SUPPORTING INFORMATION

Appendix 1: Ship and Small-Boat Survey Details

Survey Effort

Between 2002 and 2023, there were 16 NOAA Fisheries ship surveys conducted by the Southwest Fisheries Science Center (SWFSC) and Pacific Islands Fisheries Science Center (PIFSC) within the central tropical Pacific (CTP) including the U.S. EEZs of Hawai‘i, Palmyra-Kingman, Johnston, Wake, and international waters[1] (Table S1, Figure 1a). The surveys covered a total of 131,120 km of on-effort trackline over 889 days within January–December (Figure 1a, S1a), resulting in 15 killer whale sightings (Table S1, S2). One sighting was initiated by Cascadia Research Collective (CRC) during a collaborative effort off Hawai‘i Island in 2016 and is therefore excluded from the ship killer whale sighting rate calculation. The overall sighting rate was low (0.11 killer whale sightings per 1000 km of survey effort), and killer whales were the third lowest of 18 odontocete species documented in the CTP during these surveys. Photos for individual identification were collected from 12 killer whale sightings during ship surveys (Table S2). Biopsy samples were collected during five killer whale sightings and satellite tags were deployed during one sighting (Table S2). Acoustic recordings made during five PIFSC killer whale sightings were available for analysis in this study (Table S2).

Between 2002 and 2023, CRC conducted small-boat surveys around the main Hawaiian Islands and covered 149,733 km of trackline over 1273 days, which varied by location and time of year (Table S3, Figure 1b, S1b). There were seven killer whale sightings, most of which were off of Hawai‘i Island where there was the greatest amount of effort (Figure 1b, S1b). After excluding three directed sightings, the resulting sighting rate across all CRC effort is 0.03 killer whale sightings per 1000 km of survey effort. Photos for individual identification were collected from six killer whale sightings during CRC surveys (Table S2). A biopsy sample was collected during one killer whale sighting, and satellite tags were deployed during two sightings (Table S2).

In 2009–2011, PIFSC, in collaboration with Scripps Institute of Oceanography (SIO), conducted small-boat surveys around Palmyra Atoll covering 2924 km of trackline during 45 days in April–October and had one killer whale sighting just north of the atoll in August (Table S2, S4, Figure 1c, S1b). In May–June 2022, the Palmyra Bluewater Research team conducted small-boat surveys for cetaceans around Palmyra Atoll, covering 633 km of trackline during six days, and had one killer whale sighting south of the atoll in June (Table S2, S4, Figure 1c, S1b). The sighting rate for the Palmyra surveys is 0.56 killer whale sightings per 1000 km of survey effort. Photos for individual identification were collected from both killer whale sightings, and a biopsy sample was collected during the 2010 sighting (Table S2).

[1] Detailed information about each survey is available in cruise reports, technical memoranda, and peer-reviewed publications. Data (sightings and tracklines) for some surveys are housed on OBIS-SEAMAP (see Table S1 for references).

Survey Effort & Sightings by Survey Type, Location, Timing, Depth, & Shore Distance

Most of the ship survey effort (77.3%; n = 687 d) and killer whale sightings (73.3%; n = 11) were within the Hawai‘i EEZ (Figure 1a, S1a). Most of the effort (79.3%; n = 705 d) and killer whale sightings (86.7%; n = 13) occurred between July and November (Figure S1a). Effort and killer whale sightings were spread across shore distances with more effort (41.9%) between 100–299 km where there were five sightings (Figure S2a). Despite only a small amount of effort (7.7%) inside of 25 km from shore, more than a quarter (26.7%) of the killer whale sightings (n = 4) occurred there (Figure S2a). Ship survey effort was spread across depth ranges but most (78.3%) was in water depths of 4000 m or greater (Figure S2b). All killer whale sighting locations during ship surveys were in water depths >1200 m and nearly two-thirds (60.0%) were in depths >4000 m (Table S5, Figure S2b).

Most of the CRC small-boat survey effort (66.6%; n = 848 d) was off of Hawai‘i Island where five of seven killer whale sightings (71.4%) occurred (Figure 1b, S1b). The other two sightings were off Kaua‘i-Ni‘ihau (Table S2). Three of the sightings (two off Hawai‘i Island and one off Kaua‘i-Ni‘ihau) were directed by other sources including a radio call from another vessel, satellite tag transmissions, and an acoustic detection (Table S2). Survey effort by CRC spanned all months of the year but was highest in April–May, August, and October–November (Figure S1b). Killer whale sightings by CRC occurred in May, July–September, and November (Figure S1b). Most of CRC’s survey effort (87.9%) was within 24 km from shore where all but one killer whale sighting occurred (Figure S2a). CRC’s survey effort was spread across depths but most (73.4%) was in waters less than 2000 m (Figure S2b). All of the killer whale sightings made by CRC were in water depths greater than 1000 m (Figure S2b).

Nearly all of the survey effort around Palmyra Atoll was within 24 km from shore (98.4%) and in depths less than 2000 m (92.1%) where both sightings occurred (Table S5, Figure 1c, S2).

Opportunistic and directed sightings occurred in all months except December and accounted for the only sightings, within the main Hawaiian Islands, in January–April, June, and October and more than half of the sightings in May and July (Figure S1c). No effort data were recorded during opportunistic/directed sightings, but location (latitude/longitude) was collected during five sightings. Four of the five sightings occurred within 20 km from shore, while one was 32 km from shore (Table S5, Figure S2a). The sightings were spread across depths from 728–4638 m (Table S5, Figure S2b).

Supplemental Tables

Table S1: Summary of ship surveys and killer whale sightings by the Pacific Islands Fisheries Science Center (PIFSC) and the Southwest Fisheries Science Center (SWFSC) within the central tropical Pacific (CTP) between 2002 and 2023. For surveys in which the ship(s) transited to and from California (CA), the on-effort days and distance are listed for the entire survey and for the study area within the CTP (see Figure 1a). Locations include the U.S. exclusive economic zones (EEZs) of Hawai‘i (HI), Johnston (JA), Palmyra/Kingman (PA), American Samoa (AS), Wake, Guam, as well as sublocations within the Hawai‘i EEZ (main Hawaiian Islands (MHI), Northwestern Hawaiian Islands (NWHI) - also referred to as the Papahānaumokuākea Marine National Monument (PMNM)), and the surrounding international waters (IW). *One killer whale sighting during the 2016 HI-TEC survey was initiated by Cascadia Research Collective. This sighting was excluded from the ship sighting rate calculation.

Survey	Org.	NOAA Ship(s)	Dates	Location(s)	On-Effort Days (within CTP)	On-Effort Distance (km) (within CTP)	Killer Whale Sightings	Reference
2002 Hawaiian Islands Cetacean & Ecosystem Assessment Survey (HICEAS)	SWFSC	McArthur & David Starr Jordan	27 Jul – 9 Dec 2002	HI; transits between CA & HI, IW	157 (141)	24,692 (21,835)	2	Barlow (2006); Barlow et al. (2004); Bradford et al. (2021)
2005 Pacific Islands Cetacean & Ecosystem Assessment Survey (PICEAS)	SWFSC	McArthur II	28 Jul – 29 Nov 2005	HI, JA, PA, IW; transits between CA & HI	101 (94)	15,714 (14,609)	3	Barlow et al., 2008
2006 American Samoa-Johnston Atoll-Hawai‘i (AS-JA-HI)	PIFSC	Oscar Elton Sette	5 – 28 Mar 2006	AS, JA, HI, IW	19	2801	1	PIFSC unpublished data
2007 Northwestern Hawaiian Islands	PIFSC	Oscar Elton Sette	26 Mar – 12 Apr 2007	MHI, NWHI (PMNM)	12	888	0	Johnston et al., 2007
2009 Main Hawaiian Islands	PIFSC	Oscar Elton Sette	4–27 Feb 2009	MHI	18	2361	0	Hill (2023a); Halpin et al. (2009)
2010 Hawai‘i-Wake-Guam	PIFSC	Oscar Elton Sette	20 Jan – 6 Feb 2010	HI, Wake, Guam, IW	14 (9)	2353 (1396)	0	Hill (2023b); Halpin et al. (2009)

Survey	Org.	NOAA Ship(s)	Dates	Location(s)	On-Effort Days (within CTP)	On-Effort Distance (km) (within CTP)	Killer Whale Sightings	Reference
2010 Guam-Wake-Hawai‘i	PIFSC	Oscar Elton Sette	19 Apr – 4 May 2010	Guam, Wake, HI, IW	14 (9)	2754 (1800)	0	Hill (2023c); Halpin et al. (2009)
2010 HICEAS	PIFSC & SWFSC	Oscar Elton Sette & McArthur II	13 Aug – 1 Dec 2010	HI; transits by McArthur II between CA & HI, IW	158 (149)	23,791 (22,473)	1	Bradford et al. (2021); Hill (2023j,k); Halpin et al. (2009)
2011 PICEAS	PIFSC	Oscar Elton Sette	20 Oct – 18 Nov 2011	HI, PA, IW	28	4022	0	Pacific Islands Fisheries Science Center (2012a); Hill (2023d); Halpin et al. (2009)
2012 PICEAS	PIFSC	Oscar Elton Sette	23 Apr – 17 May 2012	AS, PA, HI, IW	24	3439	0	Pacific Islands Fisheries Science Center (2012b); Hill (2023e); Halpin et al. (2009)
2013 Papahānaumokuākea Associated Cetacean Ecology Survey (PACES)	PIFSC	Oscar Elton Sette	7 May – 5 Jun 2013	MHI, PMNM	28	4274	1	Pacific Islands Fisheries Science Center (2013); Hill (2023f); Halpin et al. (2009)
2016 Hawaiian Islands - Technology for the Evaluation of Cetaceans (HI-TEC)	PIFSC	Oscar Elton Sette	28 Jun – 27 Jul 2016	MHI	27	3332	3*	Hill (2023g); Halpin et al. (2009)
2017 HICEAS	PIFSC & SWFSC	Oscar Elton Sette & Reuben Lasker	6 Jul – 1 Dec 2017	HI; transits by Reuben Lasker between CA & HI, IW	161 (156)	23,823 (22,982)	1	Bradford et al. (2021); Yano et al. (2018); Hill (2023l); Halpin et al. (2009)

Survey	Org.	NOAA Ship(s)	Dates	Location(s)	On-Effort Days (within CTP)	On-Effort Distance (km) (within CTP)	Killer Whale Sightings	Reference
2019 Papahānaumokuākea Marine National Monument humpback whales	PIFSC & HIHWMNS	Oscar Elton Sette	30 Mar – 12 Apr 2019	PMNM	8	654	0	Hill (2023h); Halpin et al. (2009)
2020 Winter HICEAS	PIFSC	Oscar Elton Sette	18 Jan – 12 Feb 2020	MHI	45	5268	0	Yano et al. (2020); Hill (2023i); Halpin et al. (2009)
2023 HICEAS	PIFSC & SWFSC	Oscar Elton Sette & Reuben Lasker	22 Jul – 3 Dec 2023	HI; transits by Reuben Lasker between CA & HI, IW	130 (122)	20,241 (18,986)	3	Yano et al. (2025)
Total					**944 (889)**	**140,407 (131,120)**	**15***	

Table S2: Details of killer whale sightings in the central tropical Pacific. Sighting numbers are listed in chronological order. The sighting number is followed by a letter to signify the type of sighting (R = research, RD = research directed, D = directed (no effort data), O = opportunistic). The source of sightings is listed by contributing organization (CRC = Cascadia Research Collective, PIFSC = Pacific Islands Fisheries Science Center, PIRO = Pacific Islands Regional Office, SWFSC = Southwest Fisheries Science Center) or individual (first initial, last name) and for research sightings the specific survey, year, and sighting number associated with that survey is listed (see Tables S1, S3, and S4 for survey summaries). The Location was assigned either based on the latitude/longitude for research sightings or information provided by the contributors of opportunistic sightings (NWHI = northwestern Hawaiian Islands, IW = international waters). The best estimate for group size (Grp. Best Est.) is listed when an estimate was made in the field during the sighting. The No. photo-IDs is the observed number of identified individuals from the photo-identification (photo-ID) catalog, and the social network ID (NetID) is assigned as a letter. Individuals seen together (sometimes in multiple sightings) are part of the same social network component and share the same NetID (see Figure 4 and Table S6). The group composition includes adult males (AM), adult females (AF), 'adult female sized' (AFS) individuals (possible sub-adult males), juveniles (J), calves (C) and unknown (U). Sex/age class was determined using photos (no lowercase letter), genetic sex (g), presence of a calf (c) or observations in the field (f). See "Methods – 2.2 Photo-identification and Social Network" for details on sex/age class determination.

Sighting (Type)	Date	Source	Location	Lat	Long	Grp Best Est	No. Photo-IDs (NetID)	Group Composition	No. Biopsy Samples	No. Tags Deployed	Acoustic Recording ID	Behavior	Prey	Notes
1 (R)	11-Sep-2002	SWFSC (HICEAS 2002-D168)	NWHI west	26.933	179.730	3	0	1AMf, 2AFSf	-	-	-	fast travel	-	-
2 (R)	12-Nov-2002	SWFSC (HICEAS 2002-M36)	NWHI east	24.340	-166.234	10	9 (A)	4AM, 2AFS, 2J, 1U, 1Cf	5 (see notes)	-	-	fast travel, mill, suspected predation	possible cetacean (see notes)	milling around a large (6m x 1m) piece of fleshy white meat & very little skin with oily slick; genetically sexed (4M, 1F) but no associated photos for ID or age class, 1 sample used in Morin et al. 2010
3 (R)	10-May-2003	CRC (AK#4)	Hawai'i	19.662	-156.076	4	4 (B)	1AM, 3AFS	-	-	-	travel, suspected predation	melon-headed whale (see notes)	KW with Melon-headed whales initially. MHW fled south. Observed with blood/tissue in mouth.
4 (R)	3-Aug-2005	SWFSC (PICEAS 2005-S50)	IW north	26.484	-146.778	6	4 (C)	1AM, AFS, 1J, 1U	-	-	-	travel, vessel avoidance	-	-
5 (R)	18-Aug-2005	SWFSC (PICEAS 2005-S75)	Palmyra	6.332	-163.999	5	0	-	-	-	-	slow travel	-	-
6 (R)	23-Sep-2005	SWFSC (PICEAS 2005-S180)	Johnston	17.233	-170.094	5	2 (D)	1AM, 1AFS, 1U	-	-	-	slow travel, rest	-	-
7 (R)	12-Mar-2006	PIFSC (AS-JA-HI 2006-S07)	IW south	-3.141	-167.344	12	8 (E)	3AM, 2AFS, 3J	-	-	see notes	mill, fast travel	-	pilot whales & unidentified dolphins present but no record of chase or feeding attempts; all species were vocal & recordings were made, but acoustic analyses were not conducted

Sighting (Type)	Date	Source	Location	Lat	Long	Grp Best Est	No. Photo-IDs (NetID)	Group Composition	No. Biopsy Samples	No. Tags Deployed	Acoustic Recording ID	Behavior	Prey	Notes
8 (O)	8-Oct-2006	C. Bane	Kaua‘i-Ni‘ihau	21.923	-159.897	-	3 (F)	1AM, 2U	-	-	-	-	-	-
9 (O)	22-Oct-2008	Stranding	Kaua‘i-Ni‘ihau	-	-	-	1 (G)	1AM	-	-	-	strand, die	-	-
10 (O)	18-Apr-2009	A. Reinprecht	O‘ahu	-	-	-	1 (H)	1AM	-	-	-	-	-	-
11 (O)	9-Jun-2009	M. Ushioda	Hawai‘i	19.465	-156.115	-	2 (I)	2AM	-	-	-	-	-	-
12 (O)	2-Jul-2009	H. Yocum	Kaua‘i-Ni‘ihau	-	-	-	3 (J)	1AM, 2U	-	-	-	-	-	-
13 (R)	31-Aug-2010	PIFSC (Palmyra 2010-S04)	Palmyra	5.903	-162.069	5	4 (K)	1AFg, 2AFS, 1J	1	-	-	confirmed predation	bottlenose dolphin	-
14 (R)	15-Sep-2010	PIFSC (HICEAS 2010-S45)	NWHI west	27.321	-177.004	4	4 (L)	3AFS, 1J	-	-	-	moderate travel, vessel avoidance	-	-
15 (R)	24-Jul-2011	CRC (Enc5)	Kaua‘i-Ni‘ihau	22.111	-159.937	4	4 (M)	1AM, 2AFS, 1J	-	-	-	suspected predation (chase)	rough-toothed dolphin (see notes)	RTD seen close to KW on several surfacing occasions, consumption not observed
16 (O)	14-May-2012	J. Begeman	Kaua‘i-Ni‘ihau	-	-	-	1 (N)	-	-	-	-	-	-	west of Ni‘ihau, halfway between Ni‘ihau and Ka'ula Rock, slightly closer to Ni‘ihau
17 (R)	21-May-2013	PIFSC (PACES 2013-S40)	NWHI west	27.557	-175.380	6	1 (O)	1AM	-	-	1303070	slow travel, confirmed predation	tuna sp.	-
18 (O)	2-Jul-2013	PIRO - original contributor unknown	O‘ahu	-	-	-	0	-	-	-	-	-	-	-
19 (O)	23-Aug-2013	I. Blue	Kaua‘i-Ni‘ihau	-	-	-	0	-	-	-	-	-	-	-
20 (R)	1-Nov-2013	CRC (Enc2)	Hawai‘i	19.393	-155.944	4	4 (P)	1AM, 1AFg, 2J	1	4	-	travel	-	tagIDs: OoTag043–OoTag046.
21 (D)	2-Nov-2013	R. Andrews	Hawai‘i	19.368	-156.091	-	7 (P)	1AM, 1AFg, 3AFS, 2J	-	-	-	confirmed predation	bigeye thresher shark	satellite tag transmissions directed vessel to group
22 (O)	1-Feb-2014	M. Magennis	Kaua‘i-Ni‘ihau	-	-	-	0	-	-	-	-	confirmed predation	unknown 'bait' fish	approx. 4 miles north of Moloa'a Bay; species ID confirmed with photo

Sighting (Type)	Date	Source	Location	Lat	Long	Grp Best Est	No. Photo-IDs (NetID)	Group Composition	No. Biopsy Samples	No. Tags Deployed	Acoustic Recording ID	Behavior	Prey	Notes
23 (O)	4-Jul-2015	K. Chadick (To the Max Charters)	O‘ahu	-	-	-	0	-	-	-	-	-	-	North Shore; species ID confirmed with photo
24 (O)	14-Feb-2016	W. Castillo	Kaua‘i-Ni‘ihau	-	-	-	0	-	-	-	-	-	-	species ID confirmed with video
25 (O)	2-Jun-2016	J. Kuni	O‘ahu	-	-	-	1 (Q)	1AFS	-	-	-	-	-	North Shore
26 (R)	13-Jul-2016	PIFSC (HI-TEC 2016-S43)	Maui Nui	21.247	-156.120	8	8 (R)	1AM, 4AFS, 2J, 1C	-	-	1604077	moderate travel, breach, spy hop	-	Maui
27 (R)	16-Jul-2016	PIFSC (HI-TEC 2016-S53)	Hawai‘i	19.434	-155.964	5	5 (S)	3AFg, 1JMg, 1JFg	4	-	-	slow travel, mill, social, suspected predation (chase)	unknown fish	-
28 (R)	21-Jul-2016	CRC/PIFSC (Enc3/HI-TEC 2016-S74)	Hawai‘i	19.510	-156.129	5	5 (S)	3AFg, 1JMg, 1JFg	1	2	-	moderate travel, vessel avoidance	-	initial sighting made by CRC; satellite tags deployed by PIFSC (tagIDs: OoTagP01 & OoTagP02)
29 (O)	10-Oct-2016	T. Pupuhi	Maui Nui	-	-	-	4 (S)	2AFg, 1JMg, 1JFg	-	-	-	-	-	13 miles off the south shore of Moloka‘i
30 (O)	14-Mar-2017	K. Attix	Kaua‘i-Ni‘ihau	-	-	-	5 (T)	1AM, 3AFS, 1J	-	-	-	-	-	-
31 (O)	14-May-2017	Multiple Contributors	Hawai‘i	-	-	-	6 (S)	3AFg, 1JMg, 1JFg, 1C	-	-	-	-	-	just less than 4 miles directly offshore of Honaunau
32 (RD)	7-Aug-2017	CRC	Kaua‘i-Ni‘ihau	22.074	-159.892	1	0	1Jf	-	-	see Jarvis et al. (2019)	-	-	initial acoustic detection directed vessel to group
33 (R)	8-Oct-2017	PIFSC (HICEAS 2017-S27)	NWHI east	23.647	-163.407	4	4 (U)	1AM, 2AFS, 1J	-	-	-	vessel approach, bow ride, travel	-	-
34 (O)	24-May-2019	A. Franco	Hawai‘i	-	-	-	3 (V)	1AFc, 1J, 1C	-	-	-	-	-	-
35 (O)	22-Apr-2020	S. Conae	Hawai‘i	-	-	-	7 (S)	1AFg, 2AFS, 1JMg, 3J	-	-	-	-	-	-

Sighting (Type)	Date	Source	Location	Lat	Long	Grp Best Est	No. Photo-IDs (NetID)	Group Composition	No. Biopsy Samples	No. Tags Deployed	Acoustic Recording ID	Behavior	Prey	Notes
36 (O)	1-Jul-2020	J. Lafferty	Hawai‘i	-	-	-	5 (W)	1AM, 3AFS, 1J	-	-	-	-	-	
37 (O)	4-Jul-2020	D. Bock	O‘ahu	-	-	-	0	-	-	-	-	-	-	off Barber's Point; species ID confirmed with video
38 (O)	9-Jan-2021	C. Kauffman	Hawai‘i	19.628	-154.790	-	1 (X)	1AFS	-	-	-	-	-	-
39 (O)	24-Aug-2021	Multiple Contributors	Hawai‘i	19.629	-156.330	-	7 (Y)	1AM, 4AFS, 2J	-	-	-	-	-	-
40 (O)	1-Sep-2021	via Kohn2 News	Hawai‘i	-	-	-	1 (Z)	1AFS	-	-	-	-	-	-
41 (R)	3-Jun-2022	PIFSC (PBR 2022-S11)	Palmyra	5.850	-162.123	5	3 (AA)	1AM, 2AFS	-	-	-	suspected predation (chase)	unknown fish	-
42 (RD)	29-Aug-2022	CRC (Enc1)	Hawai‘i	19.734	-156.135	8	7 (Y)	1AM, 4AFS, 2J	-	1	-	mill, travel, attack (see notes)	-	a radio call directed vessel to group; altercation with adult male pilot whale was considered an "attack" but no predation observed (per J. Ward); tagID: OoTag057
43 (D)	30-Aug-2022	Captain Zodiac	Hawai‘i	-	-	-	7 (Y)	1AM, 4AFS, 2J	-	-	-	confirmed predation	*Kogia* sp.	satellite tag transmissions directed vessel to group
44 (RD)	7-Sep-2022	CRC (Enc2)	Hawai‘i	19.439	-156.184	8	7 (Y)	1AM, 4AFS, 2J	-	-	-	mill, travel, vessel avoidance	-	satellite tag transmissions directed vessel to group
45 (R)	5-Aug-2023	PIFSC (HICEAS 2023-S10)	Kaua‘i-Ni‘ihau	22.130	-159.934	5	0	-	-	-	2303035	travel, vessel avoidance	-	-
46 (R)	16-Sep-2023	PIFSC (HICEAS 2023-S106)	NWHI west	26.413	-179.499	2	2 (BB)	2AFS	-	-	2303160	travel, vessel avoidance	-	-
47 (O)	2-Nov-2023	Dolphin Excursions Hawai‘i	O‘ahu	-	-	-	6 (S)	2AFg, 1AFS, 1JMg, 1JFg, 1J	-	-	-	-	-	-
48 (R)	10-Nov-2023	PIFSC (HICEAS 2023-L23)	O‘ahu	21.924	-158.046	6	4 (V)	1AMf, 1Uf, 1AFS, 3J	-	-	2401080	travel, vessel approach, vessel avoidance	-	-

Table S3: Summary of small-boat surveys and killer whale sightings conducted by Cascadia Research Collective around the main Hawaiian Islands between 2002 and 2023. Maui Nui includes the islands of Molokaʻi, Maui, Lānaʻi, and Kohoʻolawe. Three killer whale sightings were directed from sources outside of the visual survey effort (e.g., satellite tag transmissions, acoustic detection, radio call).

Island Area	Span of Survey Effort	No. Years Survey	Survey Months	Survey Effort (d)	Survey Distance (km)	Killer Whale Sightings (total/directed)
Kauaʻi/Niʻihau	2003–2023	15	Jan–Feb, May–Nov	236	24,952	2/1
Oʻahu	2002–2017	6	Jan–Mar, Apr–May, Oct–Nov	83	9626	0
Maui Nui	2002–2020	11	Jan–May, Jul, Oct-Dec	106	9472	0
Hawaiʻi	2002–2023	22	Jan–Dec	848	105,683	5/2
Total	**2002–2023**	**22**	**Jan–Dec**	**1273**	**149,733**	**7/3**

Table S4: Summary of small-boat surveys and killer whale sightings around Palmyra Atoll conducted by the Pacific Islands Fisheries Science Center (PIFSC) and Scripps Institute of Oceanography (SIO) in 2009–2011 and for the Palmyra Bluewater Research project, which was a multi-species study and multi-organization collaboration with The Nature Conservancy (TNC), PIFSC, Southwest Fisheries Science Center (SWFSC), San Jose State University (SJSU), Stanford University (SU), University of California, Santa Barbara (UCSB), National Geographic (NatGeo), University of Washington (UW), University of Hawai‘i (UH), and the U.S. Fish and Wildlife Service (USFW) in 2022.

Survey	Organizations	Dates	Survey Effort (d)	Survey Distance (km)	Killer Whale Sightings
2009 Palmyra	PIFSC & SIO	13 Sep – 6 Oct 2009	15	829	0
2010 Palmyra – June	PIFSC & SIO	3–20 Jun 2010	12	947	0
2010 Palmyra – Aug/Sep	PIFSC & SIO	8 Aug – 7 Sep 2010	12	852	1
2011 Palmyra	PIFSC & SIO	30 Apr – 7 May 2011	6	296	0
2022 Palmyra Bluewater Research (PBR)	TNC, PIFSC, SWFSC, SJSU, SU, UCSB, NatGeo, UW, UH, USFW	29 May – 3 Jun 2022	6	633	1
Total		**Apr–Oct**	**51**	**3557**	**2**

Table S5: Depth (m) and distance from shore (km) of killer whale sightings in the central tropical Pacific for which latitude and longitude were recorded in the field. Records are listed in order by survey effort type. 'Ship – directed' and 'Small boat – directed' sightings are those in which the vessel was directed to the killer whale group by an outside source (e.g., satellite tag transmissions, acoustic detection, radio call). Associated effort data were collected with these sightings. The 'Directed' sighting is one in which the vessel was directed to the killer whale group but no effort information was recorded and was therefore grouped with opportunistic sightings in Figures S1c and S2. Locations include the northwestern Hawaiian Islands (NWHI) and international waters (IW).

Sighting	Date	Effort Type	Location	Latitude	Longitude	Depth (m)	Shore Distance (km)
1	11-Sep-2002	Ship	NWHI west	26.933	179.730	5391	268
2	12-Nov-2002	Ship	NWHI east	24.340	-166.234	3885	52
4	3-Aug-2005	Ship	IW north	26.484	-146.778	5081	1183
5	18-Aug-2005	Ship	Palmyra	6.332	-163.999	4517	180
6	23-Sep-2005	Ship	Johnston	17.233	-170.094	4429	83
7	12-Mar-2006	Ship	IW south	-3.141	-167.344	4862	380
14	15-Sep-2010	Ship	NWHI west	27.321	-177.004	4986	105
17	21-May-2013	Ship	NWHI west	27.557	-175.380	4855	51
26	13-Jul-2016	Ship	Maui Nui	21.247	-156.120	2825	37
28	21-Jul-2016	Ship	Hawai‘i	19.510	-156.129	2724	19
33	8-Oct-2017	Ship	NWHI east	23.647	-163.407	4224	143
45	5-Aug-2023	Ship	Kaua‘i-Ni‘ihau	22.130	-159.934	1708	18
46	16-Sep-2023	Ship	NWHI west	26.413	-179.499	5408	254
48	10-Nov-2023	Ship	O‘ahu	21.924	-158.046	3040	24
27	16-Jul-2016	Small boat/Ship - directed	Hawai‘i	19.434	-155.964	1209	5
3	10-May-2003	Small boat	Hawai‘i	19.662	-156.076	1719	5
13	31-Aug-2010	Small boat	Palmyra	5.903	-162.069	422	1
15	24-Jul-2011	Small boat	Kaua‘i-Ni‘ihau	22.111	-159.937	1665	18
20	1-Nov-2013	Small boat	Hawai‘i	19.393	-155.944	1112	4
41	3-Jun-2022	Small boat	Palmyra	5.850	-162.123	876	3
32	7-Aug-2017	Small boat - directed	Kaua‘i-Ni‘ihau	22.074	-159.892	1658	12
44	7-Sep-2022	Small boat - directed	Hawai‘i	19.439	-156.184	3977	26
42	29-Aug-2022	Small boat - directed	Hawai‘i	19.734	-156.135	2035	8
21	2-Nov-2013	Directed	Hawai‘i	19.368	-156.091	3229	20
8	8-Oct-2006	Opportunistic	Kaua‘i-Ni‘ihau	21.923	-159.897	728	16

Sighting	Date	Effort Type	Location	Latitude	Longitude	Depth (m)	Shore Distance (km)
11	9-Jun-2009	Opportunistic	Hawai‘i	19.465	-156.115	2711	18
38	9-Jan-2021	Opportunistic	Hawai‘i	19.628	-154.790	2073	11
39	24-Aug-2021	Opportunistic	Hawai‘i	19.629	-156.330	4638	32
					x̄ (SD)	**3071 (1597)**	**106 (231)**
					Mdn (range)	**2933 (422–5408)**	**22 (1–1183)**

Table S6: Central tropical Pacific killer whale photo-identified individuals (n = 113) listed in order by social network ID (NetID) and catalog ID. Summary includes the sightings during which they were photographed, the years and locations seen (NWHI-northwestern Hawaiian Islands, IW-international waters), their distinctiveness (D) rating (1-not distinctive, 2-slightly distinctive, 3-distinctive, 4-very distinctive), the highest image quality (Q) rating (1-poor, 2-fair, 3-good, 4-excellent), an indication if they were biopsy sampled (B), satellite tagged (T), or not (N), and their assigned age-class and sex. Adult males (AM) were assigned if they had a tall and erect fin. The age class of other individuals was determined by the size of the individual relative to others of within an image. (AFS-“adult female sized" (possible sub-adult male), J-juvenile, C-calf, U-unknown), The sex of one AM and nine non-AM individuals was determined by genetics (g) or the presence of an associated calf (c). See Table S2 for details of each sighting.

Catalog ID	NetID	Sighting(s)	Year(s)	Location(s)	D-Rating	Highest Q-Rating	Biopsy-Tag	Age Class & Sex
HIOo097	A	2	2002	NWHI east	2	3	N	AM
HIOo098	A	2	2002	NWHI east	2	3	N	AFS
HIOo099	A	2	2002	NWHI east	1	2	N	AM
HIOo100	A	2	2002	NWHI east	2	2	N	U
HIOo101	A	2	2002	NWHI east	3	2	N	AFS
HIOo102	A	2	2002	NWHI east	1	2	N	AM
HIOo103	A	2	2002	NWHI east	1	2	N	J
HIOo104	A	2	2002	NWHI east	2	2	N	J
HIOo105	A	2	2002	NWHI east	2	2	N	AM
HIOo001	B	3	2003	Hawai‘i	3	3	N	AM

Catalog ID	NetID	Sighting(s)	Year(s)	Location(s)	D-Rating	Highest Q-Rating	Biopsy-Tag	Age Class & Sex
HIOo002	B	3	2003	Hawai‘i	2	3	N	AFS
HIOo003	B	3	2003	Hawai‘i	2	4	N	AFS
HIOo004	B	3	2003	Hawai‘i	2	2	N	AFS
HIOo106	C	4	2005	IW north	2	2	N	AM
HIOo107	C	4	2005	IW north	1	2	N	J
HIOo108	C	4	2005	IW north	3	2	N	AFS
HIOo109	C	4	2005	IW north	2	2	N	U
HIOo110	D	6	2005	Johnston	2	1	N	AM
HIOo111	D	6	2005	Johnston	2	1	N	U
HIOo112	D	6	2005	Johnston	1	1	N	AFS
HIOo077	E	7	2006	IW south	1	1	N	AM
HIOo078	E	7	2006	IW south	1	1	N	AM
HIOo079	E	7	2006	IW south	1	1	N	AFS
HIOo080	E	7	2006	IW south	1	1	N	J
HIOo081	E	7	2006	IW south	1	1	N	AM
HIOo082	E	7	2006	IW south	1	1	N	J
HIOo083	E	7	2006	IW south	1	1	N	AFS
HIOo084	E	7	2006	IW south	1	1	N	J
HIOo034	F	8	2006	Kaua‘i-Ni‘ihau	2	2	N	U
HIOo035	F	8	2006	Kaua‘i-Ni‘ihau	2	2	N	U
HIOo036	F	8	2006	Kaua‘i-Ni‘ihau	2	1	N	AM
HIOo005	G	9	2008	Kaua‘i-Ni‘ihau	3	4	B	AMg
HIOo006	H	10	2009	O‘ahu	3	2	N	AM
HIOo007	I	11	2009	Hawai‘i	3	3	N	AM
HIOo008	I	11	2009	Hawai‘i	3	3	N	AM
HIOo009	J	12	2009	Kaua‘i-Ni‘ihau	2	2	N	AM
HIOo010	J	12	2009	Kaua‘i-Ni‘ihau	1	1	N	U
HIOo011	J	12	2009	Kaua‘i-Ni‘ihau	1	1	N	U
HIOo030	K	13	2010	Palmyra	1	3	B	AFg
HIOo031	K	13	2010	Palmyra	2	2	N	AFS

Catalog ID	NetID	Sighting(s)	Year(s)	Location(s)	D-Rating	Highest Q-Rating	Biopsy-Tag	Age Class & Sex
HIOo032	K	13	2010	Palmyra	2	3	N	J
HIOo033	K	13	2010	Palmyra	1	2	N	AFS
HIOo013	L	14	2010	NWHI west	2	2	N	AFS
HIOo014	L	14	2010	NWHI west	1	2	N	AFS
HIOo015	L	14	2010	NWHI west	1	2	N	AFS
HIOo016	L	14	2010	NWHI west	2	2	N	J
HIOo018	M	15	2011	Kauaʻi-Niʻihau	3	3	N	AFS
HIOo019	M	15	2011	Kauaʻi-Niʻihau	3	3	N	AM
HIOo020	M	15	2011	Kauaʻi-Niʻihau	1	3	N	AFS
HIOo021	M	15	2011	Kauaʻi-Niʻihau	2	3	N	J
HIOo012	N	16	2012	Kauaʻi-Niʻihau	1	1	N	AM
HIOo029	O	17	2013	NWHI west	3	3	N	AM
HIOo022	P	20, 21	2013	Hawaiʻi	3	4	BT	AFg
HIOo023	P	20, 21	2013	Hawaiʻi	3	4	T	AM
HIOo024	P	20, 21	2013	Hawaiʻi	3	4	T	J
HIOo025	P	20, 21	2013	Hawaiʻi	3	4	N	J
HIOo026	P	21	2013	Hawaiʻi	3	2	N	AFS
HIOo027	P	21	2013	Hawaiʻi	3	4	N	C
HIOo028	P	21	2013	Hawaiʻi	3	3	N	AFc
HIOo037	Q	25	2016	Oʻahu	2	1	N	AFS
HIOo038	R	26	2016	Maui	4	4	N	AFS
HIOo039	R	26	2016	Maui	3	4	N	AFS
HIOo040	R	26	2016	Maui	1	4	N	J
HIOo041	R	26	2016	Maui	3	4	N	AM
HIOo042	R	26	2016	Maui	3	4	N	AFS
HIOo043	R	26	2016	Maui	2	3	N	C
HIOo044	R	26	2016	Maui	2	3	N	J
HIOo045	R	26	2016	Maui	2	4	N	AFS
HIOo046	S	27, 28, 29, 31, 35, 47	2016, 2017, 2020, 2023	Hawaiʻi, Molokaʻi, Oʻahu	2	4	B	JMg
HIOo047	S	27, 28, 29, 31, 35, 47	2016, 2017, 2020, 2023	Hawaiʻi, Molokaʻi, Oʻahu	1	4	BT	AFg
HIOo048	S	27, 28, 29, 31, 47	2016, 2017, 2023	Hawaiʻi, Molokaʻi, Oʻahu	2	4	B	JFg

Catalog ID	NetID	Sighting(s)	Year(s)	Location(s)	D-Rating	Highest Q-Rating	Biopsy-Tag	Age Class & Sex
HIOo049	S	27, 28, 29, 31, 47	2016, 2017, 2023	Hawai‘i, Moloka‘i, O‘ahu	3	4	BT	AFg
HIOo050	S	27, 28, 31	2016, 2017	Hawai‘i	3	4	B	AFg
HIOo051	S	31	2017	Hawai‘i	2	2	N	C
HIOo113	S	47	2023	O‘ahu	2	3	N	AFS
HIOo114	S	47	2023	O‘ahu	2	3	N	J
HIOo085	T	30	2017	Kaua‘i-Ni‘ihau	1	1	N	AM
HIOo086	T	30	2017	Kaua‘i-Ni‘ihau	1	1	N	AFS
HIOo087	T	30	2017	Kaua‘i-Ni‘ihau	1	1	N	AFS
HIOo088	T	30	2017	Kaua‘i-Ni‘ihau	1	1	N	AFS
HIOo089	T	30	2017	Kaua‘i-Ni‘ihau	1	1	N	J
HIOo052	U	33	2017	NWHI east	2	3	N	AFS
HIOo053	U	33	2017	NWHI east	1	3	N	AFS
HIOo054	U	33	2017	NWHI east	1	3	N	J
HIOo055	U	33	2017	NWHI east	2	3	N	AM
HIOo056	V	34, 48	2019, 2023	Hawai‘i, O‘ahu	1	4	N	AFc
HIOo057	V	34, 48	2019, 2023	Hawai‘i, O‘ahu	3	4	N	C/J
HIOo058	V	34, 48	2019, 2023	Hawai‘i, O‘ahu	3	3	N	J
HIOo096	V	48	2023	O‘ahu	2	3	N	J
HIOo059	S	35	2020	Hawai‘i	1	2	N	AFS
HIOo060	S	35	2020	Hawai‘i	1	2	N	J
HIOo061	S	35	2020	Hawai‘i	1	1	N	J
HIOo062	S	35	2020	Hawai‘i	1	1	N	J
HIOo063	S	35	2020	Hawai‘i	1	1	N	AFS
HIOo064	W	36	2020	Hawai‘i	1	2	N	AM
HIOo065	W	36	2020	Hawai‘i	2	2	N	AFS
HIOo066	W	36	2020	Hawai‘i	1	2	N	AFS
HIOo067	W	36	2020	Hawai‘i	1	1	N	J
HIOo068	W	36	2020	Hawai‘i	1	1	N	AFS
HIOo069	X	38	2021	Hawai‘i	1	1	N	AFS
HIOo070	Y	39, 42, 43, 44	2021, 2022	Hawai‘i	3	3	N	AM
HIOo071	Y	39, 42, 43, 44	2021, 2022	Hawai‘i	1	4	T	AFS

Catalog ID	NetID	Sighting(s)	Year(s)	Location(s)	D-Rating	Highest Q-Rating	Biopsy-Tag	Age Class & Sex
HIOo072	Y	39, 42, 43, 44	2021, 2022	Hawai‘i	2	4	N	AFS
HIOo073	Y	39, 42, 43, 44	2021, 2022	Hawai‘i	2	4	N	J
HIOo074	Y	39, 42, 43, 44	2021, 2022	Hawai‘i	2	3	N	J
HIOo075	Y	39, 42, 43, 44	2021, 2022	Hawai‘i	1	4	N	AFS
HIOo076	Y	39, 42, 43, 44	2021, 2022	Hawai‘i	1	4	N	AFS
HIOo090	Z	40	2021	Hawai‘i	3	1	N	AFS
HIOo091	AA	41	2022	Palmyra	1	1	N	AFS
HIOo092	AA	41	2022	Palmyra	1	1	N	AM
HIOo093	AA	41	2022	Palmyra	1	1	N	AFS
HIOo094	BB	46	2023	NWHI west	3	1	N	AFS
HIOo095	BB	46	2023	NWHI west	2	1	N	AFS

Table S7: Acoustic characteristics of central tropical Pacific killer whale high-frequency modulated whistles by sighting number and acoustic encounter given as median values with 10th and 90th percentiles in parentheses. Acoustic encounters correspond to the acoustic recording IDs listed in Table S2.

Sighting (Acoustic Encounter)	n	Begin Frequency (kHz)	End Frequency (kHz)	Median Frequency (kHz)	Center Frequency (kHz)	Frequency Slope Mean	Duration (s)
17 (1303070)	16	24.8 (23.3, 26.4)	19.5 (18.0, 21.3)	21 (19.8, 22.4)	22.2 (20.9, 23.3)	-40435 (-60835, 25047)	120 (103, 177)
26 (1604077)	286	23.1 (17.6, 28.0)	15.7 (13.8, 19.7)	18.4 (15.7, 22.2)	19.4 (16.4, 23.0)	-22261 (-50269, -13453)	225 (115, 455)
45 (2303035)	54	24.4 (23.1, 44.4)	20 (19.3, 39.4)	21.4 (20.3, 41.4)	22.2 (21.1, 41.6)	-31614 (-51409, -18085)	143 (112, 186)
46 (2303160)	6	23.3 (17.7, 36.9)	18.1 (14.5, 27.5)	20.2 (16.2, 31.1)	20.9 (16.0, 32.0)	-32285 (-50176, -11190)	182 (117, 414)
48 (2401080)	2	39.4 (38.1, 40.8)	26.2 (25.7, 26.6)	36.1 (35.0, 37.1)	32.6 (31.8, 33.5)	-118498 (-131904, -105090)	117 (112, 122)

Supplemental Figures

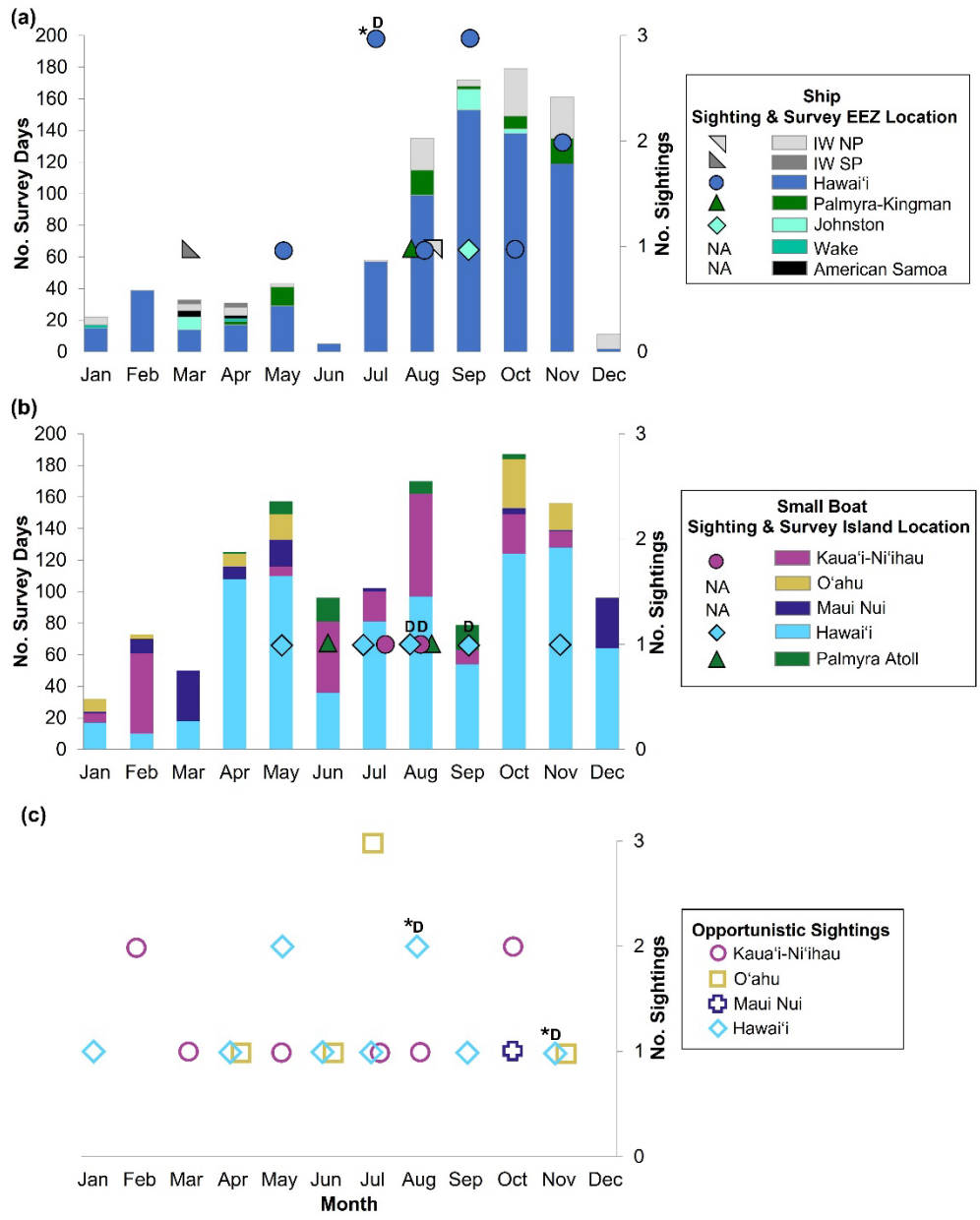

Figure S1: Survey effort (days) and killer whale sightings within the central tropical Pacific by effort type (ship, small boat, opportunistic) and month. (a) Ship survey effort (bars) and sightings (symbols) by location: U.S. exclusive economic zone (EEZ) or international waters (IW; NP – North Pacific, SP – South Pacific). There were no sightings (NA) within Wake or American Samoa EEZs. (b) Small-boat survey effort (bars) and sightings (symbols) by island location. There were no sightings (NA) off O'ahu or Maui Nui. (c) Opportunistic and directed sightings in the main Hawaiian Islands. No effort was recorded. Notes: The letter 'D' above a symbol indicates that the survey vessel was directed to the group by an outside source (see all panels). In

panel (a), one sighting was directed by Cascadia Research Collective during ship surveys. An asterisk (*) next to a symbol indicates a resight of a group in the same month, year, and island location (see panels (a) and (c)). One regular (non-directed) sighting during a ship survey (panel (a)) was a resight. Both directed sightings in panel (c) were resights prompted by satellite tag transmissions.

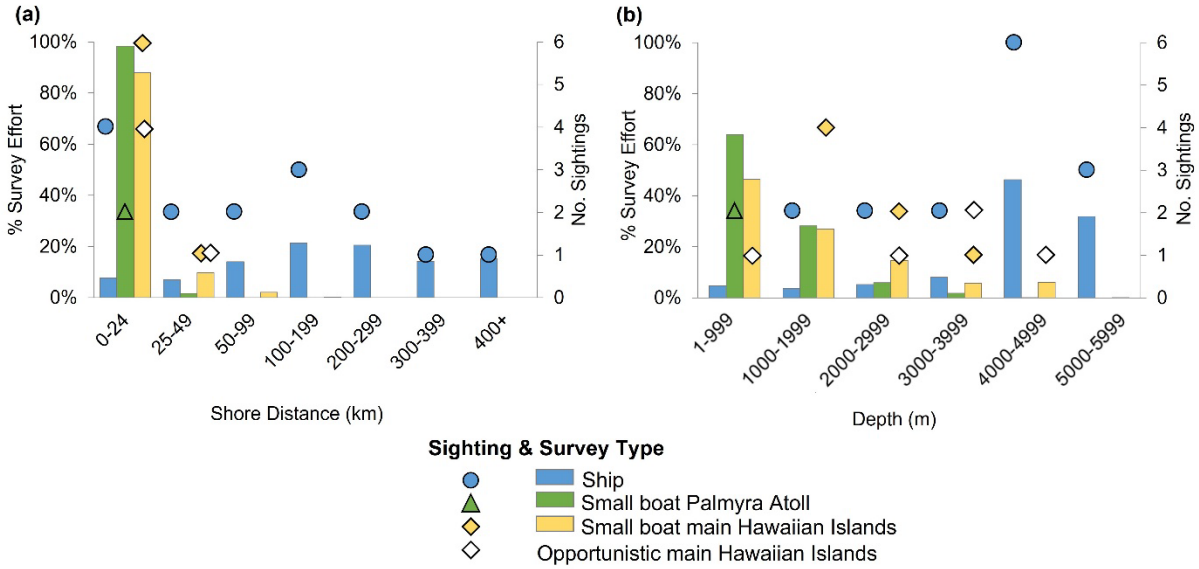

Figure S2: Effort as a percent of survey track points (bars) and number of killer whale sightings (symbols) within the central tropical Pacific by (a) distance from shore in kilometers and (b) depth in meters during ship surveys, small-boat surveys in Palmyra and the main Hawaiian Islands (MHI) and opportunistically in the MHI. There was no effort recorded for opportunistic sightings. Note: Opportunistic sightings include one sighting for which the vessel was directed to the killer whale group location by satellite tag transmissions but no associated effort data were recorded.

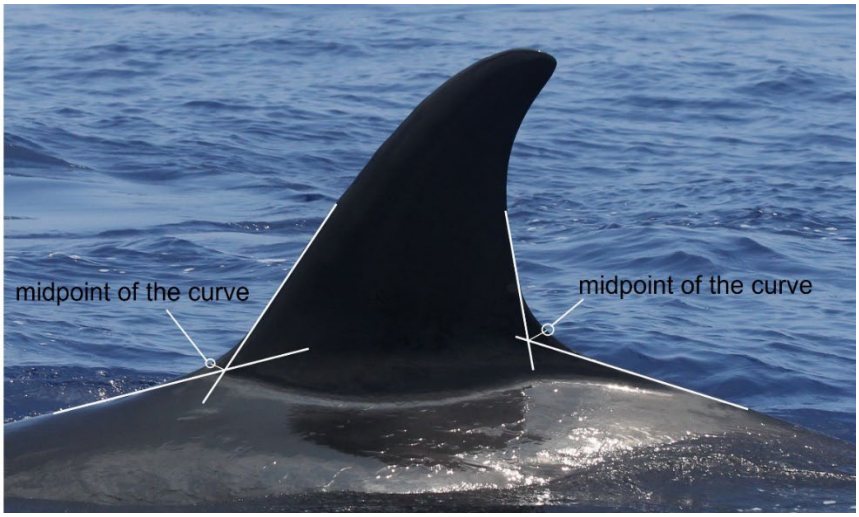

Figure S3: Determination of the anterior and posterior insertions of the dorsal fin (white circles) following Durban and Parsons (2006). Defined as the mid-point of the curve between intersecting lines that follow the main axes of the dorsal fin and body (solid white lines).

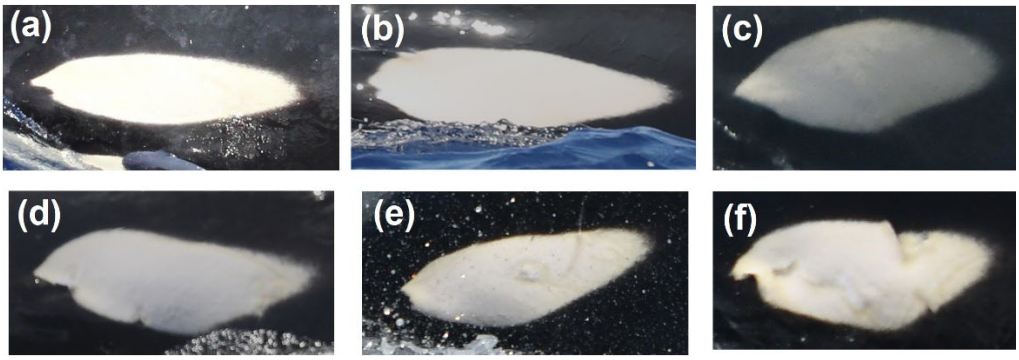

Figure S4: Examples of eye patch shapes of central tropical Pacific killer whales in order of frequency of occurrence (see Figure 5). (a) Hook & bump, (b) Bumps, (c) Narrow front, (d) Hooked, (e) Multiple hooks, (f) Rear variation. Note: Left side images showing rear taper observed in most (87%) eye patches.

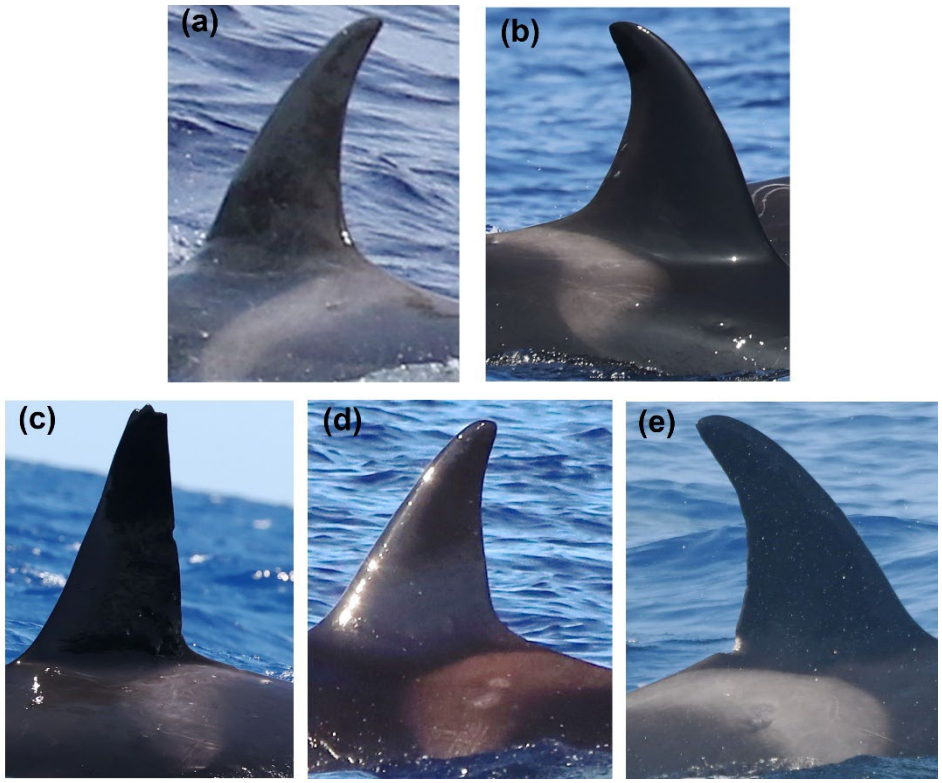

Figure S5: Example images of central tropical Pacific killer whale saddle patches showing the variation in size based on the ratio of saddle patch width (at its widest) to dorsal fin base width (at its widest) ((a) Narrow (<0.50), (b) Medium (0.50–0.70), Note: no saddle patches are categorized as wide (>0.70)) and distinctiveness/clarity ((c) Faint, (d) Intermediate, (e) Conspicuous).

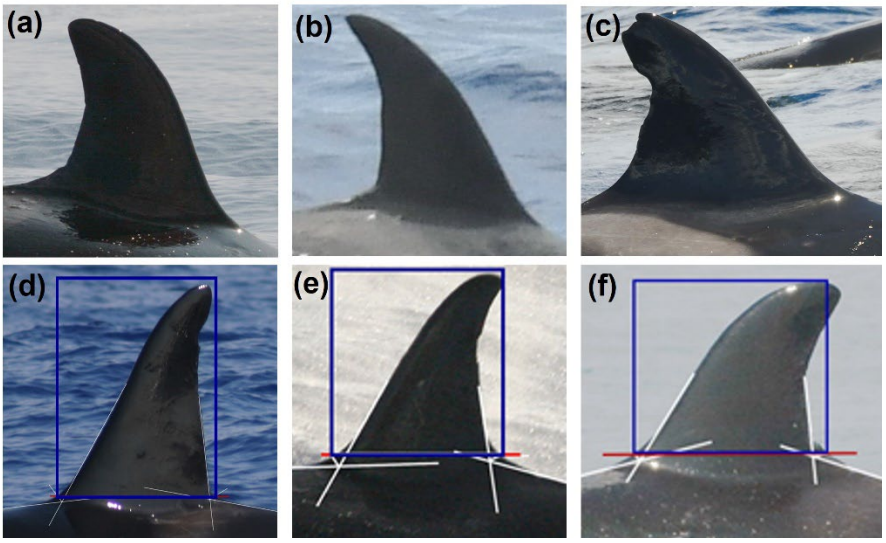

Figure S6: Example images of central tropical Pacific killer whale dorsal fins showing the variation in tip shape ((a) Round, (b) Point, (c) Tip missing) and the dorsal fin tip relative to its

base ((d) iii – between insertions, (e) iv – at posterior insertion, (f) v – beyond posterior insertion).

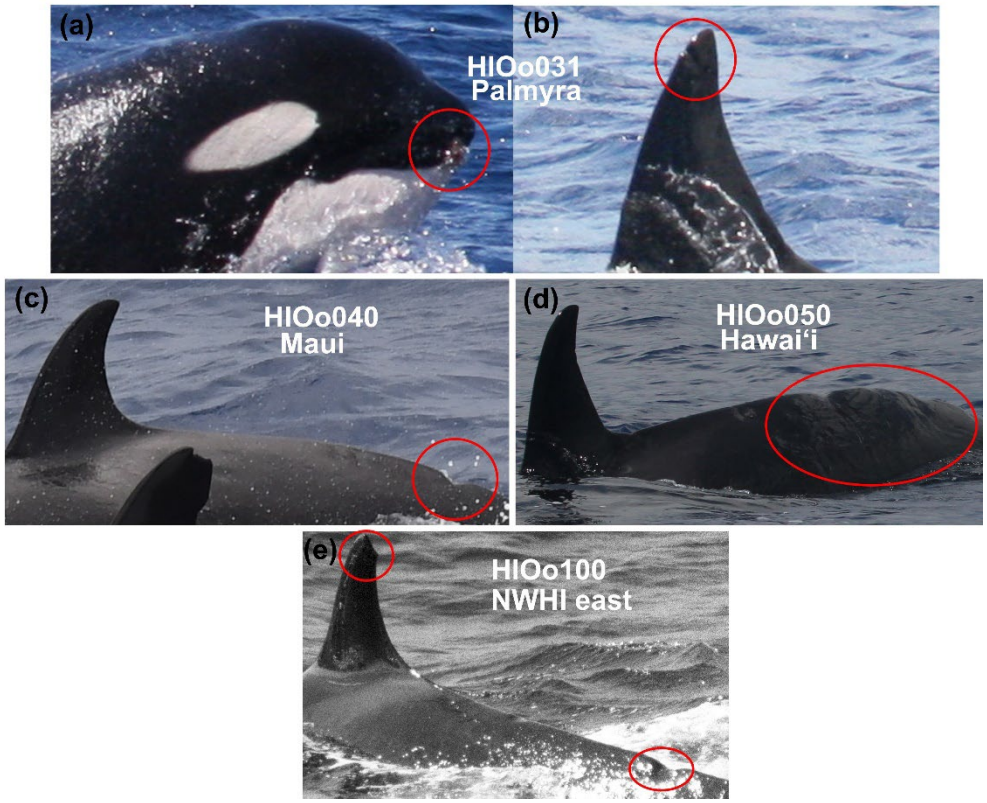

Figure S7: Central tropical Pacific killer whales with (a) mouthline, (b) dorsal fin, and (c–e) peduncle injuries consistent with fisheries interactions, and (e) a dorsal fin tip amputation possibly consistent with a fisheries interaction. The photo-identification catalog ID and location where the individual was seen is noted on the image. (NWHI – northwestern Hawaiian Islands)

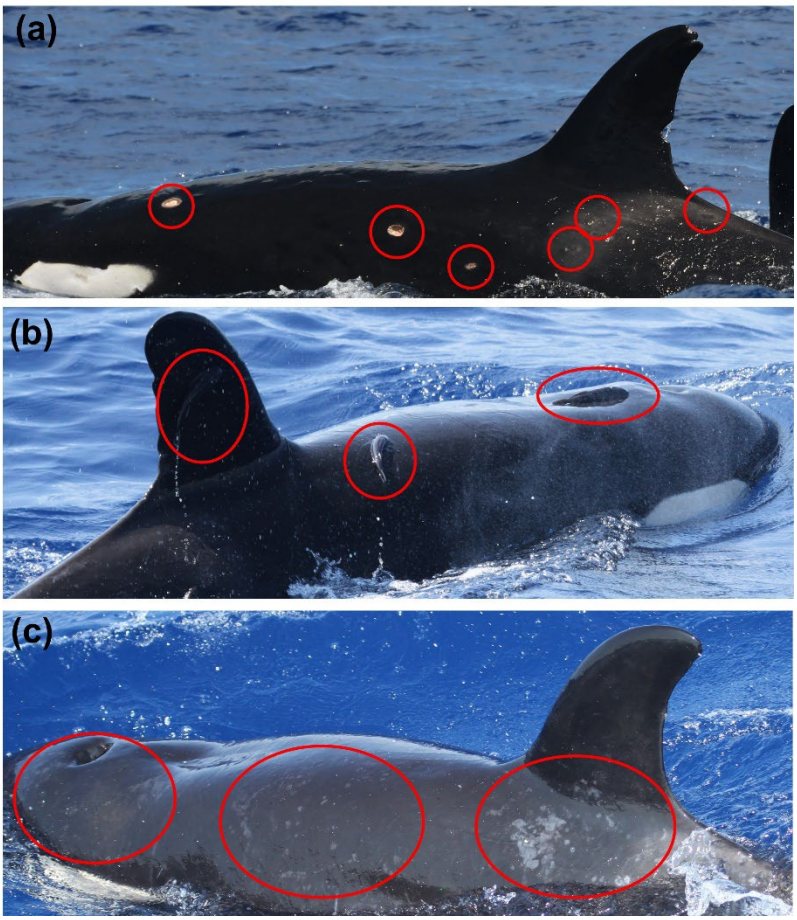

Figure S8: Central tropical Pacific killer whales with (a) cookiecutter wounds and scars, (b) remoras, and (c) an unknown skin condition resembling tattoo skin disease.

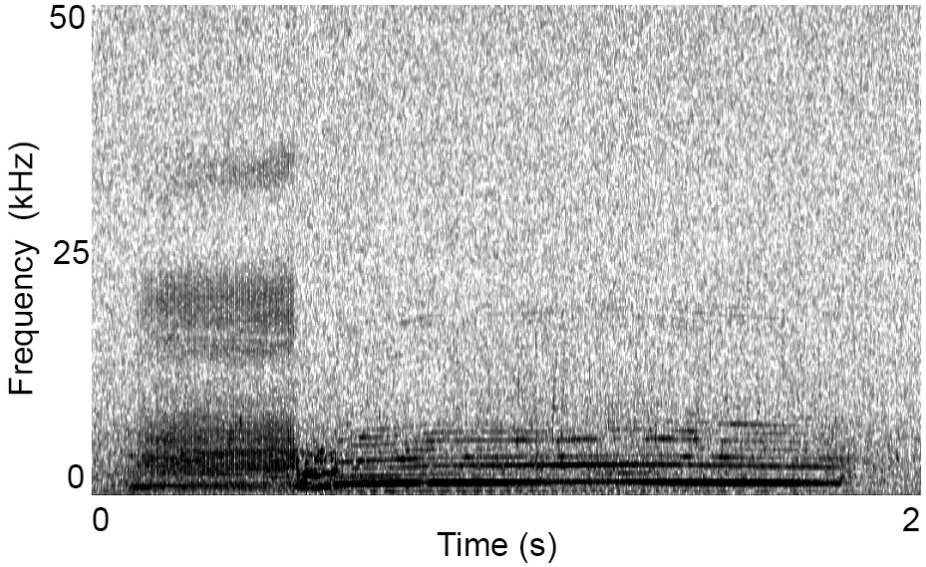

Figure S9: Example pulsed call recorded during sighting 46 (acoustic encounter 2303160).

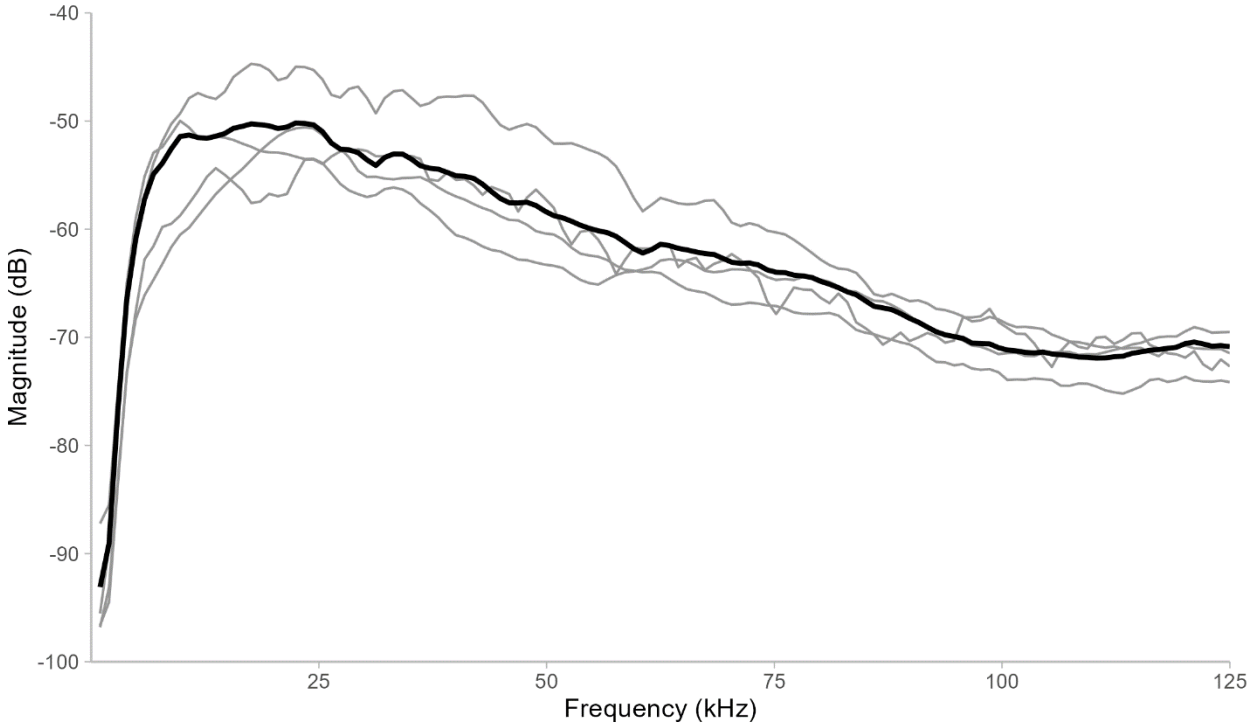

Figure S10. Spectral averages of individual towed hydrophone array event data (gray lines) for killer whale echolocation signals with the mean overlaid (thick black line). (Plotted using R-packages *PAMpal* and *ggplot2* (Sakai, 2020; Wickham, 2016))

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