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THE COST OF SEA TURTLE PRESERVATION: THE CASE OF HAWAII'S PELAGIC LONGLINERS

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The incidental capture of sea turtles in various fisheries is widely recognized as an important issue in the conservation and the recovery of these threatened and endangered species (NMFS-FWS 1991a, 1991b, 1992). Efforts to mitigate the impact of fisheries on sea turtles initially focused on the issue of forced submergence in shrimp trawls in the southeastern maritimes. However, given the status of these stocks, other fishing gears (e.g., high-seas driftnets, purse seines, and longlines) have come under increased pressure to reduce incidental takes of sea turtles.

A case in point is the 1999 court-ordered emergency closure (see "Order Setting Terms of Injunction," C.V. No. 99-0152) of more than a million square miles of international waters to vessels participating in the Hawaii longline fishery due to that fishery's incidental take of sea turtles. While the emergency closure was temporary, the court ordered the National Marine Fisheries Service (NMFS) to conduct an analysis of the interactions between sea turtles and longliners to determine the "appropriate time and area closures based upon the greatest benefit to the sea turtles and considering the costs to the Hawaii-based pelagic longline fishery." The resulting analysis conducted by the NMFS during the Spring 2000 indicated that the court-ordered closure afforded very little protection to sea turtles, overall reducing sea turtle interactions by only 12%.[1] The NMFS instead recommended closing the fishing grounds between 30 to 44°N between 137°W and 173°E throughout the year, and during April and May closing, the area between 23 and 44°N as well as between 6°N latitude and 16°N latitude between 137°W and 173°E. The NMFS projected that this closure would result in a 41% decrease in sea turtle interactions.

Although the analysis conducted by the NMFS included an economic assessment of each closure alternative, the report acknowledges that limiting this measure simply to foregone revenue was not a sufficient metric for fully evaluating the economic impact of the proposed closures. This paper provides a more formal economic analysis of each of the proposed area closures using a random-utility model of effort allocation in the Hawaii longline fishery. The model uses the fishermen's choice of location and fishing strategy to identify the factors that influence these choices. With a behavioral model in place, we measure changes in fishermen's welfare from a reduction in the geographic extent of fishing grounds. Welfare estimates indicated that the court closure resulted in a $1,900 loss per trip or $25,773 per reduction in turtle interactions, while the NMFS recommendation resulted in a $13,506 loss per trip or $52,976 per reduction in turtle interactions. In addition, significant distributional effects are identified.

Stylistic Model

Before turning to the theoretical framework, it may be useful to first characterize how effort is allocated within the fishery and identify the factors that may affect these choices. As shown in figure 1, the Hawaii longline fishery is a large, spatially differentiated fishery comprised of three subregions: the tuna fishing area (region south of 23°N); the mixed fishing area, which spans from 23 to 33°N; and the swordfish fishing area (region north of 33°N). Because the travel costs of accessing distant fishing grounds outweigh daily returns

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[1] The NMFS analysis integrates observer records of sea turtle interactions, federal logbook records of catch and effort, and secondary data on physical oceanographic information, e.g., sea surface temperature, to predict longline interactions with sea turtles in weekly 1° squares (60 x 60 miles) using GAMS.

Amer. J. Agr. Econ. 82(5) (Number 5, 2000): 1191–1197

(table 1), these choices may only be viewed as rational in an intertemporal setting in which location choice depends upon the production horizon and not simply on the next day's returns.

Let us consider the location decisions a fisherman makes during the course of a trip. From port, a fisherman chooses a fishing site from among these three broad regions. Once at sea, the fisherman remains highly mobile, traveling on average between 100–155 miles between daily fishing sets to new fishing grounds. To capture the spatial variation that may exist within the fishing regions, each region is defined over a set of contiguous fishing areas, henceforth referred to as sites. These sites range from $2 \times 3^\circ$ (120 by 180 miles) to $3.5 \times 3^\circ$ (210 by 180 miles), which is a sufficiently small scale that longliners can switch sites on a daily basis. Based on empirical evidence to date, the fisherman's choice of fishing site is likely related to his expected returns at each site, the variability of those returns, and the costs of accessing the site among other factors (Bockstael and Opaluch, Dupont, Hicks).

In addition to location choices, the fisherman can also affect catch and catch composition through his choice of targeting strategy, i.e., choice of production technology. For example, tuna fishermen set in the morning and use many hooks to weight the longline deep in the water column while both swordfish and mixed fishermen set their gear in the evening using relatively few hooks. A swordfish fishing strategy can be distinguished from a mixed fishing strategy by the high light sticks (fluorescent glow sticks) to hooks ratio.

To examine location and target decisions in more detail, let $\text{REV}_{s|fct}$ represent random revenues in period t at site s conditional on having chosen fishery-catch target fc, where revenues are uncertain due to catch variability and daily fluctuations in the fish market.[2] Random profits at site s in period t then equal

$$\pi_{js|fct} = \text{REV}_{s|fct} - \mathbf{w}_j, \mathbf{x}_{js|fct}$$

where $\mathbf{w}_j$ and $\mathbf{x}_{js|fct}$ represent the vector of input prices and variable input usage for $k = 1, \ldots, n$ inputs, e.g., fuel, bait, and lightsticks, of the jth fisherman using target strategy c at site s in fishery f.

Catch deterioration, a common feature in fresh-product fisheries, also affects effort allocation through its impact on the production horizon. For example, in the tuna fishery, in which harvest is primarily composed of highly perishable species, average trip length is thirteen days, while in the swordfish fishery, in which catch has the longest shelf life, trip length is twenty-six days. Let $\gamma_m \geq 0$ equal the daily cost per pound at which the accumulated catch of the mth species, denoted Y_{mt-1}, loses value.[3] For each additional day of production, the total loss in value of the jth fisherman's catch from all m species at time t from deterioration then equals $\gamma\mathbf{Y}_{jt-1}$, where $\gamma = (\gamma_1, \ldots, \gamma_m)$ and $\mathbf{Y} = (Y_1, \ldots, Y_m)$. The catch deterioration associated with accessing a more distant fishing site equals $\alpha_s\gamma\mathbf{Y}_{jt-1} \geq 0$ where $\alpha_s \geq 0$ equals the travel days required to access site s.

Turning now to the economic framework for analyzing production behavior, we assume that the fisherman's objective is to maximize the expected value of the sum of benefits or utility from the finite stream of daily fishing sets made during the course of a trip. In each period t, the current utility the jth fisherman expects to receive from site choice s conditional on having chosen fishing-catch target fc is defined as

$$(1) \quad EU(W_{jt}|\Omega_t)_{s|fct} = E\{U[W_{jt-1} + \pi_{s|fct} - (1 + \alpha_{st})\gamma\mathbf{Y}_{jt-1}] \mid \Omega_t\} \quad \forall s \in M^{fc}$$

where Ω_t is the fisherman's information set at time t; M_{fc} denotes the choice set of sites given fc is chosen; and $U(\cdot)$ is a von Neumann and Morgenstern utility function, which presumes that the individual seeks to maximize the expected utility of random wealth, W_{jt}, in each period. Marginal utility is assumed positive and the second derivative

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[2] $\text{REV}_{sfc,t}$ was forecast using a spatial autoregressive model,

$$\text{REV}_{sfc,t} = \sum_{p=1}^{P} \alpha_{t-p}\text{REV}_{sfc,t-p} + \sum_{p=1}^{P}\sum_{k=0}^{K} \gamma_{s-k,t-p}\varepsilon_{s-k,t-p}$$

$$\forall s = 1, \ldots, S;\ t = 1, \ldots, T$$

where REV_{st} and $\text{REV}_{s,t,-p}$ are $T \times 1$ vectors of observations on daily average returns to site s and lagged values of order p of daily average returns to site s, respectively; $\varepsilon_{s-k,t-p}$ are $T \times 1$ vectors of random disturbances associated with sites $k = 1, \ldots, K$ and time periods $p = 1, \ldots, P$; and α_p and $\gamma_{s-k,t-1}$ are parameters to be estimated. Results are available upon request from the authors but, in general, were consistent with an ARMA(3,1) specification. Additional details can be found in Curtis.

[3] γ_m estimated by extending the tuna demand model of McConnell, Strand, and Curtis to include trip length. Further details on how catch deterioration was calculated can be found in Curtis.

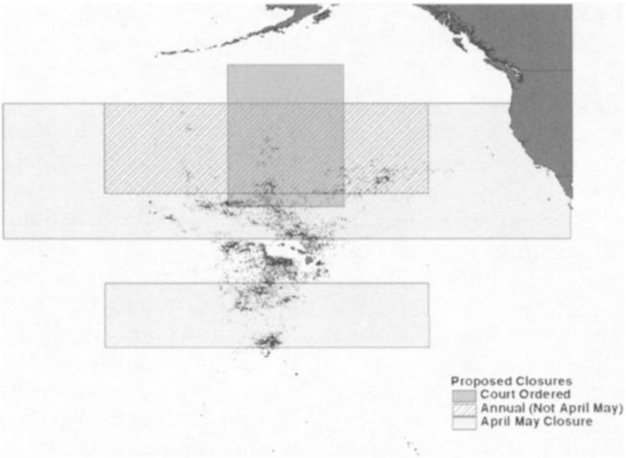

Figure 1. Hawaii longline fishery: Activity and regulation

Table 1. 1998 Hawaii Longline Trip Characteristics by Fishery Choice

	Tuna	Mixed	Swordfish
Trip length (days)	14.8	16.8	26.2
Fishing sets	10.1	11.0	14.3
Average revenue per fishing set	\$3,986	\$2,975	\$2,189
Trip revenue from bigeye tuna catch	\$25,963	\$10,861	\$7,613
Trip revenue from yellowfin tuna catch	\$5,925	\$2,090	\$809
Trip revenue from swordfish catch	\$339	\$16,869	\$22,807
Fuel cost per trip	\$5,671	\$6,884	\$9,455
Distance to initial site from port	430.8	510.4	778.7
Number of sites fished per trip	2.7	3.2	3.8
Catch deterioration	\$5,642	\$3,014	\$402
Vessel length (feet)	64	74	77
Vessel value	\$266,828	\$305,896	\$363,212

with respect to wealth is negative under risk aversion, zero under risk neutrality, and positive under risk-loving behavior.

The fisherman chooses his location and target alternative in each period to maximize the sum of expected utility from multiperiod trip production. Dropping the subscript designating the fisherman, the valuation function associated with choosing $s|fc$ in period t is defined as

$$
\begin{aligned}
(2)\quad V(s|fc;\Omega_t) &= EU(W_{s|fct}|\Omega_t) \\
&+ \sum_{t=t+1}^{T} \sum_{r=1}^{M^{fc}} \left(1 - \frac{d_s}{\sum_{r=1}^{M^f} d_r}\right) \\
&\times EU(W_{r|fct}|\Omega_t) \\
&\text{s.t. } t \leq T, \quad s \in M^{fc} \quad fc \in M
\end{aligned}
$$

where the first term on the right-hand side (RHS) is (1) and future benefits (the second term on the RHS) are calculated as a weighted average of forecasted benefits to the current site and its contiguous sites where weights are calculated using distance, d_s, to the centroid of each site choice from the fisherman's current location; and M is the choice set of all site and fishery-target alternatives. Other variables and functions are defined as above. The distance weighting function is used to capture the notion that the fisherman may choose a site in the current period based upon the site's proximity to other well-performing sites.[4]

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[4] It is important to note that our characterization of future benefits, though similar in spirit to one obtained using a decision rule based upon principles of dynamic optimization, does not reflect optimal future choices made by a fisherman given current information, Ω_t. Rather, we approximate the stream of expected future benefits from choosing a site, fishery, and target, from expected outcomes near the alternative being considered.

An Empirical Model of Location and Target Choice

The random-utility model (RUM) provides a useful way to analyze problems in which decision makers must choose from a set of mutually exclusive choices. The intertemporal model shown in (2) fits naturally into the nested logit framework because both impose additive separability on the utility function. The intuition of this approach is that each fisherman, facing a finite set of fishing choices on each choice occasion, chooses a fishing site from each fishery-target alternative based upon expected current period benefits and incorporates this information into their choice of fishery-target, which is made based upon the long-run stream of benefits associated with each of these alternatives.

For the empirical model, a logarithmic utility function is adopted. Following Bockstael and Opaluch, a Taylor series expansion around expected wealth allows expected utility in period t to be approximated as

$$(3)\quad EU[W_{s|fct}] \approx \ln(\overline{W}_{s|fct}) - 0.5\frac{\mathrm{Var\,REV}_{s|fct}}{(W_{s|fct})^2}.$$

Let SWLTH and SVAR represent, respectively, the first and second terms on the RHS of (3). A similar expression can be obtained for future expected utility resulting in an expression for expected future wealth (FWLTH) and the variance of expected wealth (FVAR) for each fishery-target alternative.[5] Dropping the subscript on time, the empirical model is then

$$\begin{aligned}(4)\quad EU_{s|fc} = {} & \beta_1\mathrm{SWLTH}_{s|fc} + \beta_2\mathrm{SVAR}_{s|fc} \\ & + \beta_3\mathrm{BOAT}_{s|fc} + \beta_4\mathrm{BOAT2}_{s|fc} \\ & + \beta_6\mathrm{SPRV}_{s|fc} + \alpha_1\mathrm{FWLTH}_{fc} \\ & + \alpha_2\mathrm{FVAR}_{fc} + \alpha_3\mathrm{FPRV}\varepsilon_{s|fc}\end{aligned}$$

where BOAT equals the number of boats at a a site; BOAT2 equals boats squared; SPRV and FPRV are dummy variables that equal one if the fisherman has fished at the site or fishery-target choice in the previous set and zero else, respectively; $\varepsilon_{s|fc}$ is the unobservable component of utility, which is assumed to be randomly distributed identically and independently distributed (i.i.d.) and to be drawn from a generalized extreme value (GEV) distribution; and other variables are defined as above. The GEV distribution allows errors to be correlated within a group though not between groups (Kling and Thomson). In this model, this implies that choices are correlated among daily site choices within a fishery but that the long-run benefits associated with a fishery choice are not correlated.

The inclusion of BOAT and BOAT2 captures the idea that a fisherman may perceive other fishermen's choice of a site as a signal of quality of fishing at that site. That is, if the fisherman has no other information on a site or doubts the quality of that information, then he may use other fishermen's behavior to infer site quality. In a similar vein, BOAT2 reflects that fishermen may perceive that "too many" vessels may result in localized stock depletion, i.e., congestion. In addition, SPRV and FPRV are included to capture habit formation effects. If a management goal is to disperse effort, then accounting for factors that may result in inertia or multiple vessels at the same site is important.

Based on (4) and the assumed error structure, the probability of choosing site s conditional on having chosen fishery-catch target fc can be expressed,[6]

$$(5)\quad P_{s|fc} = \frac{\exp[EU_{s|fc}/\rho]}{\sum_{r=1}^{M^{fc}}\exp[EU_{r|fc}/\rho]}$$

where $EU_{s|fc} = \beta_1\mathrm{SWLTH}_{s|fc} + \beta_2\mathrm{SVAR}_{s|fc} + \beta_3\mathrm{BOAT}s_{|fc} + \beta_4\mathrm{BOAT2}_{s|fc} + \beta_5\mathrm{SPRV}_{s|fc}$. Estimation of (5) provides estimates of the vector of coefficients β/ρ, where ρ provides a measure of substitutability of sites within fishery-target choices. These estimates are used to construct the inclusive value (INCVAL), a measure that captures information from the short-run, site decision and incorporates it in the long-run, fishery-target choice and is defined as

$$\mathrm{INCVAL}_{fc} = \log\sum_{r=1}^{M^{fc}}\exp EU(X_{r|fc}/\rho).$$

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[5] Analogous to (2),

$$\mathrm{FWLTH}_{fc} = \sum_{t=t+1}^{T}\sum_{r}^{M^{fc}}\left(1-\frac{d_s}{\sum_{r=1}^{M^{fc}}d_r}\right)\ln(W_{r|fct}|\Omega_t);$$

$$\mathrm{FVAR}_{fc} = \sum_{t=t+1}^{T}\sum_{r}^{M^{fc}}\left(1-\frac{d_s}{\sum_{r=1}^{M^{fc}}d_r}\right)\frac{\mathrm{Var\,REV}_{r|fct}}{W_{r|fct}|\Omega_t}.$$

[6] The model exceeds the maximum limit for choices in LIMDEP using FIML and hence was estimated sequentially.

The probability of choosing site s conditional on having chosen fishery-target fc is

$$(6)\quad P_{fc} = \frac{\exp EU_{fc}}{\sum_{gd=1}^{M} \exp EU_{gd}}$$

where $EU_{fc} = \alpha_1 \text{FWLTH}_{fc} + \alpha_2 \text{FVAR}_{fc} + \alpha_3 \text{FPRV}_{fc} + \rho \text{INCVAL}_{fc}$. Equation (6) provides an estimate of ρ that can then be used to identify the β coefficients.

Measuring the Welfare Effects of Area Closures

The intertemporal model represented by equation (2) can be used to approximate the fisherman's loss in welfare resulting from closures of fishing grounds in an effort to reduce sea turtle mortality. A dynamic welfare measure compensates the individual to equate their lifetime expected utility before and after a policy change. In applying such a welfare measure to Hawaii fishermen, several difficulties arise. First, an appropriate time horizon must be defined over which fishermen are hypothesized to make optimal intertemporal choices. In this model, we assume that the fishermen are seeking to maximize their expected utility from a fishing trip typically fourteen days in length. Second, computational constraints do not allow us to calculate the stream of expected utility resulting from all future optimal choices. We approximate this term using the empirical model. Finally, defining a welfare measure in a dynamic and uncertain context is difficult and fraught with many pitfalls (e.g., whether compensation is stochastic or certain; *ex ante* or *ex post*). With these complications in mind we develop a compensation scheme that is useful in a policy setting and one that is intended to capture the amount a fisherman would need to be compensated at the start of a trip to equate his expected utility from a trip after the closures with his preclosure level of expected utility.

This "at the dock" payment is nonstochastic—it does not vary with the uncertainties of fishing. Consequently, we interpret this payment as the option price (OP) of fishing under the status quo. Since the utility specification does not have a constant marginal utility of income, numerical techniques were used to solve for OP using the following identity (from Hanemann 1982)

$$U^1(\Omega_t, \text{OP}) - U^0(\Omega_t) = 0$$

where

$$\begin{aligned} &U^1(\Omega_t, \text{OP}) \\ &= \log\Bigg(\sum_{fc=1}^{M} \Bigg(\sum_{r=1}^{M^{fc1}} \exp(EU(W_{sfct} + \text{OP})) \\ &\quad + \sum_{t=t+1}^{T} \sum_{r=1}^{M^{fc1}} \bigg(1 - \frac{d_s}{\sum_{r=1}^{M^{fc}} d_r} \bigg) \\ &\quad \times EU(W_{rfct} + \text{OP}) \Bigg)^{1-\sigma} \Bigg) \end{aligned}$$

and recognizing that $U^1(\cdot)$ is calculated for those sites in each fishery, M^{fc1}, still open after the closure.

Data Description

Briefly, catch and effort information is obtained from the federal logbook program, which contains detailed daily information on the location, input use, and catch (number of fish) of each species for all longline trips. Catch (pounds) and price information is from a random sample of sales at a fresh-fish auction in Honolulu. Information on input costs, vessel characteristics, and fuel usage is from a cost-earnings survey of the Hawaii longline fishery implemented in 1997. (A description of the survey instrument and methodology can be found in Hamilton, Curtis, and Travis). Vessel purchase price and additional capital investment, e.g., electronics, hydraulic longline reel, etc., are used as a proxy for fisherman's wealth.

A fisherman's site choice set is defined over the current site choice and all sites contiguous to this choice. For alternative fisheries, we include the three sites in that fishery closest to the current site choice. Table 1 characterizes these location choices. To summarize, vessels that access the swordfish region switched sites an average of three and eight-tenths times per trip on the typical twenty-six-day trip, incurring $9,455 in fuel costs. Those that accessed the mixed fishing region (but not the swordfish region) switched sites three and two-tenths times per trip and incurred $6,884 on fuel costs on an average seventeen-day trip. Finally, those that only fished in the tuna region switched sites two and seven-tenths times per trip and incurred $5,671 expense for fuel on an average fifteen-day trip.

Table 2. Results from Estimation of Nested Random-utility Model

	Coefficient Estimate	t-statistic
SWLTH	12.599	12.519
SVAR	−64.016	−4.098
SPRV	10.109	330.164
BOAT	1.064	86.187
BOAT2	−0.072	−58.257
FWLTH	0.043	55.400
FVAR	−1120.90	−77.666
FPRV	60.526	1367.764
INCVAL	0.745	171.123

Empirical Results and Welfare Estimates

Results from the site choice model (table 2) indicate that all coefficients are of the expected sign and are significantly different from zero at the 1% level. In particular, an increase in wealth (SWLTH), through an increase in revenues, at a site has a positive effect on the probability of that site being chosen while an increase in the variance of those revenues (SVAR) has a negative effect on the probability of that site being chosen, which is consistent with risk-averse behavior. The results of the fishery-long-run nest of the dynamic model also indicate that an increase in the stream of wealth from the remainder of the cruise and a decrease in the variance of this stream have a positive and a negative effect, respectively, on the probability of an alternative being chosen. In addition, both habit formation variables, SPRV and FPRV, indicate that experience with a choice increases the probability of it being chosen, all else equal.

Welfare estimates from the court closure and the NMFS recommended area and seasonal closures are shown in table 3. In addition, a third alternative that would exempt tuna fishing from the seasonal closure is also presented. This management alternative was identified in the NMFS recommendation as a management alternative depending upon whether future research indicated that this exception would still provide comparable levels of protection for sea turtles. Overall, the court's closure had the lowest impact on fishermen (on average, $1,918) but since this alternative resulted in an almost imperceptible reduction in expected sea turtle interactions, this closure scheme could not be supported by the NMFS.

Under the NMFS recommended full seasonal closure, tuna fishermen would need to be compensated $8,735 per trip for losses in expected utility associated with this closure but only $4,066 if tuna fishing were exempted from the seasonal closure. Longliners who fished in the mixed fishery would need to be compensated $20,903 per trip for losses associated with the NMFS closure and virtually the same amount ($20,426) under the alternative that exempted tuna fishermen. The result for the mixed fishery demonstrates that for our estimated choice structure there is a large amount of inertia when switching out of a fishery. Even significant loosening of area closures in the tuna fishery did not benefit mixed fishermen much. Longliners fishing in the northern waters of the swordfish fishery experienced the same losses under both alternatives, $43,046. This is because the swordfish fishery is seasonal due to the migratory patterns of the stocks and there was no activity in this fishery for the months of April and May; consequently, there was no effect from the more restrictive April and May closure.

Table 3. Welfare Estimates from Turtle Closures

Closure	Swordfish	Mixed	Tuna	Mean
Court-ordered closure	$5,835.38	$3,298.89	$1,066.28	$1,918.02
Annual and seasonal (April-May) closure	$43,045.81	$20,903.36	$8,375.12	$13,506.71
Annual and season closure, tuna fishing excepted	$43,045.81	$20,426.33	$4,066.28	$10,519.68

Tuna fishing would only be exempted from the seasonal closure provided this alternative afforded a comparable level of protection to sea turtles. Assuming this is the case, the average cost of reducing longline interactions with sea turtles is $41,262 per turtle, which, though high, is considerably less than the $52,976 per turtle projected cost under the full closure.

Conclusions

Fishery managers' increasing reliance upon area and seasonal closures to protect critical habitat as well as to mitigate interactions with marine mammals, sea turtles, and other protected species underscores the need for quantitative models that can assess the impacts of policy alternatives on the fishermen. The random utility model readily provides a way to assess the economic impacts of proposed closures. Not surprisingly given the scope of the proposed closure, results from this analysis indicate that the proposed measures to protect the sea turtle in the Hawaii longline fishery will have a significant economic impact on all fishermen. In addition, results indicate that closures disproportionately affecting a fishery have a higher welfare impact on that fishery even when substitute fishing activities are included in the model. In particular, Hawaii longline fishermen operating in the swordfish fishery experience the greatest loss because this region is virtually shut down to longline activity due to the relatively high number of sea turtle interactions occurring in these northern waters. The NMFS has recommended increasing observer coverage in the Hawaii longline fishery to improve the scientific quality of the analysis, which in turn may provide a means for refining closure recommendations.

Area and seasonal closures can be blunt tools for managing a fishery as heterogeneous as the Hawaii longline fishery. Indeed, in their recommendation to the court, the NMFS indicated that it would like to pursue preliminary evidence that suggests tuna fishing may be exempted from the closures and still provide comparable levels of protection for sea turtles. The differential impact on fishermen from applying the closure to all fishing strategies versus exempting tuna fishing from these restrictions indicates that this further research as well as improved monitoring of fishing activities is warranted.

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