Assessment of the Effects of Fishing on Essential Fish Habitat in Alaska for the 2022 5-year Review

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1. Overview of Fishing Effects model
2. Review of methodology to evaluate the effects of fishing on EFH
3. Input from EC on this process

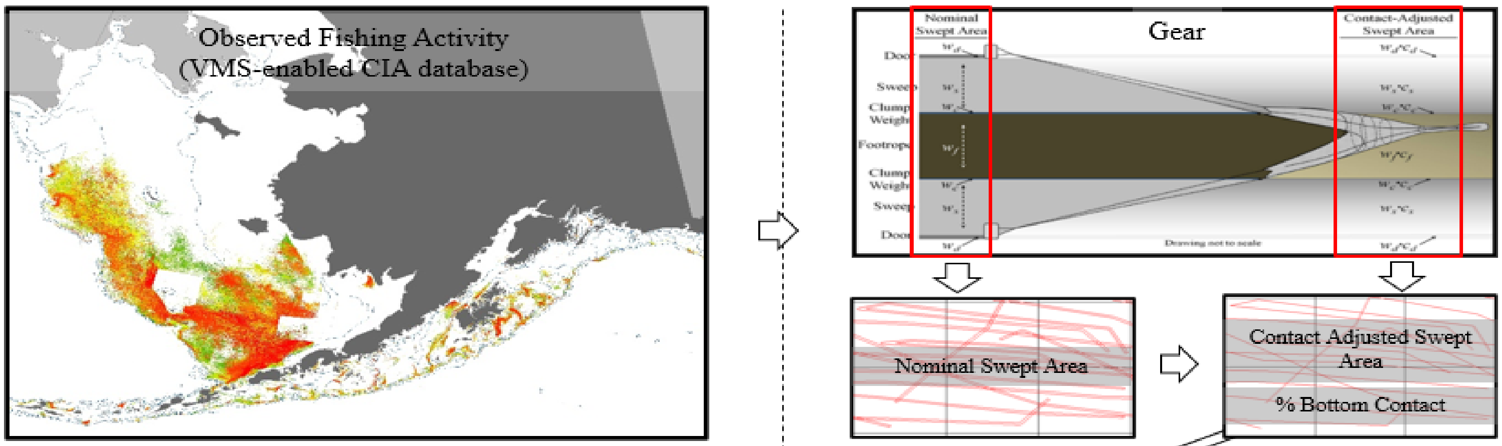
Fishing Effects (FE) Model

During the 2017 EFH 5-year review, the NPFMC/SSC requested several updates to the LEI model to make the input parameters more intuitive and to draw on the best available data. In response to their requests, the Fishing Effects (FE) model was developed.

It is based on interaction between habitat impact and recovery, which depend on the amount of fishing effort, the types of gear used, habitat sensitivity, and substrate.

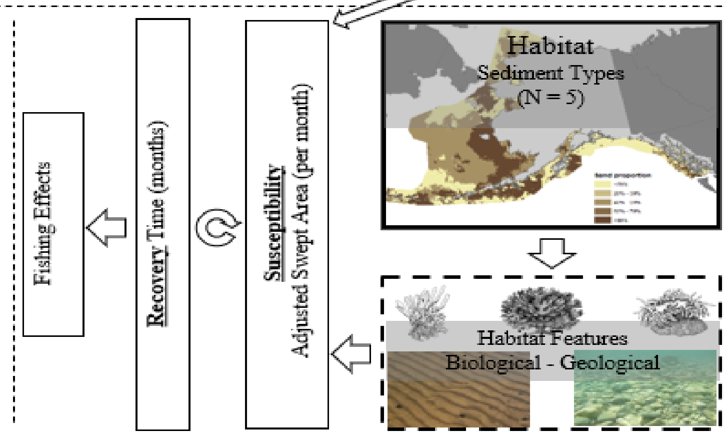
- The FE model is cast in a discrete time framework
- The FE model implements sub annual (monthly) tracking of fishing impacts and habitat disturbance.
- The FE model draws on VMS data and the Catch-in-Areas (CIA) database to use the best available spatial data of fishing locations and species targets.
- The FE model incorporates the extensive literature review from Grabowski (2014) to estimate susceptibility and recovery dynamics.

Fishing Effects Model Overview

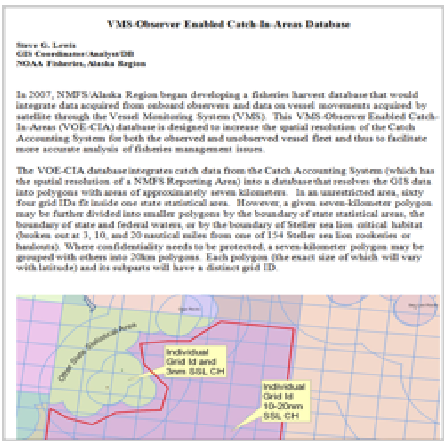


$$H_{t+1} = H_t(1 - I'_t) + h_t \rho'_t$$

H: habitat undisturbed from fishing
h: habitat disturbed from fishing
I': monthly impact rate
ρ': monthly recovery rate



VMS & Defining Fishing Gear Footprint

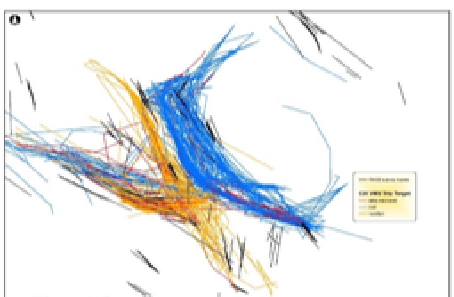


VMS-Observer Enabled Catch-In-Areas Database

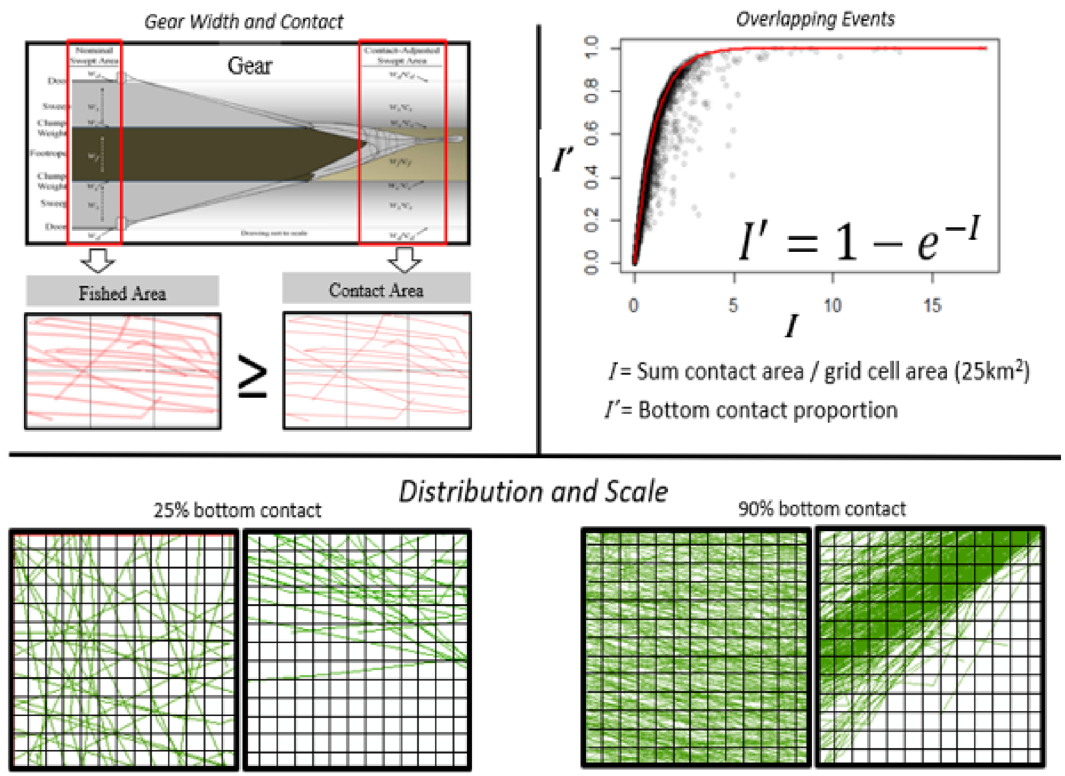
Steve G. Lewis
GIS Coordinator/Analyst/DB
NOAA Fisheries, Alaska Region

In 2007, NMFS/Alaska Region began developing a fisheries harvest database that would integrate data acquired from onboard observers and data on vessel movements acquired by satellite through the Vessel Monitoring System (VMS). This VMS-Observer Enabled Catch-In-Areas (VOE-CIA) database is designed to increase the spatial resolution of the Catch Accounting System for both the observed and unobserved vessel fleet and thus to facilitate more accurate analysis of fisheries management issues.

The VOE-CIA database integrates catch data from the Catch Accounting System (which has the spatial resolution of a NMFS Reporting Area) into a database that resolves the GIS data into polygons with areas of approximately seven kilometers. In an unrestricted area, sixty four grid IDs fit inside one state statistical area. However, a given seven-kilometer polygon may be further divided into smaller polygons by the boundary of state statistical areas, the boundary of state and federal waters, or by the boundary of Steller sea lion critical habitat (broken out at 3, 10, and 20 nautical miles from one of 154 Steller sea lion rookeries or haulouts). Where confidentiality needs to be protected, a seven-kilometer polygon may be grouped with others into 20km polygons. Each polygon (the exact size of which will vary with latitude) and its subparts will have a distinct grid ID.



Defining Fishing Gear Footprint



Gear Descriptions & Contact Adjustment

67 individual gear descriptions

Fishery	Vessel type	Area	Gear	Target1	Target2	Vessel Length (ft)	Season	Depth Range (fath.)	Nom Width (m)
GOA Pollock Pelagic Trawl Sand Point	CV	GOA	PTR	P	all others	<75			50
GOA Pollock Pelagic Trawl	CV	GOA	PTR	P	all (but K, S)	≥75			75
GOA Slope Rockfish Pelagic Trawl	CV	GOA	PTR	K	S	≥75			75
GOA Slope Rockfish Pelagic Trawl	CP	GOA	PTR	K	W	all			100
GOA PCod Bottom Trawl Inshore	CV	GOA	NPT	C	B, P	≥75			90
GOA Deepwater Flatfish Bottom Trawl	CV	GOA	NPT	D	W, X	≥75			90
GOA Shallowwater Flatfish Bottom Trawl	CV	GOA	NPT	H	all others	≥75			90
GOA PCod Bottom Trawl Sand Point	CV	GOA	NPT	C	all others	<75			55
GOA Deepwater Flatfish Bottom Trawl CP	CP	GOA	NPT	D, W	X	all			193
GOA Shallowwater Flatfish/Cod Bottom Trawl CP	CP	GOA	NPT	H, C	L, all others	all			193
GOA Slope Rockfish Bottom Trawl CP	CP	GOA	NPT	K	S	all			75
BS Pollock Pelagic Trawl (incl Mothership)	CV	BS	PTR	P	B, all others	<125 ≥300	A	≥90	62
BS Pollock Pelagic Trawl (incl Mothership)	CV	BS	PTR	P	B, all others	<125 ≥300	A	60-90	58
BS Pollock Pelagic Trawl (incl Mothership)	CV	BS	PTR	P	B, all others	<125 ≥300	A	<60	50
BS Pollock Pelagic Trawl (incl Mothership)	CV	BS	PTR	P	B, all others	<125 ≥300	B	≥90	77
BS Pollock Pelagic Trawl (incl Mothership)	CV	BS	PTR	P	B, all others	<125 ≥300	B	60-90	73
BS Pollock Pelagic Trawl (incl Mothership)	CV	BS	PTR	P	B, all others	<125 ≥300	B	<60	64
BS Pollock Pelagic Trawl	CV	BS	PTR	P	B, all others	125-151	A	≥90	93
BS Pollock Pelagic Trawl	CV	BS	PTR	P	B, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BS Pollock Pelagic Trawl	CV	BS	PTR	P	B, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BS Pollock Pelagic Trawl	CV	BS	PTR	P	B, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]

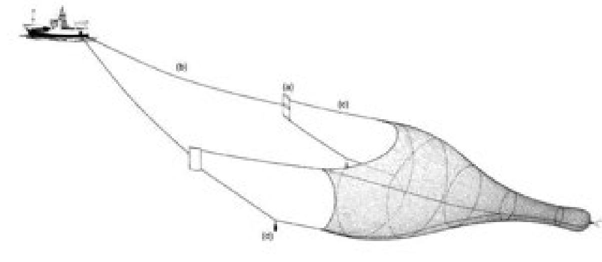
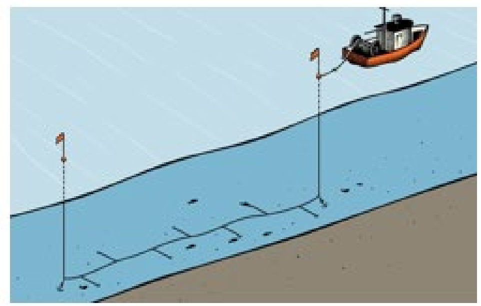


Figure 10. Single boat pelagic trawl



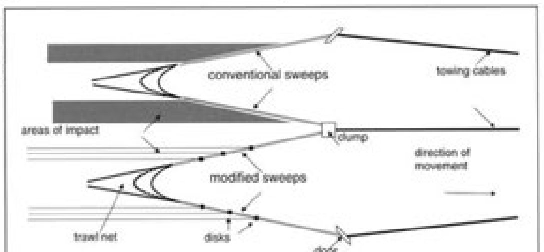
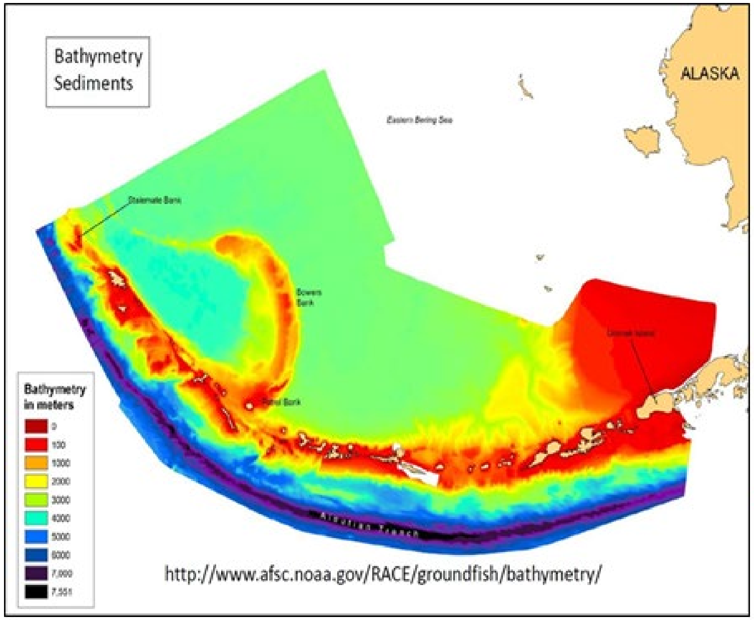
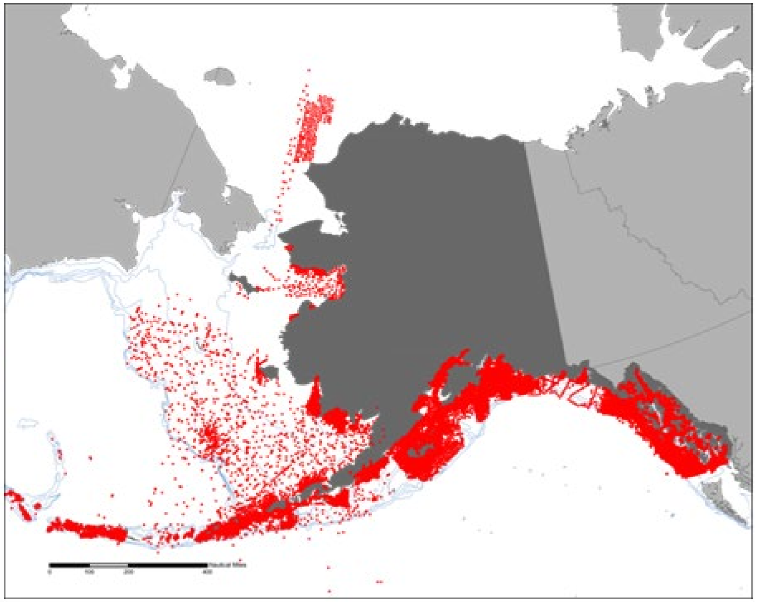


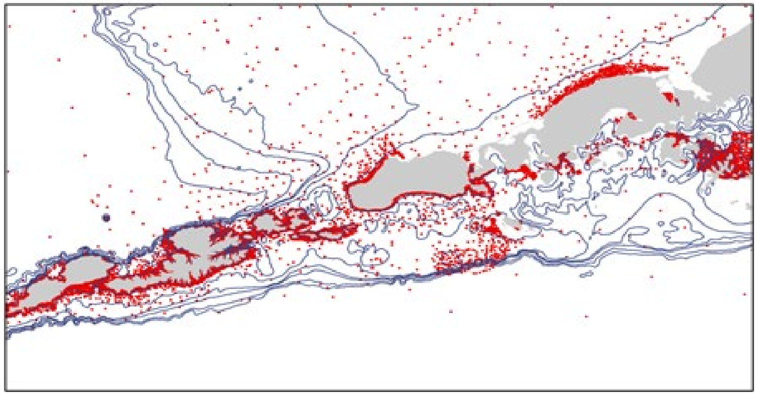
Figure 1

Diagram of the twin trawl system, complete with sweeps (conventional and modified), towed simultaneously behind a vessel and used to test whether raised trawl sweeps reduce flatfish herding. Actual total width was approximately 250 m. Shaded areas represent the area of contact with the seafloor.

Habitat Features







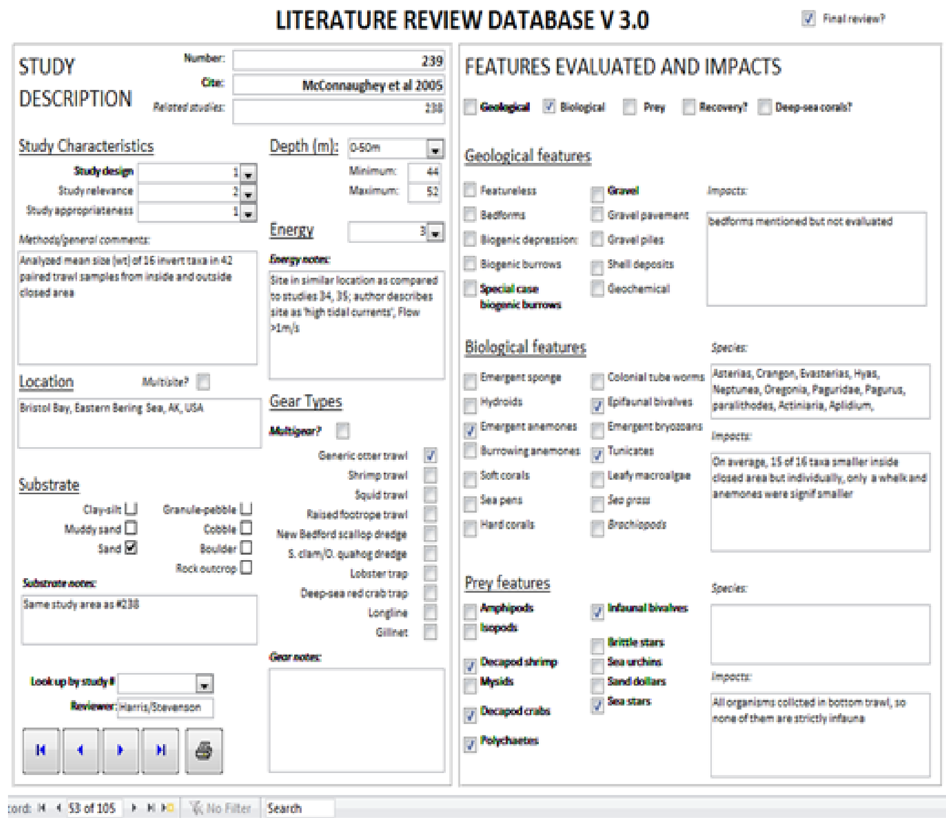
250,000+ points with 6,000+ sediment descriptions coded into 5 sediment classes: Mud, Sand, Granule/Pebble, Cobble, Boulder

Framework for Literature Review

Assessing the Vulnerability of Marine Benthos to Fishing Gear Impacts

JONATHAN H. GRABOWSKI,[1] MICHELLE BACHMAN,[2] CHAD DEMAREST,[3] STEVE EAYRS,[4] BRADLEY P. HARRIS,[5] VINCENT MALKOSKI,[6] DAVID PACKER,[7] and DAVID STEVENSON[8]

[1]Marine Science Center, Northeastern University, Nahant, Massachusetts, USA
[2]New England Fishery Management Council, Newburyport, Massachusetts, USA
[3]NOAA/NMFS Northeast Fisheries Science Center, Woods Hole, Massachusetts, USA
[4]Gulf of Maine Research Institute, Portland, Maine, USA
[5]Department of Environmental Science, Alaska Pacific University, Anchorage, Alaska, USA
[6]Massachusetts Division of Marine Fisheries, New Bedford, Massachusetts, USA
[7]NOAA National Marine Fisheries Service, Highlands, New Jersey, USA
[8]NOAA Northeast Regional Office, Gloucester, Massachusetts, USA



"develop a framework for generating and organizing quantitative susceptibility (based on percent loss of structural habitat from a single interaction with the gear) and recovery (i.e., the time required for recovery of lost structure) parameters for each biological (e.g., sponges, ascidians, mollusks) and geological (e.g., mud burrows, sand ripples, cobble, and boulder piles) feature common to the following five substrates: mud, sand, granule–pebble, cobble, and boulder"

Grabowski, J. H., M. Bachman, C. Demarest, S. Eayrs, B. P. Harris, V. Malkoski, D. Packer, and D. Stevenson. 2014. Assessing the vulnerability of marine benthos to fishing gear impacts. Reviews in Fisheries Science & Aquaculture 22:142-155.

Susceptibility & Recovery of Habitat Features

14 biological and 12 geological literature-based habitat feature categories combined into 5 sediment types (mud, sand, pebble/granule, cobble, & boulder

Recovery code	τ
0	<1 year
1	1 – 2 years
2	2 – 5 years
3	>5 years

Susceptibility code	Susceptibility
0	0 – 10%
1	10 – 25%
2	25 – 50%
3	>50%

G	Bedforms
G	Biogenic burrows
G	Biogenic depressions
G	Boulder, piled
G	Boulder, scattered, in sand
G	Cobble, pavement
G	Cobble, piled
G	Cobble, scattered in sand
G	Granule-pebble, pavement
G	Granule-pebble, scattered, in sand
G	Sediments, suface/subsurface
G	Shell deposits

B	Amphipods, tube-dwelling
B	Anemones, actinarian
B	Anemones, cerianthid burrowing
B	Ascidians
B	Brachiopods
B	Bryozoans
B	Corals, sea pens
B	Hydroids
B	Macroalgae
B	Mollusks, epifaunal bivalve, *Modiolus modiolus*
B	Mollusks, epifaunal bivalve, *Placopecten magellanicus*
B	Polychaetes, *Filograna implexa*
B	Polychaetes, other tube-dwelling
B	Sponges

Susceptibility

Feature Class	Feature	Mud	Sand	Gran-Peb	Cobble	Boulder
G	Bedforms		2			
G	Biogenic burrows	2	2			
G	Biogenic depressions	2	2			
G	Boulder, piled					2
G	Boulder, scattered, in sand					0
G	Cobble, pavement				1	
G	Cobble, piled				3	
G	Cobble, scattered in sand				1	
G	Granule-pebble, pavement			1		
G	Granule-pebble, scattered, in sand			1		
G	Sediments, suface/subsurface	2	2			
G	Shell deposits		1	1		
B	Amphipods, tube-dwelling	1	1			
B	Anemones, actinarian			2	2	2
B	Anemones, cerianthid burrowing	2	2	2		
B	Ascidians		2	2	2	2
B	Brachiopods			2	2	2
B	Bryozoans			1	1	1
B	Corals, sea pens	2	2			
B	Hydroids	1	1	1	1	1
B	Macroalgae			1	1	1
B	Mollusks, epifaunal bivalve, *Modiolus modiolus*	1	1	2	2	2
B	Mollusks, epifaunal bivalve, *Placopecten magellanicus*		2	1	1	
B	Polychaetes, *Filograna implexa*		2	2	2	2
B	Polychaetes, other tube-dwelling			2	2	2
B	Sponges		2	2	2	2

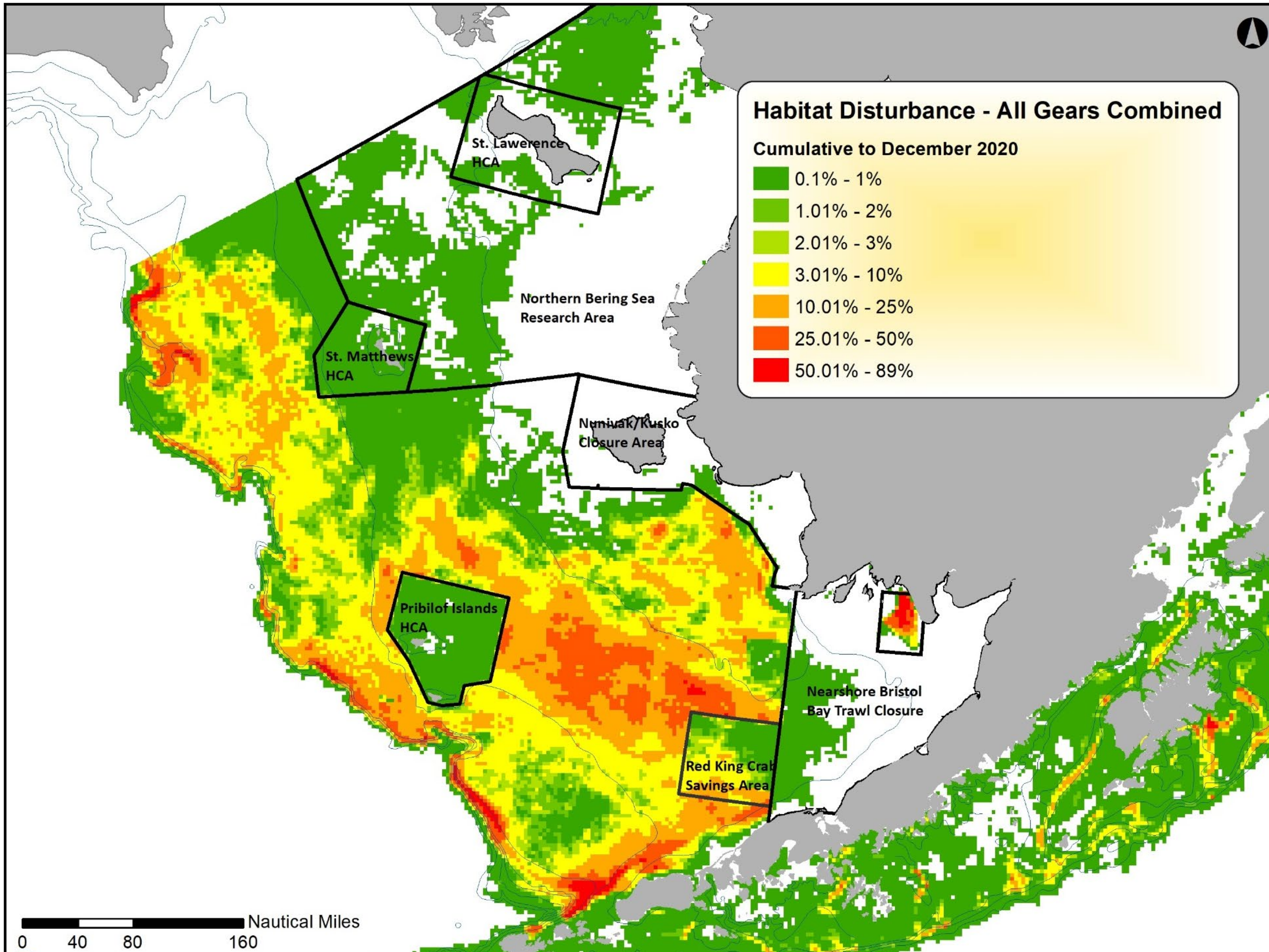
Adapted from the SASI model (NEFMC, 2011)

Recovery

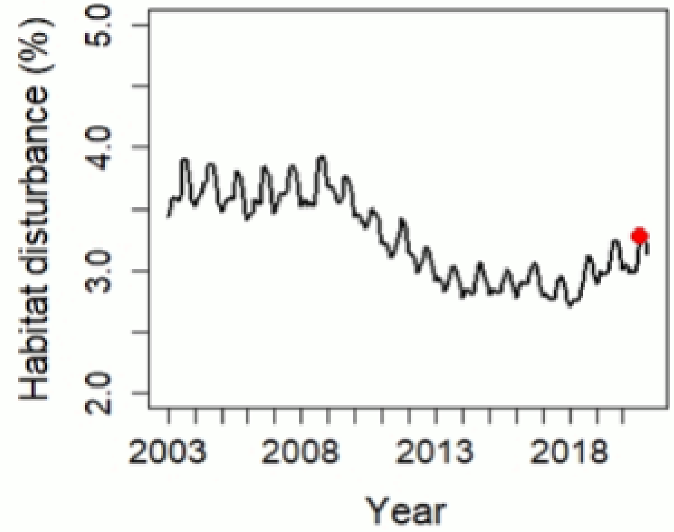
Feature Class	Features	Mud	Sand	Gran-Peb	Cobble	Boulder
G	Bedforms		0			
G	Biogenic burrows	0	0			
G	Biogenic depressions	0	0			
G	Boulder, piled					3
G	Boulder, scattered, in sand					0
G	Cobble, pavement				0	
G	Cobble, piled				3	
G	Cobble, scattered in sand				0	
G	Granule-pebble, pavement			0		
G	Granule-pebble, scattered, in sand			2		
G	Sediments, suface/subsurface	0	0			
G	Shell deposits		2	2		
B	Amphipods, tube-dwelling	0	0			
B	Anemones, actinarian			2	2	2
B	Anemones, cerianthid burrowing	2	2	2		
B	Ascidians		1	1	1	1
B	Brachiopods			2	2	2
B	Bryozoans			1	1	1
B	Corals, sea pens	2	2			
B	Hydroids	1	1	1	1	1
B	Macroalgae			1	1	1
B	Mollusks, epifaunal bivalve, *Modiolus modiolus*	3	3	3	3	3
B	Mollusks, epifaunal bivalve, *Placopecten magellanicus*		2	2	2	
B	Polychaetes, *Filograna implexa*		2	2	2	2
B	Polychaetes, other tube-dwelling			1	1	1
B	Sponges		2	2	2	2

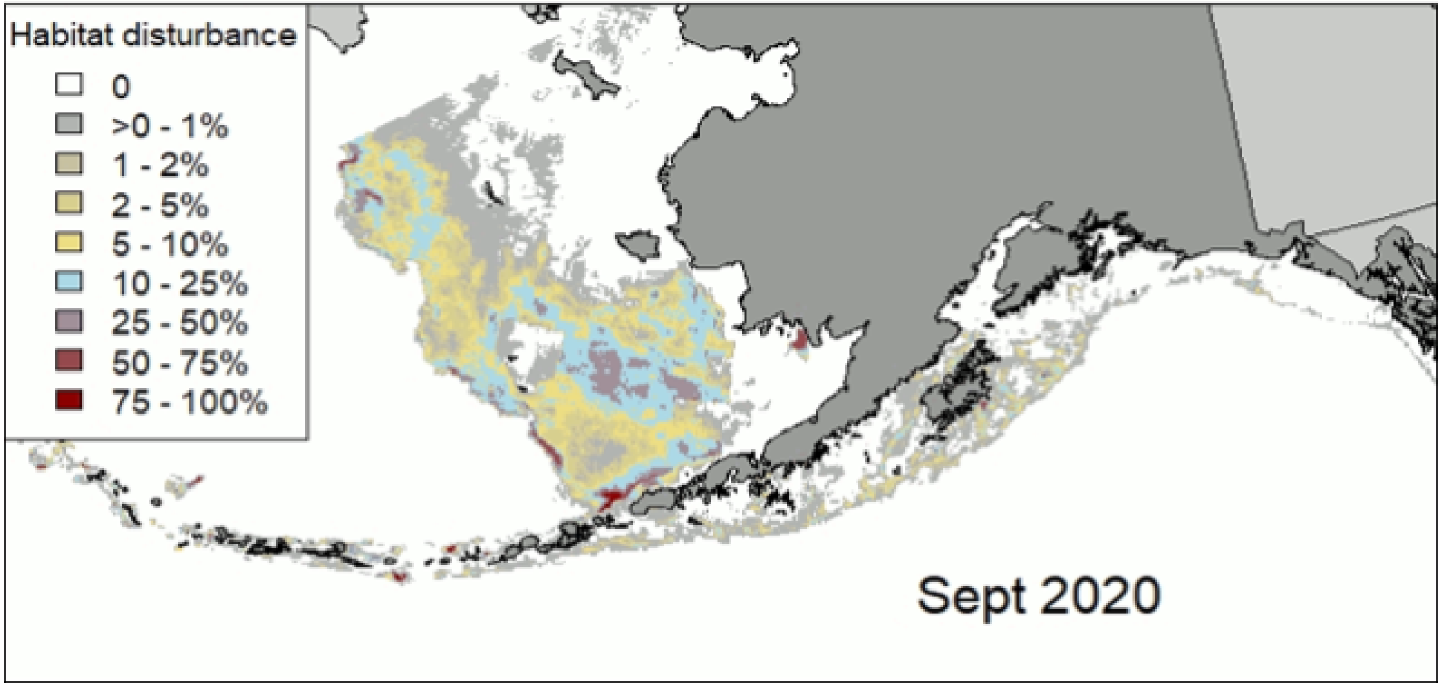
Adapted from the SASI model (NEFMC, 2011)
Recovery codes: 0: < 1 year; 1: 1–2 years; 2: 2–5 years; 3: >5 years
Blank spaces are habitat features not associated with the given sediment class
G is Geological features and B is Biological features

Cumulative Habitat Reduction



Habitat Disturbance, all gears





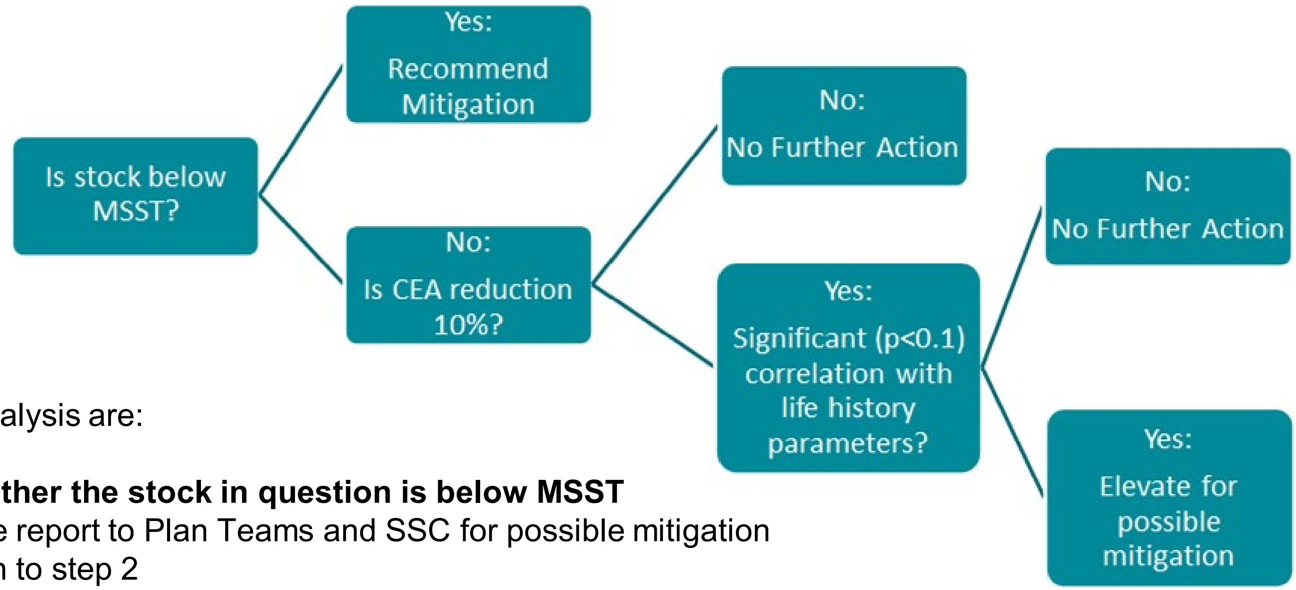
Stock Author Review Process

Methods to evaluate the effects of fishing on Essential Fish Habitat

Proposal from the SSC subcommittee

DRAFT 9/16/16

Hierarchical Impact Assessment Method



The steps of the analysis are:

1. **Determine whether the stock in question is below MSST**
   - If Yes: Provide report to Plan Teams and SSC for possible mitigation
   - If No: Move on to step 2

2. **Determine whether 10% of the CEA is affected by commercial fishing (**the predicted 50 percent quantile threshold of suitable habitat of summer abundance as defined in the species distribution models)
   - If yes: Move on to step 3
   - If no: No further action required (additional analysis is appreciated, move on to step 3)

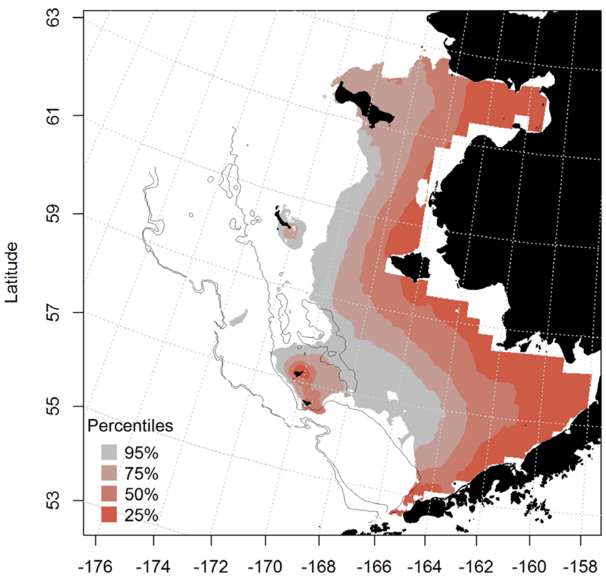
3. **Evaluate correlations between CEA habitat reduction and life history indices**
   - If significant at p<0.1: provide written report for Plan Teams and SSC
   - If not significant: No further action required

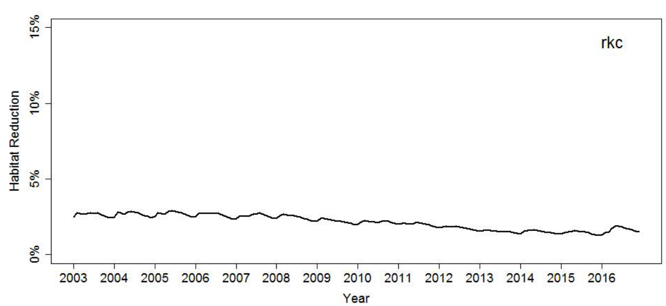
4. **Provide recommendations for EFH research activities and priorities for your species**

5. **Provide a written report for distribution to the appropriate Plan Teams, SSC, and Council.**

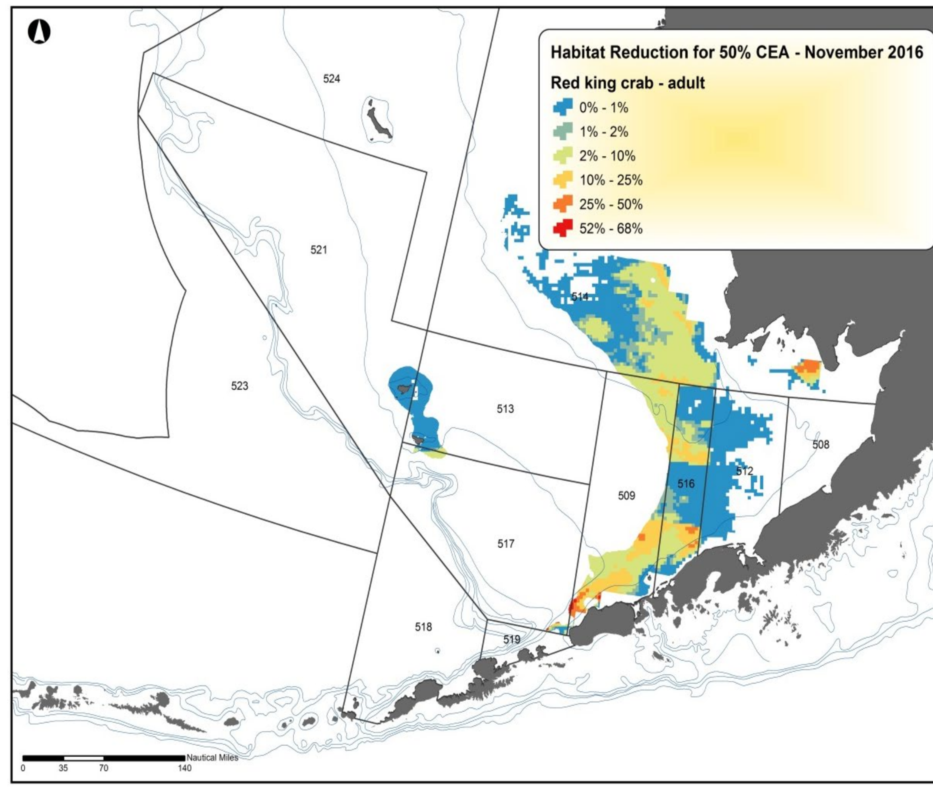
2017 Stock Author Review – Bristol Bay red king crab

Core EFH (CEA) area defined as 50% cumulative distribution





Proportion of habitat reduction (November 2016)



BB RKC Stock Author Review

The first step in the three-tiered approach is to determine whether or not the stock is below MSST. In the 2016 assessments (Hamazaki and Zheng, 2016; Turnock, Szuwalski and Foy, 2016; Zheng and Siddeek, 2016), the "current" biomass (i.e., mature male biomass, MMB, as of Feb. 15, 2017) for the Bristol Bay red king crab stock was projected to be 24.00 thousand t, while the proxy for MSST was 12.89 thousand t. ***Thus the stock is not below MSST.***

The next step in the three-tiered approach, having determined that the stock is not below MSST, is to determine whether or not the amount of habitat disturbed by commercial fishing within the stock's 50%-quantile Core Essential Area is greater than 10%. As shown in Fig. 1, *the % habitat reduction with the red king crab Core Essential Area during the 2003-2016 time period has always been less than 10%*. ***Because the habitat reduction within its Core Essential Area is < 10%, no further action is required for the red king crab stocks, so the remaining tiers are not addressed here.***

I have concern for using 50% CEA for red king crab stocks. Some habitat is much more important for red king crab spawning success than others. Even though the habitat reduction for all red king crab habitat areas is less than 10%, the most critical area for Bristol Bay red king crab spawning is southern Bristol Bay, where the habitat reduction is well over 10% (Figure 2). More analysis may be needed for Bristol Bay red king crab than just Figures 1 and 2.

Conclusion of 2017 EFH 5-year Review

In April 2017, the SSC and Council concurred with species-specific EFH fishing effects reviews conducted by stock assessment authors that no stocks needed mitigation review, and that the effects of fishing on the EFH of fisheries species managed by the NPFMC are minimal and temporary (NPFMC 2017).

At the conclusion of the 2017 EFH 5-year Review, the SSC provided several recommendations related to the Fishing Effects (FE) model. In response:

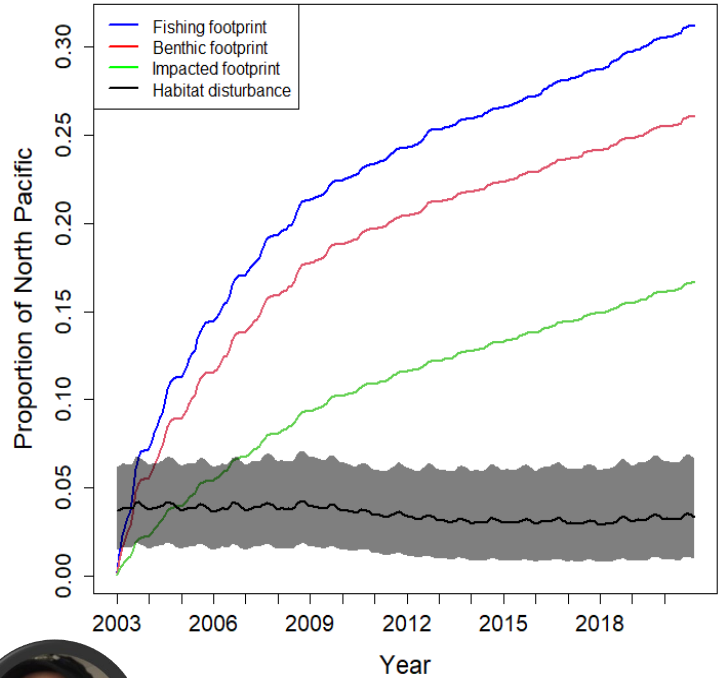
- Output from the FE model is included as an indicator (habitat disturbed) in yearly Ecosystem Status Reports
- Smeltz, T.S., Harris, B., Olson, J., and Sethi, S. 2019. A seascape-scale habitat model to support management of fishing impacts on benthic ecosystems. Canadian Journal of Fisheries and Aquatic Sciences, 76(10): 1836-1844.
- A sensitivity analysis is included in the discussion paper
- Core EFH (CEA) maps will be available to the public
- Updated gear descriptions, gear impact, and recovery parameters

Sensitivity Analysis

Model outputs for low/high habitat disturbance parameter scenarios and restricted (no recovery) models

Model version	Dec 2020 model estimate (% of North Pacific)
Habitat disturbance (lower – upper bound)	3.4% (1.0% - 6.7%)
Fishing footprint	31%
Benthic footprint	26%
Impact footprint	17%

Model outputs for habitat disturbance and each of the restricted models (no recovery). The grey band shows the bounds of habitat disturbance with all parameters fixed to their highest or lower values.



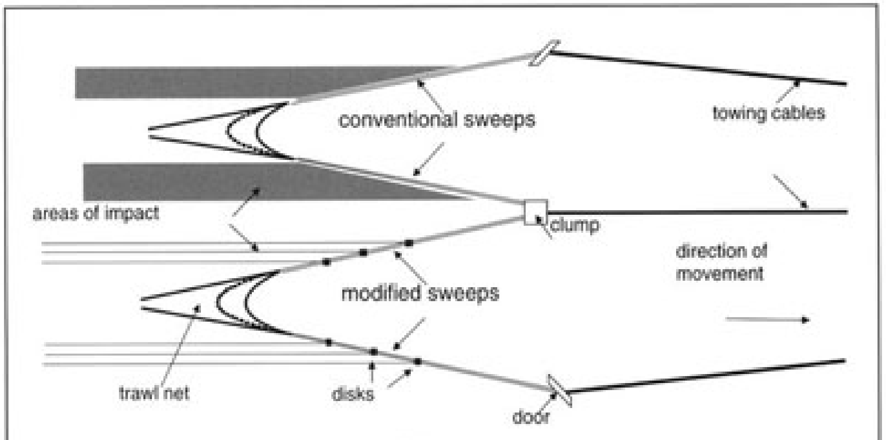


Figure 1

Diagram of the twin trawl system, complete with sweeps (conventional and modified), towed simultaneously behind a vessel and used to test whether raised trawl sweeps reduce flatfish herding. Actual total width was approximately 250 m. Shaded areas represent the area of contact with the seafloor.

Responses to SSC Comments for 2022 EFH 5-year Review

1. **Perhaps run the old dataset with old parameters and new parameters to see how they contrast. Then run new data with new parameters.**
   - Section 3.4, “FE model code”, figure 6

2. **Consider 2017 SSC minutes concerning the use of averages or alternatives for estimation of susceptibility and recovery.**
   - Section 3.6, “Feature averaging”

3. **Explain why sediment type must continue to be used as a proxy for habitat susceptibility and recovery rates.**
   - Sections 3.2, “Habitat categorization” and 3.3, “Susceptibility and recovery”

4. **Isolate how the new 2022 parameters affect results**
   - Section 3.4, “FE model code”

5. **Description of updated data inputs (including those to the catch in area database), new data sets not previously considered, and any methodological changes to the model or treatment of input data.**
   - Section 3.1, “Fishing intensity”

6. **Consider including a few key examples of overlays of updated 2022 SDMs and FE model results for species that are informative – say ones with large differences.**
   - Section 4.2, “Example 2022 FE model output with 2017/2022 SDMs”

7. **Describe whether the EFH Team plans to use the evidence-based approach for evaluation of impacts on spawning, feeding, growth to maturity used in 2017 to evaluate impacts and provide a timeline for completion of this analysis.**
   - Section 2.5.1, “Hierarchical impact assessment methods”, Section 4.1 “Thresholds”

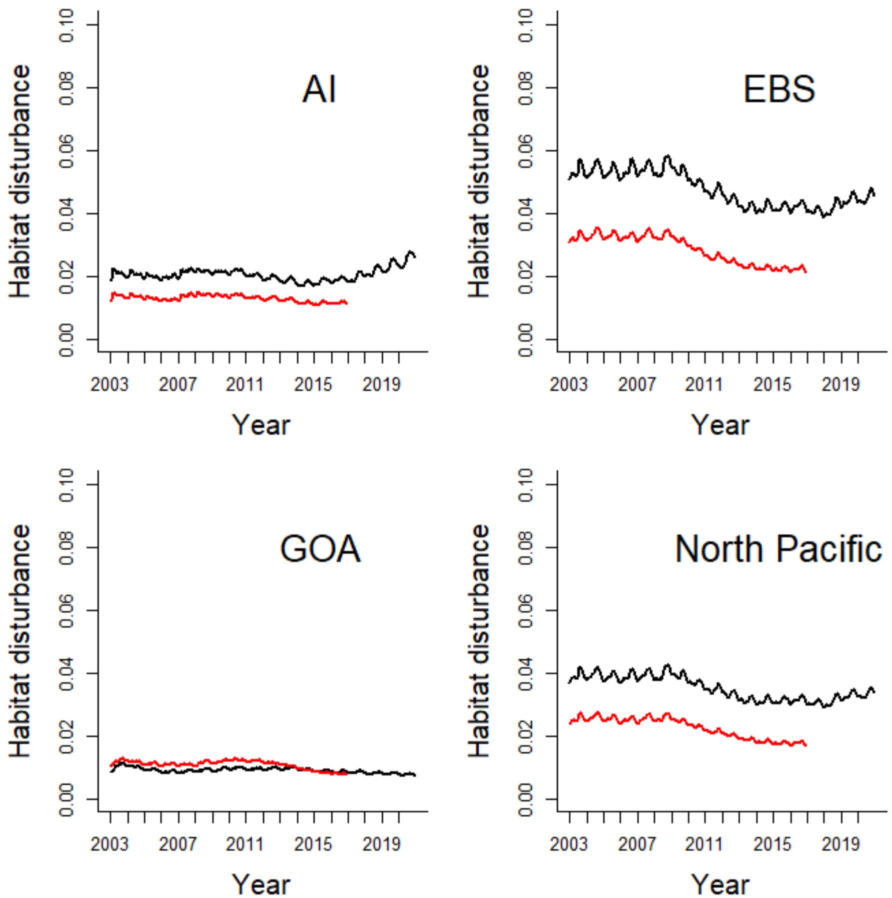
Perhaps run the old dataset with old parameters and new parameters to see how they contrast. Then run new data with new parameters

Since 2017, the model code has undergone various updates and improvements with an aim toward flexibility and efficiency.

An error was discovered in the 2017 model code that transposed the susceptibility for trawl and longline gears. Because susceptibility is generally higher for trawls than longlines, the effect was an underestimation of impacts from trawls and an overestimation of impacts from longlines.

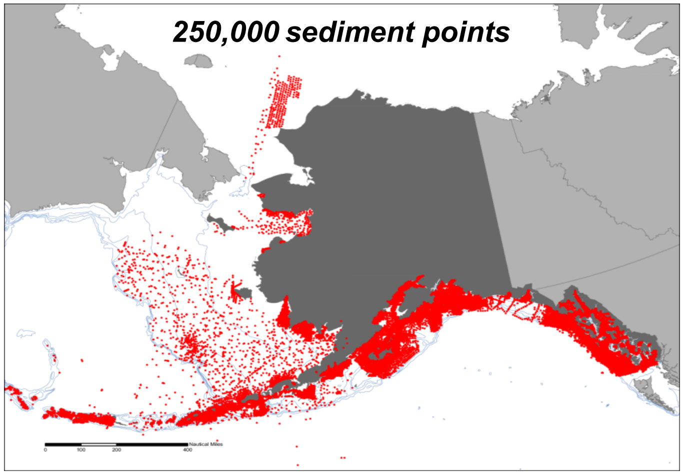
Because the total footprint of trawling throughout the North Pacific is much greater than the footprint of longlines, the net effect of this error resulted in an underestimate of habitat disturbance, with the largest difference evident in the Bering Sea.

The differences between the outputs are due to the correction made to properly attribute susceptibility to trawl and longline, as well as updates to the Gear Table parameters.



Comparison of 2017 FE output (red lines) and 2022 FE model output (black lines) among subregions and the North Pacific at large

Consider 2017 SSC minutes concerning the use of averages or alternatives for estimation of susceptibility and recovery (and sediment as a proxy)



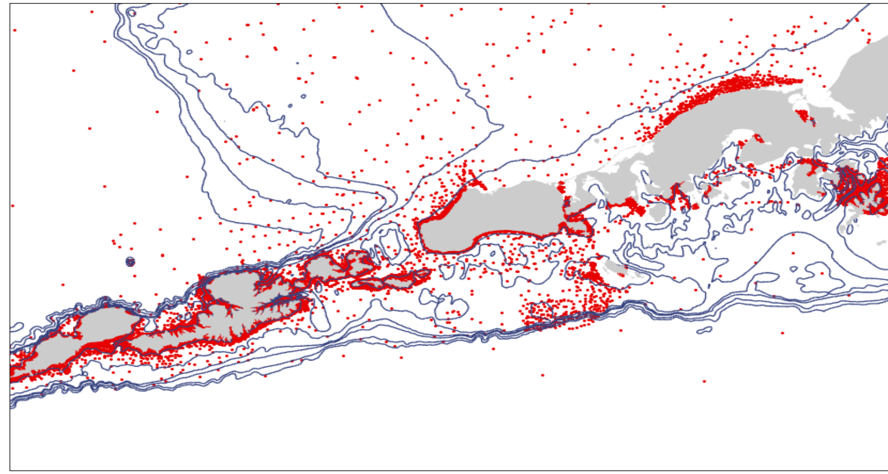


Table 4. Habitat areas and trawled areas (km^2) by base 2 categories of trawl swept-area ratio (area trawled/grid-cell area): total area; area of sediment-habitat types; total swept area; and estimates of trawl footprints (which account for overlapping trawls) assuming trawling is uniform at 0·01° or randomly distributed within 0·01° grid cells

		Habitat area					Trawl footprint	
Swept-area ratio	Total area	Mud	Muddy-Sand	Sand	Gravel	Swept area	Uniform	Random
0	1760	34	244	892	590	0	0	0
>0-0·03125	454	9	94	234	117	9	9	8
0·0625	126	1	32	66	26	11	11	11
0·125	152	2	57	66	26	28	28	25
0·25	210	0	79	95	36	74	74	62
0·5	222	2	42	136	41	160	160	113
1	307	6	100	151	50	451	307	233
2	216	0	42	121	53	590	216	200
>4	88	0	8	53	28	481	88	88
Totals	3535	55	698	1815	967	1803	892	740

"Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance"

Pitcher et al 2017

Hiddink et al 2017

Pitcher et al 2022

Description of updated data inputs (including those to the catch in area database), new data sets not previously considered, and any methodological changes to the model or treatment of input data.

Catch-in-areas data through 2020.

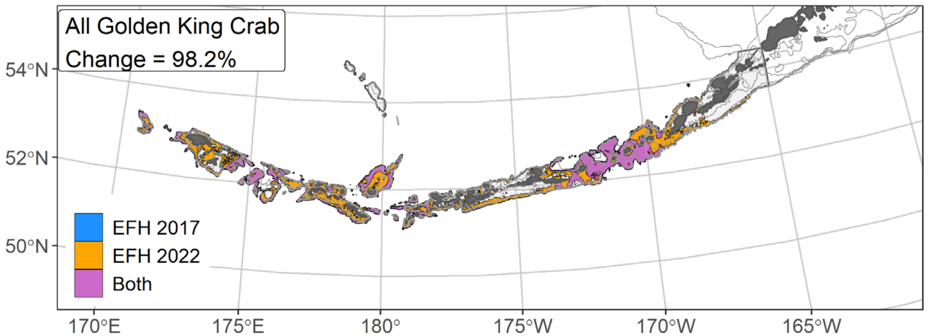
Updated longline, pot, & GOA pelagic rockfish trawl gear parameters

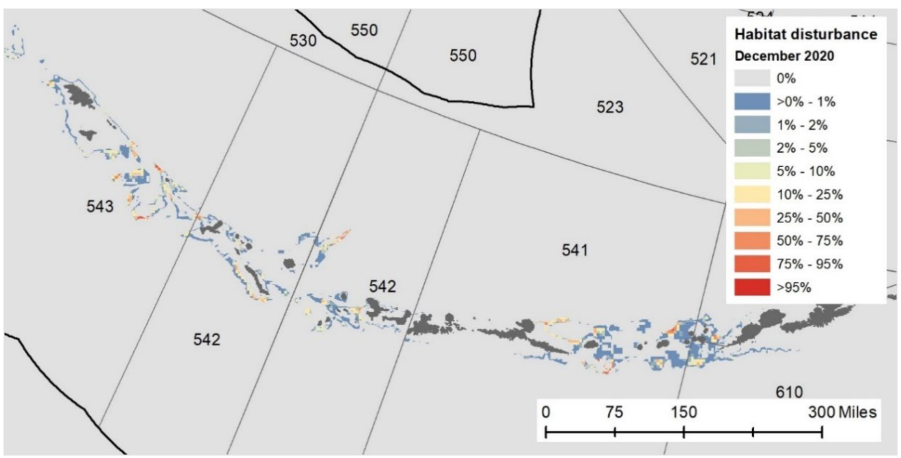
Exploratory analyses using unobserved fishing lines in the CIA
- 7-12% of fishing events
- Almost 50% of *minutes fished* or *line length*

"Incorporate Coral and Sponge Covariates into FE model"
- *Deep-Sea Coral and Sponge Initiative funded project*
- *GOA validation cruise scheduled for 2022*

Fishing Effects Model Northeast Region 2020
- *Vulnerability assessment and literature review were updated*

Consider including a few key examples of overlays of updated 2022 SDMs and FE model results for species that are informative – say ones with large differences.





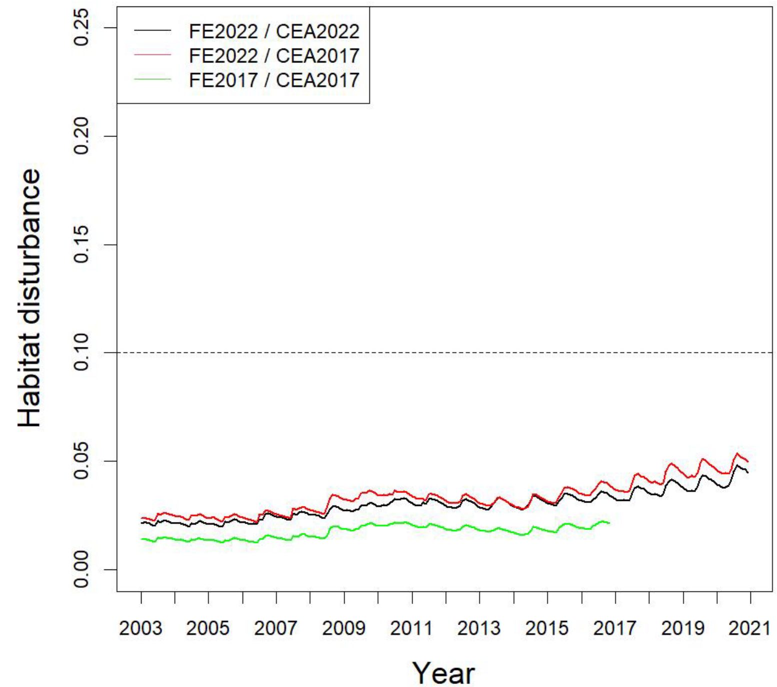


Figure 13: Time series of habitat reduction - AI Golden king crab CEA comparison

Describe whether the EFH Team plans to use the evidence-based approach for evaluation of impacts on spawning, feeding, growth to maturity used in 2017 to evaluate impacts and provide a timeline for completion of this analysis.

1. Should assessments be based on regional boundaries for the stock or species?

The CPT evaluates multiple stocks within a region, so fishing impacts should perhaps be evaluated at the stock level as identified by the individual assessment authors.

2. Is the 50% threshold the right one?

This threshold balances making sure enough areas are covered without covering areas of marginal importance. The CPT considered whether analysis should look at a 25% threshold, or others, to see differences. One possible method is to weigh the habitat disturbance proportional to abundance. Problems with weighting according to abundance in an area are: (1) animals may move to avoid areas of high impact, (2) we don't know how the models react to changes in distribution or detect movement, and (3) we don't know what impacts movement has on population level effects. A time series of maps could illustrate movement over time. Also, we could look at abundance in closed areas compared to open areas. The CPT discussed whether it would be possible to detect impacts given we only have population level data and we don't have the information necessary to make correlations. One suggestion was to overlay habitat maps over time with population distributions to indicate if there appears to be some inherent response mechanism. The CPT expressed concern that finding will likely always be of no impact as a result of weak factors to correlate due to paucity of information for crab. A suggestion was made to look at the change in disturbance and then go back and evaluate how recruitment changes (or other variable) have changed since that time to see if there is correlation. The effects will be most likely subtle and chronic.

3. Continue the 10% habitat reduction threshold?

The CPT concurred that it is not possible to answer this question because the model has not yet been applied to crab stocks.

4. Is p-value of 0.1 reasonable?

Probably, but it would be good to see the results for crab; if a lot of crab stocks fall on $p<0.05$, we may want to reconsider.

Questions for the Ecosystem Committee

- Updates to FE?
- Review of methodology to evaluate the effects of fishing developed for the 2017 EFH 5-year review?
- Potential timeline for stock author review – Spring 2022 for a June 2022 SSC presentation.

Questions that may be outside the scope of the Effects of Fishing analysis

- Separating habitat issues from bycatch or unobserved mortality issues
- Efficacy of closed areas

Additional slides

Feature averaging

During previous NPFMC meetings, both the SSC and public testimony expressed interest in a clearer explanation of feature averaging. To illustrate and clarify, we provide this example:

The Fishing Effects model computes the amount recovery each time step based on one of five sediment-based habitat types. To calculate an average recovery time for each sediment class, a recovery time (τ, in years) was first randomly selected for each habitat feature based on its score for that sediment. The mean of these recovery times was then calculated over all habitat features associated with the sediment class. The inverse of this averaged recovery time was then used in the following equation to convert the time to recovery into a proportional recovery (ρ) for each time step,

$$\rho=1-e-1/\tau$$

In practice, τ is multiplied by twelve before conversion to ρ to convert it to months, which is the time step of the FE model. This process was repeated for each grid cell at a monthly time step. The following example illustrates feature averaging for mud and deep/rocky sediments.
Simplified table of recovery scores

Recovery codes:
0: < 1 year
1: 1 - 2 years
2: 2 - 5 years
3: 5 - 10 years
4: 10 – 50 years

Habitat feature	Mud	Sand	Deep/rocky
Biogenic depression	0	0	
Anemones, cerianthid burrowing	2	2	
Mollusks, epifaunal bivalve, Modiolus modiolus	3	3	3
Long-lived species			4

Feature averaging 2

To calculate monthly recovery on mud in one grid cell for one specific time step:

Habitat feature	Mud score (range)	Random selection from range (τ)
Biogenic depression	0 (0 -1 years)	0.3 years
Anemones, cerianthid burrowing	2 (2 – 5 years)	4.1 years
Mollusks, epifaunal bivalve, *Modiolus modiolus*	3 (5 – 10 year)	6.3 years
Long-lived species	Not present	
		mean = 3.57 years

$$\tau = 3.57\ years = 42.8\ months$$
$$\tilde{p} = 1 - e^{-\frac{1}{42.8}} = 0.023 = 2.3\%$$

Thus, on the proportion of mud sediment within this grid cell and time step, 2.3% of the disturbed habitat would recover (i.e. convert to an undisturbed state in the model) for the next time step.

To calculate monthly recovery on deep/rocky sediment in one grid cell for one specific time step using the simplified table:

Habitat feature	Deep/rocky score (range)	Random selection from range (τ)
Biogenic depression	Not present	
Anemones, cerianthid burrowing	Not present	
Mollusks, epifaunal bivalve, *Modiolus modiolus*	3 (5 – 10)	5.1 years
Long-lived species	4 (10 -50)	39.8 years
		mean = 22.5 years

$$\tau = 22.5\ years = 270\ months$$
$$\tilde{p} = 1 - e^{-1/270} = 0.0037 = 0.37\%$$

Thus, on the proportion of deep/rocky sediment within this grid cell and time step, 0.37% of the disturbed habitat would recover (i.e. convert to an undisturbed state in the model) for the next time step.

Longline and pot gear parameters

Using autonomous video to estimate the bottom-contact area of longline trap gear and presence–absence of sensitive benthic habitat[1]

Beau Doherty, Samuel D.N. Johnson, and Sean P. Cox

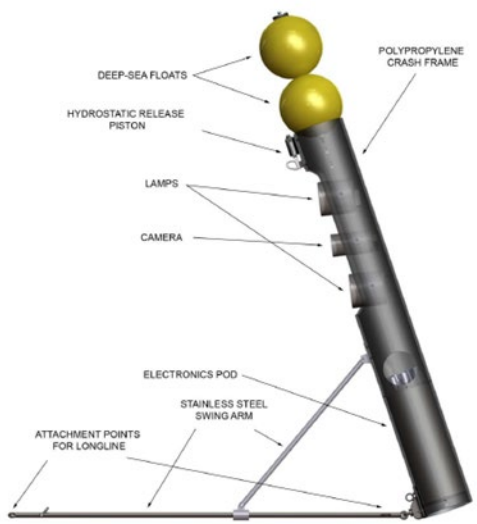


Figure A4.2. Benthic Impacts Camera System (BICS) mounted in the longline crash frame. The narrow cylindrical shape of the longline housing allows it to be deployed through a narrow shooting window, the stainless steel swing arm on the left side is attached to the longline and folds open after deployment (as shown). The floats keep the unit upright and filming down the longline during fishing and retrieval.