Essential Fish Habitat Mapping, Habitat Suitability Modeling and the CMECS standard

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NOAA Definition: Essential Fish Habitat describes all waters and substrate necessary for fish for spawning, breeding, feeding, and growth to maturity.

Our Definition: EFH is the agglomeration of all biological, geological, chemical, and physical attributes that allow a given species or species assemblage to thrive.

What do we use habitat mapping for?

1. Benthic habitat characterization/system change
   (Northeast Bentho-pelagic Observatory)

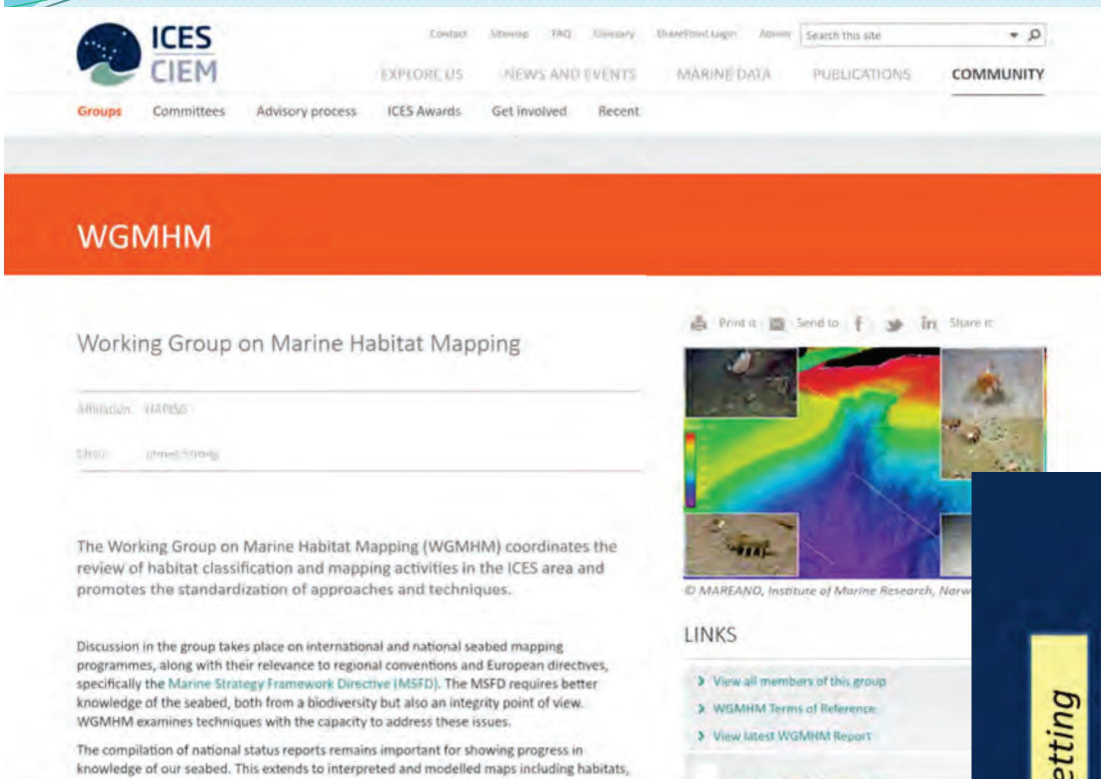
2. Scallop surveys (NOAA, RSA)

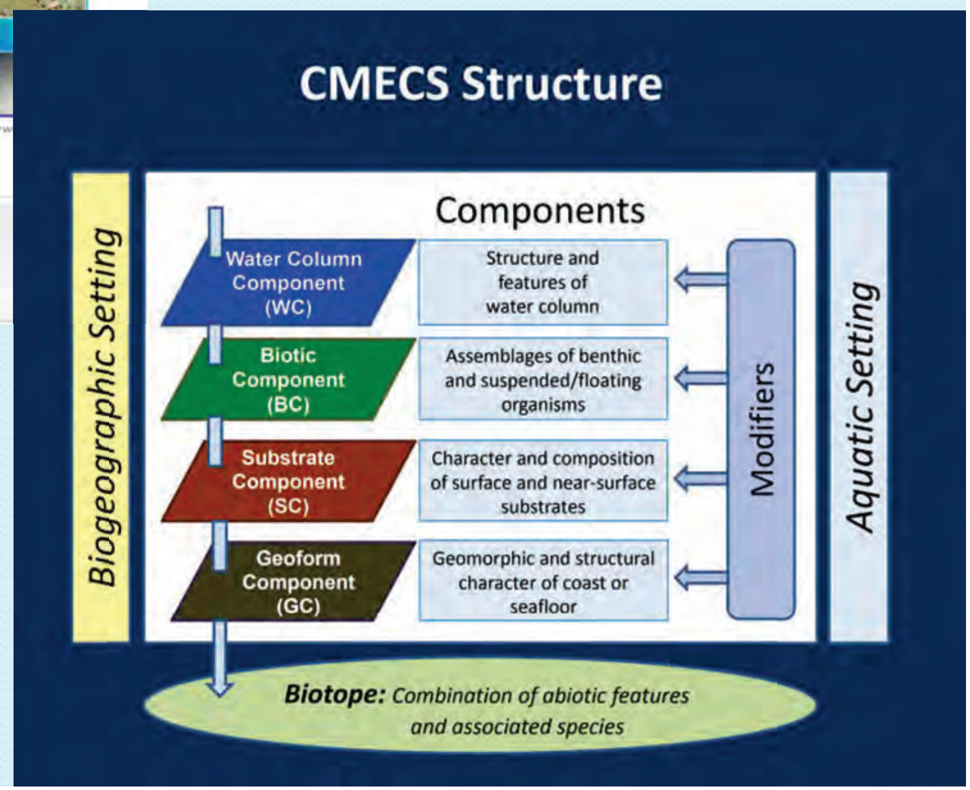
3. Before, After, Impact (BACI) of dredging on EFH

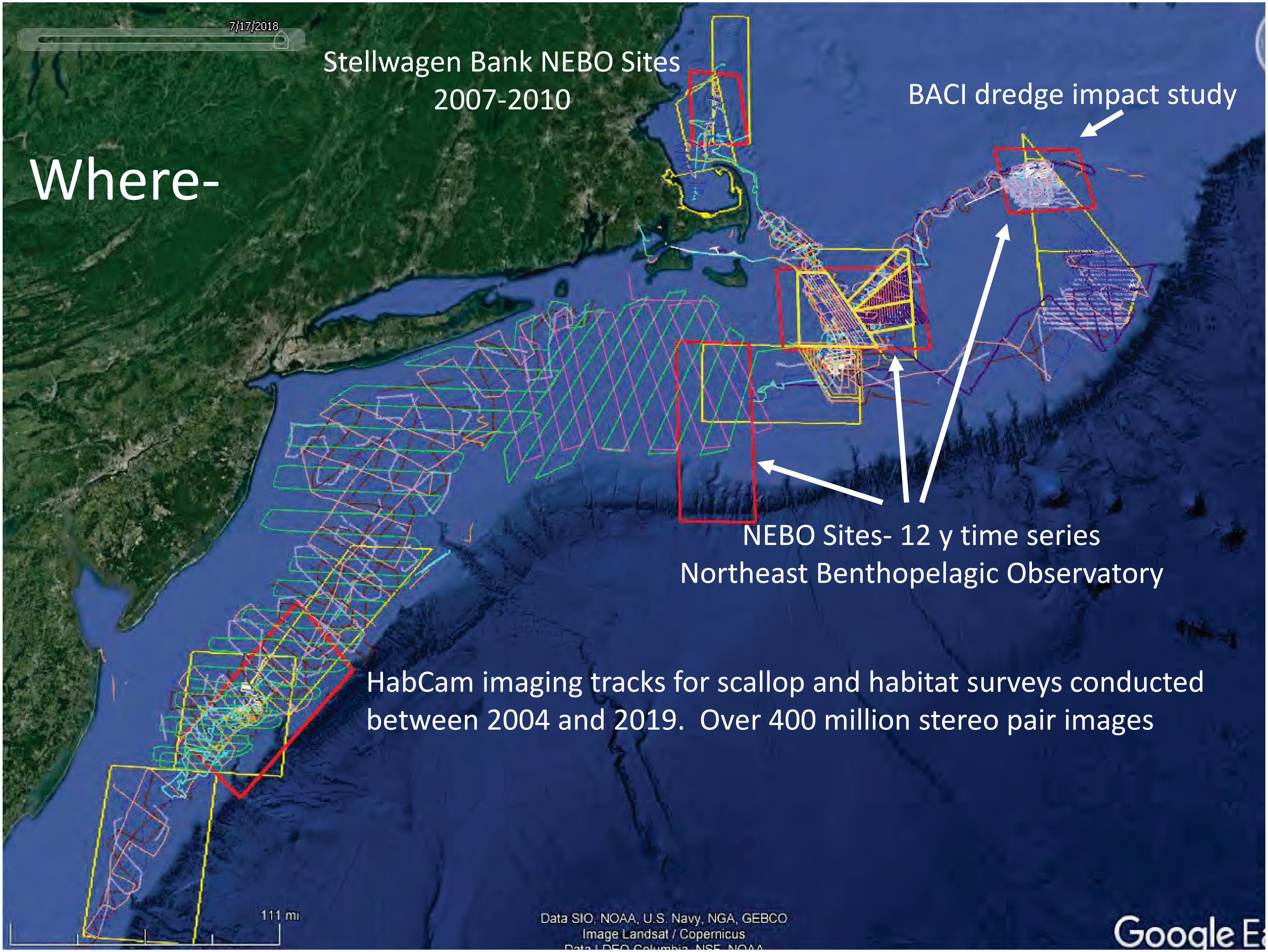
4. Marine debris assessment

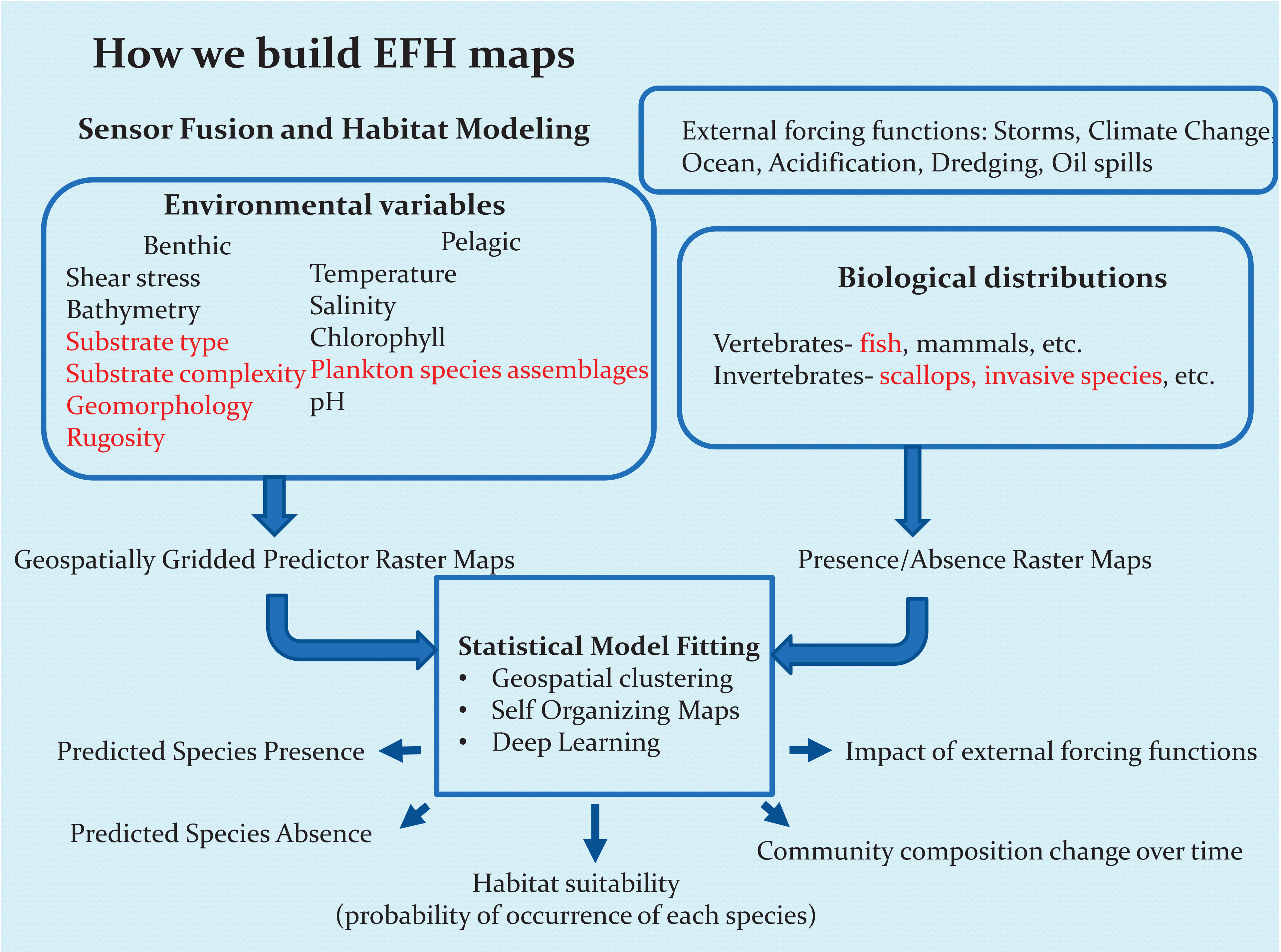
5. Offshore wind farm siting and monitoring
   (Cape Wind)

Crosswalking the ICES Marine Habitat Mapping (WGMHM) and CMECS schema

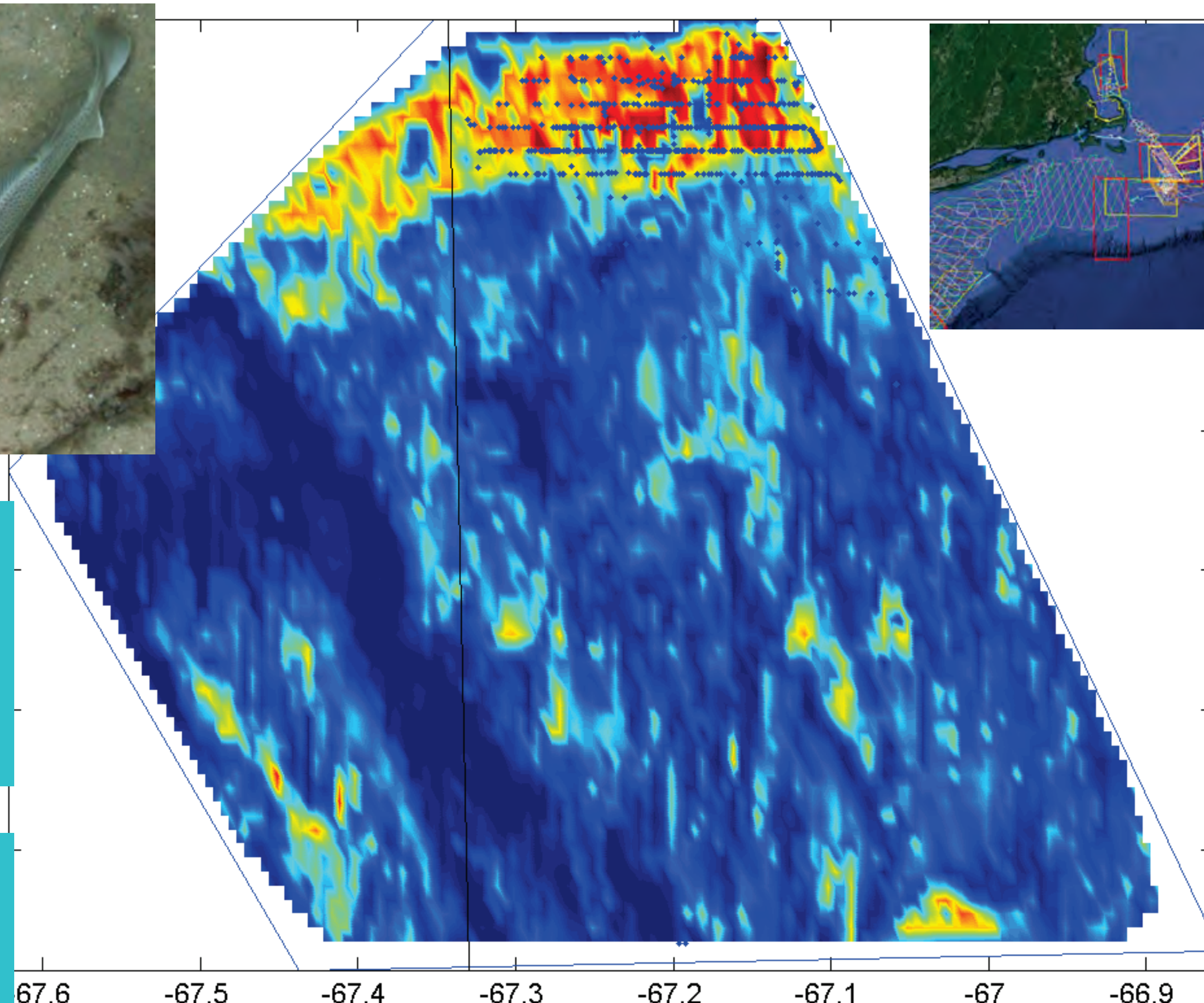





7/17/2018
Stellwagen Bank NEBO Sites
2007-2010
BACI dredge impact study
Where-
NEBO Sites- 12 y time series
Northeast Benthopelagic Observatory
HabCam imaging tracks for scallop and habitat surveys conducted between 2004 and 2019. Over 400 million stereo pair images
111 mi
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Google Ea


How we build EFH maps
Sensor Fusion and Habitat Modeling
External forcing functions: Storms, Climate Change, Ocean, Acidification, Dredging, Oil spills
Environmental variables
Benthic
Shear stress
Bathymetry
Substrate type
Substrate complexity
Geomorphology
Rugosity
Pelagic
Temperature
Salinity
Chlorophyll
Plankton species assemblages
pH
Biological distributions
Vertebrates- fish, mammals, etc.
Invertebrates- scallops, invasive species, etc.
Geospatially Gridded Predictor Raster Maps
Presence/Absence Raster Maps
Statistical Model Fitting
• Geospatial clustering
• Self Organizing Maps
• Deep Learning
Predicted Species Presence
Impact of external forcing functions
Predicted Species Absence
Community composition change over time
Habitat suitability
(probability of occurrence of each species)

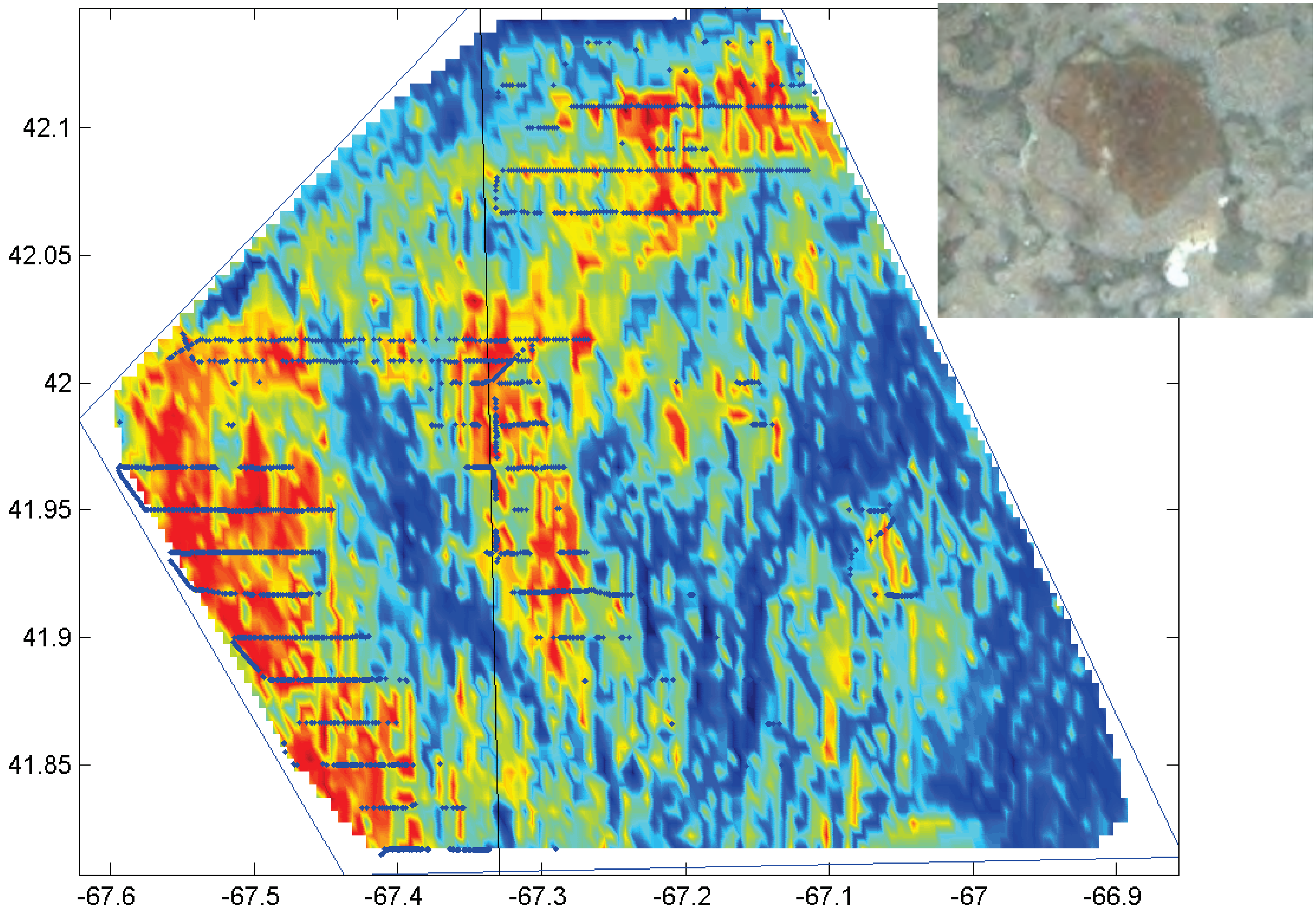
2-D Model Output: Predicted Habitat for Adult Cod and Haddock



Overlay Presence/absence observations on predictor layers

Color scale 0 to 1: probability of occurrence

Predicted Habitat for *Didemnum vexillum:* Northern Georges Bank



Sampling Design and Execution

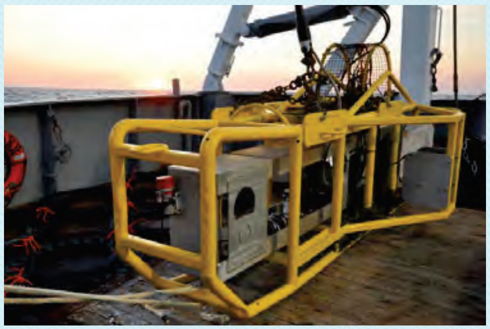
Three examples using HabCam imaging platforms:

- BACI experiment
- Scallop Survey
- NEBO

Associated Error Analysis:

- Manual annotation
- Sufficient sampling

HabCam Instrumentation



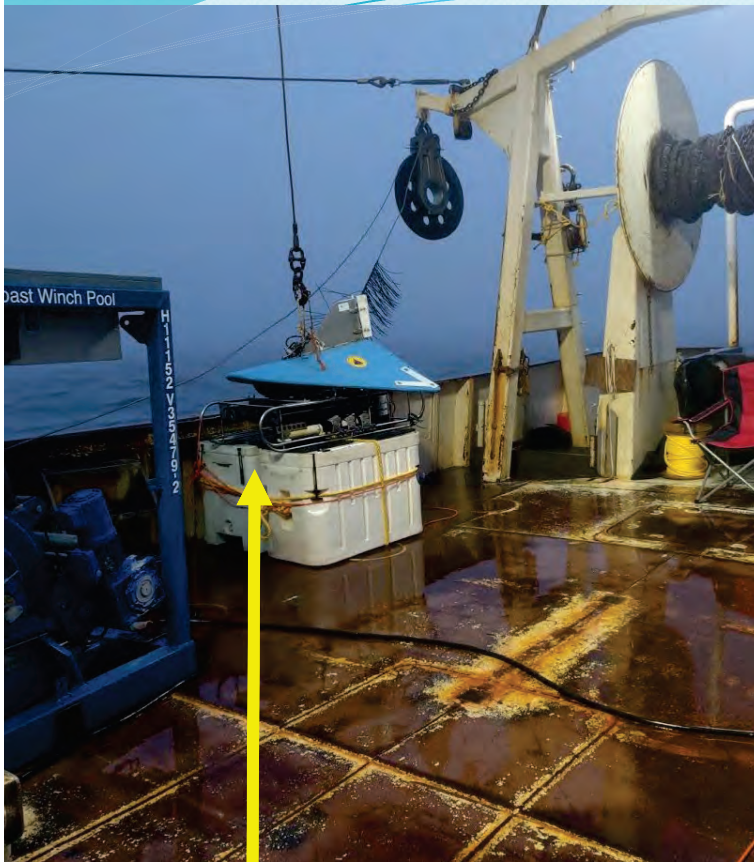
HabCamV2- 2004 (15 yr)

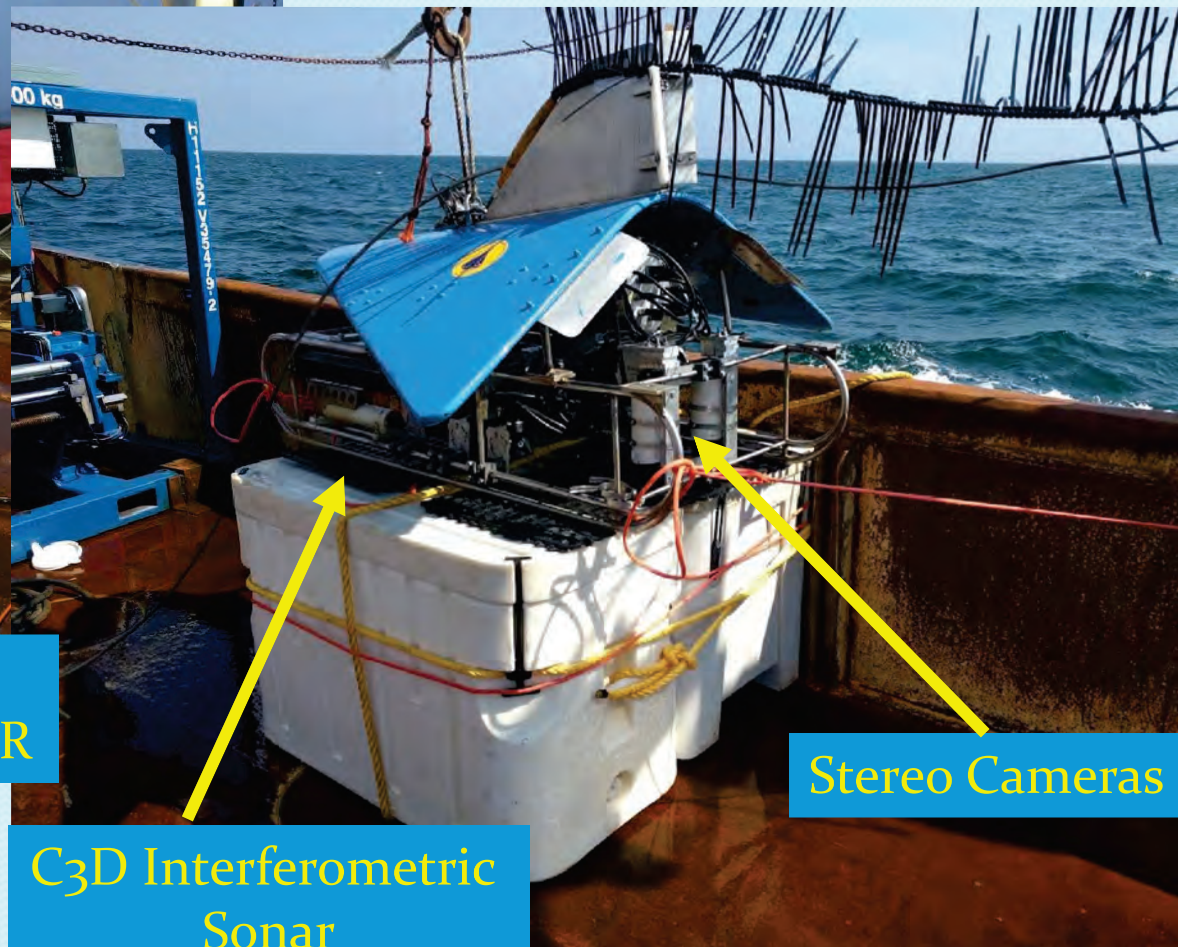
HARIM- 2017 (2 yr)

HabCamV4- 2012 (7 yr)

HabCamV5- 2016 (3 yr)

HabCamV5
V-fin



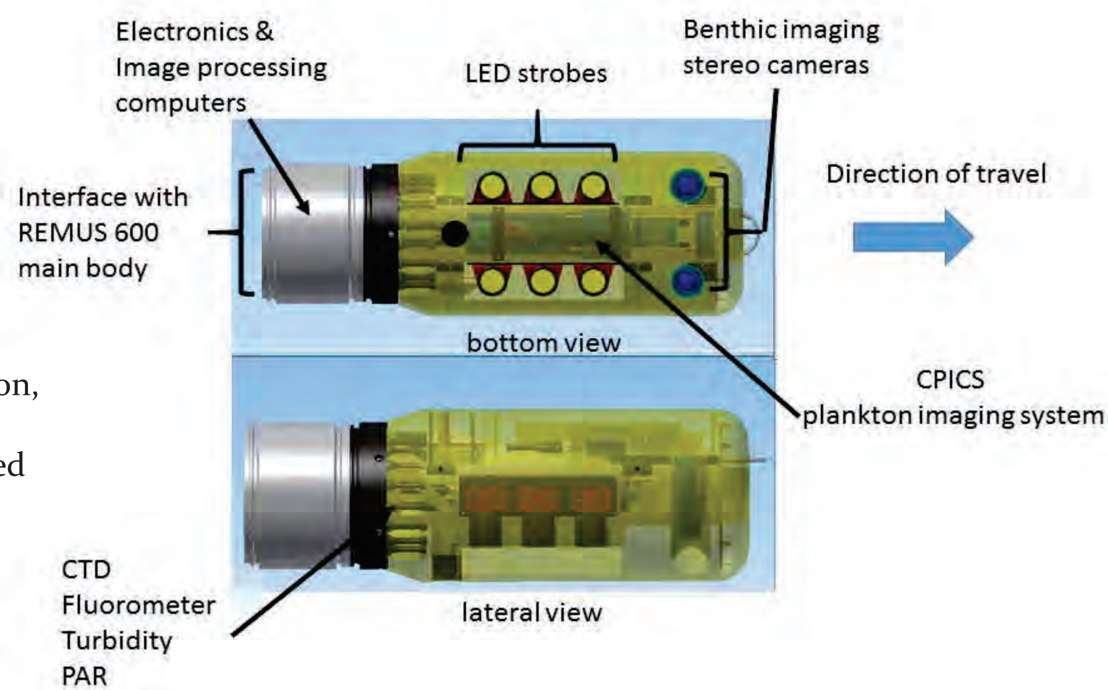


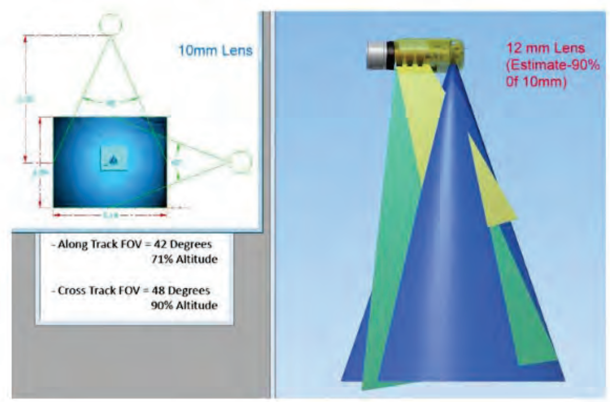
Habitat Aware Reconnaissance and Imaging Module (HARIM)

Specifications
- Vehicle: REMUS 600

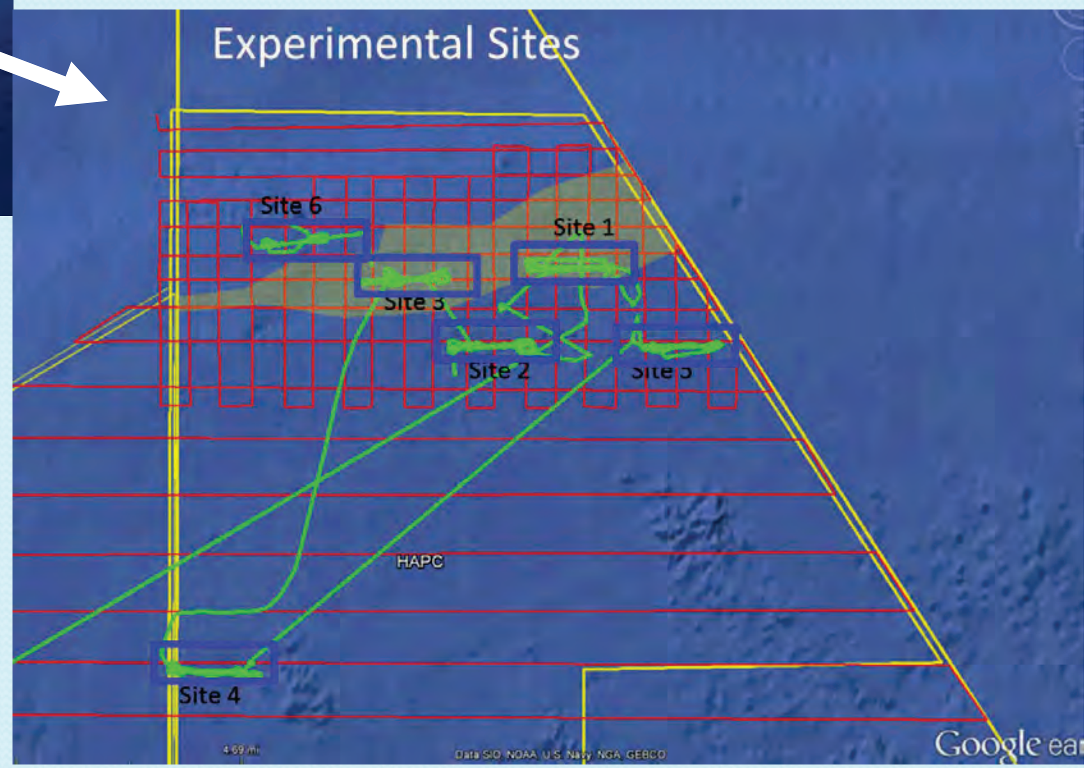
Sensors
- Stereo PT Grey 6 Mpixel cameras, 12mm lenses
- TX2 GPU processor
- CTD, Chlorophyll, turbidity
- Sidescan
- Plankton imaging and classification (CPICS)

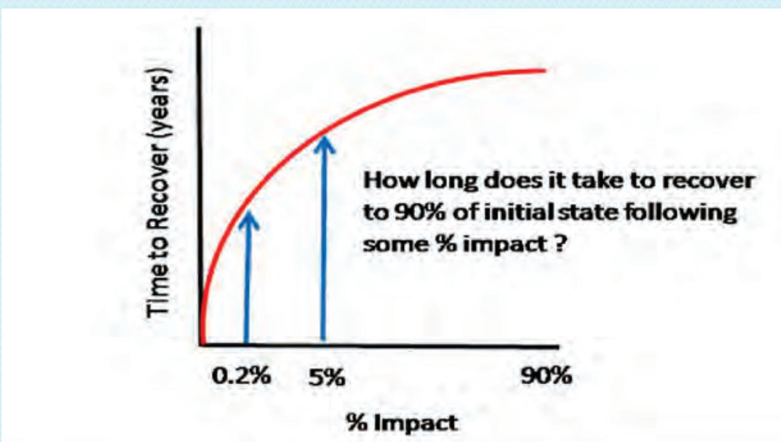
Capabilities
- On-board stereo imaging, light-field and color correction, rectification, point cloud production, and target segmentation
- Benthic target acquisition using sidescan followed by classification using stereo imaging
- On-board plankton classification
- Habitat characterization, spatial analysis, dynamic spatial sampling based on habitat type
- 10 hour deployments up to 600m depth in 3 kt current



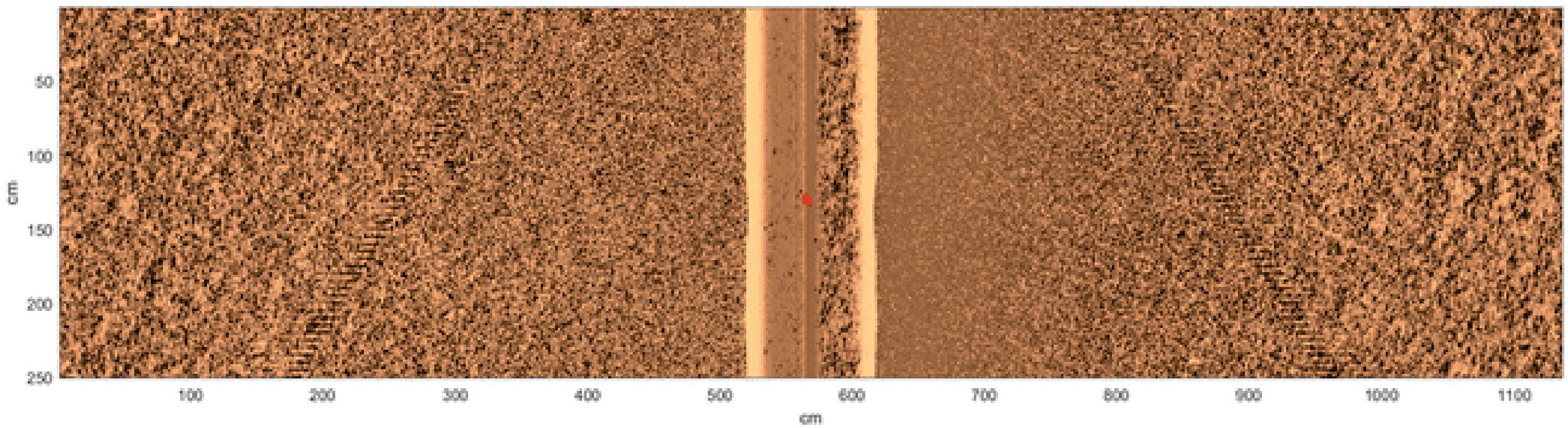


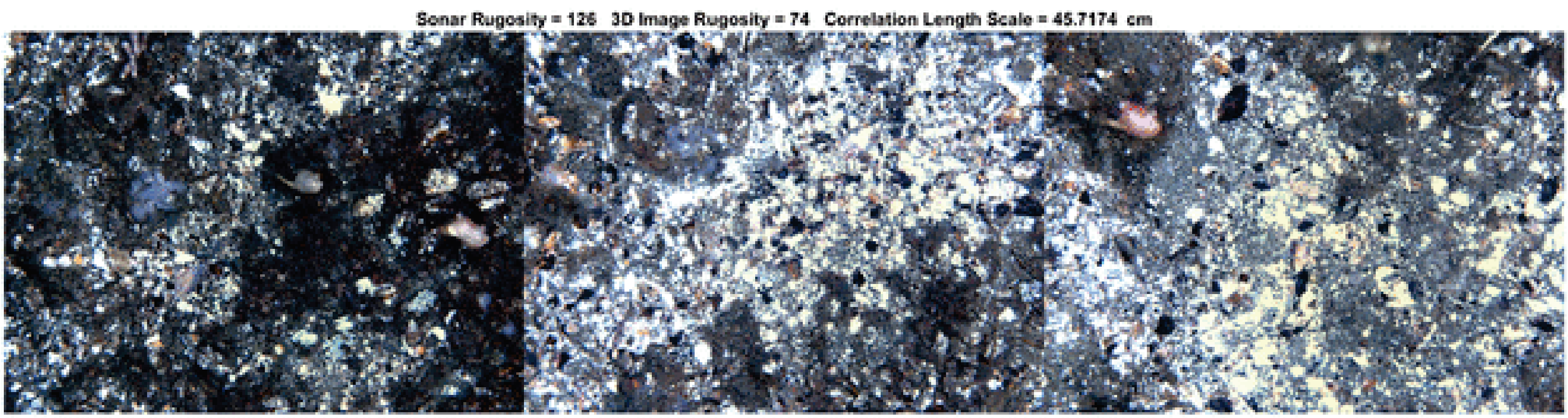
BACI- Georges Bank Closed Area II
Habitat Area of Particular Concern (HAPC)





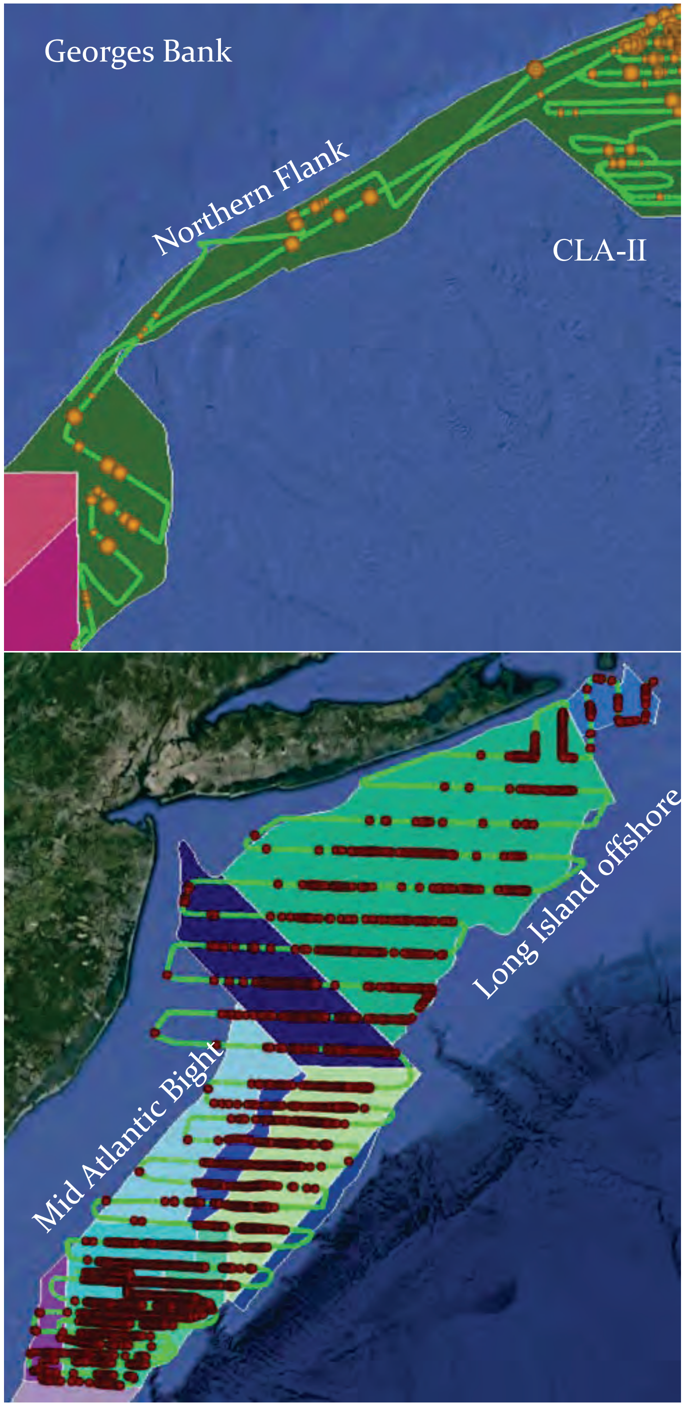
Georges Bank Closed Area II HAPC central section





Scallop Survey Data Operations

- All images collected were processed for light field, color, and stereo rectification in real-time at sea,
- ~50% images collected for annotation were annotated at sea at three annotation stations,
- Remaining images annotated in lab,
- Scallop heights binned at 5 mm intervals for frequency distributions,
- Biomass calculated using SARC 65 equations for Georges Bank and Mid Atlantic Bight, separately,
- Abundance (#/m^2), total number of scallops by sizes and SAMS area, and biomass (MT/area) were kriged using depth as a covariate,
- SAMS areas were used to bound the krig interpolation model.

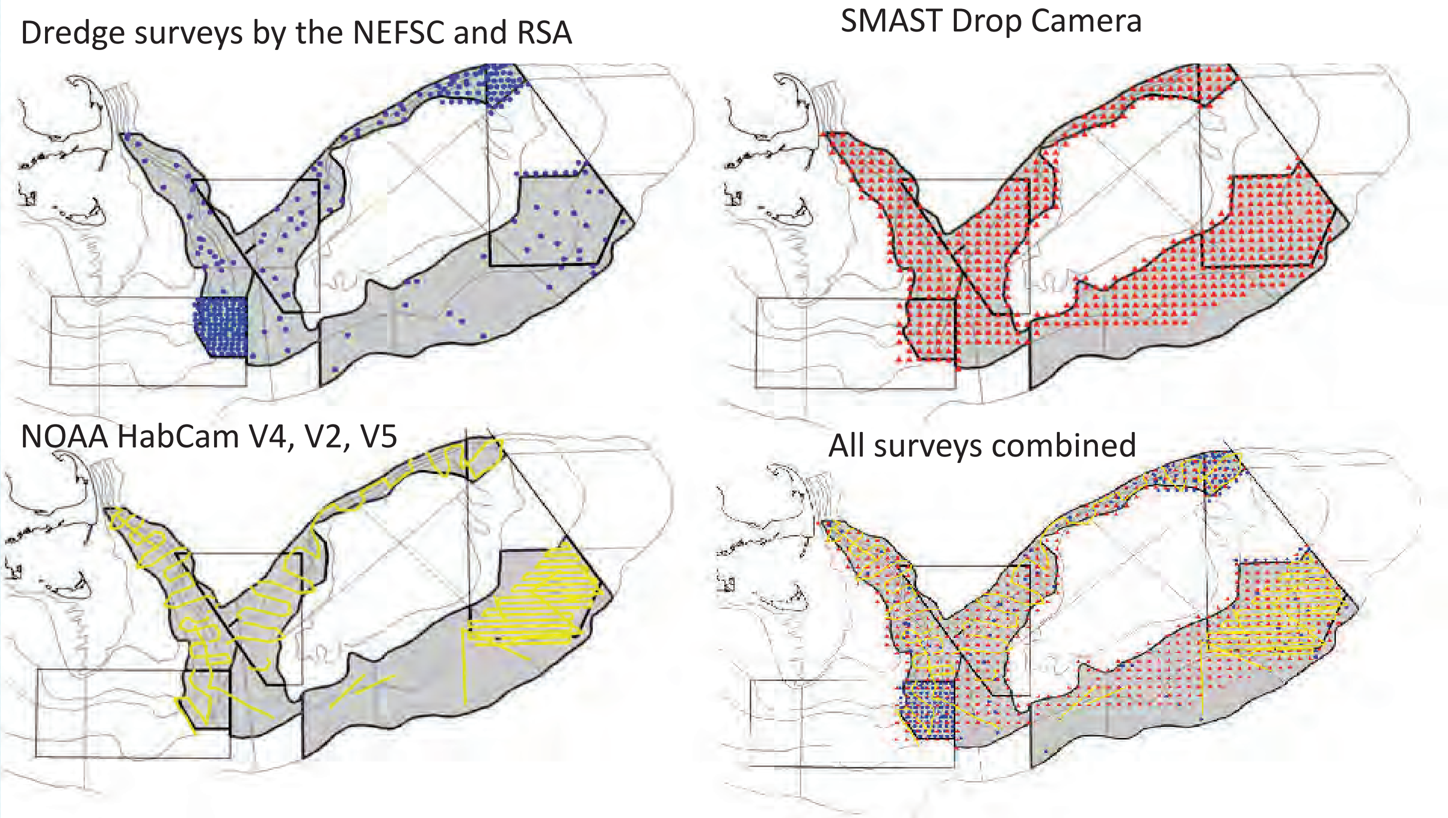


2018 HabCam Scallop Survey

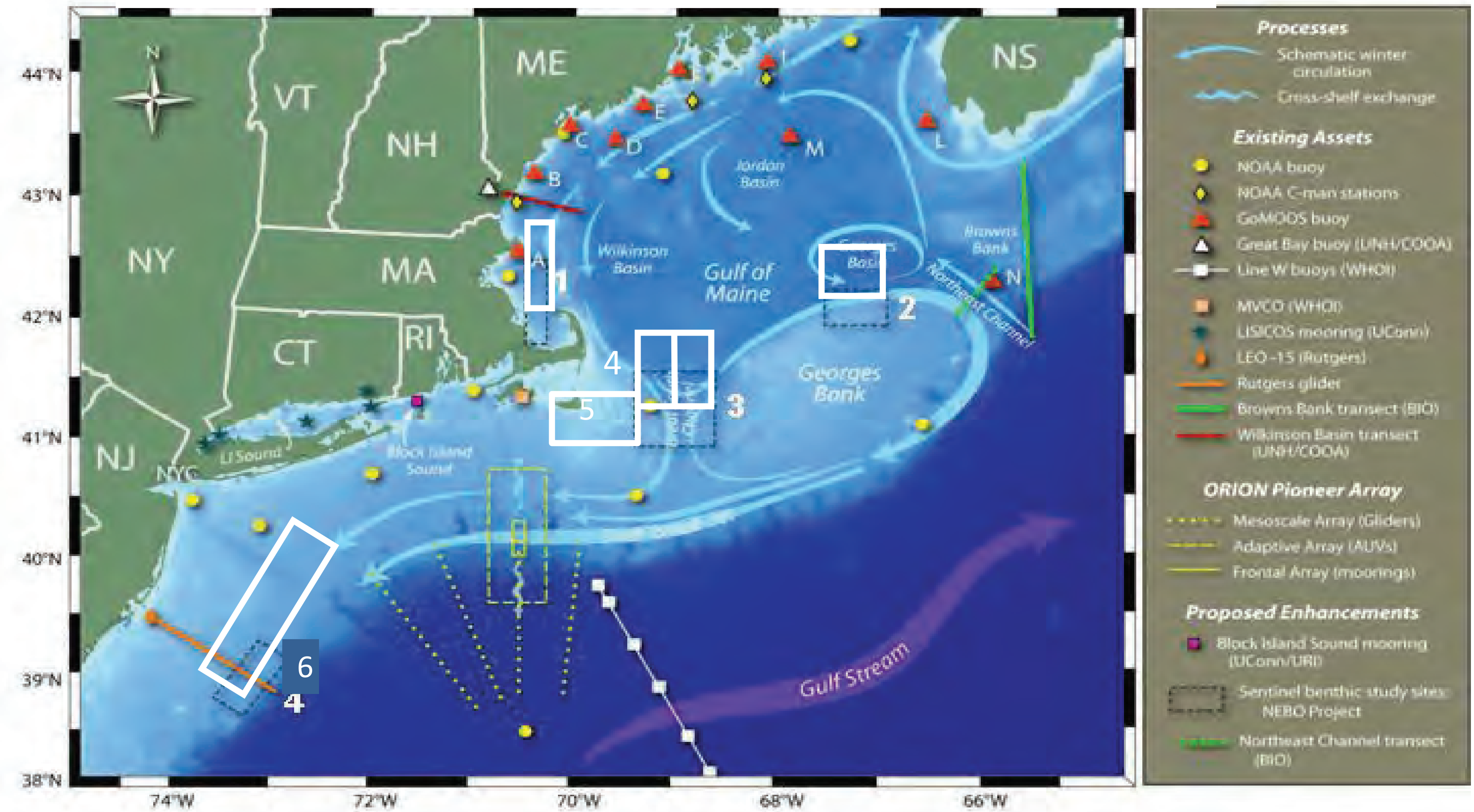
SAMS Area	Images Collected	Images Annotated	Track Length (km)	Area (km^2)
CL-2(N)	430,695	9,886 1:43	311	442
NF	732,661	20,740 1:35	595	1,807
BI	43,115	3,612 1:12	99	758
LI	591,234	41,941 1:14	1,051	13,127
NYB	196,932	15,128 1:13	367	4,002
NYB-b	61,029	4,551 1:13	158	837
NYB inshore a	73,452	5,659 1:13	160	729
NYB inshore b	179,446	14,491 1:12	398	2,908
MA inshore	90,178	6,192 1:14	253	3,585
HCS	270,701	21,748 1:12	537	3,921
ET Flex	135,787	9,782 1:14	283	1,795
ET Open	276,233	22,020 1:12	602	27,046

GAM formulation to combine surveys and mitigate error

Biomass ~ s(Latitude, Longitude) + s(Depth) + factor(SurveyType),
Weights=varIdent(form=~1|factor(SurveyType))



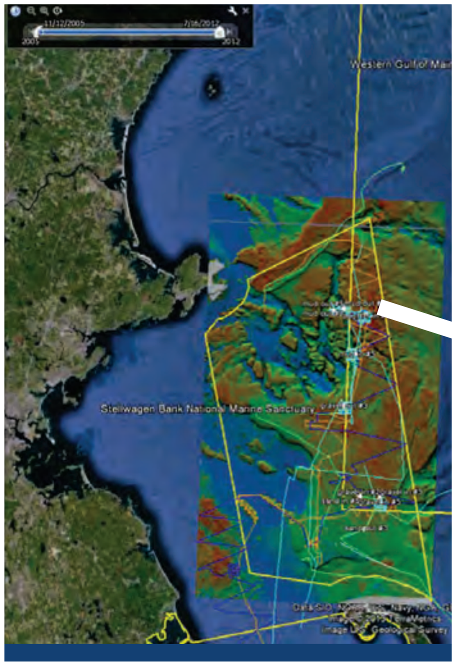
Northeast Bentho-Pelagic Observatory (NEBO) Sites

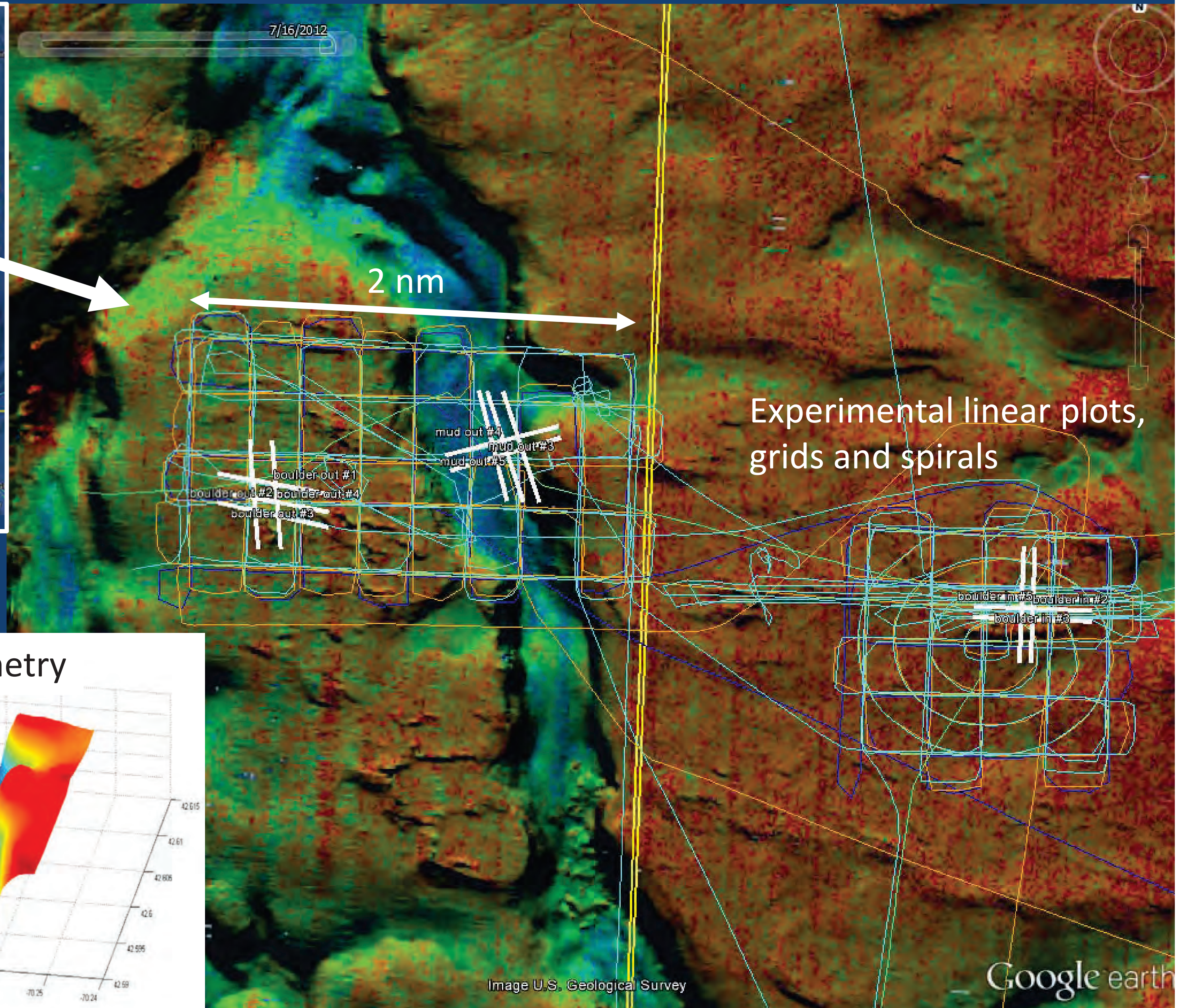


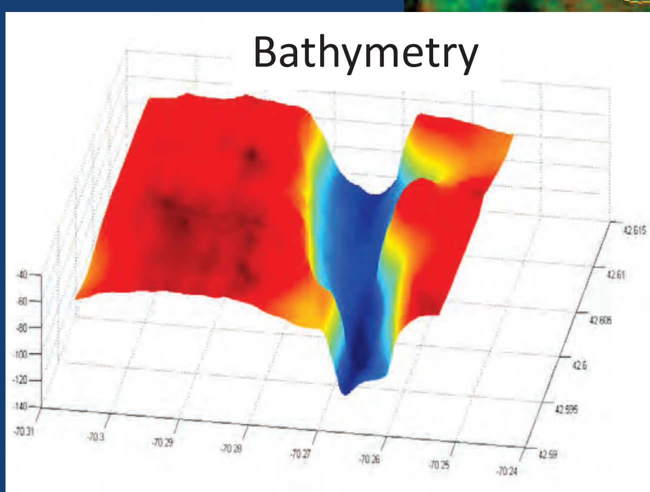
Selection of 6 Sentinel Sites

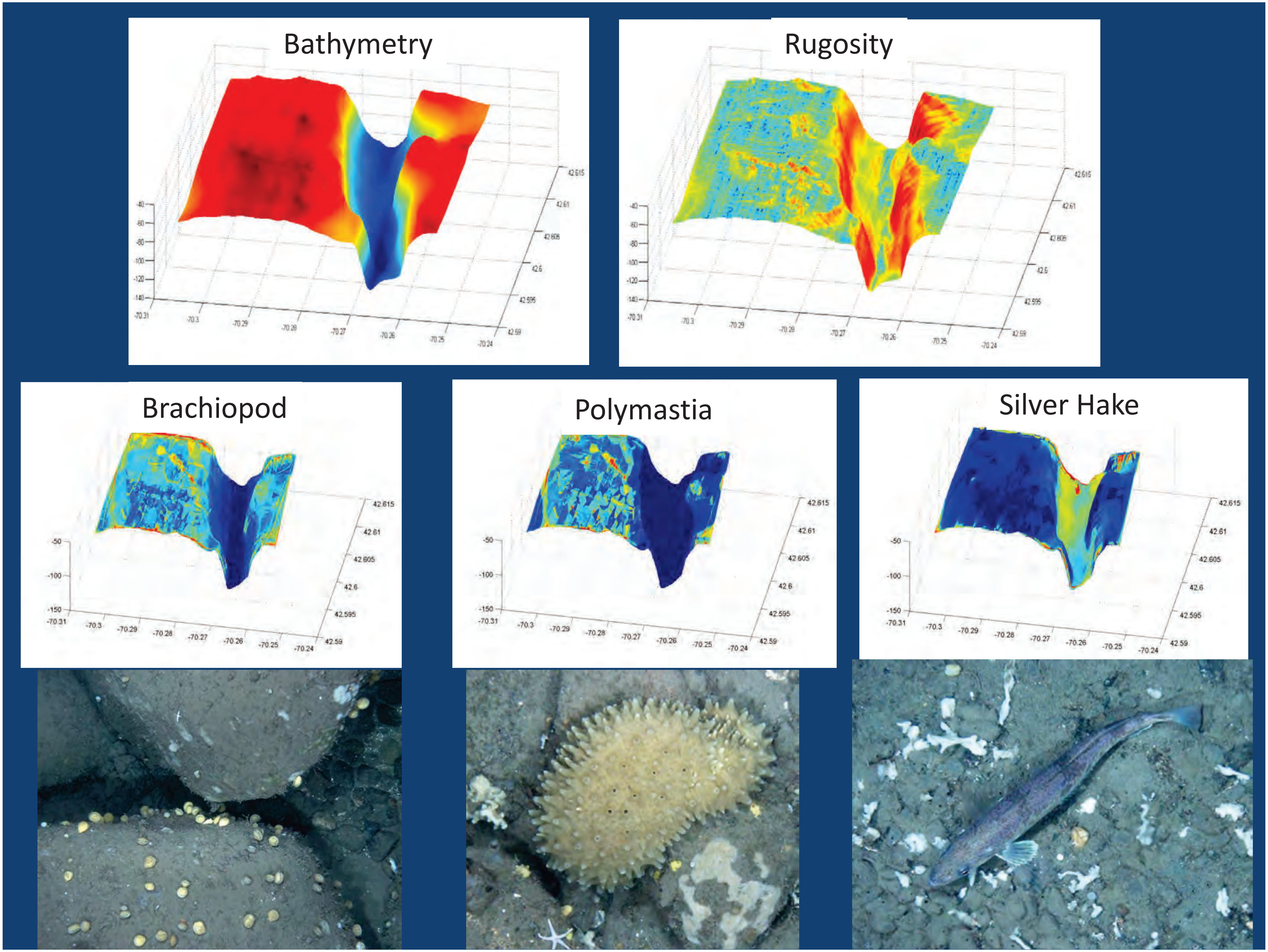
1. SBNMS: Stellwagen Bank Marine Sanctuary
2. CLAII: Northeast Peak, Closed Area II, Habitat of Particular Concern
3. CLAI: Closed Area I
4. WGSC: Western Great South Channel, HAPC?
5. NLSCA: Nantucket Lightship Closed Area
6. ET: Hudson Canyon Closed Area and Elephant Trunk

NEBO Stellwagen Bank Sites





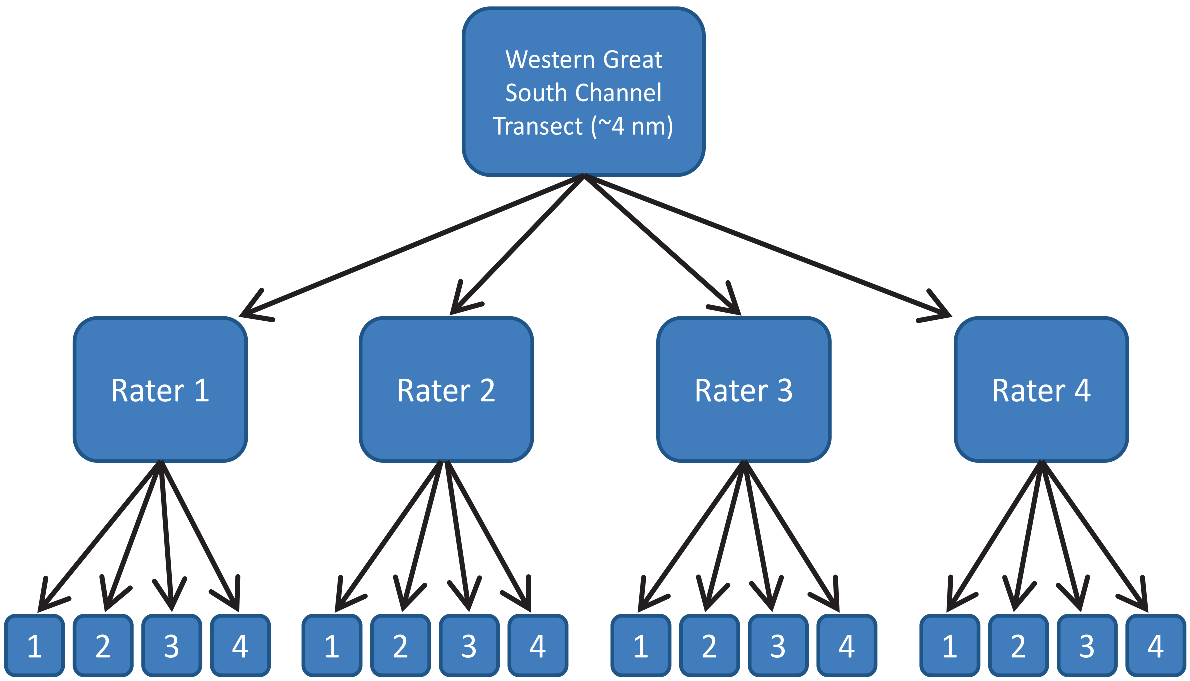



Bathymetry
Rugosity
Brachiopod
Polymastia
Silver Hake

What is the Error Associated with Human Annotation?

Inter-Class Correlation analysis of scallop shell height measurements.

Four human annotators measured scallops from one transect four times.



Two-way mixed effects model

Xij = u + ri + ci = rcij + e ij

u: population mean, r: row effects, c: column effects, e: residual effects

281 scallops x 4 raters x 4 passes = 4,496 measurements

Summary statistics in pixels. N = 277 for each run.

A total of 4,432 scallops were measured.

- Very little difference within individuals
- ~6% between individuals

rater	KLB				
	Run1	run2	run3	run4	mean
mean	132.41	132.21	132.58	132.28	132
STD	31.61	31.61	31.44	31.69	
SE	1.89	1.91	1.88	1.9	
rater	ADY				
	Run1	run2	run3	run4	mean
mean	128.48	128.46	128.41	128.75	128
STD	31.42	31.55	31.44	31.78	
SE	1.88	1.89	1.88	1.9	
rater	PK				
	run1	run2	run3	run4	mean
mean	135.57	135.88	134.95	134.28	135
STD	31.86	31.94	31.81	31.63	
SE	1.91	1.91	1.91	1.9	
Rater	DPF				
	run1	run2	run3	run4	mean
Mean	128.36	127.39	127.48	127.56	127
STD	31.74	31.63	31.45	31.57	
SE	1.9	1.9	1.89	1.89	

Overview:
Sources of measurement error

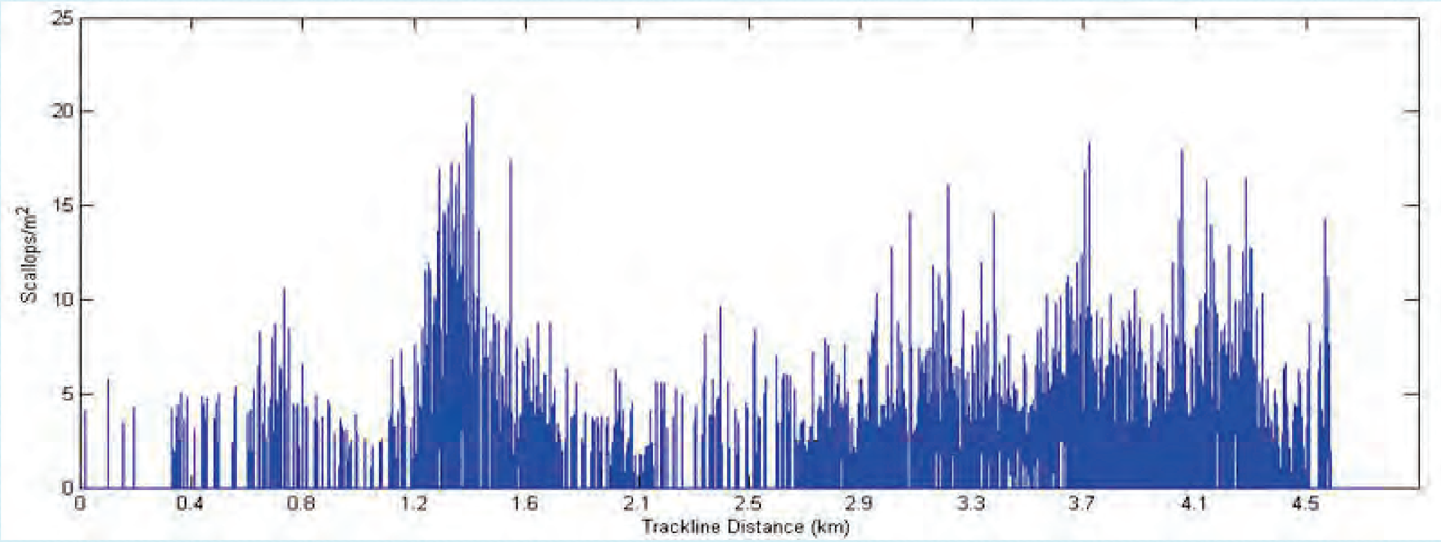
Source of error	Pixel error	Real world unit error
Intrinsic camera system	+/- 1.59 pixels	0.58-1.41 mm
Extrinsic camera and vehicle system	+/- 2 pixels	1.11-1.78 mm
Human annotation	+/- 4 pixels	3.0 -7.1 mm

Bottom line: Human error far exceeds intrinsic or extrinsic engineering errors.

Can we improve measurements using automation?

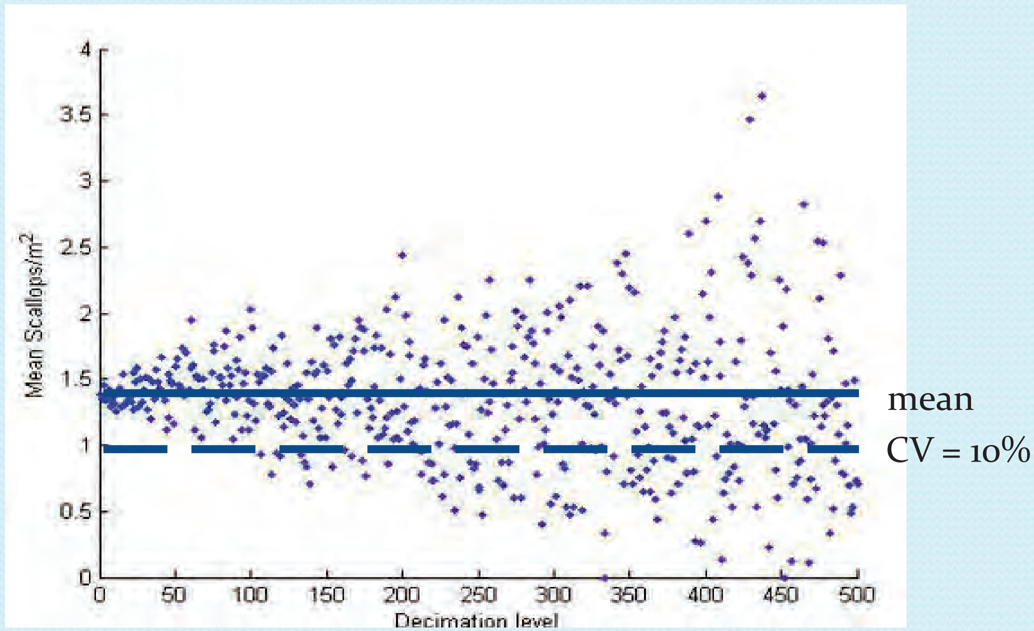
When do you know you have enough data?

Subsampling procedures to produce biomass estimates of scallops



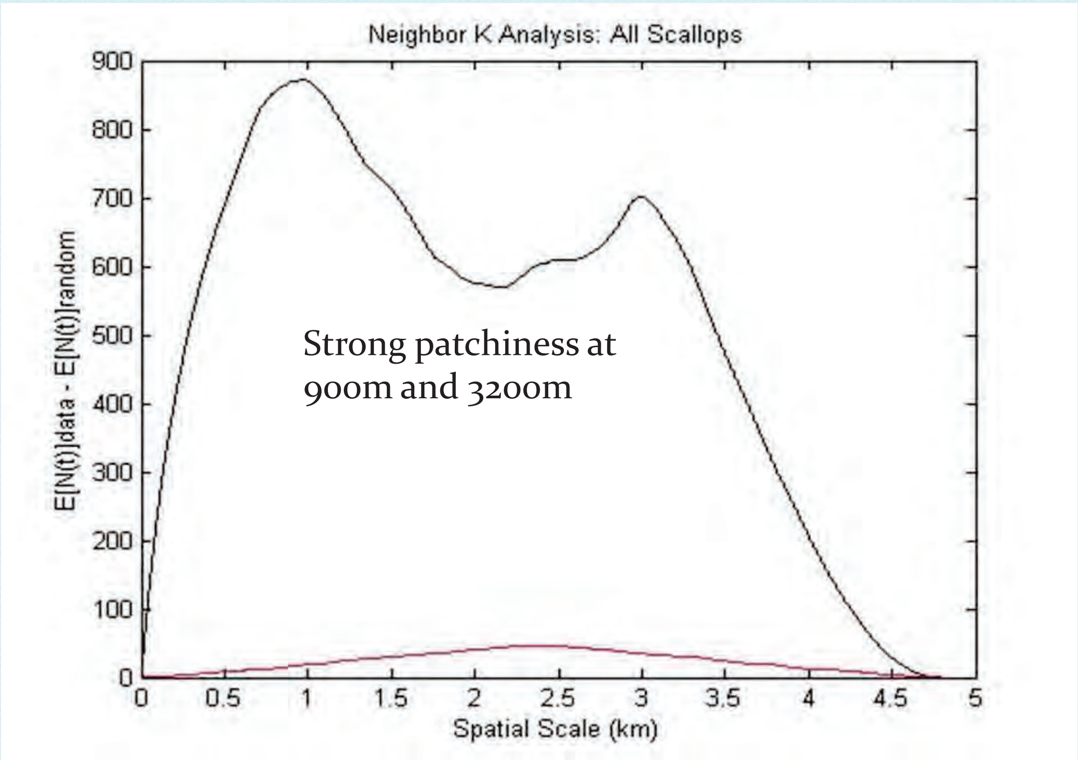
Scallop abundance in the northern section of the NLSCA survey along a 4.5 km (2 nm) track. Every other image was classified manually to establish a baseline for downsampling and patchiness. Note the very patchy distribution ranging from 0 to >20 scallops per m^2.

Subsampling exercises allow sample density estimates



The effect of downsampling from the continuous record of scallop abundance along the trackline. Images were downsampled at every 4th, 8th, 10th, 12th… out to 500 and the scallop abundance recalculated. CV of less than 10% is stable out to a downsample level of 100.

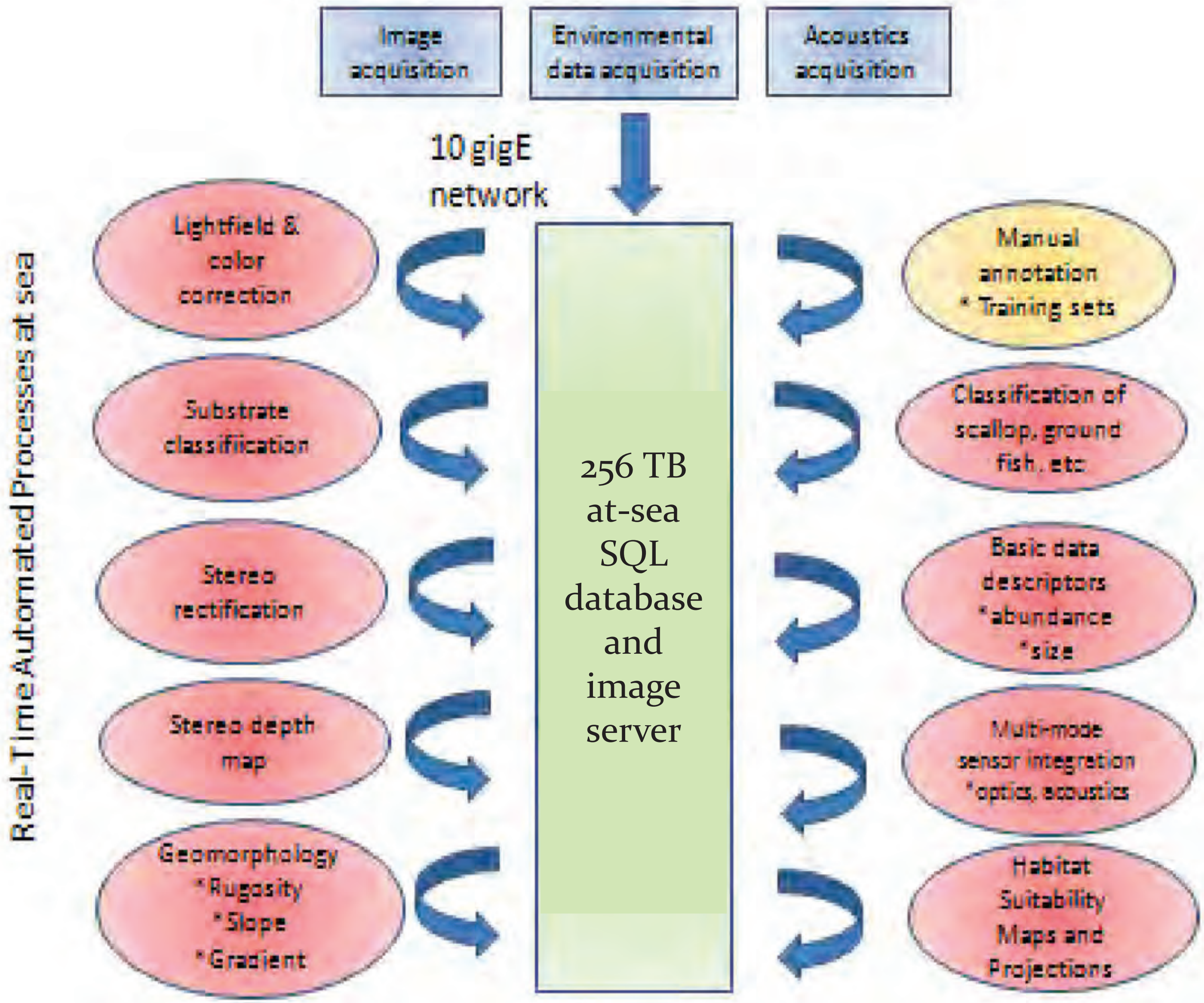
Patchiness controls sampling resolution

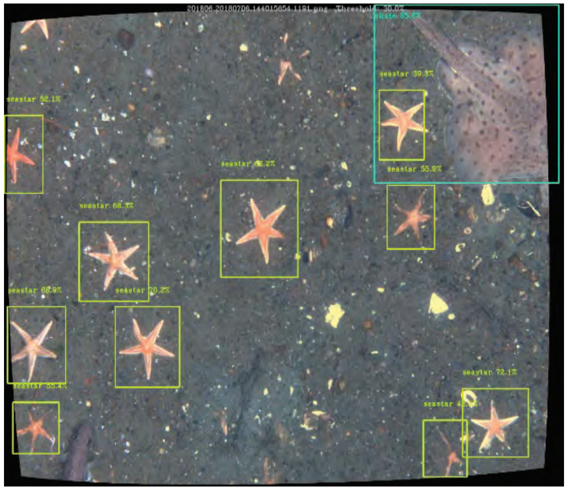


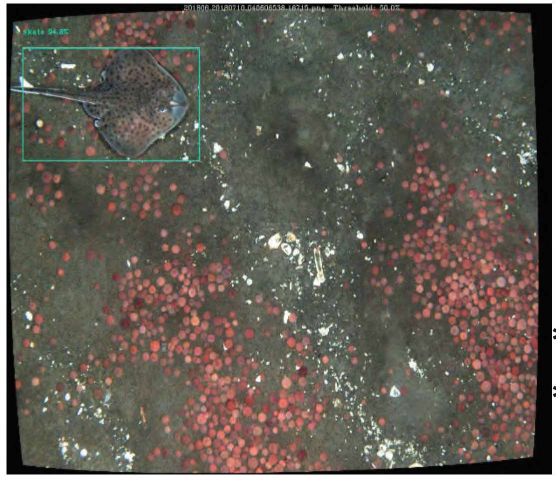
Ripley's Neighbor-k analysis of 1 dimensional patchiness of scallop distribution along the track sampled by every other image.

Data Management and Analysis

HabCam Data Acquisition and Image Processing Workflow



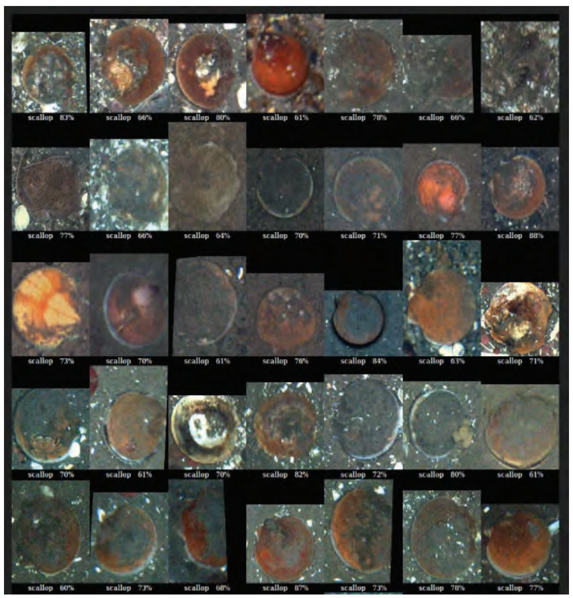


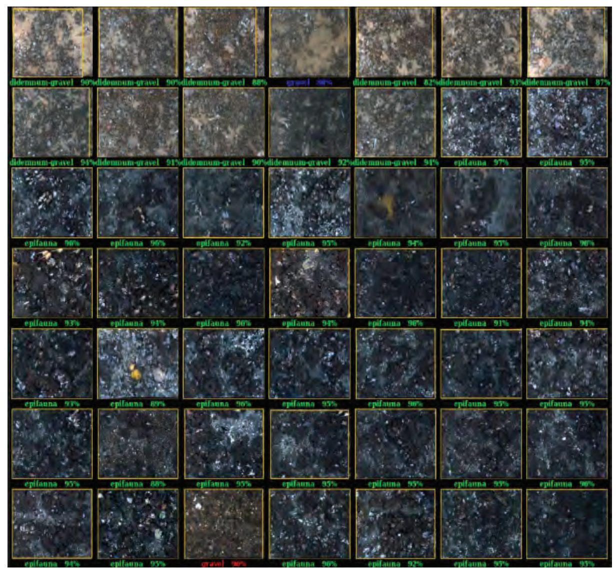


Convolutional Deep Neural Network
Classification- AI

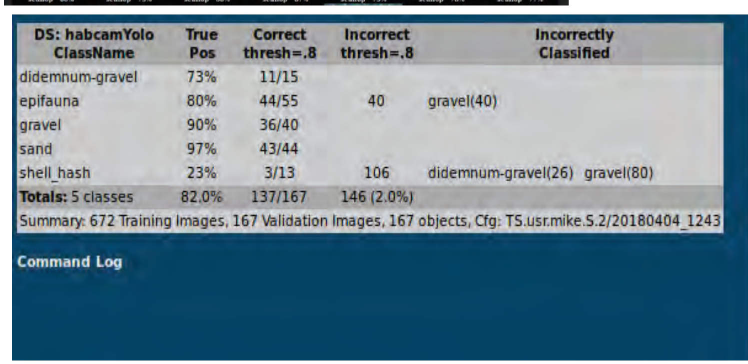
Two approaches

*Holistic- complete image (substrate)
*Targets- segmentation (scallop, seastar, fish, sand dollar, etc.)





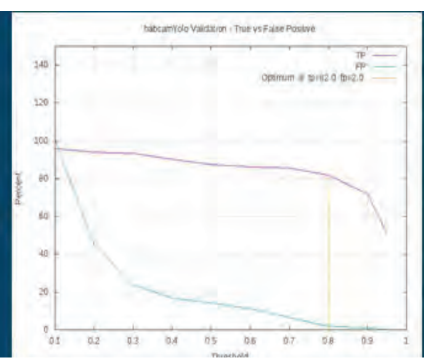
*8 images /sec
*15 classes (so far)
*90-97% accuracy
*runs on NIVIDIA Jetson TX2



DS: habcamYolo ClassName	True Pos	Correct thresh=.8	Incorrect thresh=.8	Incorrectly Classified
didemnum-gravel	73%	11/15		
epifauna	80%	44/55	40	gravel(40)
gravel	90%	36/40		
sand	97%	43/44		
shell_hash	23%	3/13	106	didemnum-gravel(26) gravel(80)
Totals: 5 classes	82.0%	137/167	146 (2.0%)	

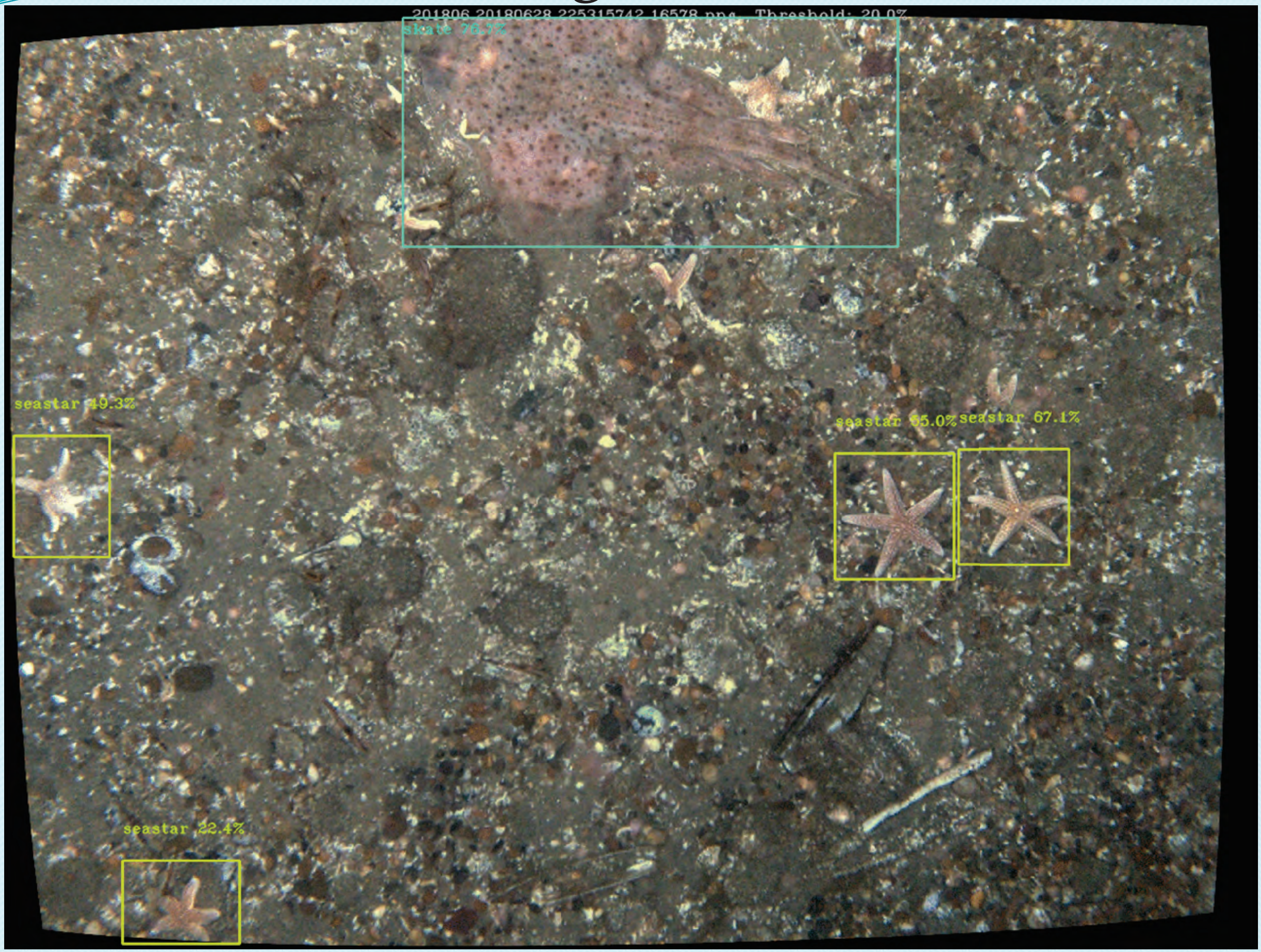
Summary: 672 Training Images, 167 Validation Images, 167 objects, Cfg: TS.usr.mike.S.2/20180404_1243

Command Log



Automated Substrate Classification

Automated target classification



Substrate Complexity (surface area) ranking based on Coastal and Marine Ecological Classification Standard CMECS

Classification
System- Marine
Subsystem- Bank or Shelf

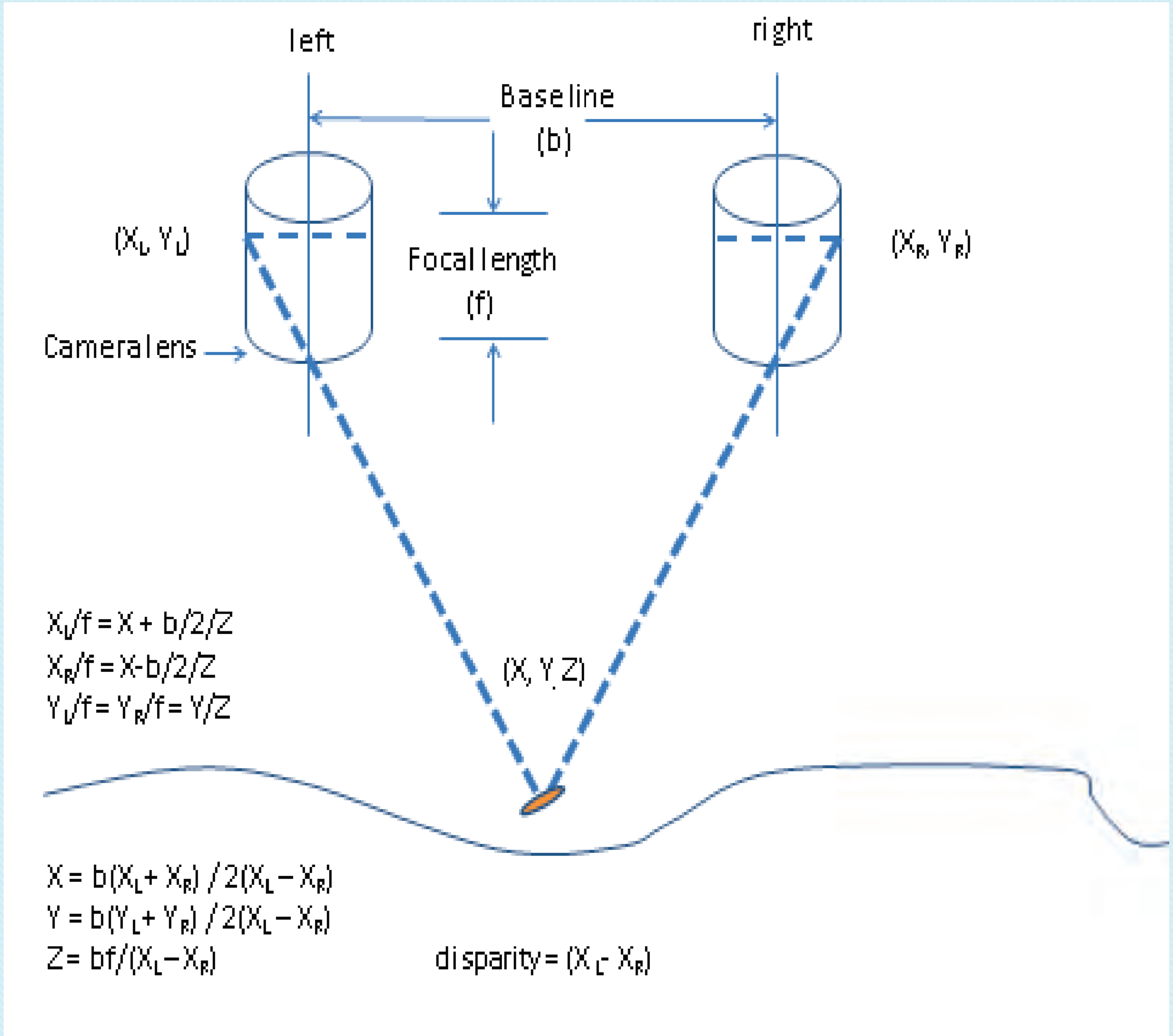
Surface Geology Component
Class- Unconsolidated mineral substrate
Subclass- Course Unconsolidated Substrate
Substrate Group- mud, sand, pebble, cobble, boulder

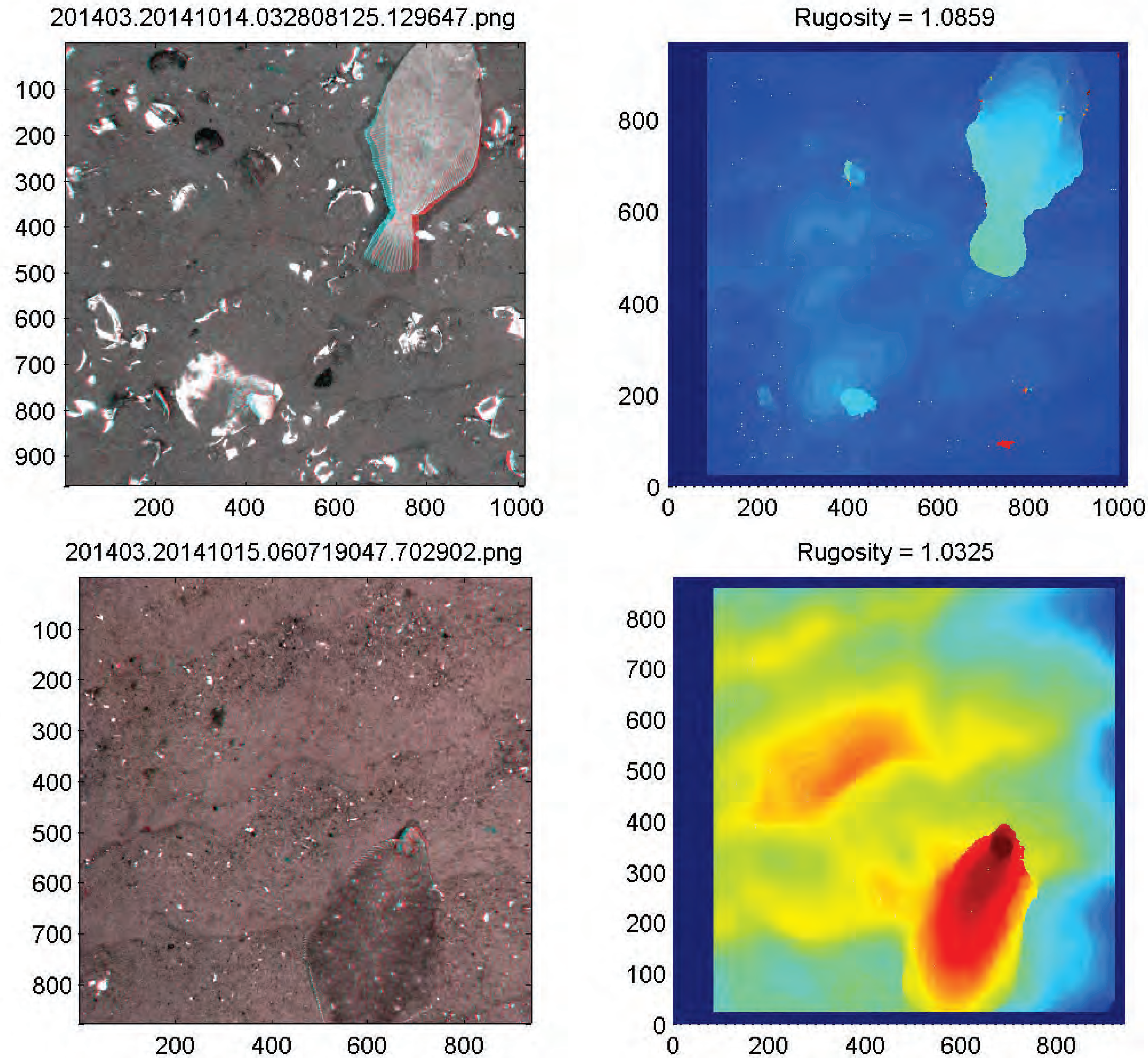
Benthic Biotic Component
Class- Faunal bed
Subclass- Epifauna, infauna
Modifier-
Biotic Group-
Secondary Element-

Automated classes

Mud	1
sand + silt	2
Sand	3
sand/shell+silt	4
sand/shell	5
sand/gravel+silt	6
sand/gravel	7
sand/clay	8
Shell	9
shell/sand	10
shell/gravel	11
shell/boulder	12
gravel/sand+silt	13
gravel/sand	14
gravel/shell+silt	15
gravel + silt	16
Gravel	17
mussels/sand	18
Mussels	19
mussels/gravel	20
mussels/shell	21
mussels/boulder	22
sand/cobble+silt	23
sand/cobble	24
sand/boulder+silt	25
sand/boulder	26
sand/epifauna+silt	27
sand/epifauna	28
cobble/sand+silt	29
cobble/sand	30
cobble/gravel+silt	31
cobble/gravel	32
cobble + silt	33
Cobble	34
cobble/boulder+silt	35
cobble/boulder	36
cobble/epipfauna+silt	37
cobble/epifauna	38
boulder/sand+silt	39
boulder/sand	40
boulder/gravel+silt	41
boulder/gravel	41
boulder/cobble+silt	43
boulder/cobble	44
Boulder	45
boulder+silt	46
boulder/epifauna+silt	47
boulder/epifauna	48
gravel/cobble+silt	49
gravel/cobble	50
gravel/boulder+silt	51
gravel/boulder	52
gravel/epifaunda	53

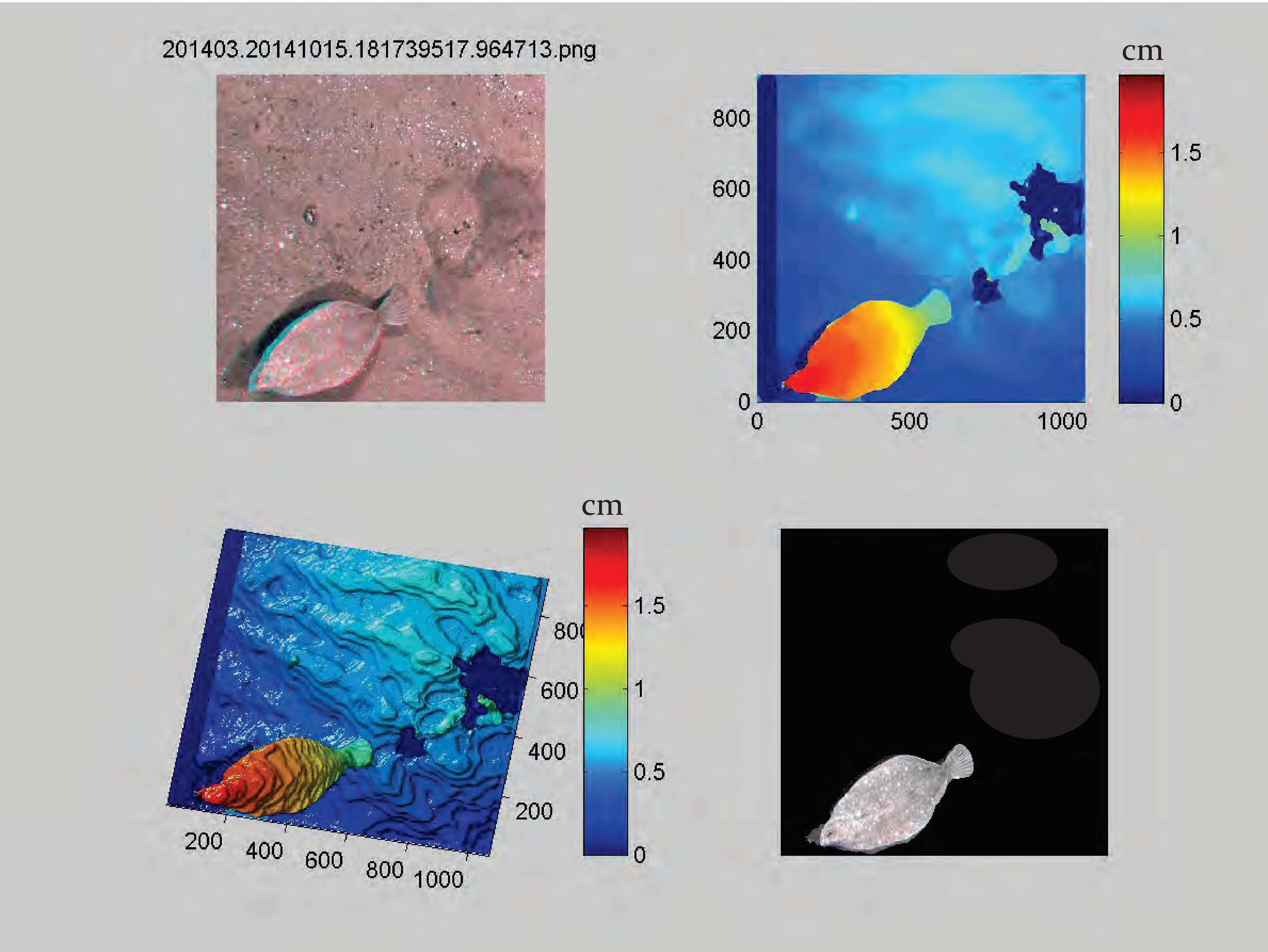
Arrangement of stereo pair cameras and geometry of 3D calculation of distance





Segmentation of Yellowtail flounder from sand background using the stereo disparity and segmentation on the point cloud.

Red colors are closer to the camera



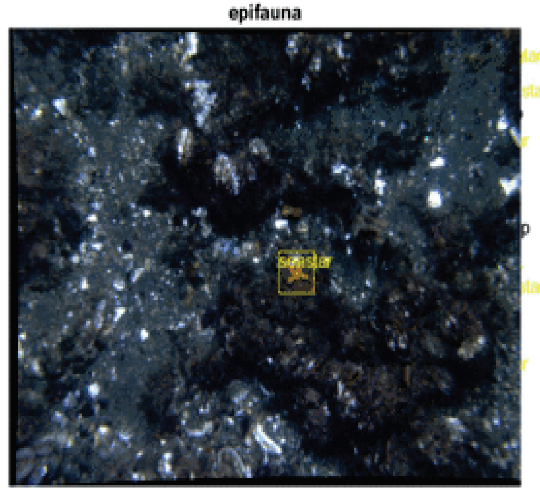
201403.20141015.181739517.964713.png
cm
800
600
400
200
0
0
500
1000
1.5
1
0.5
0
cm
1.5
1
0.5
0
800
600
400
200
200
400
600
800
1000

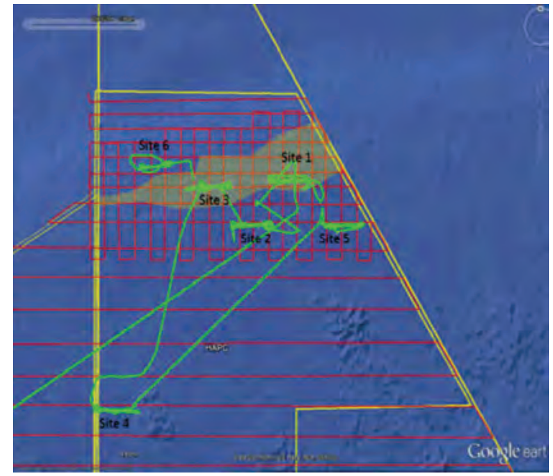
Substrate

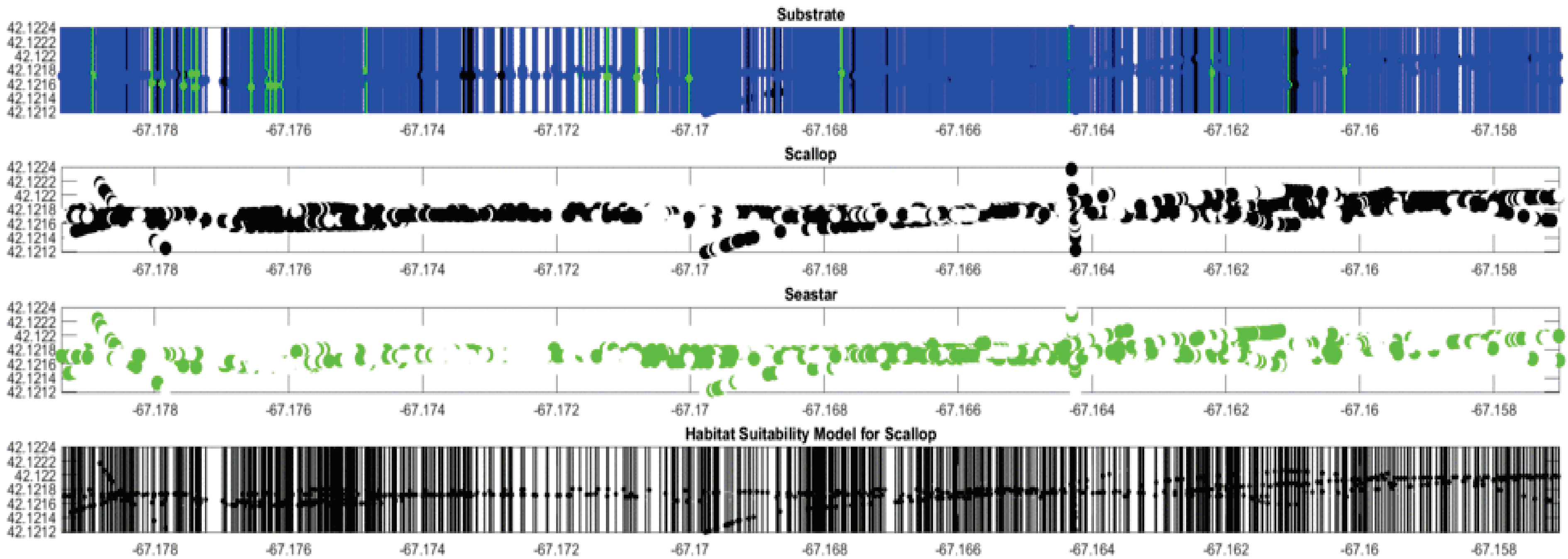
Epifauna

Sand

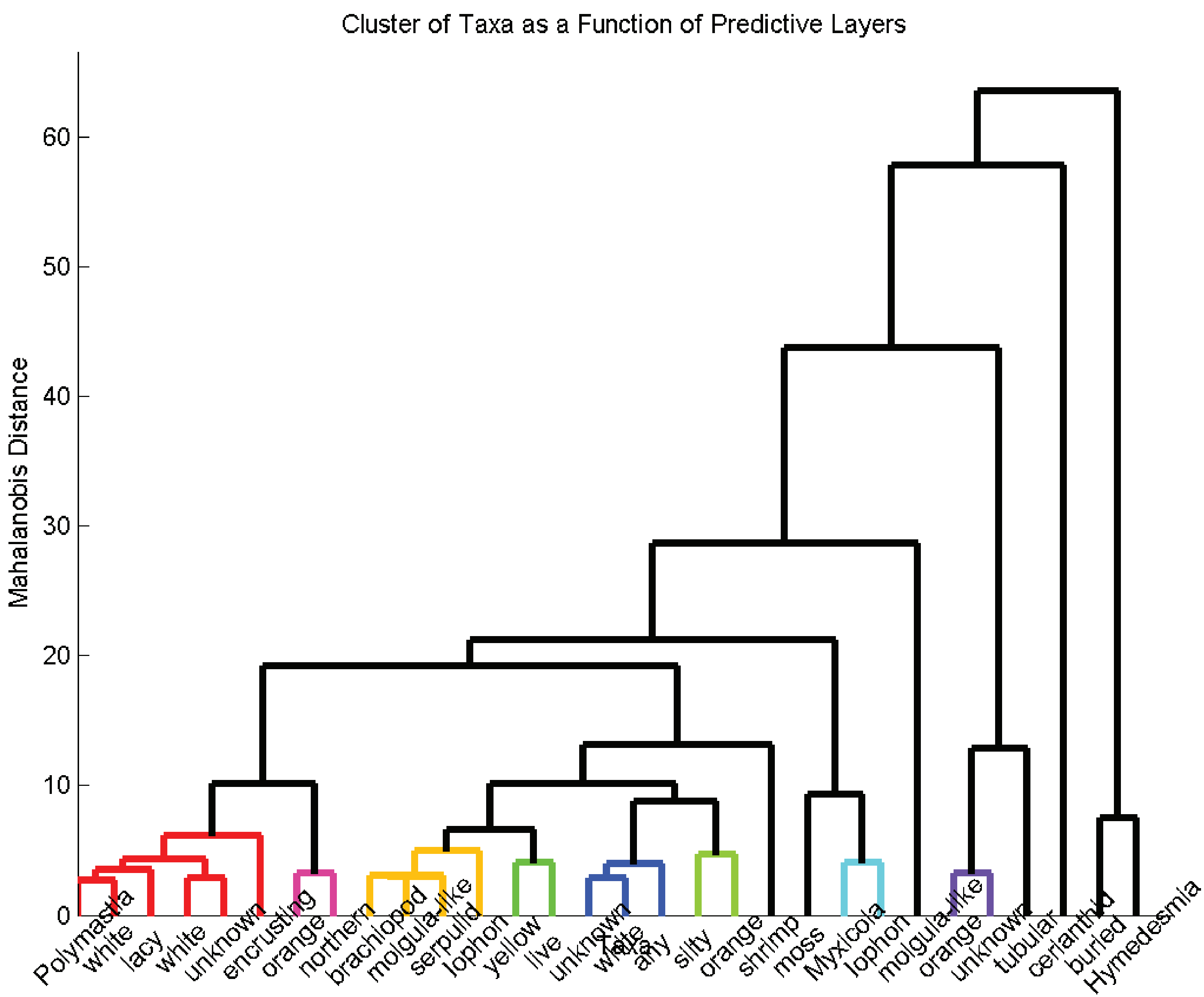
Gravel







1-D Habitat Suitability Model for scallop



Cluster of Taxa as a Function of Predictive Layers
Mahalanobis Distance
0
10
20
30
40
50
60
Polymastia
white
lacy
white
unknown
encrusting
orange
northern
brachiopod
molgula-like
serpulid
lophon
yellow
live
unknown
white
any
silty
orange
shrimp
moss
Myxicola
lophon
molgula-like
orange
unknown
tubular
cerianthid
buried
Hymedesmia

Fin Fish Communities Classified by k-means Clustering of All Predictive and Presence Rasters

Community 1

conger-eel
monkfish
ocean-pout-(eyes**)**
sea-raven
smooth-skate
sand-lance
red-hake
barndoor-skate(eyes)
summer-flounder
spiny-dogfish
smooth-dogfish
cunner

Community 2

barndoor-skate(wing)
unknown-fish
windowpane-flounder
winter-flounder

Community 3

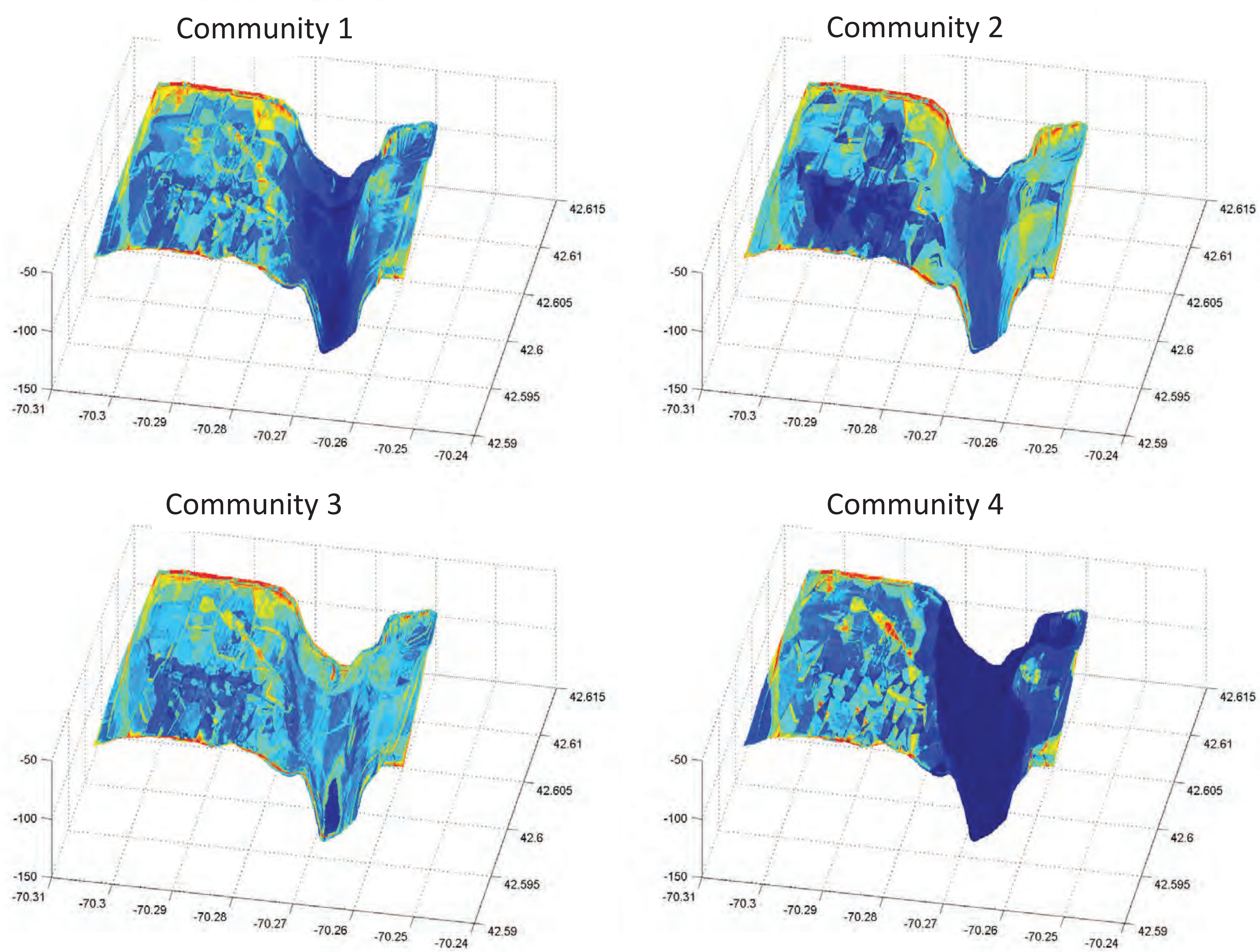
winter-little-skate
yoy-gadid
thorny-sk
atlantic-cod
rock-gunnel
silver-hake
herring

Community 4

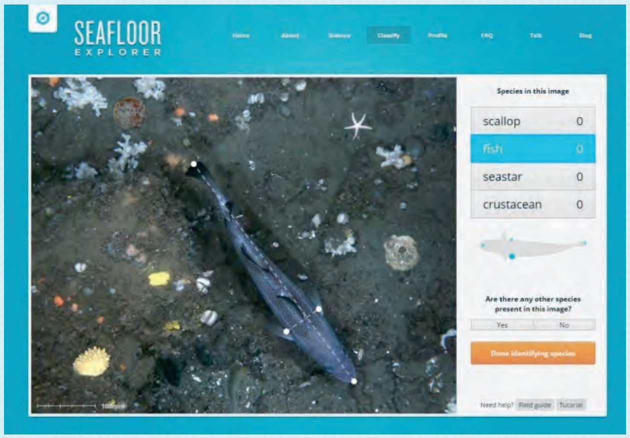
unidentified-flatfish-(less-than-half)
atlantic-hagfish
yellowtail-flounder
unknown-skate

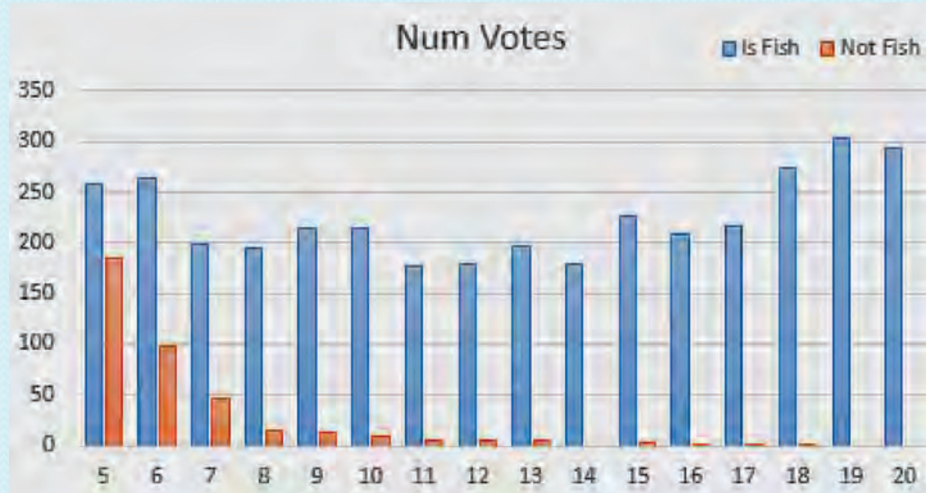
Community 5

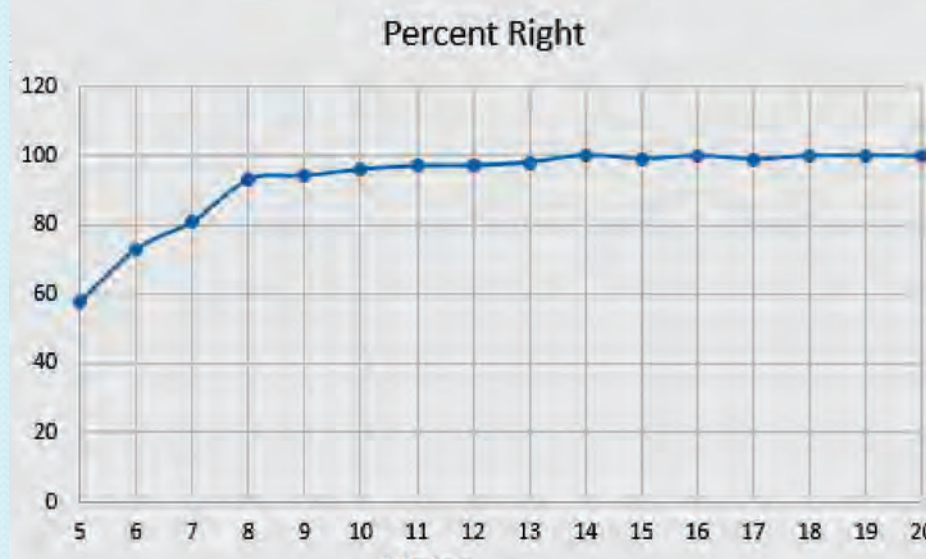
sculpin-grubby
haddock
fourspot-flounder


Community 1
-50
-100
-150
-70.31
-70.3
-70.29
-70.28
-70.27
-70.26
-70.25
-70.24
42.59
42.595
42.6
42.605
42.61
42.615
Community 2
-50
-100
-150
-70.31
-70.3
-70.29
-70.28
-70.27
-70.26
-70.25
-70.24
42.59
42.595
42.6
42.605
42.61
42.615
Community 3
-50
-100
-150
-70.31
-70.3
-70.29
-70.28
-70.27
-70.26
-70.25
-70.24
42.59
42.595
42.6
42.605
42.61
42.615
Community 4
-50
-100
-150
-70.31
-70.3
-70.29
-70.28
-70.27
-70.26
-70.25
-70.24
42.59
42.595
42.6
42.605
42.61
42.615

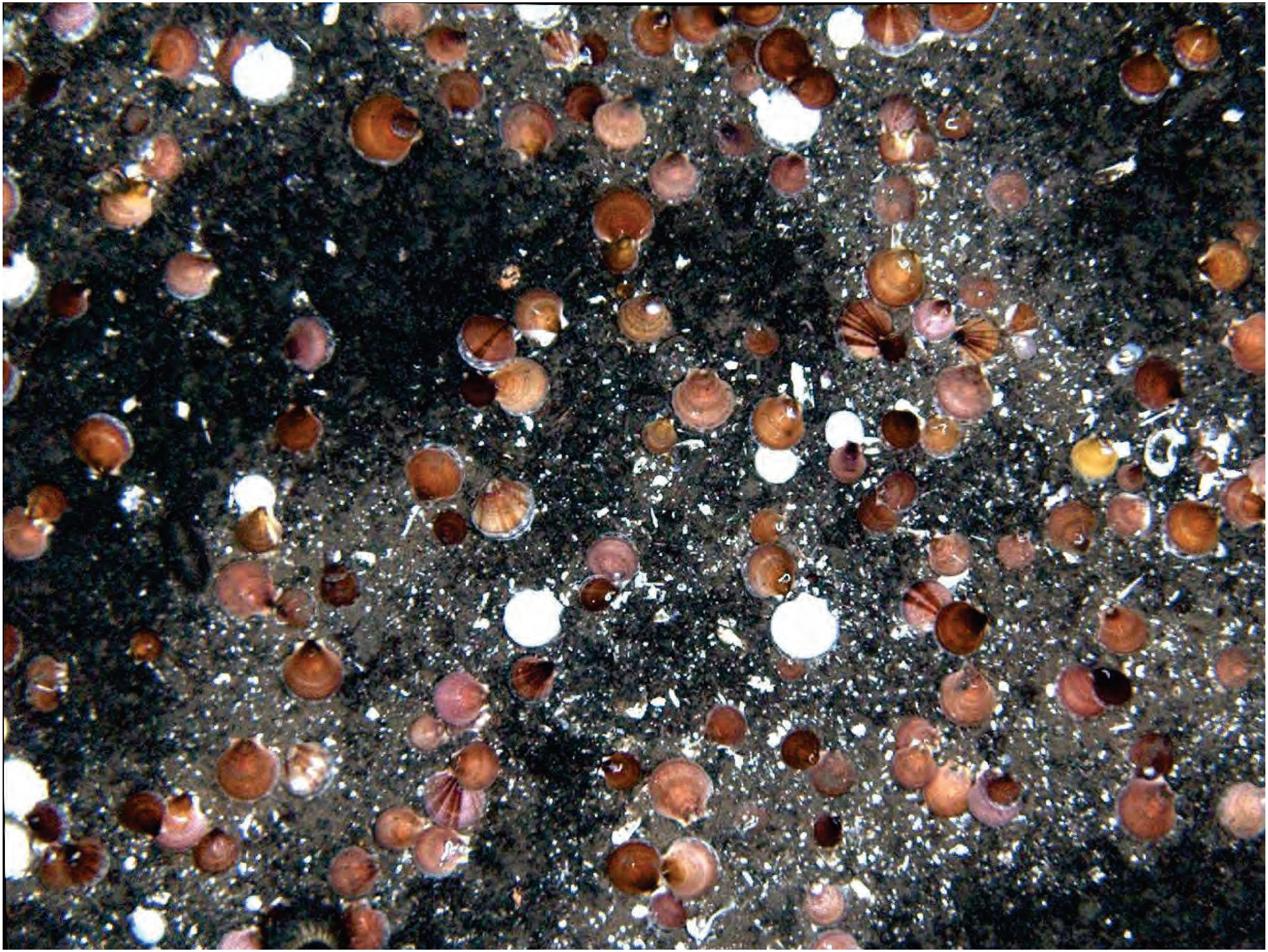
SeafloorExplorer.org: A Citizen's Science Website to Characterize the Benthos





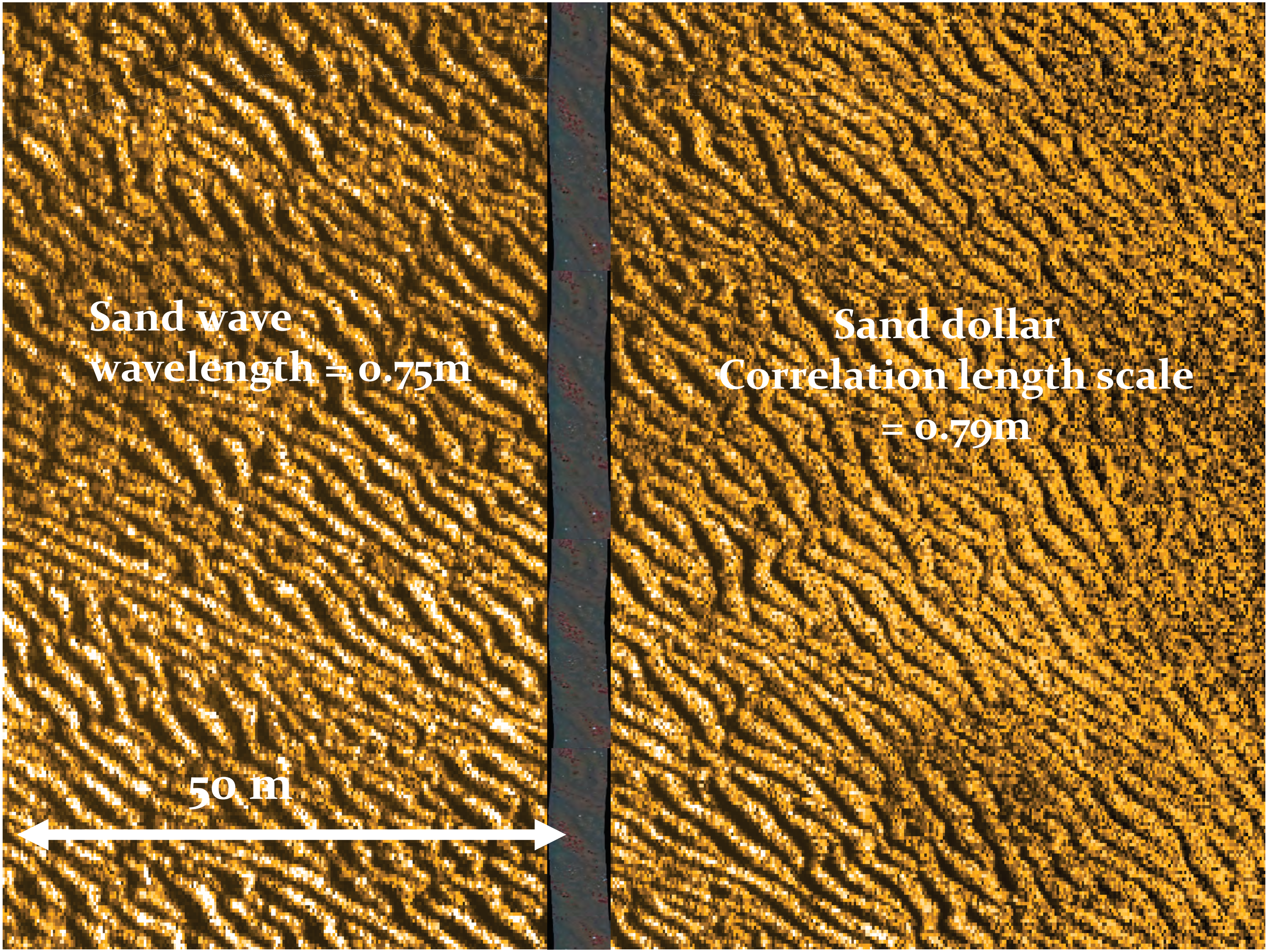


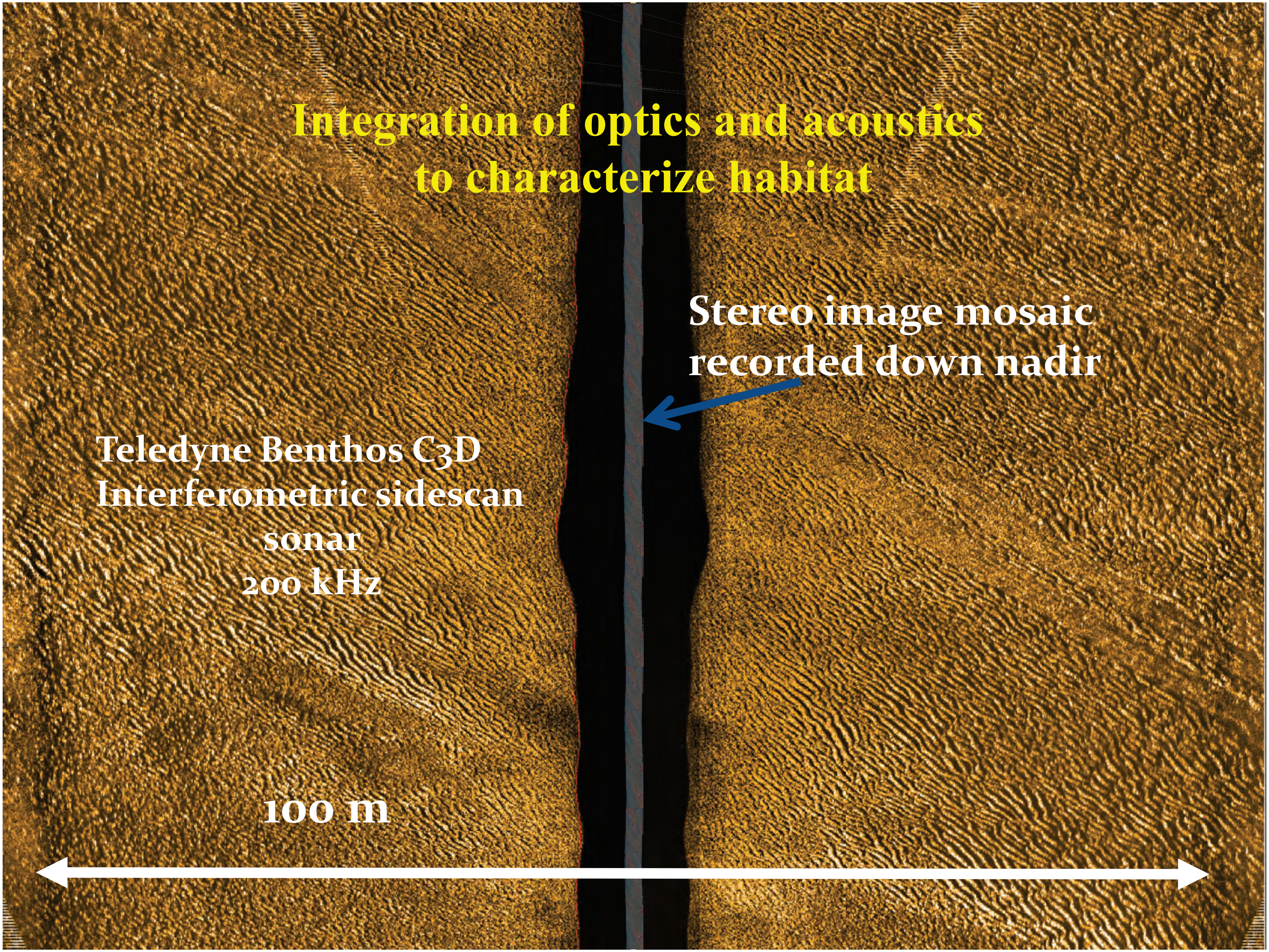
Statistic	Value
Number of registered users	23,227
Number of total users	55,971
Number of images annotated since October 2012 (includes multiple hits per target)	2,367,811
Number of unique images processed	111,360
Number of scallops marked	1,895,846
Number of fish marked	141,103
Number of seastars marked	3,607,505
Number of crustaceans marked	155,422

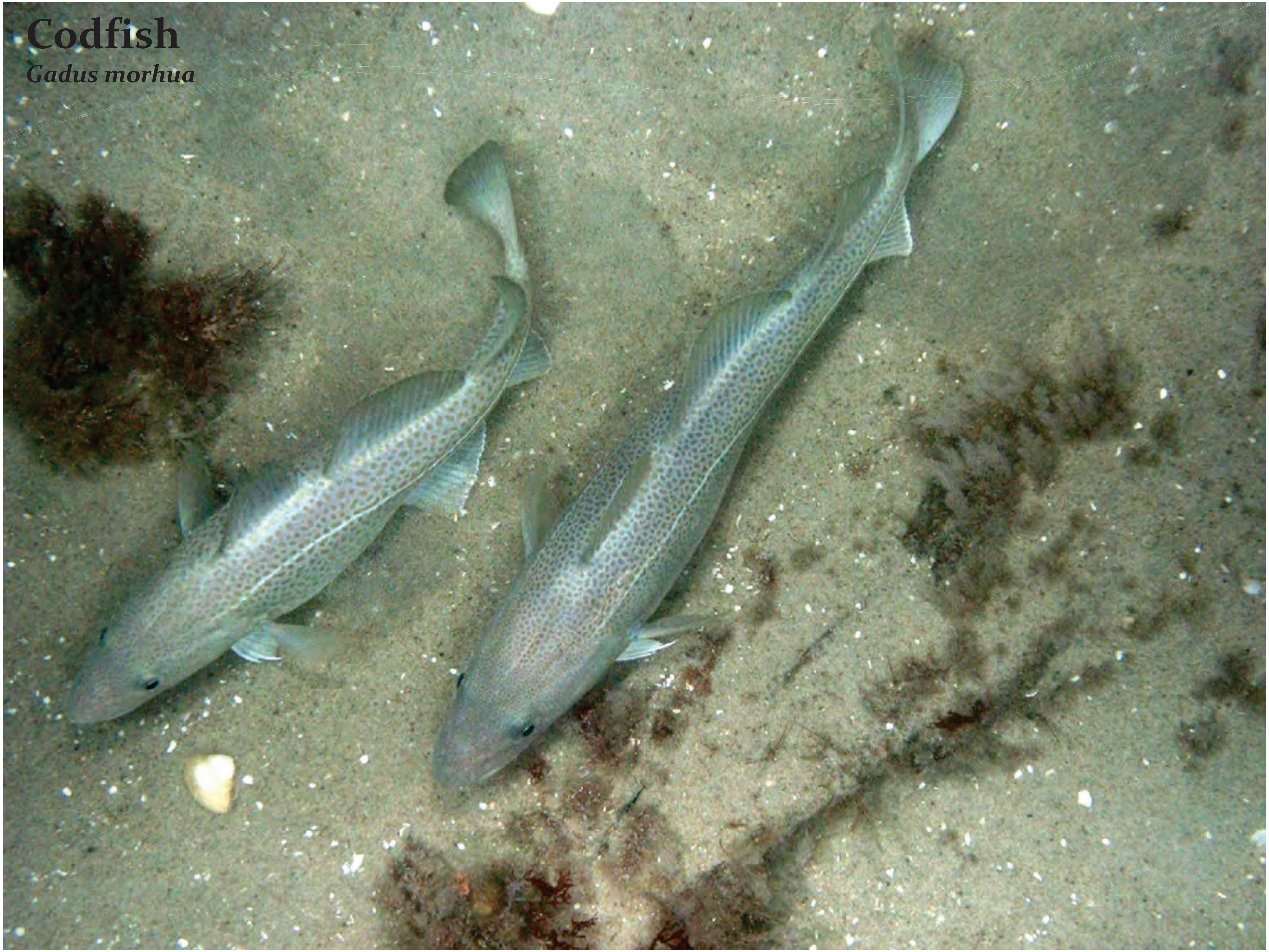


Impediments to the use of imaging technology for conserving and protecting marine resources

- Funding to support new technology and it's transition into operational oceanography and stock assessment
- Big Data Problem- we need support from the HP community and novel ways to build processing workflows and to design data products- we need to work backwards from the problem or question
- Acceptance by all communities- all the new technology in the world will not help if the community cannot be flexible


Sand wave
wavelength = 0.75m
Sand dollar
Correlation length scale
= 0.79m
50 m


Integration of optics and acoustics
to characterize habitat
Stereo image mosaic
recorded down nadir
Teledyne Benthos C3D
Interferometric sidescan
sonar
200 kHz
100 m

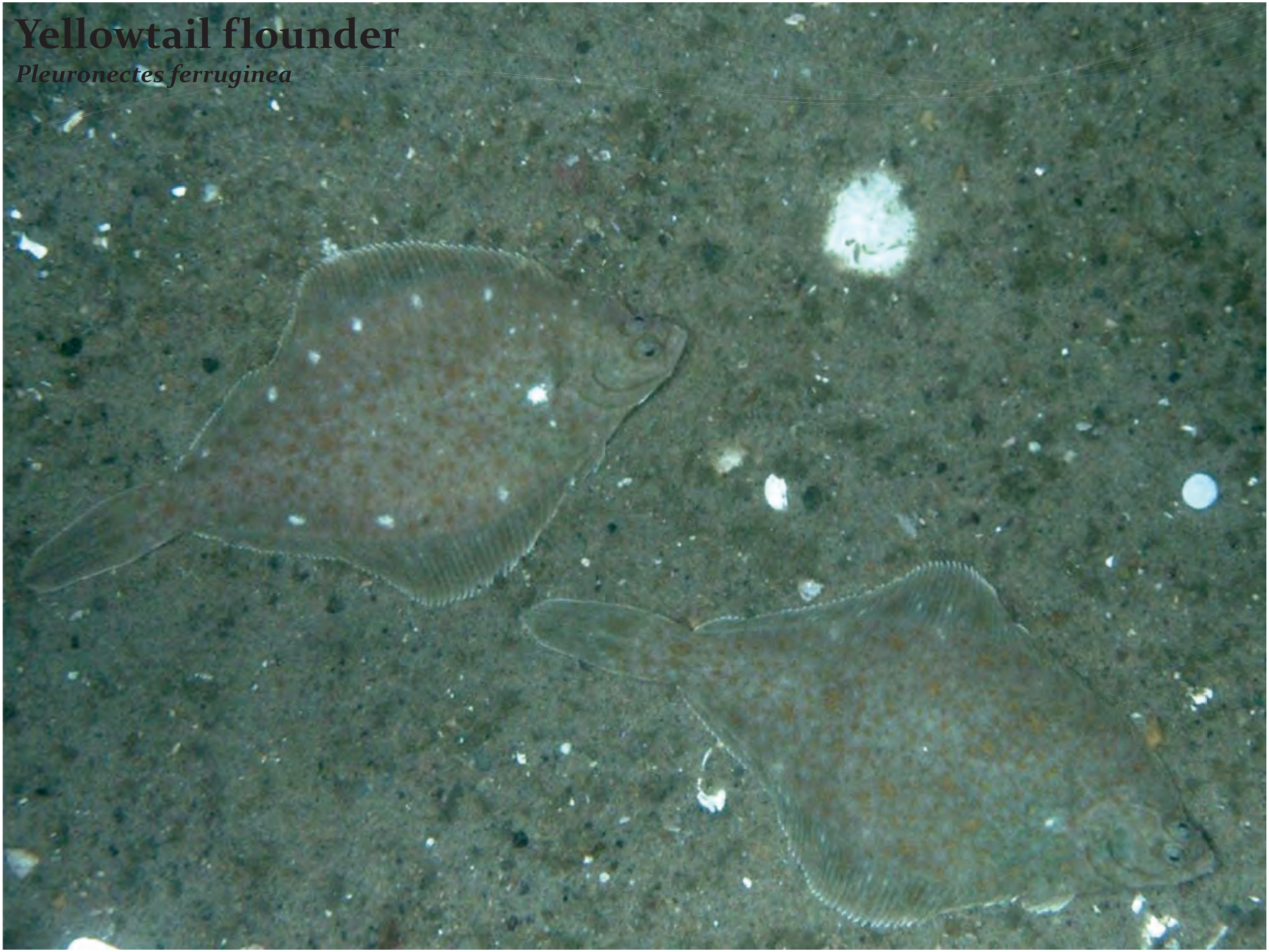

Codfish
Gadus morhua


Haddock
Melanogrammus aeglefinus


Cusk
Brosme brosme

Yellowtail flounder

Pleuronectes ferruginea



Grey sole

Glyptocephalus cynoglossus

Deeplet sea anemone

Bolocera tuediae

Unidentified anemone


Longfin squid
Loligo pealeii

Northern cerianthids

Cerianthus borealis

Redfish

Sebastes spp.


Stone Crab in Basket Sponge

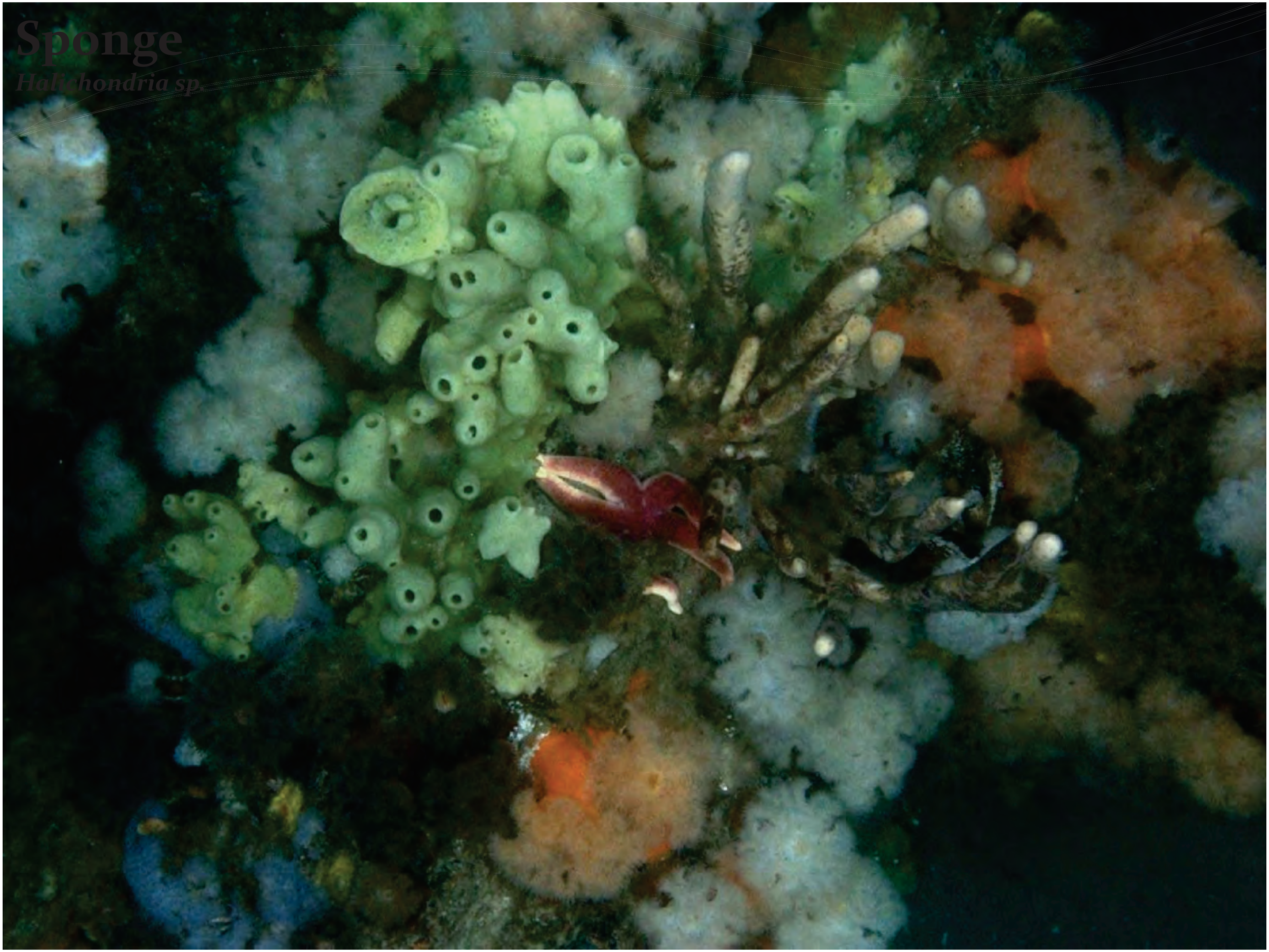
Horse star
Hippasteria phrygiana

Spiny sunstar
Crossaster papposus

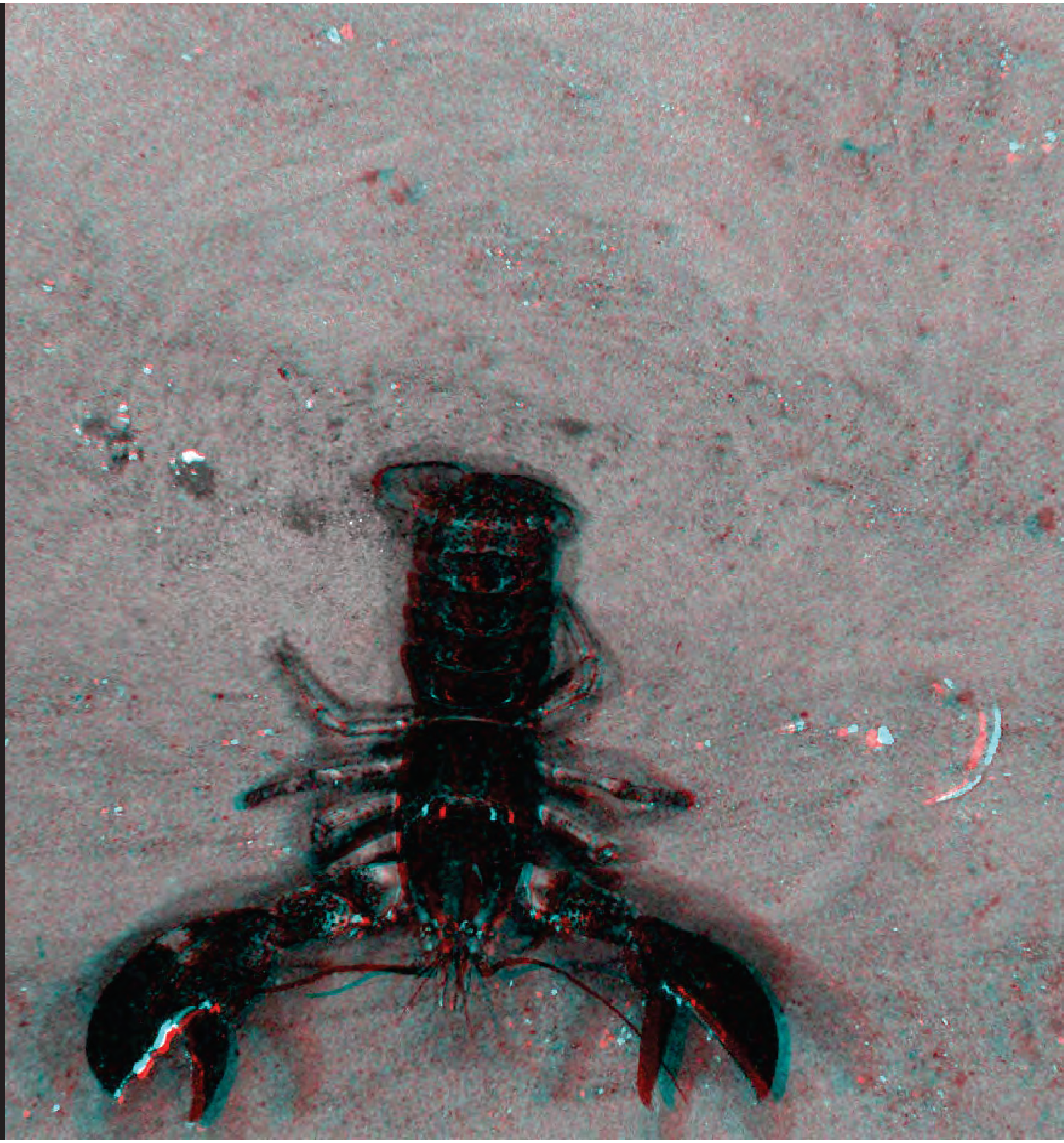
Smooth sunstars

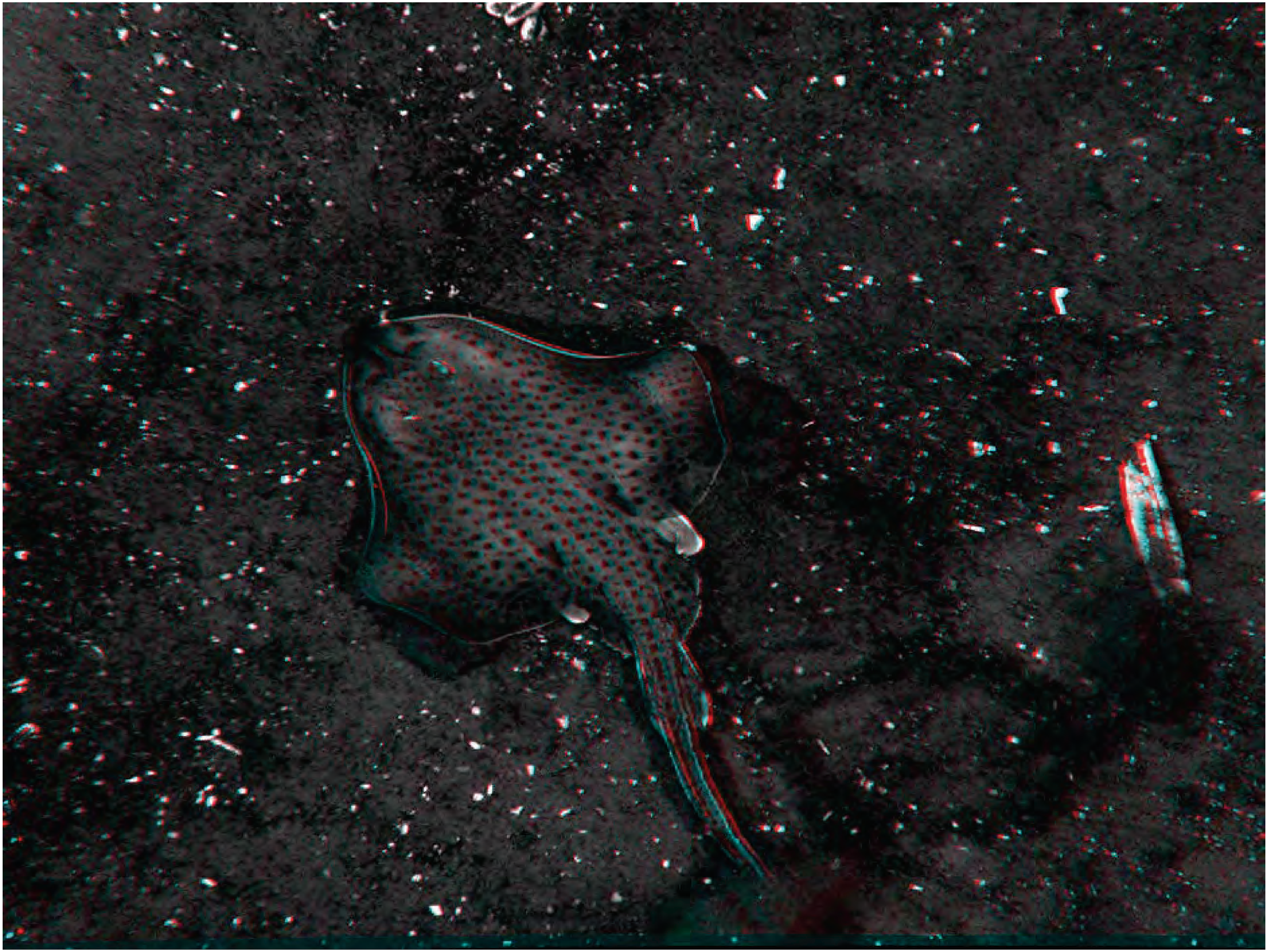
Solaster endeca

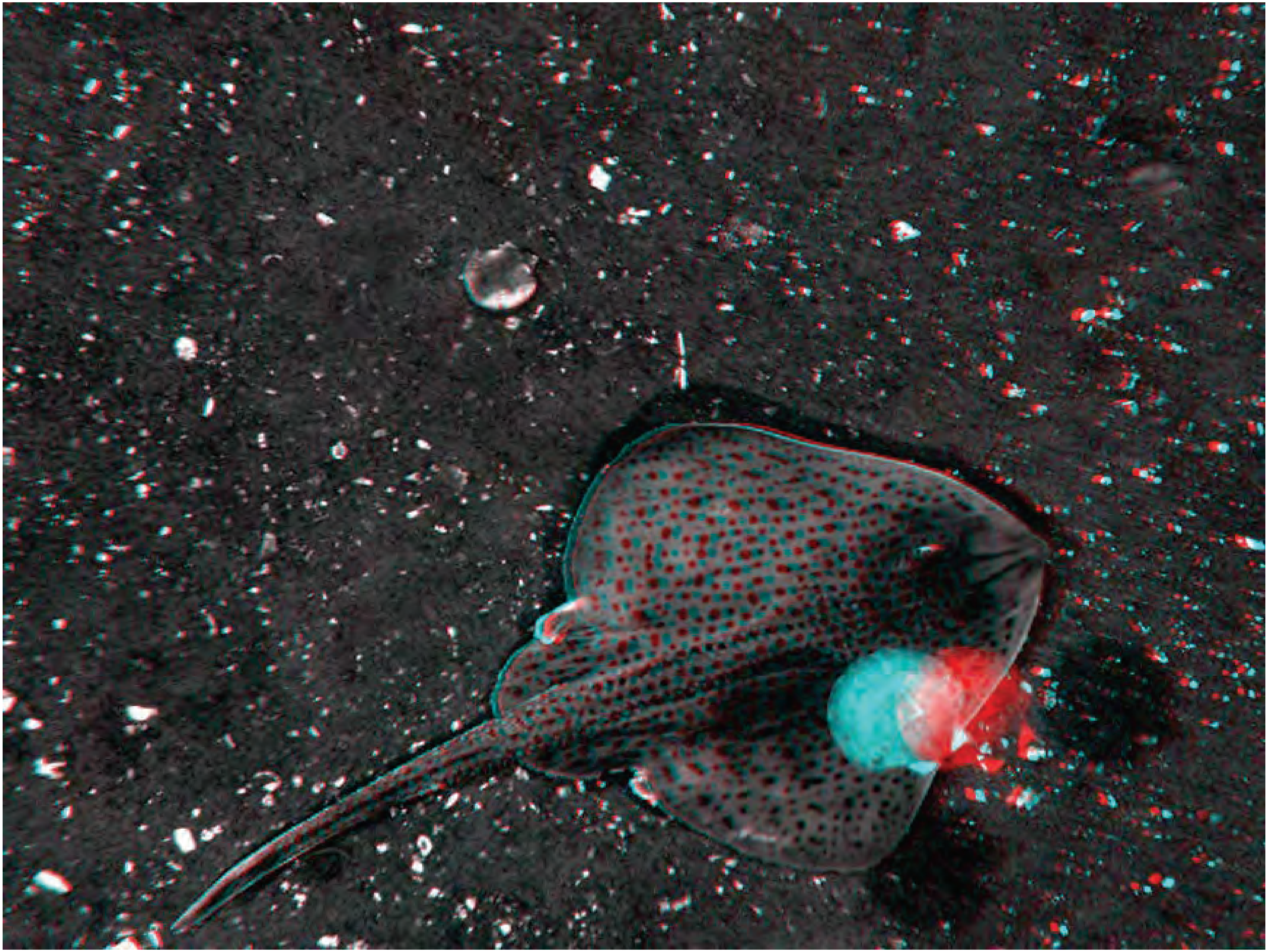

Northern lobster
Homarus americanus

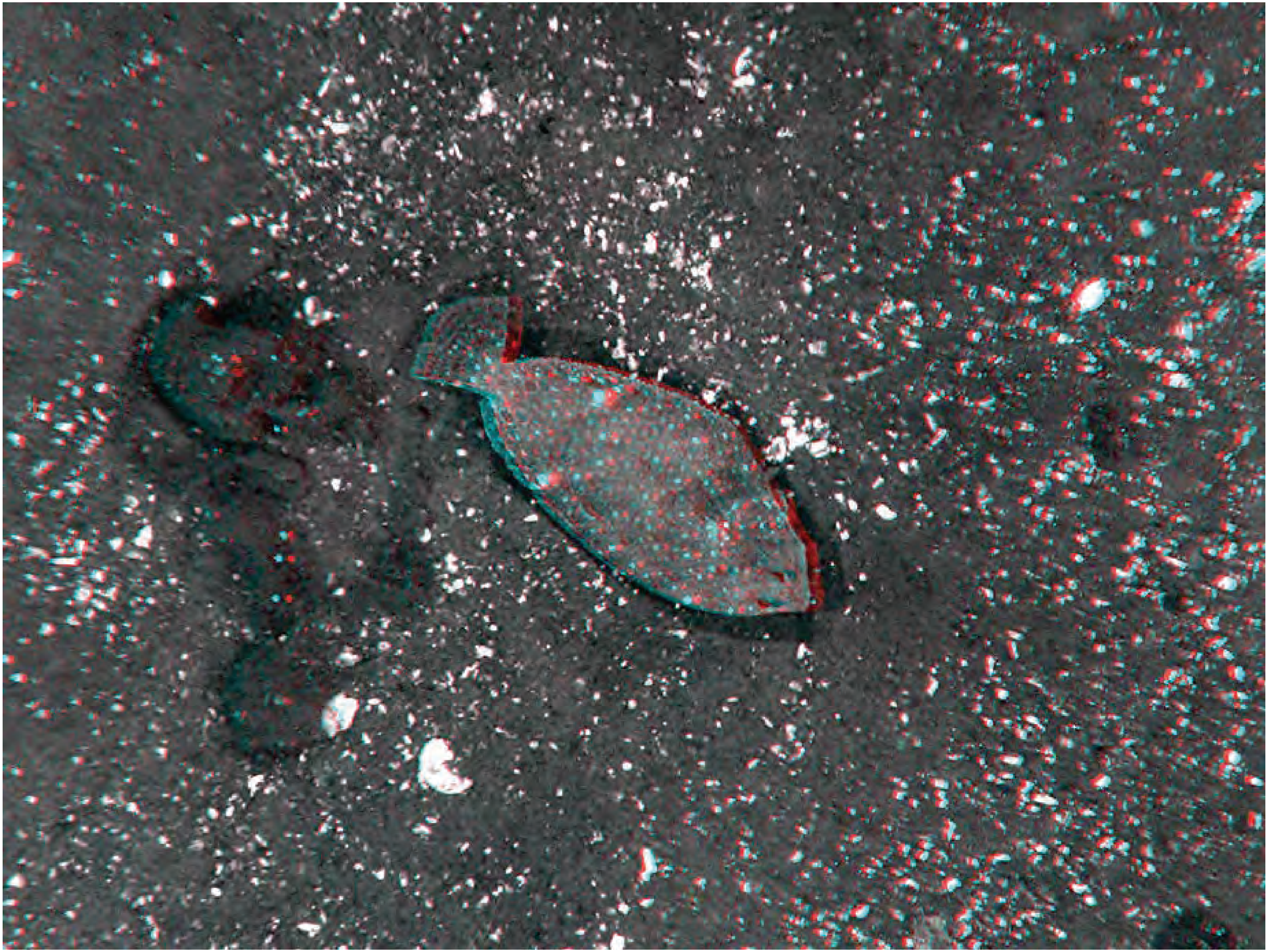

Sponge
Halichondria sp.

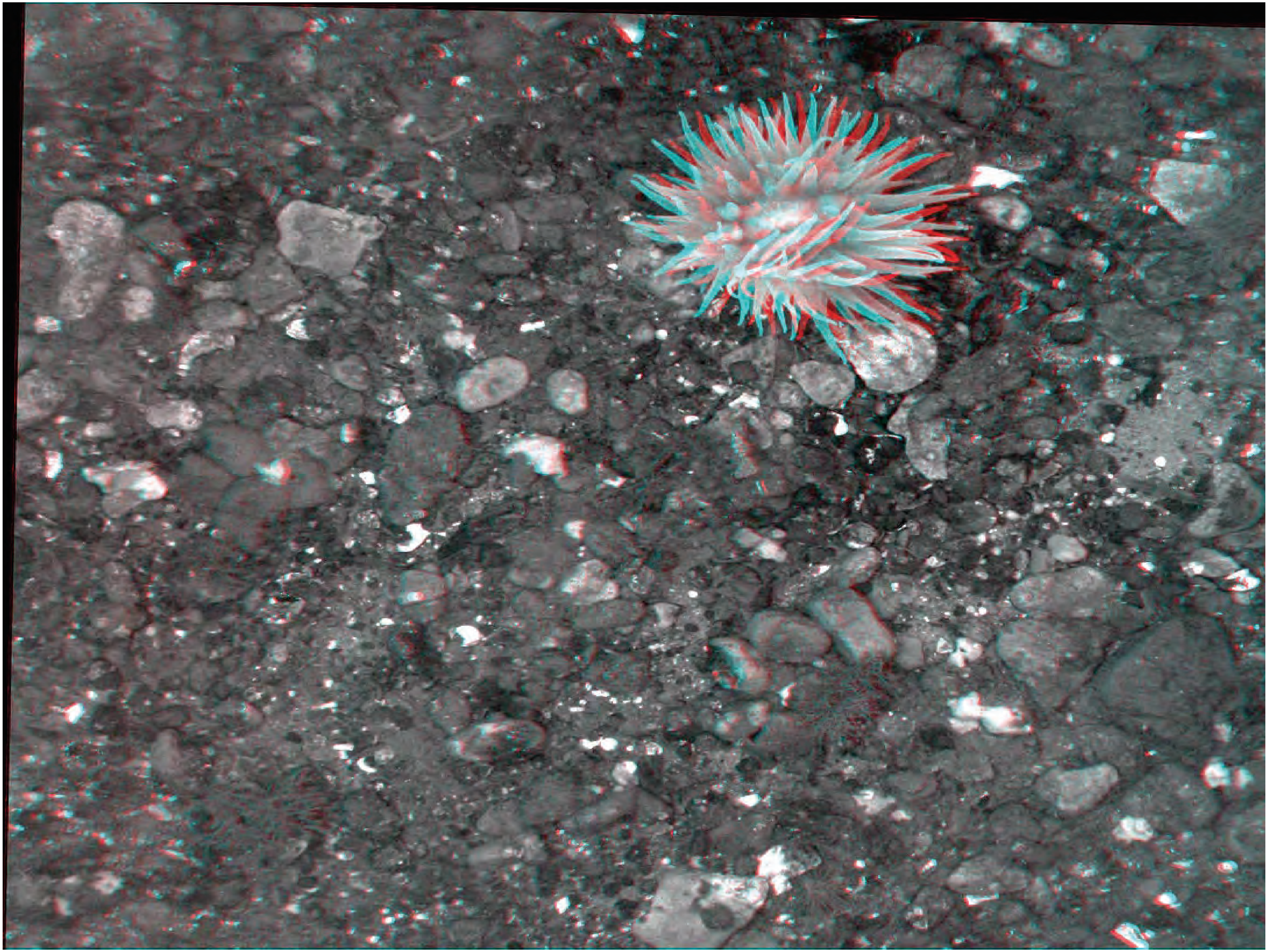

Please put on your red/cyan stereo glasses!

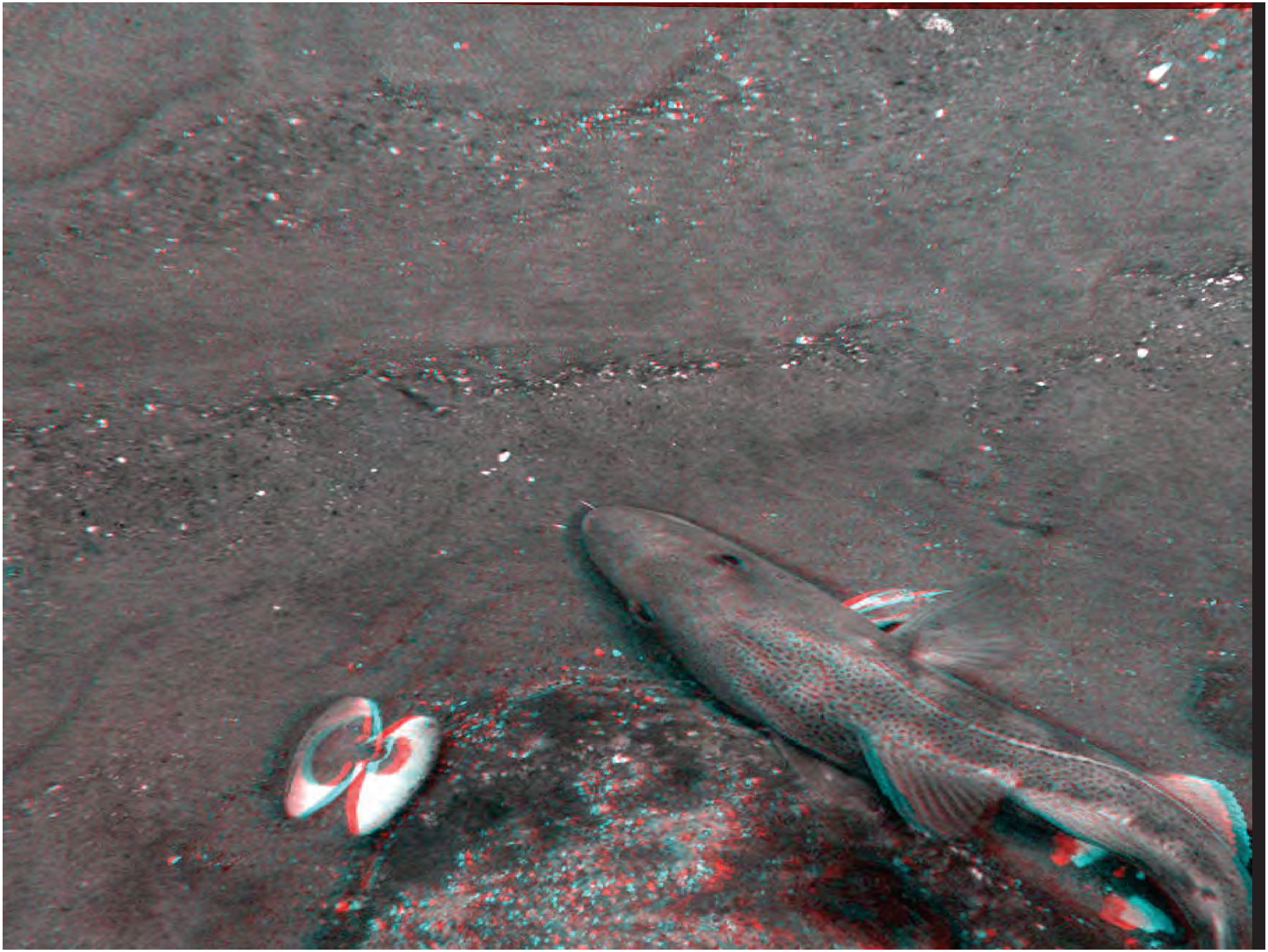


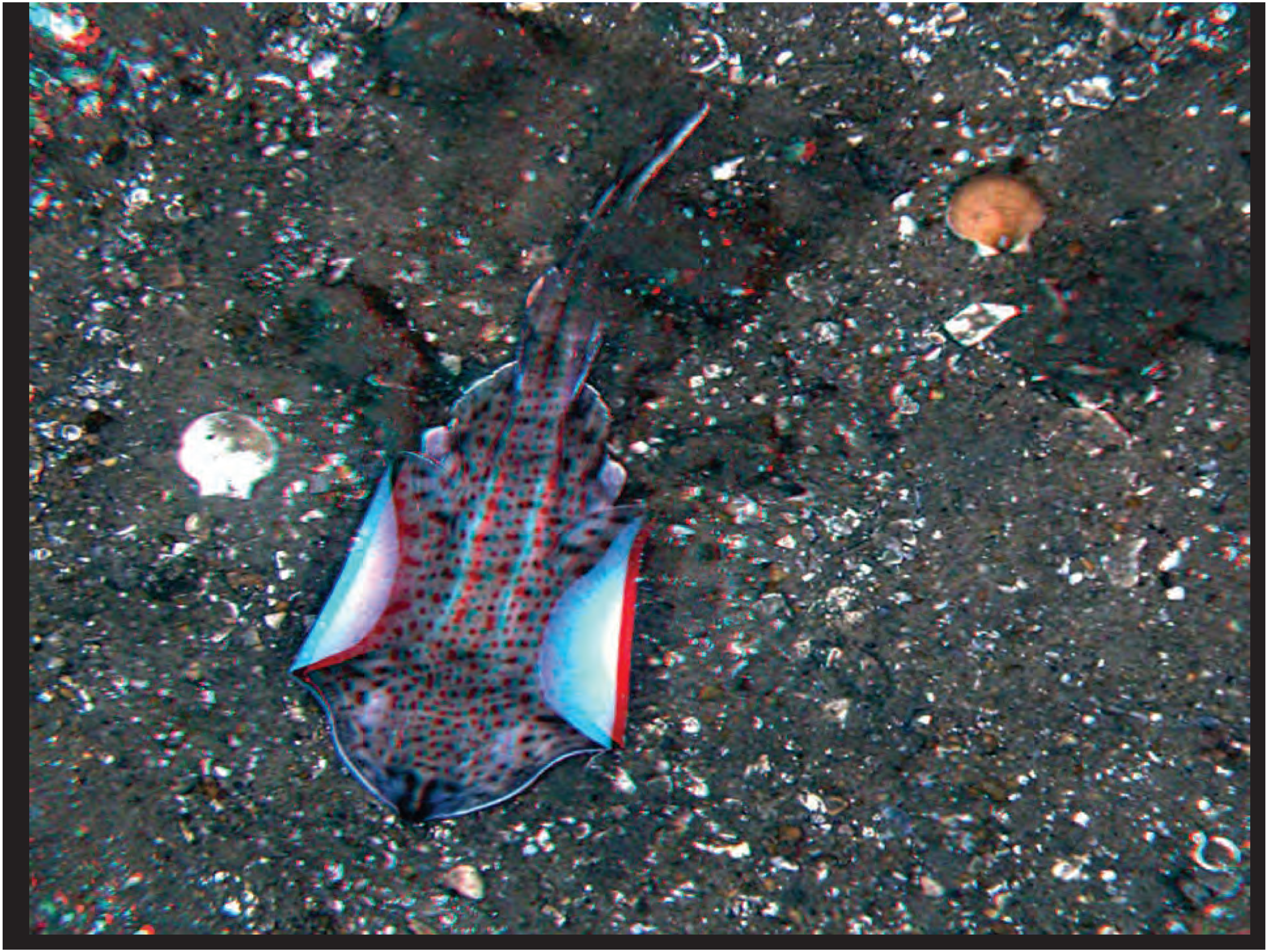


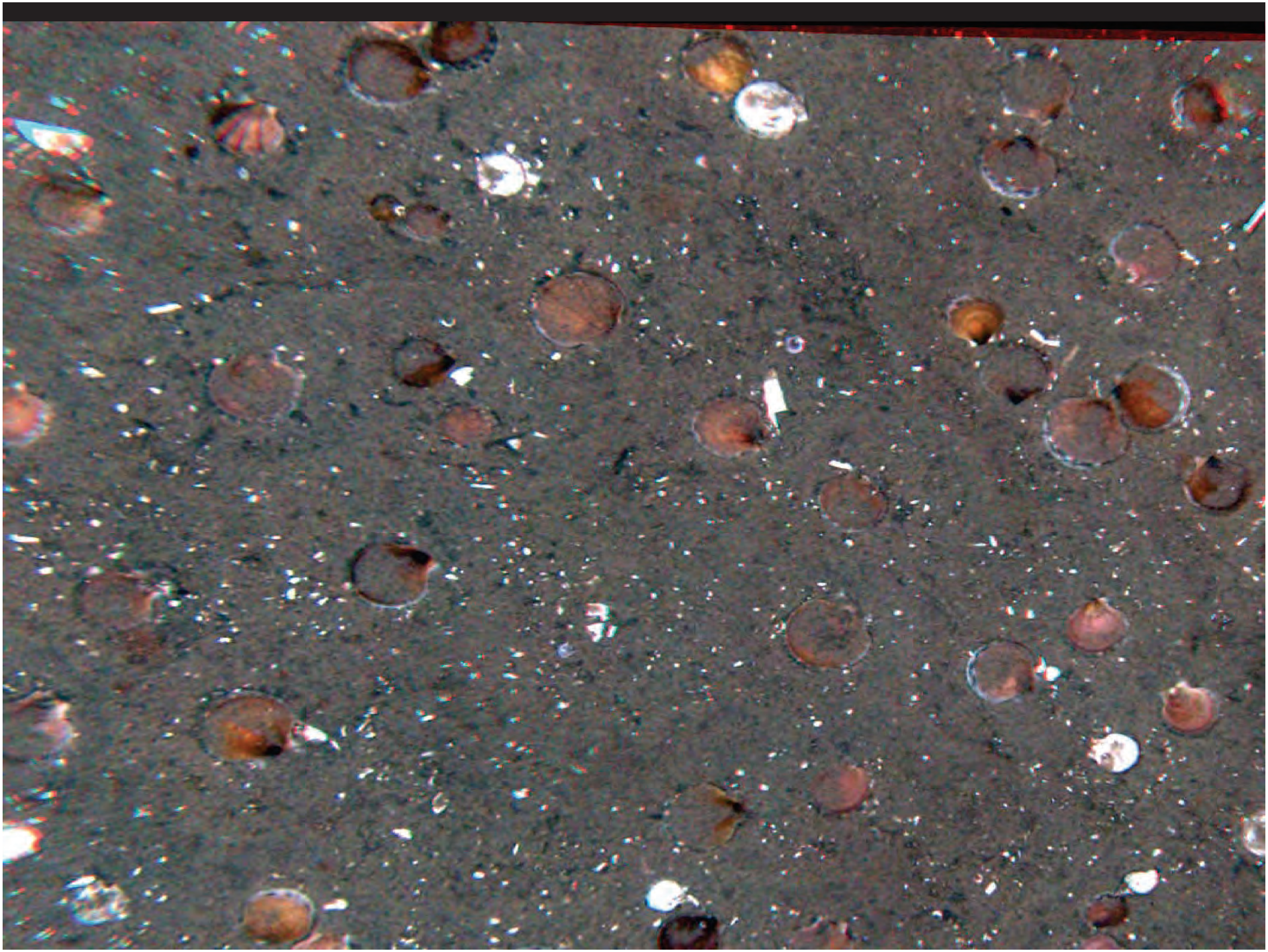


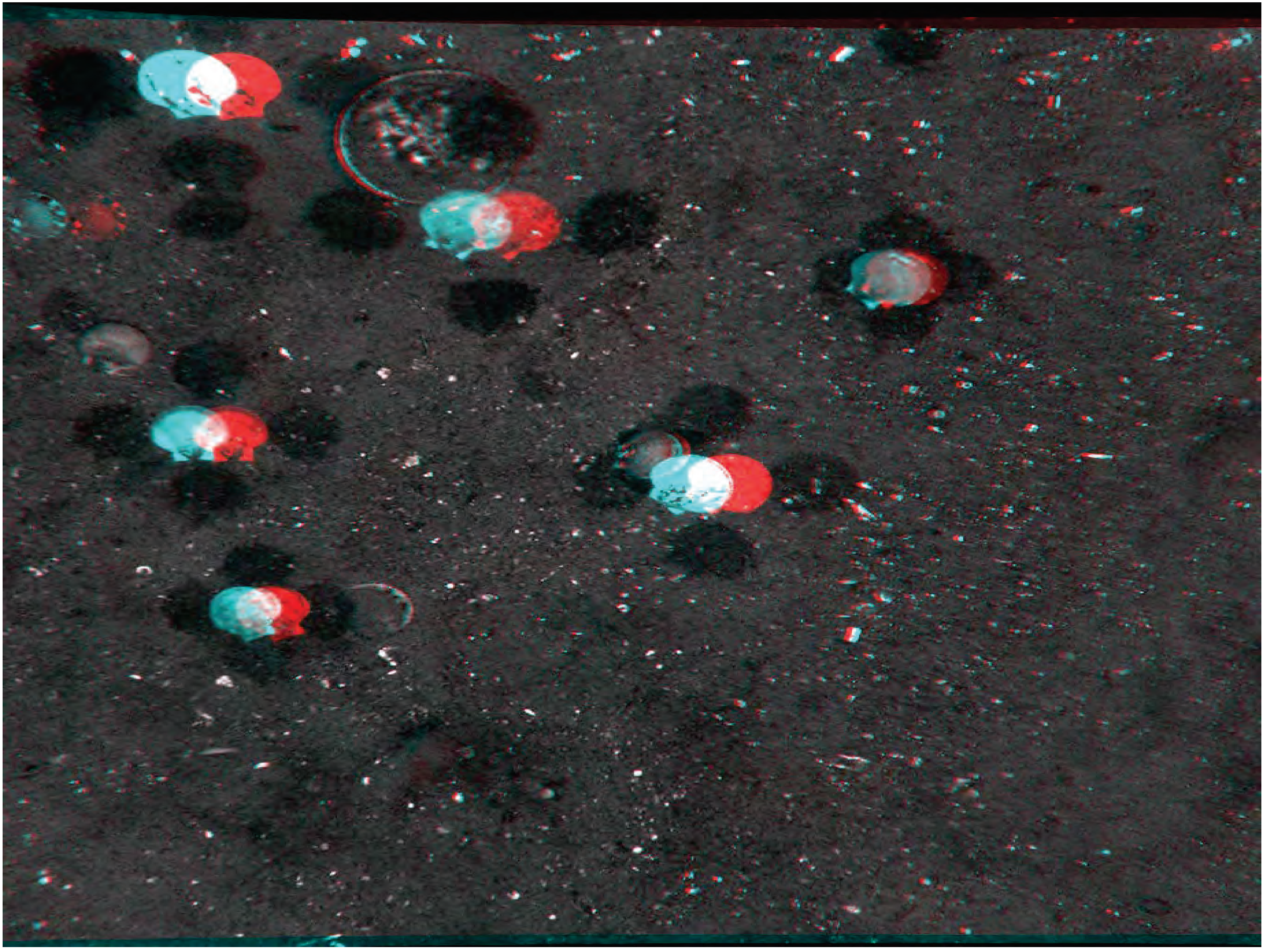


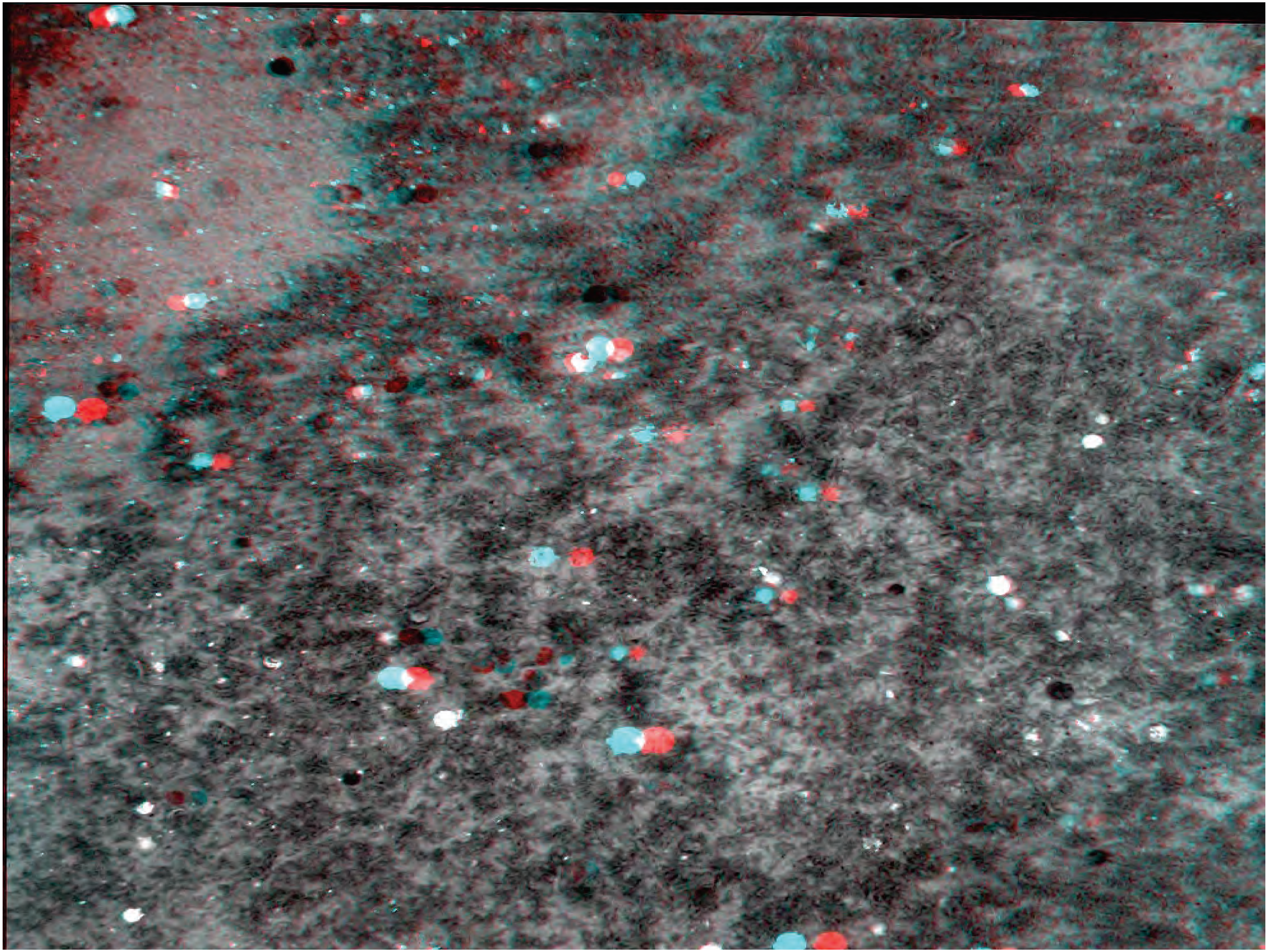


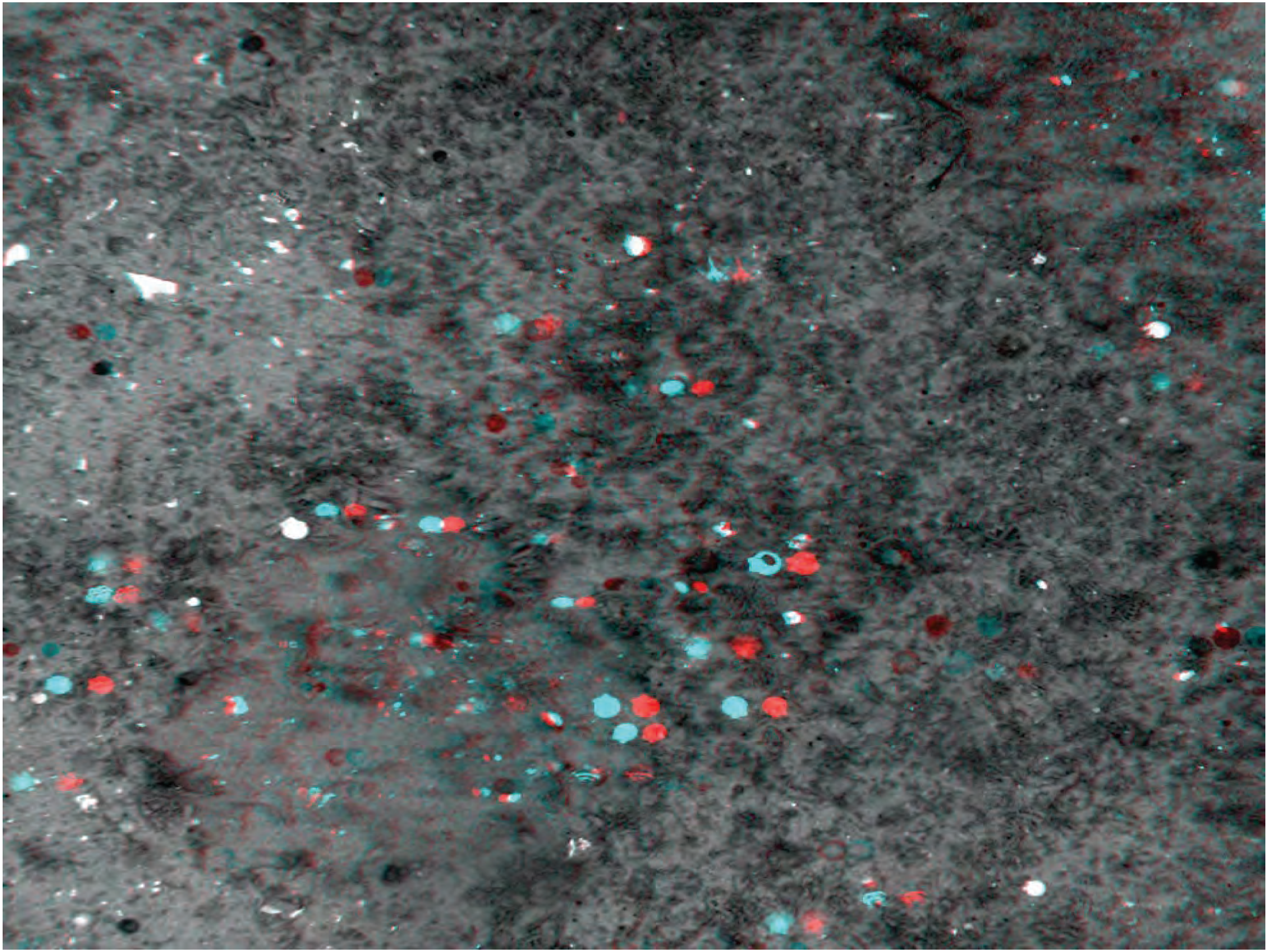


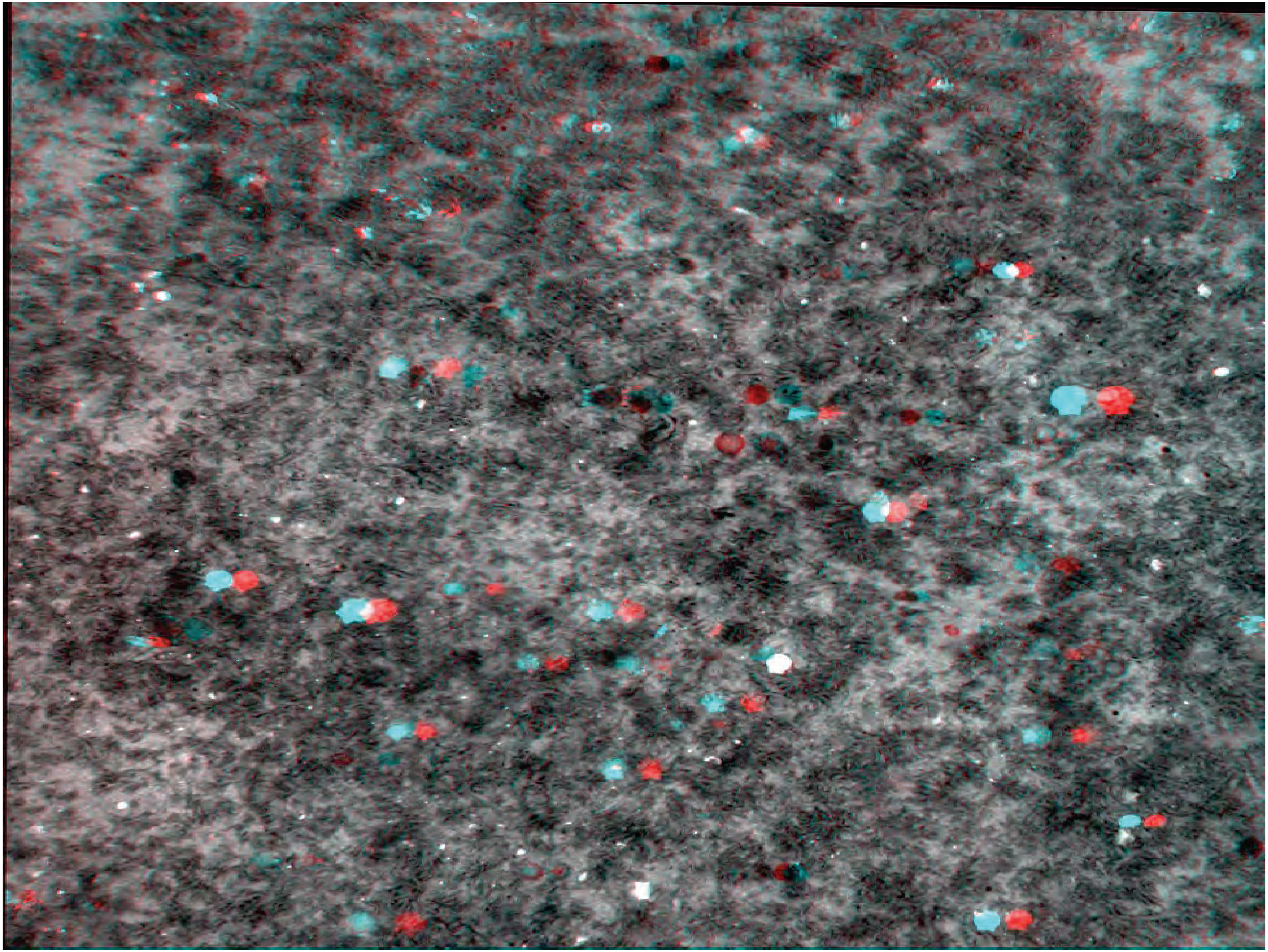


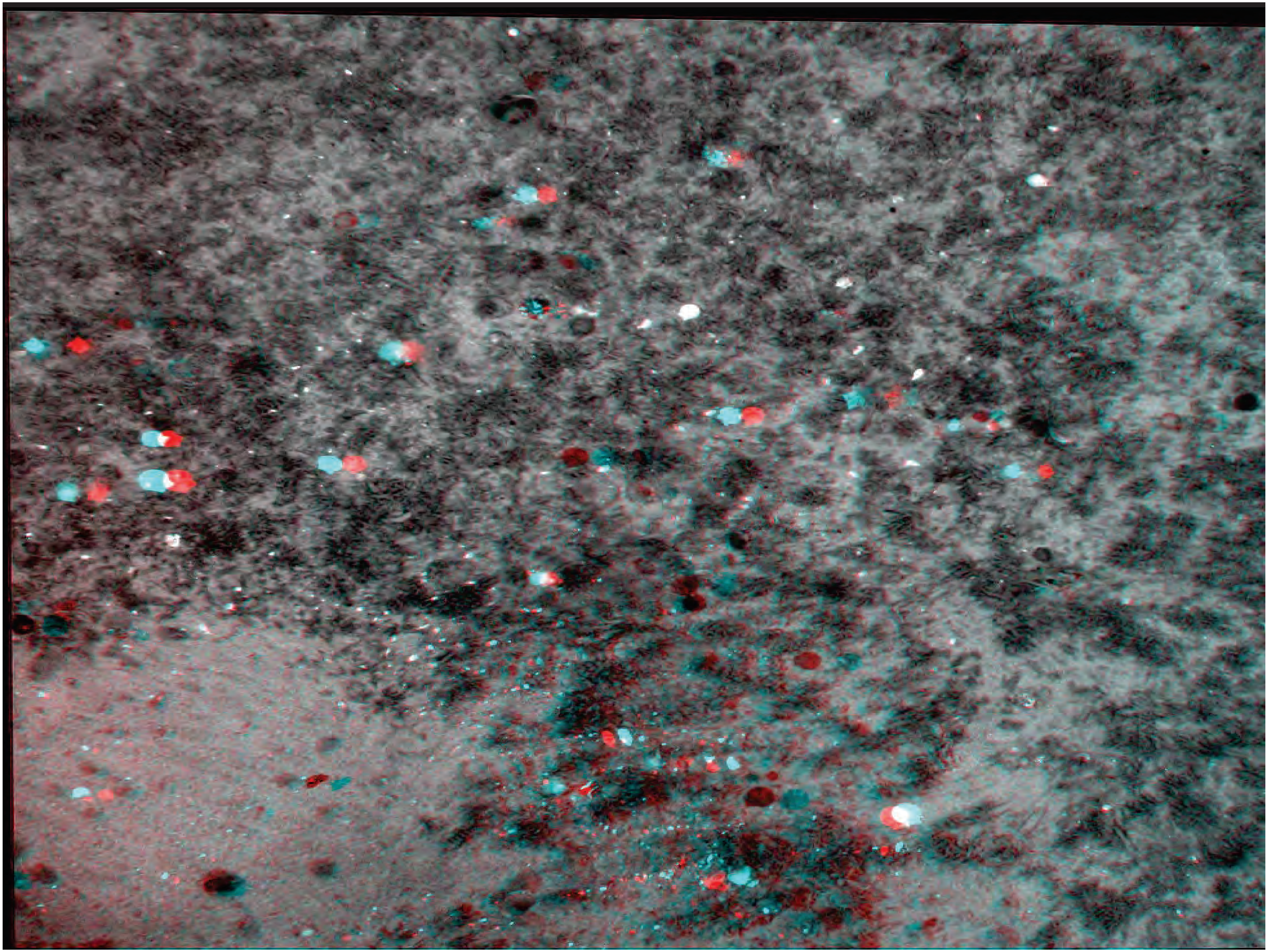


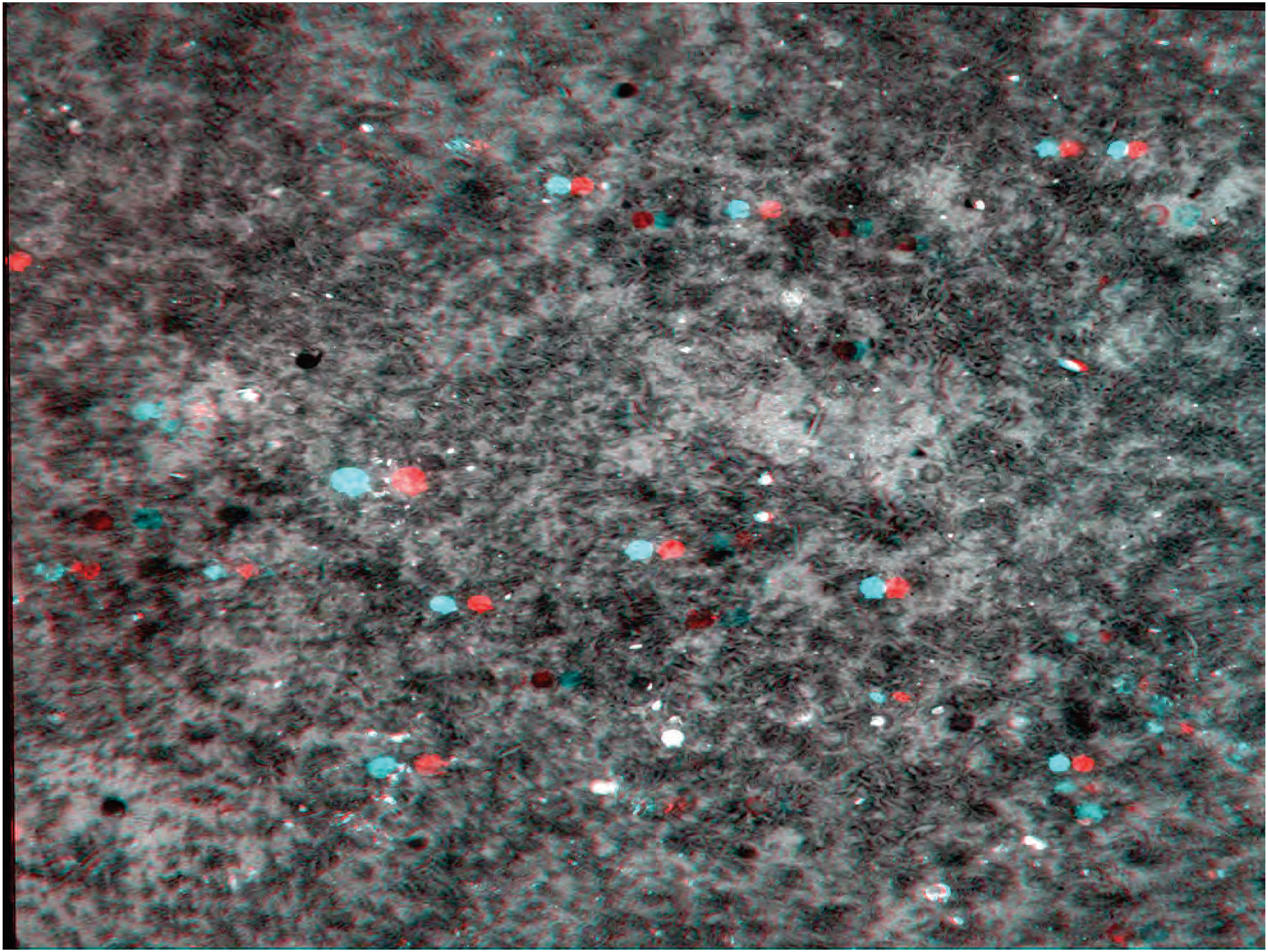






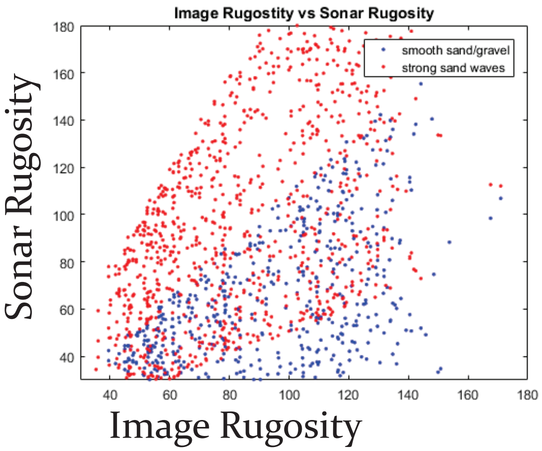


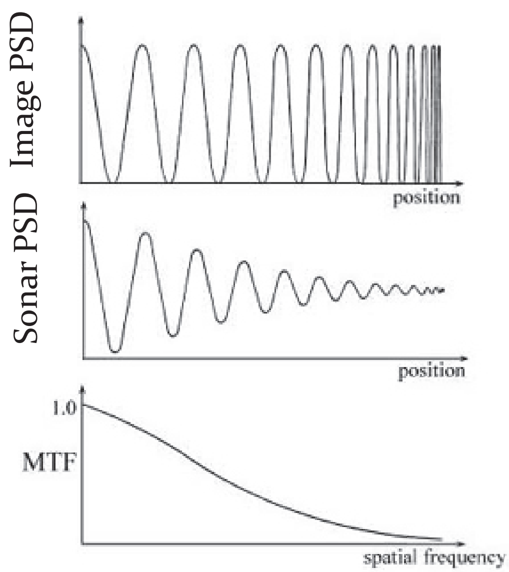




Modulation Transfer Function (MTF)

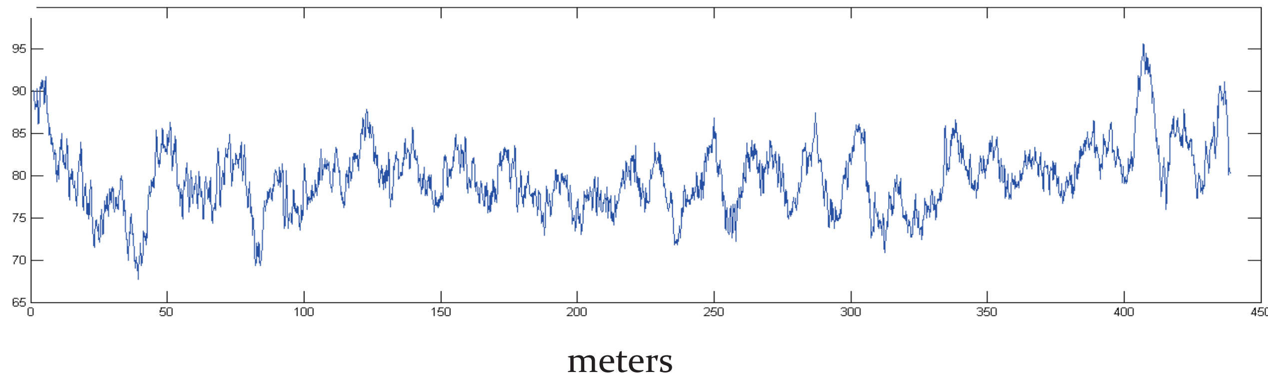
Transfer of energy (Power Spectral Density) from image scale (1 mm) to sonar scale (50 m) using Rugosity





$$MTF\ (\xi)\ =\ M_{sonar}\ /\ M_{image}$$

Along Track Seafloor Rugosity from merged acoustics and optics



Power Spectral Density of Seafloor Rugosity