BIASES AND DATA LIMITATIONS OF ODONTOCETE CETACEAN SIGHTING DATA FROM SMALL-BOAT BASED SURVEYS AROUND THE MAIN HAWAIIAN ISLANDS

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Summary

Periodic small-boat surveys were undertaken around the main Hawaiian Islands from February 2000 through February 2005, primarily to collect genetic samples and photo-identify odontocete cetaceans. A dataset of 529 odontocete sightings exists from these surveys, representing 16 different species. While the dataset is useful to note where certain species have been seen and document features such as group size and depth preferences, there are a number of biases and limitations of the dataset that must be taken into account for other analyses. There are both inter-annual and seasonal biases in survey effort. While some species are probably resident to the islands and numbers are unlikely to vary seasonally, others may use the area regularly only during certain seasons (e.g., striped dolphins, Risso's dolphins), and thus are probably under-represented in the dataset. Information is not available to assess inter-annual variability in any of the species' use of the area around the main Hawaiian Islands. Survey effort was geographically biased (by region and by depth), and particular depth preferences have been documented for most species of Hawaiian cetaceans. Thus the likelihood of documenting species will depend to a large degree on the water depths surveyed, which varied among islands and among years. Sighting probability varies among species based on dive durations, body size, group size, and surface behavior; it is likely that long-diving and/or cryptic species such as beaked whales, sperm whales, and dwarf and pygmy sperm whales are under-represented in the dataset. Additionally, given the overall low density of cetaceans in Hawaiian waters, and the low sighting rates of some species in particular, a strong small sample size bias exists for areas around Kaua'i, Ni'ihau, and O'ahu; off those areas the small amount of survey coverage relative to sighting rates for some species suggests these species are not likely to have been recorded frequently even if they may use the area on a regular basis.

Introduction

Periodic small-boat surveys were undertaken around the main Hawaiian Islands from February 2000 through February 2005, primarily to collect genetic samples and photo-identify odontocete cetaceans. A dataset of 529 odontocete sightings are available from these surveys, representing 16 different species. While all odontocete sightings were recorded in all field efforts, the primary goal of the surveys varied between each field effort, leading to considerable spatial and temporal heterogeneity in survey coverage. The purpose of this document is to review information available on surveys relevant to interpretation of data on odontocete occurrence around the main Hawaiian Islands, in particular to identify biases and limitations in the survey data in order to minimize misinterpretation of the sighting data. Additionally, results of analyses of odontocete distributions in relation to depth and residency of some odontocete populations around certain islands are discussed as it is relevant to interpreting sighting data. More information on the purpose of these surveys can be found in Baird et al. (2001, 2002, 2003, 2004, 2005).

General overview of surveys

Search effort was strongly biased geographically (Figure 1). All field efforts except for the May/June 2003 period were utilizing relatively small vessels (<20 m) which would return to a central port each night (hereafter "small-boat surveys"). In May/June 2003 a larger, live-aboard vessel was used (hereafter "large-boat survey"), and thus field efforts were more broadly distributed geographically. Field efforts were generally designed to maximize encounters with odontocetes for the purpose of biopsy sampling (for genetic studies), photo-identification (for movement and population studies), and/or tagging (to study diving behavior), rather than to produce line-transect estimates. Thus all small-boat surveys were based on the leeward (west) shores of the islands. Instead of a systematic representative coverage of a particular area, as in the case of vessel-based line-transect surveys (Barlow 2003) or aerial surveys (Mobley et al. 2000), for both small-boat and large-boat surveys routes for a particular day were determined primarily by local wind conditions, with efforts generally restricted to waters with sea states less than Beaufort 4. Given the predominant trade winds, even during the large-boat survey efforts were generally restricted to the western (leeward) shores of the main Hawaiian Islands[1]. Taking into account the restriction of survey effort to relatively calm sea conditions, efforts were made to maximize survey coverage, both along-shore and offshore, given fuel constraints and daily weather conditions. Survey effort was not distributed equally among the main Hawaiian Islands, with the majority of effort off the island of Hawaiʻi (~48%) and in the "4-island" area (Maui, Lanaʻi, Kahoʻolawe and Molokaʻi, ~33%). Relatively little effort was expended off Oʻahu (~9%) or Kauaʻi and Niʻihau (~10%).

Temporal distribution of effort

In 2000 and 2001 surveys were undertaken a couple of days a week spread over a period of several months, whereas in 2002 through 2005 survey efforts were undertaken during shorter (1-5 week) periods with survey effort every good weather day (typically 6-7 days per week). Funding available for survey efforts varied among years, thus total effort per year varied between 17 (in 2005) and 92 (in 2003) "vessel days"[2]. Survey effort is not spread evenly throughout the year, and in some areas there is no survey effort for much of the year. In two of the areas (off the island of Hawaiʻi and in the 4-island area) surveys have been undertaken in each of four different years. In the 4-island area, survey effort has been spread over seven months of the year (Figure 2), from November through May. Off the island of Hawaiʻi, survey effort is spread over eight months of the year, from September through February, and in March and April (Figure 2). Off Oʻahu the only survey effort is from April and May, while off Kauaʻi and Niʻihau effort is only available from late May and June. While some species appear to be resident to the islands (e.g., bottlenose dolphins, spinner dolphins) and are unlikely to vary seasonally in their abundance, other species (e.g., Risso's dolphins, striped dolphins) are likely to use the islands only seasonally (Risso's dolphins in cold-water periods, striped dolphins in warm-water periods).

Depth distribution of effort and sightings

Depth distribution of search effort was calculated using 5-minute GPS locations and kriging interpolation using *Surfer* (Golden Software, Ver. 7.0). Digital bathymetry data at sufficient resolution for depth interpolation (obtained from NOAA) was only available for the eastern-most islands (Oʻahu to Hawaiʻi), thus no detailed information on depth of search effort

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[1] Efforts off Kauaʻi and Niʻihau were undertaken during a period when trade winds failed, thus survey effort covered both leeward and windward coastlines (see Figure 1 and Baird et al. 2003).

[2] On most days in 2003 two vessels were operated simultaneously, each independently searching for odontocetes. In these cases two "vessel" days were tallied for days effort.

off Kauaʻi or Niʻihau is available. Depth distribution of search effort varied among island areas (Figure 3). Work in the 4-island area was primarily concentrated in shallow areas (<500 m), while work off the islands of Oʻahu and Hawaiʻi was more broadly distributed, with effort out to approximately 3,000 m off Oʻahu and out to >4,000 m off Hawaiʻi.

Analyses of sightings per unit effort in relation to depth for eight species off the island of Hawaiʻi indicated substantial differences in apparent depth preferences (Baird unpublished). Sighting rates were high for spinner dolphins and bottlenose dolphins in waters less than 500 m depth, and very low in deeper depths (Baird unpublished). Pantropical spotted dolphins and short-finned pilot whales were found over a range of depths (from <500 m to 4,500 m for pantropical spotted dolphins, and from <500 m to 3,000 m for pilot whales), but there was a peak in sighting rates for pantropical spotted dolphins in waters from 1,000-2,000 m in depth, and there was a peak in sighting rates for short-finned pilot whales from 500 to 2,500 m depth (Baird unpublished). Sighting rates for melon-headed whales and rough-toothed dolphins were highest in waters greater than 2,000 m depth (Baird unpublished). Blainville's beaked whales were found in waters ranging from 500 to 2,500 m, though sighting rates peaked between 500 and 1,000 m depth, while Cuvier's beaked whales were found in a broader depth range (1,000-4,000 m) with a peak in sighting rates between 2,000 and 2,500 m (Baird unpublished). Sample sizes to quantitatively examine depth preferences of other species (e.g., striped dolphins, pygmy killer whales) are insufficient.

Species-specific differences in depth preferences, combined with differences in the depth distribution of search effort among the islands, implies that comparisons of species sighting rates or composition among islands is not appropriate without taking into account the distribution of effort in relation to depth. In particular, given the low amount of effort in deep-water areas off Oʻahu and the 4-islands, and the overall species-specific sighting rates (see Table 2), it is unlikely that species such as rough-toothed dolphins, beaked whales, or melon-headed whales would have been recorded in the current data set off those islands, even if they occur there at the same frequency as they are found elsewhere. While we were not able to quantify the depth distribution of effort off Kauaʻi and Niʻihau, a qualitative examination of tracklines in relation to bathymetry suggests that the depth distribution of effort was more similar to effort off Oʻahu than to either Hawaiʻi or the 4-island area (see Figure 3). Thus the probability of documenting species with deep-water distributions was relatively low off Kauaʻi or Niʻihau[3].

Sighting frequency

Information on sighting frequency by species for all areas is presented in Table 2. There are a number of reasons why the frequency of sightings of different species from this study should not be considered an accurate representation of the true relative abundance of odontocetes in Hawaiian waters. These include variation in seasonal use of the study area and depth preferences, as noted above, as well as variation in the probability of detecting different species and the likelihood of identifying individuals to species. These latter issues are discussed below.

[3] It should be noted that rough-toothed dolphins were found frequently off Kauaʻi and Niʻihau, in much shallower depths than where they are typically seen off the island of Hawaiʻi, suggesting either a difference in depth preference for the same species around different islands, or a might greater density of rough-toothed dolphins off Kauaʻi and Niʻihau.

The probability of detecting different species will vary with a number of factors, including dive durations, group size, body size, surface behaviors, and avoidance (or attraction) to the research boat. Species with typically long dive durations (>20 minutes) include beaked whales, sperm whales, and both species of *Kogia* (dwarf and pygmy sperm whales). For large relatively slow-moving vessel surveys with experienced observers using high-powered binoculars, Barlow (2003) notes g(0) values (the probability of detecting a species on the trackline) as 0.23 for Cuvier's beaked whale, 0.45 for Blainville's beaked whales, 0.35 for *Kogia*, and 0.87 for sperm whales. On the smaller and faster-moving vessels used in these studies, where observers are only occasionally using binoculars for scanning, the likelihood of detecting these species on the trackline is likely lower than reported by Barlow (2003), and these species are all likely under-represented in the dataset.

For difficult to identify or evasive species, attempts were always made to obtain photographs for species confirmation. Species identification is primarily an issue for beaked whales and dwarf and pygmy sperm whales, the only two groups where the number of sightings not identified to species was large relative to the total number of sightings (7 of 23 *Kogia* sightings were not identified to species). Based on the proportion of known *K. sima* to *K. breviceps*, Baird (2005) noted that most of the unidentified *Kogia* are likely *K. sima* (dwarf sperm whales). If these sightings had been identified to species, it is likely that dwarf sperm whales would change from the 9th most frequently-encountered species to the 6th most frequently-encountered species. Combining species-recognition and dive duration information, it is likely that sighting rates for beaked whales, *Kogia* and sperm whales are all negatively biased.

However, it should be noted that such biases in detecting and identifying species correctly are greater for aerial surveys, given the high survey speed, short observation times, and greater distance between the observers and the animals in aerial surveys. Species identification from the air may be particularly difficult in poor lighting or sea conditions, and obtaining photographs for species confirmation is not always possible. There are differences in depth ranges documented for some species of cetaceans between these boat-based surveys and aerial surveys from Hawai‘i (Mobley et al. 2000), and it is unclear whether such differences are due to seasonal and/or geographic differences in search effort between the two platform types, or a higher rate of species misidentification in aerial surveys. For example, sighting rates of bottlenose dolphins and spinner dolphins are extremely low in waters greater than 500 m depth from boat-based surveys (Baird unpublished), but there are numerous sightings of these species in deeper waters from aerial surveys (Mobley et al. 2000).

Density, residency, and reproductive isolation

Density of odontocetes in Hawaiian waters is low relative to the more productive waters of the eastern tropical Pacific, but densities are higher close to the islands than in offshore waters of the Hawai‘i Exclusive Economic Zone (Barlow 2003). Genetic information is available for only a few species, but suggests that some degree of reproductive isolation exists for populations of spinner dolphins, false killer whales, and short-finned pilot whales around the Hawaiian Islands (Galver 2002; Chivers et al. 2003). Thus higher-densities close to the islands may represent reproductively-isolated "resident" populations of animals, rather than aggregations of individuals from a broader oceanic population. In addition, information available on interchange among islands and genetic differentiation within the main Hawaiian Islands suggest that for bottlenose dolphins (Baird et al. 2002, 2003; Martien et al. 2005) and probably rough-toothed dolphins (Webster et al. 2005) there may be little or no movements among island areas. Insufficient information is available to assess whether this is true for short-finned pilot whales, pantropical spotted dolphins, beaked whales or sperm whales, though both false killer whales (Baird et al. 2005) and melon-headed whales (Huggins et al. 2005) have been documented moving among islands within the main Hawaiian Islands.

For pygmy killer whales, results of a 19-year photo-identification study off the island of Hawai‘i suggest that the population size is small (likely 100-200 individuals), and the individuals show a very high level of site fidelity (McSweeney et al. 2005). This is particularly interesting given the relatively low sighting rate for this species in Hawaiian waters; they are the 11th most frequently encountered odontocete in this dataset (Table 2). Based on the overall sighting rate from the complete data set, expected sighting frequency for pygmy killer whales is one sighting per 4,500 km of search effort. Thus, despite the presence of apparently island-associated populations, given the size of the study area and the small population sizes, the amount of effort required to rigorously characterize the habitat preferences or home range of such species is considerably more than currently available.

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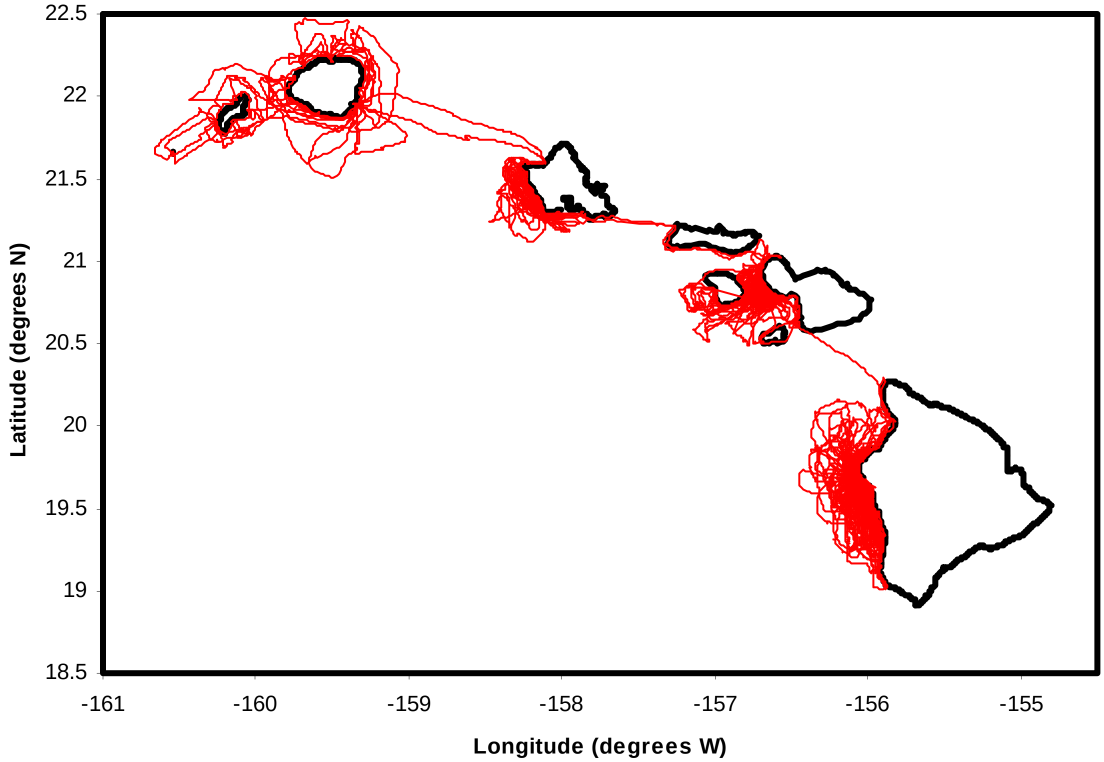

Figure 1. Geographic distribution of search effort for all years combined showing general restriction of survey effort to leeward (west) coasts, except off Kaua‘i and Ni‘ihau.

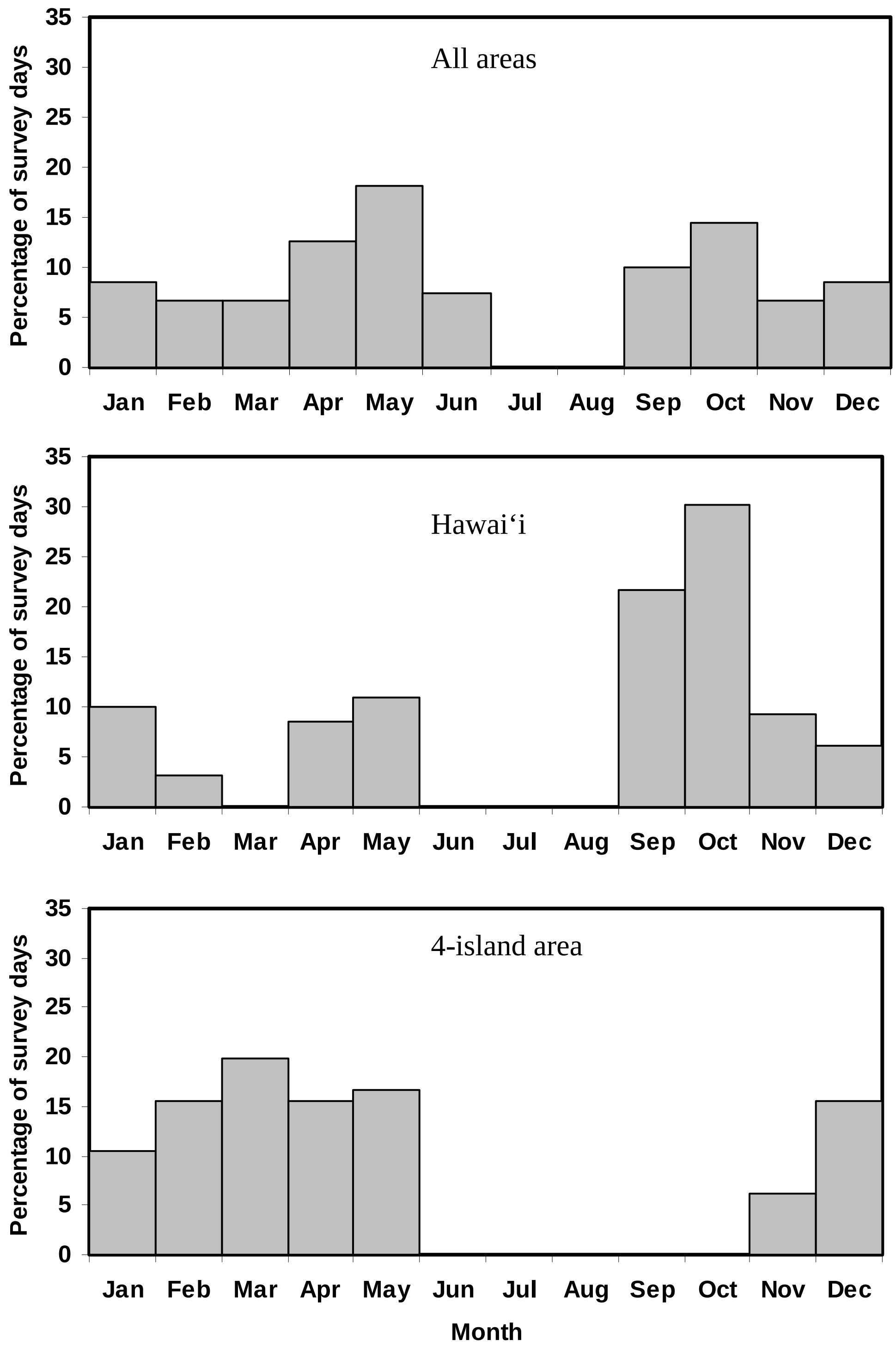

Figure 2. Seasonal distribution of search effort with all areas combined (top), for the island of Hawai‘i (middle), and in the 4-island region (bottom).

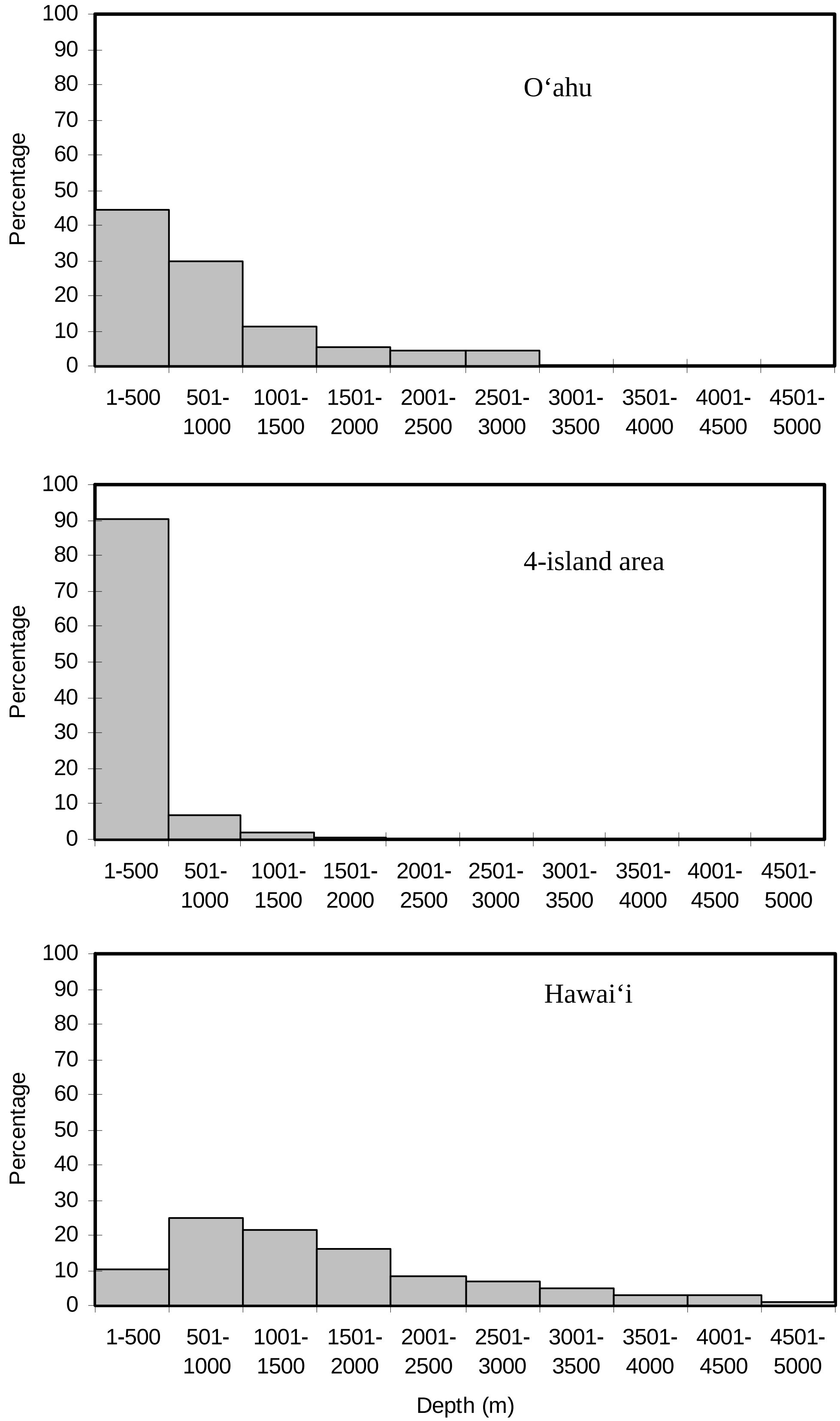

Figure 3. Depth distribution of effort by island area.

Table 1. Distribution of effort by island and field project.

Islands	Dates	# vessel days on water	# km on effort	# hours on effort	Primary focus	# vessels	Vessel type
Kaua‘i/Ni‘ihau	May 30-Jun 12, 2003	24	3,222	195	stock assessment	2	6.4 m Whaler and 18 m Striker
Sub-total		**24**	**3,222**	**195**			
O‘ahu	Apr 23-May 1, 2002	9	860	57	stock assessment	1	6.1 m Whaler
O‘ahu	May 22-29, 2003	13	1,789	111	stock assessment	2	6.4 m Whaler and 18 m Striker
Sub-total		**22**	**2,649**	**168**			
4-islands	Feb 26-Apr 18, 2000	23	1,600	158	tagging	1	6.1 m RHIB
4-islands	Nov 22-Dec 31, 2000	21	2,032	150	stock assessment	1	6.1 m RHIB
4-islands	Jan 2-Mar 24, 2001	28	2,102	203	stock assessment	1	6.1 m RHIB
4-islands	Apr 13-21, 2002	9	785	64	stock assessment	1	5.8 m RHIB
4-islands	May 13-21, 2003	16	1,659	107	stock assessment	2	6.4 m Whaler and 18 m Striker
Sub-total		**97**	**8,178**	**682**			
Hawai‘i	Apr 3-13, 2002	10	1,089	75	stock assessment	1	6.4 m Whaler
Hawai‘i	Sep 24-Oct 5, 2002	20	1,649	154	tagging	2	6.4 m and 8.2 m Whalers
Hawai‘i	May 4-12, 2003	15	1,791	108	stock assessment	2	6.4 m Whaler and 18 m Striker
Hawai‘i	Oct 8-20, 2003	24	2,495	173	tagging	2	6.4 m and 8.2 m Whalers
Hawai‘i	Sep 12 - Dec 9, 2004	42	4,656	290	tagging	1	8.2 m Whaler
Hawai‘i	Jan 19 - Feb 5, 2005	17	2,089	122	tagging	1	8.2 m Whaler
Sub-total		**128**	**13,769**	**922**			
Total		**271**	**27,818**	**1,967**			

Table 2. Details on sighting frequency and mean group size for all odontocetes for all areas/all years combined.

Species	**# of sightings**	**Rank (sightings)**	**% (sightings)**	**Sightings per 100 km effort**	**Group size (mean)**	**# ind.**	**Rank (ind.)**	**% (# ind.)**	**Ind. per 100 km effort**
Pantropical spotted dolphin	126	1	23.8	0.453	61.8	7,787	1	38.97	27.99
Bottlenose dolphin	103	2	19.5	0.370	6	618	5	3.09	2.22
Short-finned pilot whale	80	3	15.1	0.288	20	1,600	4	8.01	5.75
Spinner dolphin	57	4	10.8	0.205	57.5	3,278	3	16.40	11.78
Rough-toothed dolphin	44	5	8.3	0.158	10	440	6	2.20	1.58
Melon-headed whale	18	6	3.4	0.065	304.5	5,481	2	27.43	19.70
Cuvier's beaked whale	17	7	3.2	0.061	2.6	44	11	0.22	0.16
Blainville's beaked whale	15	8	2.8	0.054	3.5	53	10	0.26	0.19
False killer whale	14	9	2.6	0.050	17.5	245	7	1.23	0.88
Dwarf sperm whale	14	9	2.6	0.050	2.1	29	13	0.15	0.11
Sperm whale	11	10	2.1	0.040	2.8	31	12	0.15	0.11
Kogia sp.	7		1.3	0.025	2.3	16		0.08	0.06
Pygmy killer whale	6	11	1.1	0.022	11.5	69	9	0.35	0.25
Striped dolphin	5	12	0.9	0.018	43.8	219	8	1.10	0.79
Unidentified dolphin	3		0.6	0.011	11.7	35		0.18	0.13
Unidentified odontocete	2		0.4	0.007	1	2		0.01	0.01
Risso's dolphin	2	13	0.4	0.007	11.5	23	14	0.12	0.08
Unidentified beaked whale	2		0.4	0.007	2	4		0.02	0.01
Pygmy sperm whale	2	13	0.4	0.007	1.5	3	16	0.02	0.01
Killer whale	1	14	0.2	0.004	4	4	15	0.02	0.01