A review of false killer whales in Hawaiian waters: biology, status, and risk factors

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Report prepared for the U.S. Marine Mammal Commission
under Order No. E40475499
December 23, 2009

1. Executive Summary

Recent management and conservation issues have arisen concerning false killer whales in Hawaiian waters. Two demographically isolated populations have been identified, a small (estimated 123 individuals) island-associated population around the main Hawaiian Islands (hereafter Hawai'i insular stock) and a larger (estimated 484 individuals) offshore population (hereafter Hawai'i pelagic stock). Individuals within the Hawai'i insular stock regularly move among islands and have been documented at distances of 110 km offshore. Less is known of movements/range of individuals from the Hawai'i pelagic stock; one group has been documented 42 km offshore and individuals likely move beyond the Hawaiian Exclusive Economic Zone. No information is available to assess trends in the Hawai'i pelagic stock. For the Hawai'i insular stock, a significant decline in sighting rates from aerial surveys conducted between 1993 and 2003 suggests a large decline in population size. Other available evidence also supports a decline in population size for the insular stock: a reduction in sighting rates from boat-based surveys since the mid-1980s, lower than expected survival based on photo-identification data, and much higher sighting rates and larger group sizes in a 1989 aerial survey compared to boat-based surveys since 2000. False killer whales in Hawai'i feed primarily on large game fish that are also the target of commercial and recreational fisheries. A number of potential conservation threats have been identified. Individuals from the Hawai'i insular stock have elevated levels of persistent organic pollutants. Three of nine individuals sampled had levels high enough to potentially influence health. Because of the overlap between false killer whale diet and commercially harvested fish, reduced prey size or abundance could influence false killer whale foraging success or nutritional levels. Significant declines in body size and/or catch per unit effort have been documented for several false killer whale prey species in Hawaiian waters. False killer whales have been documented taking fish off lines in both nearshore and offshore fisheries. Depredation of caught fish may lead to retaliatory shooting by fishermen although, given potential fines and penalties, such shooting is not likely to occur where it may be witnessed; thus there is no information available to assess the potential for this to influence population dynamics. With the overlap in diet with commercially and recreationally harvested fish, the potential for hook ingestion, either from depredation or from free-swimming hooked fish, is relatively high. Based on studies elsewhere, hook ingestion would have a high likelihood of leading to mortality. Bycatch may occur in nearshore kaka line or shortline fisheries that use similar, but shorter gear to offshore longline fisheries, but there is no observer coverage of nearshore fisheries. False killer whales are the most frequently recorded bycaught cetacean in the Hawai'i-based offshore longline fishery. Rates of serious injury and mortality have exceeded the potential biological removal (PBR) levels since bycatch rates and population levels were first available in 2000. Bycatch rates are underestimated as they do not take into account individuals that are not positively classified as to species or individuals that may break free with gear attached before being documented by observers. A number of research recommendations are presented to help reduce uncertainty and to clarify factors that may be influencing the population trajectories of both the Hawai'i insular and Hawai'i pelagic stocks, as well as to provide information that could be used to reduce bycatch rates or otherwise mitigate anthropogenic impacts on these populations.

2. Introduction

Both residents and visitors to Hawai'i have long been familiar with false killer whales (*Pseudorca crassidens)*. The species was kept in captivity from the mid-1960s through the 1990s at Sea Life Park, one of Hawai'i's best known marine attractions, and a hybrid cross between a false killer whale and a common bottlenose dolphin (*Tursiops truncatus*) is still kept there today. In addition, because false killer whales are found near shore, often ride the bow of transiting vessels, and can be quite acrobatic (Figure 1), many frequent ocean users in Hawai'i have had opportunities to see or interact with false killer whales. Despite such opportunities, false killer whales are far less common in Hawai'i than humpback whales (*Megaptera novaeangliae*) and spinner dolphins (*Stenella longirostris*), which attract most of the attention of whale researchers and members of the marine mammal watching public.

In recent years, however, a number of important management and conservation issues have arisen concerning false killer whales in Hawaiian waters. Bycatch in U.S. longline fisheries has exceeded the potential biological removal (PBR) level since population and bycatch estimates first became available in 2000 (Forney et al. 2000). Environmental organizations have filed lawsuits against the National Marine Fisheries Service (NMFS) over this issue, including a recent suit (*Hui Mālama i Kohalā* et al. v. *National Marine Fisheries Service* et al.[1]) seeking the formation of a take reduction team (TRT) to reduce false killer whale bycatch. In addition, a petition was recently submitted to the NMFS seeking action to list the insular population of false killer whales as endangered under the Endangered Species Act (NRDC 2009). Response to these actions will require consideration of the best available information on the species' population ecology in Hawai'i and factors influencing the populations. To help meet this need, this document reviews available published and unpublished information on the status of false killer whales in Hawaiian waters and threats to their conservation, including fishery interactions, potential prey limitations, and persistent organic pollutants, among others. This report is not a comprehensive review of false killer whales worldwide. For general reviews of the biology of false killer whales, see Odell and McClune (1999), Stacey et al. (1994), and Stacey and Baird (1991).

3. Biology of false killer whales

The false killer whale is the fourth-largest member of the family Delphinidae. The maximum recorded length is 5.06 m for females and 5.96 m for males. Individuals stop growing between 25 and 30 years of age, at which point the average body length (i.e., asymptotic length) of adult males is about 75–85 cm larger than adult females (Ferreira 2008). Despite sexual differences in length, distinguishing adult females from adult males is difficult in the field. The only other sexually dimorphic feature that has been described is the projection of the melon over the lower jaw, although this feature is not particularly useful in the field to distinguish sex. In adult males, the melon extends farther forward than in adult females. Males may have accessory mammary grooves, making it difficult to confirm sex of individuals by external appearance alone. Average body length varies among populations: the average asymptotic length of females

[1] Civ. No. 09-00113 DAE BMK (D. Haw filed Mar. 17, 2009)

off Japan is 46 cm longer than those off South Africa; for males off Japan, the average asymptotic length is 58 cm longer than for males off South Africa (Ferreira 2008).

Figure 1. A false killer whale leaping while chasing prey. Photo by R.W. Baird.

Although the false killer whale is generally characterized as a tropical and sub-tropical species, it is found primarily in the tropics; densities in sub-tropical waters are much lower. In the eastern North Pacific, density is high between the equator and approximately 15°N, and drops precipitously to the north of 15°N (Ferguson and Barlow 2003). Extralimital records of individuals have been reported from as far north as Alaska (Leatherwood et al. 1982) and British Columbia (Baird et al. 1989; Stacey and Baird 1991). In the 1950s and 1960s large groups were seen in southern California (Brown et al. 1966), but there currently are no recognized populations of this species north of Mexico. False killer whales are typically oceanic, coming closest to shore around oceanic islands.

False killer whales are relatively uncommon throughout their range. In surveys of cetaceans in the eastern tropical Pacific, they were the 11th most abundant delphinid of the 13 species documented (Wade and Gerrodette 1993). Wade and Gerrodette (1993) estimated a mean group size of 11.4 whales (CV = 0.12) documented in ship-based surveys between 1986 and 1990 in the eastern tropical Pacific. Leatherwood et al. (1982) note that they are highly social and sometimes occur in schools of more than 500 individuals. Reeves et al. (2002) note that they are typically observed in groups of 10 to 20 but that these groups "belong to larger schools consisting of hundreds of individuals." Two schools estimated to number 300 individuals were documented in two different years off southern California (Brown et al. 1966). Six schools observed from research cruises off Japan ranged in size from 2 to 200 individuals, with a mean size of 55 individuals (Kasuya 1971). Comparisons of group sizes among areas and using different survey techniques, however, are problematic for several reasons. A study comparing odontocete group size estimates by experienced observers to counts of the same groups using photographs obtained from a helicopter revealed that group size estimates are typically negatively biased by about 26 percent (Gerrodette et al. 2002). In the case of false killer whales, groups are often spread over very wide areas, which also negatively biases estimates of overall group size (Baird et al. 2008a, in press). In drive fisheries off Japan, groups ranged from 10 to 201 individuals with a mean size of 99 individuals (Kasuya 1986). Ross (1984) reviewed group sizes from 14 mass strandings worldwide, which ranged from 50 to 835 animals (mean = 180 individuals). The largest known mass stranding of the species was on 10 October 1946 when an estimated 835 false killer whales stranded near Mar del Plata, Argentina (Marelli 1953). An analysis comparing group sizes of stranded false killer whales with sightings data found that group sizes from strandings were significantly larger (Ferreira 2008).

Most of what is known about the life history of false killer whales comes from animals killed in a drive fishery in Japan (Kasuya 1986) and from stranded animals (e.g., Ferreira 2008). Although sample sizes are small, and life history traits vary among populations (Ferreira 2008), generally their life history is similar to that of killer whales (*Orcinus orca*); individuals mature slowly, reproduce infrequently, and are long-lived. Onset of sexual maturity for false killer whales (i.e., age of first ovulation) occurs between 8.25 and 10.5 years of age, and gestation is estimated to last between 15.1 and 15.7 months. Thus, age at first reproduction would range from 9.5 to 11.75 years (Kasuya 1986, Ferreira 2008). The only reported birth interval, 6.9 years between calves, is from Japan (Kasuya 1986). Ovulation rates decrease with age, and females older than 44 years are thought to be post-reproductive (Kasuya 1986, Ferreira 2008). Maximum longevity is at least 57.5 years for males and 62.5 years for females (Kasuya 1986).

In captivity, false killer whales adapt more quickly to new circumstances and objects in their tanks than do most other species of delphinids, and they rapidly learn through observation (Brown et al. 1966). Prey-sharing in the wild has been observed frequently (Connor and Norris 1982, Baird et al. 2008a) and false killer whales have even been observed passing caught fish to humans in boats or in the water.

4. False killer whales in Hawaiian waters

Information on false killer whales in Hawai'i comes from a variety of sources, including (1) large-vessel surveys by NMFS (HICEAS, PICEAS, MHICS), (2) small-vessel surveys, (3) aerial surveys,(4) the longline fishery observer program, (5) anecdotal reports and observations, (6) genetic analyses using remote biopsy samples, (7) photo-identification, (8) tagging studies using both satellite-linked and archival depth-of-dive tags, and (9) studies of persistent organic pollutants using biopsy samples. Although a number of recent publications and reports on false killer whales are available (e.g., Barlow and Rankin 2007, Chivers et al. 2007, Baird et al. 2008a, 2008b), much information remains unpublished. For example, photo-identification data have increased substantially in the last two years but have not yet been fully analyzed (Figure 2). There is limited information available from stranded false killer whales in Hawai'i as strandings are infrequent: Maldini et al. (2005) note only five single strandings in the period from 1937 to 2002 (in 1974, 1980, 1986, 1990, and 1997), and no false killer whale strandings have been recorded since (K. West, pers. comm.). Although much has been learned about population structure, movements, habitat use, social organization, and foraging behavior, significant gaps in knowledge on Hawaiian populations remain (e.g., life history parameters (e.g., age at first birth, calving intervals). Recommendations for research to address data gaps follow the review of biology and risk factors.

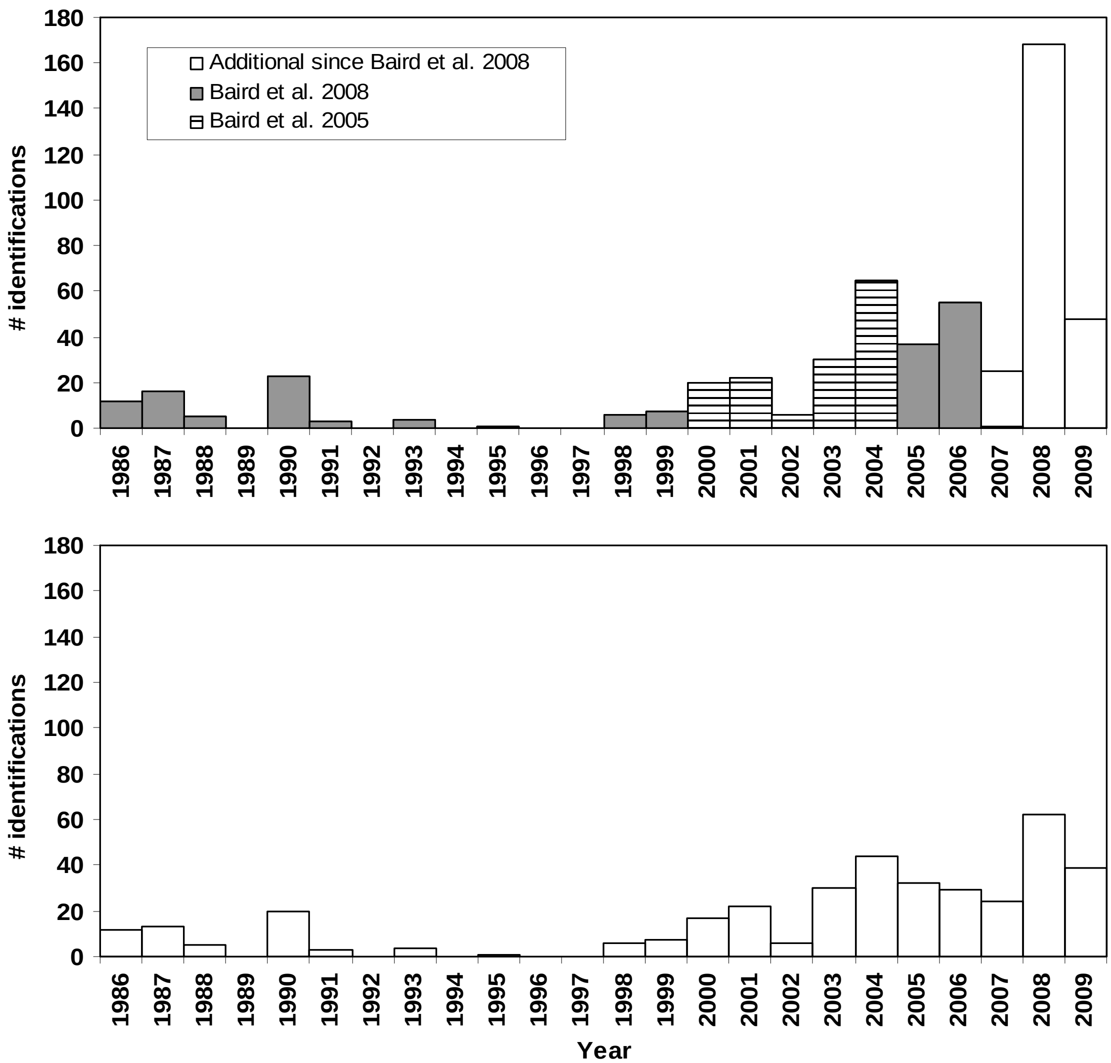

Figure 2. Top. Number of identifications of distinctive and very distinctive false killer whales with good or excellent photo qualities (see Baird et al. 2008a) from Hawaiian waters by year, not including within-year re-sightings, but including photos from both insular and pelagic stocks. Identifications used in mark-recapture analyses for insular stock (Baird et al. 2005) identified with horizontal lines, identifications used in Baird et al. (2008a) analyses include those shown in solid gray and horizontal lines. Additional identifications available since Baird et al. (2008a) analyses shown in open box (through May 2009, not including photos obtained in October or December 2009). Bottom. Number of individuals from the insular stock identified by year, including only distinctive and very distinctive individuals with good or excellent quality photos.

4.A. Population structure

Prior to 2008, NMFS recognized a single Hawaiian stock of false killer whales for the purposes of estimating bycatch rates and PBR levels. In 2008, for the first time the NMFS stock assessment reports recognized two false killer whale stocks in Hawai'i: an insular stock and a pelagic stock. A separate Palmyra Atoll stock was also recognized for the first time in 2008 (Carretta et al. 2009a).

Two lines of evidence indicate that there are at least two stocks of false killer whales in the Hawaiian Exclusive Economic Zone (EEZ): genetic data and association data among individual whales. Chivers et al. (2007) analyze genetic samples available through 2006 by comparing mitochondrial haplotypes of false killer whales sampled nearshore (<30 km) around the islands of O'ahu, Maui and Hawai'i (n=62) with samples from Mexico (n=6), Panama (n=16), Palmyra Atoll (n=6), and from offshore waters around Hawai'i (>139 km from shore, n=6), as well as areas farther away (North Atlantic, Indian Ocean, Western Pacific). No samples were available at intermediate distances from the islands. They concluded that whales sampled near the main Hawaiian Islands are demographically isolated from those in offshore waters of the EEZ and elsewhere in the tropical Pacific. Fifteen mitochondrial haplotypes were documented from the central and eastern Pacific, six of which were found in animals around the main Hawaiian Islands (Table 1). Four of the six haplotypes (representing 60 of the 62 samples) were closely related, differing by only one or two base pairs. Three of the four haplotypes were documented only in animals around the main Hawaiian Islands. The dominant haplotype from around the main Hawaiian Islands (haplotype 1) occurred in 49 of the 62 samples and was not shared with other areas. One other closely related haplotype (haplotype 2, two base-pair differences from haplotype 1) found in 9 of the 62 samples from the main Hawaiian Islands was shared with 1 of 6 Palmyra samples. The remaining haplotypes were recorded only in single individuals from around the main Hawaiian Islands. One of these (haplotype 9, which differed by four base pairs) was the most common haplotype in false killer whales off Mexico and Palmyra (Chivers et al. 2007). Chivers et al. (2007) noted that samples collected more than 139 km from the main Hawaiian Islands were either unique haplotypes (haplotype 6, n =1) or the most common haplotype recorded off Mexico and Palmyra (haplotype 9, n = 4). Since this study was published, additional biopsy samples have been collected (Table 1) that support the conclusions of Chivers et al. (2007). All additional samples collected within 30 km of the main Hawaiian Islands (n=14 samples from four groups) and analyzed were either haplotypes 1 or 2. Three samples collected about 110 km offshore were either haplotype 9 (n=1) or a previously undocumented haplotype (haplotype 25, n =2), similar to a haplotype identified from the Indian Ocean (Baird et al. 2008b). The larger sample now includes 74 samples from within 30 km of the main Hawaiian Islands, of which 58 represent haplotypes not recorded elsewhere (haplotypes 1, 3, 4, 5). Of the two shared haplotypes, 15 are haplotype 2 (which has only been recorded from one sample elsewhere), and one is haplotype 9 (which is the most common haplotype elsewhere in the central and eastern Pacific) (Table 1).

Table 1. Haplotype frequencies of false killer whale samples from the main Hawaiian Islands, surrounding areas in the central Pacific, and eastern Pacific. Updated from Chivers et al. (2007). Data from S. Chivers, Southwest Fisheries Science Center. Individuals from groups that were sampled around the main Hawaiian Islands all link by association in a single social network (see Figure 3).

Haplotype ID number	Sample Collection Region								Total
	Main Hawaiian Islands			Central Pacific (other)			Eastern Pacific		
	O'ahu	Maui	Hawai'i	>50 km offshore Hawai'i	pelagic outside Hawaiian EEZ	Palmyra	Mexico	Panama	
1	27	9	19						55
2		4	11			1			16
3		1							1
4			1						1
5			1						1
6				1[A]					1
7						1			1
8						1			1
9			1	2[A]	3[B]	3	16		25
10							3	12	15
11							5		5
12								3	3
13								1	1
14							1		1
15							1		1
16					1				1
25				2					2
Total	27	14	33	5	4	6	26	16	131

Notes to Table 1. [A]One sample collected by NMFS observer on longline vessel. [B]All three samples collected by NMFS observers on longline vessels.

Matches from photo-identification data also suggest the existence of two isolated populations in the Hawaiian EEZ (Baird et al. 2008a). An analysis of photos available through January 2007, including 313 identifications of distinctive and very distinctive individuals (including re-sightings), reveals that, with the exception of one group with 19 identified individuals between 42 to 70 km offshore, the largest group not linked to a large single social network was only two individuals (Baird et al. 2008a). All groups sampled by Chivers et al. (2007) around the main Hawaiian Islands link by association into this single large social network. No genetic samples were collected from the group of 19 individuals, but this group was suspected to be part of the offshore population based on its distance from shore and a lack of resightings. Since the analysis of Baird et al. (2008a), the sample size of identifications of distinctive and very distinctive individuals (with good or excellent quality photographs) has increased by 76 percent, with 553 identifications available as of July 2009[2] (Figure 2). While the majority of the new identifications are from the island of Hawai'i (n=136), there were substantial increases in the number of identified individuals available from Kaua'i (an increase from 1 to 9), offshore areas (an increase from 16 to 29), and O'ahu (an increase from 23 to 79). These additional identifications support the hypothesis of two populations that do not associate, an island-associated (or insular) population and an offshore (i.e., pelagic) population (Figure 3). None of the nine individuals documented off Kaua'i has been linked to either offshore groups or to individuals around the rest of the main Hawaiian Islands (Figure 2), and no genetic samples are available from those animals. Satellite-tagged individuals from the insular stock have utilized waters around Kaua'i (see below), but further research is needed to determine if the individuals that have been photo-identified off Kaua'i that do not link by association to either stock are part of a third population or are members of one of the two known populations.

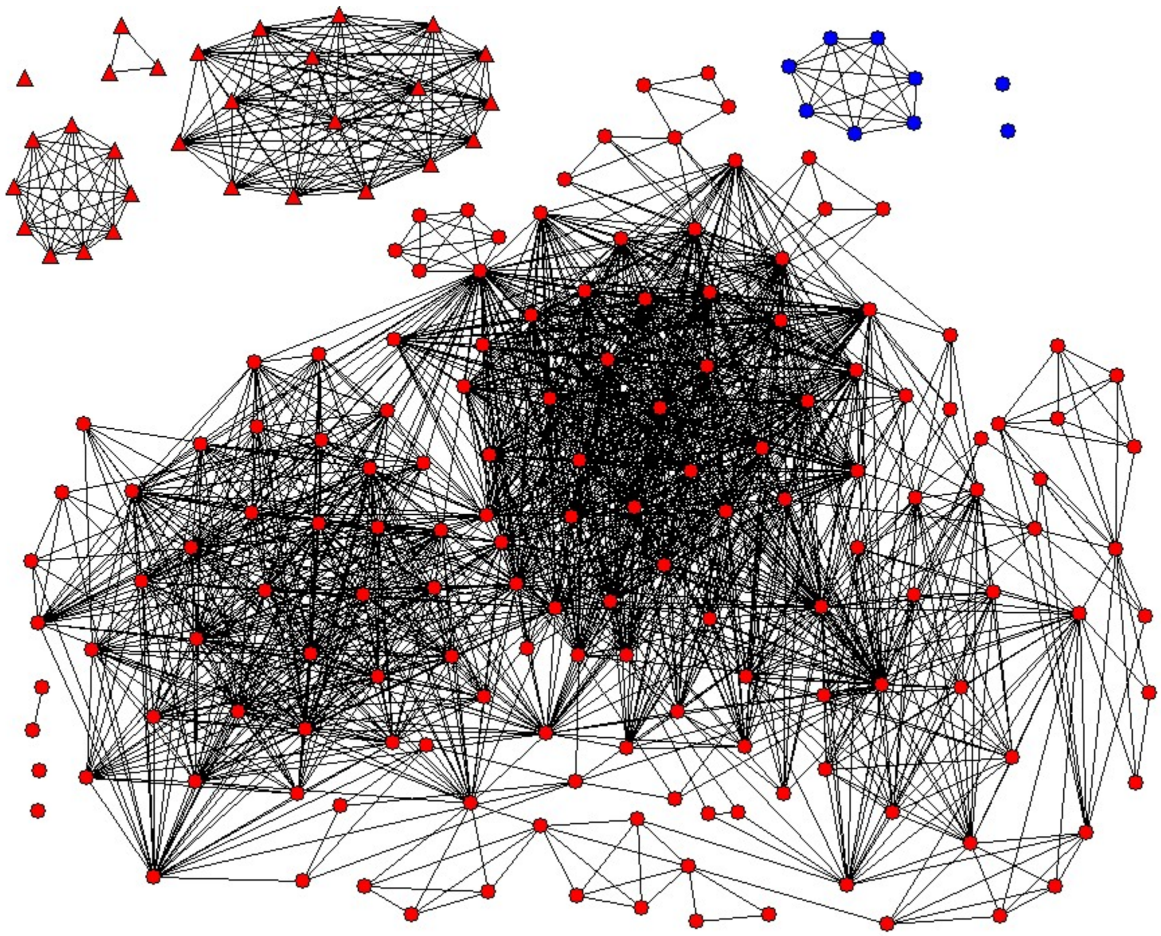

Figure 3. Social network diagram of false killer whales photo-identified around the main Hawaiian Islands and offshore (40-130 km) from 1986 through May 2009. Updated from Baird et al. (2008a). Only distinctive and very distinctive individuals with good or excellent quality photographs are shown. Individuals encountered close to shore around O'ahu, Maui, Lana'i and Hawai'i are shown in red circles. All except four individuals photo-identified close to shore around these islands are linked in a single social network. Individuals encountered close to shore

[2] Encounters off O'ahu in October 2009 and Hawai'i in December 2009 with groups from the insular stock by the Pacific Islands Fisheries Science Center and Cascadia Research Collective have not yet been fully analyzed.

around Kaua'i are shown in blue circles. Individuals encountered >40 km offshore are shown in red triangles. Note given the long time span many individuals in the network are likely to have died and others became distinctive during the time frame.

4.B. Population ranges, individual movements, and potential boundaries/overlap

There are several sources of available information for assessing the range of each population and proposed boundaries between them. These include sightings from ship-based and aerial surveys, data from satellite tags, and observations by observers on fishing vessels. Ship-based sightings and observer data are sometimes accompanied by genetic samples or photographs that can be used to assess population identity. In terms of broad-scale distribution, sightings by observers on fishing vessels indicate that false killer whales are distributed throughout the central and eastern half of the Hawaiian EEZ as well as in international waters between Hawai'i and Palmyra, within the Palmyra EEZ, and in international waters north of the Hawaiian EEZ (Chivers et al. 2007).

Sightings of photo-identified individuals from the insular population show that a large proportion of individuals documented off O'ahu were also seen off the island of Hawai'i, indicating that movements between those islands occur regularly (Baird et al. 2008a). Satellite data from three groups of insular individuals reveal that movements may occur rapidly, on the order of days (Baird et al. in press). Aerial survey data from around the main Hawaiian Islands show false killer whales occur on both the windward and leeward sides of the main Hawaiian Islands (Mobley et al. 2000; Figure 4). Individuals that were satellite-tagged on the leeward sides of Hawai'i and O'ahu used both leeward and windward sides of the islands, often moving from windward to leeward sides and back within a day (Baird et al. in press, Baird et al. unpublished; Figure 5). This suggests that it is unlikely there is a separate windward population of the species. Some of the false killer whales satellite-tagged off the island of Hawai'i remained around the island for extended periods, but all three groups ranged widely among the main Hawaiian Islands, with one individual moving to the east coast of the island of Kaua'i. On average, individuals used similar water depths and moved to similar distances offshore on the windward and leeward sides. The farthest movements offshore and into the deepest waters were documented off the leeward sides of the islands (Baird et al. in press). Individuals from all three groups satellite-tagged off Hawai'i moved into waters greater than 80 km offshore (83, 87, and 96 km). False killer whales from three groups satellite-tagged off O'ahu in October 2009 moved to the west side of Kaua'i and Ni'ihau as well as ranging east among the main Hawaiian Islands, moving as far as 110 km from shore[3].

Although the location/movement data set from satellite-tagged individuals represents the largest and least biased data set for range of the insular population (more than 3,000 locations prior to tag deployments in October and December 2009), a number of considerations need to be borne in mind when making inferences (Baird et al. in press). Prior to the October 2009 taggings, movement/location data from satellite-tagged individuals were only available for five months of the year, individuals from only three groups were tagged, and there was considerable variation among individuals within groups as well as among groups (Baird et al. in press). Also, all individuals prior to October 2009 were tagged off the island of Hawai'i, and individuals varied in

[3] Data from these tags are still being obtained and have not yet been analyzed.

habitat use when around the island of Hawai'i versus off other islands. In general, the tagged individuals spent more time off the island of Hawai'i than off other islands, yet encounter rates for groups from the Hawai'i insular stock from sighting surveys are approximately twice as high off the islands of O'ahu and Maui than off the island of Hawai'i (Baird et al. unpublished), emphasizing that movement patterns for some period after individuals are tagged are biased towards the area/island where they were tagged. Thus it may be premature to use the data set to estimate the proportion of time individuals spend off different islands or at different distances offshore. The movement data from tagged animals was obtained over an 18-month time span, and it is likely that movement patterns vary over time depending on short- and long-term changes in density and movement patterns of their prey species. In addition, if individuals learn that fishing gear provides a reliable source of food, changes in movement patterns or habitat use could occur (e.g., Chilvers and Corkeron 2001). There may be variation in movement patterns within a population depending on whether particular individuals or groups depredate fish from fishing gear (see Powell 2009). Some individuals within the insular population show clear signs of fishery interactions (Baird and Gorgone 2005), and tagging those individuals, or others closely associated with them, may be necessary to assess such variation.

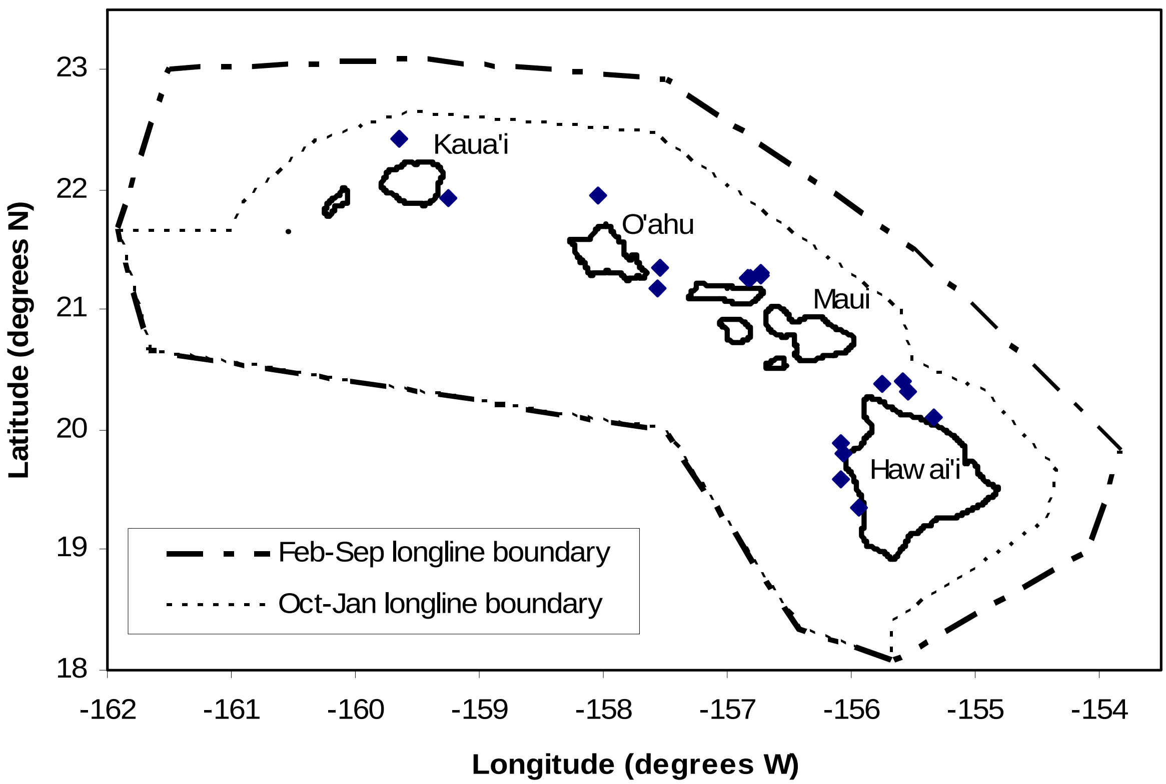

Figure 4. Sightings of false killer whales in aerial surveys from 1993, 1995, and 1998 (from Mobley et al. 2000). The seasonal longline exclusion boundaries are shown. The February through September longline boundary is currently considered by NMFS to be the boundary between the Hawai'i insular and Hawai'i pelagic stocks (Carretta et al. 2009a).

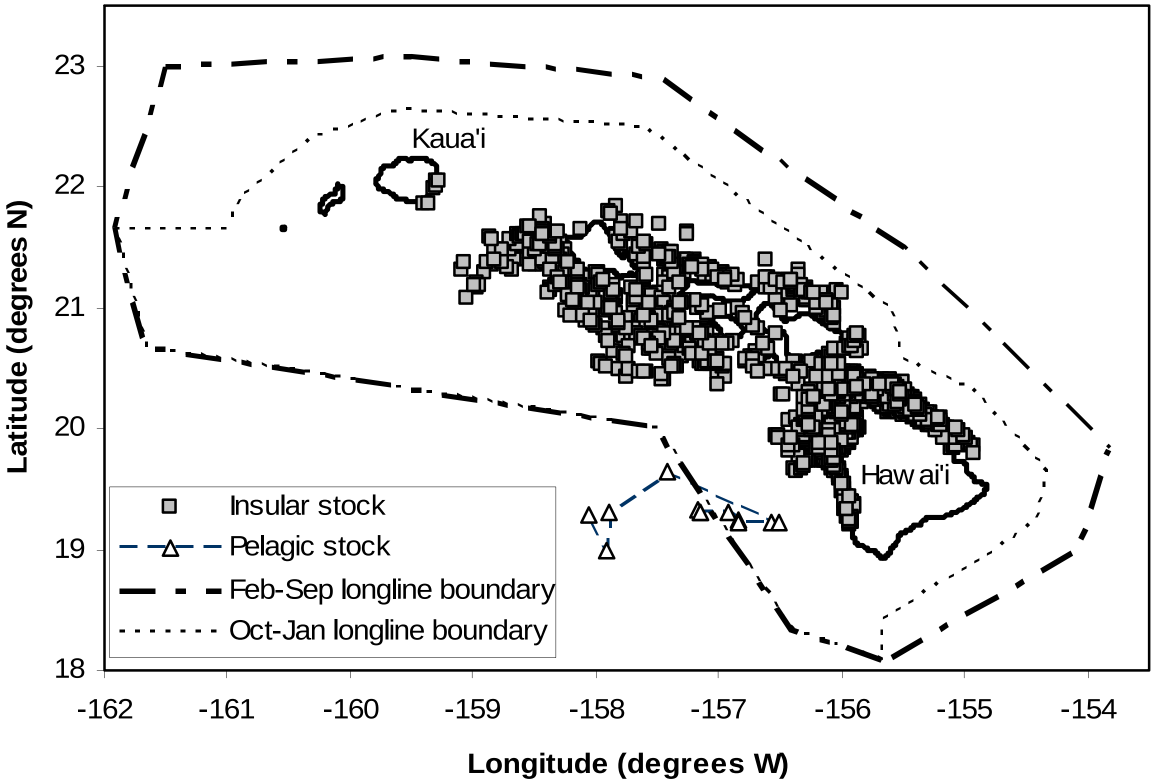

Figure 5. Locations of satellite-tagged false killer whales (from Baird et al. in press).

Little is known about the movements and range of individuals from the Hawai'i pelagic stock. Based on a continuous distribution of sightings from longline observers across the EEZ boundary, it is likely that the animals found in international waters are part of the same population as the Hawai'i pelagic stock. One individual from the pelagic stock that was satellite-tagged approximately 124 km offshore of the island of Hawai'i moved to within 62 km of shore and as far as 210 km from shore over a period of 15 days (Baird et al. in press). Individuals likely to be from the pelagic stock have been documented as near as 42 km to shore (Baird et al. 2008a; Figure 5).

In the 2008 and draft 2009 NMFS stock assessment reports, the boundary between the pelagic and insular stocks was provisionally set at the outer boundary of the longline exclusion zone around the main Hawaiian Islands (Figure 4; Carretta et al. 2009a, 2009b), but it was noted that the boundary may be revised as additional information becomes available.

4.C. Estimates of abundance/population size

Abundance of false killer whales in Hawaiian waters has been estimated using line-transect methods from both aerial and shipboard surveys, and population size has also been estimated using mark-recapture methods from photo-identification data. Such estimates were produced prior to the split of false killer whales into insular and pelagic stocks, but recent re-assessment allows for these estimates to be attributed to one or the other stocks. A summary of population estimates available by year and by stock is presented in Table 2.

Table 2. NMFS Hawai'i false killer whale population and status of stock designations and best population estimates. The first stock assessment was undertaken in 1995. The 2009 assessments are draft assessments.

Year	NMFS stock designation	NMFS best estimate of population size	NMFS status of stock designation	Source of population estimate
1995	Hawaiian	None available	Unknown	
1996	Hawaiian	None available	Unknown	
1997	Hawaiian	None available	Not assessed	
1998	Hawaiian	None available	Not assessed	
1999	Hawaiian	None available	Not assessed	
2000	Hawaiian	121 (CV = 0.47)*	Strategic	Mobley et al. 2000
2001	Hawaiian	121 (CV = 0.47)*	Strategic	Mobley et al. 2000
2002	Hawaiian	121 (CV = 0.47)*	Strategic	Mobley et al. 2000
2003	Hawaiian	121 (CV = 0.47)*	Strategic	Mobley et al. 2000
2004	Hawaiian	268 (CV = 1.08)	Strategic	Barlow 2003
2005	Hawaiian	268 (CV = 1.08)	Strategic	Barlow 2003
2006	Hawaiian	268 (CV = 1.08)	Strategic	Barlow 2006
2007	Hawaiian	484 (CV = 0.93)	Strategic	Barlow and Rankin 2007
2008	Hawaiian Pelagic	484 (CV = 0.93)	Strategic	Barlow and Rankin 2007
2008	Hawaiian Insular	123 (CV = 0.72)	Non-strategic	Baird et al. 2005
2009	Hawaiian Pelagic	484 (CV = 0.93)	Strategic*	Barlow and Rankin 2007
2009	Hawaiian Insular	123 (CV = 0.72)	Non-strategic*	Baird et al. 2005

*Now known to be likely insular stock. **Draft report, status not finalized

Aerial surveys were undertaken in June and July 1989 to provide a minimum count of false killer whales in Hawai'i (Reeves et al. 2009). Surveys were undertaken only in leeward areas off the island of Hawai'i, Lana'i and O'ahu. When groups of false killer whales were found, they were circled for as long as necessary for two experienced observers to obtain minimum counts. False killer whales were sighted on 14 occasions, all off the island of Hawai'i. Three large groups were documented on three different days, with counts of 380, 460 and 470 individuals (Reeves et al. 2009). The authors noted that it was unlikely that the entire island-associated population was concentrated in one area at the time, and thus the true population size was likely somewhat larger than 470. These large groups were all documented relatively close to shore in areas that were frequently used by satellite-tagged individuals from the insular stock (Baird et al. in press), and where individuals from the pelagic stock have not been documented. Thus, it seems likely that the large groups of animals seen close to shore were from the insular population.

The first systematic estimate of abundance for false killer whales in Hawaiian waters was based on a series of aerial surveys undertaken from February through April in 1993, 1995, and 1998 (Mobley et al. 2000). Those surveys covered both windward and leeward sides of all of the main Hawaiian Islands, including channels between the islands out to a maximum distance of about 46 km from shore. The distances from shore that were surveyed varied but generally covered out to 7 nmi (13 km) past the 1,000-fathom (1,828-m) contour (Figure 6). From 14 to 18 surveys were conducted between February and April in each of the three years. Sightings and effort from all three years were pooled in the analyses. Using distance sampling, an abundance estimate of 121 individuals (CV = 0.47) was calculated (Mobley et al. 2000). The authors noted several sources of uncertainty and potential bias. For instance, the survey aircraft did not permit observers to detect cetaceans directly below the plane, and the estimates were not corrected for individuals that may have been below the surface; thus the estimate was likely negatively biased.

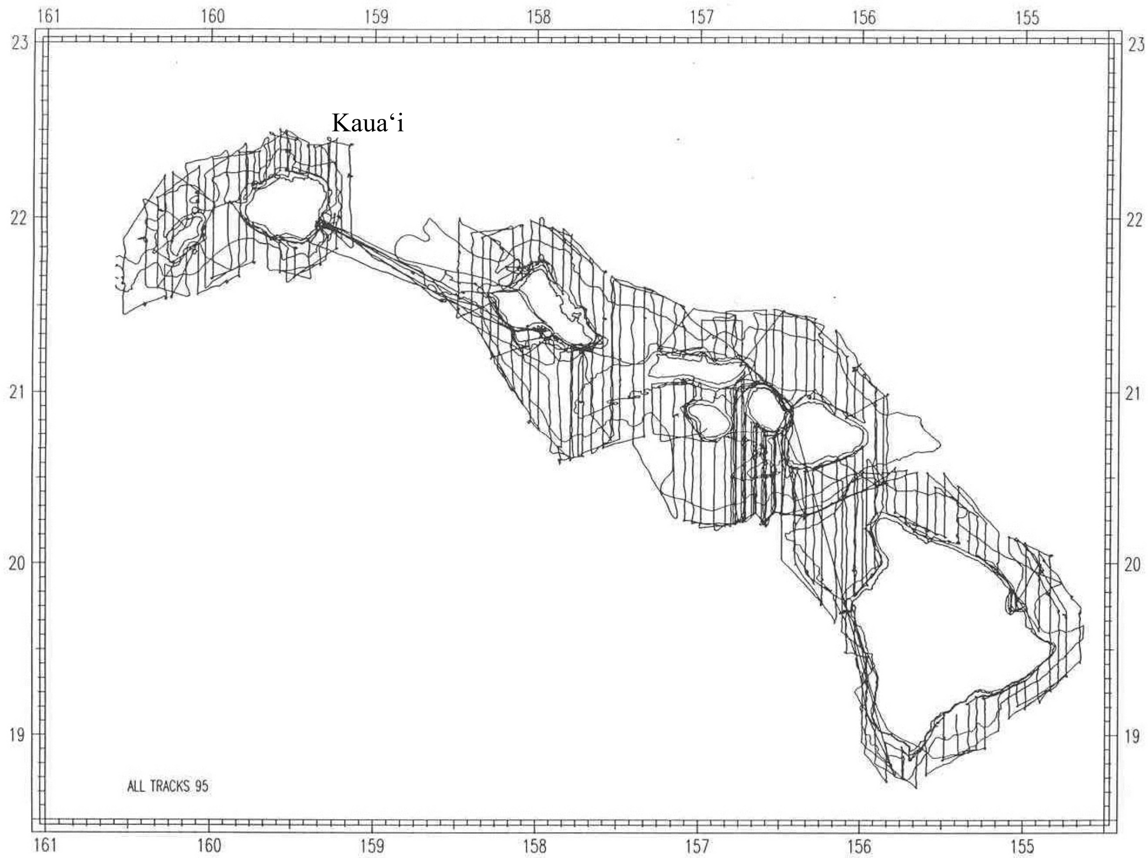

Figure 6. Example of aerial survey tracklines from 1995 survey (from Mobley et al. 2000). The 100 and 1000 fathom isobaths are shown.

A large-vessel line transect survey of the entire Hawaiian EEZ (HICEAS) was undertaken by two NOAA vessels from August through November 2002, covering 17,050 km of trackline (Barlow 2006) during approximately five months at sea. Only one on-effort sighting of false killer whales was documented, yielding an abundance estimate of 236 individuals (CV = 1.13), the smallest abundance estimate for any of the 18 species of odontocetes documented during the survey (Barlow 2006). This estimate translated into a density estimate of 0.0001 animals per km^2 for the entire Hawaiian EEZ. This density is more than an order of magnitude lower than density estimates for the eastern tropical Pacific (0.0021, Wade and Gerrodette 1993; 0.0016, Ferguson and Barlow 2003). Such low density is not unexpected given that Hawaiian waters are oligotrophic, while other parts of the eastern tropical Pacific have high productivity. Although the density of false killer whales in Hawaiian waters was substantially lower than in the eastern tropical Pacific, density of other delphinids within Hawaiian waters showed the same pattern (Wade and Gerrodette 1993, Barlow 2006). Also, within the eastern tropical Pacific, density of false killer whales is relatively high only from approximately 5°S to approximately 15°N, and is an order of magnitude lower north of 15°N (Ferguson and Barlow 2003).

In 2005 a large-vessel line transect survey (PICEAS) was undertaken in the Palmyra EEZ, the Johnston Atoll EEZ, and in international waters between the Hawaiʻi and Palmyra and Johnston Atolls EEZs (Barlow and Rankin 2007). Data from this survey were used to produce abundance estimates for the Palmyra EEZ and for the remainder of the PICEAS study area (including both international waters and the Johnston Atoll EEZ). Data from the 2002 survey of the Hawaiian EEZ were also reanalyzed using more advanced analytical methods. The larger sightings sample from both surveys was used to reassess estimated survey strip widths. The reanalysis also included short-finned pilot whales (*Globicephala macrorhynchus*) and rough-toothed dolphins (*Steno bredanensis*) in a multiple covariate analysis to estimate effective strip width and determine what covariates to include in the line-transect model (Barlow and Rankin 2007). The resulting abundance estimate for the outer Hawaiian EEZ (effectively encompassing the range of the Hawaiian pelagic stock of false killer whales) was 484 individuals (CV = 0.93). This is currently considered by NMFS to be the best estimate of abundance for the Hawaiʻi pelagic stock of false killer whales (Carretta et al. 2009a). For the Palmyra EEZ, Barlow and Rankin (2007) estimated an abundance of 1,329 false killer whales (CV = 0.65) and for the remainder of their study area they estimated an abundance of 906 false killer whales (CV = 0.68). Estimates of other species using the larger samples sizes and more advanced analytical methods were not produced.

A multi-site mark-recapture estimate of population size of false killer whales around the main Hawaiian Islands was generated from individual photo-identification data available for 2000 through 2004 (Figure 2) from Oʻahu, Maui, and Hawaiʻi (Baird et al. 2005). The model-averaged estimate, taking into account the proportion of "marked" individuals in the population, was 123 individuals (CV = 0.72). This estimate, similar to the estimate of Mobley et al. (2000), is currently considered by NMFS to be the best available estimate for the Hawaiʻi insular stock (Carretta et al. 2009a).

4.D. Population trends

Because only one systematic survey has been done in offshore waters of the Hawaiian EEZ, no trends can be assessed using this method for the Hawaiʻi pelagic stock. In theory, sighting data from the fishery observer program could be used to assess trends in sighting rates for individuals in the Hawaiʻi pelagic stock; however, changes in observer protocols and possible changes in false killer whale distribution or reactions to vessels in responses to longline fishing effort (e.g., learning that longlines may provide a source of food) could obscure changes in population size. Thus, no information is available to assess trends for the Hawaiʻi pelagic stock.

In addition to the three aerial surveys around the main Hawaiian Islands undertaken by Mobley et al. (2000) in the 1990s, two additional surveys in 2000 and 2003 (Mobley 2004, Mobley pers. comm.) provide a time-series that are used here to assess trends (Table 3). A regression of sighting rates over time reveals a significant decline ($p = 0.028$, $r^2 = 0.8429$). There were no false killer whale sightings in the 2000 or 2003 surveys. It is possible that variations in weather conditions or survey methods could have affected sighting rates. To test whether this was the case, data from sightings of other species in the five years of the aerial surveys were also examined to assess trends in sighting rates. Data were used for the four species with the largest sample sizes: common bottlenose dolphins, pantropical spotted dolphins (*Stenella attenuata*), spinner dolphins, and short-finned pilot whales (Table 3). These include nearshore and offshore delphinids with a range of body sizes that bracket the size of false killer whales. Regressions of sighting rates over time for each species independently showed no consistent pattern. Two species had slightly increasing trends (common bottlenose dolphin, pantropical spotted dolphin) and two had slightly decreasing trends (spinner dolphin, short-finned pilot whale), but trends for all four species were not significant ($p = 0.75, 0.40, 0.60, 0.82$, respectively). To assess whether one underlying factor, such as weather, influenced sighting rates, each species' sighting rate for a particular year was considered a replicate sample (i.e., $n = 4$ for each year). A regression of sighting rates for all four species showed no trend ($p = 0.89$, $r^2 = 0.001$). Thus, it is unlikely that weather or change in survey methods was responsible for the declining trend in sighting rates of false killer whales. This analysis supports the findings of Reeves et al. (2009) that suggest the size of the insular stock of false killer whales has declined markedly.

Table 3. Aerial survey effort and sighting data from J. Mobley, University of Hawai'i (pers. comm.).

Year	Effort (km)	Effort (hrs)	Mean Beaufort sea state	# false killer whale sightings	Sighting rate (per 10 on-effort survey hours)				
					False killer whale	Bottlenose dolphin	Pantropical spotted dolphin	Spinner dolphin	Short-finned pilot whale
1993	13,618	75.5	3.00	8	1.06	0.662	0.132	1.060	1.457
1995	17,091	92.3	2.83	9	0.975	2.492	0.542	2.167	1.625
1998	13,174	71.1	3.08	1	0.141	0.985	1.266	1.266	4.782
2000	11,007	59.4	3.43	0	0	1.178	2.020	1.347	1.347
2003	11,925	64.4	3.43	0	0	1.863	0.621	1.087	0.776

Reeves et al. (2009) note several additional lines of evidence suggesting that the Hawai'i insular stock of false killer whales has undergone a significant decline in size in recent years. One researcher working off the island of Hawai'i since the mid-1980s has noted that encounter rates have declined since he began his studies (D. J. McSweeney, pers. comm. in Reeves et al. 2009). In addition, in 1989 aerial surveys by Reeves et al. (2009), false killer whales were the third most frequently encountered species, representing 16.7 percent of all odontocete groups observed, whereas boat-based surveys around the main Hawaiian Islands from 2000 through 2006 found false killer whales the eleventh most frequently encountered species representing less than 2 percent of odontocete sightings (Baird et al. 2008a).

A comparison of the largest group sizes documented in the 1989 survey with recent population estimates for the insular stock also suggests that the population has declined. The largest group documented in 1989 contained 470 individuals (Reeves et al. 2009), almost four times the estimated population size from more recent surveys (Mobley et al. 2000, Baird et al. 2005). A preliminary analysis of photo-identification data since the mid-1980s (Figure 2) also indicated that the mean annual survival rate of distinctive and very distinctive individuals (i.e., adults) appeared lower (0.92) than would be expected for a cetacean with the life history characteristics of false killer whales (Baird and Barlow unpublished). All available lines of evidence thus suggest a decline in the abundance of the insular false killer whale population.

4.E. Social organization and group structure

Shallenberger (1981) reports that false killer whale groups encountered in Hawaiian waters are often spread over very wide areas. Baird et al. (2008a) note that estimates of group size increase as encounter duration increases because widely dispersed sub-groups, apparently acting in concert (e.g., all moving through the area in the same direction), are more likely to merge or come into close proximity with one another the longer they are followed. For individuals thought to be from the pelagic stock, Baird et al. (2008a) report one encounter with the most widely separated sub-groups 28 kilometers apart. Information from satellite tags deployed on multiple individuals within a group shows that individuals may separate by more than 100 kilometers over periods of hours or days before rejoining (Baird et al. in press[4]). Such dispersal of individuals apparently acting in concert has implications for the likelihood of a group detecting and interacting with fishing gear. That is, the likelihood of depredation occurring and the potential for bycatch may be high because individuals within dispersed sub-groups may effectively search a large area and converge on captured prey when one sub-group locates a prey source (see later discussion).

Based on analyses of association data from photo-identified individuals, false killer whales in Hawaiian waters appear to have strong long-term bonds (Baird et al. 2008a). However, the groups encountered in the field are likely to be an aggregation of multiple smaller stable sub-groups with sub-groups joining or leaving the larger aggregation regularly. Since these analyses of social organization were completed, the sample sizes of photo-identifications available have increased substantially (Figure 2), which will allow for more detailed assessments of association patterns.

4.F. Diet and foraging ecology

Cetacean diets are typically assessed by examining the stomach contents of stranded animals or fisheries bycaught animals. As noted above, false killer whales strand infrequently in Hawaiian waters, and apparently stomach contents from the five stranded false killer whales were not saved. However, false killer whales feed during the day, capture large prey, and frequently share their prey, including prey caught at depth and brought to the surface (Baird et al. 2008a); thus, there is information on diet from observational studies. Ten species of pelagic fish have been documented as prey of false killer whales from the insular stock around the main Hawaiian Island, including seven species caught commercially: yellowfin tuna (*Thunnus albacares*), albacore tuna (*T. alalunga*), skipjack tuna (*Katsuwonus pelamis*), broadbill swordfish (*Xiphias gladius*), dolphin fish (or mahimahi, *Coryphaena hippurus*), wahoo (or ono, *Acanthocybium solandri*), and lustrous pomfret (or monchong, *Eumegistus illustrus)* (Table 4; Baird et al. 2008a). Mahimahi were the most commonly observed prey (Baird et al. 2008a) but are also easily recognizable even by relatively inexperienced observers. Thus opportunistic observational studies may over-represent the occurrence of mahimahi in the diet. False killer

[4] An animation showing movements of five satellite-tagged individuals from the insular population over a 10-day period can be viewed at www.cascadiaresearch.org/hawaii/falsekillerwhale.htm

whales that are known or thought to be from the pelagic stock have been observed feeding on mahimahi and ono (Baird et al. unpublished data).

Table 4. Prey species documented for false killer whales in Hawaiian waters[1].

English name	Hawaiian name	Scientific name	Source
Yellowfin tuna	Ahi	*Thunnus albacares*	Baird et al. 2008a
Albacore tuna	Ahi palaha	*Thunnus alalunga*	Baird et al. 2008a
Skipjack tuna	Aku	*Katsuwonus pelamis*	Baird et al. 2008a
Scrawled File fish	Loulu or Oilepa	*Aluterus scriptus*	Baird et al. 2008a
Broadbill swordfish	A‘u ku	*Xiphias gladius*	C. Babbit pers. comm.
Dolphin fish	Mahimahi	*Coryphaena hippurus*	Baird et al. 2008a
Wahoo	Ono	*Acanthocybium solandri*	Baird et al. 2008a
Lustrous pomfret	Monchong	*Eumegistus illustrus*	Baird et al. 2008a
Threadfin jack	Kagami ulua	*Alectis ciliaris*	D. Perrine pers. comm.

[1]*Aluterus scriptus* and *Eumegistus illustrus* probable identifications.

The sample size of observations of predation by individuals from the pelagic stock is small, and for the insular stock, observations of predation are limited to leeward areas off the islands of Hawai‘i, Maui, and O‘ahu. The small sample sizes are not adequate for reliable assessments of whether their diets varies seasonally, geographically, or between the insular and pelagic stocks. Although observations of predation have been documented incidentally during other studies, no directed studies of predation have been undertaken. It is possible that species caught at depth are less likely to be documented through observational methods. In addition, the likelihood of detecting prey captures or prey sharing may vary with the size of prey and the amount of time necessary to capture and subdue the prey. Assessment of prey preferences and contributions to overall dietary intake could be undertaken using genetic analyses of fecal samples, a method currently being used to assess diets of killer whales (Hanson et al. in press). There is limited information available on diel foraging patterns. Data on diving behavior by one individual instrumented with a time-depth recorder for more than 28 hours indicated that all deep dives (>100 m) occurred during daylight hours, with a maximum dive depth exceeding 234[5] m (Baird et al. unpublished). Dive patterns were more regular at night, and swim speed was lower and less variable at night, suggesting less foraging at night (Baird et al. unpublished).

Information on food intake rates is not available from wild false killer whales but is available from captive individuals. Average monthly nutrition data is available from the Hawai‘i Institute of Marine Biology for an adult female captive false killer whale (Kina) from January 2006 through September 2009. Body weight during this period ranged from 476 to 533 kg (mean = 476 kg, SD = 16.5), with daily food intake ranging from 14.4 to 21.2 kg (mean = 17.4 kg, SD =

[5] The time-depth recorder used recorded only to 234 m, although the tagged whale spent more than eight minutes below that depth, thus likely could have been foraging to as deep as 700 m given the rate of ascent and descent documented.

1.4 kg). Daily food intake in relation to body weight varied from 3.0 to 4.2 percent (mean = 3.4 percent, SD = 0.3 percent), while daily energy intake varied from 27 to 44 kcal/kg body weight (mean = 35.7, SD = 3.6). There was no relationship between daily energy intake rates (kcal/kg body weight) and body weight or month, although in the case of the body weight, the range in body weight over the 45-month period was small and the whale was an adult during the entire time period.

5. Potential conservation threats

Although 10 false killer whales were captured alive in Hawai‘i for the captive display industry prior to 1980 (Shallenberger 1981), there have been no capture permits requested in recent years. Potentially limiting factors are discussed here, focusing on the anthropogenic impacts for which there is the most information available or that are thought to have a significant potential to affect false killer whale populations in Hawaiian waters in the short term. Some longer-term issues, such as the impact of ocean acidification on prey species through food web effects (e.g., Fabry et al. 2008, Brewer and Peltzer 2009), are important management concerns, but their assessment is beyond the scope of this review. Little is known about diseases in false killer whales. However, infectious disease threats also may be an issue for the long-term viability of false killer whale populations (Gaydos et al. 2004). Given the nature of false killer whale grouping patterns and food sharing (Baird et al. 2008a), infectious diseases may be transmitted to a large proportion of a population relatively quickly (Guimaraes et al. 2007).

It should be noted that an absence of evidence of an impact by such factors as ship strikes, anthropogenic noise sources, ingestion of fishing gear, shooting, or other human interactions is not evidence of an absence of impacts. Given the estimated population size of the insular stock (123 individuals, Baird et al. 2005), and expected survival rates for long-lived odontocetes (e.g., 96 percent annual adult survival), one would expect the death of five adult individuals in the insular stock each year due to natural causes. Thus, over the last 20 years approximately 100 individual adult false killer whales in the insular stock might be expected to have died of natural causes. Over the last 20 years only two dead false killer whales have been documented in Hawaiian waters (Maldini et al. 2005, K. West, pers. comm.), which comprises only 2 percent of the number of individuals expected to have died of natural causes. There are a variety of factors that reduce the likelihood that dead or moribund animals strand or wash ashore in Hawai‘i (e.g., strong currents, large numbers of scavenging sharks, fringing reefs) or that dead animals will be detected if on a beach (e.g., inaccessibility of many coastlines due to sea cliffs, low human population density, particularly on some islands [e.g., Ni‘ihau, Kaho‘olawe]; Faerber and Baird in press). All of these factors suggest that the likelihood of detecting dead or moribund false killer whales in Hawaiian waters is extremely low. Even much larger and very abundant species such as humpback whales are rarely detected stranded in Hawai‘i. Analyses by Antonelis et al. (2007) suggest that several hundred die in Hawaiian waters each year, yet typically only one or two strandings are documented.

Purvis et al. (2000) note that extinction risks in declining species are positively correlated with four primary factors: high trophic level, low population density, delayed maturity and low reproductive rate, and small geographical range. All of these factors apply to the insular stock of false killer whales around the main Hawaiian Islands, and the first three also apply to the pelagic stock. The current estimate of PBR for the insular population is 0.8 individuals per year (Carretta et al. 2009a). Thus, even a low level of anthropogenic mortality could result in a negative population trajectory for a species with these characteristics.

5.A. Persistent organic pollutants

Given their high trophic level and life history characteristics such as low reproductive rate, delayed maturity, and extended longevity (Kasuya 1986), false killer whales are likely to accumulate higher levels of persistent organic pollutants than other cetaceans in Hawaiian waters. Persistent organic pollutant levels assessed in blubber biopsy samples from nine individuals from the insular stock have been found to be high in PCBs and DDTs (Ylitalo et al. 2009). As expected, levels were highest in adult males and subadults. Three individuals had levels of PCBs that were high enough to potentially influence the health of those individuals (Ylitalo et al. 2009).

5.B. Changes in prey base

Reduced prey abundance or reduced size of individual fish (e.g., Sibert et al. 2006) could affect false killer whale foraging success and increase the amount of time or energy they must expend to meet nutritional requirements. Changes in the relative abundance of mid-trophic and upper-tropic level fish could result in increased variability in fish abundance (Polovina et al. 2009), potentially increasing the variability in rates of false killer whale food intake. Reduced food intake combined with increased variability in food availability could result in mobilization of persistent organic pollutants sequestered in blubber or reduce nutritional state, potentially affecting the immune system response (Jepson et al. 2005, Krahn et al. 2009). Information on the population status of fish species known to be prey of false killer whales in Hawai'i is limited. Trends in false killer whale prey abundance are primarily limited to analyses of data on catch per unit effort in the longline fishery and nearshore fisheries that catch known false killer whale prey, such as the troll fisheries. However, variations in fishing practices over time complicate analyses of both catch per unit effort and apparent changes in the size and body weight of caught fish over time.

Data on average body weight for target fish species and catch per unit effort are available from 1987 through 2007 from both offshore longline fisheries and nearshore troll and handline fisheries, but quantitative analyses are limited (WPRFMC 2009, see Polovina et al. 2009). Utilizing these data, several analyses (presented below) suggest potential declines in either body weight or catch per unit effort for some of the prey species eaten by false killer whales. These analyses are for a 21-year time period, but it is possible that some fish populations were reduced to levels that could have affected false killer whale prey availability prior to 1987 (Sibert et al. 2006).

Data on average body weight of three false killer whale prey species taken by the longline fishery from 1987 through 2007 (WPRFMC 2009) show a significant decline in body weight over time (yellowfin tuna, regression, $p < 0.001$, $r^2 = 0.66$; mahimahi, regression $p = 0.01$, $r^2 = 0.29$; skipjack tuna, regression $p = 0.003$, $r^2 = 0.38$). For yellowfin tuna, mean body weight declined from an average of 48 kg from 1987 to 1991 to 30 kg from 2003 to 2007. WPRFMC (2009) suggests that this decline likely reflects increasing effort in the EEZ of Palmyra Atoll in recent years, although no information is presented to assess this. Catch-per-unit-effort data from WPRFMC (2009, measured in weight of fish per day of fishing effort) for yellowfin tuna over the same period in the main Hawaiian Islands handline (regression $p < 0.001$, $r^2 = 0.49$) and troll (regression $p = 0.023$, $r^2 = 0.24$) fisheries also show significant declines. These analyses do not take into account potential changes in fishing methods over the 21-year period but suggest cause for concern that reduction in prey availability or prey size could be affecting false killer whale foraging success. Polovina et al. (2009) note more recent (1996–2007) reductions in catch per unit effort in the tuna longline fishery for albacore tuna and bigeye tuna (*Thunnus obesus*) among other species, and Sibert et al. (2006) note large reductions of the biomass of both yellowfin and bigeye tuna stocks in the western-central Pacific Ocean over the last 25 years.

5.C. Ship strikes

Accidental ship strikes have the potential to kill or seriously injure both large and small cetaceans. Non-fatal ship strikes as evidenced by propeller wounds have been documented for most large and medium-sized cetaceans, although it is likely that most propeller wounds on small cetaceans would be fatal, thus less likely to be documented. Species that are slow-moving, large, or spend a substantial amounts of time at the surface are probably most susceptible to ship strikes; however, species that bow ride or show curiosity toward vessels can also be injured or killed by propellers. Although infrequent, records document deaths of killer whales due to ship collisions; in at least one case this was of a juvenile showing interest in vessels (Laist et al. 2001, Gaydos and Raverty 2007). Individuals in both insular and pelagic stocks of false killer whales bow ride or wake ride on waves produced by transiting vessels and often come in close proximity of propellers on moving vessels (Baird pers. obs.). Thus, there may be at least a low risk of false killer whale injury or death from wounds by propeller strikes or collisions. Ship or propeller-related deaths of false killer whales have not been reported, but one individual from the insular population photographed off O'ahu in September 2009 bears a fresh wound on the head that may be from a propeller strike (Figure 7).

5.D. Anthropogenic sounds

High-intensity anthropogenic sounds have the potential to interfere with the echolocation that toothed whales use to detect prey, mask communication they need to maintain contact between widely dispersed sub-groups, and, in some circumstances, cause individuals or groups to strand. False killer whales off Japan were hunted in drive fisheries utilizing sound to herd individuals (Kishiro and Kasuya 1993, Brownell et al. 2008). The U.S. Navy's Hawai'i Range Complex, which encompasses all of the main Hawaiian Islands, is regularly used for training exercises that broadcast high-intensity mid-frequency sound from sonar[6]. Although impacts on false killer whales have not been documented in Hawaiian waters, the power of methods used to detect acoustic impacts is low. In 2004 during a Navy Rim-of-the-Pacific exercise, a large number of melon-headed whales (*Peponocephala electra*) became temporarily trapped in a coastal embayment on Kaua'i that may be have been related to the use of Navy sonar (Southall et al. 2006, Brownell et al. 2009). Similar impacts from high-intensity mid-frequency sonar might affect false killer whales. Information to assess areas of overlap between the locations where

[6] Hawai'i Range Complex Final Environmental Impact Statement/Overseas Environmental Impact Statement (May 2008). www.govsupport.us/navynepahawaii/FEIS.aspx

mid-frequency sonar is used most frequently and the range of insular or pelagic false killer whales is not currently available.

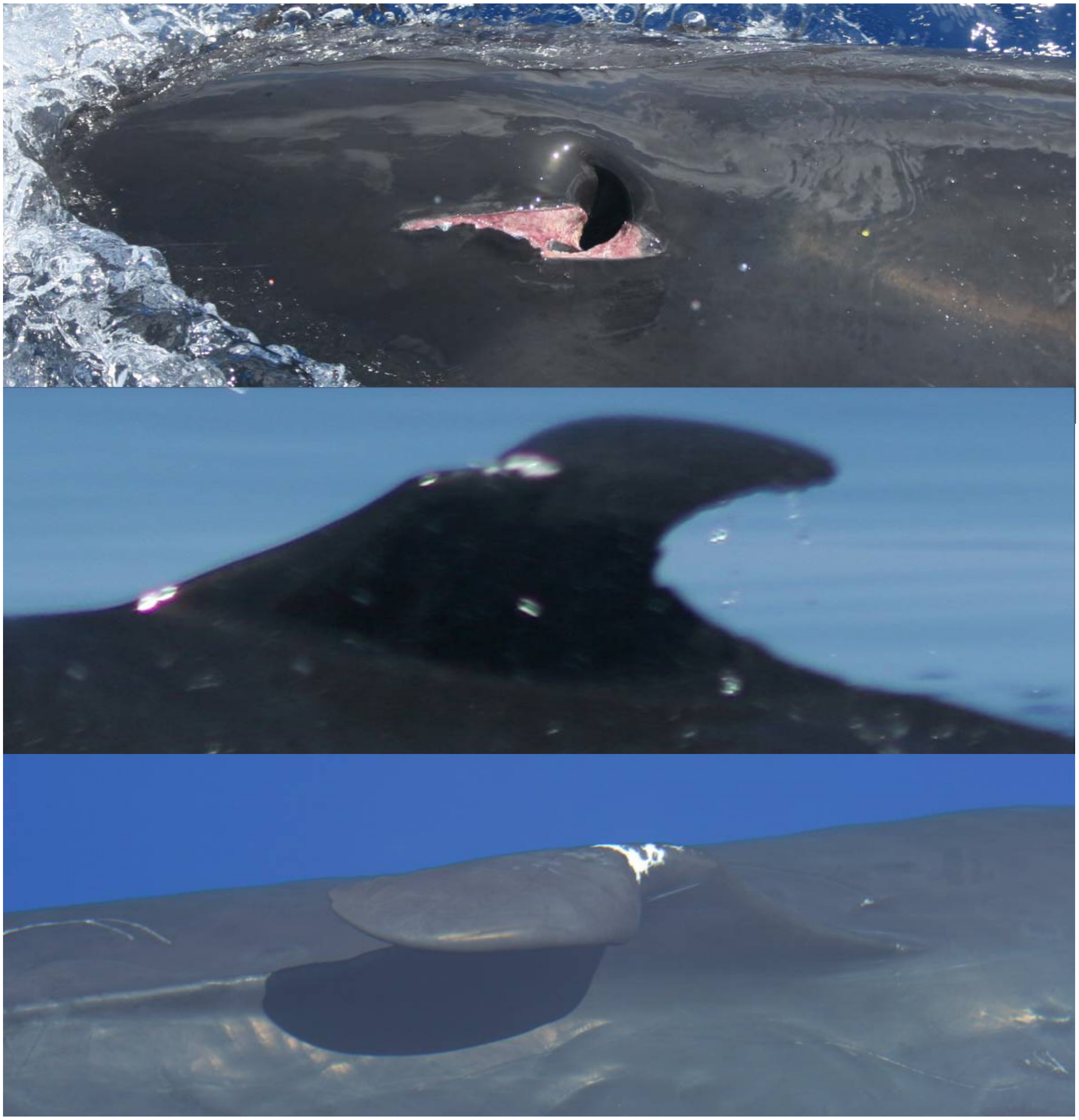

Figure 7. Top. False killer whale from the insular population documented off O'ahu in September 2009 with linear cut through blowhole, possibly due to propeller strike or hooking. Middle/Bottom. Insular individual documented off O'ahu from April 2008 with a recent dorsal fin disfigurement. Middle. Left side of fin showing linear cut on leading edge associated with white scar tissue. Bottom. Photograph taken through the water showing top and part of right side of fin. Note the linear horizontal scar below the white scar tissue. All photos by Tori Cullins.

5.E. Fishery interactions

Information on fisheries interactions is available from fishery observer programs, reports by fishermen, and observations of free-ranging whales. False killer whales are known to take hooked fish off lines (Brown et al. 1966, Mizue et al. 1969). In Hawaiian waters, such depredation has been noted in both nearshore troll fisheries and offshore longline fisheries (Shallenberger 1981, Nitta and Henderson 1993). Information on how often such depredation occurs in the nearshore fisheries is not available. In offshore fisheries, longline fishermen have noted that depredation by whales (including both false killer whales and short-finned pilot whales) could range from 5 to 60 percent (median = 27 percent) of their annual catch (TEC Inc. 2009). Depredation rates may change over time in response to reductions in prey availability, changes in fishing practices, and as individual whales learn that hooked fish may be a readily available prey source, something that has been documented for other cetacean species (Powell 2009). TEC Inc. (2009) noted that some participants in the Hawaiʻi-based longline fishery (owners and captains) believe that depredation interactions by false killer whales have increased over time. Depredation on hooked fish by false killer whales may result in the death of whales due to entanglement in fishing lines or ingestion of hooks. Entanglements may cause drowning, amputation of appendages due to wraps and constrictions of fishing gear, or interference with swimming and the whale's ability to catch prey. Ingestion of hooks and associated fishing gear may puncture the lining of the digestive tract leading to lethal infections or blockage of food passage.

Depredation of caught fish also may lead to retaliatory measures by fishermen (Read 2008). Nitta and Henderson (1993) note that reports of shooting bottlenose dolphins to deter them from taking catch in Hawaiian waters have been received since the early 1970s. Small-scale commercial fishermen in Hawaiʻi often carry firearms to kill or deter sharks depredating catch or occasionally to kill large billfish they catch before pulling them aboard. Environment Hawaiʻi (1997) notes that "about a dozen dolphins were killed near a fish aggregating device off the South Kona coast in August," based on a witness report filed with the Hawaiʻi Division of Conservation and Resource Enforcement. Given potential fines and other penalties for shooting cetaceans, retaliatory shooting of false killer whales, to the extent they may occur, are now likely to happen in areas and at times when no witnesses are present. Because injuries on false killer whales re-pigment relatively quickly, detecting non-fatal gunshot wounds more than a few months after an incident would be difficult. Because of the black coloration on the mouth-line, other types of scarring that are associated with fisheries interactions (e.g., linear mouth-line scars) would be much more difficult to detect than for other cetacean species with white mouth-lines such as pygmy killer whales (*Feresa attenuata*). In addition, as noted above, strandings are infrequent and thus the carcasses of individual cetaceans that are shot are not likely to wash ashore and those that do are unlikely to be found (see Faerber and Baird in press). Thus, there is no quantitative information to assess whether or how often deliberate shooting of false killer whales or other cetacean species in Hawaiʻi may occur.

Ingestion of fishing gear from recreational or commercial fisheries has the potential to result in death. Ingestion of fishing gear could occur either when hooked fish are taken off lines or when a free-swimming fish breaks free or is released from fishing gear with a hook and possibly other attached gear (e.g., leader and line) and is eaten by a whale. Wells et al. (2008) document 11 cases of fishing gear (all from recreational fisheries) ingested by common bottlenose dolphins in Florida , and one additional case suggesting either ingested gear or gear wrapped around the gape. All 11 cases of ingested gear were documented from carcasses, and in at least seven of those cases, the cause of death was attributed to injuries from hooks embedded in the mouth, throat, and goosebeak (laryngeal spout) and line wrapped around the goosebeak (Wells et al. 2008). Some of those cases apparently involved consumption of free-swimming fish carrying attached hooks (Gorzelany 1998). In the other four cases, ingested gear was considered a contributing factor for one animal and may have played a role in mortality for two others although the cause of death varied (Wells et al. 2008). The magnitude of this issue can be significant; in Sarasota, Florida, an estimated 2 percent of the resident bottlenose dolphin community died from gear ingestion in 2006 (Powell and Wells 2009, R. Wells, pers. comm.). Given the combined level of fishing effort by all fisheries in Hawai'i, the potential frequency of depredation (Nitta and Henderson 1993), and the overlap between false killer whale diets and fish species targeted by commercial, recreational, and subsistence fisheries in Hawai'i, ingestion of fishing gear may be an important threat to false killer whales in Hawaiian waters.

For insular false killer whales in Hawai'i, Baird and Gorgone (2005) noted that the rate of dorsal fin disfigurement, likely caused by line injuries, was approximately four times higher than for any of the other 13 populations of eight species of odontocetes for which dorsal fin disfigurement data were available. They suggest that this high rate of dorsal fin disfigurement in comparison to other odontocete populations is an indicator of relatively frequent interactions between individuals from the insular population and fishing gear (Baird and Gorgone 2005). Since this analysis, one additional individual from the insular population documented in April 2008 was observed with a dorsal fin disfigurement possibly due to fishing line (Figure 7). As noted earlier, false killer whale wounds re-pigment quickly, limiting the detection of such wounds. Given the visible white scar tissue, this injury was likely less than six to 12 months old, suggesting that fisheries interactions with this population continue.

There are a variety of large-scale and small-scale commercial fisheries in Hawaiian waters, as well as a substantial number of recreational fishermen and some subsistence fisheries. Although there are clearly large numbers of recreational fishermen throughout the main Hawaiian Islands and subsistence fishing is an important activity for many Native Hawaiians, there is no license system is in place for recreational or subsistence fisheries. Thus reliable records of their numbers are not available. The Hawai'i-based longline fishery is currently the largest fishery in Hawai'i (WPRFMC 2009), although other fisheries predominated prior to the 1970s (Pooley 1993). Recent observer data are available only for this fishery, which has been recognized as a primary source of false killer whale serious injury and mortality since 2000 (Forney et al. 2000). Other fisheries that could cause death and injuries to false killer whales could include shortline and kaka line fisheries, troll fisheries, and other hook and line fisheries. Shortline and kaka line fisheries both use gear similar to longline fisheries, but lines are restricted to less than one nautical mile in length. Multiple lines may be set at one time, however. The kaka line fishery is regulated by the state of Hawai'i and is generally prosecuted in relatively nearshore waters, while the shortline fishery was added to the federal List of Fisheries for 2010[7] and is generally prosecuted in offshore waters. There are anecdotal reports of the bycatch of "blackfish" (potentially including any of false killer whales, pygmy killer whales, melon-headed whales, or short-finned pilot whales) in nearshore shortline or kaka line gear (J. McDonald pers.

[7] 50 CFR Part 229 (Federal Register 74(219):58859-58901.

comm.), and it is likely that false killer whales are one of the species taken, given their tendency to depredate fish off lines. Because of data limitations for these fisheries, it is not possible to assess interaction probabilities, but observer programs are warranted given the similarities in gear types with longline fisheries and the anecdotal information on bycatch, as well as the overlap (particularly with kaka line gear) with individuals from the Hawai'i insular stock of false killer whales. Information on exactly where these fisheries are prosecuted and what species are targeted are limited because of confidentiality issues as well as cases where fishermen use a variety of gear types simultaneously and thus underreporting the use of kaka line or shortline gear.

The remainder of this section focuses on observed bycatch records and estimated bycatch for the Hawai'i-based longline fishery (see Boggs and Ito 1993, Gilman 2007, WPRFMC 2009). Information on catches and area of fishing for this fishery are available from the Hawai'i Longline Fishery Logbook program[8]. Information on false killer whale bycatch and other observer data are from Forney and Kobayashi (2007), Forney and McCracken (2008), McCracken and Forney (2008), and unpublished data from the NMFS Pacific Islands Regional Office (PIRO).

Longline fishing in Hawaiian waters began in 1917, and through the 1970s it was carried out from relatively small boats (12–19 m) typically fishing within 40 km of shore (Boggs and Ito 1993). Over the last 30 years, Hawai'i long-line fishing has undergone a number of changes in regulatory measures, fishing effort, and monitoring requirements. Relevant regulatory and monitoring changes are summarized in Table 5. Prior to 1992 longline fishing occurred around the main Hawaiian Islands (Boggs and Ito 1993, He et al. 1997); since 1992 a longline exclusion zone has existed around the main Hawaiian Islands (Figure 4). This has been characterized as a "25–75 nautical mile exclusion zone," although the distance between the boundary and the main Hawaiian Islands varies depending on the area as well as seasonally. The boundaries of the two seasonal exclusion areas were set as amendments to the Pelagic Fisheries Management Plan based on coordinates of inflection points along its perimeter. To assess the actual distance between the boundaries and the main Hawaiian Islands, a GIS analysis was undertaken, using locations at 10-km intervals along the boundary line, determining the distance to the closest point of land at each 10-km node. From February through September, the closest that longline fishing is allowed to the main Hawaiian Islands is 78.6 km (42.4 nm), and less than 7 percent of the boundary is between 75 and 85 km from shore (Figures 4, 8). From October through January, the closest point is 45.1 km (24.3 nm) from land. More than 25 percent of the boundary during this period lies between 45 and 50 km from shore, but some parts of the boundary are no closer than 194 km (104 nm).

The number of vessels in the longline fleet more than doubled between 1987 and 1989 (37 in 1987, 88 in 1989), and by 1991 it had increased to 141 vessels (WPRFMC 2009). In 2007 there were 129 active vessels (Figure 9). Although the number of vessels in the fleet has fluctuated between about 100 and 140 since 1990, the number of hooks in the water has increased steadily over that period (Figure 9). The increase in the number of hooks reflects, at least in part, an increase in the number of vessels fishing for tuna with deep-set gear compared to those targeting swordfish with shallow-set gear (Figure 10). Deep-set gear is set at sunrise at

[8] Available from www.pifsc.noaa.gov/fmsd.reports.php

depths of 100 to 400 m (median depth of approximately 250 m; Bigelow et al. 2006). Because of the way the gear is suspended, the depth of hooks on any particular line may vary by several hundred meters. Retrieval begins at or after sunset and typically takes three to six hours to retrieve all the gear. Shallow-set gear is set at sunset at depths to approximately 50 m and is retrieved before or at sunrise.

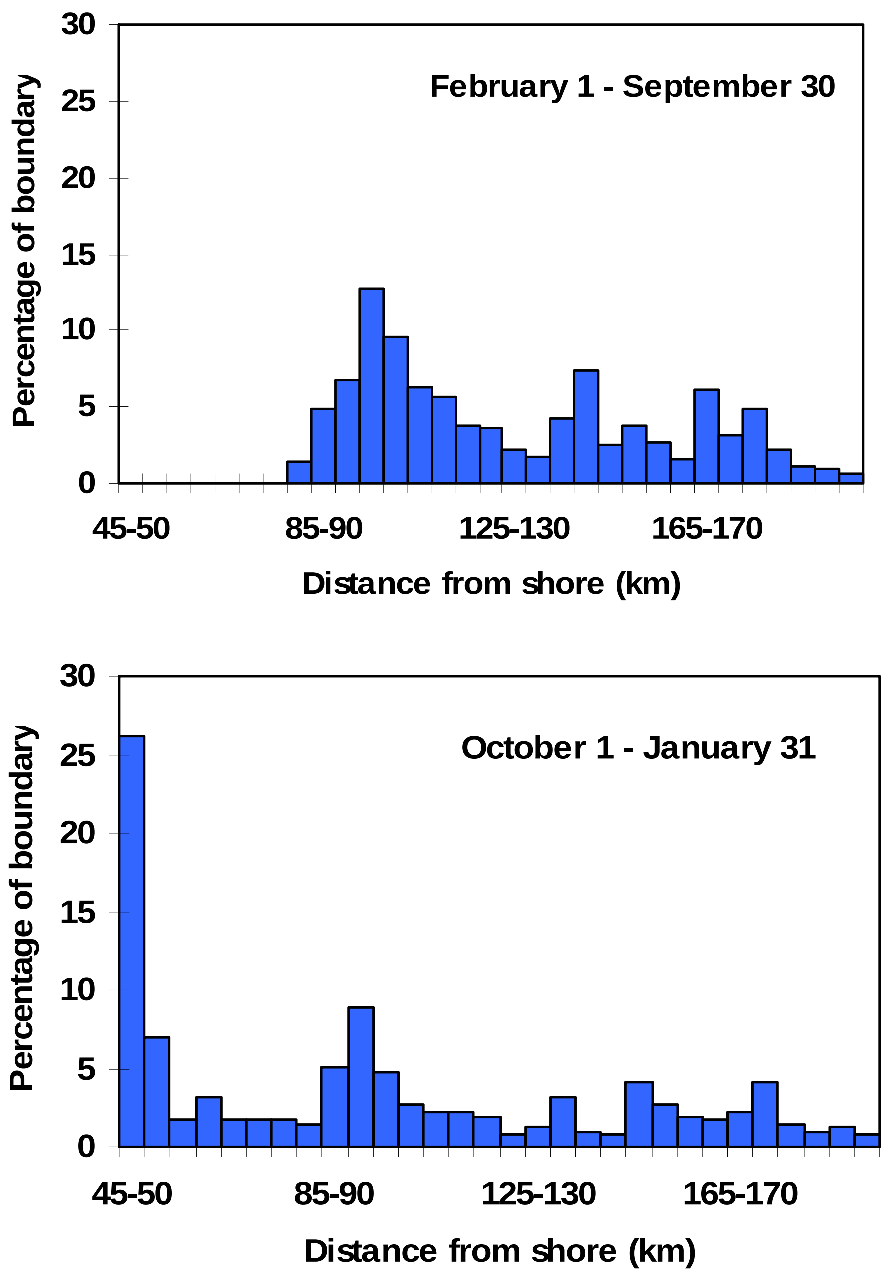

Figure 8. The distance from shore of the main Hawaiian Islands of the long-line exclusion boundary for October through January (top) and February through September (bottom). See Figure 4 for map of boundaries.

Table 5. Selected regulatory and monitoring changes for longline fishing in Hawai'i.

Year/Month	Regulatory or monitoring changes
1990 Nov	Implementation of log-book program with 100% coverage for recording of catch and fishing effort
1991 Oct	Three-year moratorium on new entry into fleet imposed
1991 Oct	Exclusion zone implemented around Northwestern Hawaiian Islands ("50 nm") to protect monk seals
1991 Oct	Requirement for implementation of NMFS-owned vessel monitoring system (VMS) transmitters, with VMS data monitored by NMFS Office of Law Enforcement to ensure compliance with protected areas
1992 Mar	Exclusion zone around main Hawaiian Islands to reduce conflict with near-shore fisheries
1992 Nov	Modification of main Hawaiian Island Exclusion zone with northern and eastern boundary contracting towards islands from October 1 through January 31 each year
1994 Jun	Start of NMFS longline observer program
1994 Jun	Limited entry program instituted (164 vessels maximum, maximum length 101')
2000	Increase in observer coverage in swordfish component of longline fleet to 100% and 20% observer coverage in the deep-set tuna fleet.
2002 Jun	Ban on swordfish fishing north of the equator to Hawai'i-based fleet for turtle protection
2004	Hawai'i longline fishery reclassified as Category I fishery in 2004 List of Fisheries. Re-opening of swordfish fishing with new turtle protection requirements, including use of circle hooks instead of J hooks
2006 Jun	Establishment of Papahānaumokuākea National Marine Monument around Northwestern Hawaiian Islands with exclusion of long-line fishing (boundaries similar to "50 nmi" exclusion zone)
2008 Dec	Hawai'i longline fisheries officially split into a Hawai'i deep-set (tuna target) longline and Hawai'i shallow-set (swordfish target) longline fishery in the List of Fisheries.

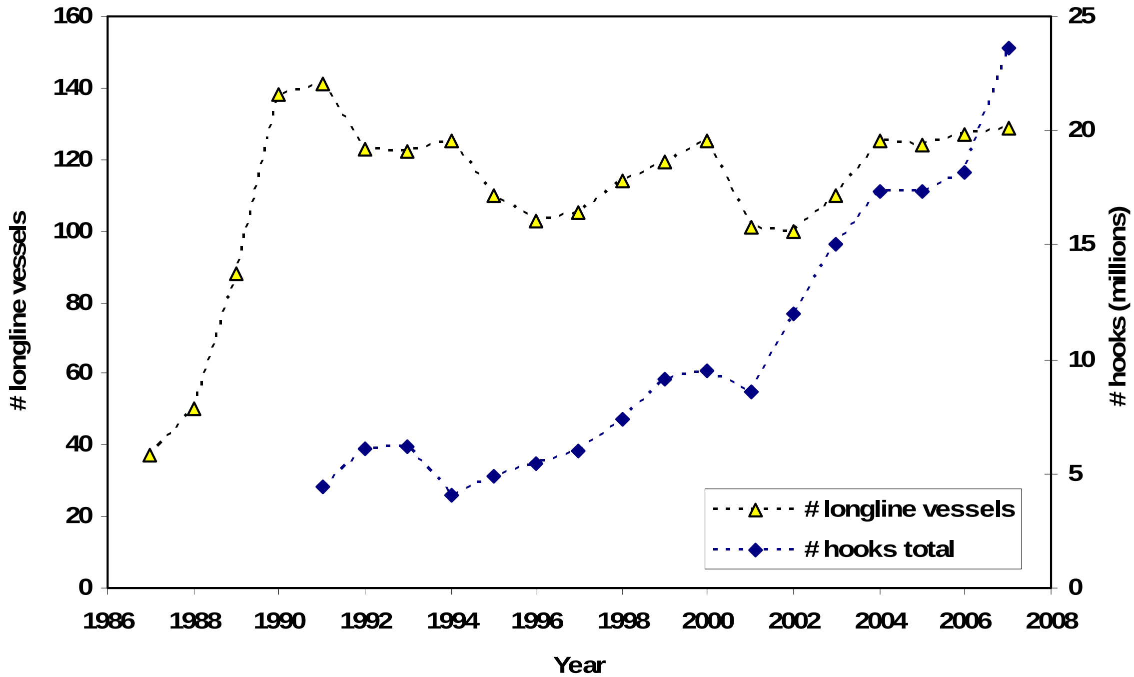

Figure 9. Number of Hawai'i-based longline vessels and number of hooks in the water by year from the longline fishery. Data from WPRFMC (2009).

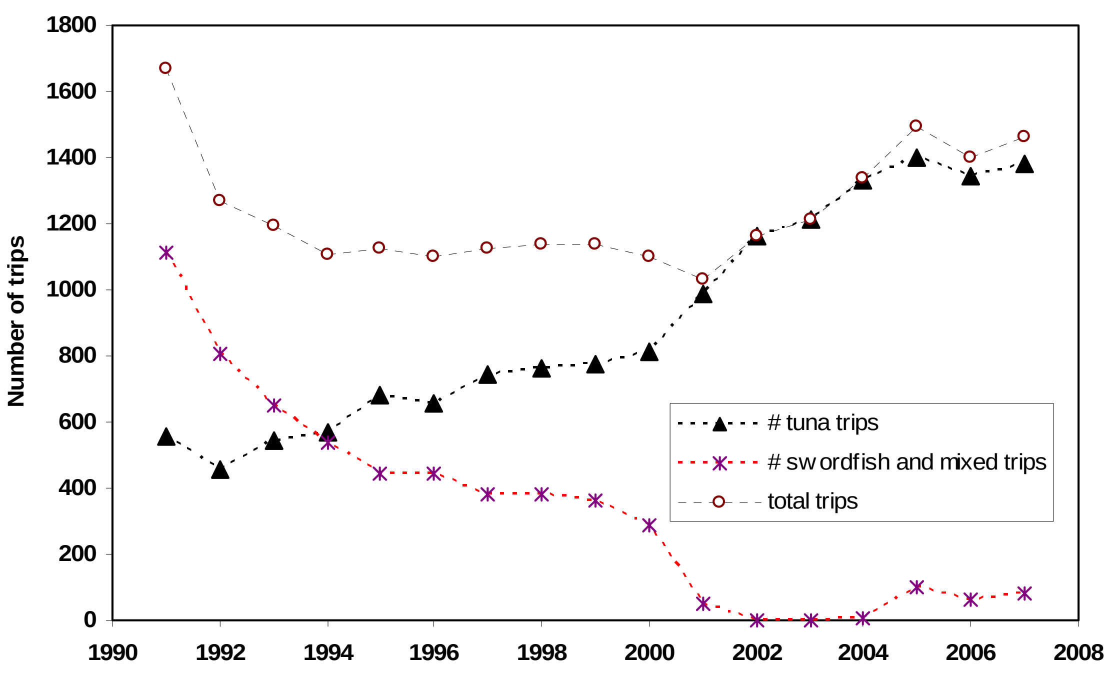

Figure 10. Number of trips per year for Hawai'i-based longline vessels by primary fishing method (deep-set for tuna or shallow-set for swordfish). Data from WPRFMC (2009).

Observer effort in the fishery began in 1994. There is no quantitative information to assess bycatch prior to that date. Given that longline fishing occurred closer to shore prior to the implementation of the 1992 exclusion area, it is likely that interactions between false killer whales in the insular stock and the longline fishery were higher before 1992 than they have been more recently, unless movement patterns of individuals from the insular stock have changed in response to the boundary implementation. The percentage of observer coverage in the longline fleet has varied over time (Table 6). Prior to 2000 it averaged less than 4 percent (Forney and Kobayashi 2007). Between 1994 and 1999 a combined total of 874 tuna sets were observed (approximately 3.4 percent of all tuna sets). Based on data from 1994 through 2004, the average rate of take (i.e., deaths and serious injuries) of false killer whales in deep-set longline gear was 0.88 per 1,000 sets (Forney and Kobayashi 2007). Given the low level of observer coverage compared to more recent years, the likelihood of any false killer whale takes being documented in the deep-set fishery was low prior to 2000.

Depredation of longline-caught fish by both sharks and cetaceans is widespread throughout the fishery. If fish remains are left on hooks, it is possible to assess whether sharks or cetaceans are responsible for depredation, but as most depredation is not witnessed by observers, there is no information available to assess what proportion of the cetacean depredation is by false killer whales rather than by other cetacean species. Overall false killer whales are the most frequently recorded species of cetacean taken in the fishery; the number of observed false killer whale takes accounted for more takes than the next three most frequently recorded species combined (i.e., Risso's dolphin [*Grampus griseus*], short-finned pilot whale, common bottlenose dolphin: Forney and Kobayashi 2007). The first observed take of a false killer whale in the fishery was in 1997. Between 1997 and 2007 there were 11 observed takes inside the Hawaiian EEZ, 9 on deep-set (tuna) longlines and 2 on shallow-set (swordfish) longlines. In addition, 14 observed takes have been recorded outside of the Hawaiian EEZ, including 4 inside the Palmyra Atoll EEZ (Figure 11). Overall take rates have been highest at Palmyra Atoll (Forney and Kobayashi 2007). Estimates of annual takes within the Hawaiian EEZ have varied by year from 0 to 74 (Table 6; Forney and Kobayashi 2007). Over the 11-year period, the total estimated take (deaths and serious injuries) of false killer whales in the Hawaiian EEZ was approximately 124 whales.

There are several reasons why estimates of false killer whale bycatch may be negatively biased. In addition to the 11 observed takes in the Hawaiian EEZ between 1997 and 2007, 7 observed takes were not identified to species but could have been false killer whales (Table 6). The NMFS assesses observer notes for all bycaught animals that cannot be classified to species in the field to determine the possible or probable species. Five of those seven cases were ultimately classified as "either false killer whale or short-finned pilot whale," one was classified as "one of either false killer whale, short-finned pilot whale or Risso's dolphin," and the last one was classified as one of any of seven species of delphinids (including false killer whales). A valid approach to incorporate these takes would be to prorate these takes to the respective species based on the ratios at which identified species have been taken in the fishery; this could also incorporate latitude in assessing species probabilities as there is latitudinal variation in species bycaught. This would reflect a more accurate bycatch level, but this has not yet been done.

Table 6. Information on observer coverage, observed false killer whale serious injuries and mortalities, and estimated numbers of takes (serious injuries and/or mortalities) within the Hawaiian EEZ. Information from Forney and Kobayashi (2007), Forney and McCracken (2008) and McCracken and Forney (2008).

Year	Percent observer coverage (sets) combined deep- and shallow-set	Observed # false killer whale serious injuries or mortalities	Fishery type bycatch documented	PBR	Point estimates of combined mortalities and serious injuries (CV)	Five-year mean annual takes (CV)	Observed possible false killer whale serious injuries or mortalities[A]
1994	4.4%	0	N/A	ND	0	-	0
1995	4.3%	0	N/A	ND	0	-	0
1996	4.6%	0	N/A	ND	0	-	0
1997	2.2%	1	Shallow-set	ND	74 (1.0)	4.8	0
1998	3.2%	1	Shallow-set	ND	12 (1.0)	9.4	0
1999	4.2%	0	N/A	ND	0	9.4	0
2000	10.6%	0	N/A	0.8	0	9.4	0
2001	25.0%	0	N/A	0.8	0	9.4	1
2002	23.1%	0	N/A	0.8	0	7	0
2003	23.9%	2	Deep-set	0.8	8 (0.71)	4.6	2
2004	24.0%	3	Deep-set	1.0	13 (0.58)	4.2 (0.43)	0
2005	33.0%	2	Deep-set	1.0	3 (1.0)	4.9 (0.41)	1
2006	20.1%	1	Deep-set	1.0	6	5.7 (0.64)	3
2007	25.4%	1	Deep-set	2.4	8	7.4 (0.19)	0
Total		11			124		7

Note: Methods used to estimate bycatch rates vary among sources, most recent sources (2008) used when information available. [A]Based on analysis of observer descriptions by K. Forney, NMFS, five were false killer whales or short-finned pilot whales, one was a false killer whale, short-finned pilot whale or Risso's dolphin, and one was any one of seven species of small delphinid (including false killer whale).

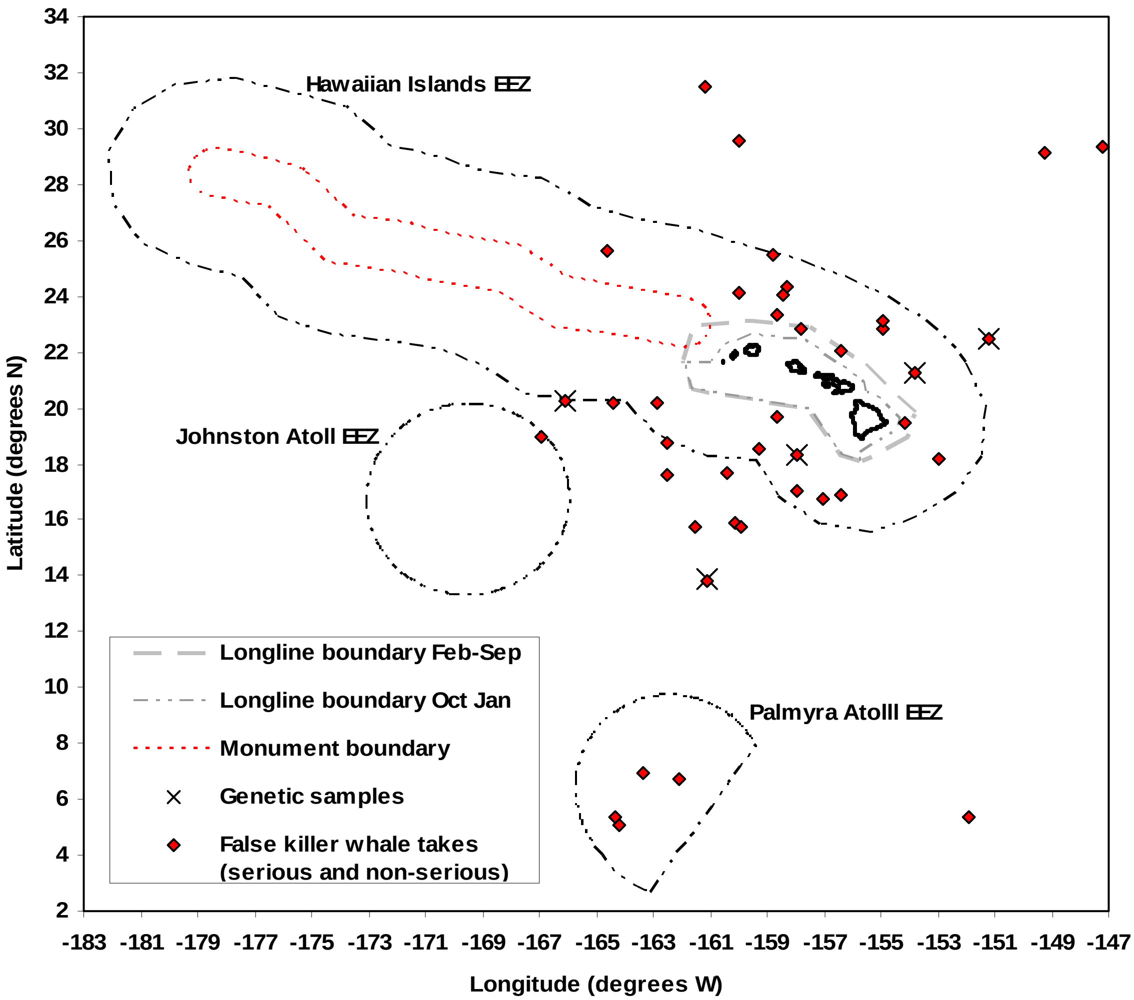

Figure 11. Locations of hooked false killer whales in the Hawai'i-based longline fishery from 1997 through July 2009 (n=41), including mortalities, serious injuries, non-serious injuries, and cases where outcome has not yet been classified (i.e., records from 2009). Location data from Pacific Islands Regional Office, National Marine Fisheries Service. Locations where hooked individuals were first detected not noted for seven records; in these cases the location where the set haul began is used.

Another possible source of negative bias is that bycatch estimates do not account for hooked animals that break off fishing gear before it is retrieved. Evidence of such interactions may be reflected by lost fishing gear, including hooks lost from branch lines, the separation of branch lines from main lines, or loss of entire segments of main lines. When main lines break, observers record the number of main line segments that are retrieved, but because the number of branch lines varies along the main line's length, observers have not recorded when branch lines are lost, and there is no current requirement for observers to record when hooks are lost from branch lines (E. Forney pers. comm.). As depredation from sharks and several species of cetaceans is known to occur, assessing what proportion of lost gear is due to hookings of false killer whales would require an overall assessment of depredation/bycatch rates by sharks and other odontocetes as well as false killer whales. Such analyses may be useful but have not yet been done.

For purposes of comparing bycatch estimates to PBR levels, NMFS uses a five-year running average of bycatch estimates to account for inter-annual variability in various factors. Each stock assessment report (SAR) for marine mammals in Hawai'i is reviewed by the NMFS Pacific Scientific Review Group before being circulated for public comment and additional review. Thus SARs generally use five years of bycatch data covering a period that ends two years before the published date of the SAR (e.g., the 2008 SARs use bycatch data from 2002 to 2006). The five-year average take rates within the Hawaiian EEZ have exceeded PBR consistently each year since bycatch rates and PBR levels were first available in 2000 (Forney et al. 2000, Carretta et al. 2009a). In 2008, when two Hawai'i stocks were recognized based on information on stock discreteness, all bycatch in the longline fishery was allocated to the pelagic stock. This was based on the locations were bycaught animals were observed and genetic analyses using samples collected by fishery observers since 2004. From 2004 through 2006 genetic samples were obtained from five bycaught false killer whales, two inside the Hawaiian EEZ (229 km and 240 km from the main Hawaiian Islands) and three from international waters (one just outside the EEZ boundary and two farther offshore; Figure 11). Four of the five samples were of mitochondrial haplotype 9, while the fifth was haplotype 6 (Table 1). Although haplotype 9 is a shared haplotype (recorded once from the insular population), this haplotype is the most frequent haplotype recorded in the eastern Pacific and elsewhere in the central Pacific (Table 1; Chivers et al. 2007). Thus, based on frequency, individuals with this haplotype are considered to be from the pelagic stock. The location of bycaught animals (determined either by exact location or, when that is unavailable, the set's end location) also indicated the bycaught false killer whales were from the pelagic stock (Carretta et al. 2009a). All locations were outside of the February-to-September longline exclusion boundary that is currently being used to approximate the geographic boundary between the insular and pelagic stocks.

There are several issues regarding the allocation of takes between the two Hawaiian stocks. From 2004 through 2006, 12 bycaught false killer whales were observed (10 serious injuries or deaths, 2 non-serious injuries; PIRO unpublished data) including animals both inside and outside of the U.S. EEZ. As noted previously, genetic samples were collected from five of these bycaught animals, but samples were not available to assess population identity for the remaining seven individuals. Given that an estimated 22 false killer whales were taken within the Hawaiian EEZ during this three-year period (Table 6), just 9 percent of the estimated animals taken within the EEZ could be attributed to stock on the basis of genetic methods. Two of the takes recorded from 2003 without precise locations noted had set end locations outside the February-September longline boundary (and thus were allocated to the pelagic stock); however, the set start locations were inside the February-September longline boundary (PIRO unpublished data). In addition, two takes in the tuna (deep-set) component of the fishery that were classified as either false killer whales or short-finned pilot whales (in November 2003 and October 2005) were recorded inside of the February-September longline boundary (Forney and Kobayashi 2007). Within the tuna (deep-set) longline fishery, Forney and Kobayashi (2007) report five bycaught short-finned pilot whales and 18 bycaught false killer whales. Given the ratio of the two species among the bycatch for which species identification was conclusive, it is most likely that at least one and possibly both of the individuals documented in November 2003 and October 2005 were false killer whales. Considering these factors, it seems doubtful that all takes in the longline fishery have been from the Hawai'i pelagic stock. In addition, the failure to account for known takes that have not been identified to species negatively biases the bycatch calculations. Logbook data from longline fishermen could be used to assess the amount of fishing effort within the February-September longline exclusion area. By combining that information with data on levels of observer coverage and overall bycatch estimates, it should be possible to estimate the probability of takes being documented inside the exclusion area.

Because depredation is a learned behavior that is passed on maternally (Powell 2009), not all individuals within a population may depredate fish off lines. Given that longline gear is encountered, it is probable that the likelihood of false killer whales depredating fish off gear varies among populations. However, no information is currently available to assess whether this is the case with insular and pelagic stocks of false killer whales. Given the restricted home range of insular false killer whales and the broad overlap of fishing effort with this home range prior to 1992 (Boggs and Ito 1993), individuals from the insular population likely interacted with longline gear regularly and depredation behavior may have been widespread throughout the population.

In 2008 there were four false killer whale hookings within the Hawaiian EEZ, three in the deep-set longline fishery and one in the shallow-set longline fishery. The three in the deep-set fishery were classified as serious injuries, and the one in the shallow-set fishery was classified as a non-serious injury (K. Forney pers. comm.). Thus, although the stock assessment report for 2009 had not been finalized as this report was prepared, it is almost certain that false killer whale bycatch rates will again exceed the PBR for the Hawai'i pelagic stock. For the first eight months of 2009, four false killer whales had been documented hooked in the Hawaiian EEZ, three in the deep-set fishery and one in the shallow-set fishery (PIRO observer program unpublished data). Serious injury determinations for those individuals, however, are not yet available.

This review has focused on false killer whales within Hawaiian waters and the potential impact of interactions with U.S. fisheries. There is, however, additional fishing effort by foreign fleets outside U.S. waters (Williams and Terawasi 2009) that likely takes false killer whales. In international waters between Hawai'i and Johnston and Palmyra Atolls to the south, U.S. fishing effort is a small fraction of the total longline fishing effort (Williams and Terawasi 2009). Given that individuals from the Hawai'i pelagic stock, as well as the Palmyra Atoll stock, likely move frequently across the U.S. EEZ international boundaries, and bycatch by the U.S. fleet alone exceeds estimated PBR levels based on the existing population estimates for the remainder of the PICEAS study area (Barlow and Rankin 2007, Carretta et al. 2009a), combined bycatch with international fleets may well far exceed PBR, further affecting populations within U.S. waters.

6. Research Recommendations

The following research recommendations are divided into three categories: (1) analyses that could be undertaken with existing data or samples; (2) analyses that could be undertaken with existing data or samples but where conclusions would benefit from additional data; and (3) analyses that require additional data or samples. No attempt has been made to set priorities for the recommendations or to identify potential funding sources. For some recommended actions, the costs should be relatively low (e.g., those involving analyses of existing data sets), and for others data or samples could be collected to address multiple research goals from single platforms or field efforts (e.g., items 1–10 of analyses requiring additional field studies). Sources of information for those based on existing data are noted.

6.A. Analyses of existing data

1. Assessment of historical and current fishing effort within the insular stock boundary to provide a basis for evaluating past and currently undocumented interactions with that stock. This should include examining geographic and seasonal changes in fishing effort over time. Data are available from the Hawai'i longline fishery logbook program, Pacific Islands Fisheries Science Center (PIFSC), and for nearshore fisheries from the Hawai'i Division of Aquatic Resources, Commercial Fishing and Marine Dealer Report data.
2. Assessment of the status and trends of primary prey species of false killer whales. This could be done by examining changes in catch per unit effort and body weight of known prey species, taking into account changes in fishing practices and areas. Data are available from the Hawai'i longline fishery logbook program, Pacific Islands Fisheries Science Center, and for nearshore fisheries from the Hawai'i Division of Aquatic Resources, Commercial Fishing and Marine Dealer Report data.
3. Assessment of boundary violations to assess the extent to which illegal fishing may have affected bycatch rates in the insular population of false killer whales. Vessel tracking data are available through the NMFS Office of Law Enforcement, Hawai'i.
4. Comprehensive characterization of the nature of depredation and interactions between false killer whales and longline gear, and examination of correlates and trends. Data are available from the PIRO fishery observer program, and some preliminary analyses have been conducted by PIFSC and Southwest Fisheries Science Center staff.
5. Assessment of the frequency of gear loss (loss of main line portions) in the longline fishery that could indicate undocumented takes. Data are available from the PIRO fishery observer program.

6.B. Analyses of existing data which would benefit from additional samples or data

1. Assessment of gene flow within and between populations using microsatellites obtained from biopsy samples. Sample size for the insular population is relatively large, but additional samples from the offshore population both within and outside the Hawaiian EEZ are needed. Additional analyses of mitochrondrial haplotypes with larger samples sizes and broader geographic representation will also help refine population structure. These analyses are currently ongoing through the Southwest Fisheries Science Center.
2. Mark-recapture population estimation for the insular stock based on photo-identification data available since the analyses of Baird et al. (2005). Data have been compiled by Cascadia Research Collective.
3. Determination of whether members of different false killer whales populations (e.g., Hawai'i insular and pelagic stocks) can be distinguished acoustically, using recordings available from the Southwest Fisheries Science Center, Pacific Islands Fisheries Science Center, and others.

6.C. Analyses requiring additional field studies or data collection

1. Examination of the movements of whales in the insular false killer whale population during the period when the longline exclusion zone contracts towards the islands (i.e., from October through January), using satellite tags. This approach is currently being used to assess movements of false killer whales by Baird et al. (in press).
2. Assessment of year-round habitat use of both the insular and pelagic stocks to determine areas of critical habitat and potential overlap with naval training exercises, using satellite tags.
3. Examination of movements of individuals from the pelagic stock using satellite tags to assess group movements in relation to stock boundaries and fishing activities. Fishing activity data could be obtained from the fishery logbook program or vessel tracking system data data to assess movements relative to fishing activities.
4. Determination of diet using genetic analyses of fecal samples to assess relative proportions of different species in the diet and how this may vary seasonally and geographically. This approach is currently being used successfully to assess diet of killer whales (e.g., Hanson et al. in press).
5. Assessment of trophic level and variations in diet in relation to population, season, sex, or age class through stable isotope and fatty acid analyses of biopsy samples.
6. Assessment of reproductive status through hormone analyses of biopsy samples. These analyses are currently being undertaken for other species of cetaceans through the Southwest Fisheries Science Center.
7. Assessment of population trends from mark-recapture analysis of photo-identification data. Given the low encounter rates but high re-sighting rates, variance associated with mark-recapture estimates is likely to be substantially lower than for line-transect estimates, thus facilitating trend analyses.
8. Assessment of persistent organic pollutant levels (POPs) as well as cytochrome P4501A1 enzyme (CYP1A1) expression in individuals from both the pelagic and insular stocks, particularly males and juveniles, given the high levels of POPs documented in males and juveniles by Ylitalo et al. (2009). Understanding how much of the chemical burdens is being mobilized in various population members can be assessed with CYP1A1, an indicator of the mobilization of endocrine-disrupting compounds (Montie et al. 2008).
9. Determination of pathogens to assess exposure to viral and bacterial disease agents. This could be done through viral screening of fecal samples and sampling of pathogens in breath samples. Both techniques are currently being used to assess pathogens in southern resident killer whales (e.g., Schroeder et al. 2009).
10. Assessment of non-fatal fishing gear interactions by collection and examination of photographs of scarring on features visible above-water (dorsal fin) and below water (mouth-line, pectoral flippers and tail flukes) of false killer whales. The latter could be undertaken using a pole camera of bow-riding individuals or through in-water photography.
11. Assessment of seasonal use of areas through the deployment of acoustic recording packages. These efforts would be particularly valuable if the pelagic and insular stocks can be discriminated acoustically. If so, deployment of acoustic recording packages should be targeted particularly in areas that are difficult to survey (e.g., offshore seamounts, Ka'ula Rock, windward sides of the islands).

12. Population viability analysis of the insular population. Demographic data required to undertake a population viability analysis would include age of first reproduction, age-specific birth and death rates, inter-birth interval, and age and sex structure of the population, none of which is known for false killer whales in Hawaiʻi. Assessment of demographic characteristics can be determined through long-term photo-identification combined with genetic studies.
13. Determination of bycatch rates using fishery observers in shortline and kaka line fisheries or other fisheries that may take false killer whales.
14. Assessment of the nature of false killer whale interactions with the longline fishery, including possible acoustic cues produced during the setting, soaking, or hauling process, and how false killer whales behave around longline gear.
15. Assessment of reactions of insular false killer whales to playback of sounds associated with longline fishing (e.g., setting, hauling gear) to determine reactions and how reactions may vary with distance.
16. Assessment of trends of pelagic stock. Given the high variance associated with the current abundance estimate of the pelagic stock, this will require substantial investment of resources.

7. Acknowledgments

This was review was funded by the U.S. Marine Mammal Commission. This report would not be complete without the information provided by the National Marine Fisheries Service, including the Pacific Islands Regional Office (John Kelly, Eric Forney, Kevin Busscher for fishery information), the Pacific Islands Fisheries Science Center (Russel Ito and Kurt Kamamoto for confirming prey species), and the Southwest Fisheries Science Center (Susan Chivers for providing unpublished haplotype data, Karin Forney for providing information on bycatch, and Jay Barlow for survival analyses), as well as Joe Mobley of the University of Hawaiʻi. Paul Dalzell of the Western Pacific Regional Fisheries Management Council provided information on fisheries and regulations and quickly answered a long series of questions regarding changes in regulations and practices over time. Marlee Breese and Paul Nachtigall, Hawaiʻi Institute of Marine Biology, provided unpublished information on nutritional intake by Kina, their captive false killer whale. Unpublished information from photo-identification of false killer whales was provided by Tori Cullins, Dan McSweeney, Erin Oleson, and Dan Salden, as well as Daniel Webster and Greg Schorr from Cascadia Research Collective. Annie Gorgone provided photo-identification matches for assessing population structure, Sabre Mahaffy assisted with social network analyses, and Damon Holzer assisted with GIS analyses. Discussions with Jay Barlow, Brad Hanson, Karin Forney, Erin Oleson, Julie Oswald, Shannon Rankin, and Barb Taylor were all helpful in refining research recommendations. I thank Jay Barlow, Bob Brownell, Susan Chivers, Annie Douglas, Karin Forney, David Laist, Suzanne Montgomery, Erin Oleson, Randy Reeves, and Gretchen Steiger for reviewing all or part of the report.

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