**REPORT OF THE**
**ECOSYSTEM BASED FISHERY MANAGEMENT WORKSHOP:**

# EXPLORING THE EFFECT OF SPATIAL DECISION MAKING BY FISHERS IN THE HAWAII SHALLOW-SET LONGLINE FISHERY

November 21, 2022
9am - 4pm
Pier 38 NOAA Office
Honolulu

## Executive Summary

The Western Pacific Regional Fisheries Management Council (WPRFMC), NMFS Pacific Islands Fisheries Science Center (PIFSC) and the University of Florida convened a workshop on November 21, 2022, with representatives from the Hawaii Longline Association (HLA), Hawaii shallow-set longline (SSLL) fishery, and NMFS Pacific Islands Regional Office (PIRO) to discuss a case study evaluating the effects of spatial decision making by fishery participants on the protected species interactions and catch of target species. The case study focused on scenarios of SSLL fishers avoiding loggerhead sea turtles in the first or fourth quarter of the year either by using the TurtleWatch product (based on 17.5–18.5ºC sea surface temperature band) or areas identified by the Protected Species Ensemble Random Forests (PSERF) model based on the probability of loggerhead interactions. The workshop provided an overview of the spatial tool developed to do the evaluation, highlighted where industry feedback from an initial session with HLA/SSLL participants was used in the model, and presented the evaluation results.

The spatial tool consisted of four submodels: 1) PSERF models of the probability of interactions with loggerhead and leatherback sea turtles with the SSLL fishery; 2) a spatiotemporal model of fishery effort; 3) a spatiotemporal model of fishery Swordfish catch-per-unit-effort (CPUE); 4) an avoidance area design model using the TurtleWatch product or the PSERF models' outputs. These were then used to predict the fishery effort, CPUE, protected species interaction distribution, and avoidance areas for the months in quarters 1 and 4 in 2019–2021. A fifth submodel redistributed fishing effort out of avoidance areas.

The model results were summarized as the amount of effort that would need to avoid one of the spatial avoidance areas, the percent change in swordfish catch, the change in the number of loggerhead sea turtle interactions, and the change in the number of leatherback sea turtle interactions from avoidance. The tool identified that no matter how the avoidance area was defined, there was a strong chance that avoiding loggerhead interactions by the SSLL fishery would result in increasing the leatherback interactions in at least one of the months in quarters 1 and 4. The TurtleWatch-defined avoidance area resulted in the highest increase in leatherback interactions per loggerhead interaction avoided.

Workshop participants discussed the results of the submodels of the spatial tool and concluded that most of the submodels did a decent job of capturing the environmental covariates important for determining where fishing effort, CPUE, and protected species interactions occurred. As the models did not account for size of swordfish in the catch and other market drivers (secondary species, spatial variation in catch quality, competition), participants discussed at length how market forces influence the decision making of SSLL fishers. As the spatial tool identified a strong inverse tradeoff between avoiding loggerhead interactions and increasing leatherback interactions, participants discussed alternative solutions to avoiding protected species interactions. These encompassed discussions on vessel-to-vessel communication and information sharing amongst the fleet on interaction hotspots, training of new fishery participants on best practices to avoid protected species, and dissemination of avoidance areas or model-generated protected species hotspots to vessels at sea. Further discussions centered on what incentivizes fishers with a focus on how the market and market forces interact with swordfish behavior to constrain fishers' spatial and temporal decision making. The rest of the discussions considered applications of the spatial tool to the Hawaii deep-set longline (DSLL) fishery, the time and information needed to apply the tool, and potential species or spatial scenarios to test.

## 1. Workshop Overview

The WPRFMC, PIFSC, and the University of Florida convened a workshop on November 21, 2022, with representatives from the HLA, Hawaii SSLL fishery, and PIRO. The purpose of the workshop was to gather industry input on and discuss the utility of a spatial tool that would help inform fisher, scientist, and manager decisions for avoiding protected species interactions. Specifically, the workshop was focused on a case study evaluating the effects of spatial decision making by fishery participants to avoid protected species on protected species interactions and catch of target species.

Protected species interactions can have negative impacts on fishing through reduced catch, lost gear and time, and crew safety, and may also affect protected species population status. In the Hawaii SSLL fishery, significant reductions in loggerhead and leatherback turtle interactions were achieved through gear and bait measures implemented in 2004. The SSLL fishery currently operates under an individual vessel-based trip interaction limit for loggerhead and leatherback turtles, as well as a fleet-wide interaction limit for leatherback turtles. The goal of this workshop was to explore whether interactions with sea turtles could be avoided further while maintaining swordfish catch through spatial strategies and evaluate their tradeoffs. Spatial strategies, such as industry-based avoidance or voluntary avoidance (e.g. Turtle Watch), are among a suite of strategies for reducing protected species interactions; however, their impact on target species and protected species catch rates had not been evaluated for the SSLL fishery.

The Council, PIFSC and PIRO, in collaboration with the University of Florida, initiated an ecosystem-based fisheries management (EBFM) project in 2018 for protected species impacts assessment for the Hawaii and American Samoa longline fishery. The collaboration stemmed from a Council recommendation to evaluate ecosystem factors influencing protected species interactions in the longline fishery, and resulted in the development of a PSERF model that utilized the NMFS Pacific Islands Regional Observer Program data as well as NOAA and other oceanographic data products.

The PSERF model was adapted for the case study explored in this workshop to predict potential changes to swordfish catch-per-unit effort and protected species interactions from spatial changes in the fishery. The case study focused on scenarios of SSLL fishers avoiding loggerhead sea turtles in the first or fourth quarter of the year (January-March or October-December) either by using the TurtleWatch product (based on 17.5–18.5ºC sea surface temperature band) or areas identified by the PSERF model based on the probability of loggerhead interactions.

One of the objectives of the workshop was to evaluate the model design and results to improve the predictions for what might happen under different effort distribution scenarios. To achieve this objective, organizers solicited feedback from industry representatives in advance of the workshop to learn how the spatial tool might be tailored to better match realistic decisions fishery participants make on the water and to more faithfully reproduce real world behavior. This insight was used to better account for ways fishers may respond to information about fishing conditions, interactions with protected species, or other factors, and how that may affect target catch and interactions with other protected species.

During the workshop, Zach Siders, University of Florida, provided a series of presentations on the overview of the collaborative EBFM project, overview of the spatial tool applied to the SSLL case study, and model outputs. Workshop discussions included participant feedback on the tool, factors influencing fishery participants' spatial decisions, utility of the tool for avoiding sea turtle interactions in the SSLL fishery, and potential broader utility of the spatial tool to the SSLL fishery and the Hawaii DSLL fishery.

The following participants attended the workshop:

- HLA and SSLL representatives: Eric Kingma, Roger Dang, Calvin Huynh
- Invited Expert: Steve Martell (Sea State Inc. and WPRFMC SSC)
- PIFSC: Robert Ahrens, T. Todd Jones, Kirsten Leong, Emily Crigler
- PIRO: Jarad Makaiau
- University of Florida: Zachary Siders
- WPRFMC: Asuka Ishizaki

## 2. Overview of the Spatial Tool for Avoiding Sea Turtle Interactions in the Hawaii Shallow-set Longline Fisheries

Several past research efforts have focused on avoiding loggerhead interactions in the SSLL fishery. These efforts include 1) the experimental TurtleWatch product based on sea-surface temperature (17.5–18.5ºC; 63.5–65.5ºF band); 2) historical evaluation of swordfish and loggerhead CPUE in and out of the TurtleWatch band; and 3) recent evaluation of TurtleWatch performance from 2006–2021. The recent evaluation of TurtleWatch showed that it is still a valid product that is most useful in quarter 1 and 4 (Jan–Mar and Oct–Dec), and indicated that many interactions in quarter 1 also occur north of the TurtleWatch band in colder water.

Potential challenges of avoiding a spatial area include increases in competition with other vessels (SSLL or otherwise) already fishing outside the area, tradeoffs resulting from the spatial overlap of loggerhead turtle interaction distribution with other protected species, and changes in fleet distribution as a result of avoidance. In the past research efforts, these potential tradeoffs of avoiding one protected species resulting in an increase in interactions with other protected species, or the effect on fishing effort distribution and target catch rates had not been evaluated.

The spatial tool developed for this workshop's case study used PSERF to model the probability and distribution of the loggerhead interactions with the SSLL fishery based on PIROP observer data and oceanographic covariates. A separate fishery effort and CPUE models were built to model SSLL effort in hooks/hr and CPUE in swordfish/hook/hr and used a subset of oceanographic covariates from the PSERF model. Spatial areas were designed based on TurtleWatch and PSERF probability of interaction. An effort redistribution model was built to reallocate effort from a spatial area based on a gravity model where the gravity weights were set based on the average effort in the last three years (2019-2021). Lastly, an accounting scheme used all the modeling components to calculate the average number of turtle interactions and the average swordfish catch.

Fishery participant input from the April 15, 2022 pre-workshop feedback session indicated that temperature, sea surface height, currents, winds, lunar phase (full moon) and seamounts were key variables in determining where and when the SSLL fishery put out effort. These variables were used in the effort and CPUE models. The utility of the spatial tool is to facilitate the discussion, provide insight into tradeoffs, highlight key uncertainties and data gaps. This tool is designed to provide information on mean (fleet-wide) behavior rather than individual experiences and is based on the PIROP observer data which may or not reflect the decisions made on the water.

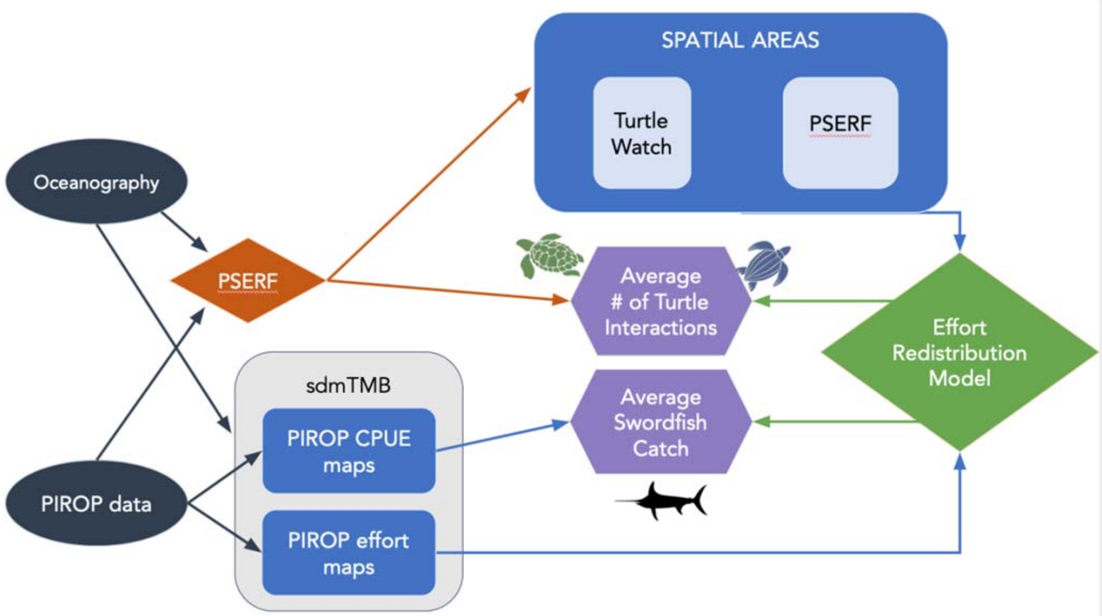


*Figure 1: Schematic of the spatial tool with data sources (ovals), PSERF interaction submodel (orange diamond), effort and CPUE submodel modeled using sdmTMB (grey rectangle), spatial area submodel (blue rectangle), effort redistribution submodel (green diamond), and spatial tool outputs of change in swordfish catch and number of turtle interactions (purple hexes).*

### a. PSERF loggerhead and leatherback interaction submodels

The PSERF loggerhead interaction submodel results show key oceanographic variables that determined loggerhead interactions with the SSLL fishery. These variables, in order of decreasing importance, were as follows: chlorophyll-a, sea surface temperature, current divergence, current vorticity, eddy kinetic energy, sea level anomaly, wind direction, wind speed, distance to seamount, distance to wind front, distance to chlorophyll-a front, distance to current front, distance to sea surface temperature front, current speed, Okubo-Weiss parameter, current direction, and lunar phase (Figure 2; see Appendix for definitions).

The ranges for the top eight environmental variables highlighted several features that align with previous studies. Chlorophyll-a coming in as the top variable aligns with the TurtleWatch band (17.5–18.5ºC) as defined by Howell et al. (2008) study while the region between 17–19.5ºC SST had higher interactions which encompasses the TurtleWatch band as well as the recent TurtleWatch evaluation. Additionally, the suite of current divergence, current vorticity, sea level anomaly, and wind direction indicate that interactions tend to occur in areas of stable ocean currents, slight downwelling, in the N. Pacific Transition Zone, and winds from the S-SSW (Figure 3). As the PSERF model does not define statistical significance, the variables can instead be interpreted as top drivers of the change in the interaction probability.

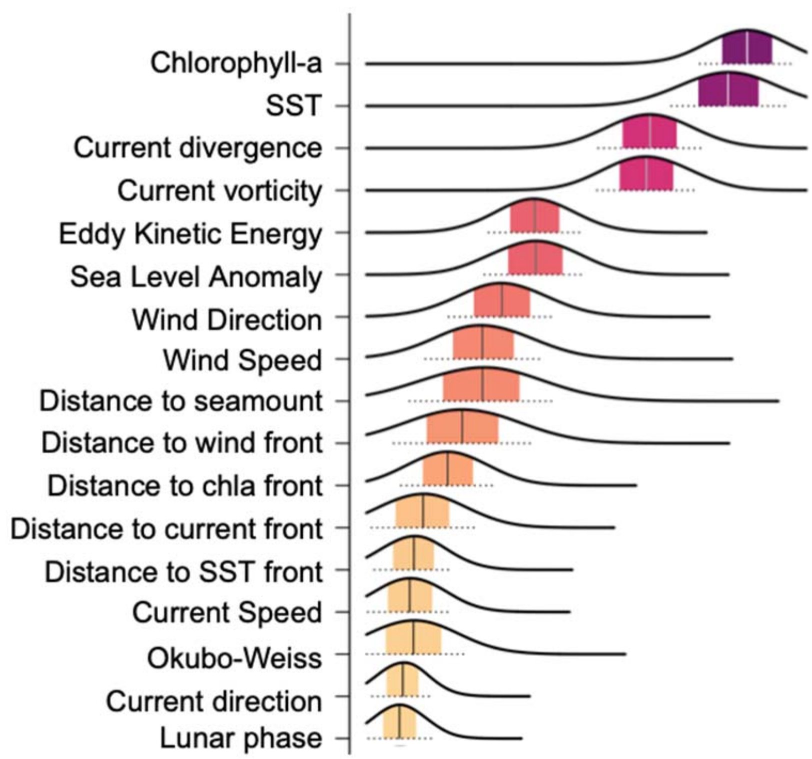


*Figure 2: Environmental variable importance from the PSERF loggerhead interaction model; top of graph, darker colors, and to the right of the x-axis indicate more important covariates. See Appendix for definitions of the variables.*

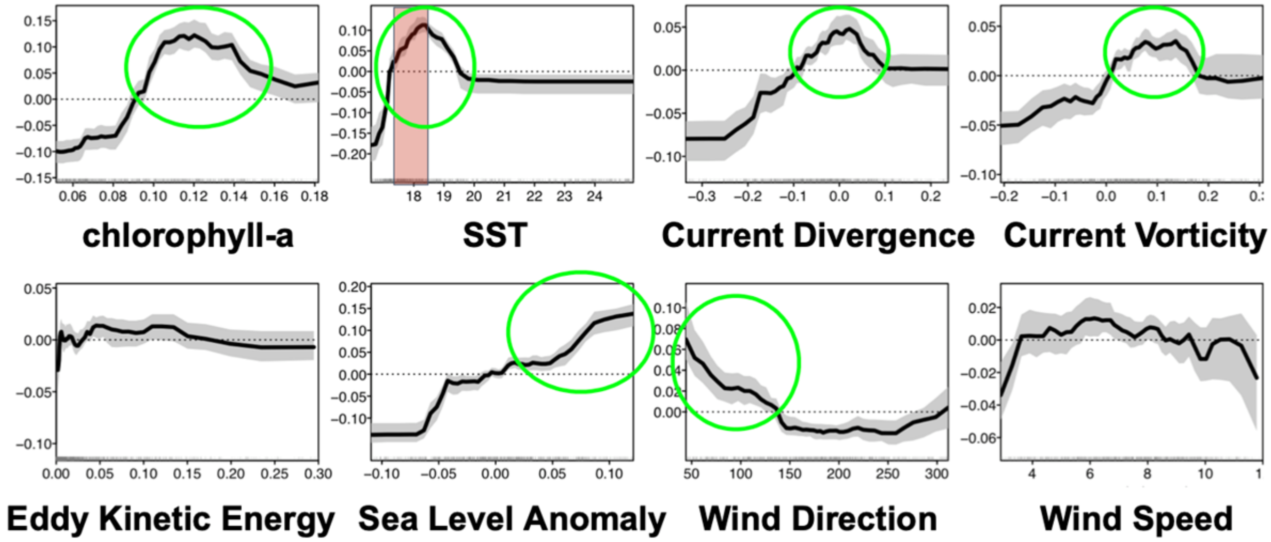


*Figure 3: Change in probability of interaction across the environmental variable's range for top eight variables for the loggerhead PSERF. Values above the dotted line indicate higher probability of interaction and peak environmental conditions resulting in higher probabilities are denoted with green circles. The TurtleWatch band (17.5–18.5ºC) is noted in red on the sea surface temperature panel. See Appendix for definitions of the variables.*

Another PSERF model was applied to the leatherback interaction with the SSLL fishery. Key oceanographic variables that determined leatherback interactions with the SSLL fishery were, in order of decreasing importance: current speed, distance to current front, current vorticity, wind speed, distance to wind front, sea surface temperature, wind direction, sea level anomaly, eddy presence, current divergence, current direction, Okubo-Weiss parameter, distance to seamount, eddy kinetic energy, distance to sea surface temperature front, bathymetry, chlorophyll-a, and distance to the chlorophyll-a front (Figure 4; see Appendix for definitions).

Overall, the distribution of leatherback interactions with the SSLL fishery was more diffused and patchy than the loggerhead distribution. The top eight environmental variables highlighted two features, one somewhat new and another SST feature that aligns with Howell et al. (2015). The combination of variables including current speed, distance to current front, wind direction, current vorticity, and wind speed indicated that leatherback interactions occur in fast currents, close to current fronts, when wind is from the east, and when slight wind-driven downwelling is occurring (Figure 5). While for SST, the increase in interaction probabilities predicted by the PSERF submodel between 21–24ºC encompasses the 22.4–23.4ºC expanded leatherback TurtleWatch band defined by Howell et al. (2015).

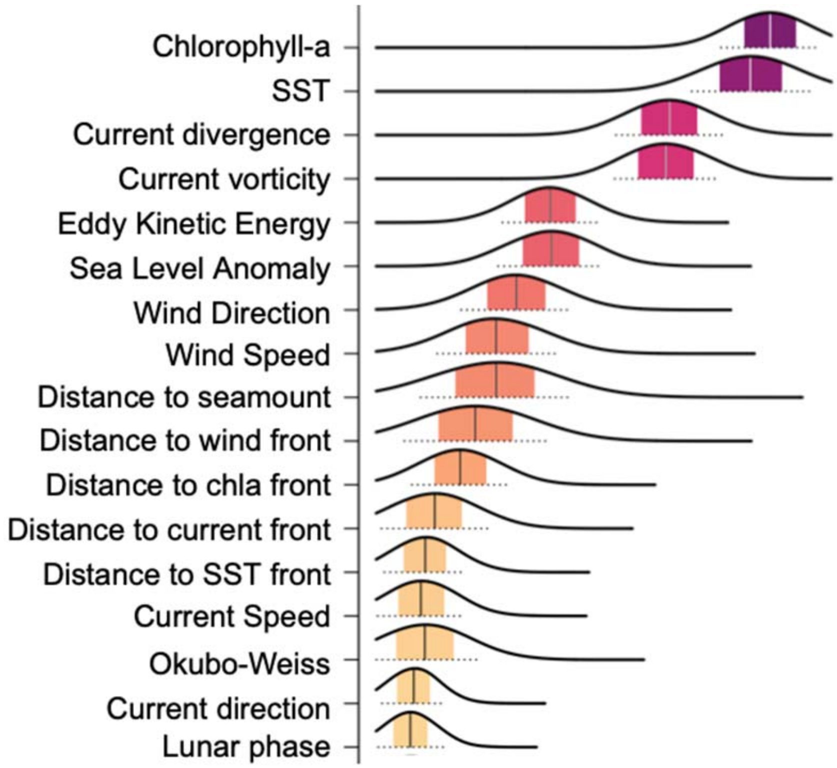


*Figure 4: Environmental variable importance from the PSERF leatherback interaction model; top of graph, darker colors, and to the right on the x-axis indicate more important covariates. See Appendix for definitions of the variables.*

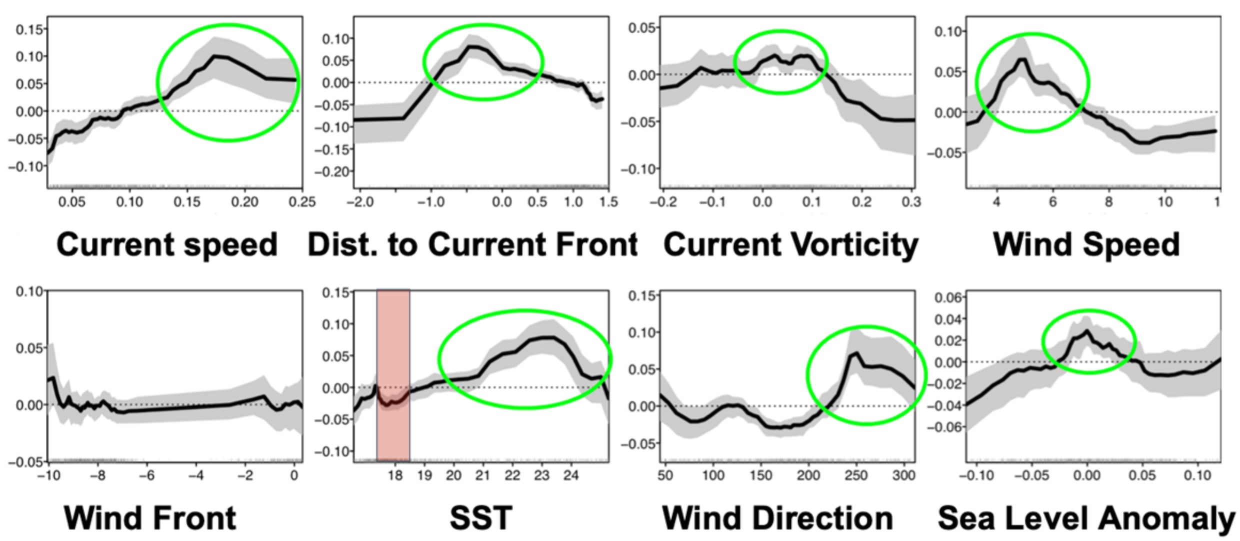


*Figure 5: Change in probability of interaction across the environmental variable's range for top eight variables for the leatherback PSERF. Values above the dotted line indicate higher probability of interaction and peak environmental conditions resulting in higher probabilities are denoted with green circles. The TurtleWatch band (17.5–18.5ºC) is noted in red on the sea surface temperature panel. See Appendix for definitions of the variables.*

### b. SSLL Effort and SSLL Swordfish CPUE submodels

The SSLL effort and swordfish CPUE submodels included information on the fishing effort in the current fishing year using the month prior to the modeled effort and from the previous fishing year's effort in the same fishing month at 1x1º, 2x2º, and 3x3º spatial scales as predictor variables. Overall, effort in the last month was not a good indicator of where fishing will occur in the current month, but effort in the previous year at the 1x1º localized scale predicted less effort in that location the next year, but increases in effort at the 2x2º and 3x3º scales. This indicates that last year's effort is a good indicator broadly for where effort will occur next year, but not at small, local scales, and that changes in oceanography probably drive effort at local scales.

Effort model outputs of important environmental covariates, including sea surface temperature, E-W winds, sea surface temperature anomaly, and N-S winds, showed that less effort occurs in area with strong winds, more effort occurs in sea surface anomaly of +2ºC but less in +0.5ºC, and more individual set effort than the average occurs outside of the 16–20ºC SST band.

CPUE model outputs indicated that SST anomaly, lunar phase, chlorophyll-a, and E-W winds were important environmental covariates and showed that higher CPUE occurred in low SST anomalies, around the full moon, in higher productivity areas (greater chlorophyll-a concentration), and when winds were from the west.

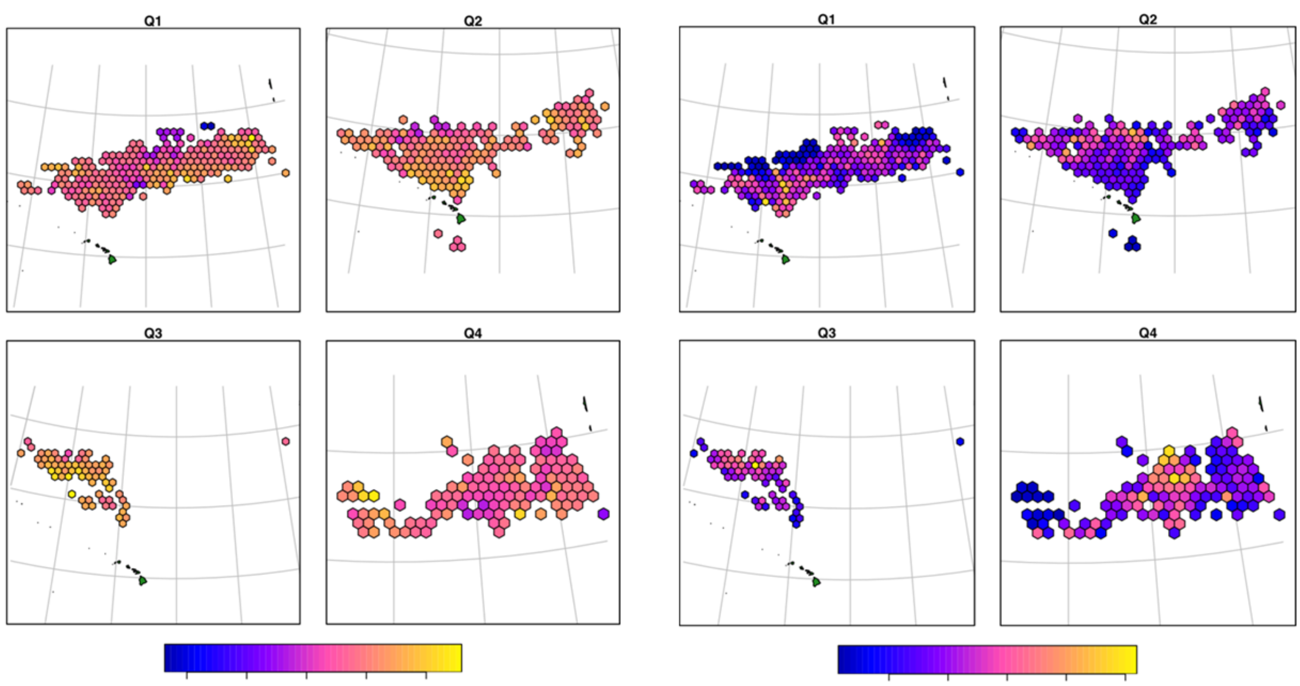


*Figure 5: Average predictions of effort in hook hours (left four panels) and Swordfish CPUE (right four panels) in numbers per hook per hour. Warmer colors indicate higher values.*

### c. Projecting turtle interactions and swordfish catch

To calculate the expected number of loggerhead and leatherback interactions as well as the expected swordfish catch, the model averages conditions over 2019-2021 in terms of oceanography, turtle interactions, effort placement, and expected CPUE. The model does not predict individual fisher experience. To do the model prediction, oceanographic covariates were extracted for each week of quarters 1 and 4 for 2019–2021, and the PSERF, effort, and CPUE models were predicted onto the oceanographic covariates then averaged by month.

The spatial area design modeling component was used to define avoidance areas based on the TurtleWatch band (17.5–18.5ºC) and the PSERF-generated probability of loggerhead interaction using the > 33% chance, > 39% chance, and >46% chance thresholds (Figure 6) , which correspond to the 50th, 75th, and 90th percentiles of PSERF-generated probabilities. The results for each avoidance scenario for the quarter 1 and 4 months were summarized in terms of the percent of total effort that would need to avoid the avoidance area, the percent change in swordfish catch, and the change in the number of loggerhead and leatherback interactions.

In general, the results showed that the TurtleWatch scenario affected less effort and had less effect on swordfish catch than any of the PSERF avoidance areas. However, the TurtleWatch scenario prevented more loggerhead interactions compared to 46% PSERF area but resulted in more leatherback interactions in all months except March and December (Table 1). These tradeoffs can be observed by looking at the TurtleWatch-defined avoidance area in January as an example, where 8.6% of the average total SSLL effort needs to relocate to avoid the area which is expected to reduce swordfish catch by 7.8% relative to not avoiding the area. This January TurtleWatch avoidance nets a reduction of 2.5 loggerhead sea turtle interactions at the cost of a 1.2 increase in leatherback sea turtle interactions. Said another way, for every 10 loggerheads the fishery avoids in January using TurtleWatch, they would have about 5 additional leatherback interactions. In contrast, the PSERF > 46% avoidance area needs more effort to relocate (14.2%) resulting in greater impacts to swordfish catch (-13.7%) but results in a greater loggerhead interaction reduction (2.8) with a minimal reduction in leatherback interactions (0.1). Expanding the PSERF defined avoidance area by lowering the probability cutoff (>39% or >33% chance) reduced loggerhead interactions without increasing leatherback interactions but affected more of the fishing effort and lowered expected swordfish catch (Table 2). The magnitude of the effort avoidance was substantial for the PSERF >39% and >33% chance scenarios (a max of 32.3% and 59% of effort affected, respectively), thus it is likely that potential cost to the fishery would outweigh the relatively small decrease in loggerhead interactions (Figure 6).

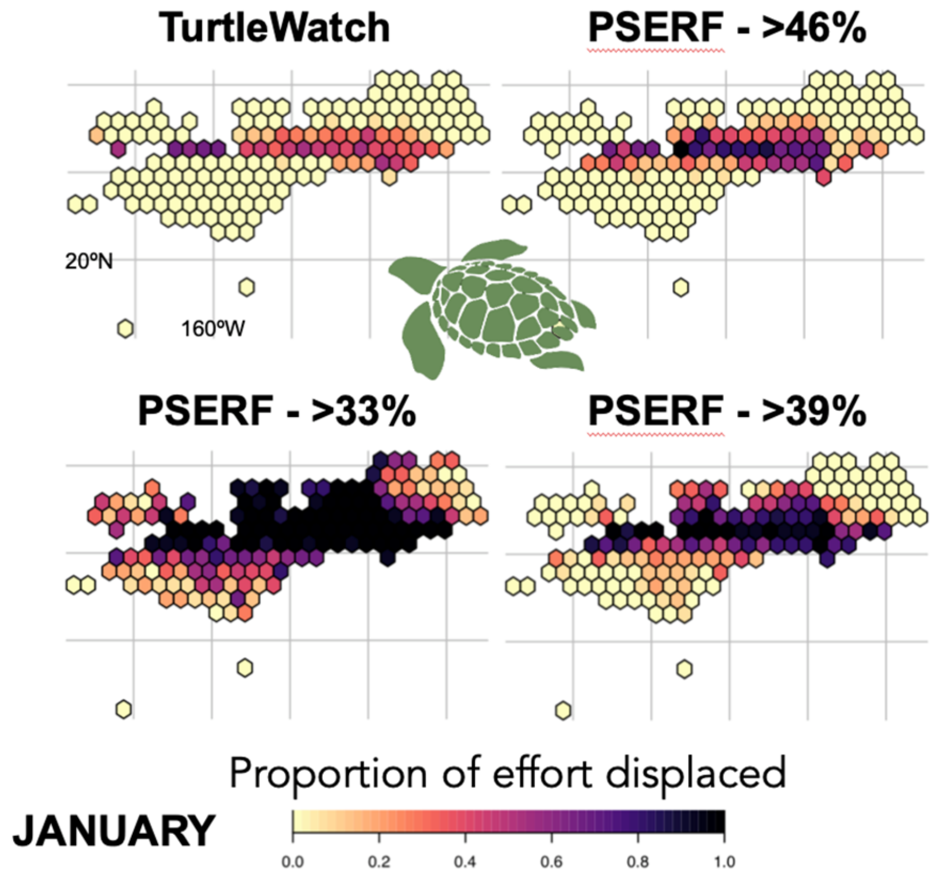


*Figure 6: Avoidance areas for the month of January from 2019–2021 conditions. Darker colors indicate more SSLL fishery effort displaced to avoid the area.*

*Table 1: Percent of SSLL fishery effort affected, percent change in SSLL swordfish catch, and numbers of loggerhead and leatherback interactions for the TurtleWatch band avoidance scenario and the PSERF > 46% chance of loggerhead interaction avoidance scenario.*

| | TurtleWatch band | | | | PSERF > 46% chance | | | |
|---|---|---|---|---|---|---|---|---|
| Month | % effort | % change sword catch | # of loggerhead | # of leatherback | % effort | % change sword catch | # of loggerhead | # of leatherback |
| Jan | 8.6 | -7.8 | -2.5 ±8.4 | 1.2 ±8.3 | 14.2 | -13.7 | -2.8 ±8.1 | -0.1 ±8.3 |
| Feb | 8.1 | -3.7 | -1.4 ±8.5 | 2 ±8.7 | 5.8 | -1.8 | -0.9 ±8.2 | -0.6 ±8.1 |
| Mar | 6.7 | -3.7 | 1.2 ±8.6 | -0.5 ±8.4 | 5.6 | -2.4 | -1 ±8.9 | -1.3 ±9.4 |
| Oct | 2.2 | -2.5 | -0.6 ±6.9 | 1 ±7.6 | 3.5 | -0.3 | -1.1 ±7.5 | -0.4 ±9.2 |
| Nov | 6.5 | -4.1 | 0 ±9.4 | 0.5 ±9.1 | 11.1 | -0.4 | -2.9 ±7.9 | -1.8 ±9.5 |
| Dec | 10.4 | -4.9 | 0.7 ±8.4 | -1.4 ±8.5 | 14.3 | -4.8 | -3 ±9 | 0.5 ±8.3 |

*Table 2: Percent of SSLL fishery effort affected, percent change in SSLL swordfish catch, and numbers of loggerhead and leatherback interactions for PSERF > 39% chance avoidance scenario and the PSERF > 33% chance of loggerhead interaction avoidance scenario.*

| | PSERF > 39% chance | | | | PSERF > 33% chance | | | |
|---|---|---|---|---|---|---|---|---|
| Month | % effort | % change sword catch | # of loggerhead | # of leatherback | % effort | % change sword catch | # of loggerhead | # of leatherback |
| Jan | 31.5 | -22.6 | -7.1 ±8.4 | -0.6 ±8.1 | 59 | -27.5 | -12.5 ±7.7 | -0.9 ±7.5 |
| Feb | 16.6 | -2.3 | -2.2 ±8.9 | 0.3 ±8.7 | 45.5 | 12 | -6 ±7.8 | 1 ±7.1 |
| Mar | 18.4 | -2 | -3.9 ±7.6 | -2 ±7.7 | 43.8 | 18.9 | -6.3 ±8.6 | -1.6 ±7.6 |
| Oct | 12.4 | -2.1 | -2.7 ±7.6 | -0.6 ±8 | 31.2 | -4.5 | -4.8 ±8.1 | -0.4 ±8.6 |
| Nov | 28.2 | 1.1 | -4.8 ±7.6 | -1.4 ±8.5 | 51.1 | 0.1 | -10.5 ±7.7 | -0.4 ±9.2 |
| Dec | 32.3 | -7.5 | -7 ±8.7 | 0 ±8.4 | 55.8 | -8.8 | -10.2 ±7.3 | -3.5 ±7.2 |

## 3. Summary of Workshop Discussions

The case study for this workshop was the first comprehensive effort to evaluate tradeoffs of spatial strategies for avoiding protected species in the Hawaii SSLL fishery. Workshop discussions included participant feedback on the tool, factors influencing fishery participants' spatial decisions, utility of the tool for avoiding sea turtle interactions in the SSLL fishery, and potential broader utility of the spatial tool to the SSLL fishery and the Hawaii deep-set longline (DSLL) fishery.

### a. Model output alignment with fisher experiences on factors influencing spatial decisions

Workshop participants discussed the results of the submodels of the spatial tool and agreed that most of the submodels did a decent job of capturing the environmental covariates important for determining where fishing effort, CPUE, and protected species interactions occurred. Participants provided additional input on the key factors identified in the interactions submodels, and effort and swordfish CPUE submodels. Participants also identified market factors as a key factor in fisher decisions on whether and where to fish, which is not currently included in the spatial tool. These discussions are summarized in further detail below. Participants also noted that climate change is a key uncertainty for how the SSLL might change in the future.

*Alignment of interaction submodel outputs with fisher experiences*

Participants discussed how the interaction submodel outputs align with fisher experiences on the water. Industry representatives indicated that SST is the main metric that captains use for fishing, but the accuracy of the SST depends on the calibration of the on-board SST sensors. Representatives also noted that different SST providers use different satellite products and algorithms, and there can be 1-2 ºC differences between the satellite products and on-board sensors. These differences could be equivalent to the range of SST used to define the TurtleWatch band, highlighting the difficulty of implementing spatial management using SST for this fishery, and the need to ensure that any spatial tool is consistent with data captains have access to in real time at sea.

Industry representatives indicated that captains rely less on other variables such as current divergence or chlorophyll-a. They noted that data products for current divergence is not accurate for the areas fished by the SSLL fishery. They also noted that a representative from their main environmental data service provider described the chlorophyll-a product as inaccurate, and that past efforts to utilize chlorophyll-a data to find swordfish was not successful.

*Alignment of effort and CPUE submodel outputs with fisher experiences*

Participants discussed how the effort and CPUE model outputs align with fisher experiences. Industry representatives stressed that the fish were behaving very differently in 2022 and year-to-year differences in where effort goes will make things a challenge to use the data from one year compared to the previous years. As an example, one representative indicated that there appears to be a two-month lag this year, noting that boats typically see eggs in swordfish by the end of March but in 2022 they did not see them until June, and that fish were still being caught in the north in June when they typically head south. Representatives also indicated that in the fourth quarter, the SSLL fishery used to fish closer to California, but for the past two years the fishery has been fishing closer to Hawaii, and wondered what changes in swordfish behavior and fishing effort will mean for the turtle interactions.

In terms of environmental covariates in the model, industry representatives confirmed that SST anomaly is important, noting that captains will drive through an area looking for cold spots before setting gear. Regarding moon phase, an industry representative indicated that SSLL vessels change target depth depending on the phase of the moon, and organizers indicated further analysis could be done to look at whether hooks per float vary across moon phases.

*Other key factors influencing fisher decisions: Market forces*

Workshop participants noted that market forces could severely affect the decision making for SSLL fishers. For example, it was noted that while as many as 30 boats expressed interest in participating in the SSLL fishery for the 2023 season, it was unlikely that all of them would end up fishing as the market is limited by the amount of swordfish the auction can handle in a day (about 15,000 lbs), and in some cases the some boats wait 5-11 days to unload after returning to port. Such lengthy wait times for unloading could deter some boats from entering the fishery for the season.

For the DSLL fishery, the market is driven primarily by high quality ahi but secondary catch (monchong, billfish, opah, whitefish) can make or break a trip in terms of profitability. Industry representatives indicated that captains generally know the catch composition based on fishing location when planning a trip and can, depending on time of year, tailor a trip to what is paying at the auction. Tourism was noted as a strong driver of the local market demand with tourists from the continental US desiring whitefish and Asian tourists desiring tuna. It was noted that building this information into the effort and CPUE models would be difficult as data on individual fish price and catch location are not available.

Participants also discussed the broader market context and the need to consider the impact of the SSLL fishery on sea turtles compared to the potential negative impact of putting more effort into international fisheries to meet the US demand, noting that the US is one of the biggest consumers of swordfish so closure of the SSLL fishery leads to higher imports of swordfish. It was also noted that the SSLL fishery is one of the only US operated sources of data on north Pacific loggerhead turtles, while the US must rely on other nations to provide information on the production of loggerheads at nesting beaches. Information from interactions are key data that the SSLL fleet collects and data is still lacking on the biology and ecology of loggerheads that interact with fisheries.

### b. Utility of the spatial tool and associated strategies

Workshop participants found the results from the spatial tool to be informative in considering tradeoffs of potential fleet-wide avoidance of certain spatial areas based on loggerhead turtle interactions and the associated impacts on fishing effort, swordfish catch, and other protected species such as leatherback turtles. The model results showed that avoiding single protected species could come with tradeoffs to other protected species as well as potentially high cost to the SSLL fishery. Industry representatives discussed that these tradeoffs could disincentivize captains to avoid areas, noting that moving could be very costly depending on the advice. Industry representatives also highlighted that there is financial incentive for the individual vessels to minimize interactions if they are approaching the trip limit of 5 loggerhead turtles, and that tradeoffs become especially important in that context. How the information on tradeoffs and individual interaction information reaches the vessels while at sea in those situations would be critical in aiding the captains making the decision to move, especially when the conditions differ from year to year. Participants discussed associated strategies for disseminating information on interactions and tradeoffs, as well as alternative strategies for avoiding protected species interactions, which are summarized in further detail below. Participants also discussed that the spatial tool could help communicate the tradeoff of potential regulations and other strategies to managers.

*SSLL communication*

Participants discussed how the SSLL fishers communicate between boats and where opportunities might lie for communicating avoidance area information. Generally, SSLL captains share information with each other and monitor the information on a trip-by-trip basis to avoid the area where a lot of turtles are caught. Participants agreed that it is difficult to predict whether the current or upcoming fishing year will be a high turtle interaction year, but industry representatives noted that interactions generally occur only in a few months and with only a few high interaction years. In response to a question about where fishers move to when trying to avoid the turtles, an industry representative indicated they would go north or south of the TurtleWatch band but not east or west.

Representatives pointed out that SSLL boats have KVH satellite uplink so it is easier to share data now, and that this system could be used to send the avoidance areas to captains directly. This was noted as an opportunity to communicate protected species avoidance information directly with the boats and perhaps establish an information sharing system for more than just turtle interactions.

*Training and information dissemination*

Industry representatives and organizers expressed concern for the loss of knowledge of how to avoid protected species as new participants join the SSLL fishery. Industry representatives remarked that old captains are trained to move a certain way to avoid turtles, whereas new captains would need to be trained as they would not have that same knowledge. Industry representatives suggested adding information on best practices for avoiding turtle interactions to the mandatory annual protected species workshops to facilitate information sharing with new captains. Specifically, information could be provided in the protected species workshop on the TurtleWatch area and where to go to avoid turtles in relation to the TurtleWatch band (e.g., going north or south, rather than east or west). Participants also discussed providing some decision-rule type of information where tradeoffs for moving in a certain direction would be described.

Participants also discussed whether the spatial model could be turned into a real-time product or near real-time product to provide updates on high swordfish catch areas versus risk of turtle interactions. However, it was noted that the swordfish CPUE model is not good enough to predict at that scale given that the fine-scale dynamic features the fishery is using to fish are not available. It was noted that the model could not have predicted how the last fishing season has unfolded.

In light of the information on the on-board satellite uplink, participants also discussed capitalizing on the capability for real-time information sharing among SSLL fishers and presenting easily digestible information on the tradeoffs between target catch and protected species interactions to the SSLL fishery through that system. Trust would need to be established for information sharing among fishers to occur, but if fishers can agree to share their anonymized data, real-time data feedback and individual vessel-level model validation would be possible.

*Alternative strategies for reducing interactions*

Participants discussed other potential non-spatial strategies for reducing interactions, including studying alternative bait strategies such as luring turtles away with non-hooked squid bait or changing light stick spectrums, and switching gears mid-trip from shallow-set to deep-set (considering that DSLL has lower sea turtle interaction rates). Industry representatives noted that switching gear mid-trip would be impractical to do given the space the gear takes up on deck and different bait types.

### c. Future applications of the spatial tool to the SSLL and DSLL fisheries

Industry representatives agreed that looking at the tradeoffs for the SSLL through this workshop case study was useful, and identified areas of interest for future applications of the spatial tool in the SSLL as well as the DSLL fishery.

*Further exploration and modification of the tool for the SSLL fishery*

Industry representatives identified oceanic whitetip shark, black-footed albatross and Laysan albatross as species of interest for further exploration of the spatial tool in the SSLL fishery. A suggested improvement to the model was to include size of fish as this may offset the economic cost of moving.

*Applications of the tool to the DSLL fishery*

Industry representatives expressed interest in the spatial tool being applied to the tuna-targeting DSLL fishery, with high priority species of interest identified as oceanic whitetip shark, false killer whales, leatherback turtles, and seabirds, but noted the need to apply the tool to all protected species. Participants also identified potential case studies for the DSLL fishery, including looking at the Southern Exclusion Zone or the monument expansion to explore what the tradeoffs have been or might be in avoiding those spatial management areas.

Industry representatives also expressed interest in building in market factors when applying the tool to the DSLL, which would require developing an economic submodel, but it was noted that there is a lack of data on individual fish price and catch location.

Participants discussed necessary steps to extend the tool to the DSLL fishery, noting that a DSLL application would require a more careful consideration of temporal data and a number of other refinements, as well as an expansion of the model to include secondary catch and other protected species impacts. The close of 2023 or beginning of 2024 was mentioned as a time when the EBFM project will be in a better situation to begin to look at DSLL scenarios.

**APPENDIX: Definition of oceanographic variables**

| Variable Name | Definition |
|---|---|
| SST | sea surface temperature |
| Distance to SST front | standardized effect size distance to the nearest SST front |
| Chlorophyll-a | chlorophyll-a, measure of ocean productivity |
| Distance to chla front | standardized effect size distance to the nearest Chl-a front |
| Current speed | ocean current speed |
| Current direction | ocean current direction |
| Distance to current front | standardized effect size distance to the nearest ocean current front |
| Current divergence | ocean current divergence, measure of currents moving away from each other |
| Current vorticity | ocean current vorticity, measure of currents moving towards each other |
| Wind speed | ocean wind speed |
| Wind direction | ocean wind direction |
| Distance to wind front | standardized effect size distance to the nearest ocean wind front |
| Sea Level Anomaly | the difference between the average sea level height and the current sea level height |
| Eddy Kinetic Energy | measure of the kinetic energy of eddy currents |
| Okubo-Weiss | measure of upwelling or downwelling by calculating the relative importance of deformation and rotation at a given point. It is calculated as the sum of the squares of normal and shear strain minus the relative vorticity |
| Lunar phase | phase of the moon |
| Bathymetry | ocean depth |
| Distance to seamount | standardized effect size distance to the top of the nearest seamount |