Methods and criteria to evaluate the effects of fishing on EFH
Proposal from the SSC subcommittee
DRAFT: 9/9/2016

1. Introduction and Background

The Magnuson Stevens Fishery Conservation and Management Act (MSA)[1] requires regional Fishery Management Councils to describe and identify Essential Fish Habitat (EFH) for all fisheries and to minimize to the extent practicable the adverse effects of fishing on EFH. The North Pacific Fishery Management Council (Council) is currently evaluating potential updates to EFH in its Fishery Management Plans (FMPs), including reassessing the adverse impacts of fishing and non-fishing activities on EFH. At initial review of new EFH descriptions (April, 2016), the Council's Scientific and Statistical Committee (SSC) recommended that new criteria by which to evaluate the potential impacts of fishing on EFH should be developed. The Council approved the SSC recommendation and directed the SSC to form a subcommittee to develop the criteria. This discussion paper presents a potential new method and new criteria to evaluate the effects of fishing, and represents the recommendation of the subcommittee.

Requirement to mitigate fishing effects that are more than minimal and not temporary

Under Section 303(a)(7) of the Magnuson-Stevens Act and 50 CFR 600.815(a)(2), every FMP must minimize, to the extent practicable, adverse effects of fishing on EFH. The Council must act to prevent, mitigate, or minimize any adverse effects from fishing, to the extent practicable, if there is evidence that a fishing activity adversely affects EFH in a manner that is more than minimal and not temporary in nature. Should the fishing effects evaluation indicate that there are adverse effects on EFH, the Council must identify a range of potential new actions that could be taken to minimize the adverse effects and analyze the practicability of potential new actions. Potential new actions could include gear restrictions, time/area closures, harvest limits, or other measures as appropriate. In determining whether it is practicable to minimize an adverse effect from fishing, the Council would consider the nature and extent of the adverse effect on EFH and the long and short-term costs and benefits of potential management measures to EFH, associated fisheries, and the nation.

Habitat Areas of Particular Concern (HAPCs) are areas within EFH that are ecologically important, sensitive to disturbance, subject to stress from development, or rare. EFH regulations [50 CFR 600.815(a)(8)] provide a means for Councils to identify HAPCs within FMPs. When conducting an evaluation under 50 CFR 600.815(a)(2) of fishing activities that may adversely affect EFH, the Council should give special attention to adverse effects on HAPCs and should

[1] As originally amended in 1996 and as amended through January 12, 2007.

identify for possible designation as HAPC any EFH that is particularly vulnerable to fishing activities.

History of EFH in the North Pacific

EFH EIS effects of fishing analysis initial development (2001-2005)

The duration and degree of fishing effects on habitat features depends on the intensity of fishing, the distribution of fishing with different gears across habitats, and the sensitivity and recovery rates of habitat features. While at least some information was available on all of these factors during the 2005 EFH EIS, it varied in quality, spatial coverage, and applicability to Alaska fisheries. There was also no accepted model or analysis for relating this information to the questions posed by the EFH regulations. An initial approach was developed in April 2002 by the NPFMC (Witherell 2002) and was based on guidance from the Magnuson-Stevens Fishery Management and Conservation Act. It described the steps necessary to perform the evaluation (description, evaluation of effects, identification of potential management actions, and evaluation of practicability), and combined regional statistics into a gear factor, a habitat recovery factor, and a percent coverage factor for each fishery. These factors were then combined into two scores related to whether potential effects are minimal or temporary.

In May of 2002, a numeric model was developed by Dr. Jeff Fujioka (NMFS - retired) as a tool to structure the relationships between available sources of information on these factors. The Long-term Effects Index (LEI) model was designed to estimate proportional effects on habitat features that would persist if current fishing levels were continued until affected habitat features reached an equilibrium with the fishing effects. At equilibrium, habitat features will neither further degrade nor improve if fishing effects persist at a constant level. Therefore, such effects would not be of limited duration and would meet the ‘not temporary’ test. This model is described in Fujioka (2006), and was a step forward from both the initial NPFMC approach as well as the process described in NRC (2002) in that it added recovery attributes to previously impacts-only approaches.

A preliminary analysis was presented by Dr. Craig Rose (NMFS – retired), based on the LEI model and applied on a 25km^2 spatial scale, was provided in August 2002 to aid the Council’s EFH Committee in selecting potential alternative actions to minimize adverse effects of fishing. Improvements to that model were made based on input from participants in the Council process and scientists inside and outside of NMFS, as well as outside peer review by the Center for Independent Experts (Drinkwater 2004).

2004 CIE Review

In order to provide an independent assessment of the evaluation of the 2005 EFH EIS effects of fishing on habitat, NMFS contracted with the Center for Independent Experts (CIE) to conduct a peer review focused on the technical aspects and assessment methodology. Given the limited review of the model, the importance of this analysis for Alaska's fisheries, and the controversial nature of the subject matter, NMFS determined that an outside peer review would be a prudent step.

The reviewers focused on two broad issues: 1) the fishing effects model used to assess the impact of fishing on different habitat types, and 2) the analytical approach employed to evaluate the effects of fishing on EFH, particularly the use of stock abundance relative to the Minimum Stock Size Threshold (MSST) to assess possible influence of habitat degradation on the productivity of fish stocks. Many of the panel's comments, criticisms, and concerns were provided in the panel chair's summary report and are embodied as a succinct set of 22 short-term and long-term recommendations (Drinkwater 2004). The CIE panel's reports included the following findings:

- The model was well conceived and is useful in providing estimates of the possible effects of fishing on benthic habitat. However, as acknowledged in the DEIS, the parameters estimates are not well resolved and have high uncertainty due in large part to a paucity of data. Results must be viewed as rough estimates only.
- The use of stock status relative to the Minimum Stock Size Threshold to assess possible influence of habitat degradation on fish stocks is inappropriate. MSST is not a sufficiently responsive indicator and provides no spatial information about areas with potential adverse effects. Instead, the approach should include examination of time series indices such as size-at-age, population size structure, fecundity, gut fullness, spatial patterns in fish stocks relative to fishing effort, and the history of stock abundance.
- The analysis did not give adequate consideration to localized (versus population level) habitat impacts.

2004 AFSC Response to CIE Review

Following the CIE review, the AFSC published a draft response (AFSC 2004) to numerous criticisms highlighted by the CIE, foremost being the use of Minimum Stock Size Threshold (MSST). NMFS scientists responded that they agreed that only considering stock abundance relative to MSST does not provide a sufficiently detailed analysis of the influence of habitat degradation on the productivity of fish stocks. They noted that the evaluations of habitat effects were not limited to as assessment of stock status relative to MSST, but considered a full set of more detailed information on stock status, although those were not thoroughly described and incorporated into the materials provided to the CIE reviewers.

2005 EFH EIS

The final EFH EIS was published in April, 2005. This document examined the effects of fishing in Appendix B. The 2005 EFH EIS concluded that fisheries do have long term effects on habitat, but these impacts were determined to be minimal and not detrimental to fish populations or their habitats. The analysis found no indication that continued fishing activities at the current rate and intensity would alter the capacity of EFH to support healthy populations of managed species over the long term. Nevertheless, the Council acknowledged that considerable scientific uncertainty remains regarding the consequences of habitat alteration for the sustained productivity of managed species. Consequently, the Council adopted a number of management measures designed to reduce adverse impacts to habitat, including expanded closures for bottom contact gear in the Aleutian Islands and the Gulf of Alaska, as a precautionary measure.

2010 EFH Review

Fishing effects were again evaluated for the 2010 EFH review. After an analysis of the distribution and intensity of fishing, new habitat distribution (sediment, etc) data available, and new information in the literature regarding impacts and recovery, the EFH review was completed. The EFH Review for 2010 concluded because fishing intensity decreased overall, with moderate shifts causing increases or decreases in relatively limited areas, and because there were no substantial changes in other components of the model, there were no changes that would raise concerns for the effects of fishing on FMP managed species.

2015 EFH Review

Model-based Essential Fish Habitat definitions

Essential Fish Habitat descriptions consist of text descriptions and maps. In Alaska, most EFH descriptions for groundfish have been limited to qualitative statements on the distribution of adult life stages. While these are useful, they could be easily refined by using species distribution models and available data from a variety of sources. Recently, species distribution models have been developed for coral and sponge species in the Eastern Bering Sea, Gulf of Alaska, and Aleutian Islands (Rooper et al. 2014, Sigler et al. 2015). Since the completion of the 2010 EFH review, substantial new data have been made available to describe habitat in the Large Marine Ecosystems (LMEs) around Alaska, and in some cases, the effects of habitat on abundance of species of interest.

For this review, scientists at NMFS Alaska Region, the Alaska Fisheries Science Center, and academic researchers produced species distribution models of EFH for all major species of groundfish and invertebrates in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska. Models and text descriptions of EFH were generated for each species where data exists for egg, larval, juvenile, and adult life history stages in four seasons. From these, complementary distribution maps were generated that showed the location of EFH.

Data available to describe species distribution were available at different scales, and with different coverage. FOCI's ECODAAT database contains historical ichthyoplankton catches from across the entire eastern Bering Sea, from 1991 to 2013. These were collected during a number of different survey types with different objectives. Therefore, many different gear types have been used and samples were collected from a variety of depths in the water column.

Samples were collected across all months and seasons of the year. Because of these disparities, data were combined across years for this analysis. Each species in the ECODAAT data was classified as either egg, larval, or juvenile (early stages because they were not settled to the benthos). These data were used for presence-only models where the number of presence observations in a species-life stage combination exceeded 50. An important caveat is that these data were not collected over the entire area of the eastern Bering Sea, but rather, typically, from a smaller regional survey grid, which should be considered when considering maps produced from these data.

Data were also collected during bottom-trawl surveys of the eastern Bering Sea ecosystem. These data were the most comprehensive, all collected from the summer season and surveys are conducted with a rigorous statistical design. The NMFS, AFSC has conducted standard bottom-trawl surveys in the BSAI and GOA since 1982. All fishes and invertebrates captured were sorted either by species or into larger taxonomic groups and the total weight in the catch was determined. Catch per unit effort (CPUE) for each taxonomic group was calculated using the area swept. For some species both juvenile and adult sizes were captured during the bottom trawl survey. In these cases, an approximate length at first maturity was used to partition the catches into juvenile and adult stages. For some species, only a subset of years was used in the modeling due to taxonomic changes that have occurred throughout the time series.

Data from the catch-in-areas (CIA) observer database were used to model fishes caught in commercial catches during the non-summer seasons. Data from observed catches were combined across years for analysis. Presence of species in catches was used for MaxEnt (presence-only) models where the number of presence observations for a species exceeded 50. For most species, the distribution of catches was dependent on the distribution of fishing activity. This caveat should be considered when comparing to fishery-independent data.

Modeling Methods – Bottom trawl survey data

Three types of distribution modeling were used for the bottom trawl survey data based on the frequency of occurrence for each species in the catch. For species that occurred in > 30% of bottom trawl hauls, such as arrowtooth flounder, a standard Generalized Additive Modeling (GAM) method was used to produce maps of predicted density.

For species where frequency of occurrence was between 10% and 30% a hurdle model (Cragg 1971, Potts and Elith 2006) predicting spatial distribution of fishes was used. Hurdle models predict the spatial distribution of abundance (or in this case abundance and height) in three stages: 1) probability of presence is predicted from presence-absence data using a GAM and binomial distribution for each species; 2) a threshold presence probability is determined that defines presence or absence of the species; 3) a separate GAM is constructed that predicts abundance by modeling the forth-root transformed CPUE data from the bottom trawl survey where the species was present in the catch. As for the standard GAM's above, the number of inflection points were limited and insignificant terms were sequentially removed to determine the best-fitting model.

For species with < 10% frequency of occurrence, but > 50 presence observations, the MaxEnt methodology was used to develop suitable habitat models.

For all models, separate training (80%) and testing (20%) data were randomly selected from the total available trawl hauls for assessing the performance of each type of modeling. The training and testing data sets were the same across all species for the analysis of bottom trawl survey data.

Modeling Methods – Commercial catch (observer) data

The maximum entropy (*MaxEnt*) modeling method was used for estimating species distribution for commercial catch data in the CIA database (Phillips et al. 2006, Elith et al. 2011).

Modeling Methods – Essential Fish Habitat Maps

Maps of essential fish habitat based on model predictions were developed for each species and life history stage. These maps were produced as population quantiles from predictions of the distribution of suitable habitat (for species where *MaxEnt* modeling was used) or predictions of the distribution of abundance (for species where CPUE was modeled using either a GAM or hurdle GAM). For each map of model predictions 300,000 points were randomly sampled from the raster surface. These values were then ordered by cumulative distribution and zero abundance values were removed. Four population quantiles were selected from these cumulative distributions (5%, 25%, 50% and 75%). These quantiles were then used as break points to translate the model predictions (maps of suitable habitat or abundance) to map the distribution of categories of the amount of the species abundance or suitable habitat. For example, if the 5% quantile of species A was 0.024 individuals/ha, this meant that 95% of the population occurred at values higher than 0.024. Similarly, a 75% quantile of species A at 2.1 individuals/ha meant that values above 2.1 represented the top 25% of the population proportion, or the predicted highest abundance areas. The four categories for each species, life history stage, and season were mapped to show the distribution of the areas containing 95%, 75%, 50% and 25% of the population. It is important to note that these values were chosen somewhat arbitrarily (except 95% which is the current definition of EFH in Alaska), and other values could be equally appropriate.

Fishing Effects model

During the 2015 EFH cycle, the NPFMC 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. Like the LEI model, it is run on 5km grid cells throughout the Aleutian Islands, Bering Sea, and Gulf of Alaska. 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 updates the LEI model in the following ways:

- The FE model is cast in a discrete time framework. This means rates such as impact or recovery are defined over a specific time interval, compared to the LEI model which used continuous time. Using discrete time makes fishing impacts and habitat recovery more intuitive to interpret compared to continuous time. For example, an impact rate can be defined as 25% habitat disturbed per month.
- The FE model implements sub annual (monthly) tracking of fishing impacts and habitat disturbance. While this was theoretically possible in the LEI model, the LEI model was developed primarily to estimate long term habitat disturbance given a constant rate of fishing and recovery. The FE model allows for queries of habitat disturbance for any month from the start of the model run (January 2003). This aids in the implications of variable fishing effort within season and among years.
- The FE model draws on the spatially explicit Catch in Areas (CIA) database to use the best available spatial data of fishing locations. The CIA database provides line segments representing locations of individual tows or other bottom contact fishing activities. The LEI model in comparison, used endpoint only representations of fishing activity. The use of the CIA database provides more accurate allocation of fishing effort among grid cells.

The FE model incorporates the extensive literature review conducted by the New England Fisheries Management Council (NEFMC 2011) to estimate susceptibility and recovery dynamics. A consequence of this change is that the FE model splits habitat into 26 unique features rather than the four of the LEI model. Typical outputs of the FE model will average over all 26 features, or aggregate them into Biological or Geological features. However, the FE model is designed to be flexible to produce output based on any single habitat feature or unique combination of features.

To date, no prior fishing effects analyses have identified adverse effects of fishing on EFH in the Council's FMPs. However, the 2005 EFH EIS led to the Council adopting expanded closures for bottom contact gear in the Aleutian Islands and the Gulf of Alaska as a precautionary measure.

2. Fishing Effects model description

The Fishing Effects (FE) model is conceptualized as an iterative model tracking habitat transitions between disturbed and undisturbed states in monthly time steps within 5 km X 5 km grid cells across the US EEZ within the North Pacific. The amount of undisturbed habitat in any given time step reflects the undisturbed habitat from the previous time step that remained undisturbed (not impacted by fishing activity) plus the disturbed habitat from the previous time that recovered. Conversely, the amount of disturbed habitat in any given time step reflects the undisturbed habitat from the previous time step that did not recover plus undisturbed habitat that was impacted by fishing. The following general equations are used to calculate undisturbed (?) and disturbed (h habitat from one time step (? to the next, where $?^{?}_{?}$ represents the proportion of habitat impacted by fishing activities and $?^{?}_{?}$ represents the proportion of disturbed habitat that recovers,

$$?_{??\,?} \quad ?_{?}(\grave{E} - ?^{?}_{?}) \quad h_{?}?^{?}_{?}$$

$$h_{??\,?} \quad ?_{?}?^{?}_{?} \quad h_{?}\text{Æ}\grave{E} - ?^{?}_{?}$$

It is not necessary to use both equations as, ? or h can be directly computed from the other since the sum of ? and h will always equal 100%.

Fishing impacts ($?'$), which determine the proportion of undisturbed habitat transitions that to disturbed habitat each time step, are determined by 1) the location (grid cell) where fishing events occur, 2) what type of gear was used, and 3) the sediment, as a proxy for habitat features, at that location. The location and gear used are provided by the Catch-In-Areas database, a spatially explicit GIS database of commercial fishing activity dating back to 2003. Sediment is based off a sediment distribution map created specifically for the FE model from nearly 250,000 historical sediment samples. Sediment is mapped as relative proportion of mud, sand, granule/pebble, cobble, and boulder in each 5 km grid cell. The impacts from a single fishing event, then, are calculated as the product of the nominal area swept of the fishing gear (as a proportion of the total area of the grid cell), the proportion of gear that is in contact with the sea floor within the nominal area, and the susceptibility of habitat features to that gear. Susceptibility is the proportion of habitat that will be disturbed if contacted by fishing gear, and is defined for 26 habitat features (e.g. sponges, macroalgae, boulder piles, etc.) on each gear-sediment combination on a four interval scale: 0 - 10%; 10% - 25%; 25 - 50%; and >50%. At each monthly time step, the susceptibility score for a habitat feature is randomly drawn from its corresponding susceptibility interval. Because the distribution of individual habitat features is not known, the susceptibility values for habitat features are averaged for each sediment type based on the habitat features that may occur on that sediment. When multiple fishing events occur within a grid cell in a given time step, the overlap of the fishing events is accounted for to calculate a total impact for that cell for that month with fishing overlaps not counted multiple times.

Recovery ($?'$), which determines the proportion of disturbed habitat that returns to an undisturbed state each time step, is driven by the sediment profile of the grid cell. Similar to susceptibility, recovery for each sediment type is calculated as the mean recovery of all habitat features associated with that sediment. Recovery for each habitat feature is estimated on a four interval scale representing average time to recovery: <1 year; 1 – 2 years; 2 – 5 years; and 5 – 10 years. Like susceptibility, a recovery time is randomly selected for each habitat feature from its associated recovery interval. Recovery for a given sediment type, then, is averaged over all habitat features associated with that sediment. The recovery times are converted to a proportion representing what proportion of disturbed habitat recovers each month. A time-to-failure equation (i.e failure of habitat to remain disturbed) is used to make the conversion from years to monthly proportions,

?′ È − Æ −È / ÈÉÆ

where ?′ is proportion of habitat that recovers in a month and ? is average years to recovery.

The FE model outputs proportion of disturbed (or undisturbed) habitat on 5 km grid cells for each month of the model run (Figure 1). The output can be clipped and averaged over any region of interest (e.g. Management Area, EFH for a specific species), producing a monthly time series of habitat reduction for that region (e.g. Figure 2).

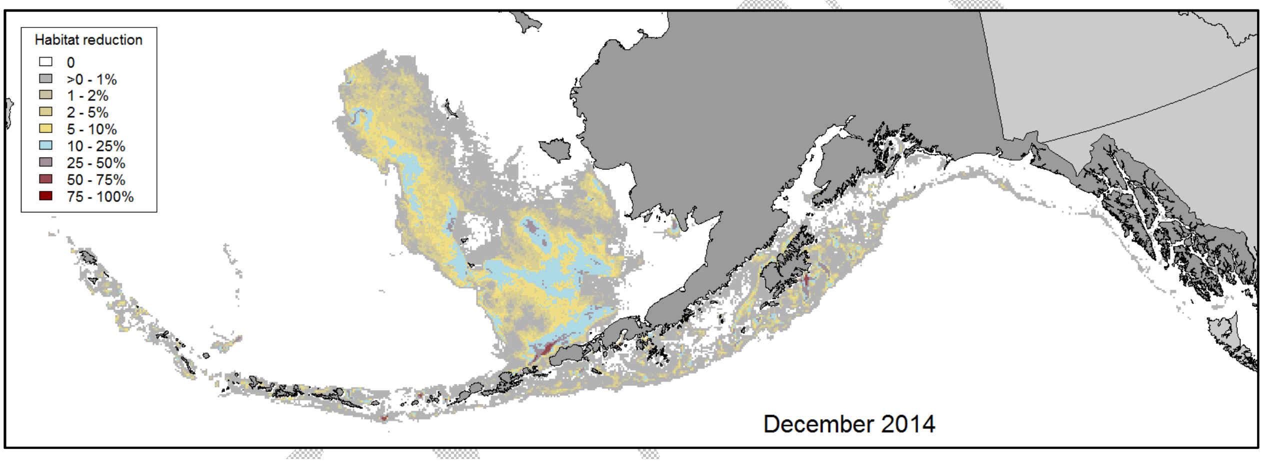


Figure 1. Habitat reduction (proportion disturbed habitat) in 5 km grid cells across the North Pacific for December 2014. Maps like this are the primary output of the FE model and will be constructed for each month the model is run.

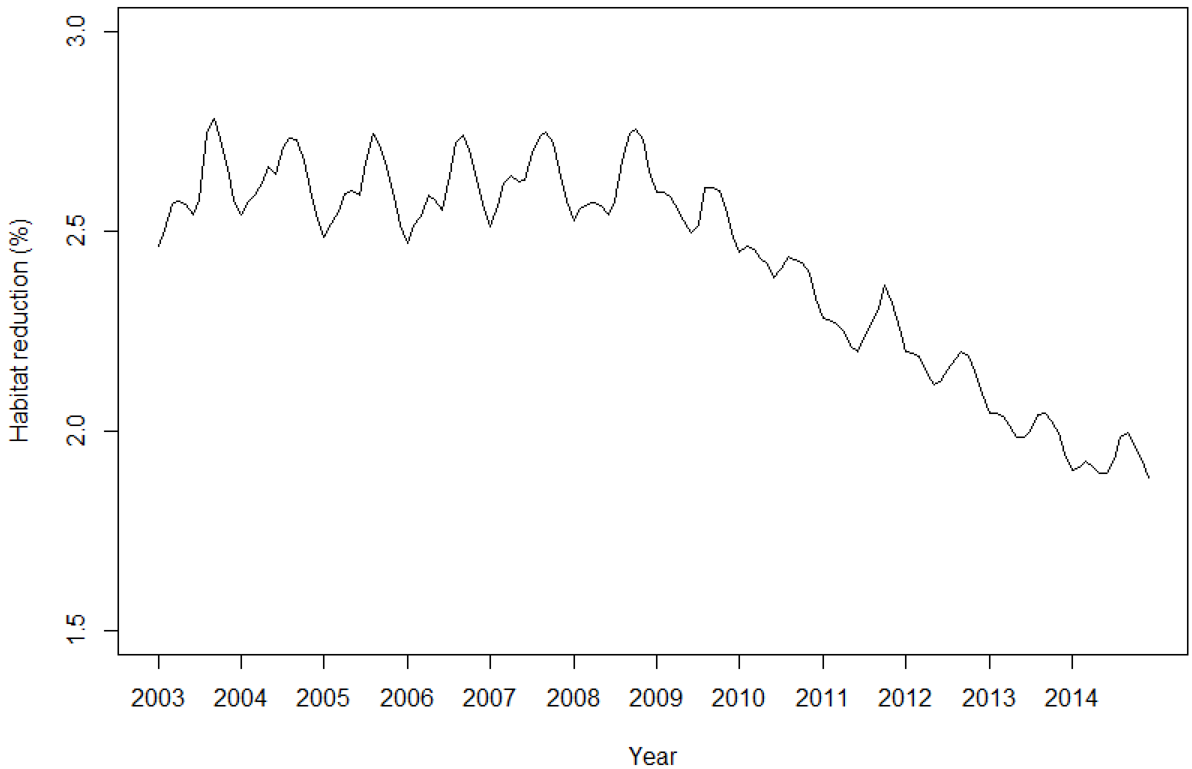


Figure 2. Habitat reduction aggregated for all areas less than 1000 m depth for the Aleutian Islands, Eastern Bering Sea, and Gulf of Alaska combined.

The SSC felt that these updates and the additional data that informed them could allow more systematic methods and criteria to assess the effects of fishing on EFH, and to determine when management measures may be necessary to mitigate the effects of fishing.

3. Hierarchical assessment methods

The Fishing Effects subcommittee formed by the SSC recommends a three-tiered method to determine the effects of fishing on EFH. The analysis will consider impacts of commercial fishing at the population level, initially, then use objective criteria to determine whether additional analysis is warranted to evaluate the likelihood of vulnerability of EFH features to fishing impacts.

Because EFH is defined for populations managed by Council Fishery Management Plans (FMPs), the first consideration of the Fishing Effects analysis is at the population level. As in previous analyses, stock assessment authors will determine whether the population in question is above or below MSST. To the extent possible, the MSST should equal whichever of the following is greater; one-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years, if the stock or stock complex were exploited at the Maximum Fishing Mortality Threshold (MFMT). Mitigation measures may be recommended for any stock that is below MSST if the stock author determines that there is a plausible connection to reductions of EFH as the cause.

To investigate the potential relationships between fishing effects and stock production, the stock assessment authors will examine trends in life history parameters and the amount of disturbed habitat in the “core EFH area” (CEA) for each species and life stage. The CEA will be defined using the predicted 50% population quantile threshold reviewed by the Council in April 2016 (Rooper et al. 2016). The 50% quantile is chosen to represent the “core” area in order to avoid the likelihood that important areas are excluded (if using the smaller area, 25% quantile) and to avoid statistically minimizing the amount of habitat reduction by using the larger, 95% quantile. Seasons will be considered to ensure that impacts to any areas that are used during specific seasons or for specific activities (spawning, feeding, settling, etc.) are not overlooked by analyzing EFH on a larger, annual basis. Any stocks for which the proportion of habitat disturbed by fishing in the CEA is ≥10% will be subject to additional analyses.

Stock assessment authors will next examine indices of growth-to-maturity, spawning success, breeding success, and feeding success (e.g., time trends in size-at-age, recruitment, spawning distributions and feeding distributions.) to determine whether there are correlations between those parameters and the trends in the proportion of the CEA impacted by fishing. If a correlation exists (negative or positive), the authors will next determine whether the correlation is significant at a p-value of 0.1. A p-value of 0.1 has been recommended to minimize the likelihood of Type II error. The purpose of this criterion is not to determine whether any correlation is statistically significant, but rather to provide an objective threshold to ensure that a “hard look” has been taken for each species, as appropriate. Because multiple parameters will be examined for correlation to habitat reduction, it is possible that spurious significant ($p > 0.1$) correlations will be found. Whenever significant correlations are found, the expert judgement and opinion of the stock assessment authors will be important to determine whether there is a plausible connection to reductions in EFH as the cause, or if the result is spurious. If stock assessment authors determine that the correlation between the impacts to the CEA and life history parameter(s) suggest a stock effect, then they will raise that potential impact to the attention of the Plan Teams, SSC, and Council. Any mitigation measures will be recommended by the Plan Teams and SSC, and enacted by the Council.

4. Changes to regulations

Should the fishing effects evaluation indicate adverse effects on EFH, the Council would follow its standard fishery management plan amendment process to mitigate any adverse effects. The Council would likely explore alternate solutions to any adverse fishing effects through a discussion paper and subsequent analysis upon completion of the fishing effects evaluation. If mitigation measures are necessary to avoid adverse impacts to EFH, the Council would recommend changes to NOAA Fisheries, AK Region, who would then write the new regulations and proceed with the public process to implement the changes.

5. Applied example of hierarchical method

Fishing impacts on pollock EFH in the Gulf of Alaska

For pollock in the Gulf of Alaska, two maps of habitat impact were developed. The first map is based on summer bottom trawl survey data. A spatial generalized additive model GAM) was fit to CPUE data, and used to develop a map of relative abundance of pollock in the Gulf of Alaska. The core EFH area was defined as 50% percentile of the cumulative distribution of pollock. It is the area within the Gulf of Alaska where the highest abundances of pollock occur so that 50% of the total abundance is within that area (Figure 3). Impacts on pollock habitat were evaluated by overlying the results from the FE model and summing impacts (percent reduction in habitat) within the pollock core EFH area.

An example of the habitat impacts is shown in Fig. 4 for December 2014, but other time periods are likely to show a similar pattern. Although the overall picture is one of low impact on habitat, there small areas of higher habitat reduction (>25%) distributed throughout the GOA shelf. The largest area habitat reduction occurs on the east side of Kodiak Island in area 630 in Barnabus and Chiniak Gullies, which is to be expected as this is an important fishing grounds for the Kodiak trawl fleet. Smaller areas of higher habitat reduction also occur near Sand Point, suggesting that areas closer to major fishing ports may experience high levels of habitat reduction.

Overall fishing impacts in the pollock core EFH area are very low. The average percent reduction for the Gulf of Alaska as a whole is 1.7%, and the average for area 630, where trawl impacts are highest, is 3%, and did not exceed 4.1% in any month. All these values are much below the 10% habitat impact that was established as the trigger for further analysis. The time trend of habitat impacts is relatively stable, but there was in uptick in area 630 in spring of 2008, which may be associated with increase in effort due to the central GOA rockfish pilot program.

If the 10% threshold for additional analyses had been exceeded, the recommendation for further analysis is to examine indices of growth- to- maturity, spawning success, breeding success and feeding success (e.g., time trends in size-at-age, recruitment, spawning distributions and feeding distributions) to determine whether there are correlations between those parameters and the trends in the proportion of the CEA impacted by fishing. Below we provide a correlation analysis with the annual average percent habitat distributed in areas 610-630 with 1) the weight at age anomaly from the Shelikof Strait acoustic survey 2) log recruitment and 3) length at 50% mature from the Shelikof Strait acoustic survey (Fig. 6). The weight at age anomaly was calculated by subtracting the mean weight at age for 2004-2015, then averaging across ages 2-10. Since the Shelikof Strait survey occurs in the beginning of the year, we examined lagged indicators, that is, habitat impacts for one year were correlated with the indicator from Shelikof Strait in the following year. Similarly, habitat impacts were correlated with estimated recruitment in the following year. Results indicate a positive correlation between the proportion of habitat disturbed and the weight at age anomaly, but no obvious relationship for log recruitment, and the length at 50% mature. P-values based on the Pearson correlation coefficient and a t-test with n=2 degrees of freedom were as follows:

Habitat impact vs weight at age anomaly: p=0.12.

Habitat impact vs log recruitment: p = 0.99.

Habitat impact vs length at 50% mature: p=0.61.

Since none of the p-values were less than 0.1, the conclusion is that habitat impacts on pollock growth- to- maturity, spawning success, breeding success and feeding success are not detectable, and that mitigation measures are not needed. Interestingly, the correlation between habitat impacts and the weight at age anomaly is relatively strong and positive, which would suggest that habitat impacts lead to increases in pollock growth, the since both time series are strong autocorrelated, the p-value almost certainly overstates the strength of the relationship.

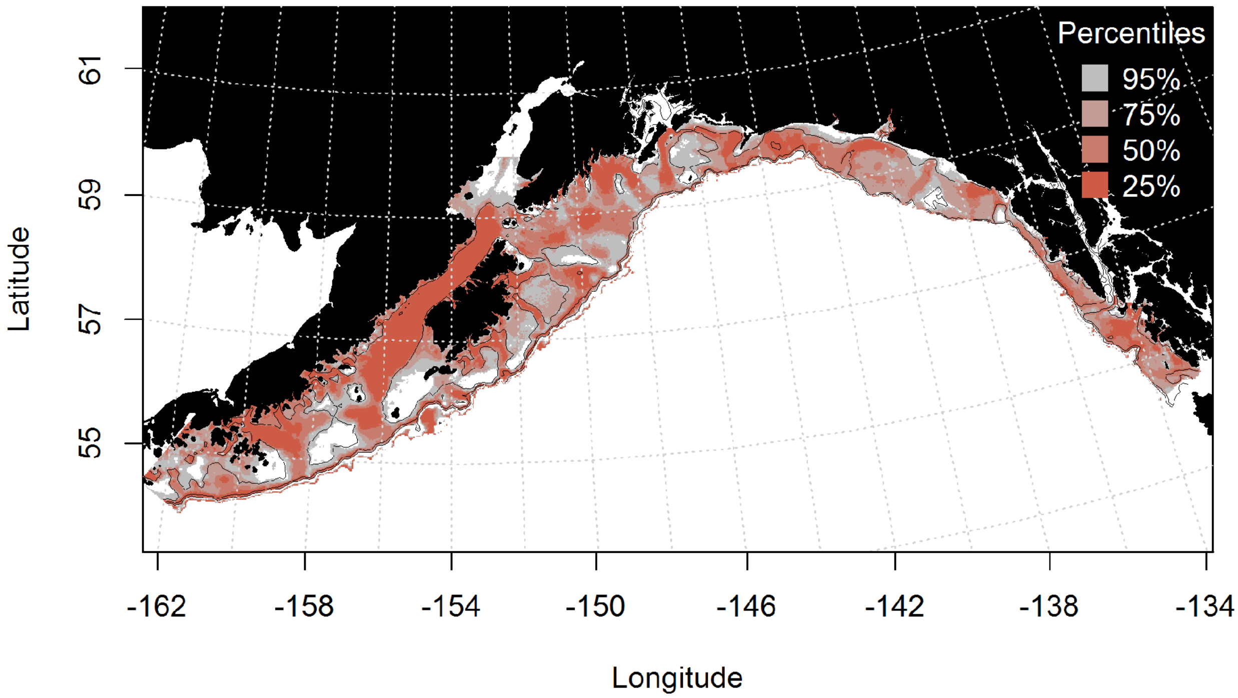


Figure 3. Areas representing various cumulative percentiles of pollock abundance in the Gulf of Alaska.

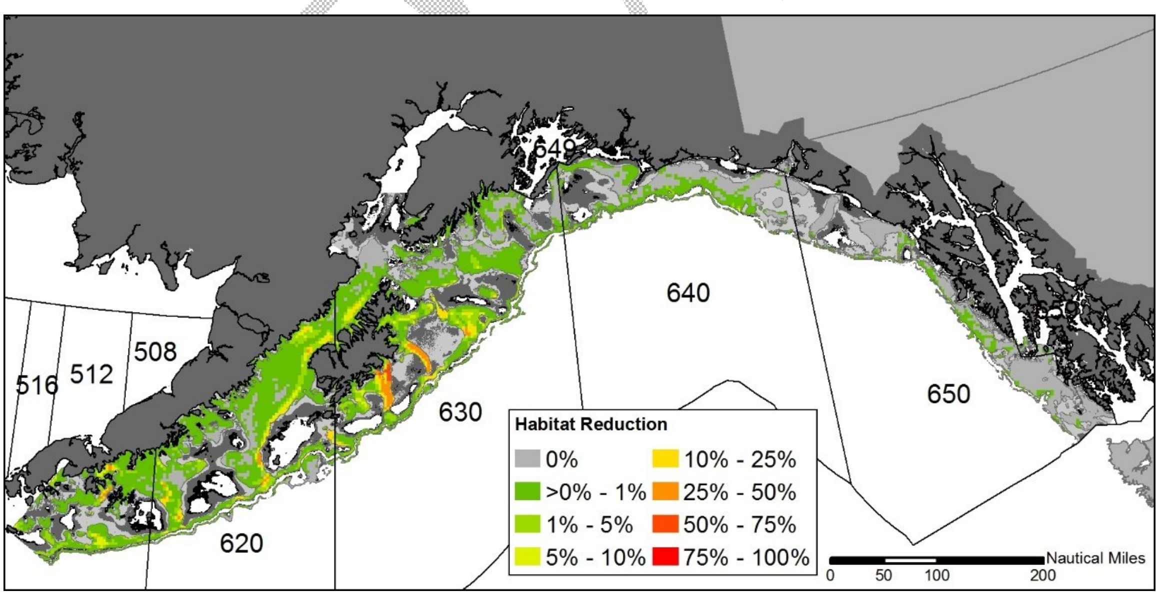


Figure 4. Habitat reduction for December 2014 in GOA pollock summer core EFH area.

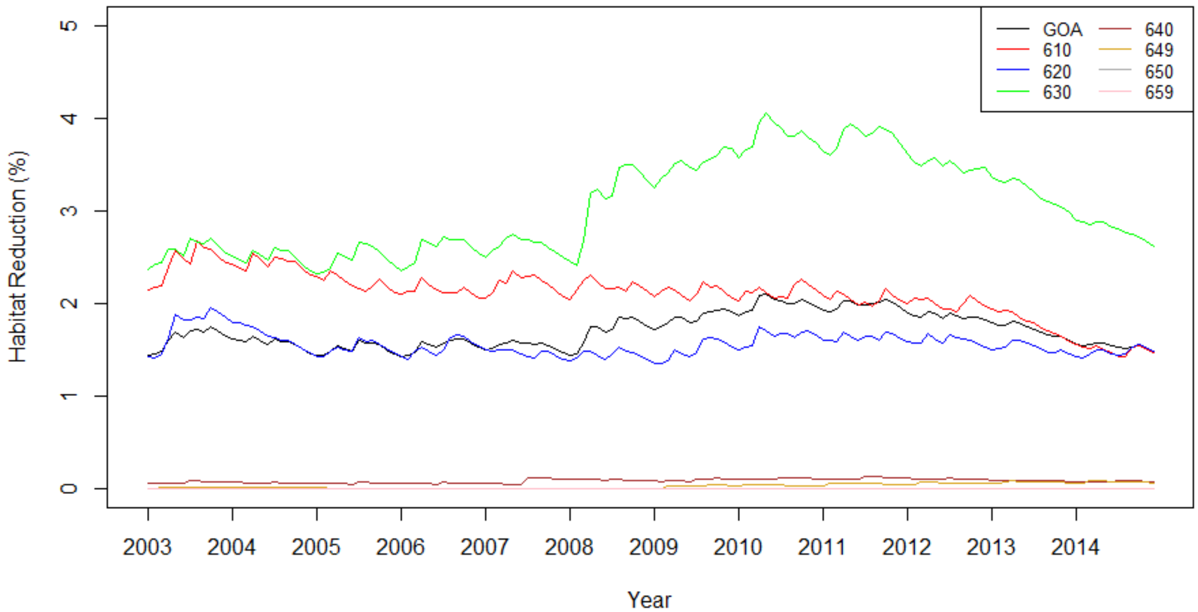


Figure 5. Monthly time series of habitat reduction for GOA pollock summer core EFH area, by management area and the entire GOA.

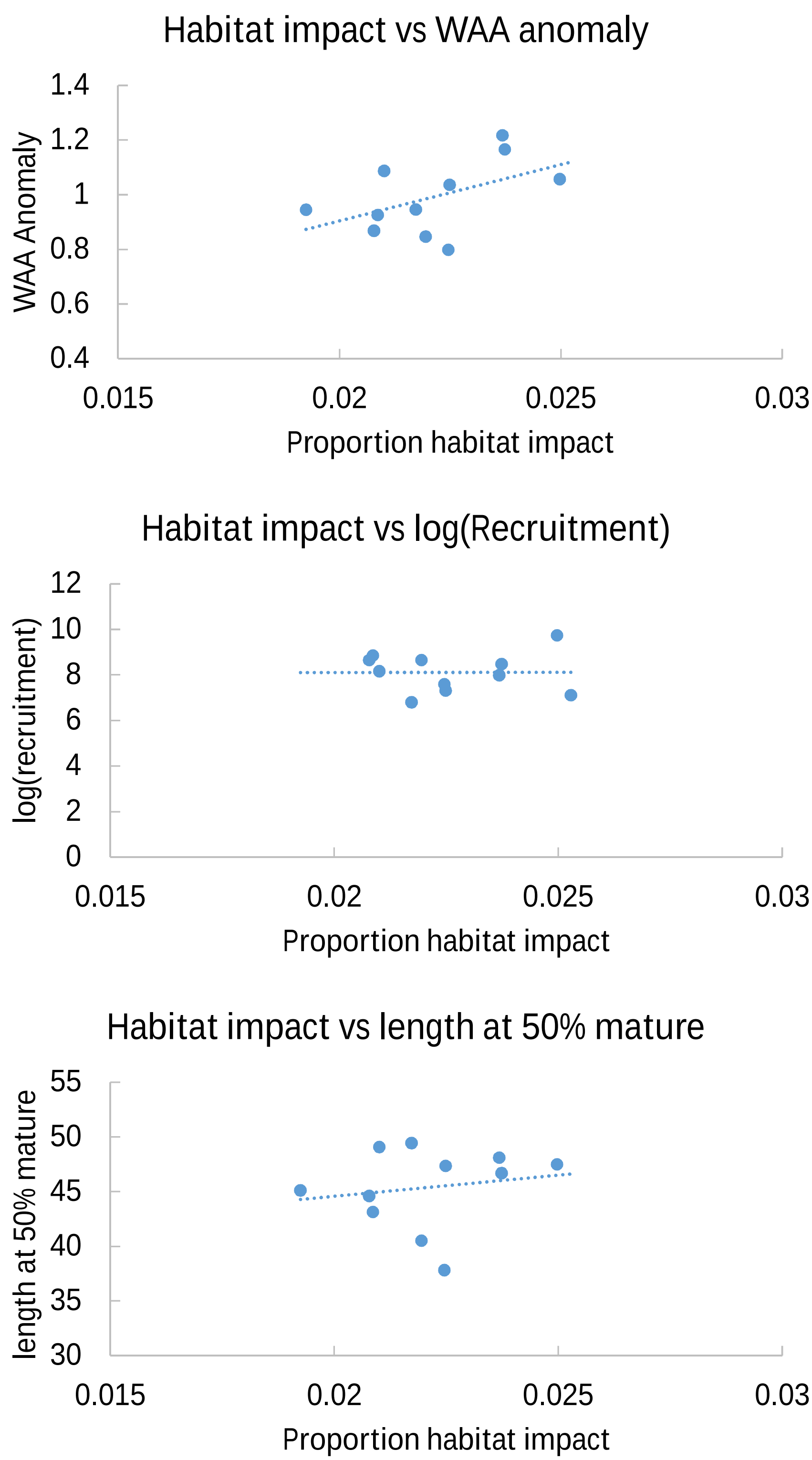
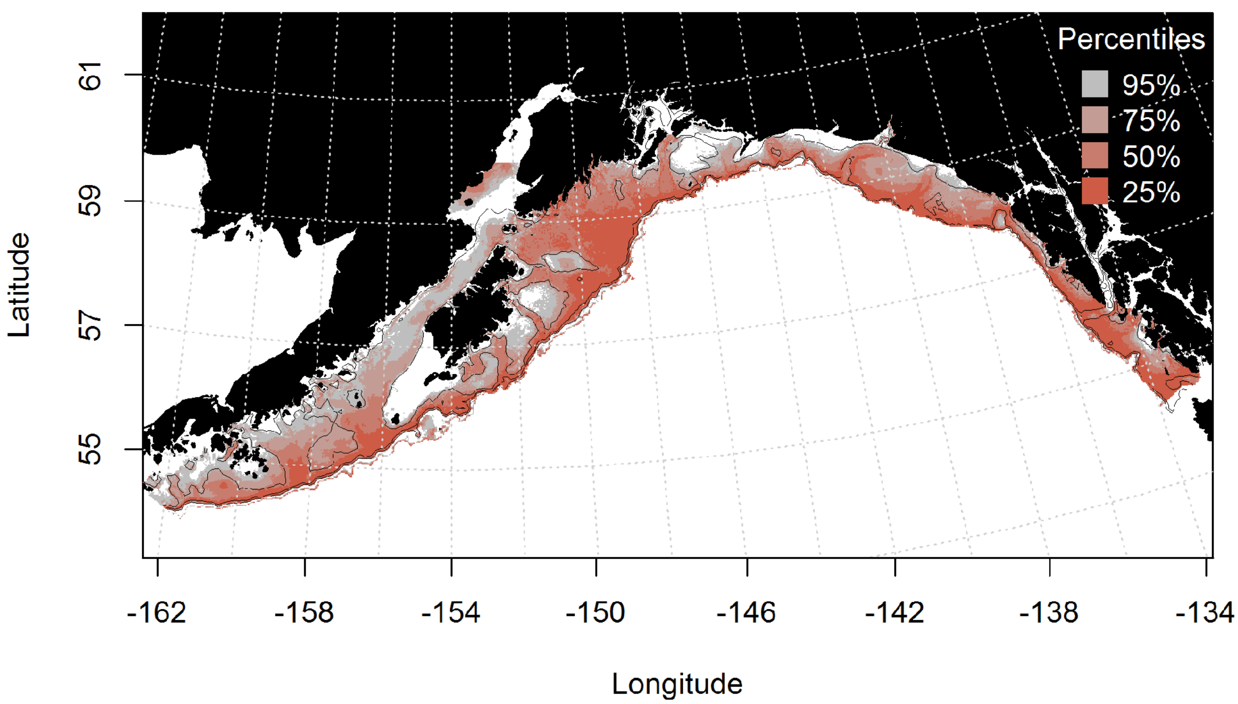


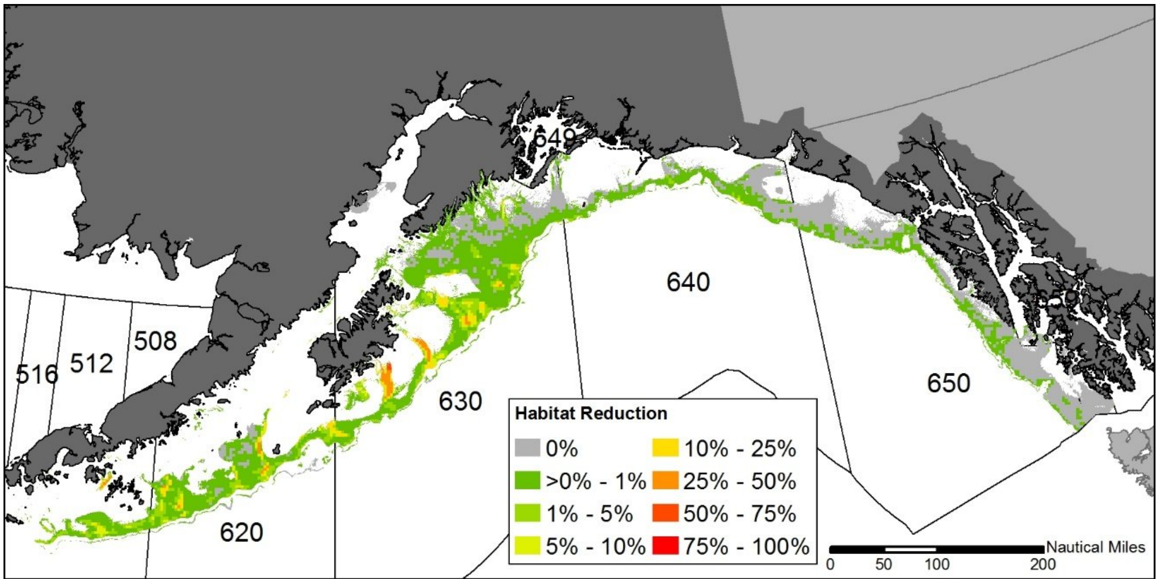
Figure 6. Correlations between annual habitat impact (2003-2014) in areas 610-630, and GOA pollock indicators for growth, recruitment, and maturation.

POP Fishing effects section: trial run #1

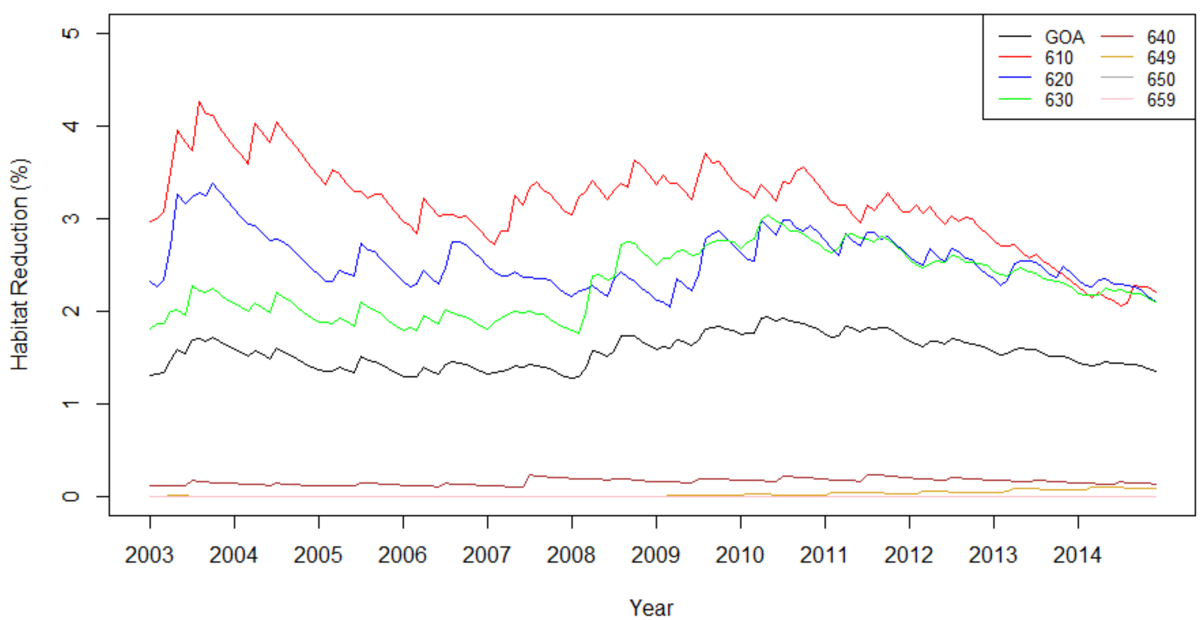
Similar to pollock in the Gulf of Alaska (GOA), two maps of habitat impact were developed for Pacific ocean perch (POP) in the GOA. The first map is based on summer bottom trawl survey and fishery observer data. A spatial generalized additive model (GAM) was fit to CPUE data, and used to develop a map of relative abundance of POP in the GOA. The core EFH area was defined as 50% percentile of the cumulative distribution of POP. It is the area within the GOA where the highest abundances of POP occur so that 50% of the total abundance is within that area, shown in the following figure.



Impacts on POP habitat were evaluated by overlying the results from the FE model and summing impacts (percent reduction in habitat) within the POP core EFH area. In the map below is an example of the proportion of habitat reduction in the GOA POP Core EFH area (shown for December 2014, other time periods of the year may also presumably show a similar pattern).

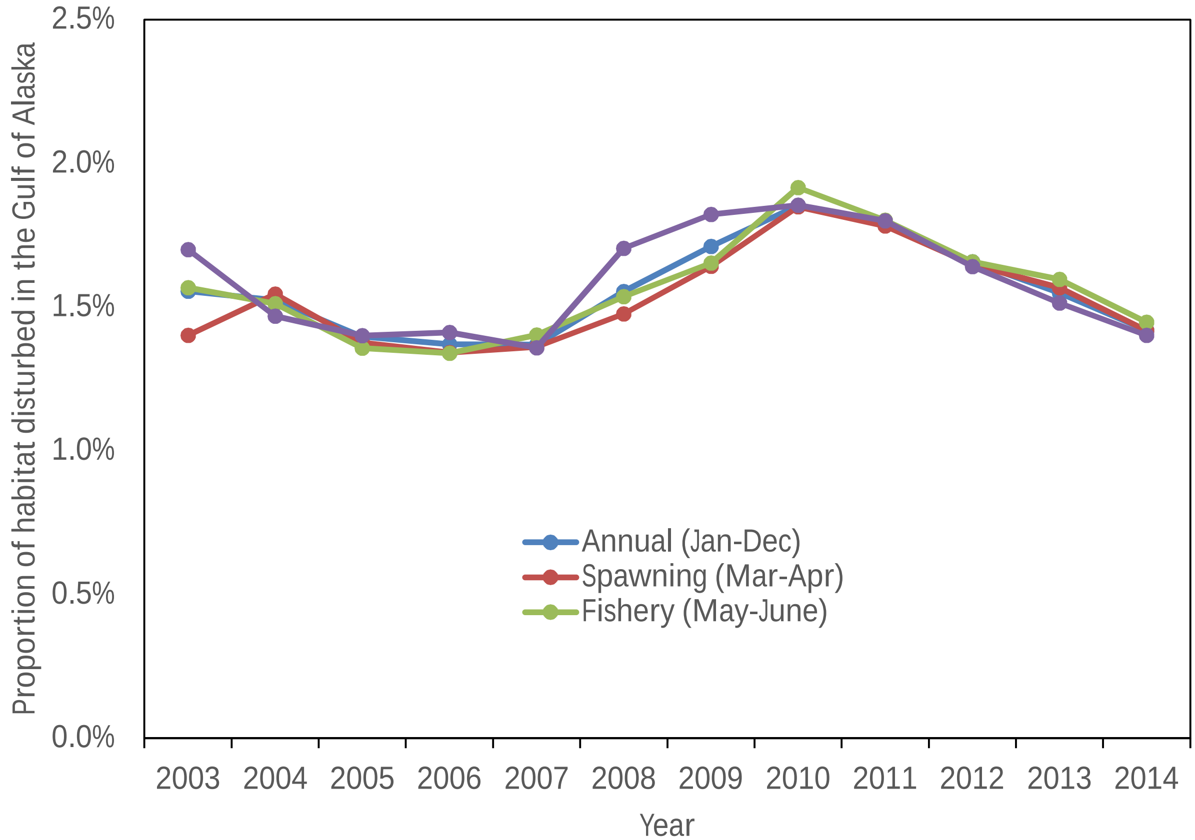


The majority of habitat reduction occurs south of Kodiak in area 630, which is to be expected as this is a focus area for the trawl fleet to capture POP as well as other groundfish species. The habitat reduction time series by month for the POP CEA by management area and across the entire GOA is shown in the following figure.



As seen in the example map above, the area with the most habitat reduction impact by fishing gear is area 630, but, integrated over the entire 630 area the proportion of habitat reduction does not exceed 5%, nor do any of the other areas or the entire GOA exceed 3.5%.

To more closely investigate the time series of habitat reduction across the entire GOA four time periods were evaluated for the proportion of habitat disturbed by fishing in the GOA CEA for POP. These time periods coincided with important life-history events including an annual index, an index of what is believed to be the peak spawning period (March to April), an index of when the majority of fishing occurs that targets POP (May-June), and an index of when breeding is believed to be occurring (October-November). These time periods are plotted in the figure below.



None of these time periods, or any other combination of months across the years for which the proportion of habitat distributed index is available exceeded 10%, indeed, no year exceeded 2% when the habitat disturbed by fishing in the GOA POP CEA was averaged across months. In addition, the trends across time for each of the four time periods are very similar.

If the 10% threshold for additional analyses is exceeded, correlation between the proportion of habitat disturbed by fishing with time trends in indices of growth-to-maturity, spawning success, breeding success, and feeding success are requested. Even though the 10% threshold was not exceeded for POP correlations were performed for evaluation. To satisfy the request with growth-to-maturity, correlation analysis was performed between the proportion of habitat disturbed and indices of growth from the AFSC bottom trawl survey in the GOA (the domeshaped selectivity for POP from the commercial fishery is such that growth parameters are difficult to estimate). These indices of growth included average size-at-age of the most frequently caught ages in the bottom trawl survey (age-3 to age-15) and annual Von Bertalanffy function growth parameter estimates. Spawning success in this case was defined as the recruitment (age-2) estimated from the stock assessment model that survived to join the adult population. There is no time series of maturity data available for POP for correlation analysis. It is also unclear how to perform correlation with spawning or feeding distributions. However, to satisfy this request the simplifying assumption made here is that the stock assessment model's estimates of total (feeding) and spawning biomass across time are proportional to spatial distribution contraction/expansion so that correlation with the proportion of habitat disturbed could be performed. As the time series of average proportion of habitat disturbed across the time periods investigated were extremely similar the annual index of proportion of habitat disturbed by fishing was used to correlate with the life-history indices. The results of the correlation analysis, along with the *p*-values, is shown in the table below. Correlations for which the *p*-value were ≤0.1 are shown in bold

		ρ	*p*-value
Average size-at-age	age-3	-0.49	0.33
	age-4	-0.25	0.63
	age-5	-0.56	0.24
	age-6	-0.58	0.23
	age-7	-0.20	0.71
	age-8	-0.71	0.11
	age-9	-0.25	0.63
	age-10	-0.60	0.21
	age-11	0.02	0.97
	age-12	-0.40	0.43
	age-13	-0.38	0.46
	age-14	0.42	0.41
	age-15	-0.14	0.79
LVB params	L_∞	0.56	0.33
	κ	-0.64	0.24
	t_0	-0.64	0.24
Assessment output	Spawning biomass	0.43	0.17
	Total biomass	0.37	0.24
	Recruitment	0.33	0.30

The results of the correlation analysis did not result in *p*-values ≤0.1 Overall, the proportion of habitat disturbed in the POP CEA is minimal (<5%), and no life-history correlation with fishing effects is cause for concern at this point in time.

6. Future application and research needs

To date, there has been very little effort in any region to develop objective criteria to assess the effects of fishing on EFH, or to consider how those habitat impacts affect fishery stocks. The FE model that was developed for the 2016 review of EFH at the North Pacific Fishery Management Council was a continuation and modification of the Swept Area Seafloor Impact (SASI) model developed for the New England Fishery Management Council. Similarly, the Fishing Effects subcommittee felt that the methods and criteria developed for the NPFMC could be applied in other areas of the world, with appropriate modifications to address their local concerns and species. The subcommittee recognized that data limitations remain, particularly links between specific habitat impacts and population level effects on fish stocks. In order to continue development of these methods and criteria to evaluate the impacts of fishing on EFH, the subcommittee recommends that research should continue to better elucidate those linkages.