A review of the NEFMC's assessment of adverse effects from fishing on habitat

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Outline

- Objectives and approach
- Models and analyses
  - Vulnerability Assessment
  - SASI Model
  - LISA Analysis
  - Cost-efficiency Analysis
  - Area Closure Analysis
- Conclusions
- Next steps

Phase 2 Objectives

- Identify all major fishing threats to the EFH of those species managed by the Council
- Identify and implement mechanisms to protect, conserve, and enhance the EFH of those species managed by the Council, to the extent practicable.
- Define measurable thresholds for achieving the requirements to minimize adverse impacts to the extent practicable
- Integrate and optimize measures to minimize the adverse impacts to EFH across all Council managed FMPs

PDT’s Phase 2 Research Questions

1. Which fishing activities are likely to have impacts that reduce the quality or quantity of EFH in a manner that is more than minimal and not temporary in nature?
2. Where within the management domain are potential adverse effects from fishing most likely to be found?
3. Have the NEFMC’s management measures minimized adverse effects from fishing over time, and if so, how well or by how much?

First principles

- Literature indicates that primary effect of fishing is the physical modification of structural features
- Different species utilize structure differently, but gear impacts to structure are independent of species
- *Adverse effects from fishing are primarily a function of gear impacting physical features*

Safety tips

- We do not address the more fundamental issues that deal with the relationship between fishery productivity and fish habitat
- We do not seek to define "essential", nor which habitats are essential for which species of fish. *This has been done in a prior assessment, with a different set of research questions* (*Phase I*)
- **We focus on the modification of structure by fishing gears**

Models and analyses

1. Vulnerability Assessment
2. SASI Model
3. LISA Analysis
4. Cost-efficiency Analysis
5. Area Closure Analysis

Vulnerability Assessment

The purpose of the vulnerability assessment is two-fold:

1. Summarize the vulnerability of seabed habitats to bottom-tending fishing gears, by gear type
2. Parameterize spatially-referenced SASI model using susceptibility (S) and recovery (R) scores (0-3)

Comprehensive, quantitative, traceable

Literature review

- 101 studies pertinent to our area and our gears
- Majority of studies examined effects of trawls (>70)
- Fewer studies for hydraulic dredges (17) and scallop dredges (11)
- Even fewer studies for fixed gears (5)
- Experimental fishing studies found to be most useful for S determinations (≈50, 25 for single gear pass)
- Recovery examined in only a third of studies, many of those short-term or open vs. closed areas

Susceptibility and recovery

Susceptibility = percentage reduction in functional value of a habitat component following a single tow or haul

Recovery = time (years) required for the functional value of that unit of habitat to be restored

Code	Susceptibility	Recovery
0	0 – 10%	< 1 year
1	>10%-25%	1 – 2 years
2	25 - 50%	2 – 5 years
3	> 50%	5-10 years

Evaluate S/R matrices

- S and R were evaluated for each gear/feature interaction

Gear: Trawl							
Substrate: Mud							
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S High**	**S Low**	**R High**	**R Low**
Biogenic burrows (G)	filling, crushing	334, 408, 409	97, 101, 313, 333, 336, 407	2	2	0	0
Biogenic depressions (G)	filling	236, 408, 409	101, 247, 336	2	2	0	0
Sediments, surface (G)	re-suspension, compression, geochemical	88, 92, 211, 236, 330, 334, 406, 408, 409, 599	88, 97, 211, 247, 277, 283, 313, 320, 333, 335, 336, 338, 372, 407, 414	3	3	0	0
Amphipods, tube-dwelling (B) – see note	crushing	34, 113, 119, 211, 228, 292, 334, 408, 409, 599, 658	89, 80, 97, 113, 149, 320, 575	1	1	0	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	2	2	2	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	101, 164	2	2	2	2
Hydroids (B)	breaking, crushing, dislodging, displacing	408, 409	368	1	1	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	21, 34, 368, 408, 409	89, 203, 360, 368	2	2	3	3

Susceptibility – major results

Broadly:

- moderate S scores for trawls and scallop dredge gears
- high S scores for hydraulic dredge gears
- low S scores for fixed gears

In most cases the literature did not support:

- Disaggregating susceptibility between high and low energy environments
- Disaggregating susceptibility across features common to multiple substrates
- Different susceptibility scores for scallop dredges and otter trawls (inadequate information for scallop dredges)
- Different susceptibility scores for different types of trawls (so, S was evaluated uniformly for all four trawl types)

Recovery – major results

- Recovery times for biological features were generally independent of energy and substrate
- Recovery times for geological features were often independent of energy and substrate
- Due to different qualities of gear effect, longer recovery times associated with trawls/scallop dredges vs. hydraulic dredges vs. fixed gears
- Biological feature recovery times more homogeneous that geological feature recovery times

Which fishing activities are likely to have impacts that reduce the quality or quantity of EFH in a manner that is more than minimal and not temporary in nature? (PDT Research Question (1))

- All gear types have the potential for more than minimal adverse effects (i.e. susceptibility values > 0)
- All gear types have the potential for generating adverse effects that are not temporary (i.e. recovery values >0)
- To understand gear-specific adverse effects spatially, plug VA-derived S and R values into model

SASI model

$$Z = A\omega$$

Where:

Z = adverse effect; the swept area seabed impact measured as area swept (km^2)

A = nominal area swept by one unit of fishing effort

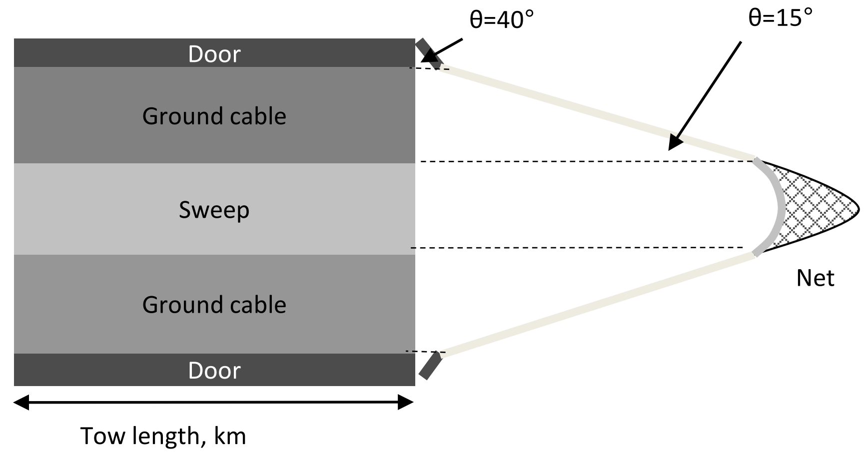
ω = vulnerability, a combination of:

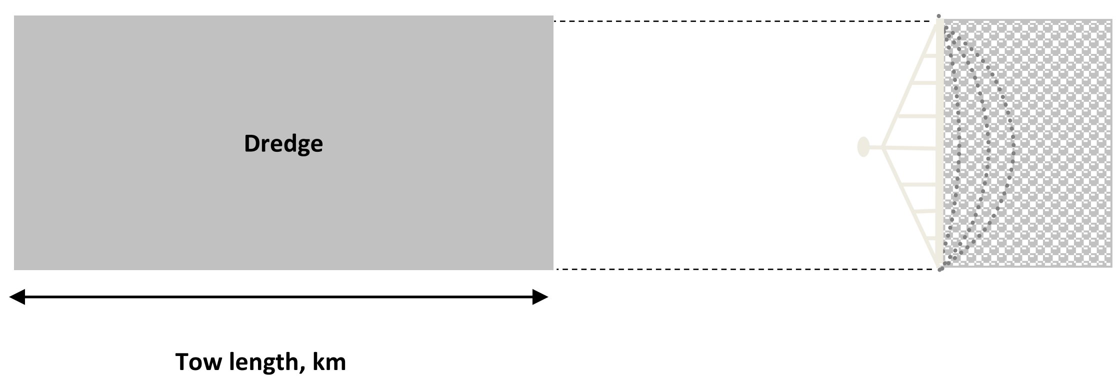
- Dominant substrate
- Energy environment
- Fishing gear type

SASI is a *spatial model* that represents the vulnerability of physical structure to the adverse effects of fishing

Area Swept

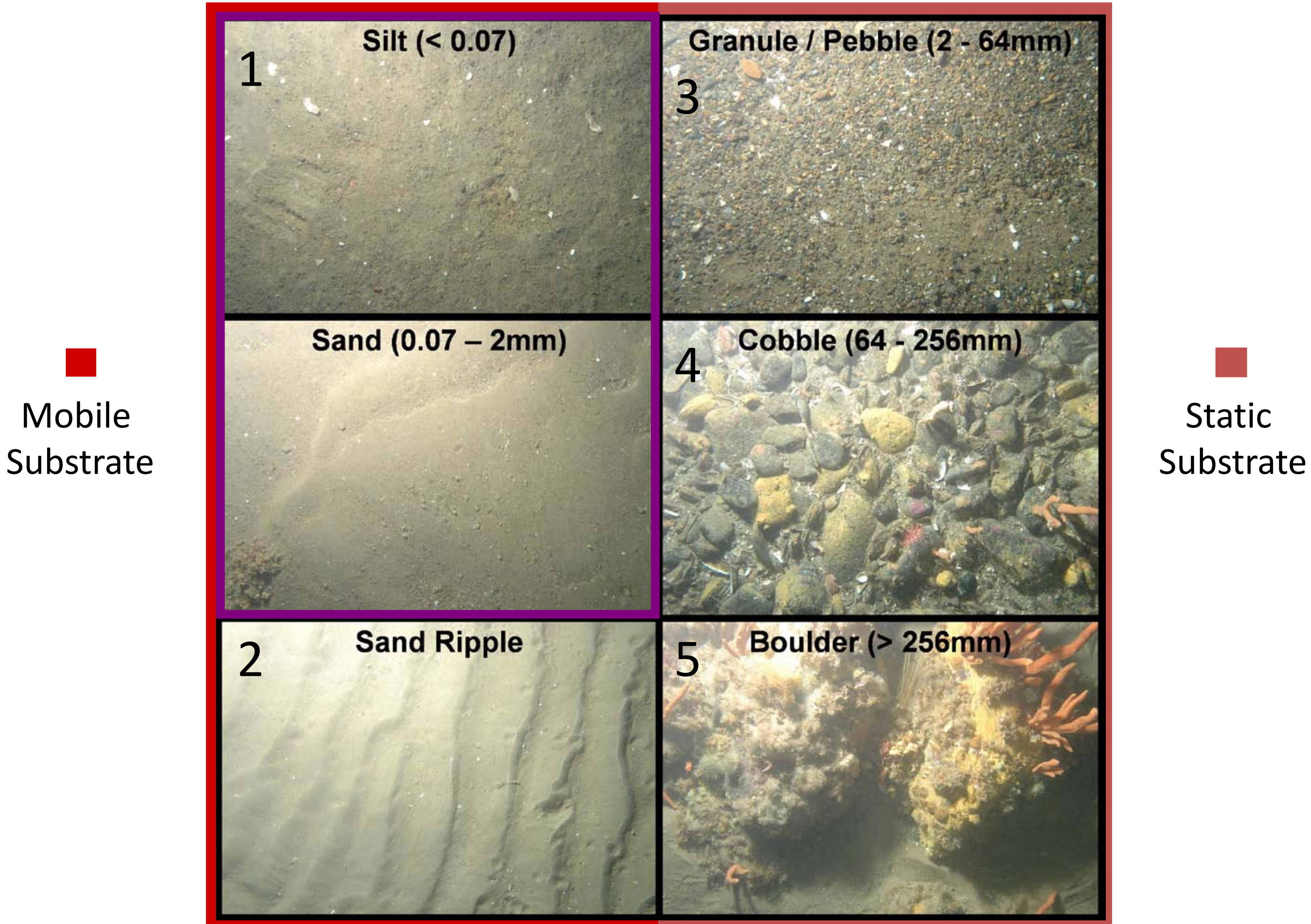
- Generic otter trawl
- Squid trawl
- Shrimp trawl
- Raised footrope trawl
- General category scallop
- Limited access scallop
- Hydraulic clam dredge
- Longline
- Gillnet
- Trap





Dominant substrate

Substrates are visually identified following the Wentworth particle grade scale



Continental Shelf Scale Geological Datasets

Figure 1. ecstdb2005, 1955 – 2004
Geological Data (N = 16,500)

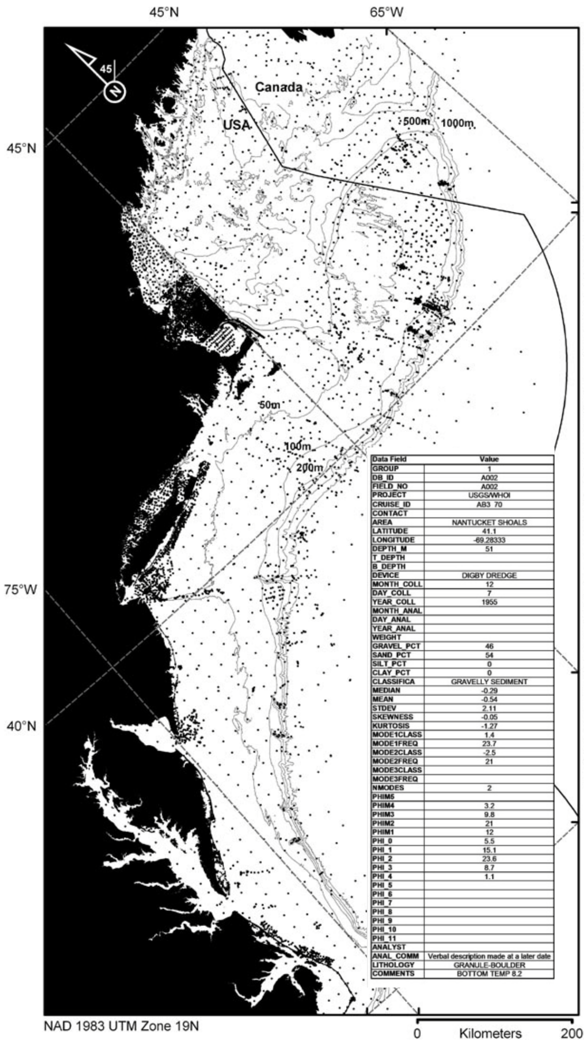


Figure 2. usSEABED alt_ext, ?? years
Geological Data (N = 23,000)

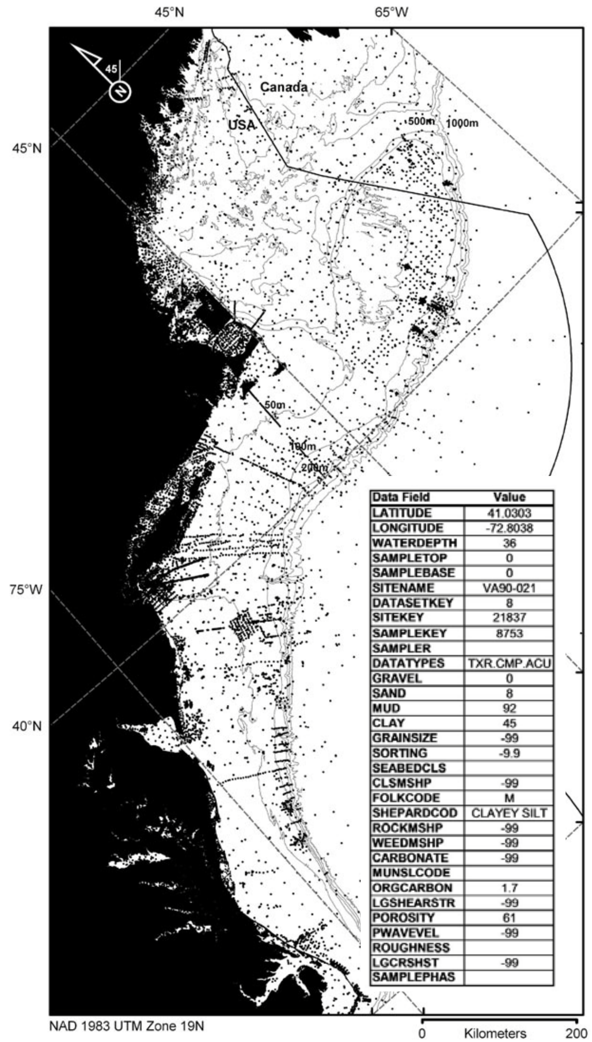
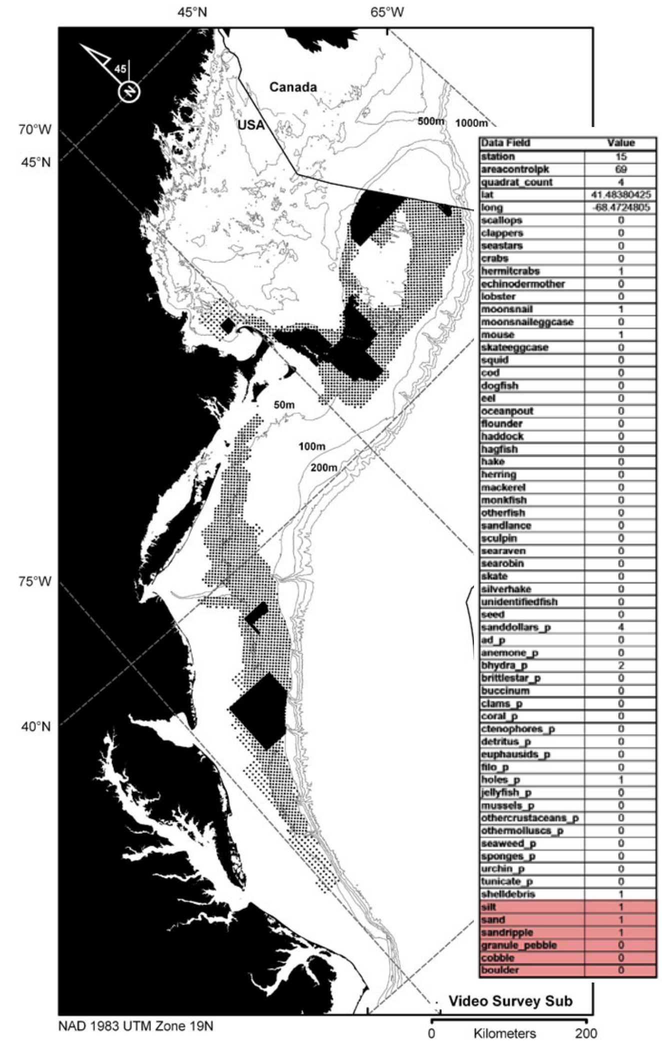
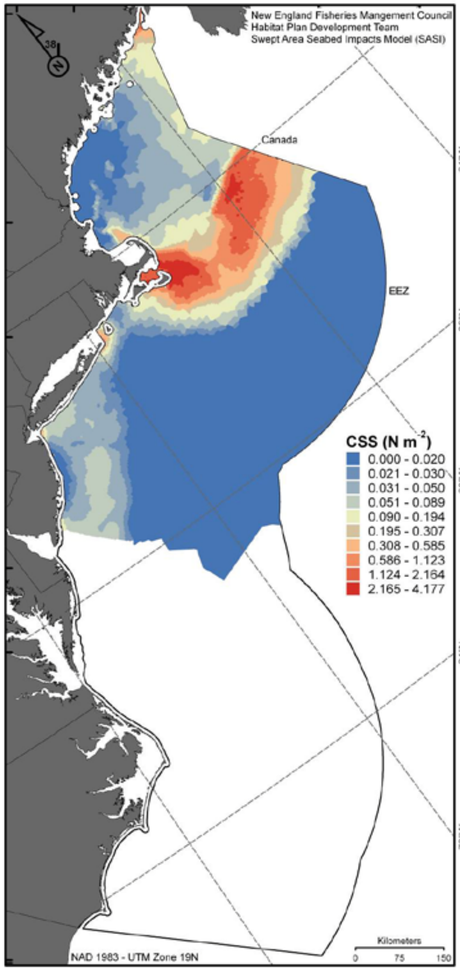
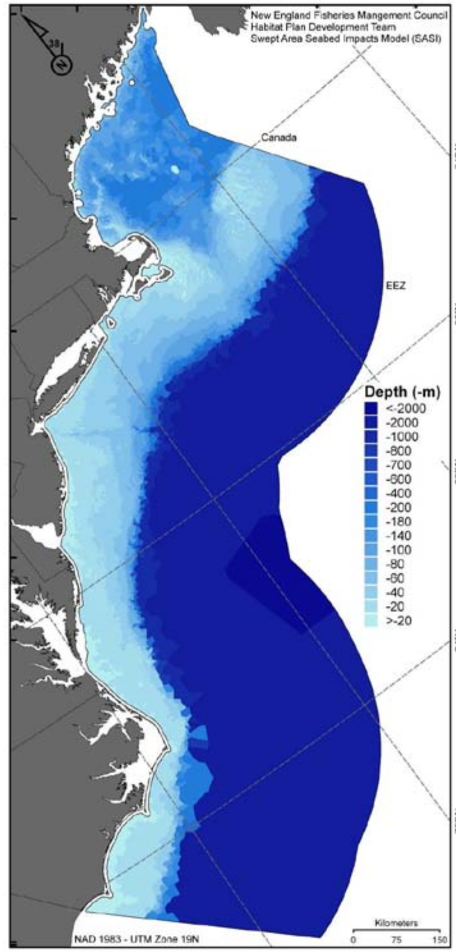


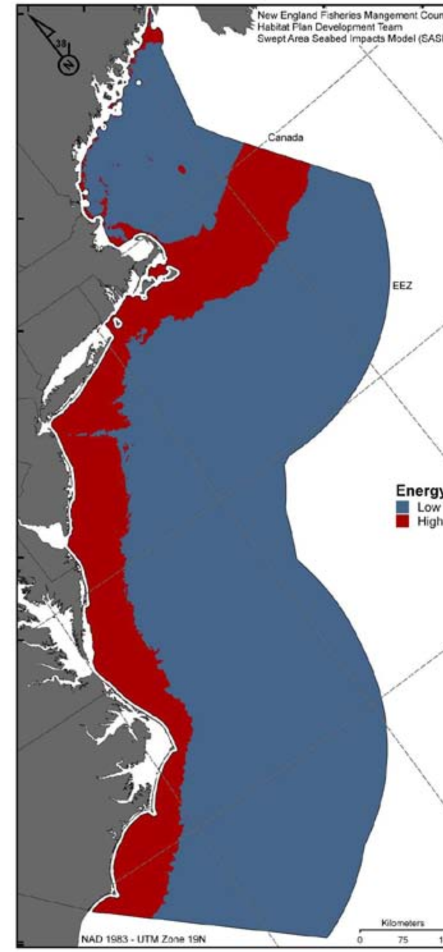
Figure 3. SMAST Video Survey, 1999 – 2007
Geological (red) and Biological Data (N = 143,327)



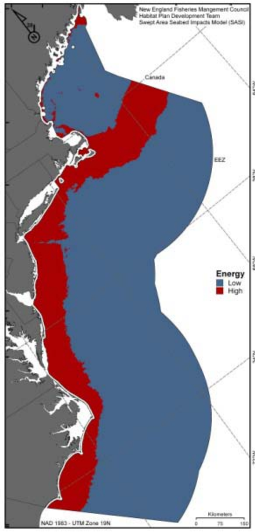
Sheer stress + Depth = Energy (H/L)





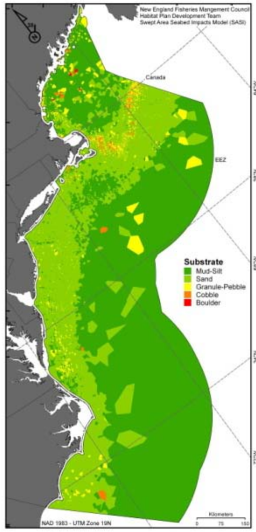


Energy and substrate, structured grid



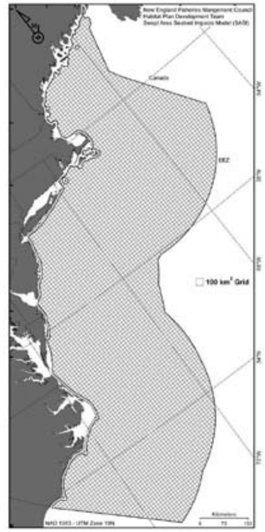
Energy

+



Substrate

+



Structured

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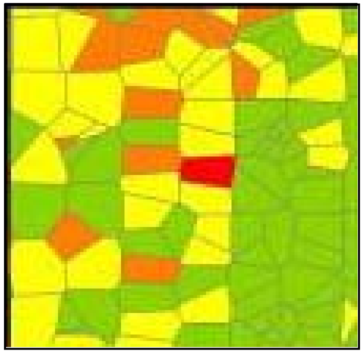


Individual structured grid cell with unstructured cells cracked to fit

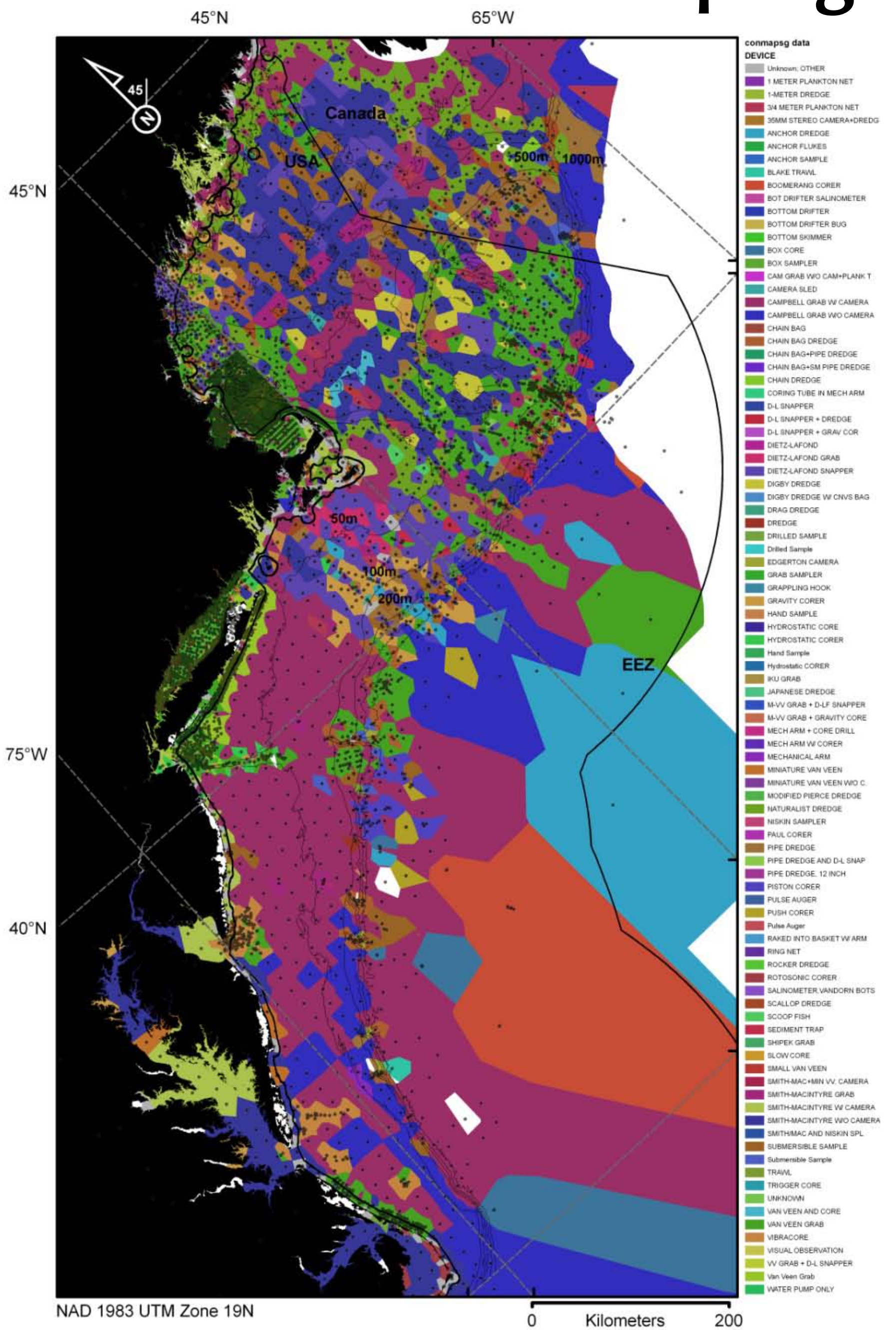
Uncertainties

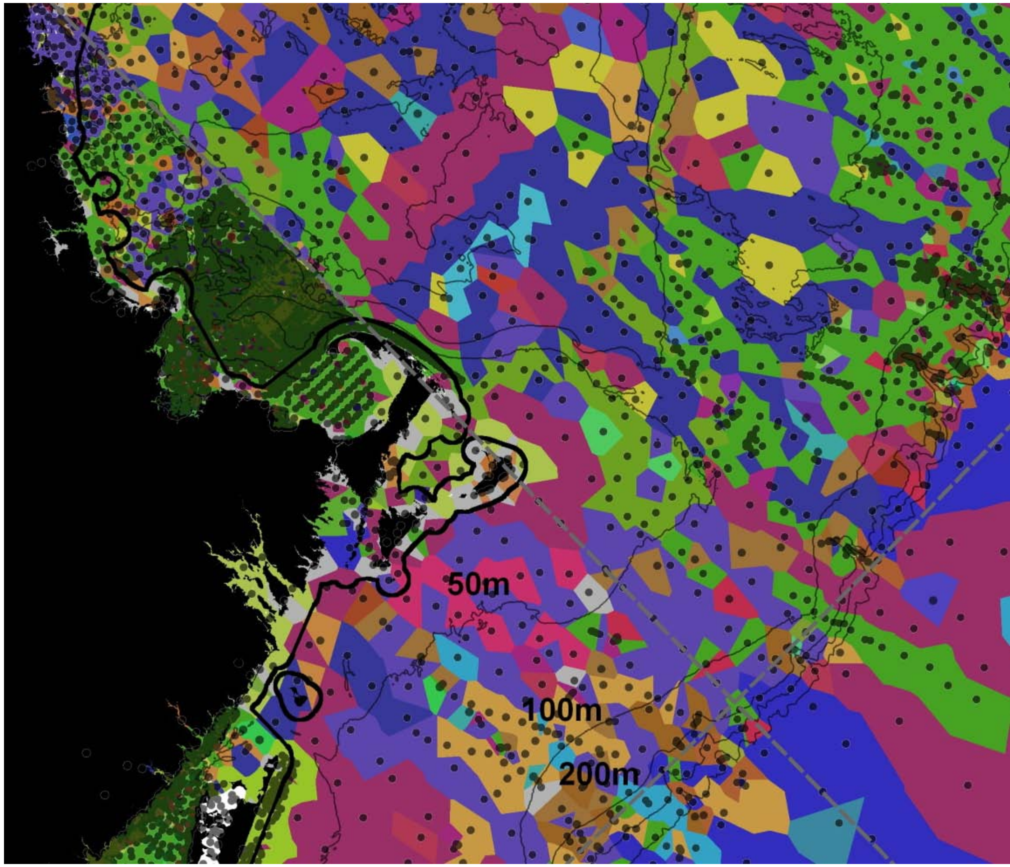
- S and R estimates reflect effects of single gear encounters
  - Effects of multiple tows are additive and linear
  - Recovery is independent of subsequent fishing events
- Direction of bias depends on whether first pass is more damaging than subsequent passes:
  - Impacts may be overestimated if yes
  - Impacts may be underestimated if cumulative effects get progressively worse with fishing intensity

Uncertainties, cont.

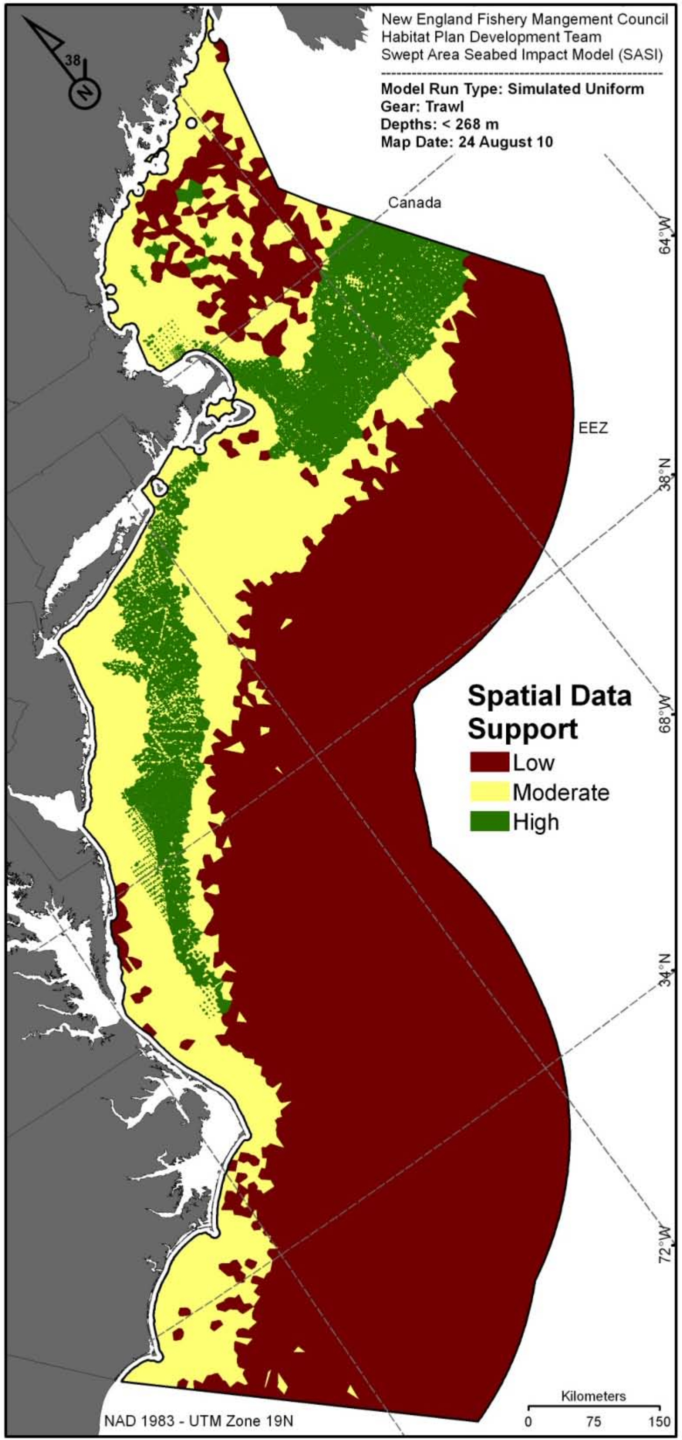
- Spatial resolution of fishing effort data is coarse (VTR)
- Data on frequency of use of different gear configurations (i.e. types of trawl sweeps) are not available
  - Gear effects homogenized
  - Gear area swept differentiated based on contact indices
- Model domain excludes areas inside 3 nm
- SASI time step is 1 year
  - adverse effects on shorter time frames (eg. seasonality) cannot be examined

Sampling Device (N = 64)





- Sample areas LIKELY range from 0.04 – 0.3 m^2.
- May not be capable of collecting coarse substrates (**pebbles, cobbles, boulders**).
- Data from different devices may mean different things.
- The *sample areas* for each device are NOT provided in the dataset.



Spatial Data Support

High = full range of substrates detectable, high sampling frequency

Moderate = only mud- granule pebble detectable or low sampling frequency

Low = only mud- granule pebble detectable and low sampling frequency.

Model outputs

Z (km2), two variants:

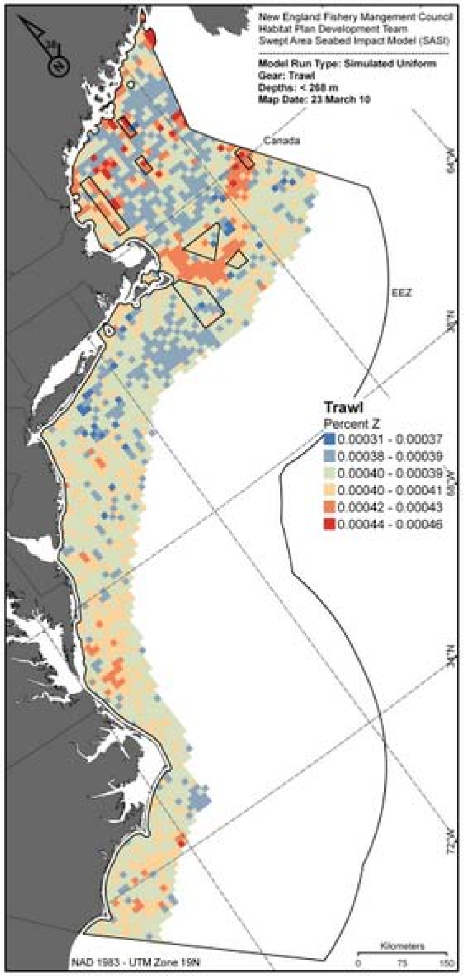
1. Z_{∞} (Z_{inf}): theoretical equilibrium Z by gear type based on a uniform-area swept model

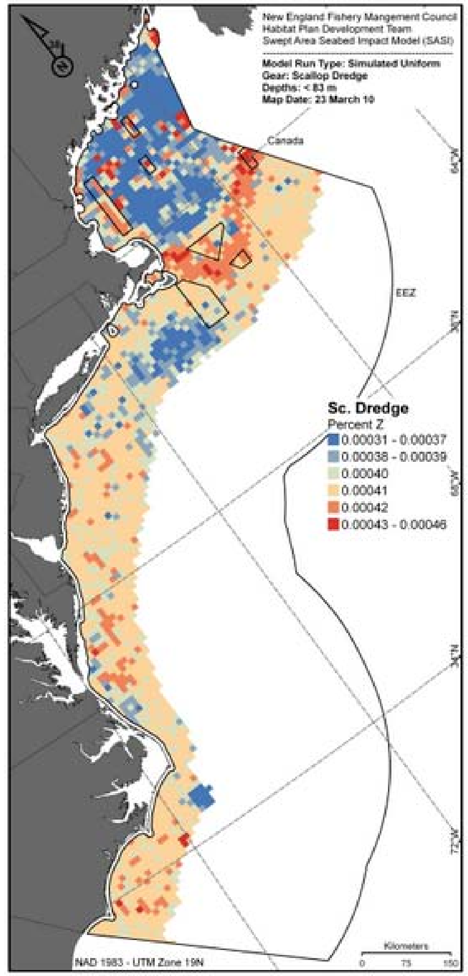
Addresses PDT research question (2): *"Where within the management domain are potential adverse effects from fishing most likely found?"*

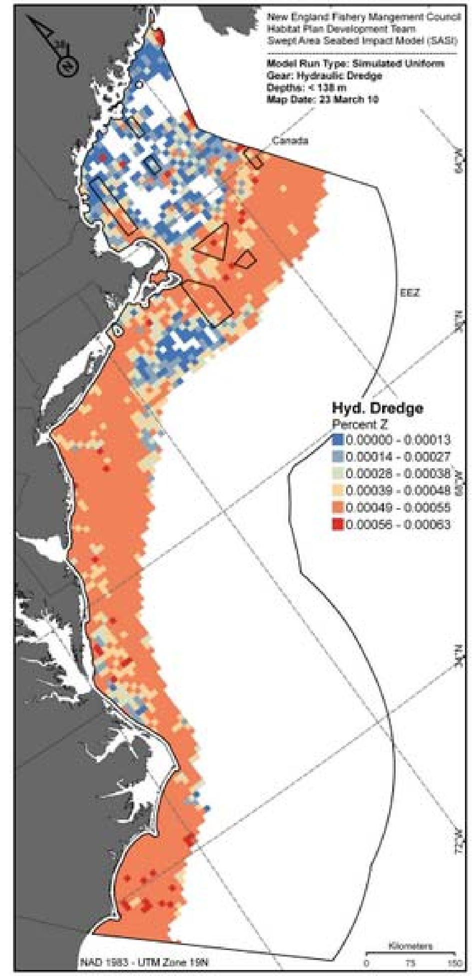
2. $Z_{realized}$: actual Z by gear type based on empirical fishery data

Address PDT research question (3): *"Have NEFMC's management measures minimized adverse effects from fishing over time, and if so, how well or by how much?"*

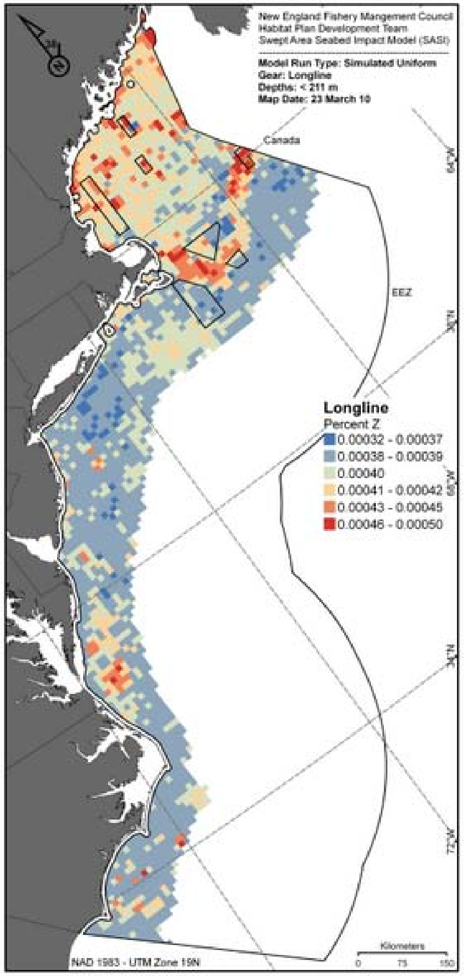
Z_{∞} – mobile gears

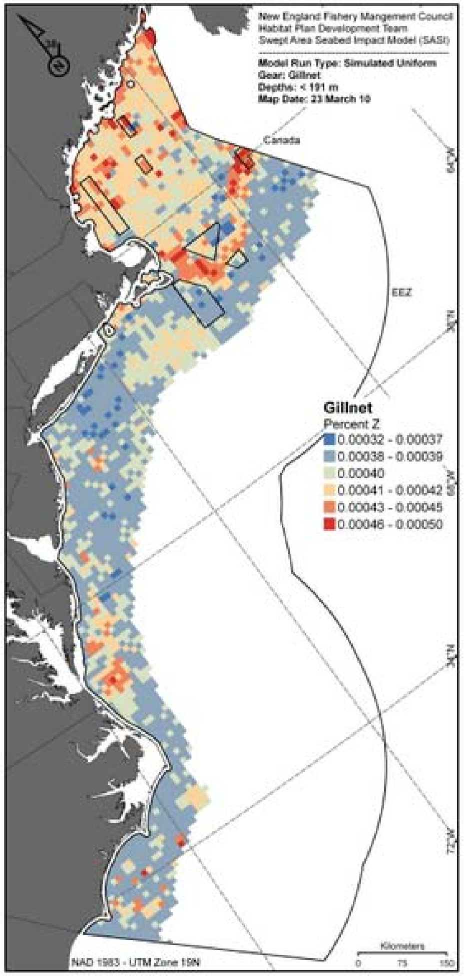


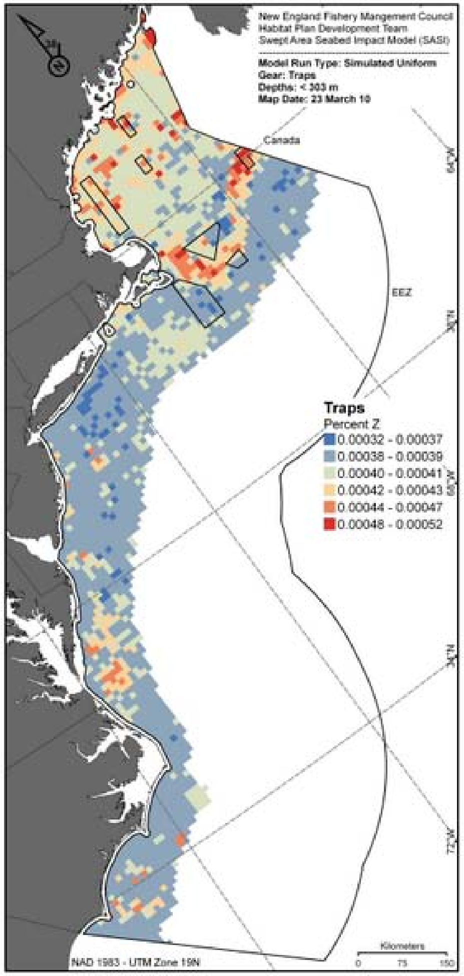




Z_∞ – fixed gears







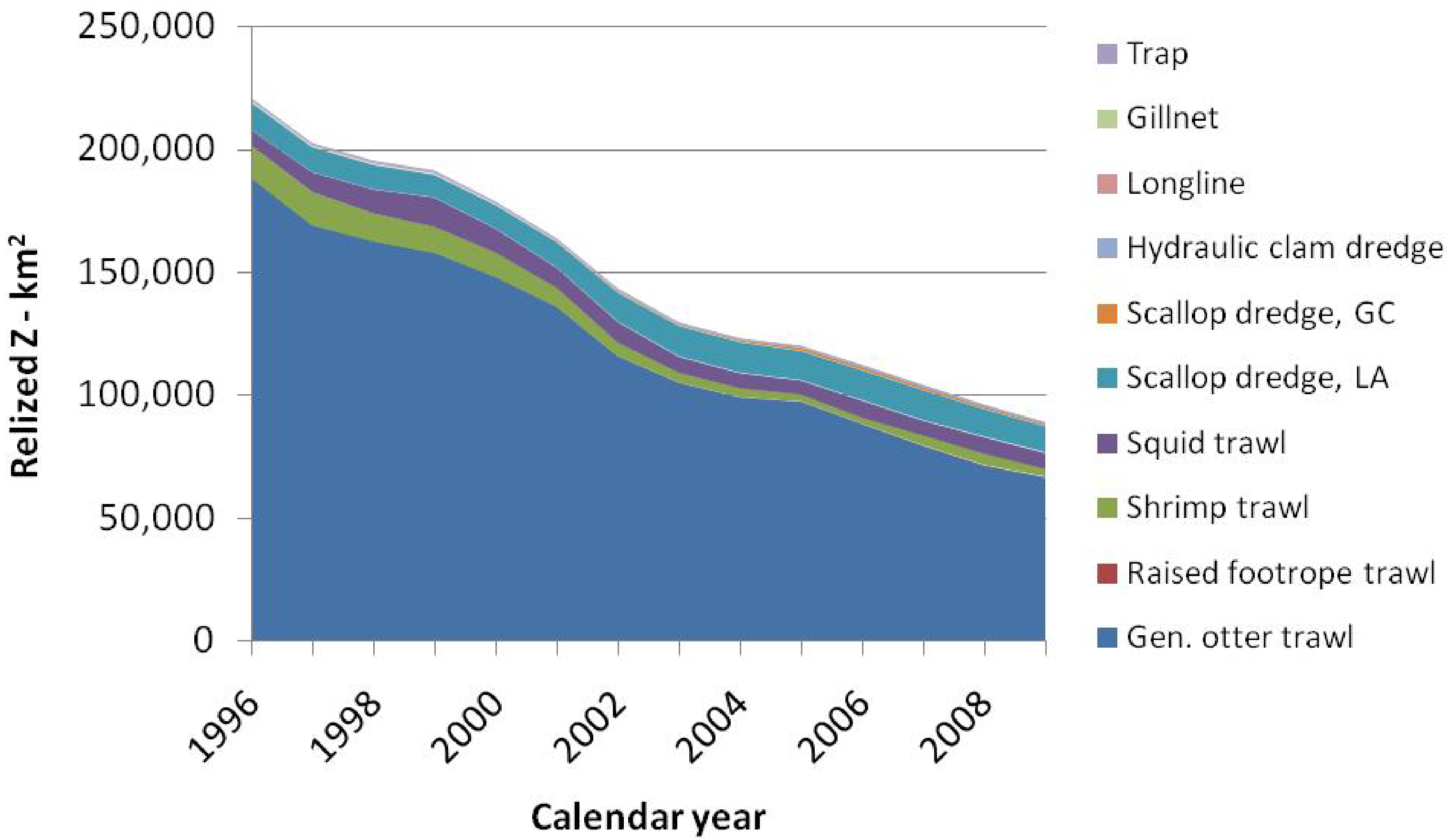
Z_∞ conclusions

- Distribution of adverse effects by parcel are strongly skewed
  - For all gears except TRAP, between 5-7% of parcels have Z_∞ greater than one stdev from mean
  - TRAP gear = 24.3% parcels > 1 stdev from mean
- Per-unit area swept, *potential* for adverse effects:
  - Highest for hydraulic clam dredge
  - Otter trawl and scallop dredge gears nearly identical, next-highest
  - Fixed gears similar, much lower

Estimating $Z_{realized}$

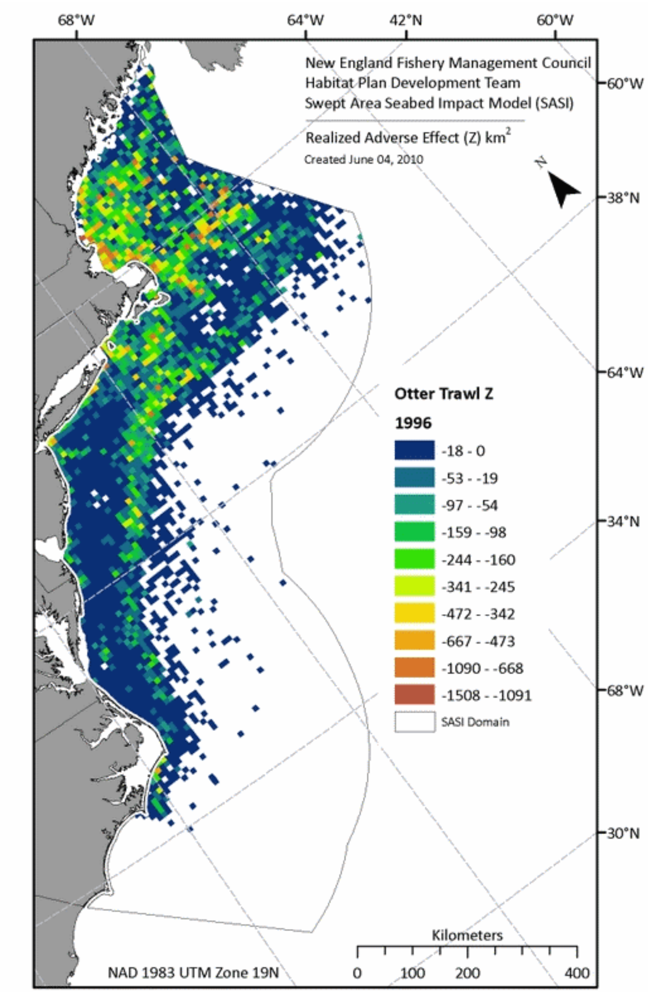
- Based on estimates of area swept
- Data from 1996 – 2009
  - Adverse effects accumulated long before initial year of data availability
  - To initiate model, run an 11-year Z_{∞}-like model using 1996 data
    - Provides a non-virgin adverse effects surface to build upon
- Run model through 2009

$Z_{realized}$ over time

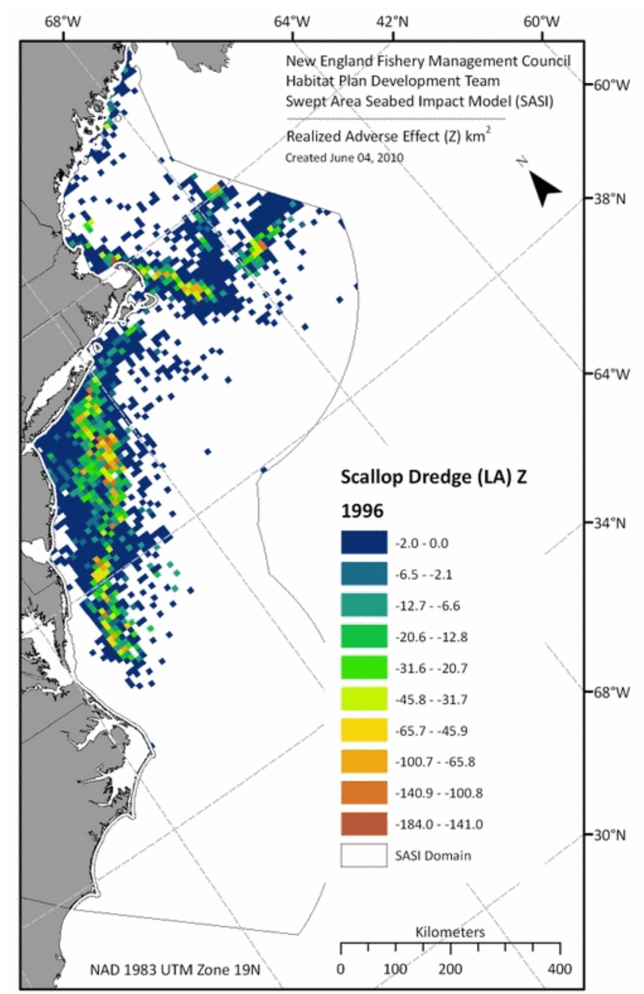


$Z_{realized}$

<u>Generic otter trawl</u>



<u>Limited access scallop dredge</u>



Change in $Z_{realized}$

Gear type	2003 realized Z km2	2009 realized Z km2	% change
Generic otter trawl	105,208	66,680	-37%
Raised footrope	93	190	104%
Shrimp trawl	4,232	3,408	-19%
Squid trawl	6,453	6,486	1%
Scallop dredge (LA)	12,360	10,501	-15%
Scallop dredge (GC)	488	811	66%
Hydraulic dredge	618	919	49%
Longline	122	18	-85%
Gillnet	34	20	-41%
Trap	404	349	-14%
Total:	***130,012***	***89,382***	***-31%***

$Z_{realized}$ conclusions

- Mobile gears comprise the majority of the adverse effects from fishing estimated in our region (99.5% in 2009)
  - Trawl gears 85%, dredge gears 14%
- Adverse effects from fishing by all gears have declined by 31% since last FMC action (2003)
  - Generic otter trawl adverse effects have declined by 37%
  - Limited access scallop dredge adverse effects have declined by 15%

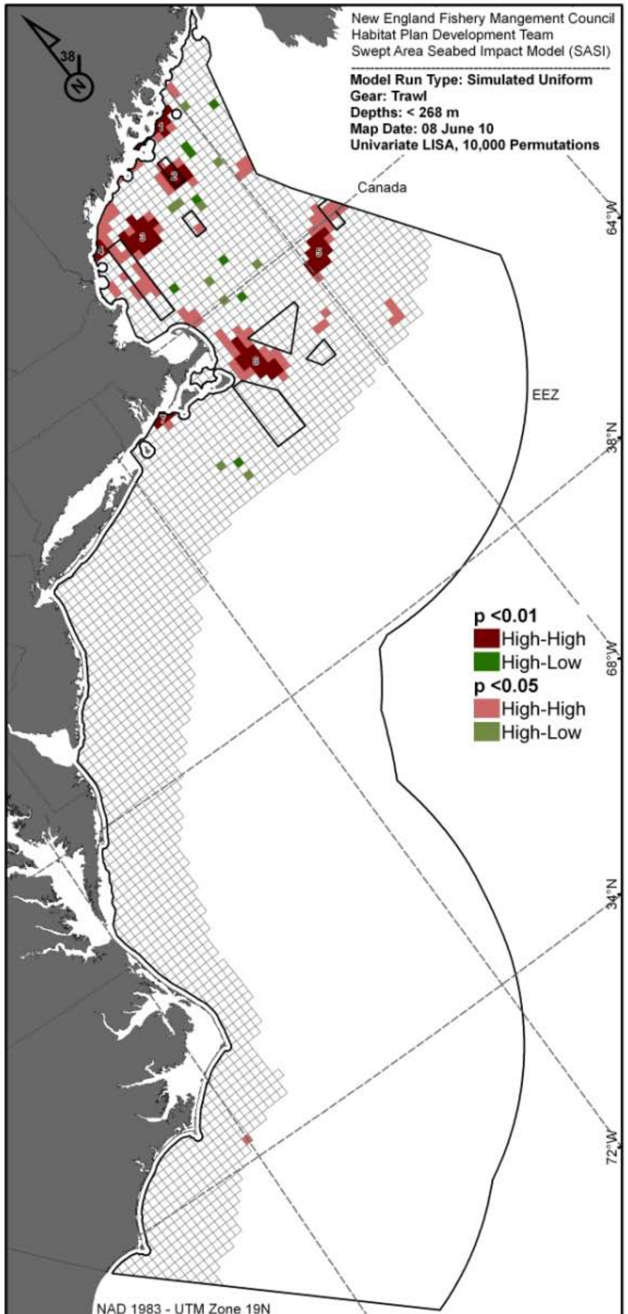
LISA Analysis

Local Indicators of Spatial Association (LISA) were used to explore the spatial structure of $Z\infty$ and to delimit clusters of model cells with statistically high and low $Z\infty$ (Anselin 1995).

$$I_i = \frac{x_i}{Q_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j} x_i, \quad \text{where} \quad Q_i^2 = \frac{\sum_{j=1, j \neq i}^{n} w_{i,j}}{n-1} - \overline{X}^2$$

The neighborhood weights, $w_{i,j}$, were determined using Queen Contiguity (the 8-neighbor rule)

1	2	3
8	**x_i**	4
7	6	5



LISA Analysis - Trawl

Gear	Global Morans *I*	*p*
Trawl	0.4790	≤0.0001
Dredge	0.5075	≤0.0001
H. Dredge	0.8264	≤0.0001
Gillnet	0.4080	≤0.0001
Longline	0.4100	≤0.0001
Trap	0.6775	≤0.0001

Cluster	Trawl
Not Significant	76.27%
High-High	6.79%
Low-Low	14.98%
Low-High	1.24%
High-Low	0.72%

LISA Analysis

- Enables the Council, Ctte and public to understand the spatial structure of the SASI outputs in terms of clustering
- Highlights areas that contain concentrated clusters of model grid cells with significantly greater adverse effect accumulation
- Points towards the "right" areas to focus attention on, but DOES NOT adequately define boundaries for management—will need refinement based on other inputs

LISA Conclusions

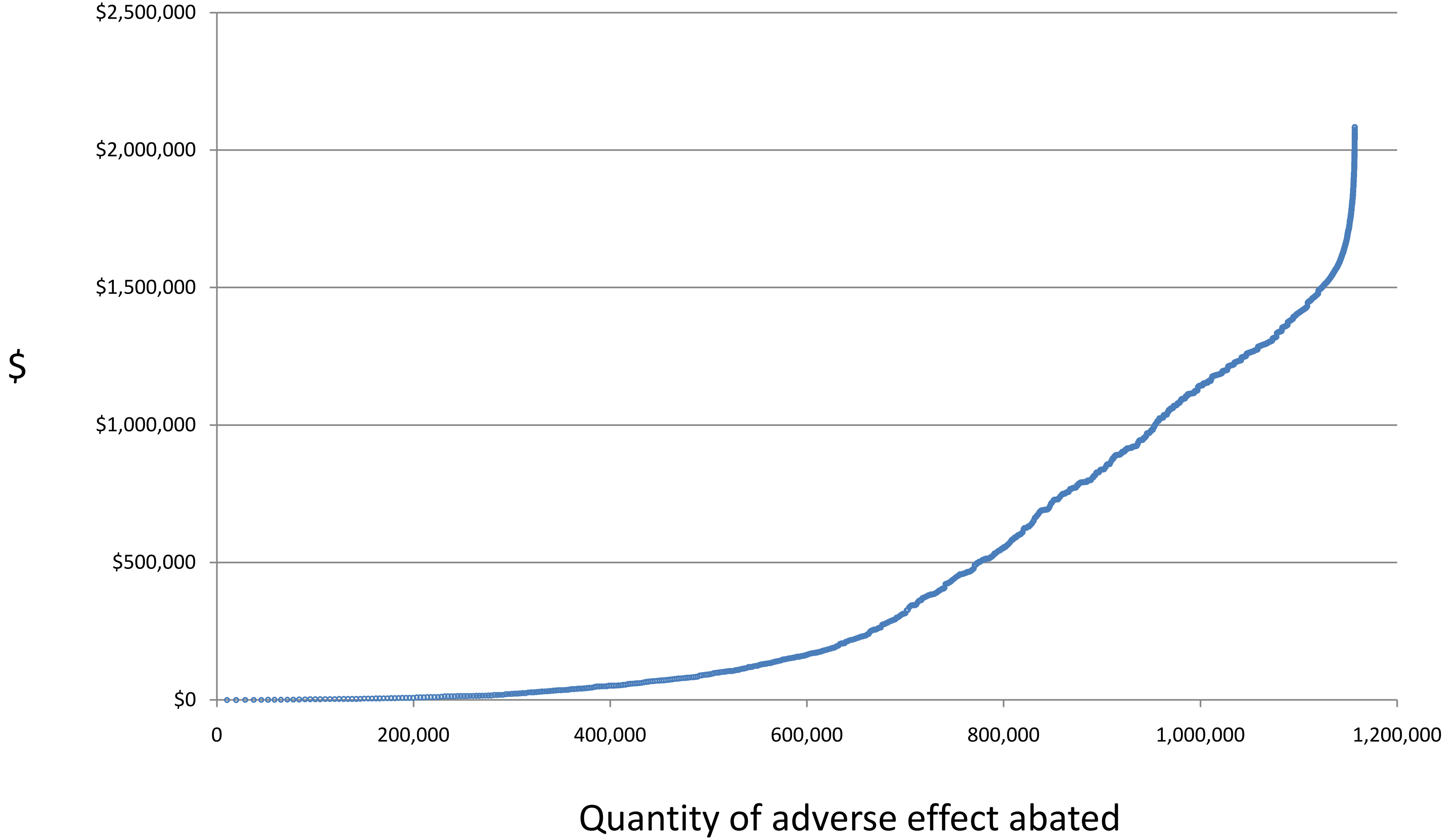
- Seven significant clusters emerge
- GOM clusters near known geomorphic features; some overlap with existing habitat closure areas
- GB clusters near higher-energy gravel, cobble and boulder dominated habitats; little overlap with existing habitat closure areas
- Results should be treated as first-pass; data issues influence cluster size and in certain cases areas suspected to contain vulnerable substrates are not highlighted—some interpretation required

Cost-efficiency analysis

MSA: "…minimize to the extent practicable adverse effects on such habitat caused by fishing…"

- Practicability undefined in rulemaking
- Implies need to balance trade-offs
- Benefits of abating adverse effects are not directly quantifiable
  - Research insufficient to quantify relationship between adverse effect and fishery productivity
  - Adversity of effect likely to be species/life stage specific
- Cost-efficiency analysis may be appropriate

Cost-efficiency approach:



Cost efficiency

COST ESTIMATE

ENVIRONMENTAL IMPACT COEFFICIENT

$$e_{ip} = \left(\frac{z^{net}}{x} \right)_{ip}$$

BENEFIT ESTIMATE

where Z^{net}_{ip} is the net stock of quality-adjusted area swept (km^2) that has had its functional value as structure-forming habitat reduced as a result of fishing by gear type *i* at parcel *p*,

and

x_{ip} is the profit ($) derived as a result of fishing by gear type *i* at parcel *p*

Cost estimate

- Z_{net} is the sum of Z values for each gear type (i) and parcel (*p*) from year 1 through the terminal year of recovery (year *n*).
- It is a non-discounted net present value estimate of $Z_{realized}$

$$Z^{net}{}_{ip} = \sum_{t=1}^{n} Z_{ip}$$

Benefit estimate

X calculated as trip-level net revenues

- Revenue minus trip costs
- OLS trip cost models estimated, differentiated by trip length

< 24 hr

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	2.90496	0.06213	46.75	<.0001
gillnet	-0.57755	0.02764	-20.9	<.0001
longline	0.24488	0.06531	3.75	0.0002
CREW	0.32479	0.01631	19.92	<.0001
ln_dur	0.86415	0.02679	32.26	<.0001

> 24 hr

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1.8691	0.09207	20.3	<.0001
vhp2	1.81E-07	3.35E-08	5.41	<.0001
gillnet	-0.76861	0.04381	-17.54	<.0001
CREW	0.14529	0.01171	12.41	<.0001
ln_dur	1.2594	0.02187	57.58	<.0001

Cost-efficiency

- Z_{net} captures the magnitude of adverse effect at the trip level
  - Allows for comparisons across areas, gear types, years
- *e* captures the amount of benefit (net revenue) generated per unit of adverse effect (Z_{net})
- Allows for evaluation of trade-offs associated with habitat management measures in various areas and for different gear types

Implications

Three primary management tools (NRC)

- Closed areas (durable, seasonal, etc)
- Gear modifications
- Effort reductions

Thinking in terms of marginal costs and benefits:
how practicable are these tools for minimizing adverse effects in the Northeast US?

Costs

- Closed areas - differential catch rates between fishable and off-limits parcels (redistribution of effort)
- Gear modifications - direct costs plus those associated with gear selectivity/catchability
- Effort reduction - costs associated with foregone yield but have second-order effects
  - May be hard to decouple from biological objectives
  - May result in increased CPUE/profits

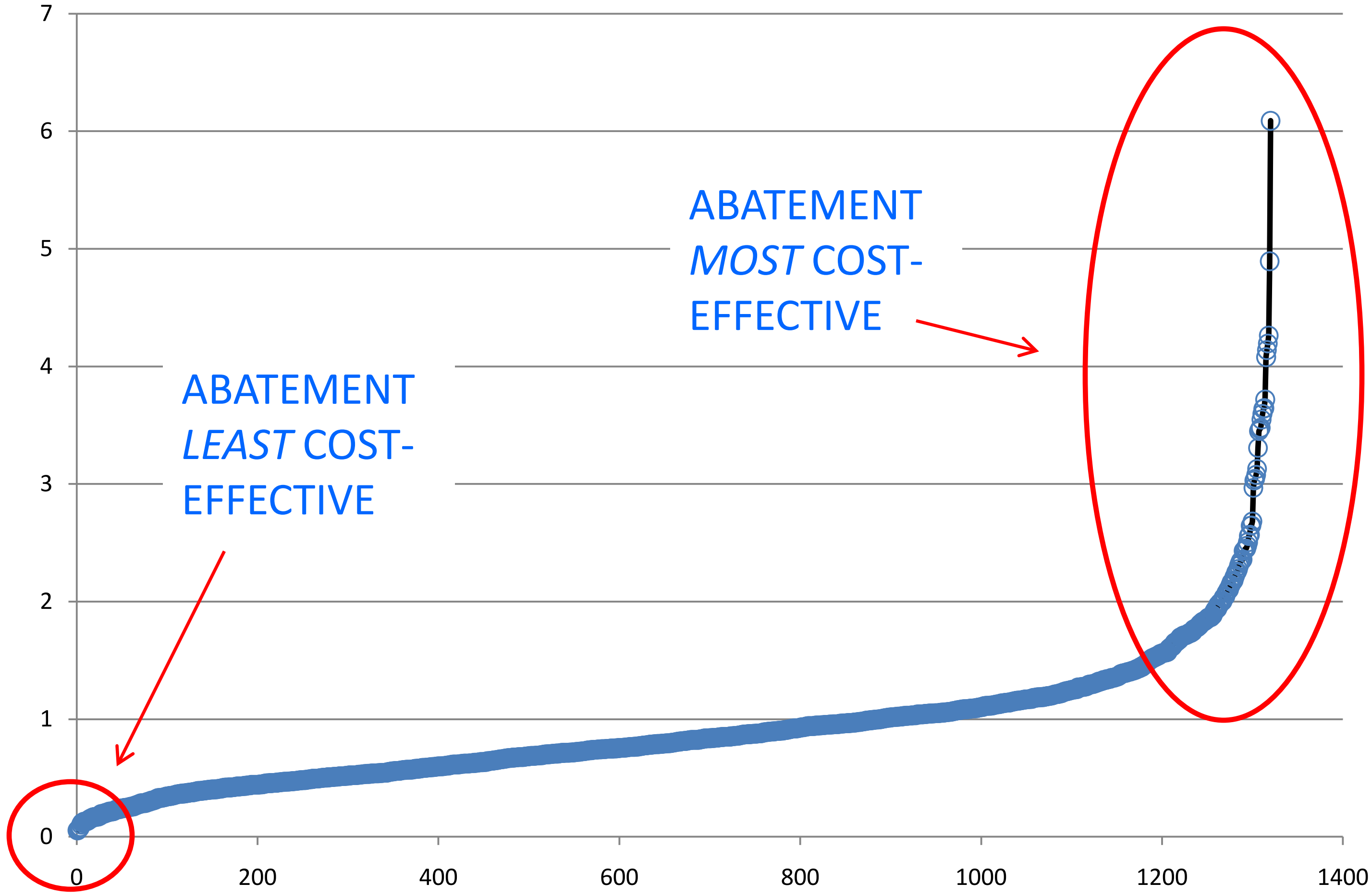
<u>Realistically, minimizing Z is conditioned on achieving OY</u>

e – by gear type

gear	*e* mean	Z_{net} mean	*X* ($1K's) mean
g. otter trawl	**0.91**	693.7	898.6
shrimp trawl	**1.28**	406.2	374.0
squid trawl	**0.67**	284.2	545.0
raised trawl	**0.47**	92.7	203.3
scallop dr, la	**0.1**	159.7	2,713.7
scallop dr, gc	**0.16**	24.5	252.6
longline	**0.04**	8.6	284.7
gillnet	**0**	0.7	544.9
pots and traps	**0.01**	6.3	781.7

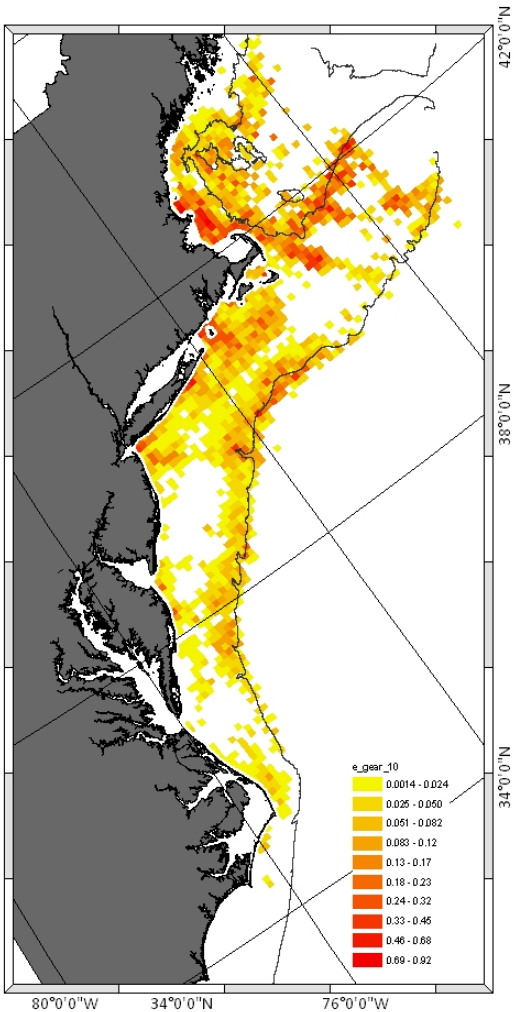
Note: hydraulic clam dredge excluded due to data quality concerns

e for generic otter trawl gear (y-axis) and parcels (x-axis)



Gen. otter trawl gear

z_{net} (cost proxy)



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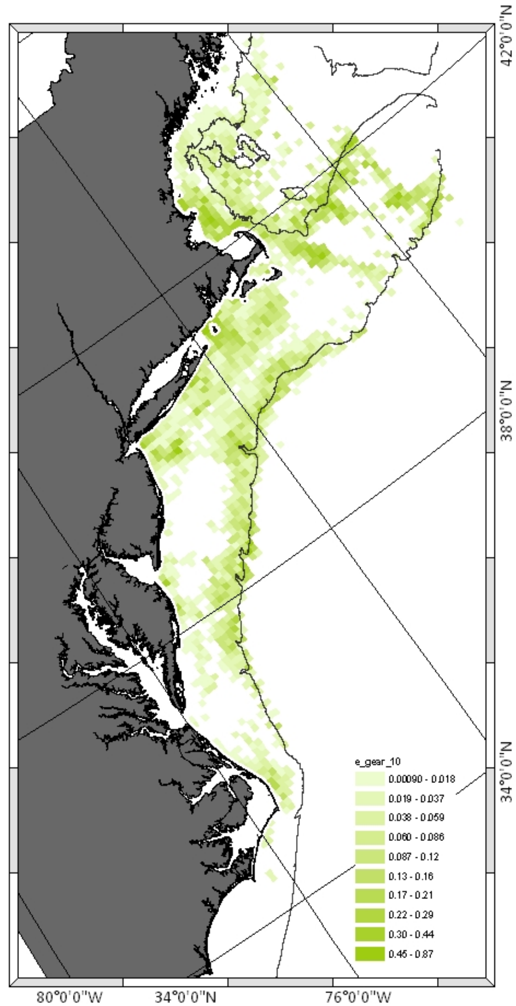
x (benefit)



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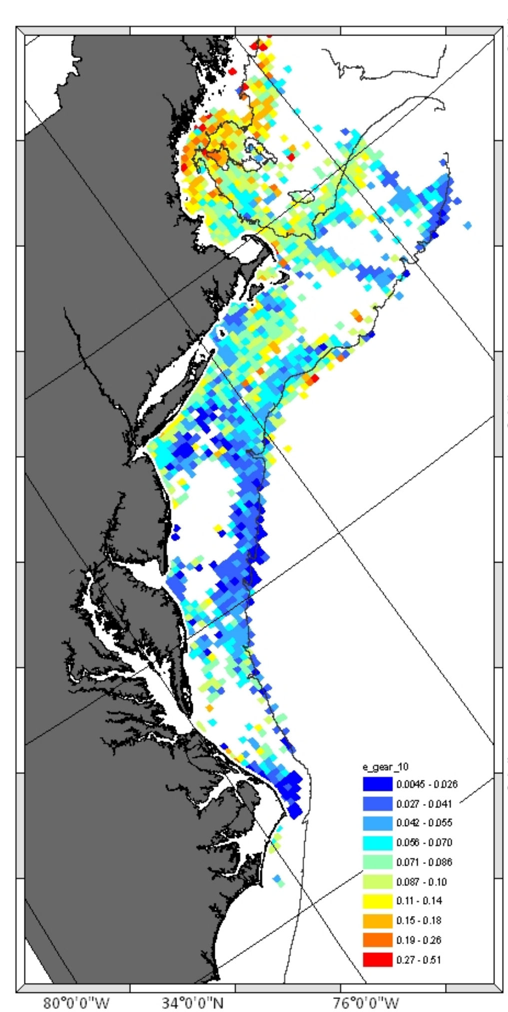
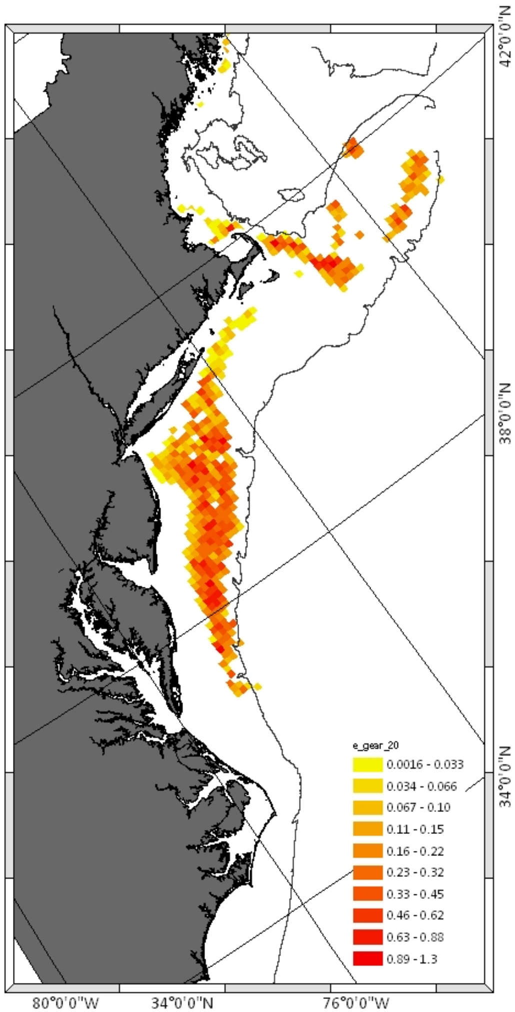
e



LA scallop dredge gear

z_{net} (cost proxy)



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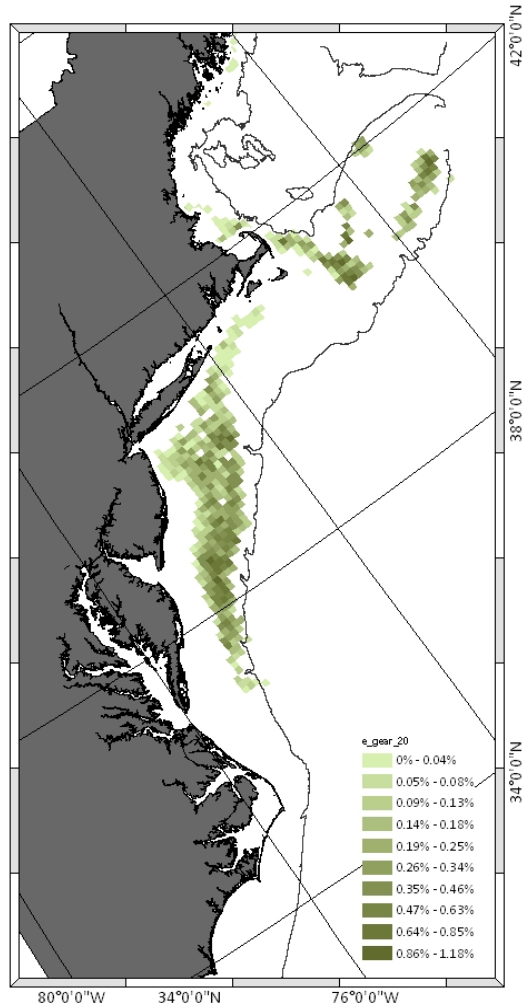
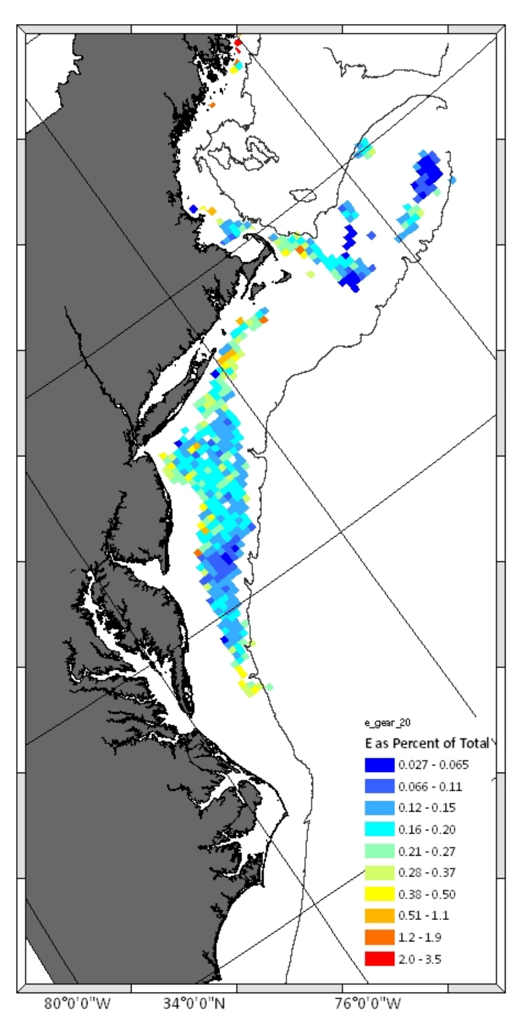
x (benefit)



=

e



Abatement through gear modifications

- For harvesting bottom-dwelling finfish, wholesale gear substitution will result in orders-of-magnitude reductions in Z
  - *to generate a dollar of profit, otter trawls produce ~600 times more Z (adverse effect) than gillnets*
  - *Comes at a cost: catch composition, bycatch, protected resources*
  - *Besides gillnets, some other bottom-contact gears are also highly habitat-efficient*

Abatement through gear modifications

Within-gear gear modifications should be explored

- *Ground cable lengths have increased by > 15% between 2003 and 2009 on observed tows*
- *Costs to ground cable reduction include reduced CPUE through loss of herding*

reduction in ground cable length	resulting reduction in area swept
10%	-6.55%
20%	-13.09%
30%	-19.64%
40%	-26.18%
50%	-32.73%
60%	-39.27%
70%	-45.82%
80%	-52.36%
90%	-58.91%

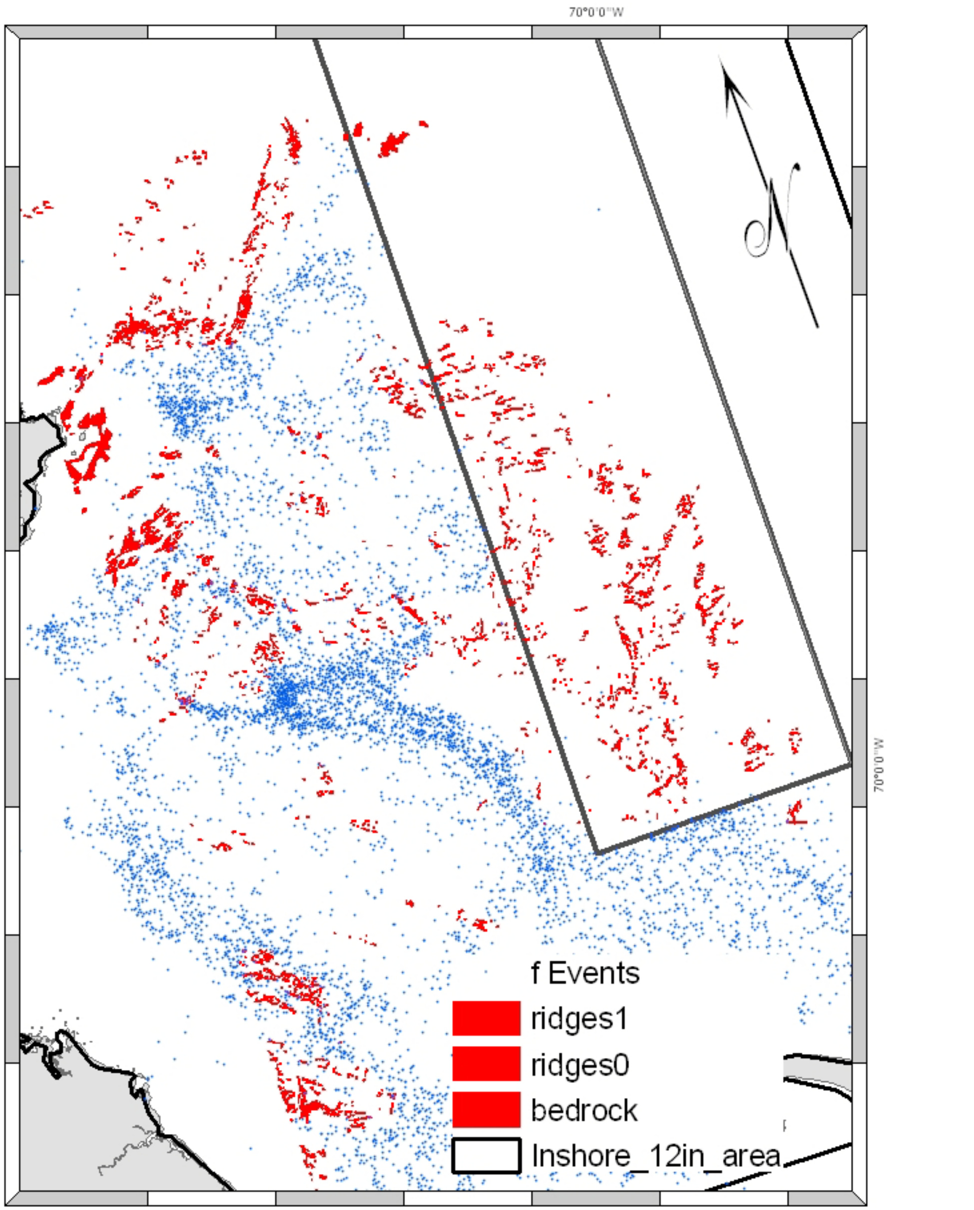
Abatement through gear modifications

Footrope configurations:

- *Changing from a cookie or chain sweep to a raised footrope sweep may reduce area swept by ~30%*
- *Eliminating large-diameter rockhopper gear may alter fishing behavior, keeping gear off most vulnerable habitats*
- *Costs include gear selectivity (esp. flatfish) and decreased fishable bottom*

Distribution of boulder ridges and bedrock in the WGOM

- All boulder ridges on map are within the 12 in roller gear restricted area



Area closure analysis

Assumptions:

- Fishing effort covaries with ABCs, catch will be consistent with OY
- Area closure moves this relatively constant effort around
- Adverse effects abatement depends on:
  - *Vulnerability/profitability of the areas closed or opened, and*
  - *Vulnerability/profitability of areas fishing effort displaced from, or displaced to*

$$e_{ip} = \left(\frac{z^{net}}{x} \right)_{ip}$$

Vulnerability proxy

Profitability proxy

*Our **e** parameter allows us to directly compare the costs and benefits of fishing, between all combinations of gears and locations*

A simple case

- Fishing grounds divided into four ‘blocks’
- Each area has different vulnerability and net revenue potential (one gear only)
- One block closed
- Fishing effort remains constant pre/post closure
  - Net revenues used as proxy for effort
- Revenues inaccessible due to closure are re-distributed evenly across other three blocks
- Vulnerability within open blocks applied to ‘new’ net revenues

Example

BLOCK 1	***BLOCK 2***
Znet (adverse effects) = 100 X (net revenues) = 50 **e = 2**	Znet (adverse effects) = 300 X (net revenues) = 75 **e = 4**
BLOCK 3 Znet (adverse effects) = 50 X (net revenues) = 50 **e = 1**	***BLOCK 4*** Znet (adverse effects) = 50 X (net revenues) = 100 **e = 0.5**

BASE CASE:
Total adverse effects = 500
Total net revenues = 275
Global *e* = 1.8

*CLOSE **BLOCK 2**:*
Total adverse effects = **287**
Total net revenues = 275
Global *e* = **1.05**

*CLOSE **BLOCK 4**:*
Total adverse effects = **683**
Total net revenues = 275
Global *e* = **2.5**

Adverse effects analysis conclusions

- VA: *Otter trawl and dredge gears have the highest adverse effect, driven by high susceptibility and longer recovery times in substrates dominated by larger sediments*
- SASI:
  - *Overall adverse effects have declined by 31% since 2003 and over 60% since 1996 ($Z_{realized}$)*
  - *Per unit area, mobile bottom tending gears have highest potential for adverse effects and should be focus of AE minimization options (Z_{∞})*
- LISA: *High-Z_{∞} parcels clustered at manageable scales do not overlap well with existing habitat closures on GB, align better in GOM.*

Adverse effects analysis conclusions, cont.

- Cost-efficiency:
  - *Useful for understanding habitat-efficiency of various gears*
    - *Fixed gears more habitat-efficient than mobile by orders of magnitude*
    - *Scallop dredges next*
    - *Otter trawls least habitat-efficient of evaluated gear types*
  - *Potential for increases in otter trawl habitat-efficiency through gear modifications, though gear modifications come with costs:*
    - *targeting, bycatch, inefficiencies, etc.*
- Area closure:
  - *Costs incurred from displaced effort*
  - *Effectiveness depends on differences between parcel-specific habitat vulnerabilities and catch rates*
  - *To provide positive benefits, proper siting of durable area closures is critical*

SSC and Peer Reviews

- *VA, SASI, LISA all appropriate for use in alternative development*
  - Model sensitivity tests performed, spatial distribution of Z robust to all assumptions tested
  - Will integrate sensitivity results into SASI model outputs by bounding Z estimates with high and low estimates from sensitivity runs
- *Cost-efficiency and area closure analyses appropriate for qualitative discussion*
  - Cost-efficiency (*e*) estimates not robust to all sensitivity runs, further development needed to fully understand implications
  - Area-closure analysis, as constructed, relies on assumptions that need additional validation…further development required before suitable for use in impacts analysis

Overall

- Adverse effects are a function of fishing effort—*catching fish quickly and efficiently will yield the largest gains in abating adverse effects*
- Of three tools (closure, gear change, effort reduction) only first two appear realistic
  - Fishing effort must be commensurate w/ achieving OY
  - Adverse effects abatement constrained by effort needed for OY
- Given observed changes in $Z_{realized}$, the Council's objective may most likely be to:
  - Capture high-efficiency abatement gains where possible
    - Targeted area closures
    - Potential gear modifications
  - Prevent abatement loss due to effort displacement
  - Provide suitable platforms for furthering much-needed research

There is much we don’t know:

- Shelf-wide seabed and habitat characterization
- Gear effects
  - With particular attention to susceptibility and recovery
  - Fixed gears
- Effects of energy, energy modeling
- Biogenic features, macro-level feature distribution, seasonality
- Fine-scale habitat feature and fishing effort distributions
- ***The functional relationship between fish stocks and habitat***

Next steps

- Integrate sensitivity results into published model results as quasi-uncertainty bounds
- Prepare document highlighting additional ("extra-SASI") info to inform decisions (Cashes Ledge, SBNMS)
- Continue developing cost-efficiency and area-closure analyses for potential use in impacts analysis (*focus on qualitative interpretation of results*)

Using all available info, Ctte will craft adverse effects abatement options

Area-based options strongly influenced by the flexibility of existing groundfish rebuilding closure boundaries