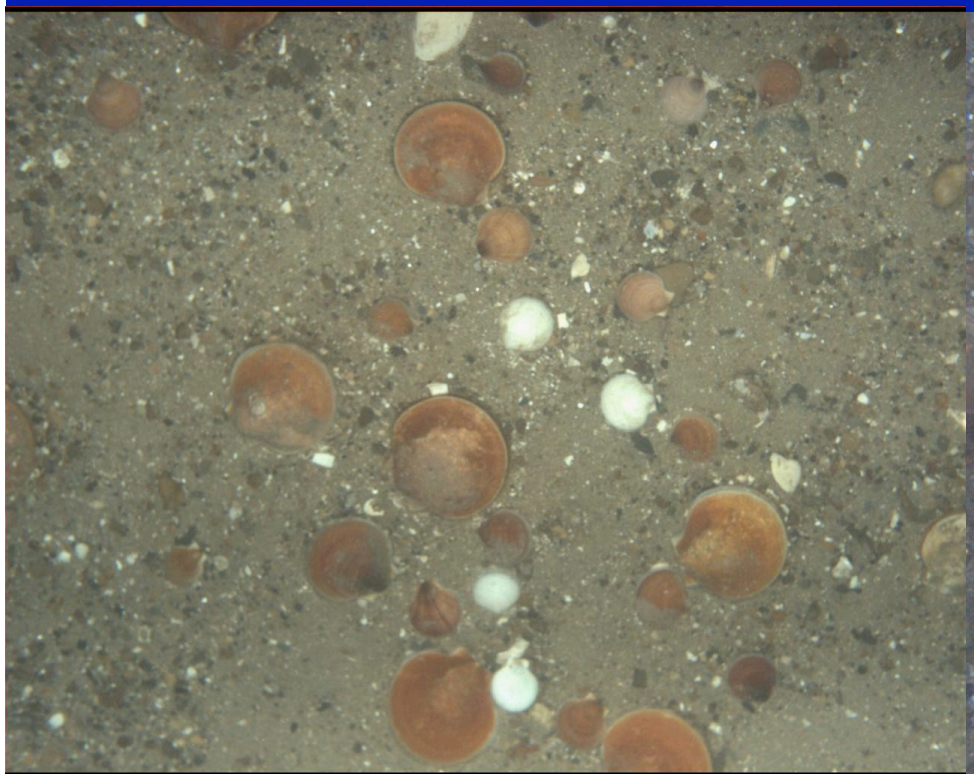
HABCAM

- HabCam is short for “Habitat mapping camera system”
- Developed by WHOI scientists and Cape Cod scallop fishermen
- Looking for non-invasive survey method
- Tow body, takes images of sea floor to count and measure scallops on bottom
- Tows camera 3 m above bottom

HABCAM

- 300k images/day, 1 GB data/day
- Piece images together to form mosaic
- Collect raw .tiff images, process, color correct to end up w/ .jpg images of manageable size
- Matlab software (written by Amber York) to measure scallops and translate image to a true size measurement

SCALLOP IMAGES



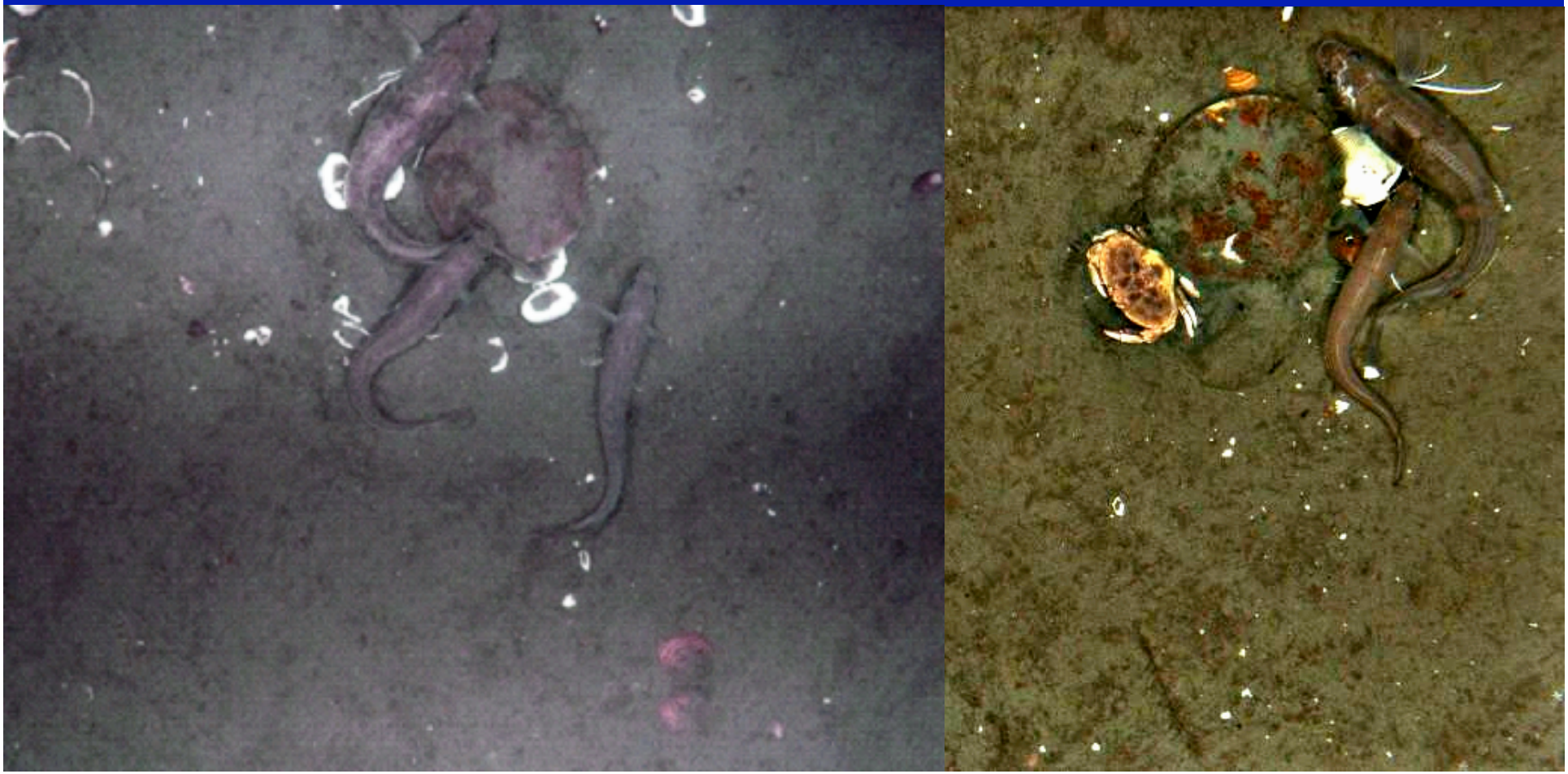
Habcam shows Predatory/Prey Interactions

Predation of sea scallops by *Asterias vulgaris* sea stars

Predation of sea scallops by *Buccinum undatum* whelks

Habcam also shows other ecosystem interactions - mutualism

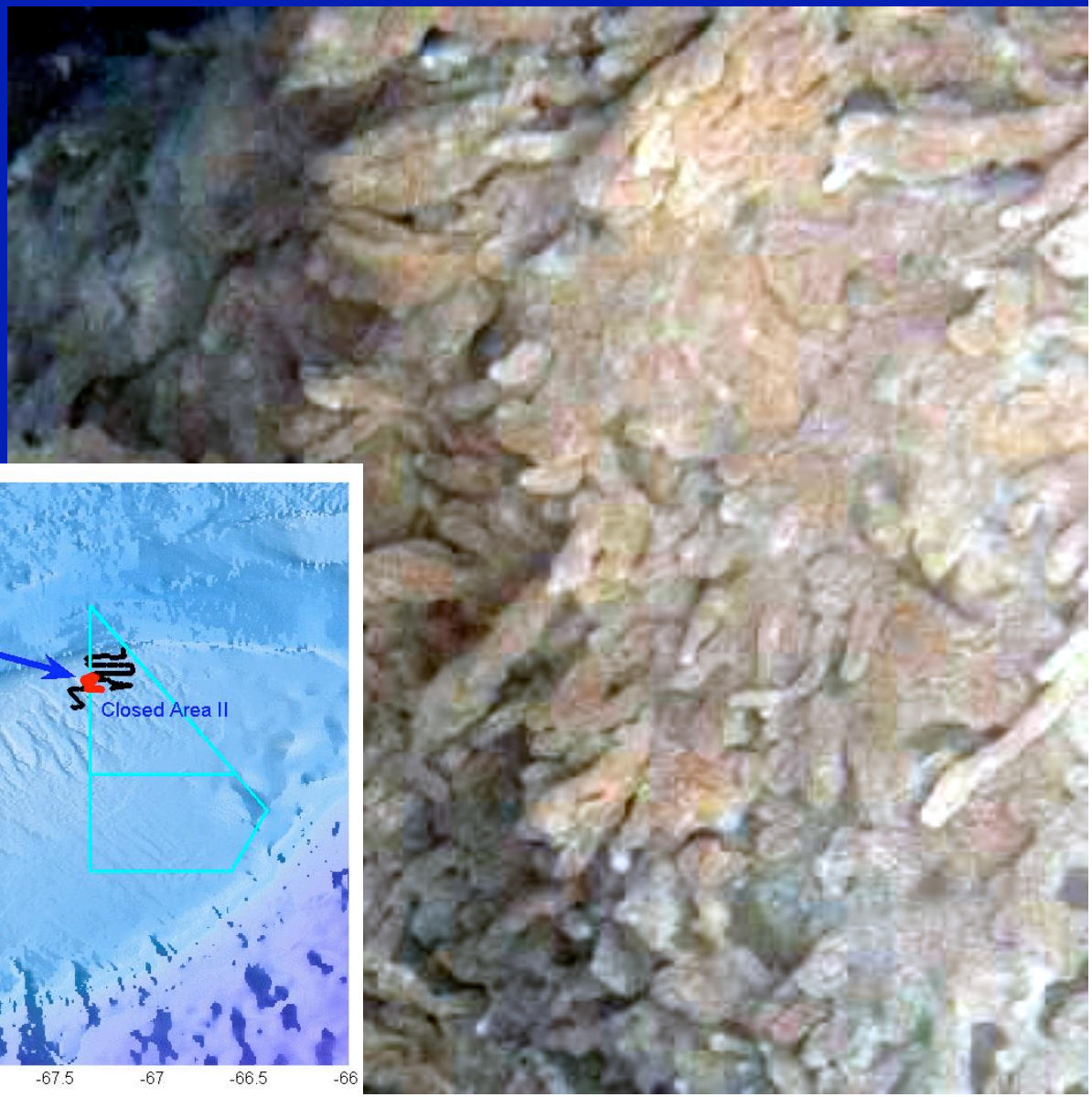
Red hake (*Urophycis chuss*) and sea scallops

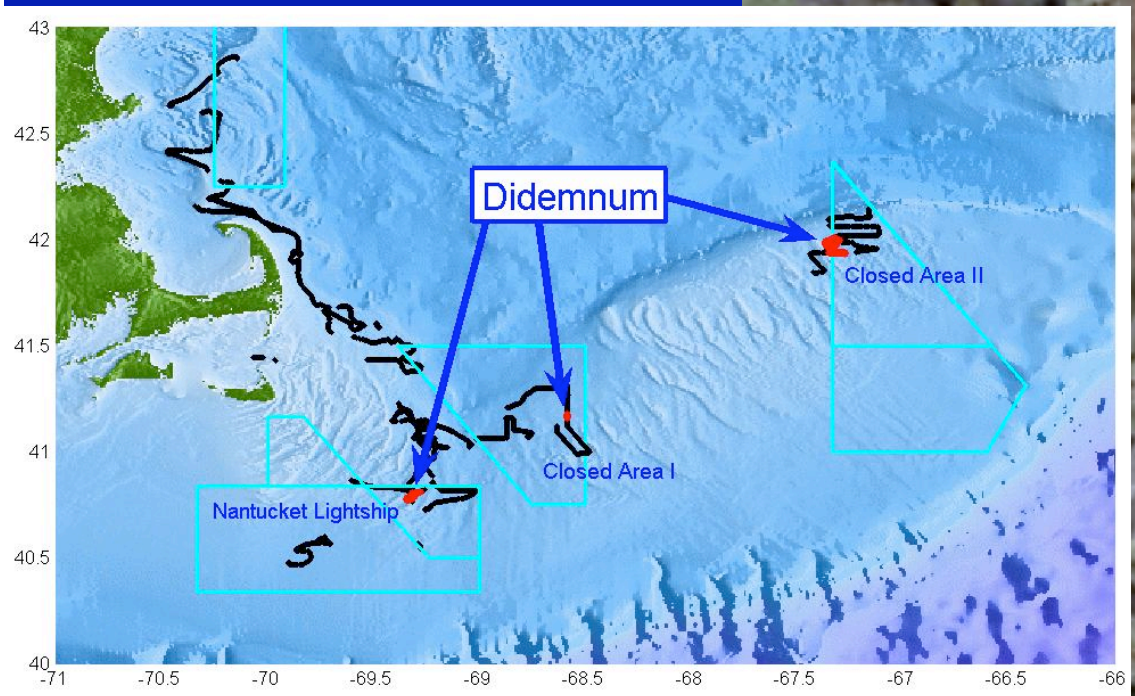


Habcam is also a useful tool for enumerating demersal finfish

Invasive species

Didemnum sp. a.k.a., “the tunicate from hell”





University of MA, Dartmouth
School for Marine Science and Technology (SMAST)

- Video Survey conducted since1999
- Conducted by joint effort of SMAST researchers and commercial fisherman

Photos from: http://www.smast.umassd.edu/Fisheries/Scallops/

SMAST Video Survey Objectives

Spatially Specific Estimates

Abundance / Density

Size Distribution

Recruitment

Natural Mortality

Benthos Mapping / Gear Impacts

Survey Characteristics

Cooperative

Inexpensive

Non-Invasive (vs. Mobile Gear)

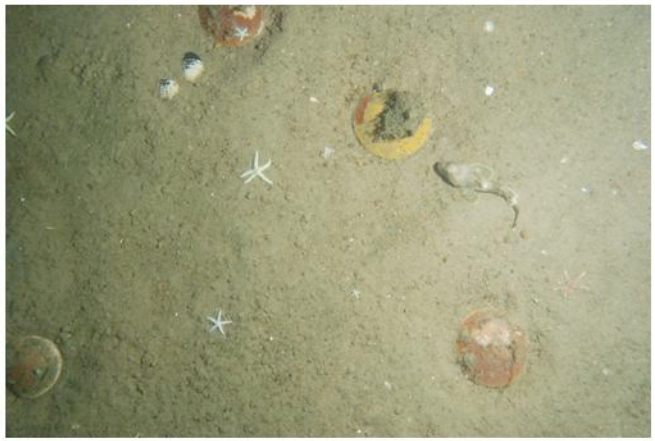
Technologically Simple (Biologists not Engineers)

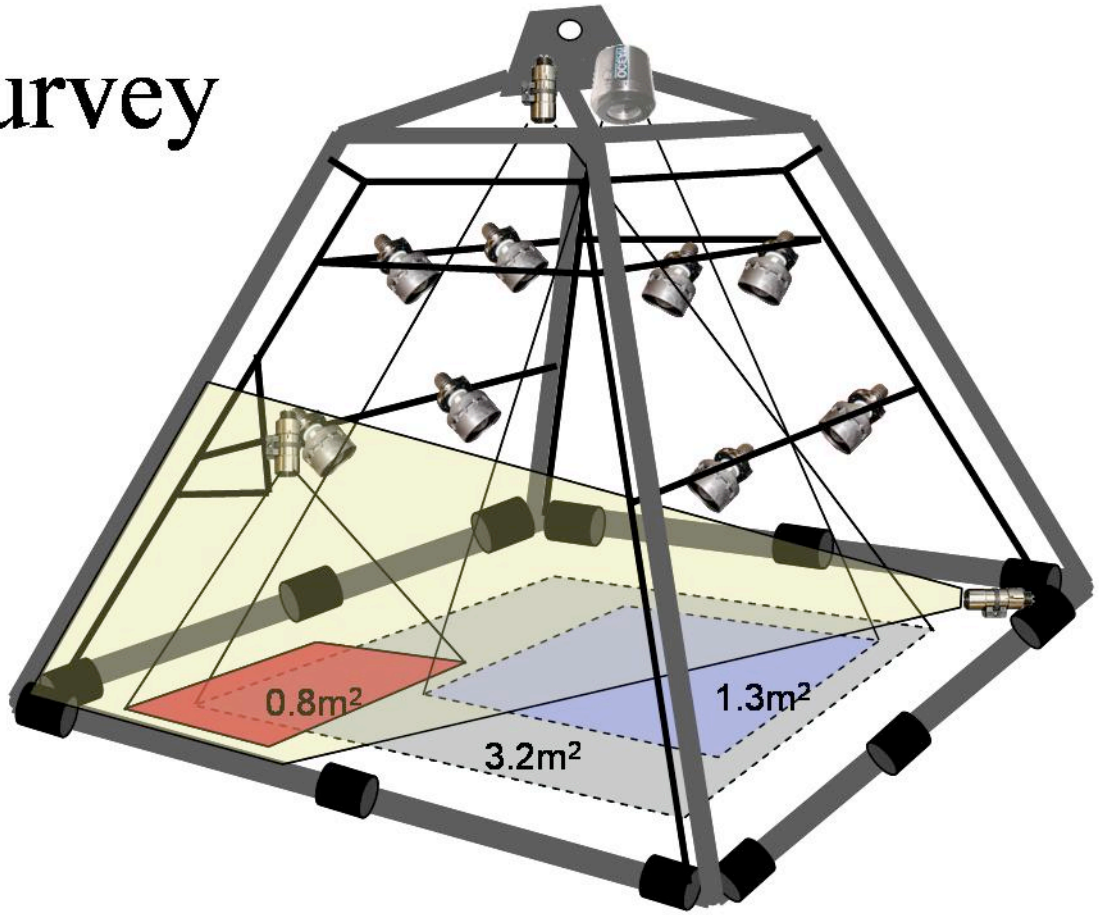
Adaptable to Management Changes (Spatial Management)

Step off the vessel with estimate (Real-Time)

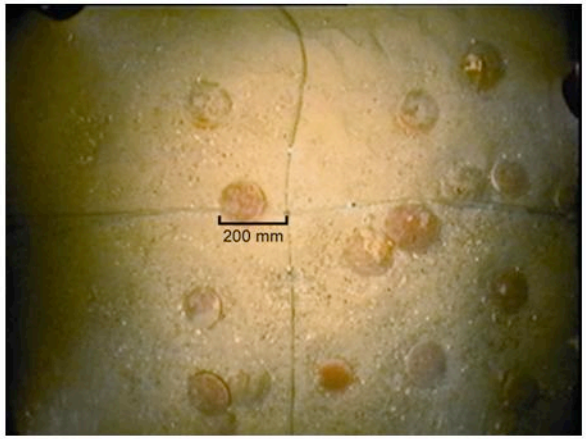
SMAST Video Survey

Digital Still Camera = 1.3 m²





Large Camera = 3.2 m²



Small Camera = 0.8 m²

Side Camera

How do the dredge survey and the Habcam optical survey compare?

Basic Comparisons

	Dredge Survey	Optical Survey (Habcam Specifics)
Platform	UNOLS Vessel (formerly NOAA vessel)	Commercial Vessel
Survey Gear	Modified New Bedford Dredge	High resolution video camera, towed by vessel
Station Selection	Stratified Random sampling	Continuous Imaging System
Sampling Method	Dredge tows (3.8 knots; over 4500 m^2)	Line, pinwheel Transects (5 knots); Best design up for question
Purpose	Scallop Biomass Estimate	R&D; Small scale surveys & investigations; Potential for widespread scallop biomass estimate

Cost comparisons

	Dredge Survey	Optical Survey (Habcam)
Cost	High: ~$20K √	Lower: ~12K (60% less) √ √ BUT: High capital investment
Staff needed	20-22 (Boat:8; Scientific 12-14)	6-8 (3x less; Boat: 4; Scientific 2-4) √
Sampling Area Covered/Survey	Over 500 stations; 17,000 NM	TBD; Habcam can cover 2x area /day as Dredge survey √
Tow Analysis	▪5 people √ ▪ 30-60 minutes to count, measure 1 tow ▪Post Cruise QA/QC: 3-4 wks	▪Depends on decimation, # of scallops; Range: 1-10 hrs/person/tow. If count 1/100 image, likely 1-2 hrs/tow ▪Post Cruise: TBD
Survey DAS	32 - 36 per Summer ---	Unclear; Estimate 16-24 days ---

Information Comparisons

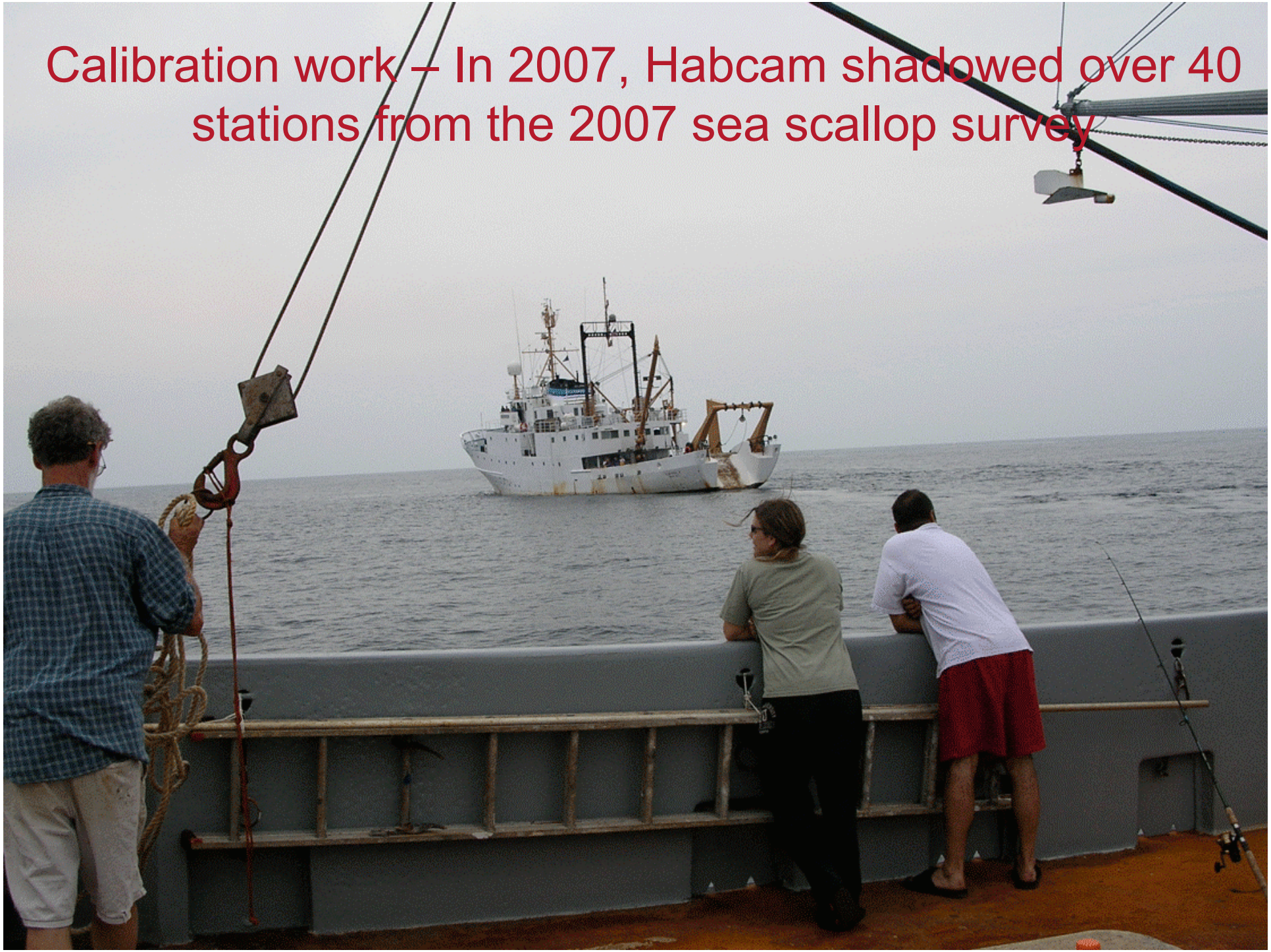
	Dredge Survey	Optical Survey (Habcam)
Scallop Biology	Scallop weights, shells for age and growth √	Limited biological sampling capacity
Ecosystem level information	Limited capacity	Obtains information on habitats, other species, & interactions √
Credibility	▪Historic time series √ ▪Sampling methodology accepted	▪Support from industry √ ▪Appropriate survey design not yet understood
Causes habitat damage?	Yes	No √
Abundance?	Yes- Relative Index	Yes - Absolute Abundance √
Size frequency?	Yes, dredge efficiency, selectivity √	Yes, measurement error

Comparison Overview

- Cost Winner: Habcam
- Information Winner: Both
  - Dredge and optical surveys each provide unique sets of information
- Habcam still in R&D phase; If both were to measure the same scallops in the same area, how would they compare?
- 2007 Calibration Experiment

Part III.Calibration Experiment between Dredge Survey and Optical Survey (Habcam)

2008 NRAP Project Focus


Calibration work – In 2007, Habcam shadowed over 40 stations from the 2007 sea scallop survey

Comparison of dredge survey and Habcam at the same sites

Calibration Requires Analysis of:

- Measurement Error
- Dredge Selectivity
- Dredge Efficiency

The first step is to look at Measurement Error: (2008 NRAP project)

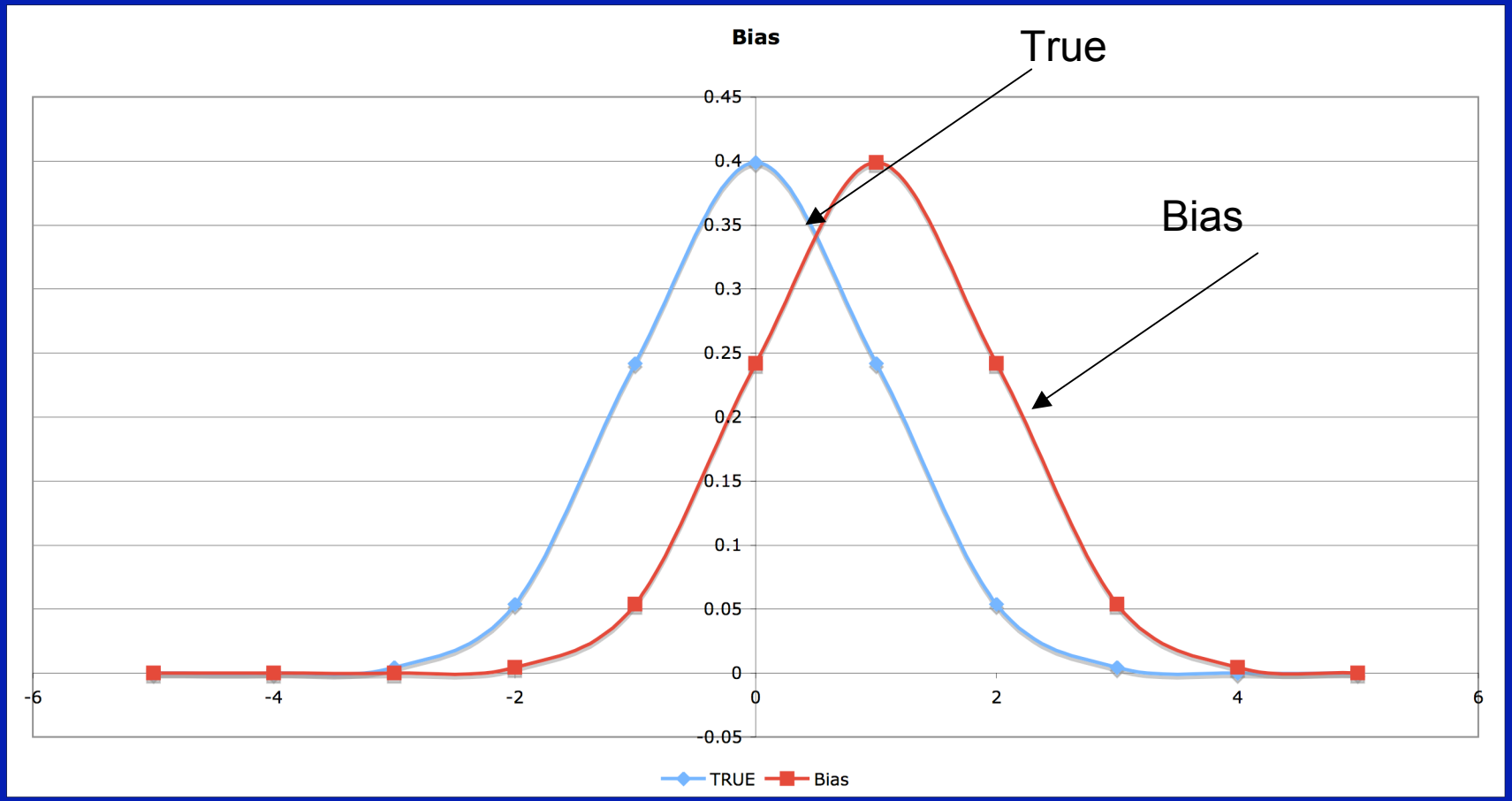
Measurement Error Analysis

Methodology based on recent, combined work of NMFS and SMAST researchers

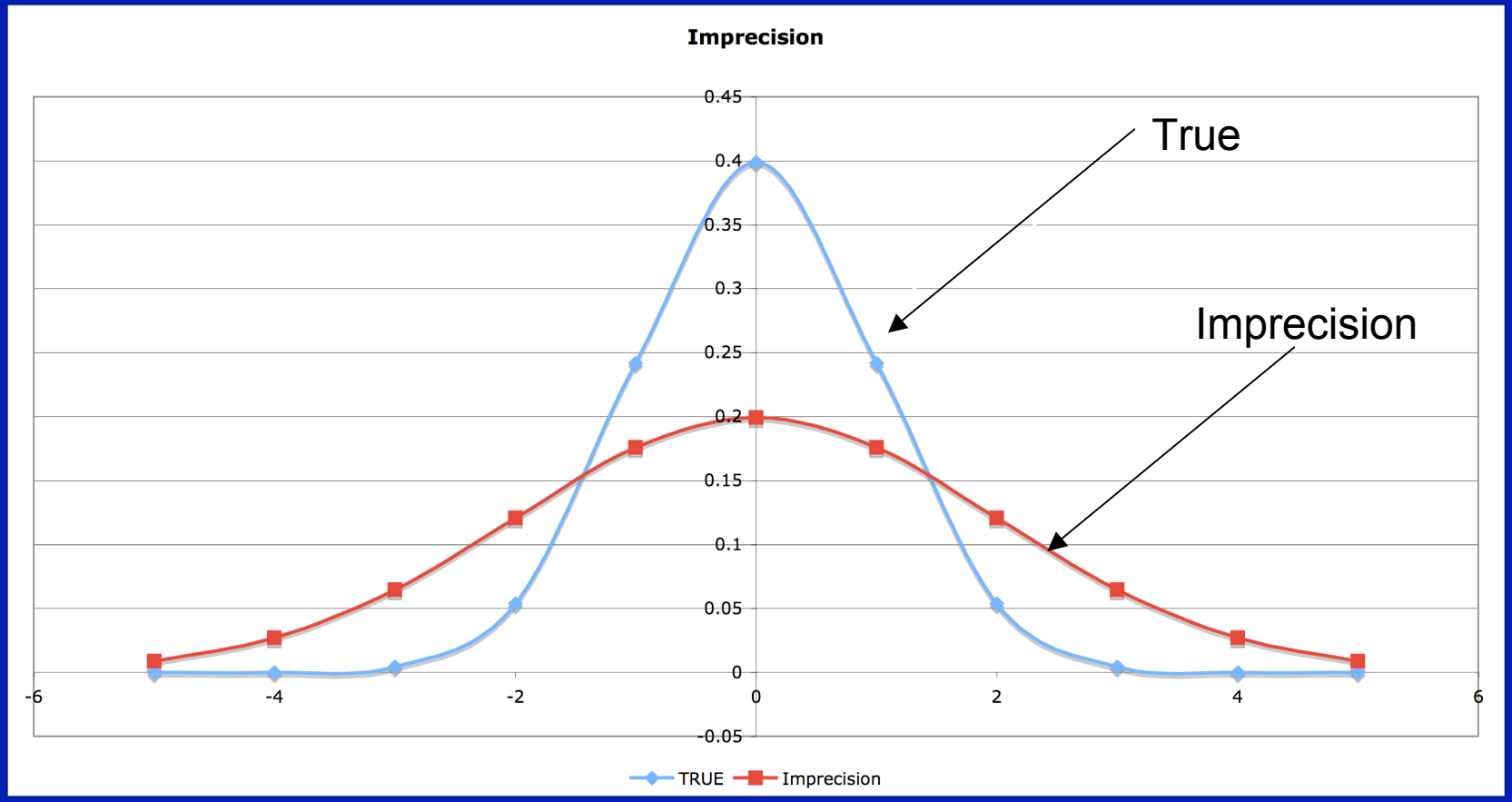
Two Types of Measurement Errors

- Bias: Systematic Error
  - Effects all obsevations equally; Shell height measurements off by a given amount on average
- Imprecision: Random error
  - Shell heights would fall within a given range of +/- mm on average
- Bias easier to correct

Types of Measurement Errors: Bias



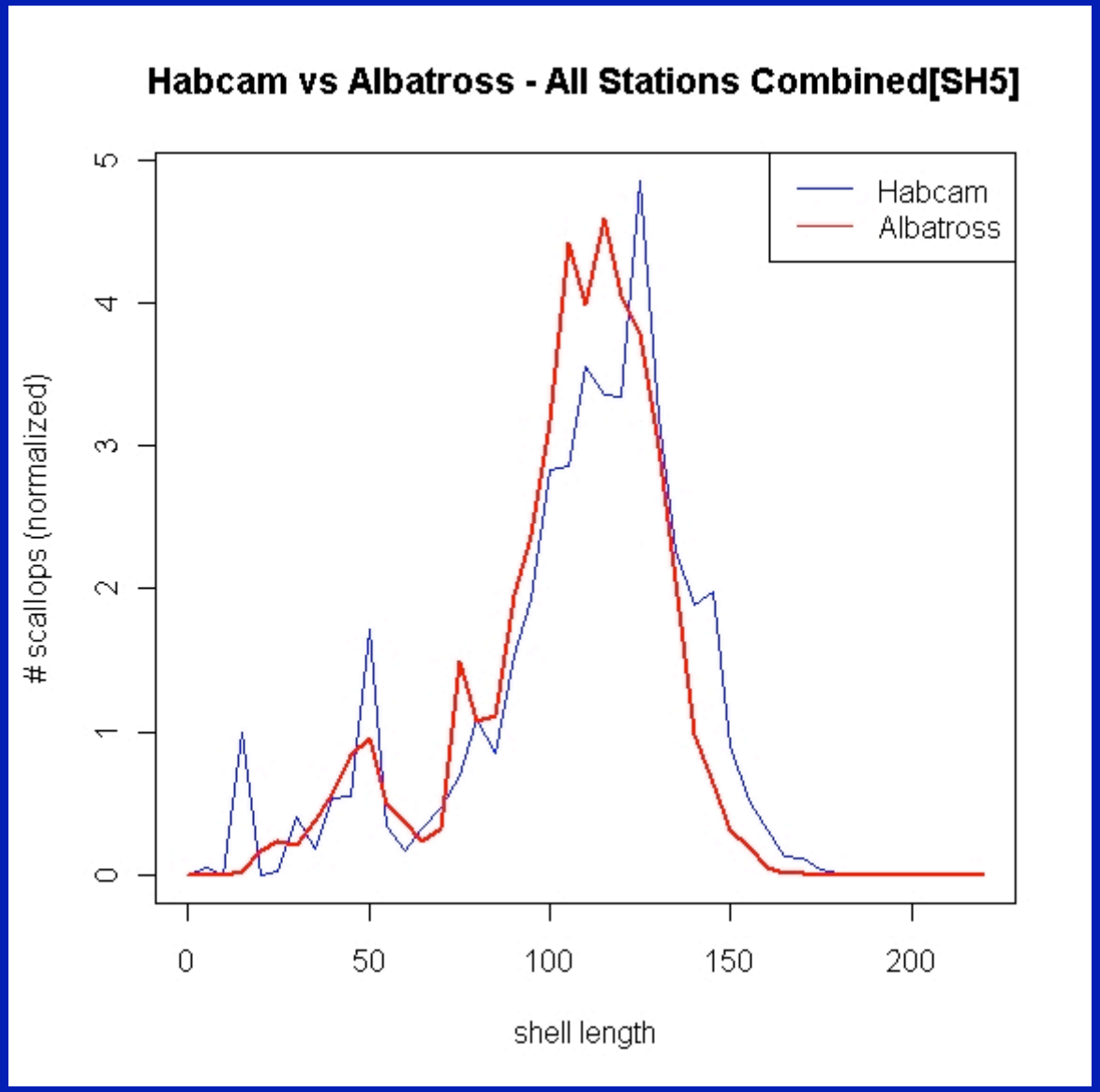
Types of Measurement Errors: Imprecision



Methods

- Overview
  - R (Language and environment for stat computing and graphics)
  - Determine, compare size frequencies for dredge and Habcam to nearest groups of 5mm (SH5)
  - Standardize size frequencies per tow, by total number of scallops
  - Assess for measurement error
  - Determine possible sources of measurement error if it exists

Initial Comparison of Albatross (Dredge) vs Habcam using SH5 size classes combined over all tows


Habcam vs Albatross - All Stations Combined[SH5]
Habcam
Albatross
scallops (normalized)
0
1
2
3
4
5
0
50
100
150
200
shell length

Assess for Measurement Error

Assessment of Measurement Errors - Step 1

How to compare Albatross and Habcam

- Assumption: Dredge survey scallop size measurements are “true values”
- Apply measurement error estimates to dredge size distribution and try to best fit Habcam data
- Easy to add measurement errors; difficult to remove them
- Imprecision: Affects spread of data; Measured by Standard Deviation
- Bias: Affects mean of the data

Assessment of Measurement Errors - Step 2

3 Indices of Goodness of Fit

Observed = Habcam

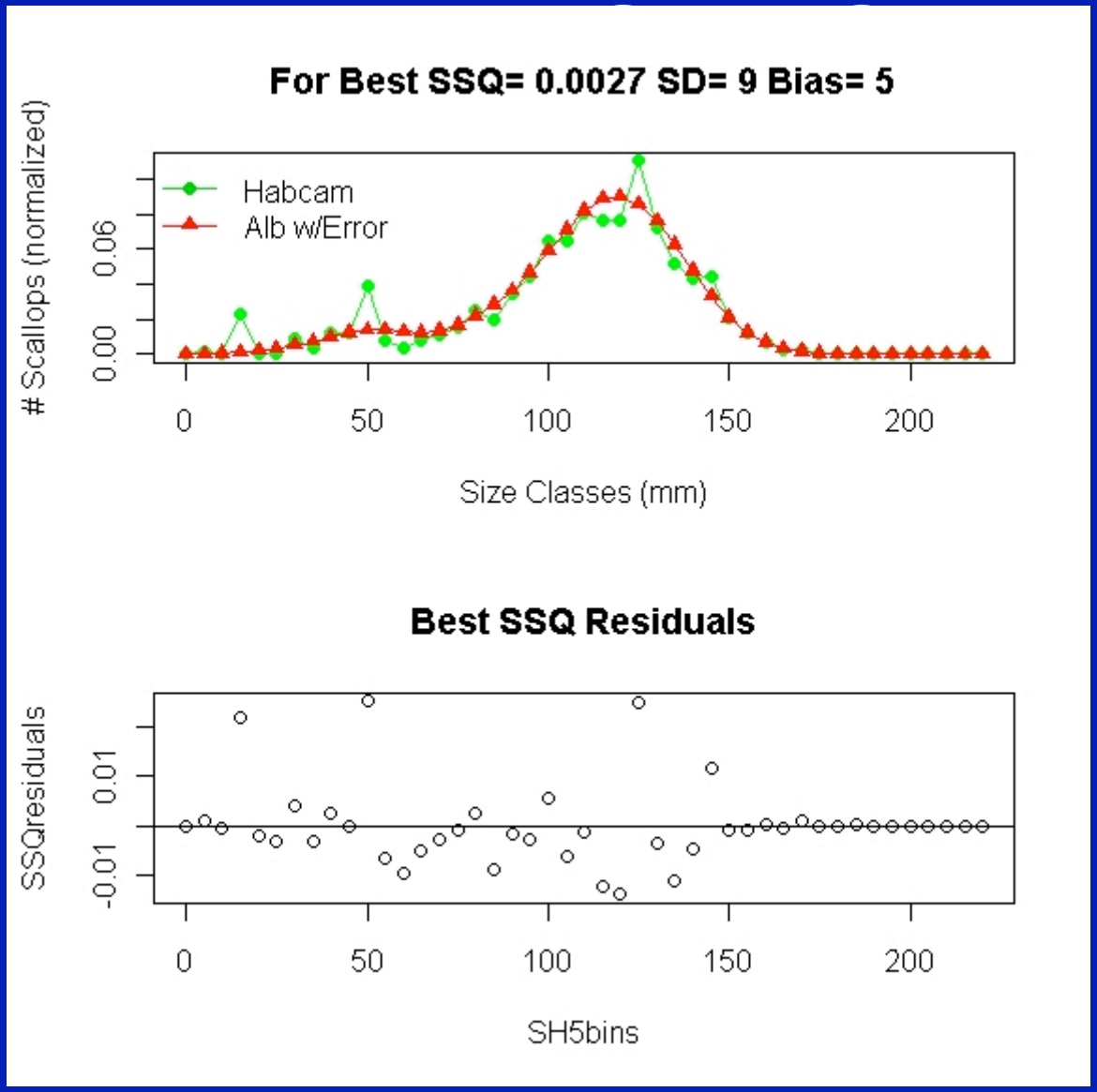
Predicted = Albatross w/Meas Errors Applied

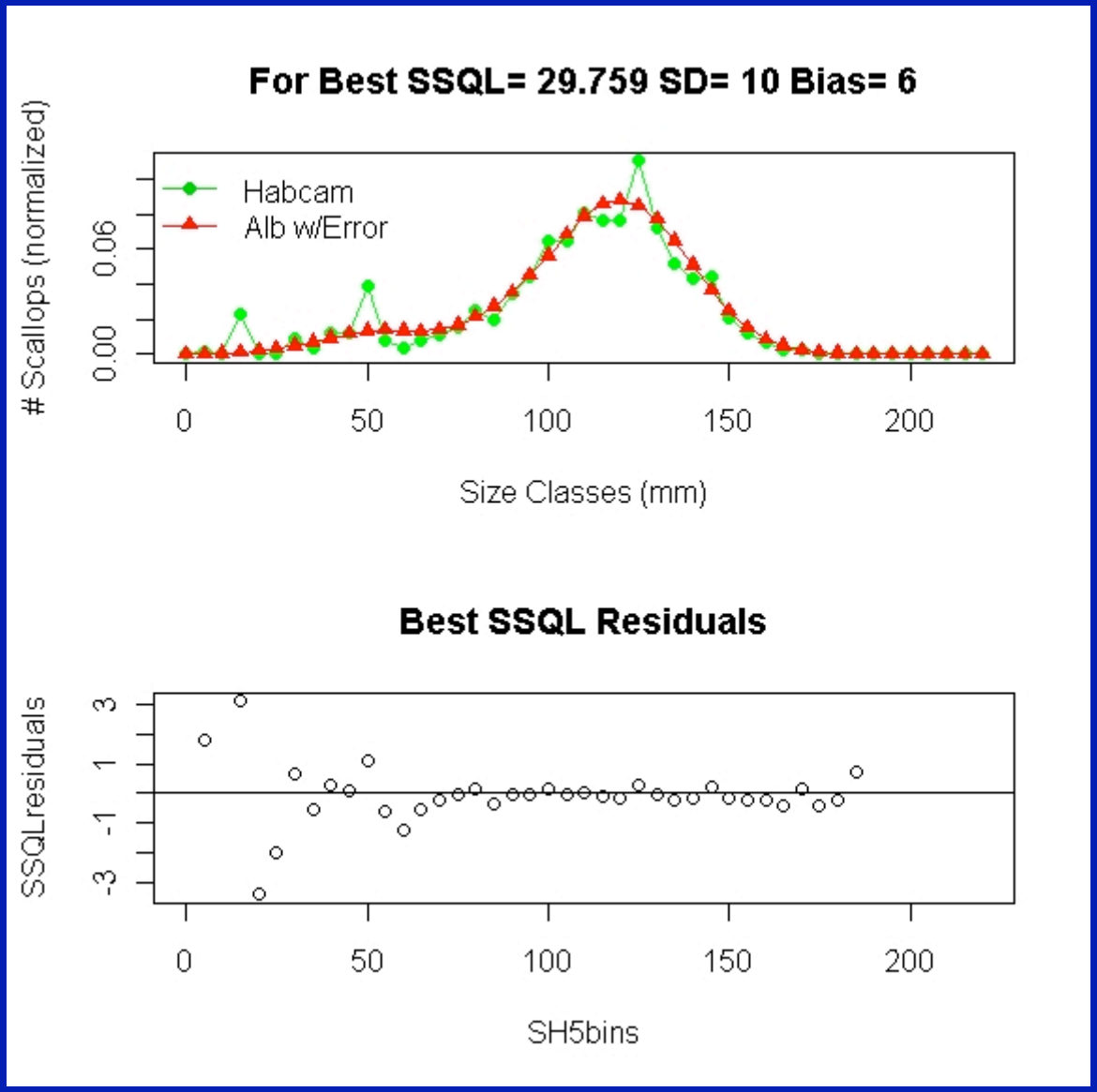
- Sum of Squares (SSQ)
  - (Observed - Predicted)^2
- Sum of Logarithmic Differences (SSQL)
  - (Log[Observed] - Log[Predicted])^2
- Negative Log Likelihood (L)

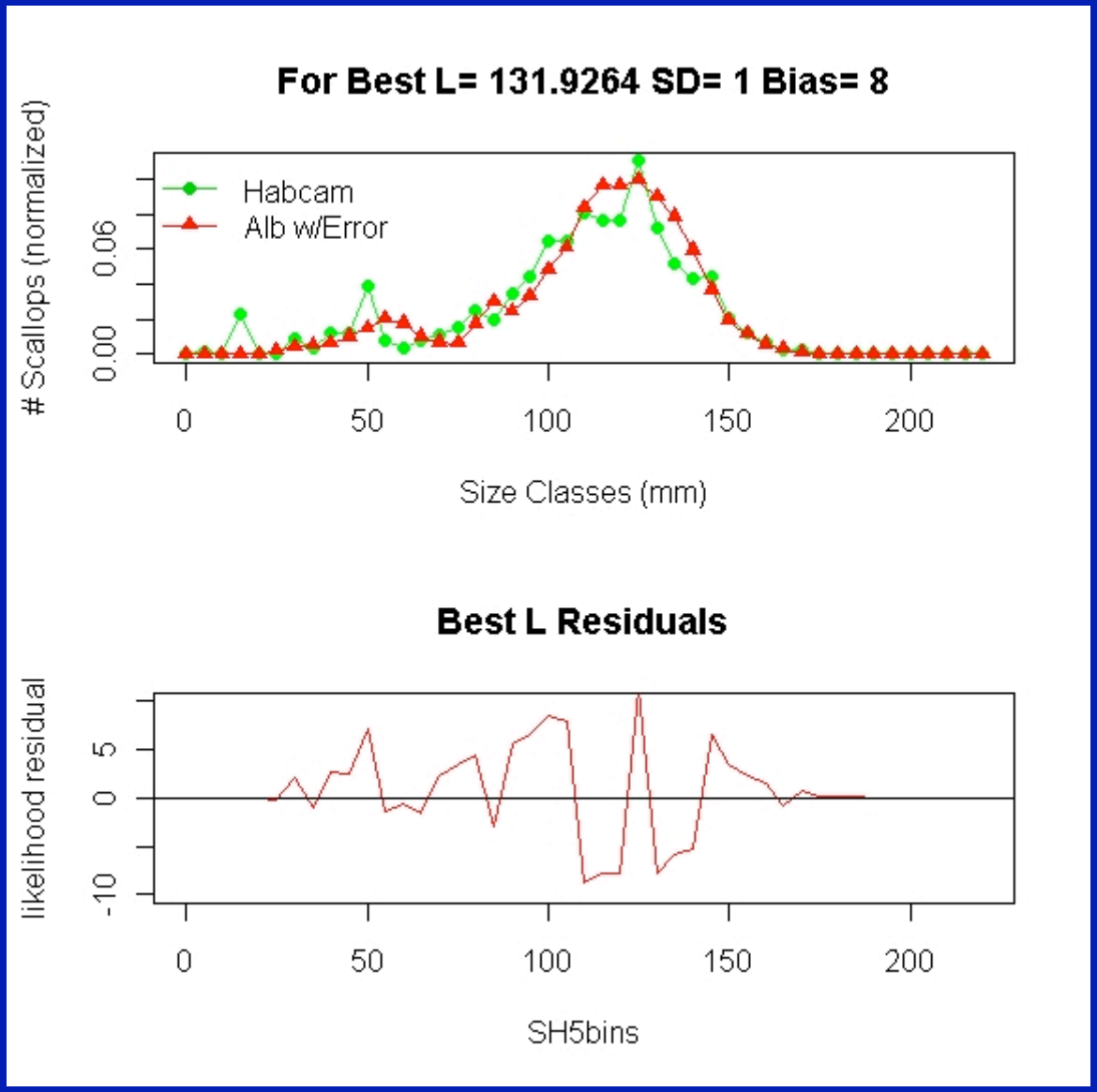
  $= - n * ({}^{z}\sum_{j=1} p_j \ln (\Omega_j))$
  - Symbols (n=# tows; z=# of size classes; p_j = observed proportions (habcam) (j); Ω_j = predicted proportions (Albatross w/ meas error)

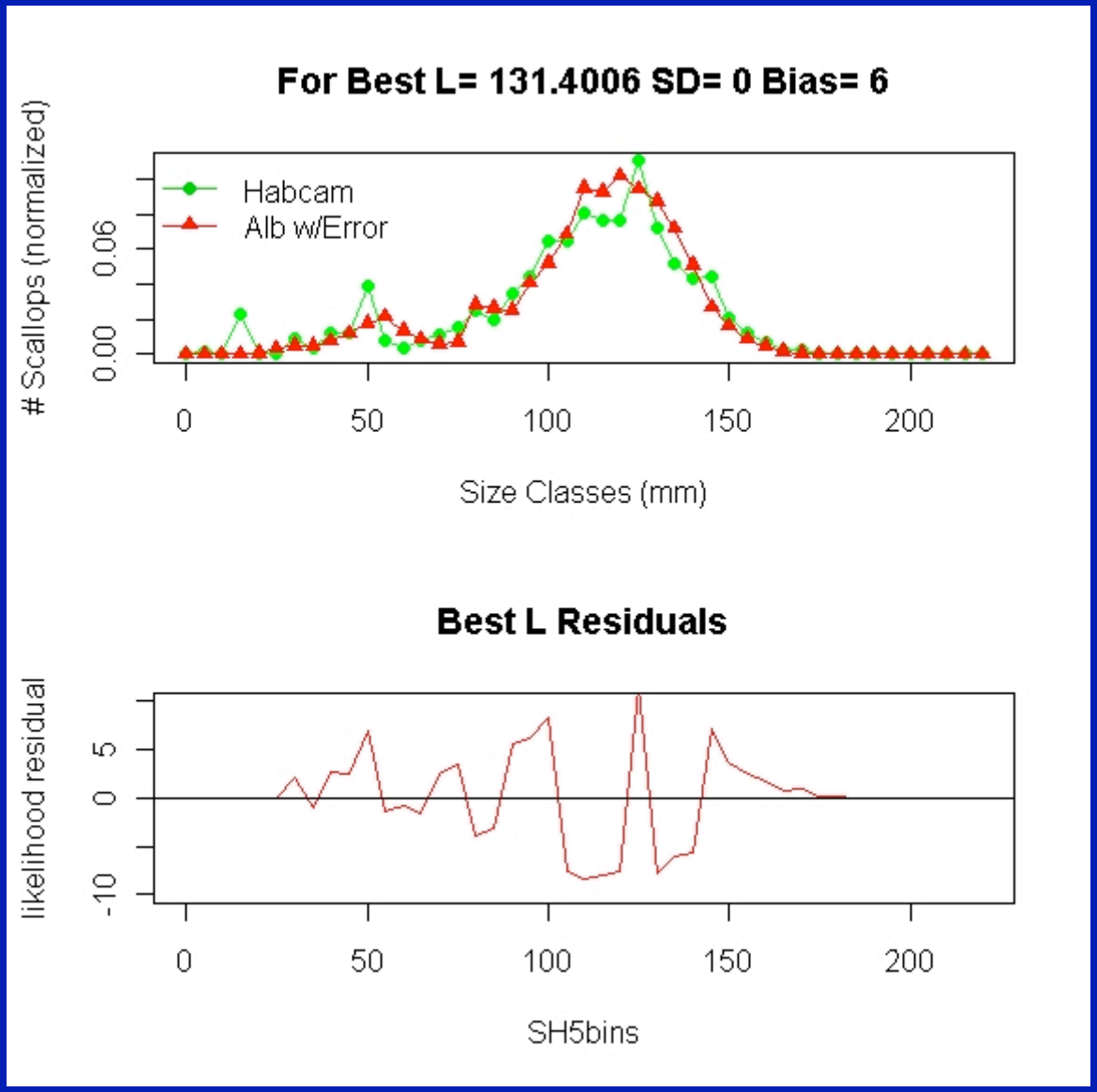
Assessment of Measurement Errors - Step 3

- Apply different combinations of standard deviation (imprecision) and bias to minimize SSQ, SSQL, L
  - SD: 0 - 15 (+/- 15 mm)
  - Bias: -10 to 10 (range of 20 mm)
- Minimize SSQ, SSQL, L
- Review the residuals of SSQ, SSQL, L by size class


For Best SSQ= 0.0027 SD= 9 Bias= 5
Scallops (normalized)
0.00
0.06
Habcam
Alb w/Error
0
50
100
150
200
Size Classes (mm)
Best SSQ Residuals
SSQresiduals
-0.01
0.01
0
50
100
150
200
SH5bins


For Best SSQL= 29.759 SD= 10 Bias= 6
Scallops (normalized)
0.00
0.06
Habcam
Alb w/Error
0
50
100
150
200
Size Classes (mm)
Best SSQL Residuals
SSQLresiduals
-3
-1
1
3
0
50
100
150
200
SH5bins


For Best L= 131.9264 SD= 1 Bias= 8
Scallops (normalized)
0.00
0.06
Habcam
Alb w/Error
0
50
100
150
200
Size Classes (mm)
Best L Residuals
likelihood residual
-10
0
5
0
50
100
150
200
SH5bins


For Best L= 131.4006 SD= 0 Bias= 6
Scallops (normalized)
0.00
0.06
Habcam
Alb w/Error
0
50
100
150
200
Size Classes (mm)
Best L Residuals
likelihood residual
-10
0
5
0
50
100
150
200
SH5bins

Preliminary Summary of Error Analysis

	Minimum Value	Standard Deviation	Bias
SSQ	.0027	9	5
SSQL	29.76	10	6
L - Best	131.40	0	6
L- Alternative	131.9	1	8

The possible range of parameters to describe measurement errors over a normal distribution is then

- Imprecision:
  - Either High (+/- 9 -10 mm)
  - Or Low (+/- 0-1 mm)
- Bias
  - Range: [5 -8 mm]

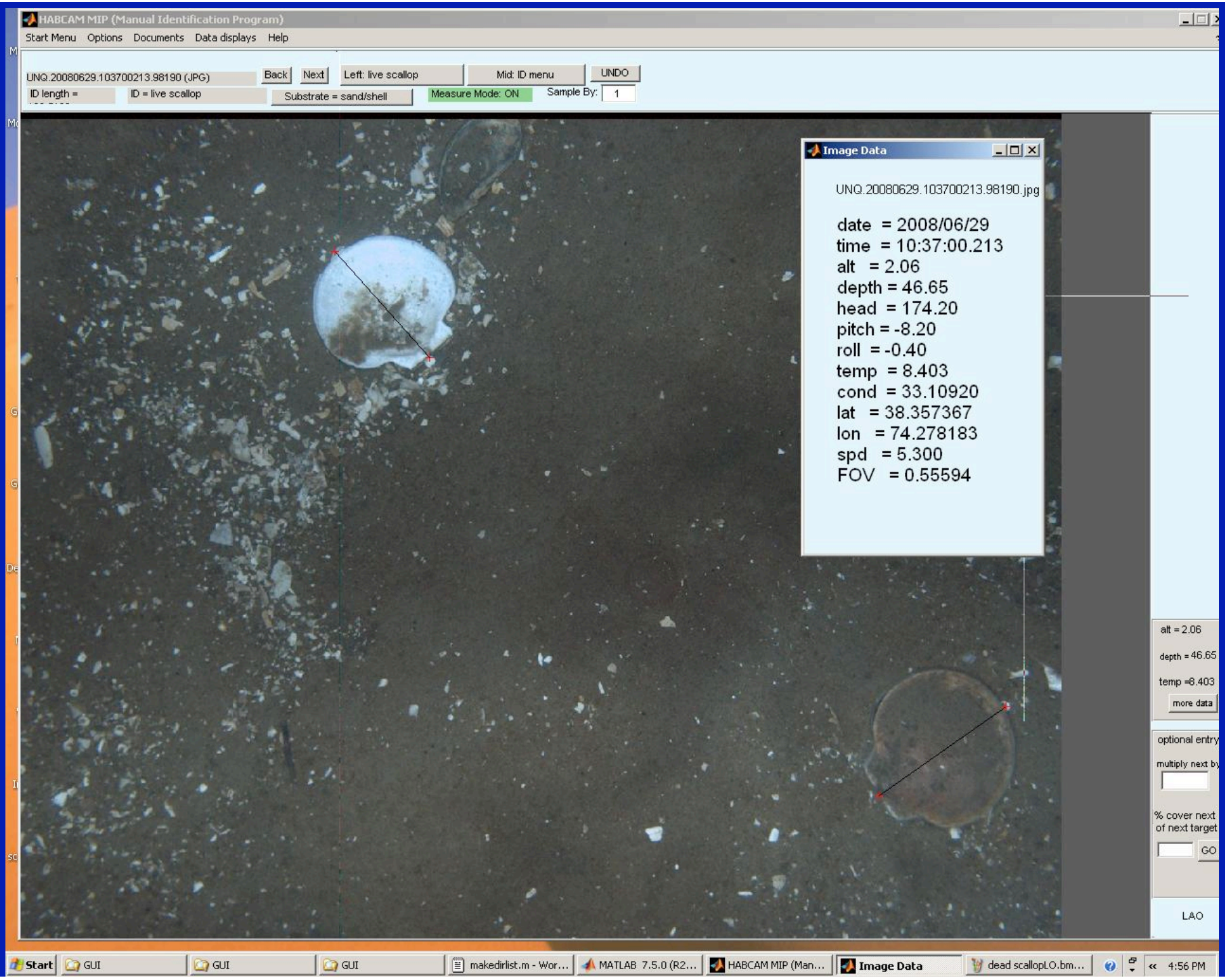
What can we say then about measurement error?

- Estimates for bias and variance are correlated if there are good fits to a wide range of parameter values
  - The data are unclear on this point
- L provides an interesting perspective (no variance, high bias) but results seems surprising
- Differences between the answers probably results from how well we fit the low proportions which have low expected variance in the L-based solution

If Measurement Error exists in Habcam, what could be the source?

Possible Sources of Measurement Error

- Scallop size only a function of altitude
- Sensitivity of size measurements to pixel variations is unknown
  - Could lead to up to 3 mm measurement error, though it may vary by altitude
- Scallops at angles on bottom


HABCAM MIP (Manual Identification Program)
Start Menu
Options
Documents
Data displays
Help
UNQ.20080629.103700213.98190 (JPG)
Back
Next
Left: live scallop
Mid: ID menu
UNDO
ID length =
ID = live scallop
Substrate = sand/shell
Measure Mode: ON
Sample By:
1
Image Data
UNQ.20080629.103700213.98190.jpg
date = 2008/06/29
time = 10:37:00.213
alt = 2.06
depth = 46.65
head = 174.20
pitch = -8.20
roll = -0.40
temp = 8.403
cond = 33.10920
lat = 38.357367
lon = 74.278183
spd = 5.300
FOV = 0.55594
alt = 2.06
depth = 46.65
temp =8.403
more data
optional entry
multiply next by
% cover next
of next target
GO
LAO
Start
GUI
GUI
GUI
makedirlist.m - Wor...
MATLAB 7.5.0 (R2...
HABCAM MIP (Man...
Image Data
dead scallopLO.bm...
4:56 PM

So, can an Optical Survey Replace the Dredge Survey?

- Not by itself
- BUT, the combination of a dredge and optical survey would obtain the best possible information on scallop populations
- Combined surveys would:
  - Maintain historical dredge survey time series
  - Obtain relative and absolute abundance estimates
  - Biological sampling
  - Ecosystem information and Interactions
  - Reduce bottom damage

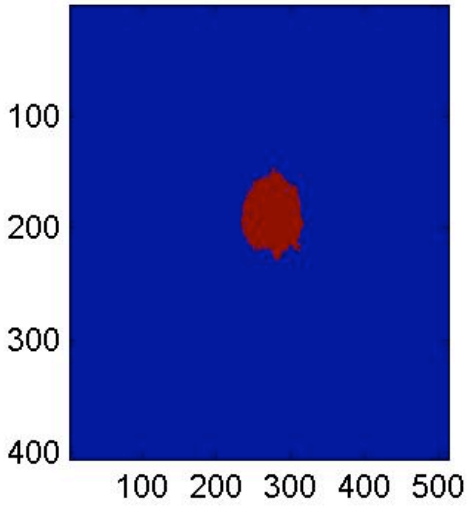
Conclusions

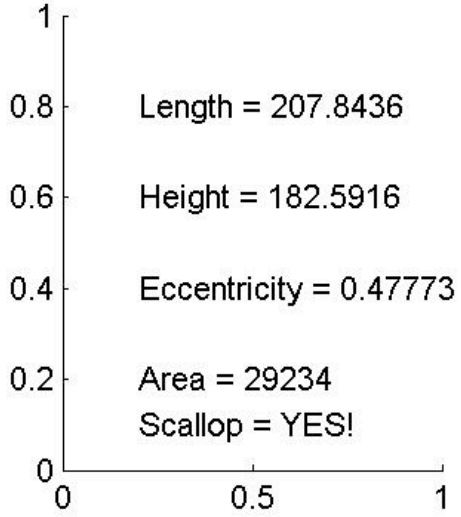
- Scallop Surveys of the future
- A unique combination of dredge and optical survey methods that:
  - Maximizes information on scallop populations
  - Provide ecosystem information (e.g., scallops, habitats, other species of interest)
  - Minimizes fiscal costs

Ongoing work with Habcam also includes

- New stereo imaging system being developed would reduce potential measurement errors
- Automated image classification
- **Combination of Habcam with sidescan and multibeam sonar**
- **More calibration work**

Automated image classification





Acknowledgements

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  - Toni Chute
  - Liz Brooks
  - Colleen Close
  - NRAP Program
- WHOI
  - Scott Gallagher
  - Richard Taylor
  - Amber York
  - Norman Vine
  - Munroe Tyler
- Crew of Kathy-Marie
  - (Paul, Jerry, Tony, Donald)

More info at website: http://habcam.whoi.edu

Appendix Slides

Comparison Set 1

Dredge Surveys

	Albatross	Sharp	Habcam	SMAST
Platform	NOAA Vessel	UNOL vessel	Commercial vessel	Commercial Vessel
Survey Gear	New Bedford Dredge (2.44 m w; 5.1 cm rings, 3.8 cm liner)	Same as Albatross with some modifications	High resolution video camera, towed by vessel	3 streaming video cameras and 1 high-res digital still camera
Station Selection	Stratified Random sampling	Stratified Random Sampling	Cont. imaging system	Systematic Grid
Sampling Method	Dredge tows (Each 15 min @ 3.8 knots over ~ 4500 m^2)	Same as Albatross	Transects (e.g., line, pinwheel); Best design is up for question	4 quadrats (3.2 m^2 each) per station

Comparison Set 2

Dredge Surveys

	Albatross	Sharp	Habcam	SMAST
Stations or Area Sampled Per survey	Over 500 stations; Survey area= 17,000 NM, Sample area is >2.25Million m^2	Same as Albatross	TBD; Habcam can cover 2x area /day that Dredge survey can sample	~1850 stations (23K m^2)
Tow Analysis	5 people, 30-60 minutes to count/measure 1 tow on ave	Same as Albatross	Depends on decimation, # of scallops; Range: 1-10 hrs/person/tow. If count 1/100 image, likely 1-2 hrs.	1 person; 2 min/quad (8 min/stn)
Survey DAS	~ 30/summer	32- 36/ summer	Unclear; Estimate 16-24 days	54 days (9 6-day cruises)*
Post cruise data analysis	3-4 wks (2-4 staff) for QA/QC	Same as Albatross	TBD; Tow analysis (above) and QA/QC	47 days; During field collection

Comparison Set 3

Dredge Surveys

	Albatross	Sharp	Habcam	SMAST
Boat Crew	18	8	4	2
Science Personnel	12-14	12-14	2-4	2
Cost/day of boat and crew only	$15-20K	$13K	$8K	$0; boat, crew, time, etc- donated by scallop fishing fleet, industries
Cost/day of Science Personnel	$6K	$6K	$2.4K	$346
Cost/day supplies	$1.5-2K	$1.5-2K	Unknown	~$30-45K/year*

Comparison Set 4

Dredge Surveys

	Albatross	Sharp	Habcam	SMAST
Purpose	Scallop Biomass estimate	Scallop Biomass estimate	Small scale surveys & investigations; R&D; Potential for widespread scallop biomass estimate	Scallop Biomass Estimate
Image Collection	N/A	N/A	4 images/sec	32 images/hour (8 images/hr, 4 cameras)
Image Capacity	N/A	N/A	2006 Alone: 2.2 Million images over 672 Nautical Miles in 163 hours	1998-2008: Examined 245,916 quadrats (video); 31,535 images of seafloor along 60,000 km^2 shelf

Comparison Overview

	Dredge	Habcam	SMAST
Unique Capabilities	▪ Sampling History ▪Minimal Measurement Error ▪Bio Sampling (e.g., weights, shells for age/growth) ▪Stratified Random Sampling significant; Adaptive sampling	▪In -situ ▪Absolute abundance ▪Non-invasive ▪Cooperative Research ▪Provides ecosystem info (e.g., habitats, other spp.) ▪Images high resolution ▪Low operating cost ▪Sample greatest area in least amt of time	▪In situ ▪Absolute abundance ▪Non-invasive ▪Coop. Research ▪Ecosystem info ▪Technologically simple ▪Adaptable survey design ▪Real time estimate ▪Inexpensive
Drawbacks	▪Labor Intensive ▪High Cost ▪Relative index of abundance only ▪Dredge efficiency uncertain ▪Habitat damage	▪Lacks bio sampling ▪ Measurement Error ▪Add. Time required for tow analysis ▪Appropriate survey design not understood ▪High capital investment	▪Lacks bio sampling ▪Measurement Error, but less due to fixed camera position ▪Lower res. images ▪Covers smaller sampling area ▪Weather, turbidity dependent