Adjustments to False Killer Whale and Short-finned Pilot Whale Bycatch Estimates[1]

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Section 1: Introduction

The purpose of this report is to present different methodologies for estimating the bycatch in two situations that require splitting an estimate of bycatch into two categories. The first situation pertains to the false killer whale bycatch estimates in the overlap zone and splitting it into bycatch estimates for the Hawaii insular and pelagic stock of false killer whales. The second situation involves splitting the estimated bycatch of blackfish (a blackfish is either a false killer whale or a short-finned pilot whale but which of these two is unknown) into bycatch estimates of blackfish that are false killer whales and blackfish that are short-finned pilot whales.

On a yearly basis, the bycatch summarized as the total number of incidental interactions (death, serious injury, and non-serious injury) and the total number of incidental interactions resulting in death or serious injury classification (DSI) by the Hawaii longline fishery are estimated. A marine mammal incidental interaction is defined as an event where a marine mammal is restrained in some manner by the fishing gear; typically this involves being hooked or entangled in the gear. An estimate of total incidental interactions refers to the total number of times the event occurred and does not necessarily represent the number of individual animals that interacted with the fishery. An animal can be taken multiple times, even if it is seriously injured in a subset of the encounters. Thus it is possible for multiple interaction events for an individual animal to be included in the estimate. For example, an estimate of 5 may represent 1 to 5 individual animals. Similarly, an estimate of DSI may include multiple events for an individual animal.

When relevant, the bycatch estimates for years 2002 through 2009 are presented. The current sampling design for the deep-set fishery was adopted in 2002; therefore, bycatch estimates for 2002 through 2009 use the same estimators. As the shallow-set fishery has 100% coverage, the reported bycatch of false killer whales and blackfish is the sum of observed bycatch. The estimators and bycatch for both fisheries from years 2004 through 2009 are given in McCracken and Forney (2009) and McCracken (2010). The Horvitz-Thompson estimator is used to estimate the total number of interactions. The general form of the Horvitz-Thompson estimator is

$$\hat{\tau} = \sum_{i=1}^{n} \frac{y_i}{\pi_i},$$

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where n is the number of unique trips sampled, π_i is the probability trip i is included in the sample, and y_i is the response variable of interest for trip i. The general form of the estimator used for the total number of interactions resulting in a DSI classification is

$$\hat{\delta} = (\hat{\tau} - x)\hat{p}_{DSI} + x_{DSI},$$

where $\hat{\tau}$ is the estimated total interactions of interest, $\hat{p}_{DSI}$ is the probability an interaction results in a death or serious injury, x is the number of observed interactions whose injury classification is known, and x_{DSI} is the number of observed interactions known to be DSI.

Section 2 describes the problem of separating the false killer whale bycatch estimates into estimates for the insular stock and pelagic stock of false killer whales. Different methods for estimating the bycatch of these two stocks and their assumptions are presented. The resulting bycatch estimates in the overlap zone are given for relevant years. Section 3 describes the problem of splitting the estimated blackfish bycatch into bycatch estimates of false killer whales and short-finned pilot whales. Different methods for making this split and their assumptions are presented. The resulting bycatch estimates are presented and then incorporated into previously reported bycatch estimates of false killer whales and short-finned pilot whales. Section 4 revises the false killer whale insular and pelagic stock bycatch estimates incorporating the estimates in Section 2 and 3.

Section 2: Bycatch Estimates of the Insular and Pelagic False Killer Whale Stocks in the Overlap Zone

Within the U.S. Exclusive Economic Zone (EEZ) surrounding the Hawaiian Islands there are two stocks of false killer whales that utilize the waters: the Hawaii insular false killer whale stock and the Hawaii pelagic false killer whale stock. Hawaii insular false killer whales are genetically distinguishable from pelagic false killer whales (Chivers et. al. 2007, 2010). The 2009 Stock Assessment Report for the false killer whale (Carretta et al. 2010) gives an abundance estimate for the Hawaii insular stock of 123 individuals, citing Baird et al. (2005), and an abundance estimate for the Hawaii pelagic stock of 484 individuals within the U.S. EEZ surrounding Hawaii, citing Barlow and Rankin (2007). The Hawaii insular stock remains close to the Hawaiian Islands and primarily uses waters that are relatively shallow. The Hawaii pelagic stock inhabits waters farther away from the shoreline. Although the specific boundaries of this stock are unknown, their population range is known to extend into high-seas waters (Oleson et al. 2010). The range of the insular stock overlaps a portion of the pelagic stock range (Forney et al. 2010). The Marine Mammal Protection Act requires separate estimates of annual deaths and serious injuries that occur within U.S. waters for these two stocks.

Using the three boundaries defined by (1) 40 km from the shoreline of the main Hawaiian Islands, (2) 140 km from the shoreline of the main Hawaiian Islands, and (3) the Hawaiian Islands EEZ boundary, the 2010 Stock Assessment report for the false killer whale (Carretta et al., 2010) defines three zones (based on justifications in Forney et al., 2010): (1) a nearshore zone defined as the waters between the shoreline of the main Hawaiian Islands and the 40 km boundary that the insular stock primarily inhabits, (2) an overlap zone defined as the waters between the 40 km and 140 km boundaries that the insular and pelagic stocks both inhabit, and (3) an outer zone defined as the waters between the 140 km and the EEZ boundaries that the pelagic stock inhabits. The areas for the outer, overlap, and nearshore zones are approximately 2,179,217 sq km, 202,277 sq km, and 66,149 sq km, respectively.

From 2000 to 2009, 15 of the 18 observed interactions of false killer whales with the longline fishery within the Hawaiian EEZ were outside the 140 km boundary and three were within the overlap zone: 2 in 2003 and 1 in 2006. All three observed interactions in the overlap zone occurred in the deep-set fishery. Figure 1 shows the locations of the 2000-2009 false killer whale interactions within the different zones inside the Hawaiian EEZ.

When an observer aboard a longline vessel witnesses a false killer whale interaction, the observer typically can't identify the stock (insular or pelagic) of the individual. Photographic or genetic identification of individuals is usually required to determine the stock. Tissue samples for genetic analysis were obtained for 6 of the 31 interactions observed during 1994–2008. All of the samples were obtained outside the 140 km boundary and determined to be from individuals belonging to the pelagic stock. No samples are available for any of the false killer whale interactions within the 140 km boundary (Oleson 2010).

If there were a sufficient sample of false killer whale interactions throughout the three zones identified as being from the insular or pelagic stock, then probabilities that false killer whale interactions were from the insular stock could be estimated from this sample and used to estimate the insular stock and pelagic stock bycatch, separately. However, because there is an insufficient sample, probabilities are assigned based on a mathematical model. Underlying each mathematical model is a set of assumptions that are not validated. The model's parameters are estimated using current information. The term "assign" is used here to highlight the fact that a mathematical model is being assumed.

The 2009 Stock Assessment Report (Carretta et al., 2010) makes four assumptions that are maintained in the models presented in this paper. The first assumption is that there are two mutually exclusive stocks of false killer whales within the EEZ boundary. Thus, given a false killer whale interaction within the EEZ boundary, the probability it is from the insular stock and the probability it is from the pelagic stock sum to 1. The second assumption is that individuals from the pelagic stock do not enter the nearshore zone; therefore, the probability a false killer whale interaction in this zone is from the insular stock is assigned the value 1. The third assumption is that individuals from the insular stock do not enter the outer zone; therefore, the probability a false killer whale interaction in this zone is from the insular stock is assigned the value 0. The final assumption is that the probability an interaction results in a death or a serious injury classification, p_{DSI}, is the same for insular and pelagic false killer whales. Based on these assumptions, we are now left with the problem of assigning the probability that a false killer whale interaction in the overlap zone is from the insular stock.

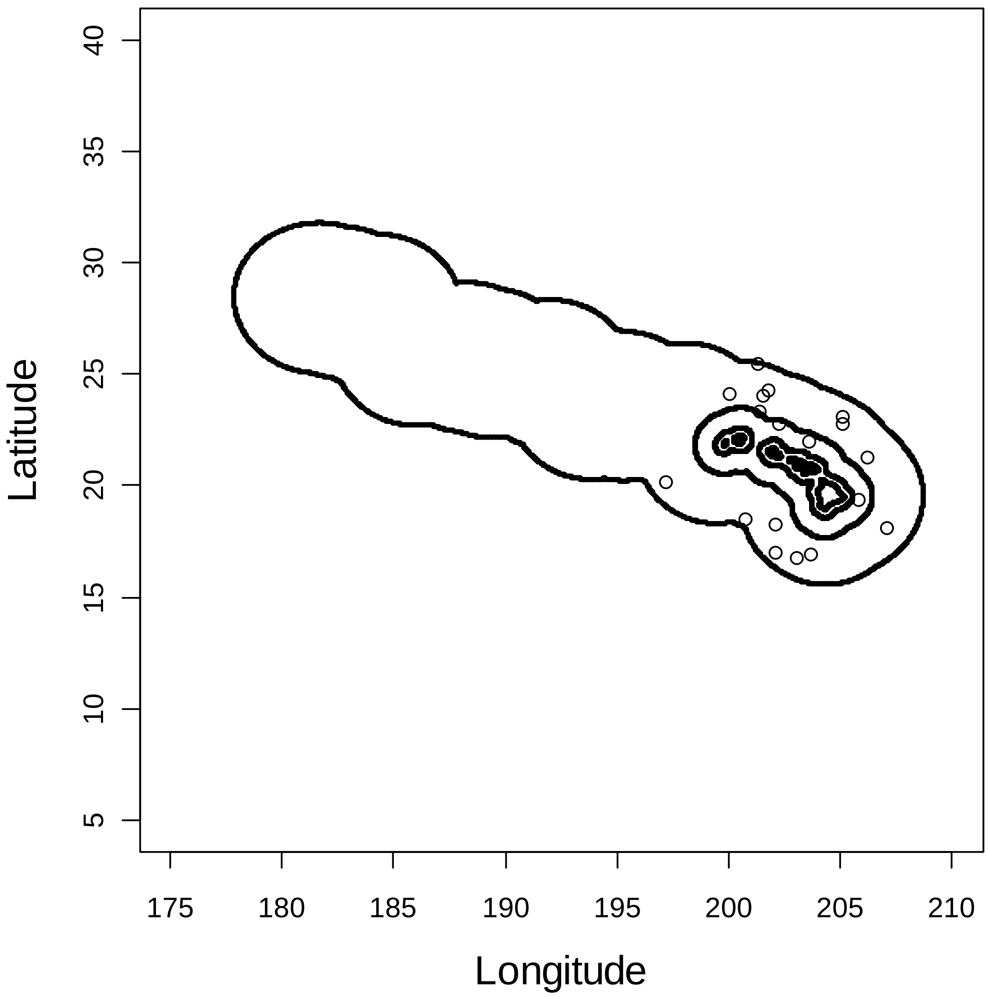

Figure 1. Locations of false killer whale interactions within the Hawaiian EEZ from 2000 through 2009. The main Hawaiian Islands are shown as well as the 40 km boundary and 140 km boundary.

Five different mathematical models were used to explore a range of possible false killer whale stock assignments in the overlap zone and their affect on the resulting bycatch estimates for each stock. These five models have different underlying assumptions. To simplify outlining these assumptions, the following notation and properties are used. Let N denote the number of individuals in a population, τ denote the total incidental interactions of a population, δ denote the total number of interactions resulting in a DSI classification, and λ denote the average number of times an animal interacts with the fishery. Furthermore, let the subscripts '+' denote the false killer whale population in the overlap zone, '1' denote the Hawaii insular false killer whale stock in the overlap zone, and '2' denote the Hawaii pelagic false killer whale stock in the overlap zone. For example, N_+, N_1, and N_2 denote the number of individuals in the Hawaii false killer whale population, Hawaii insular false killer whale population, and Hawaii pelagic false killer whale population in the overlap zone, respectively. Using these subscripts, let $p_{1|+}$ and $p_{2|+}$ denote the conditional probabilities that a false killer whale interaction in the overlap zone is from the insular stock or pelagic stock, respectively, and let w_{ij} and ε_{ij} represent the number of times animal j from population i (i=1,2,+) interacts with the fishery and the number of times it is exposed to the fishery in the overlap zone, respectively. The word exposed in this context means that the animal comes upon a longline operation by chance or through attraction to the gear by sight, smell, sound, or other sense. Finally, let A_{out} denote the area of the outer zone, A_{over} denote the area of the overlap zone, and A_{near} denote the area of the nearshore zone.

By definition, $N_+=N_1+N_2$ and $\tau_+= \tau_1+ \tau_2$. If it is assumed that $\tau_1= \tau_+(N_1/ N_+)$ and $\tau_2= \tau_+(N_2/ N_+)$, as assumed in the 2010 Stock Assessment Report (Carretta et al., 2010), then it is being assumed an equal proportion of the insular and pelagic stocks are interacting with the fishery within the overlap zone and this proportion is τ_+/ N_+.

If the w_{1j}s (j=1,…,N_1) are independent, identically distributed (iid) Poisson(λ_1) random variables and the w_{2k}s (k=1,…,N_2) are iid Poisson(λ_2) random variables then the random variables τ_1 and τ_2 are distributed as Poisson($N_1 \lambda_1$) and Poisson($N_2 \lambda_2$), respectively. Furthermore, $E[\tau_1]=N_1 \lambda_1$, $E[\tau_2]=N_2\lambda_2$, and $E[\tau_+]=N_1 \lambda_1+N_2 \lambda_2$. If we make the additional assumptions that τ_1 and τ_2 are independent and $\lambda_1= \lambda_2= \lambda_+$ then τ_+ is a Poisson($N_+ \lambda_+$) random variable, the conditional distribution of τ_1 given τ_+ is binomial with parameters τ_+ and $N_1/(N_1+ N_2)$, and the maximum likelihood estimates (MLE) of $p_{1|+}$, $p_{2|+}$, τ_1, τ_2 are N_1/N_+ , N_2/N_+ , $(\tau_+ N_1)/N_+$, and $(\tau_+ N_2)/N_+$, respectively. Although the estimators $\tau_+(N_1/N_+)$ and $\tau_+(N_2/N_+)$ for τ_1 and τ_2 do not need to be MLE to be used, MLE have desirable properties. If this suite of assumptions is valid for false killer whale interactions in the overlap zone, then using the estimators $\tau_+(N_1/N_+)$ and $\tau_+(N_2/N_+)$ for τ_1 and τ_2, respectively, within the overlap zone is well justified.

In practice, τ_+, N_+, N_1, and N_2 are replaced by estimates. The methodology for estimating τ_+ is described in McCracken (2010). The assumptions behind the model used for assigning probabilities determine how N_+, N_1, and N_2 are estimated. As the same value for τ_+ is used throughout the five models, the assigned probabilities will be given in terms of the conditional probabilities $p_{1|+}$ and $p_{2|+}$.

Next, a brief introduction of the five models is given, followed by the details of each model. Models 1 and 2 provide the lowest and highest estimates possible given the estimated total interactions and DSI in the overlap zone. Models 3 and 4 assume that the bycatch from each stock is proportional to its abundance in the overlap zone and that the constant of proportionality is $\alpha= \tau_+/ N_+$. These two models differ in the assumptions they make to determine N_1 and N_2. Model 5 also assumes the bycatch from each stock is proportional to its abundance but assumes that the densities of the pelagic and insular stocks in the overlap zone are functions of distance from the shoreline. Within the overlap zone, as this distance increases the density of the pelagic stock increases and the density of the insular stock decreases. Thus, N_1 and N_2 are functions of this distance.

Model 1.

Model 1 assumes that all interactions in the overlap zone are from the insular stock. The assigned conditional probabilities are $p_{1|+}$= 1.0 and $p_{2|+}$= 0.0. This is the worst case scenario for the insular stock and the best case scenario for the pelagic stock.

Model 2.

Model 2 assumes that all interactions in the overlap zone are from the pelagic stock. The assigned conditional probabilities are $p_{1|+}$= 0.0 and $p_{2|+}$= 1.0. This is the worst case scenario for the pelagic stock and the best case scenario for the insular stock.

Model 3.

Model 3 assumes (1) insular and pelagic false killer whales could interact with the fishery in the overlap zone and that for each stock the proportion of interactions is τ_+/ N_+ and (2) the pelagic stock is uniformly distributed over the outer and overlap zone and the insular stock is uniformly distributed over the nearshore and overlap zone. Under these assumptions, the density of the pelagic stock is D_{pel}= 484/(A_{out} + A_{over})=0.000203 animals per sq km and the density of the insular stock is D_{in}=123/(A_{near} + A_{over})=0.000458 animals per sq km. The assumption that the stocks are uniformly distributed over their ranges implies $E[N_1]=D_{in} A_{over}$ =92.69 and $E[N_2]=D_{pel}A_{over}$=41.11. The expected density of false killer whales (insular and the pelagic stocks combined) in the overlap zone is $(E[N_1]+ E[N_2])/ A_{over}$ =0.000661 animals per sq km. This density is higher than the densities of false killer whales in the outer and inner zones.

Under Model 3, the assigned conditional probabilities are $p_{1|+}$= 0.69 and $p_{2|+}$= 0.31. It was these assigned conditional probabilities that were used in the bycatch estimates reported in the 2009 stock assessment report (Carretta et al. 2010), incorporating recommendations made by the Pacific Scientific Review Group at their November 2009 meeting.

Model 4.

Model 3 assumes that each stock has full utilization of the overlap zone and that the density of false killer whales in this area is higher than in the outer and nearshore zones. Model 4 assumes that a stock does not have full utilization of the overlap zone but only partial utilization. This partial utilization is incorporated by assuming that the fraction of the overlap zone utilized by a stock determines the 'effective area' of the zone for that stock.

Specifically, Model 4 assumes (1) insular and pelagic false killer whales interact with the fishery in the overlap zone and that the proportion of interactions from each stock is τ_+/ N_+ , (2) each stock's effective area in the overlap zone is 50% of the overlap zone , (3) the pelagic stock is uniformly distributed over the outer zone and their effective area in the overlap zone, (4) the insular stock is uniformly distributed over the nearshore zone and their effective area in the overlap zone. Under these assumptions, the density of the pelagic stock is D_{pel}=484/(A_{out}+0.5A_{over})=0.000212 animals per sq km and the density of the insular stock is D_{in}=123/(A_{near}+0.5A_{over})=0.000735 animals per sq km. The assumption that the stocks are uniformly distributed over their effective ranges implies $E[N_1]=D_{in} (0.5A_{over})$ =74.36 and $E[N_2]=D_{pel}(0.5A_{over})$=21.74. The expected density of false killer whales (insular and the pelagic stocks combined) in the overlap zone is $(E[N_1]+ E[N_2])/ A_{over}$ =0.000474 animals per sq km.

This density is greater than the density of false killer whales in the outer zone but less than the density in the near shore zone. The assigned conditional probabilities are $p_{1|+}$= 0.78 and $p_{2|+}$= 0.22.

Model 5.

Model 5 makes the same assumption as Model 4 concerning each stock having a 50% effective area in the overlap zone. However, Model 5 does not assume that the stocks are uniformly distributed over their effective area in the overlap zone; instead, it assumes the density of each stock is a function of the minimal distance to the shoreline. Denote this distance as d. Basically, it assumes that between 40 km and 140 km from the shoreline the density of the insular stock declines and the pelagic stock increases as d increases. The function relating the conditional probabilities to d is assumed to be the logistic curve. Specifically, for z=(d-40)/100 and using the values of D_{in} and D_{pel} derived in Model 4, the conditional probability for the insular stock is assigned the value $p_{1|+}$=exp(f(z))/(1+f(z)) where f(z)=b_0+$b_1 z$, b_0=log(.984D_{in}/((1-.984)D_{pel})), and b_1=-2(log(D_{in}/D_{pel})b_0).

Under these assumptions; $p_{1|+}$=0.78 and $p_{2|+}$=0.22 at d=90 km (the midpoint). Figure 2 shows curves for the conditional probabilities and Figure 3 has the conditional probability $p_{1|+}$ contours overlapped with the interaction locations of false killer whales.

The minimal distance to shoreline is computed using data from the World Vector Shoreline database. The distance between an interaction location (haul begin location is used if the interaction location is unknown) and shoreline coordinates is computed using the haversine formula assuming the earth's mean radius of 6371 km (final results were the same using this radius, the radius at the equator (6378 km), or an intermediate value).

The next step is to estimate τ_1, τ_2, δ_1, and δ_2. Let ny_i be the number of false killer whale interactions in the overlap zone for trip i, x the number of false killer whales in the overlap zone with known injury classification, x_{DSI} the number of false killer whales in the overlap zone with known DSI injury classification, and $p_{1|+(j)}$ the conditional probability for interaction j during trip i. To estimate τ_1 the value of y_i inputted in the Horvitz-Thompson estimator is

$$y_i = \sum_{j=1}^{ny_i} p_{1|+(j)}.$$

To estimate δ_1 let $x_1 = \sum_{k=1}^{x} p_{1|+(k)}$ and $x_{1\cdot DSI} = \sum_{k=1}^{x_{DSI}} p_{1|+(k)}$. Then $\hat{\delta}_1 = (\hat{\tau}_1 - x_1)\hat{p}_{DSI} + x_{1\cdot DSI}$., where $\hat{p}_{DSI}$ has the same value, 0.92, as used in McCracken (2010) for false killer whale interactions. For the pelagic stock, τ_2 and δ_2 are estimated in a similar manner but using $p_{2|+(j)}$. The assigned probabilities in Models 1-4 are constant over the overlap zone. For these models, the estimators described above for τ_1, τ_2, δ_1, δ_2 simplify to multiplying τ_+ and δ_+ by the appropriate conditional probability, $p_{1|+}$ or $p_{2|+}$.

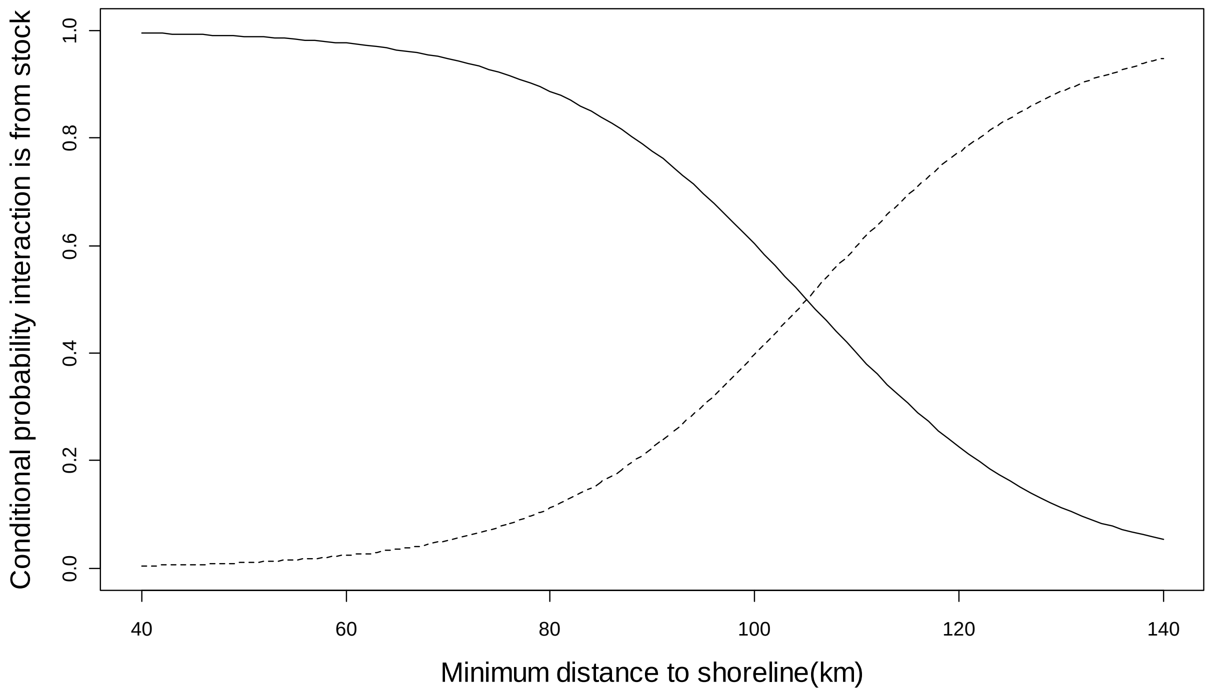

Figure 2. The conditional probability a false killer whale interaction in the overlap zone is from the insular stock (solid curve) or the pelagic stock (dash curve) as a function of the minimal distance from the interaction location to the shoreline.

Table 1 gives the bycatch estimates for each stock in the overlap zone. Behind these estimates are a series of underlying assumptions that if met would justify the estimator. I am unaware of any data available that could be used to verify these assumptions. Animal behavior makes many of these assumptions questionable. The following is a list of some of the underlying assumptions.

1) All five models assume that animals from the insular and pelagic stock have the same probability of an incidental interaction resulting in death or serious injury.

2) Models 3-5 assume that the expected number of times an individual false killer whale in the overlap zone interacts with the fishery is identical over all individual false killer whales in this zone, $E[w_{+j}]=E[w_{+j}]$ over all values of j $(j=1,..,N_+)$. A suite of assumptions that leads to this property are (1) the $w_{1j}|\varepsilon_{1j}$s (the conditional value of w_{1j} given ε_{1j}) are iid binomial(ε_{1j},p_+), (2) the $w_{2j}|\varepsilon_{2j}$s are iid binomial(ε_{2j},p_+), (3) the $w_{1j}|\varepsilon_{1j}$s are independent of the $w_{2j}|\varepsilon_{2j}$s, and (4) $E[\varepsilon_{+j}]=m$ for all values of j $(j=1,..,N_+)$. Under these assumptions, $E[w_{+j}]=E[E[w_{+j}|\varepsilon_{+j}]]= E[\varepsilon_{+j}]p_+=mp_+$ over all values of j $(j=1,..,N_+)$. Basically what is being assumed is that regardless of whether a false killer whale belongs to the insular or pelagic stock (1) each false killer whale in the overlap zone is expected to be exposed to the longline fishery the same number of times (*m)* and (2) each false

killer whale in the overlap zone has the same probability of interacting with the fishery during a longline operation given it is exposed to the operation (it cannot be restrained by the gear if not exposed), p_+, and the probability an individual interacts with the fishery is independent of all other false killer whales. If Hawaii insular false killer whales behave differently than Hawaii pelagic false killer whales in ways that influence their chances of being exposed to the longline operation or restrained by the longline operation once they are exposed to it, then these assumptions are likely not met.

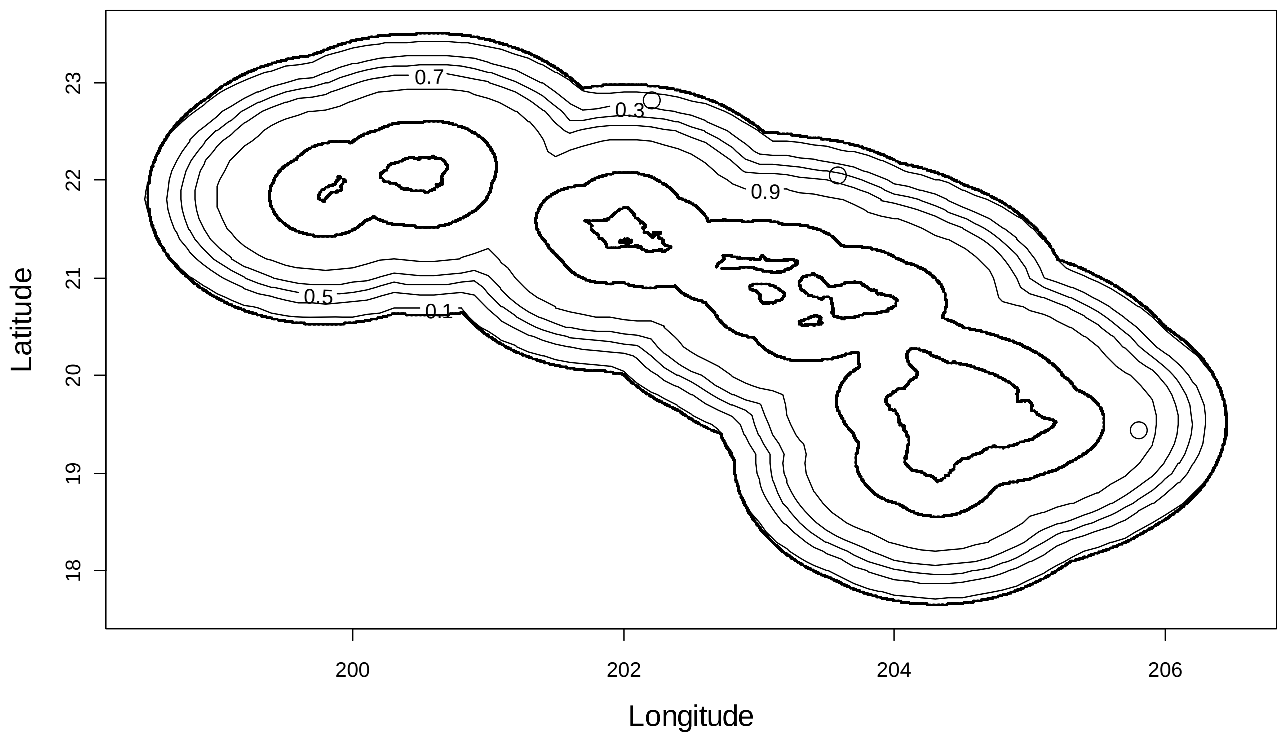

Figure 3. Contours of the conditional probability that a false killer whale interaction in the overlap zone is from the insular stock. Locations of observed false killer whale interactions in the overlap zone are denoted by a circle.

3) Models 3-5 assume the ratio N_1/N_+ is constant over the period of estimation (from years 2002 through 2009 in this paper). Models 3 and 4 assume further that the two stocks are uniformly distributed over the overlap zone. In this situation, the individual animals could be uniformly distributed over the zone or the pods could be uniformly distributed over the zone if the expected pod size of the insular stock and pelagic stock is the same within the zone. In Model 5, the density gradients for the two stocks in the overlap zone are assumed to be constant over the period of estimation.

Table 1. Insular and pelagic false killer whale stock total interactions and DSI estimates within the overlap zone. The methods of estimation are the five models described in Section 2. Estimates are for the deep-set longline fishery and do not include blackfish. There were no observed false killer whale interactions in the overlap zone in the shallow-set longline fishery.

			Method of Estimation				
Year	Stock	Estimated Total	Method 1	Method 2	Method 3	Method 4	Method 5
2003	Insular	Takes	7.0	0.0	4.8	5.5	5.5
		DSI	6.6	0.0	4.6	5.1	5.1
	Pelagic	Takes	0.0	7.0	2.2	1.5	1.5
		DSI	0.0	6.6	2.0	1.5	1.5
2006	Insular	Takes	6.1	0.0	4.2	4.8	1.1
		DSI	4.7	0.0	3.2	3.7	0.8
	Pelagic	Takes	0.0	6.1	1.9	1.3	5.0
		DSI	0.0	4.7	1.5	1.0	3.9

As summarized in Table 1, Models 1 and 2 produce the highest and lowest estimates of bycatch for each stock in the overlap zone and Model 3 produces estimates as reported in the 2009 stock assessment report (Carretta et al. 2010). Model 4 always produces higher bycatch estimates of the insular stock in the overlap zone than Model 3, because the 50% reduction in utilization of the overlap zone by each stock (50% effective area) reduces the density of the pelagic stock in the overlap zone more than it reduces the density of the insular stock. This is because the overlap zone still represents a much larger fraction of the total stock range for the insular stock than it does for the pelagic stock. Model 4 could be more realistic than Model 3, if it is more reasonable for the density of the combined stocks in the overlap zone to be intermediate between whale density in the nearshore and outer zones. For Model 3 density in the overlap zone is the sum of densities in the nearshore and outer zones, making it higher than the density in either of these zones. Model 5 also assumes an intermediate whale density in the overlap zone, but sometimes results in estimates of insular stock interactions that are higher or lower than those produced by Model 3. In this case, the results depend on how far from shore the interactions in the overlap zone were observed to occur. If they are far enough from shore, Method 5 produces lower estimates of insular interactions than Method 3.

The methodology and computer subroutines to estimate standard errors and confidence intervals for the bycatch estimates presented here are still under development.

Section 3: Splitting the Blackfish Bycatch Estimates into False Killer Whales and Short-finned Pilot Whale Bycatch Estimates

There are instances where a cetacean has been observed to interact but the cetacean can only be identified as being a false killer whale or a short-finned pilot whale. The term ‘blackfish’ has been used to identify this level of identification. The reported bycatch estimates of false killer whales and short-finned pilot whales in McCracken (2010) and McCracken and

Forney (2010) do not incorporate blackfish interactions, only interactions where the animal was identified to the species. For years when there are observed blackfish interactions, if these interactions are not incorporated into the false killer whale and short-finned whale bycatch estimates then the bycatch for these species are underestimated.

Since 2000, 11 interactions with short-finned pilot whales, 39 with false killer whales, and 10 with blackfish have been observed in the deep-set fishery and 1 interaction with a short-finned pilot whale, 2 with false killer whales, and 1 with a blackfish have been observed in the shallow-set fishery. All observed blackfish interactions were within the Hawaiian EEZ. There have been three longline sets in which two whales interacted with the gear: one set had two false killer whales, one set had two short-finned pilot whales, and the third set had one false killer whale and one blackfish. Given that there were only two sets where the species of both interactions is known, there is insufficient information to make conclusions about the possible dependence between interactions within a set. In the set where the blackfish was recorded, there was a long interval between the two interactions, so the blackfish was treated the same as other observed blackfish in the estimation process. There also have been trips with multiple interactions, but not enough of them to make conclusions about the possible dependence between interactions within the same trip. Figure 4 shows the recorded interaction locations (location where the interaction is first noticed by the observer) and species identification of observed blackfish interactions. When the interaction locations are unknown the location where the hauling of the gear began is used as the interaction location. The results are robust to using the location of the beginning or ending of the haul back as the proxy for interaction location.

Herein the term identified blackfish (IB) is used to denote that the species of the blackfish has been identified and the term unidentified blackfish (UB) is used to denote that the species of the blackfish has not be identified. The following notation is now adopted: F denotes a false killer whale; P denotes a short-finned pilot whale; $y_{F|IB}$ and $y_{F|UB}$ denote the number of observed IB interactions that are F interactions and UB interactions that are F interactions, respectively; n_{IB} and n_{UB} denote the number of observed IB interactions and observed UB interactions, respectively; and $\Pr(F \mid UB)$ and $\Pr(P \mid UB)$ denote the conditional probability that an interaction is a F or P interaction, respectively, given it is a UB interaction.

The first step taken to estimate the number of UB that are F is to estimate $\Pr(F \mid UB)$. As $\Pr(F \mid UB) + \Pr(P \mid UB) = 1$, specifying the assumptions and models behind estimating $\Pr(F \mid UB)$ involves both probabilities. If we make the assumption that the probability of identifying the species of the blackfish, or not, is independent of the species being F or P, $\Pr(IB \mid F) = \Pr(IB \mid P)$ and $\Pr(UB \mid F) = P(UB \mid P)$, then $\Pr(F \mid IB) = \Pr(F \mid UB)$. Thus, under this assumption the IB can be used to estimate $\Pr(F \mid UB)$ by estimating $\Pr(F \mid IB)$. If each IBs identification (1=F,0=P) are iid Bernoulli random variables with parameter Pr(F|IB) then $y_{F|IB}$ has a binomial distribution with parameters n_{IB} and $\Pr(F \mid IB)$. Under the assumptions outlined above, methods used for modeling binomial variates (or even quasi-binomial variates) can be used to construct a prediction model from which $\Pr(F \mid UB)$ can be predicted for each UB.

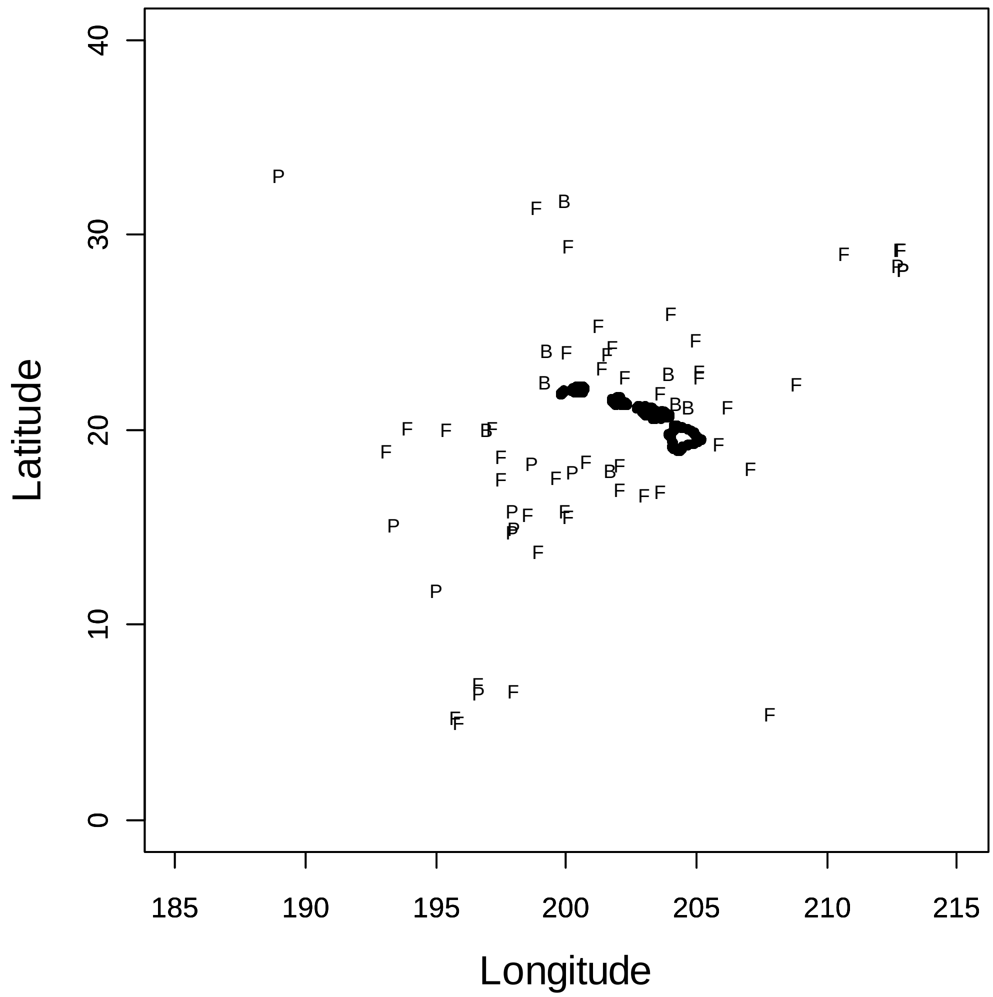

Figure 4. Locations of observed false killer whale interactions (F), short-finned pilot whale interactions (P), and unidentified blackfish interactions (B). The main Hawaiian Islands are shown.

As there are very few observed interactions of identified blackfish in a year, it is assumed that $\Pr(IB \mid F)$ does not vary between years, within the year, or between fisheries (deep-set and shallow-set). Under this assumption, data from observed interactions from years 2000 through 2009 are used without regard to the year, time of the year, or fishery. The advantage of increasing the number of observed interactions (sample size) by pooling over years, seasons, and fisheries is an increase in precision of bycatch estimates, although estimates of precision have not yet been computed. A disadvantage is the potential of introducing bias if the relevant bycatch patterns change between fisheries, years, or within the year and the model does not adequately account for these variations. When looked at graphically, there were no obvious clumps of F or P interactions during a season or year.

Three different prediction methods have been used to estimate $\Pr(F \mid IB)$. A brief introduction to the three methods is given, followed by the details of each method. All three methods assume that the probability of identifying the species of a blackfish, or not, is independent of the species being F or P and that $y_{F|IB}$ is a binomial variate. These methods differ in their assumption concerning how $\Pr(F \mid IB)$ varies over space. Method 1 assumes that $\Pr(F \mid IB)$ is constant over space.

Method 2 uses a GAM with a logistic link to model the variation of $\Pr(F \mid IB)$ over space. The GAM was fitted using the R package mgcv with thin plate regression splines as the smoothing bases (Wood 2008, 2006, 2004, 2003). Along with specifying the location using the coordinates of latitude and longitude, the minimal distance from the interaction location to the shoreline was computed and considered as a predictor. Methods 2 and 3 use the two prediction models that model diagnostics suggested were the better models. When the equivalent models were fitted assuming quasi-binomial variates, the estimated scale parameter was close to 1, indicating the absence of overdispersion (more variation then expected under the binomial assumption). The significance of the smooth term in each model was approximately 0.05.

Method 1

Method 1 assumes $\Pr(F \mid UB)$ is constant over the relevant fishing grounds. Under this assumption and those listed previously, the MLE for $\Pr(F \mid UB)$ and $\Pr(P \mid UB)$ are $y_{F|IB}/n_{F|IB}$ and $y_{P|IB}/n_{P|IB}$. The resulting estimates are 0.78 and 0.22, respectively.

Method 2

Method 2 fitted a GAM to a smoother for the minimal distance to shoreline. . The estimated degrees of freedom of the fitted smoother was 2.00. The Un-Biased Risk Estimator (UBRE) score was -0.024. The fitted conditional probability contours of the fitted smoother are shown in Figure 5.

Method 3

Method 3 was a GAM that fitted a smoother over latitude and longitude. As data were sparse away from the main Hawaiian Islands, it was necessary to restrict the degrees of freedom of the smoother to be no more than 5 to prevent overfitting. The estimated degrees of freedom of the fitted smoother was 3.81. The UBRE score was 0.026, indicating a slight superiority of Method 2 based on the UBRE. The fitted probability contours of the fitted smoother are shown in Figure 6.

Once $\Pr(F \mid UB)$ is estimated, the next step is to estimate the total bycatch of UB that are F. For the shallow-set fishery, each observed UB was assigned the value of $\Pr(F \mid UB)$ estimated by the method being considered. The estimated number of false killer whale bycatch that were UB was the sum of these probabilities. Estimates for short-finned pilot whales were done in a similar manner but with the appropriate values for short-finned pilot whales substituted in for false killer whales.

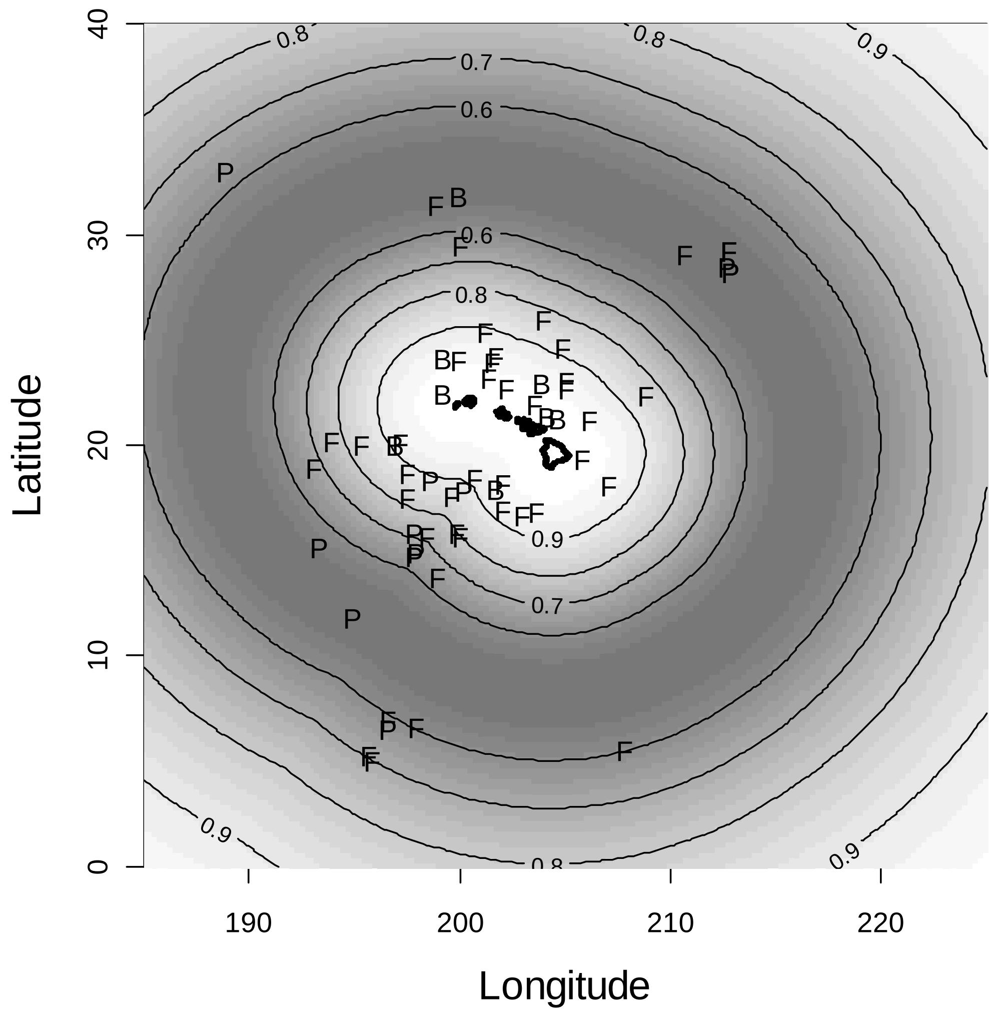

Figure 5. A perspective and contour plot for the fitted GAM in Method 2. The contours are the conditional probability that a blackfish interaction is a false killer whale. The color shade increases as this conditional probability decreases. The interaction locations of observed false killer whales (F), short-finned pilot whales (P), and unidentified blackfish (B) are shown.

The estimators for the deep-set fishery are now presented. Let $\tau_{F|UB}$ and $\tau_{P|UB}$ be the number of UB interactions that are F and P interactions, respectively, and let $\delta_{F|UB}$ and $\delta_{P|UB}$ be the number of $\tau_{F|UB}$ and $\tau_{P|UB}$ resulting in a DSI classification. Let nub_i be the number of UB interactions for trip i, x the number of UB interactions with known injury classification, x_{DSI} the number of UB interactions with known DSI classification, and $\widehat{\Pr}(F \mid UB)_j$ the estimated conditional probability for interaction j (j=1,…,nub_i) during trip i. To estimate $\tau_{F|UB}$ the value of y_i inputted in the Horvitz-Thompson estimator is

$$y_i = \sum_{j=1}^{nub_i} \hat{\Pr}(F \mid UB)_j .$$

To estimate $\delta_{F|UB}$ let $x_{F|UB} = \sum_{k=1}^{x} \hat{\Pr}(F \mid UB)_k$ and $x_{F|UB \cdot DSI} = \sum_{k=1}^{x_{DSI}} \hat{\Pr}(F \mid UB)_k$ then $\hat{\delta}_{F|UB} = (\hat{\tau}_{F|UB} - x_{F|UB})\hat{p}_{DSI} + x_{F|UB \cdot DSI}$., where $\hat{p}_{DSI}$ has the same value, 0.76 as used in McCracken (2010) for unidentified blackfish interactions. For the short-finned pilot whales, $\tau_{P|UB}$ and $\delta_{P|UB}$ are estimated in a similar manner but using $\hat{\Pr}(P \mid UB)_j$.

When $\hat{\Pr}(F \mid UB)$ and $\hat{\Pr}(P \mid UB)$ are constant, as in Method 1, the estimators described above for $\tau_{F|UB}$, $\tau_{P|UB}$, $\delta_{F|UB}$, $\delta_{P|UB}$ simplify to multiplying the estimated bycatch for unidentified blackfish, τ_{UB} and δ_{UB}, by the appropriate estimated conditional probability.

Table 2 gives the resulting estimates for those years when there were unidentified blackfish and Table 3 gives revised estimates of total false killer whale and short-finned pilot whale bycatch estimates for years 2005 through 2009 that incorporate the estimates in Table 2. As all unidentified blackfish were within the Hawaiian EEZ, the estimated total blackfish bycatch for Hawaiian Island EEZ is equivalent to the estimated total blackfish bycatch over all regions. There is very little difference in the estimates derived from Method 2 and Method 3.

The one observed unidentified blackfish interaction in the shallow-set fishery was in 2008 outside U.S. EEZ waters and was seriously injured. The estimated $\Pr(F \mid UB)$ s under Methods 1-3 are 0.77, 0.52, and 0.91 respectively. The adjusted bycatch estimates for false killer whale interactions in the shallow-set fishery is given Table 4.

The methodology and computer subroutines to estimate standard errors and confidence intervals for the estimates presented here are still under development.

Table 2. Interactions of false killer whales (F) and short-finned pilot whales (P) and associated DSI estimated from animals originally classified as unidentified blackfish. The methods of estimation are the three methods described in Section 3. The estimates are for the deep-set longline fishery.

		Methods of Estimation					
		Method 1		Method 2		Method 3	
Year	Estimated Total	F	P	F	P	F	P
2003	Takes	3.3	1.0	4.1	0.1	4.0	0.3
	DSI	2.7	0.8	3.4	0.1	3.3	0.2
2005	Takes	0.8	0.2	1.0	0.0	1.0	0.0
	DSI	0.6	0.2	0.7	0.0	0.7	0.0
2006	Takes	11.1	3.2	13.6	0.7	13.7	0.6
	DSI	8.8	2.6	10.8	0.6	10.9	0.5
2008	Takes	6.8	2.0	8.2	0.6	8.0	0.8
	DSI	5.7	1.7	6.9	0.5	6.8	0.7

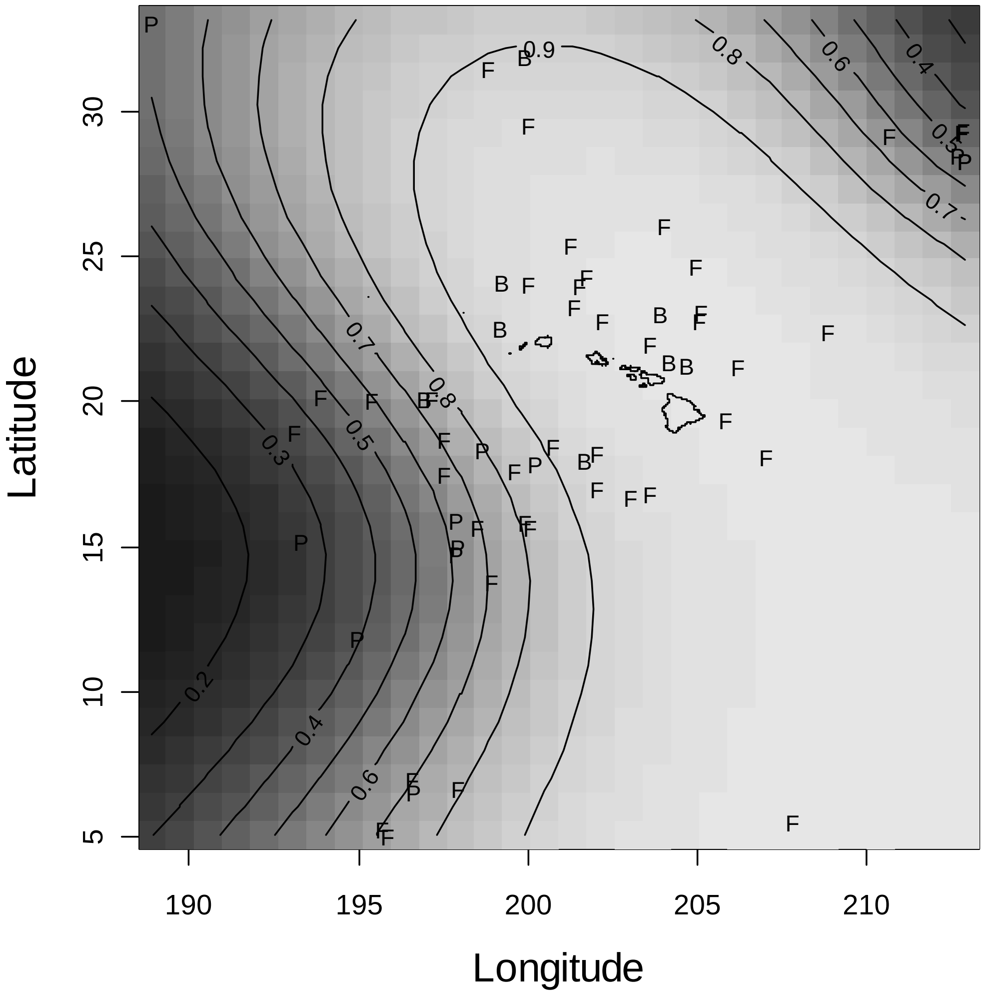

Figure 6. A perspective and contour plot for the fitted GAM in Method 3. The contours are the conditional probability that a blackfish interaction is a false killer whale. The color shade increases as this conditional probability decreases. The interaction locations of observed false killer whales (F), short-finned pilot whales (P), and blackfish (B) are indicated.

Table 3. Revised false killer whale (F) and short-finned pilot whale interactions and DSI over all regions and within the Hawaiian Islands EEZ. The methods of estimation are the five methods described in Section 2. The estimates are for the deep-set longline fishery. The last two rows give the revised average bycatch estimates and DSI from 2005 to 2009.

		All Regions						Hawaiian Islands EEZ					
		Method 1		Method 2		Method 3		Method 1		Method 2		Method 3	
Year	Estimated Total	F	P	F	P	F	P	F	P	F	P	F	P
2002	Takes	21.9	0.0	21.9	0.0	21.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	DSI	20.6	0.0	20.6	0.0	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	Takes	10.3	1.0	11.2	0.1	11.0	0.3	10.3	1.0	11.2	0.1	11.0	0.3
	DSI	9.3	0.8	10.0	0.1	9.9	0.2	9.3	0.8	10.0	0.1	9.9	0.2
2004	Takes	27.8	3.3	27.8	3.3	27.8	3.3	13.3	0.0	13.3	0.0	13.3	0.0
	DSI	26.1	2.7	26.1	2.7	26.1	2.7	12.4	0.0	12.4	0.0	12.4	0.0
2005	Takes	7.4	5.7	7.6	5.5	7.6	5.5	4.1	0.2	4.3	0.0	4.3	0.0
	DSI	6.8	4.4	7.0	4.3	7.0	4.3	3.7	0.2	3.9	0.0	3.9	0.0
2006	Takes	28.3	9.0	30.8	6.4	30.9	6.3	19.3	8.0	21.8	5.4	21.9	5.3
	DSI	24.0	7.3	26.0	5.3	26.1	5.2	15.6	6.3	17.6	4.3	17.7	4.2
2007	Takes	14.4	2.4	14.4	2.4	14.4	2.4	9.3	0.0	9.3	0.0	9.3	0.0
	DSI	11.5	2.0	11.5	2.0	11.5	2.0	7.7	0.0	7.7	0.0	7.7	0.0
2008	Takes	18.3	7.1	19.7	5.7	19.5	5.9	18.3	2.0	19.7	0.6	19.5	0.8
	DSI	16.5	4.2	17.7	3.0	17.5	3.2	16.5	1.7	17.7	0.5	17.5	0.7
2009	Takes	54.7	0.0	54.7	0.0	54.7	0.0	13.3	0.0	13.3	0.0	13.3	0.0
	DSI	51.0	0.0	51.0	0.0	51.0	0.0	12.4	0.0	12.4	0.0	12.4	0.0
ave(05-09)	Takes	24.6	4.8	25.4	4.0	25.4	4.0	12.8	2.0	13.7	1.2	13.7	1.2
	DSI	22.0	3.6	22.6	2.9	22.6	2.9	11.2	1.6	11.8	1.0	11.8	1.0

Table 4. Revised false killer whale (F) and short-finned pilot whale interactions and DSI over all regions and outside U.S. EEZ. The methods of estimation are the five methods described in Section 2. The estimates are for the shallow-set longline fishery. Only the year that was affected by revision is shown. The last two rows give the revised average bycatch estimates and DSI from 2005 to 2009.

		All Regions						Outside U.S. EEZ					
		Method 1		Method 2		Method 3		Method 1		Method 2		Method 3	
Year	Estimated Total	F	P	F	P	F	P	F	P	F	P	F	P
2008	Take	1.8	0.2	1.5	0.5	1.9	0.1	0.8	0.2	0.5	0.5	0.9	0.1
	DSI	0.8	0.2	0.5	0.5	0.9	0.1	0.8	0.2	0.5	0.5	0.9	0.1
ave(05-09)	Take	0.6	0.0	0.5	0.1	0.6	0.0	0.2	0.0	0.1	0.1	0.2	0.0
	DSI	0.4	0.0	0.3	0.1	0.4	0.0	0.2	0.0	0.1	0.1	0.2	0.0

Section 4: Revised Bycatch Estimates for the Insular and Pelagic False Killer Whale Stocks.

There were three observed interactions of unidentified blackfish in the overlap zone. All interactions were in the deep-set fishery, thus no further adjustment of the shallow-set bycatch estimates was required. The three deep-set interactions occurred in 2003, 2005, and 2006. Two of the interactions were classified as resulting in a serious injury and the other (in 2005) was classified as undetermined. The UB interactions in relation to the zones for the pelagic and insular stock defined in Section 2 are shown in Figure 7.

The bycatch estimates in this section assume the conditional probability $\Pr(F \mid UB)$ estimated in Section 3 is independent of the conditional probability $p_{1|+}$ estimated in Section 2. Under this assumption, the probability that an unidentified blackfish in the overlap zone is a false killer whale from the insular stock is the product of the two conditional probabilities, $\Pr(F \mid UB)$ and $p_{1|+}$. For the pelagic stock, $\Pr(F \mid UB)$ is multiplied by $p_{2|+}$.

Let $\tau_{1|UB}$ and $\tau_{2|UB}$ be the number of UB interactions in the overlap zone that are insular false killer whale interactions and pelagic false killer whale interactions, respectively, and let $\delta_{1|UB}$ and $\delta_{2|UB}$ be the number of $\tau_{1|UB}$ and $\tau_{2|UB}$ resulting in a DSI classification, respectively. Let nub_i be the number of UB interactions in the overlap zone by trip i, x the number of UB interactions with known injury classification in the overlap zone, x_{DSI} the number of UB interactions with known DSI classification in the overlap zone, and $\hat{\Pr}(F \mid UB)_j$ and $p_{1|+(j)}$ the estimated conditional probabilities for interaction j during trip i. To estimate $\tau_{1|UB}$ the value of y_i inputted in the Horvitz-Thompson estimator is

$$y_i = \sum_{j=1}^{nub_i} \hat{\Pr}(F \mid IB)_j \, p_{1|+(j)}.$$

To estimate $\delta_{F|UB}$ let $x_{F|UB} = \sum_{k=1}^{x} \hat{\Pr}(F \mid IB)_k \, p_{1|+(k)}$ and $x_{F|UB \cdot DSI} = \sum_{k=1}^{x_{DSI}} \hat{\Pr}(F \mid IB)_k \, p_{1|+(k)}$ then $\hat{\delta}_{1|UB} = (\hat{\tau}_{1|UB} - x_{1|UB})\hat{p}_{DSI} + x_{1|UB \cdot DSI}$., where $\hat{p}_{DSI}$ has the same value, 0.76 as used in McCracken (2010) for UB interactions. For the pelagic false killer whale stock, $\tau_{2|UB}$ and $\delta_{2|UB}$ are estimated in a similar manner but using $p_{2|+}$.

The estimates of false killer whale insular bycatch in the overlap and nearshore zones that were UB were added to derive the estimate of insular bycatch that were UB within the EEZ of Hawaii. This sum was then added to the insular stock estimates derived using identified false killer whales to produce a revise estimate of insular false killer whale interactions and DSI. The estimates of false killer whale pelagic bycatch in the overlap and outer zones that were UB were added to derive the estimate of pelagic bycatch that were UB within the EEZ of Hawaii. This sum was then added to the pelagic stock estimates derived using identified false killer whales to produce a revise estimate of pelagic false killer whale interactions and DSI. Tables 5 to7 give the estimates for the overlap Models 3-5 (Section 2) and blackfish Methods 1-3 (Section 3), respectively.

The methodology and computer subroutines to estimate standard errors and confidence intervals for the estimates presented here are still under development.

Section 5. Summary

This report presents different methodologies for (1) estimating the bycatch for the Hawaii insular and pelagic stock of false killer whales in the overlap zone and (2) revising the false killer whale and short-finned pilot whale bycatch estimates incorporating unidentified blackfish estimates. The results from the different methodologies provide a range of bycatch estimates that are derived under different sets of assumptions. Comparison of these bycatch estimates with allowable levels of bycatch should consider the validity of the underlying assumptions and also take into account the uncertainty associated with the estimates.

Table 5. Total interactions and DSI estimates for the Insular and Pelagic Stock of False Killer Whales. The estimates were derived using Method 3 from Section 2 and Methods 1-3 from Section 3 (BF method). The five year averages from 2005 through 2009 (ave(05-09)) were also computed.

		Insular Stock		Pelagic Stock	
Year	BF method	Take	DSI	Take	DSI
2002	1	0.0	0.0	0.0	0.0
2003	1	6.6	6.0	3.0	2.7
2004	1	0.0	0.0	13.3	12.4
2005	1	0.4	0.3	3.5	3.3
2006	1	5.4	4.3	13.4	10.9
2007	1	0.0	0.0	9.3	7.7
2008	1	0.0	0.0	18.3	16.5
2009	1	0.0	0.0	13.3	12.4
ave(05-09)	**1**	**1.2**	**0.9**	**11.5**	**10.1**
2002	2	0.0	0.0	0.0	0.0
2003	2	7.0	6.4	3.2	2.9
2004	2	0.0	0.0	13.3	12.4
2005	2	0.5	0.4	3.5	3.3
2006	2	5.8	4.6	13.5	11.0
2007	2	0.0	0.0	9.3	7.7
2008	2	0.0	0.0	18.3	16.5
2009	2	0.0	0.0	13.3	12.4
ave(05-09)	**2**	**1.3**	**1.0**	**11.6**	**10.2**
2002	3	0.0	0.0	0.0	0.0
2003	3	7.0	6.3	3.1	2.8
2004	3	0.0	0.0	13.3	12.4
2005	3	0.5	0.4	3.5	3.3
2006	3	5.8	4.6	13.5	11.0
2007	3	0.0	0.0	9.3	7.7
2008	3	0.0	0.0	18.3	16.5
2009	3	0.0	0.0	13.3	12.4
ave(05-09)	**3**	**1.3**	**1.0**	**11.6**	**10.2**

Table 6. Total interactions and DSI estimates for the Insular and Pelagic Stock of False Killer Whales. The estimates were derived using Method 4 from Section 2 and Methods 1-3 from Section 3 (BF method). The five year averages from 2005 through 2009 (ave(05-09)) were also computed.

		Insular Stock		Pelagic Stock	
Year	BF method	Take	DSI	Take	DSI
2002	1	0.0	0.0	0.0	0.0
2003	1	7.4	6.8	2.1	1.9
2004	1	0.0	0.0	13.3	12.4
2005	1	0.5	0.4	3.4	3.2
2006	1	6.2	4.8	12.6	10.3
2007	1	0.0	0.0	9.3	7.7
2008	1	0.0	0.0	18.3	16.5
2009	1	0.0	0.0	13.3	12.4
ave(05-09)	**1**	**1.3**	**1.0**	**11.4**	**10.0**
2002	2	0.0	0.0	0.0	0.0
2003	2	8.0	7.2	2.2	2.0
2004	2	0.0	0.0	13.3	12.4
2005	2	0.6	0.4	3.5	3.2
2006	2	6.5	5.1	12.7	10.4
2007	2	0.0	0.0	9.3	7.7
2008	2	0.0	0.0	18.3	16.5
2009	2	0.0	0.0	13.3	12.4
ave(05-09)	2	**1.4**	**1.1**	**11.4**	**10.0**
2002	3	0.0	0.0	0.0	0.0
2003	3	7.9	7.1	2.2	2.0
2004	3	0.0	0.0	13.3	12.4
2005	3	0.6	0.5	3.5	3.2
2006	3	6.5	5.2	12.7	10.4
2007	3	0.0	0.0	9.3	7.7
2008	3	0.0	0.0	18.3	16.5
2009	3	0.0	0.0	13.3	12.4
ave(05-09)	**3**	**1.4**	**1.1**	**11.4**	**10.0**

Table 7. Total interactions and DSI estimates for the Insular and Pelagic Stock of False Killer Whales. The estimates were derived using Method 5 from Section 2 and Methods 1-3 from Section 3 (BF method). The five year averages from 2005 through 2009 (ave(05-09)) were also computed.

		Insular Stock		Pelagic Stock	
Year	BF method	Take	DSI	Take	DSI
2002	1	0.0	0.0	0.0	0.0
2003	1	7.3	6.6	2.3	2.1
2004	1	0.0	0.0	13.3	12.4
2005	1	0.6	0.4	3.3	3.1
2006	1	2.4	1.9	16.4	13.2
2007	1	0.0	0.0	9.3	7.7
2008	1	0.0	0.0	18.3	16.5
2009	1	0.0	0.0	13.3	12.4
ave(05-09)	**1**	**0.6**	**0.5**	**12.1**	**10.6**
2002	2	0.0	0.0	0.0	0.0
2003	2	7.7	7.0	2.5	2.2
2004	2	0.0	0.0	13.3	12.4
2005	2	0.7	0.5	3.3	3.1
2006	2	2.7	2.2	16.5	13.3
2007	2	0.0	0.0	9.3	7.7
2008	2	0.0	0.0	18.3	16.5
2009	2	0.0	0.0	13.3	12.4
ave(05-09)	**3**	**0.7**	**0.6**	**12.1**	**10.6**
2002	3	0.0	0.0	0.0	0.0
2003	3	7.7	6.9	2.4	2.2
2004	3	0.0	0.0	13.3	12.4
2005	3	0.7	0.5	3.3	3.2
2006	3	2.7	2.2	16.5	13.3
2007	3	0.0	0.0	9.3	7.7
2008	3	0.0	0.0	18.3	16.5
2009	3	0.0	0.0	13.3	12.4
ave(05-09)	**3**	**0.7**	**0.6**	**12.1**	**10.6**

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