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by

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DELPHINID ABUNDANCE, DISTRIBUTION AND HABITAT USE OFF THE WESTERN COAST OF THE ISLAND OF HAWAI‘I

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Introduction

This study focused on the smaller delphinid species found within approximately 8 kilometers (4.5 nautical miles) of shore in waters up to about 1.8km deep (1,000 fathoms), off the western side of the Island of Hawai‘i. We investigated which species are found in these waters, their abundance, movements, habitat usage, and evidence of long-term residency. We also examined mixed-species schools and species association patterns. Spinner dolphins (*Stenella longirostris*), spotted dolphins (*S. attenuata*), bottlenose dolphins (*Tursiops truncatus*), short-finned pilot whales (*Globicephala macrorhynchus*) and pygmy killer whales (*Feresa attenuata*) were the most commonly sighted small odontocete species in these near-shore waters during previous surveys between 1989 and 1992 (Östman 1994, Driscoll 1995) and were the only odontocetes seen in this study.

Materials and Methods

Study Area

The region of interest was divided into six areas: four inshore and two offshore (Fig. 1). Inshore areas, defined as all the waters inshore of the 100-fathom contour, corresponded to the four study areas used during research conducted between 1989 and 1992 (Östman 1994, Driscoll 1995). Our intent was to extend survey Area D north to Upolu Pt. However, surveys conducted in Area D had to be cut short due to rough sea conditions, thus no surveys were done north of Malae Pt. The coastline between Area A and Area D was not covered, as dolphins are rarely sighted in this area (Norris and Dohl 1980, Norris et al. 1994, Östman-Lind pers. observations) and water conditions can be very rough when trade winds are funneled through the saddle between the Mauna Kea and the Kohala volcanoes.

Research Vessels and Vessel Surveys

Three different survey vessels were used during this study: a 38-foot Bertram, set up for big game fishing charters, was mostly used for the offshore surveys; an 18-foot Boston Whaler Outrage with a 130 Hp Honda four-stroke outboard was used for most of the inshore surveys; and, a 13-foot Boston whaler with a 50 Hp Honda four-stroke outboard was used for two inshore surveys.

During inshore surveys, the vessel was piloted about 300 meters offshore along the coastline heading away from Honokohau Harbor. Each survey was extended as far as the conditions allowed. The vessel was turned around if a sea-state of Beaufort 4 or higher was encountered. The survey track was often farther offshore on the return, sometimes as far as 1.5km offshore in Area B and 3.5km offshore in Area A.

The offshore surveys were conducted with the 38-foot commercial fishing vessel. They were divided into two study areas, based on bottom topography and following the observations of commercial fishers: Area E, north of Kaiwi Pt.; and Area F, south of Kaiwi Pt. (Fig. 1). Offshore surveys primarily followed depth contours, such as the 700- or 800-fathom isobaths. They were adjusted to take the vessel past moored fish aggregating devices (FADs), looking for both game fish and marine mammals, and were also adjusted based on information received from other vessels, to maximize the likelihood of encountering marine mammals.

Data Collection and Analysis

Vessel surveys and sightings

When a school of dolphins was found, initial sighting information was recorded. The school was generally followed for at least 20 minutes, while dorsal fins were photographed for individual identification purposes. Notes were taken on a narration tape recorder, including information on the weather (initial sea-state, wind direction, swell size & direction, wave size & direction, cloud cover and any changes in conditions during the day), research vessel (location, heading and position relative to the school), dolphin school (size, composition, heading, location, and visually recognizable individuals), and the photo-identification effort (rolls and frames taken of each school and subgroup).

The number of dolphins in each school was counted exactly for smaller schools (up to about 20 dolphins) and estimated for larger schools. School size estimates were based on extensive previous experience where surface estimates were verified by exact counts from an underwater viewing chamber (Östman 1994). In addition to the estimate, a minimum and a maximum school size was determined. The exact count or, if not available, the estimate was used for the statistical analysis in this report. The number of calves was also counted or estimated. Calf-age was approximated based on total length relative to that of an adult. Thus, calves were defined as animals roughly less than two-thirds the adult total length. Calves measure less than about 130 cm total length after one year (Barlow 1984; Perrin and Henderson 1984; Perrin and Gilpatrick 1994).

Photo identification

All photographs were taken using auto-focus cameras with motor drives, either a Nikon (8008Ss, F4) or a Minolta, with either a zoom telephoto lens (80-200mm or 80-300mm), or a 300mm telephoto lens. Kodachrome 64 ISO or Fuji 100 ISO color slide film was used. An effort was made to photograph all dolphins in each school, without regard to the presence of conspicuous marks. However, during the July surveys, conducted in collaboration with Kim Andrews (University of Hawai‘i, Manoa) who collected genetic samples from spinner dolphins, some of the effort focused on specific individuals that were recognized in the field either as resightings from previous work, or as good candidates based on especially conspicuous markings. Each roll of film was demarcated by photographing non-dolphin subjects, such as the boat engine and landmarks (blanks), between schools and subgroups whenever possible. A log was kept to track the frames taken of each school, following the protocol developed by Östman (1994) studying the same population.

Slide analysis also followed a previously developed protocol and was done in two steps, (Östman 1994). First, slides were studied by eye through a handheld 8-power magnifier (lupe), allowing for the most obviously marked individuals to be identified in photos showing the dorsal fin perpendicular to the line of sight, or at a slight angle. Dorsal fin shape, notches (in the leading and trailing edges of the dorsal fin), as well as scratches and scarring on the fins and body were used to identify individual dolphins. Dorsal fins that could not be positively identified by eye, either because they were taken at an angle or because the fin had less obvious marks, were projected on to tracings of previously identified fins. This allows for the size and exact location of each identifying marks, as well as the shape of the fin to be matched between the photo and the tracing. For photos of dorsal fins taken at an angle, the angle of the tracing was adjusted to allow for a match. If a dorsal fin was not positively matched with a previously identified fin, it was considered a new individual. In these cases a tracing was made, a new identification code was provided, and the photograph was added to the catalogue. Each photograph added to the catalogue was rated for quality and when higher quality photos were found, both the photo in the catalogue and the tracing was replaced. Occasionally, a new photograph allowed for two different tracings to be matched to the same dorsal fin and the two tracings were assigned to the same individual. The more recently assigned code was added to a list of retired ID codes. Thus, although the ID catalogue kept growing throughout the analysis, occasionally it was reduced in size as two different tracings were determined to be of the same individual.

Genetic samplings

Genetic sampling was conducted in collaboration with K. Andrews. All genetic samples are being analyzed by K. Andrews, and details of methodology and preliminary results are to be included in future reports.

Human – Dolphin interactions

Human activity around dolphin schools was grouped into three categories: (a) boats focusing on the dolphins, i.e. boats that were maneuvered so that the pilot and passengers could get a closer view of the dolphins and/or could enter the water to swim with them; (b) other boats that were in the area but did not approach the school, including moored and anchored boats, as well as vessels just drifting in the area when the dolphin school was less than 400m away and continued drifting until the school had passed; and, (c) swimmers, with or without snorkeling gear, that approached and swam in the area used by the dolphins. Most of the swimmers entered from boats focusing on the dolphins and were often squealing in their snorkels while approaching the dolphins.

To quantify the human disturbance, a Human Disturbance Index (HDI) was calculated for each 10-minute time-period during the day, where each swimmer and each boat focusing on the dolphins during that time-period was given a value of 1 and each other boat was given a value of 1/3. These values were added for each time-period and divided by the number of schools followed by the research vessel during that time-period.

To look at the type of human activity over the course of the day, a similar index was calculated for each of the three human activity categories (boats focusing on dolphins, other boats, swimmers) for each 10-minute period and averaged for each hour of the day. Each category was given the value of 1, added up for all the schools followed during that time-period and divided by the number of schools followed by the research vessel during that time-period.

Critical spinner dolphin resting habitat

Spinner dolphin resting areas were assigned to one of three categories, (critical, secondary or probable) based on several criteria. The coastline from Upolu Point to Kauhako Bay (Areas A-D), was evaluated based on observations during this study, as well as, extensive analysis of data collected between 1989 and 1992 and published accounts from previous studies (Norris and Dohl 1980 and Norris et al. 1994). In addition, a survey was conducted of people that have lived on the island for many years and utilize parts of the coastline from south of Kauhako Bay to Hilo Bay.

Results

Vessel Surveys

One thousand fifty kilometers of surveying, representing 117.3 hours of field effort, were conducted on 22 days, from March through November 2003, in the waters off the western side of the Island of Hawaiʻi. These surveys covered the coastline from Kauhako Bay (19° 23' N, 155° 54' W) in the south to Malae Point (20° 07' N, 155° 53' W) in the north (Fig. 1, Table 1).

Twenty inshore surveys were conducted, covering approximately 800km. Surveys were conducted between March 26 and November 19, with the majority of the field effort (17 days) conducted between May 29 and July 20 (Table 2). The March 26 survey was the only survey divided between inshore and offshore waters. It covered Area A in the morning, until 10:20, and then went offshore into Area E. In addition two all-day offshore surveys were conducted on October 10 and 20.

A total of 48 schools of dolphins were sighted during these surveys (Table 3), for an over-all sighting rate of 4.6 schools per 100km. The sighting rate was higher in the inshore areas (5.25 schools per 100km) than in the offshore areas (2.4 schools per 100km).

Thirty-nine of the 48 schools contained spinner dolphins (*Stenella longirostris*), with at least one school containing spinner dolphins sighted per day on 19 of the 20 inshore survey days (mean 1.95, se =1.0) schools per day. Schools containing spinner dolphins were sighted in all four inshore areas (A-D), with 30 of the schools (76.9%) sighted in Area A (Fig. 2). No spinner dolphins were found in either of the two offshore areas (E and F). Of the 32 schools containing only spinner dolphins, all were in waters less than 100m (60 fathoms) deep, and 23 (72%) were in waters less than 50m deep. All but four of the sightings were within 500m of shore, and these four were well within the 100-fathom isobath. Seven mixed-species schools of spinner and spotted dolphins were all found in Area A, with five of the schools sighted north of Keahole Pt. These schools were all found in waters less than 60m deep, within 500m of shore.

Six schools containing only spotted dolphins (*S. attenuata*) were sighted. Four schools were sighted during the three offshore survey days, providing a mean of 1.3 (se = 0.7) schools per day. All four schools were sighted in the southern part of Area F, between six and eight km offshore, in waters between 1.3 and 1.7km deep. Two schools were sighted within the 100-fathom contour in Area A. One school was 5.5km offshore in 135m deep waters and the other 600m offshore over a depth of 35m.

Two schools of bottlenose dolphins (*Tursiops truncatus*) were sighted. A group of two animals briefly joined a school of spinner dolphins in Area A, about 400m offshore in 20m-deep waters. It is recorded as a mixed species school in Figure 2. The second school was sighted in Area B, among the moorings in Kailua Bay, 300m offshore in 10m-deep waters.

A mixed-species school of short-finned pilot whales (*Globicephala macrorhynchus*) and pygmy killer whales (*Feresa attenuata*) was sighted in Area F, about 6.5km offshore at a depth of 1.3km. Finally, an unidentified whale was sighted from a distance of about 2 to 3km on July 28, in the northern part of Area A. We approached the whale to within about 1.5km when it was last seen to blow. The blow was reminiscent of that of a medium sized rorqual.

Species distribution

Spinner dolphin schools

The number of spinner dolphins per school (including mixed-species schools) ranged from 1 to 175. The single-animal school was sighted 600m away from a school of nine spinners. The individual had a remora attached to it and was spinning repeatedly, moving away from that school. It is treated as a separate school in Figure 3, but was excluded from calculations of mean school size as it is considered highly anomalous. This is the first time that J. Östman-Lind has ever sighted a spinner dolphin school confirmed to consist of only one individual. Schools containing spinner dolphins, including mixed-species schools, had an average 58.5 (se = 8.5, n=38) spinner dolphins per school, while schools of only spinner dolphins had a mean school size of 47.7 (se = 7.8, n= 31).

The most frequently sighted school sizes were between 1 and 20, representing 33% of all spinner dolphin schools (Fig. 3). Twenty-nine (76.3%) schools contained up to 80 spinner dolphins. The number of spinner dolphins encountered per day varied greatly from 7 to 242, with a mean of 118 (Fig 4). For example, the change from field day #3 (June 2) to field day #4 (June 3) showed a great increase in number of dolphins (93 - 199) in Area A over night, while day #11 – #13 (July 20 to 22) showed a similar decrease (239 – 135 - 92) in the same area over three days. There was no correlation between the amount of time spent per survey and the number of dolphins seen per day (correlation coefficient, r = 0.32).

There was an estimated 55 calves sighted in 25 schools during this study, representing a mean of 2.9% spinner dolphins calves over all. The proportion of calves varied between the months surveyed, with the highest proportion sighted in November and March (Fig. 5). These two peaks result from sightings of a minimum 8 calves in a school of 75 and 1 calf in a school of 12, respectively.

Mixed *Stenella* schools

Eight (20.5%) of the observed dolphin schools containing spinner dolphins were mixed-species schools, for at least part of the observation period. The seven mixed-species schools encountered during the summer all included spotted dolphins in addition to the spinners. The remaining school included bottlenose dolphins and is discussed below. The mixed *Stenella* schools were larger on average than schools containing either just spinner or just spotted dolphins (Fig. 6). The mixed *Stenella* schools were all sighted during the inshore surveys and contained an average 106.0 (se = 24.7) spinner dolphins and 13.6 (se = 1.5) spotted dolphins (Fig. 7). On average, these mixed schools contained more than twice as many spinner dolphins than schools containing only spinners (47.7, se = 7.8). However, for the spotted dolphin schools, a different pattern emerged. The mean number of spotted dolphins (13.6, se = 1.5) in mixed *Stenella* schools, all sighted inshore, was almost identical to the mean school size of the two inshore schools containing only spotted dolphins (13.5, se = 1.5), but much smaller than the offshore schools only containing spotted dolphins (Fig. 7).

Spotted dolphin schools

Spotted dolphins were encountered both during inshore and offshore surveys. The number of dolphins per school (including mixed-species schools) ranged from 6 to 125, with a mean of 36.8 (se = 11.5). However, there was a distinct difference in the number of spotted dolphins found in schools between inshore and offshore areas (Figs. 7 and 8). Inshore schools containing spotted dolphins contained a mean 13.3 (se = 1.3, n = 9) spotted dolphins, while the mean school size for offshore spotted dolphin schools was 83.8 (se = 18.5, n = 4). Of the nine schools containing spotted dolphins sighted during the 20 inshore survey days (0.4 schools/day), seven (77.8%) also included spinner dolphins (Fig. 7). None of the four spotted dolphin schools sighted during the offshore surveys included any confirmed spinner dolphins.

Spotted dolphin calves were also documented during this study. A calf that was two-thirds adult length was sighted inshore twice in June and once in July. At least 14 calves one-half adult length or smaller were sighted in the offshore schools in October. Figure 9 shows the mean proportion of spotted dolphin calves sighted per month.

Other species of marine mammals

The two schools of bottlenose dolphins were small (2 in one and 3 in the other). No bottlenose dolphin calves were sighted during this study.

The group size of the mixed school of short-finned pilot whales and pygmy killer whales was not accurately assessed. Because of the constraints of working on a fishing vessel we did not approach the school close enough for photo-ID, nor spend enough time with it to get an accurate count. Two short-finned pilot whales and one pygmy killer whale were sighted. The short-finned pilot whales were seen from over two kilometer away, as we approached the school and one of them was still at the surface as we passed about 300m inshore, but the pygmy killer whale was just briefly sighted as we passed the school. It is thus likely that more animals were in the area, but did not surface during the 10-minute period it took us to pass.

Photo identification

Dolphins were photographed for individual identification purposes from 46 of the 48 schools sighted. One school of about 25 spinner dolphins resting in Kealakekua Bay, and the mixed-species school of short-finned pilot and pygmy killer whales were not approached within photo range. A total of 135 rolls of film (approximately 4,860 images) were used for photo identification purposes during this study.

Photo-identification analysis

Photo-ID analysis has initially focused on spinner dolphins. The first 54 rolls of film (18 schools) were analyzed completely, and an additional 63 rolls (20 schools) were partially analyzed for the most obviously marked individuals. At this point, 217 individual spinner dolphins (144 in the first 18 schools) have been identified. A mean of 6 new individuals (range 1–30) were identified for each additional school analyzed (Fig. 10). For the first 18 schools, up to 60.0% (39 of an estimated 65) of the individuals were identified (mean 24%, se = 3%), based on estimated school size (Fig. 11). One school (#28 in Fig. 11) contained 10 dolphins, eight of which were identified. The school that was 100% identified contained only 1 dolphin.

Abundance estimate

A rough population estimate was calculated for the spinner dolphin population using the same method used in two earlier studies of this population (Norris et al. 1994, Östman 1994), using the following calculation:

Total Number of Identified Individuals / Mean Percent of Individuals identified per school

By using two slightly different methods to get the mean percent of individuals identified per school, two different abundance estimates were produced: (1) by dividing the total number of individuals identified in all school with the sum of all school size estimates, a mean identification rate of 21.7% was produced. Applying this identification rate to the number of individuals in the photo-ID catalogue (217) provides a population estimate of 1,001; (2) by averaging the identification rate for each school, a mean identification rate of 25.4% is produced, providing a population estimate of 855.

Repeated sightings of known individuals

Eight individual spinner dolphins identified during our 1989 –92 study were resighted during this study. All of these animals were determined to be males by a close inspection of the genital area from an underwater viewing chamber, during that previous study (Östman 1994).

Of the eight re-sighted dolphins, Pincer High Step and Square Hook were each sighted in five schools during this study and they were documented together in the same school three times. 4-Nip was sighted in three different schools, all containing Pincer High Step. These last two males had a coefficient of association in the 40^{th} percentile during the 1989-92 study. Square Hook and 4-Nip, who were sighted together in one of the 24 schools in this study, had a coefficient of association in the 50^{th} percentile in the last study. Wart and Finger Fin, sighted on 6 and 3 occasion respectively, were seen in the same school twice.

Movement between areas

Of the 217 identified spinner dolphins, 110 were sighted in two or more schools and 72 of these (65.4%) were seen in more than one area (Fig. 12). Two of these schools were sighted in the late morning (10:50 and 11:30 hours) of June 17. They were made up of splinter groups from two schools sighted earlier in the morning (07:22 and 09:03 hours) about 7km apart in Area A. These original schools must subsequently have broken up, with subgroups recombining into at least two new schools, approximately 2km apart, between the locations of the original sightings. Since insufficient time was spent photographing the latter two schools, they were only used to analyze movements between areas.

Of the 12 spinner dolphins seen in three different study areas, seven (58.3%) were identified in Areas A, B and D, and one of these seven was followed around Kaiwi Point between areas A and B. The remaining five (41.7%) spinner dolphins were identified in Areas A, B and C. The number of dolphins documented to have moved between different study areas can be seen in Figure 13. Thirty-four dolphins were photographed in both Area A and D, a minimum of 28km apart, while 5 dolphins were photographed in both Area A and C, a minimum distance of about 21km apart.

Of the 110 dolphins with multiple sightings, 38 (34.5%) were only identified in one area, 37 in Area A and one in Area B. Of the dolphins only found in Area A, one (2.7%) was sighted seven times, and eighteen (48.6%) were sighted on three to five occasions each. This can be compared with the 12 dolphins sighted in three different areas. One (8.3%) of them was sighted six times, nine (75.0%) were sighted between three and five times, and two were only sighted twice. However, in one of the sightings six of the 12 dolphins, including the two only sighted twice, were followed around Kaiwi Point between areas A and B.

Genetics

Well over 30 genetic samples were collected from well-marked spinner dolphins. As stated above, all genetic samples are being analyzed by K. Andrews and details of methodology and results are to be included in future reports.

Resting Areas and Human-Dolphin Interactions

Spinner dolphin resting areas

Spinner dolphin resting areas are divided into three categories, (1) critical resting areas that are frequently used and considered very important to the spinner dolphin population, (2) secondary resting areas, that are either only used seasonally or just occasionally, and (3) probable resting areas based on information obtained in a survey of ocean users, warranting more study. Figure 14 shows the currently known resting areas and potential resting areas around the Island of Hawai‘i. It is notable that no critical resting area is known for the Kohala coast, from Puako north (Area D in Figure 1). Very little is known about the southeast and northeast parts of the island and these are difficult areas to work because of the generally rough sea conditions.

Human activities in and around spinner dolphin resting areas

To investigate human-spinner dolphin interactions, the 17 vessel surveys carried out with an 18-foot vessel between May 29 and July 30, 2003, were analyzed. Of the 17 analyzed surveys, ten were conducted in the morning, four in the afternoon and three covered both mornings and afternoons. The total effort, by 10-minute period, is displayed in Figure 15. Most of the effort was in the mornings, when spinner schools are relatively active, often moving along the coast in search of a resting area (Norris et al. 1994, Östman 1994). This period corresponded with a peak in the number of contacts per effort (Fig. 15). There was also a second peak in number of contacts per effort in the afternoon, when a couple of known resting areas (Kealakekua Bay and Kauhako Bay) were targeted.

All schools that were approached by humans contained spinner dolphins. Four of 38 schools containing spinner dolphins (10.5%) were approached by boats only, while another 13 schools (34.2%) were approached by both boats and swimmers with snorkeling gear. The majority of swimmers were dropped from boats. Thus, humans in boats and/or swimmers were observed to target 17 (44.7%) of the 38 schools sighted and followed during these surveys.

Most of the human activity around the schools was observed in the mornings, with a small peak in the HDI after 07:00 and a larger peak between 09:30 and 11:00 hours. There were additional HDI peaks in the mid-afternoon, between 14:40 and 15:20 hours, and the late afternoon, at 17:00 hours (Fig. 16).

Temporal patterns of human activity around the dolphins showed several diel peaks (Fig. 17). The first peak in the morning was primarily caused by fishing boats leaving the harbor on their way to the fishing grounds, passing the spinner schools milling in front of the harbor mouth as they headed out. Most of these boats did not change their direction or speed of travel as they left, although the passengers often got a glimpse of some of the dolphins surfing in the boat wake. The boats focusing on the spinner dolphin schools and the swimmers mostly spent time with the dolphins in the mid-morning, creating the mid-morning peak. The peak of human activity around spinner dolphin schools in the mid-afternoon was mostly observed in the two resting bays south of Kailua-Kona, Kealakekua and Kauhako Bays. Most of the human activity in Kealakekua Bay was boat based, either motorboats or kayaks, while people swam out from shore to swim with dolphins resting in Kauhako Bay. The research effort tapered off in the afternoon (Fig. 1) so the data set is too small to assess the accuracy of the late afternoon peak.

Discussion

Abundance Estimate

Spinner Dolphins

Photo-identification analysis presented here provides a rough population size range of 855 to 1,001 for spinner dolphins utilizing the near-shore waters off the western coast of the Island of Hawaiʻi for daytime resting and socializing. This approximates that given by Norris et al. (1994) for a 1979 to 1981 study (960), but is much smaller than the estimate provided by Östman (1994) for the population between 1989 and 1992 (2,334). However, all of these estimates suffer from inaccuracies inherent in this method, when a relatively small proportion of the population is identified (20%— Norris et al. 1994; 21.7% –25.4% – this study; 29% – Östman 1994). It is also instructive to consider that the two studies with the lowest population estimates, had the smallest photo-ID catalogues (192 – Norris et al. 1994; 217 – this study; 677 – Östman 1994).

The size of the photo-ID catalogue for this study (217), after 38 photographed schools, is very similar to the size of the catalogue (221) of Östman (1994) after 38 schools. The cumulative number of identified dolphins per sighting day for that study continued to increase at a similar rate through the first 133 schools, suggesting that a large number of identifiable individuals still remain in this population of spinner dolphins (Fig. 18). Furthermore the drastic day-to-day changes in number of spinner dolphins sighted in Area A and the sudden appearance of new individuals in the ID catalogue for certain schools indicate that subgroups and/or schools of dolphins move between areas and that the total population size is much larger than the number of dolphins encountered.

It would be preferable to establish a population estimate using a photo-ID catalogue approaching or exceeding that of Östman (1994) and using a more robust method, such as mark-recapture. To accomplish this, the current photo-ID effort should be continued, to increase the size of the catalogue and a recapture study should be conducted when the catalogue has grown sufficiently. The results from this study suggest that one more year is need to establish a sufficient data base, with a second field season for the recapture study.

Mark-recapture analysis can also be done on the 1989-1992 data set, using a set of unanalyzed slides from 1992-season as the recapture data and the analyzed data-set from 1989 through 1991 field seasons as the marked population. Thus, it would be possible to compare the results from two mark-recapture studies, one for 1992 and one for the present, providing two robust, comparable population estimates, 13 years apart, spanning the time-period when the swim-with-wild-dolphin tour industry expanded dramatically.

The sighting data for spinner dolphins indicate that there are individual differences in home range size. Some individuals appear to be found during the day in more delimited areas, only found within Area A when near-shore, while other individuals appear to move more widely, e.g. from Area A to either Area C or Area D. Previous studies also support this notion (Norris et al. 1994, Östman 1994). There may be a difference in movement patterns between males and females, as is the case for sperm whales (*Physeter macrocephalus*) (Best 1979) and many terrestrial mammals, e.g. river otters (Erlinge 1968). Further analysis of data collected during this study, the 1989-92 study, as well as, future studies will address this issue.

The survey data were also analyzed for calving rate, one parameter determining population growth. Previous observations (Östman-Lind and Driscoll-Lind unpublished) suggest two calving peaks during the year for spinner dolphins in Hawaiian waters, in August and February. The monthly calving rate data, while limited by sample size for most months except June and July, corroborate this finding. The peak in November resulted from a minimum of 8 half-adult-length calves sighted in a school of 75 spinner dolphin on November 18. Following Perrin and Henderson (1984) their size would put them at roughly 2.5 months of age, suggesting that they were born in early August. In the eastern tropical Pacific, the whitebelly spinner dolphin also have a bimodal calving distribution while inshore and offshore eastern spinners only have one calving peak per year (Barlow 1984). However, just as in Hawaiian waters, calves are born year around (Barlow 1984). Although the sample size from this study is small for some months, the data presented here may suggest that there are two calving peaks during the year, comparable to whitebelly spinner dolphins. It would be valuable to continue to collect these data to establish what the current calving rate is.

Serum hormone levels in spinner dolphins in a captive facility in Honolulu also showed seasonal peaks. One male had peak testosterone levels in June and July, and two females had elevated estradiol levels in June and October, respectively (Wells 1984). Two estradiol peaks were recorded for one of the two females, both in October of consecutive years, suggesting that individual females may only give birth at one time of the year, even though the population may show a bimodal calving rate. More research is needed to establish life-history patterns for individual females.

Spotted Dolphins

There are some indications that a small number of the same spotted dolphins regularly spent time inshore, associating with the spinner dolphins. First, the seven mixed *Stenella* schools contained up to 16 spotted dolphins per school. Second, two different observers (S. Rickards and

J. Östman-Lind) repeatedly sighted two individual spotted dolphins, recognizable in the field by extensive scarring and skin conditions. Since several of the spotted dolphins had identifiable markings on their dorsal fins, the slide analysis will confirm or refute this idea.

For the offshore spotted dolphins, more photo-ID data are needed to establish a baseline, before a mark-recapture study can be done on that population and to establish any possible associations with inshore animal. In the mean time, observations made during this study provide some indications of minimum spotted dolphin abundance. On October 20, two schools of approximately 155 spotted dolphins were sighted in the southern part of Area F. While still with these two schools, the captain on our boat was in contact with other fishers, fishing in the northern part of Area E, some 50km to the north, where they were working another large school of spotted dolphins. Their description suggested that there were at least a hundred spotted dolphins in that area. Thus, there were simultaneously two large schools of over 100 dolphins, one each in areas E and F. Based on this information we can assume that a reasonable minimum population estimate would be approximately 250 spotted dolphins off the western coast of the Island of Hawai‘i.

This study was funded as a cooperative venture with commercial fishing vessels, which in turn influenced the data collection methods and our results on the offshore spotted dolphin schools. There was no real impact on the nearshore research because there is no commercial fishing activity associated with these areas and so the boats and the crew that were used were not interested or involved in fishing while these surveys were conducted. However, the areas that were surveyed offshore are also prime fishing areas for large game fish and an important additional source of income for the boats involved in this study. For example, the amount of time spent with the different spotted dolphin schools was affected by the fishing potential of the school. Thus we only spent enough time with the small school of 12 spotters to photograph them and then moved on, while we spent over 4 hours with the larger spotted dolphin schools associated with yellow-fin tuna (*Thunnus albacares*), a highly priced game fish. A main advantage of working with commercial fishers is access to the knowledge that they have accumulated over the years. The network of contacts with other fishers that they have developed and use while on the water can also be very useful and increase the likelihood of finding marine mammals. A potential disadvantage is that scientific needs and interests are not necessarily the only consideration for determining courses of action.

A potentially valuable use of commercial fishing boats as research platforms exists for further research on the associations between the spotted dolphins and the yellow-fin tuna, as well as the impacts of this fishery on the spotted dolphin population. While we were on the large, offshore spotted dolphin schools, there were often up to ten different fishing vessels attempting to catch fish, primarily tuna, in and around the dolphins. Different fishing gear was used with different strategies, and the boats were generally spread out around the dolphin school. The prime vessel position for fishing was near the front of the spotted dolphin school. Some boats crossed in front of the school, dragging long lines hanging from a “Green Stick”, with five hooks coming down from high in the air. Others rushed through or around the school from the back to the front, where they either stopped and dropped down their fishing gear or kept their position, so that their hooks were moving along in the water near the dolphins. More accurate information about the seasonality of the association between the tuna and dolphins, the abundance, range in movement patterns of the schools and residency of the spotted dolphins and the impacts of the various fishing methods on the dolphin population is needed to evaluate the degree to which the population may be impacted by this industry. While conducting this research, boat captains volunteered information and suggested that further research would be helpful to them in their efforts to minimize their potential impact on the dolphins.

Habitat Usage and Niche Partitioning

The three main delphinid species for which data were collected during this study, were spinner, spotted and bottlenose dolphins. Our data reveal some evidence of unique habitat utilization and, thus, niche partitioning among these species. The spinner dolphins were primarily found in very near-shore waters during the day, generally in waters less than 50m deep and just a few hundred meters from shore. We followed a few spinner dolphin schools in the early to mid afternoon, when they were transitioning from inshore to offshore waters, presumably on their way to feeding grounds, where they are known to feed nocturnally on the deep scattering layer (or mesopelagic-boundary community), some times up to 200m deep (Norris and Dohl 1980, Norris et al. 1994, Östman 1994, Driscoll 1995, Benoit-Bird and Au 2003). The mesopelagic-boundary community is a distinct land-associated assemblage of mesopelagic micronekton, which exists around the Hawaiian Islands (Reid et al. 1991). Spinner dolphins usually do not feed during the day. During more than a hundred hours of observations from a research vessel with an underwater viewing chamber within 500m of shore, in 1991 and 1992, spinner schools were seen to swim through schools of small fish on several occasions, with no indication of interest in feeding, even though the fish were of the right size and within a meter of several individual spinner dolphins on each occasion (Östman-Lind and Driscoll-Lind unpublished data). The behavior of a few spinner dolphins in this study, however, indicated that they may have been feeding within the mixed-species *Stenella* schools, suggesting that some individuals may adjust their behavior under these circumstances.

Mixed-species *Stenella* schools were not observed between 1989 and 1991, and in 1992, only one or two spotted dolphins were identified within a few schools of spinner dolphins (Östman-Lind and Driscoll-Lind unpublished data). According to local tour-boat operators, these mixed-species schools started to become more prevalent in the mid 1990's in Area A, so it is a relatively new development which has not been studied until now. The spotted dolphins found in these mixed-species schools were often observed in a subgroup on the offshore side of the spinner dolphin school, sometimes with a few spinner dolphins associated closely with them.

The four offshore spotted dolphin schools behaved in a more typical fashion for their species, located several km offshore on the island slope, in waters over one km deep. They spent most of the daytime observation period feeding near the surface and were associated with yellow-fin tuna schools. Their nocturnal movement patterns are not known, so it would be valuable to track their movements at night to ascertain whether they move inshore to feed on the mesopelagic boundary community during the night as suggested by Baird et al. (2001), like spinner dolphin schools (Benoit-Bird and Au 2003). There may be a complete separation of the food resources, with spotted dolphins foraging diurnally near the surface, on species such as mackerel scad, and spinner dolphin feeding nocturnally on the fish, squid, and shrimp (e.g. *Abralia trigonura*, Clarke and Young 1998) in association with the diel vertical and horizontal (Benoit-Bird et al. 2001) migration of the mesopelagic-boundary community (Norris and Dohl

1980, Benoit-Bird and Au 2003). Another odontocete species believed to feed on the resident mesopelagic community is the short-finned pilot whale. These animals were only seen once in this survey in offshore waters. During hundreds of hours of near-shore surveys in the earlier study, short-finned pilot whales were never encountered near-shore and were consistently found resting during the day in offshore waters (Östman-Lind and Driscoll-Lind pers. observations, J. Stern pers. communication). Their nocturnal movement pattern while feeding and its relationship to the nocturnal movement patterns of the spinner dolphin schools are unknown. The great size difference between these two species makes it likely that they are feeding on different types of prey items within the vertically migrating mesopelagic boundary community. During daylight hours they are resting in different areas of the western coast, with spinner dolphins utilizing near-shore shallow (< 40m) and calm areas, while the short-finned pilot whales are found farther offshore in deeper (> 200m) waters. Finally, it should be mentioned that pygmy killer whales are seen sporadically in these waters both in nearshore areas (Area A) as well as farther offshore (Area F) (Östman-Lind and Driscoll-Lind pers. observations). Because of the unpredictability of their movement patterns in and out of the area, a long-term study would be required to document their movement patterns.

During our surveys, bottlenose dolphins were found in waters less than 50m deep, in small schools. Based on initial results from two years of data from all of the main Hawaiian Islands, Baird et al. (2003) states,"... it is clear that bottlenose dolphins are not mixing freely between islands. Sample sizes for this comparison are reasonable for O‘ahu (79 individuals in 2002/2003) and Kaua‘i/Ni‘ihau (49 individuals in 2003), though less so for Hawai‘i (13 individuals in 2002/2003), thus additional effort off the island of Hawai‘i is warranted." Studies in other parts of the world have found bottlenose dolphins to be very opportunistic in their feeding behavior (see review in Connor et al. 2000). At present, there is very little information about the prey species or feeding behavior of the bottlenose dolphins off the Island of Hawai‘i. Although, they are known to steal live baitfish directly from the marlin-hooks of commercial fishing charter boats. Some footage of this occurring was recorded during earlier field efforts in 1993 in conjunction with a team of researchers from Woods Hole Oceanographic Institute. These boats are often fishing in waters of between 1km and 2.5km depth (Areas E and F). They were sighted offshore on a few occasions during surveys between 1989 and 1992 and they are frequently sighted there in association with the fishing boats. It appears that the bottlenose dolphins in this region travel in small groups (generally two or three, but some times as many as 12 to 15), ranging throughout the island slope and feeding opportunistically. More information is needed to establish the abundance, residency patterns and habitat use of the bottlenose dolphin population. Additional research on these dolphins, particularly in relation to the interactions with the local commercial fisheries could provide important information for management and conservation.

Long Term Residency

The spinner dolphin population off the western coast of the Island of Hawai‘i is the only species for which we have a large long-term photo-identification catalog and therefore it is the only population that we can evaluate with any accuracy. All re-identified dolphins in this study have fairly obviously marked dorsal fins, which allow for a relatively easy re-identification. This is especially important when trying to re-identify animals after an 11-year time period (1992 – 2003). Dorsal fins can change by the addition of small or large nicks, changes in fin shape, or by major disfigurement, such as the loss of a large part of the fin (pers. observations). The fin of one of the re-sighted animals (Pincer High Step) changed drastically between 1992 and 2003. The fin of this male is now markedly more upright, after a growth spurt in the trailing edge of the dorsal fin, as first described by Perrin (1975) for eastern spinners. This male was re-identified by the size, shape and location of several large nicks near the top of the trailing edge.

Most of the re-identified spinner dolphins were first photographed in the summer and fall of 1989, approximately 14 years ago, and one of them, Four-Nip, was initially sighted and photographed by researchers as an adult male in Kealakekua Bay in 1979 (Norris et al. 1994), approximately 24 years ago. As an adult male, he would have been at least eight years old (Perrin and Henderson 1984), which would put his age today at least in the mid thirties. All of the re-sighted dolphins were found off the same coastline where they resided 14 or more years ago. It is thus apparent that at least a core component of this population of spinner dolphins are lifetime residents of this coastline and we suspect there is relatively little inter-island movement between the islands of Hawai'i and Maui. Current genetic research by K. Andrews should be able to provide essential information about the degree of gene flow between theses two populations.

Genetic samples of identified individuals

Genetic samples will be analyzed by K. Andrews over the next six months for genetic markers, allowing for determination of both gender and whether individuals are closely related. An added benefit to these samples is that they will ensure that the identity of these individuals will not be permanently lost if their fin changes drastically, since the genetic signature for each of these individuals will be on file for future comparison.

Human - Dolphin interactions

The Human Disturbance Index (HDI) was designed to capture the relative frequency of disturbance for different types of approach modes. Human swimmers and boats focusing on the dolphins were given similar weight. Data collection methodology would need revision to capture the relative impact of different human approach modes. However, the main purpose in this study was to find how the level of human impact varied over daylight hours not its impact.

Similarly, the data collected on human disturbances is likely to be biased by the data collection methods used. Since we only followed each school for a short period of time, all incidents of human disturbances were not documented for each school, thus underestimating the amount of human disturbance during that part of the day. On the other hand, conducting surveys primarily in the morning hours and targeting known resting bays may have biased the data upwards. Finally, because all observations were made from a boat, the research vessel may have affected the behavior of the schools as well. The research vessel is also likely to have an impact on school behavior when collecting genetic samples. However, samples were not collected near other vessels and we generally moved offshore a few hundred meters, once we got into a resting area, to be able to observe the effects of other vessels and swimmers on the dolphins. A study with a shore based component and using a focal group protocol (Altman 1974) would be preferable and would eliminate any such bias.

Data from this study suggest that human disturbance is highest in mid-morning, at the time when most spinner dolphin schools are in the process of finding and settling into a resting area. If commercial operations and the general public are allowed to continue approaching spinner dolphins in these areas, it may have serious long-term consequences. We observed a school of spinner dolphins apparently being temporarily displaced by vessel and swimmer presence out of what we consider one of the most important resting areas on the coastline, based on frequency of use and mean size of resting schools. We also found potential evidence of long-term impacts, where a very little-used secondary resting area (as documented in 1989-1992) was, in this study, apparently being utilized to a much greater extent, apparently due to a lower incidence of vessel traffic. Human disturbance has been documented as having geographically displaced a number cetacean species in various locations. For example, both mammal-eating and fish-eating killer whales (*Orcinus orca*) were displaced from known habitat for a matter of years in response to high amplitude sound in British Columbia (Morton and Symonds 2002); gray whales (*Eschrichtius robustus*) temporarily abandoned a calving lagoon in Baja California during an increase in vessel traffic (Gard 1974, Bryant et al. 1984); and humpback whale (*Megaptera novaeangliae*) mothers and calves have been shown to move offshore of Maui in response to recreational vessel activities (Salden 1988, Glockner-Ferrari and Ferrari 1990).

The mean number of spinner dolphins per school in this study (58.5, se = 8.5, n = 38) was significantly smaller than the mean school size between 1989 and 1992 (77, se = 4.4; n = 134) ($P << 0.001$; $t = 25.9$; d.f. = 54.7) and represents a 26% reduction in size. This difference was noticeable in the field. Also, in contrast to previous years, it was more common to find two or three schools of spinner dolphins each field day than it was to find just one school. However, it is not clear what caused this reduction in school size. It could be due to a response to changing environmental conditions, an artifact of a relatively short field effort, or a seasonal change. It could also be caused by the apparent large increase in human pressure on the dolphins. The dolphins were generally approached by one or more boats during each field day, and often had two or three vessels in the area dropping snorkelers in the waters, or driving ahead of the school and dropping people in the water in their path of travel. It seems especially serious that this was going on in the very core of the most frequently used resting area (as documented during previous studies), Makako bay (Östman 1994).

The presence of dolphins in the next bay north of Makako seems especially telling. This bay was used only occasionally as a resting area during the previous study, and then mostly in the winter (Östman-Lind and Driscoll-Lind unpublished data) when the dolphins spent the majority of their time in the middle of the bay, approximately 200-300m offshore. During this study, this bay had the second highest rate of first sighting of the entire study area, and the dolphins used a different part of the bay. They were generally found within 75m from shore in the very northern part of this bay, as opposed to the center, and we never had another boat join the school in this location. It is possible that the increased pressure from boats and swimmers has caused the spinner dolphins to utilize Makako Bay less, instead resting in other areas, in smaller schools.

An illustration of the effect this human attention may have on these animals was provided on May 29, when two vessels followed a school into the resting area in Makako Bay, where they joined two more vessels and spent almost an hour putting 10 or more people in the water in the very core resting area. The dolphins exited the bay and headed about a km offshore, where they were milling for about half an hour until the boats left the resting area, at which time the dolphins re-entered the bay. At that time, there were two rental boats anchored approximately 150m south of the resting area and very close to shore.

Comparing the distribution of school sizes in this study with that of Östman (1994) suggests that this is primarily the result of a drastic increase in schools of 1-20 individuals and a decrease in schools ranging in size from 41-60 and 81-120 (Fig. 19). The two data sets also differ in terms of school composition. It was very unusual to find mixed schools of spinner and spotted dolphins between 1989 and 1992. In fact, only two spotted dolphins were seen to mingle with spinner dolphin schools on a few occasions. Since the numbers presented here only represent the spinner dolphin portion of seven of the schools, the actual sizes of the schools encountered is slightly higher (59.5, se = 10.0, n = 30).

The reduction in school size could be due to human disturbance factors. The increase in attention given to the spinner dolphin schools is quite dramatic compared to the situation in the late 1980's and early 1990's. While further studies focusing on the level of human interactions with the dolphins are important to ascertain how much disturbance is taking place, determining whether this continued human presence has resulted in long-term changes in school size, resting patterns and/or changes in abundance is also crucial. More data collected over a longer time period are clearly needed.

Conclusion

This study has helped to shed further light, not only on which species of delphinid can be found off the western coast of the Island of Hawaiʻi, but on their relative abundance, distribution and habitat use. Details of spinner dolphin long- and short-term residency, association patterns and life history parameters will continue to be elucidated with further photo-ID data collection and analysis. Details of potential niche specialization, the ecological variables involved, as well as potential reasons for the apparent recent movement of spotted dolphins to nearshore waters all warrant further study. It is further suggested that the human impact to which spinner dolphins in this region are subjected has dramatically increased since a decade ago, and its potential effects merit further investigation.

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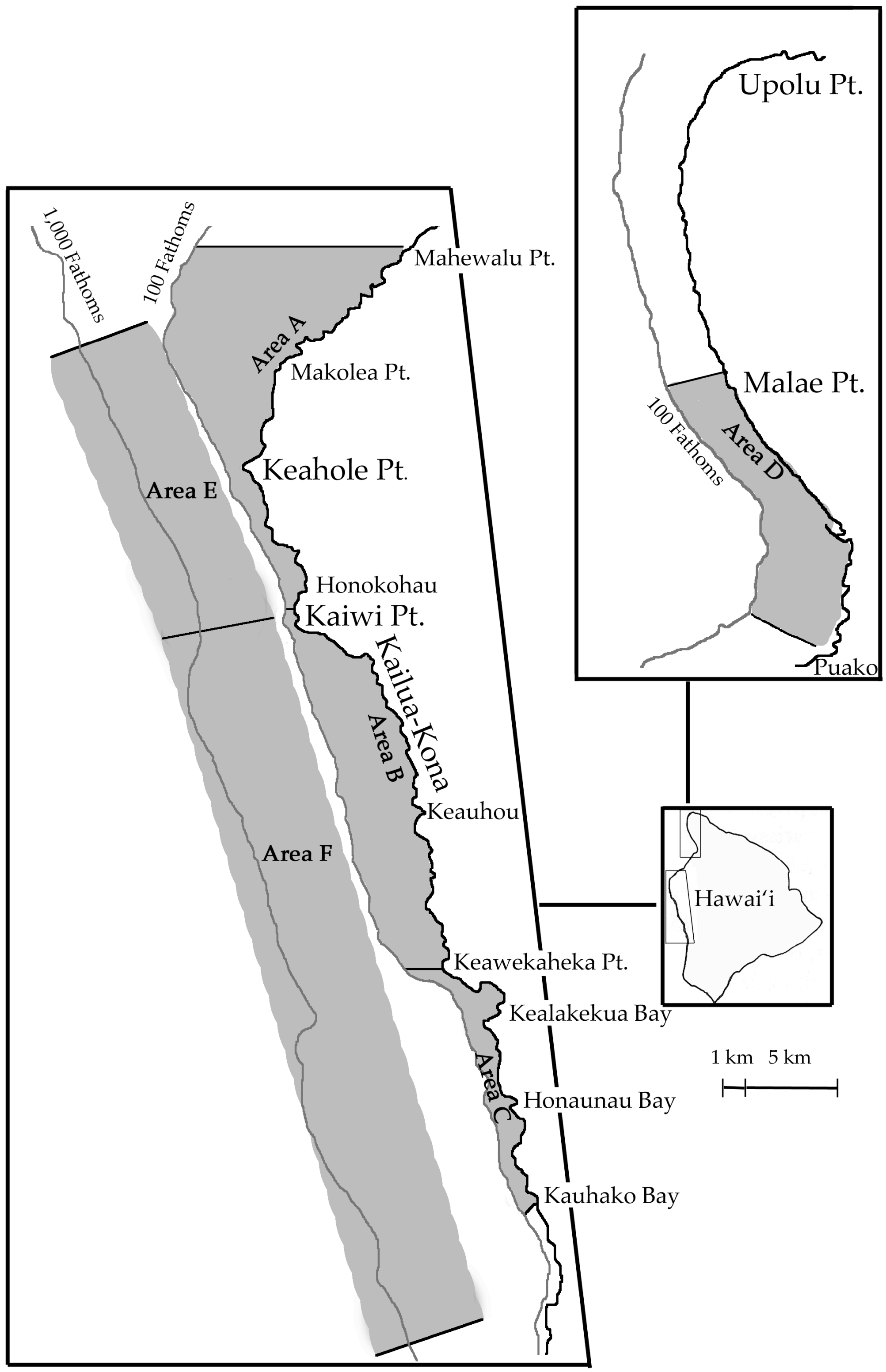

Figure 1. Surveys were conducted in 6 areas, four inshore and two offshore, off the western side of the Island of Hawai'i. The 100-fathom (185m) and 1,000-fathom (1,852m) isobaths are indicated, and some bays and points of land referred to in the text are also named.

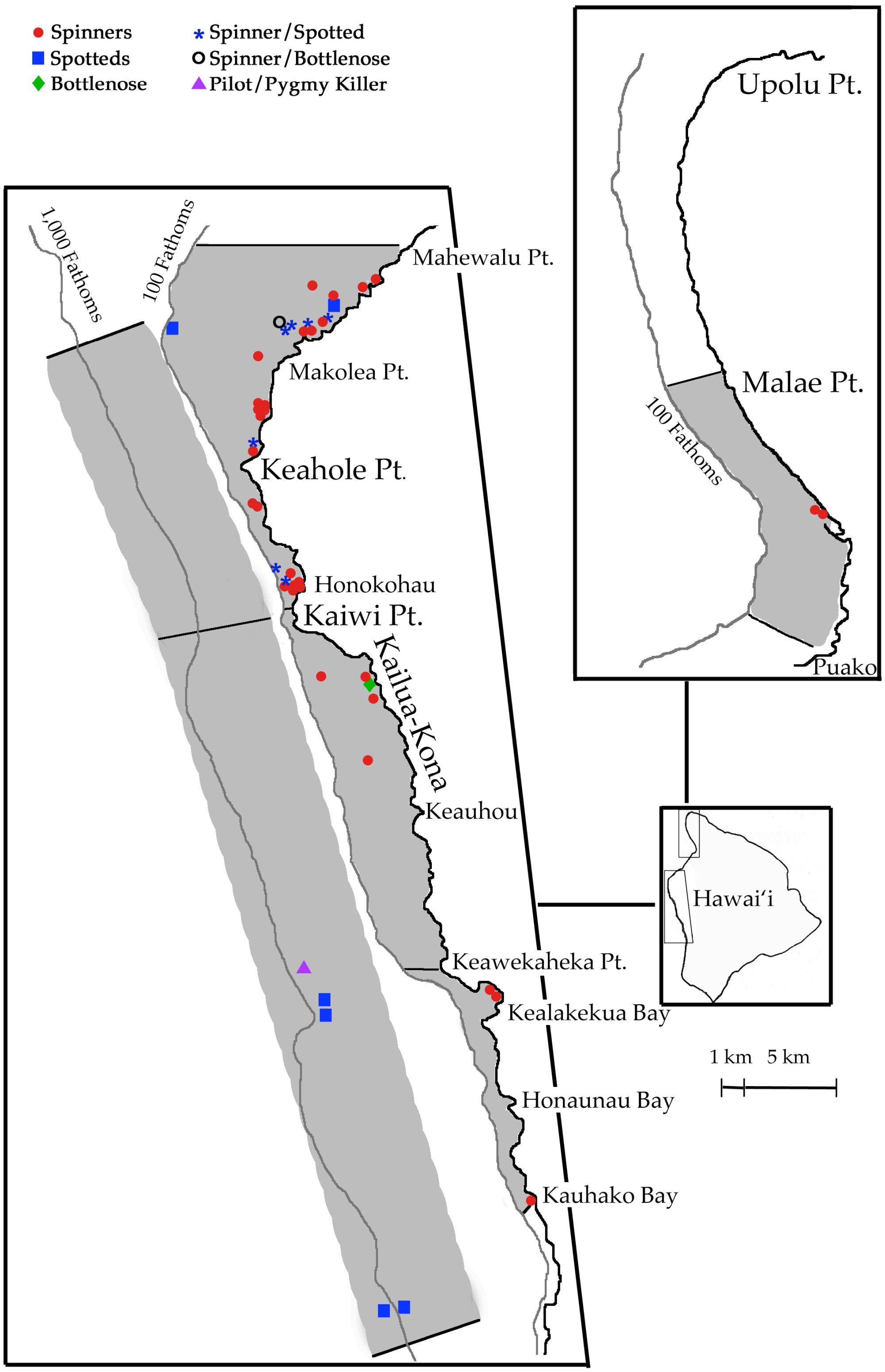

Figure 2. Location of first sighting for each school, based on species composition. The mixed species spinner-bottlenose dolphin school (unfilled circle above Makolea Pt.) was a school of 12 spinner dolphins and a school of 2 bottlenose dolphins that affiliated in that area for approximately 10-20 min.

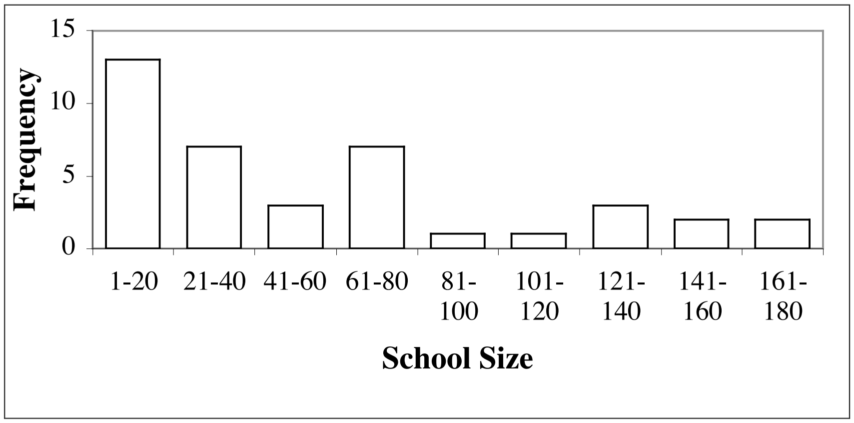

Figure 3. Distribution of mean estimated spinner dolphin school size. N=39.

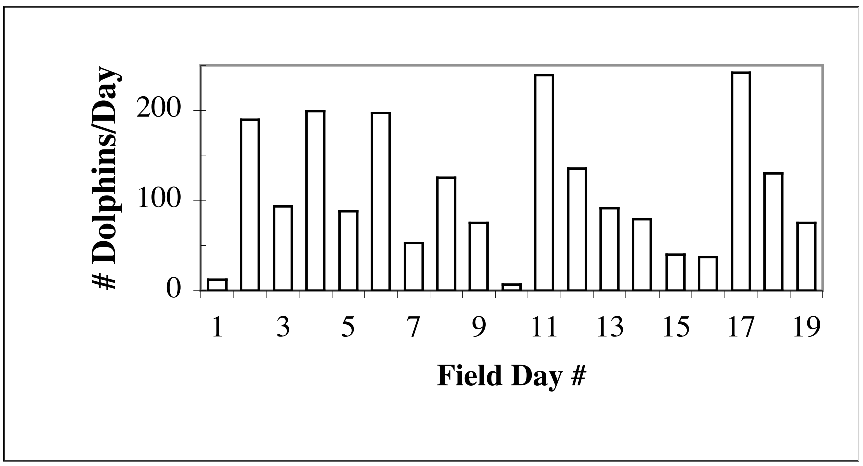

Figure 4. Number of spinner dolphins encountered per field day.

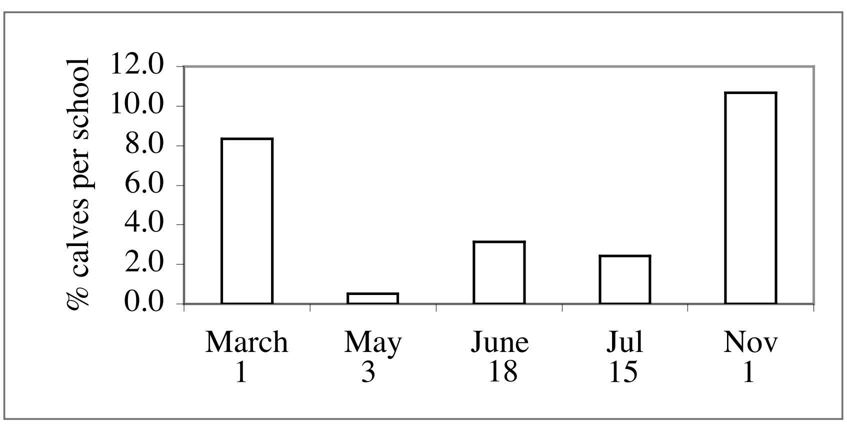

Figure 5. Mean proportion of spinner dolphin calves sighted per month. The sample size is indicated for each month.

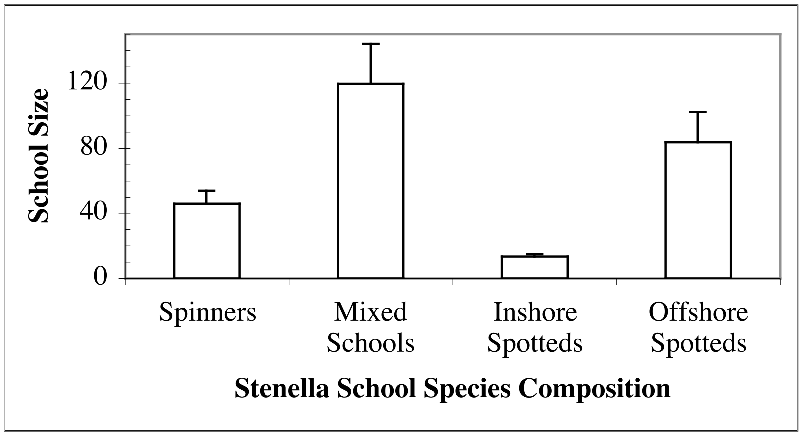

Figure 6. Size (mean ± se) of *Stenella* schools with different species composition. All spinner dolphin schools and mixed species *Stenella* schools were found inshore.

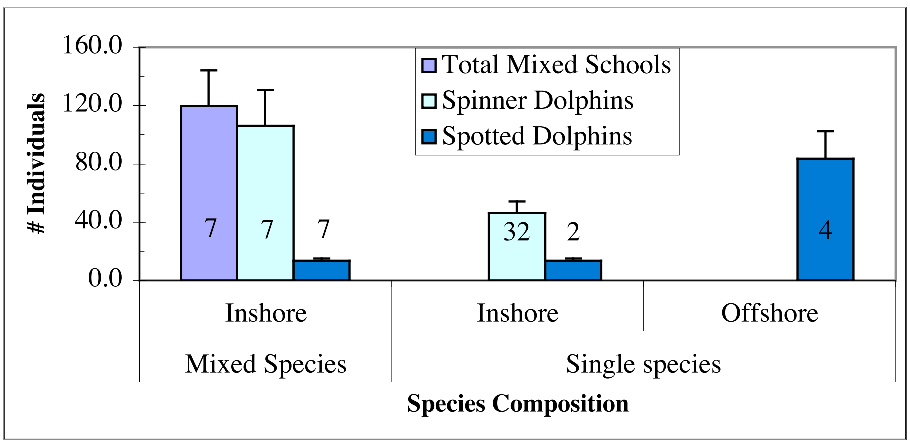

Figure 7. Mean (± se) number of spinner and spotted dolphins in *Stenella* schools of different species composition (n is shown inside each bar).

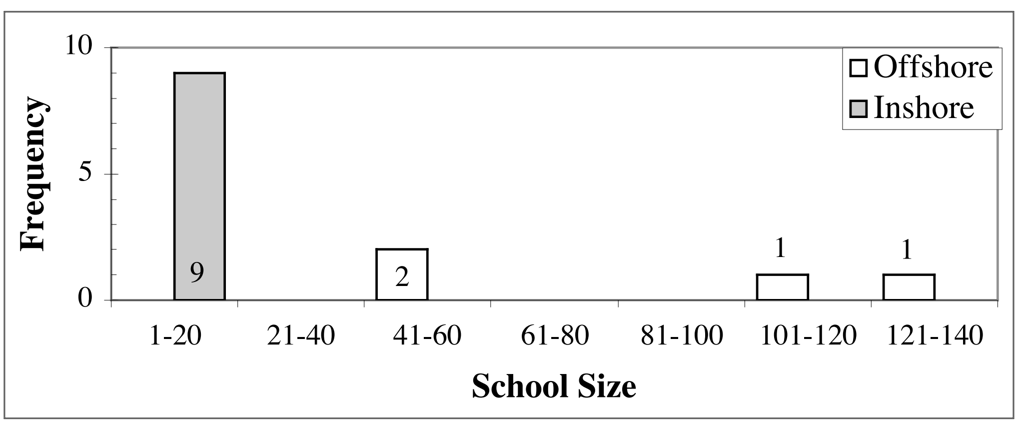

Figure 8. Distribution of mean (± se) number of spotted dolphins per school in inshore and offshore waters. Sample size is indicated.

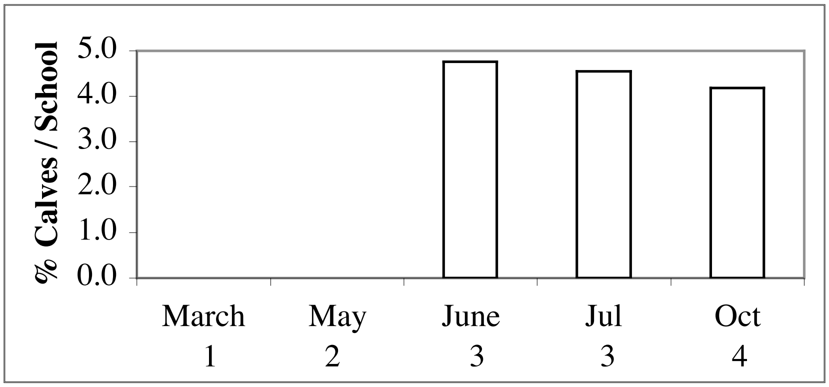

Figure 9. Mean proportion of spotted dolphin calves sighted per month. The sample size is indicated for each month.

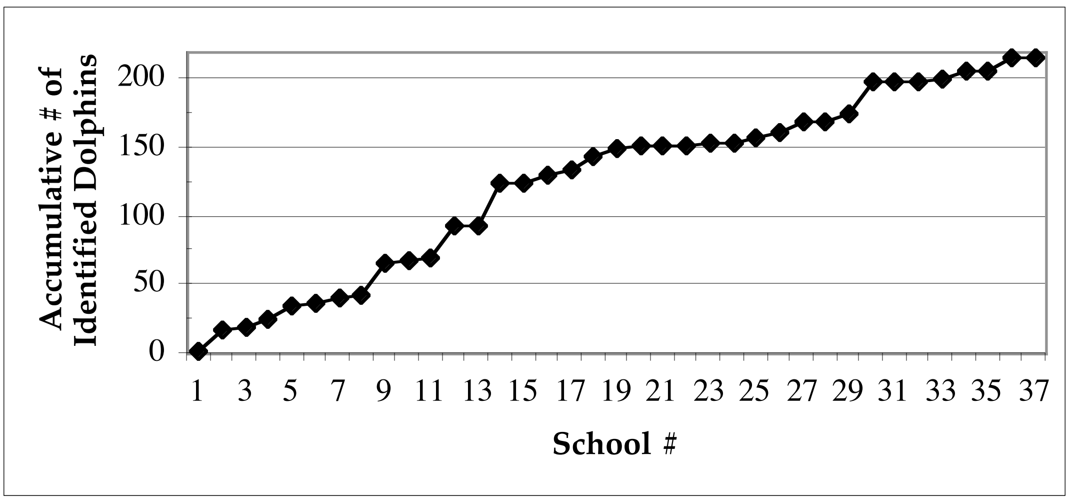

Figure 10. Cumulative number of identified spinner dolphins per school.

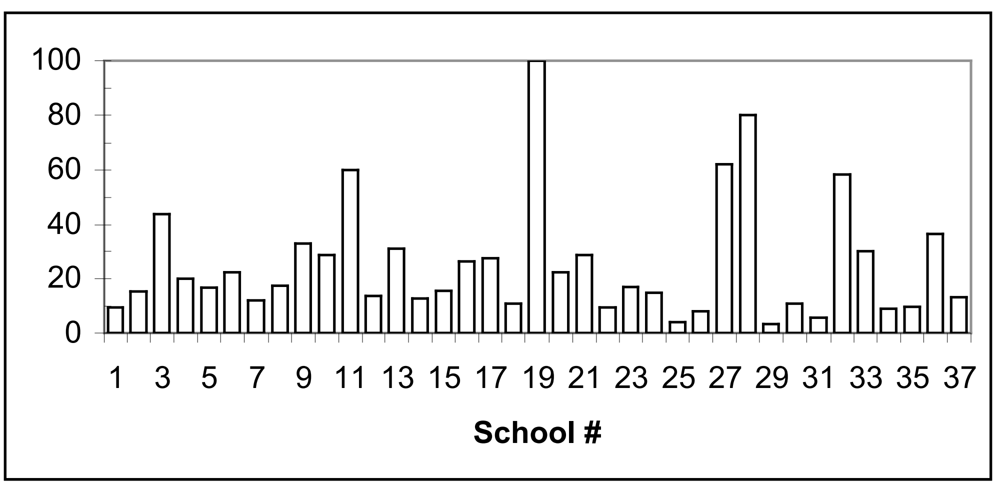

Figure 11. Proportion of identified spinner dolphins per school.

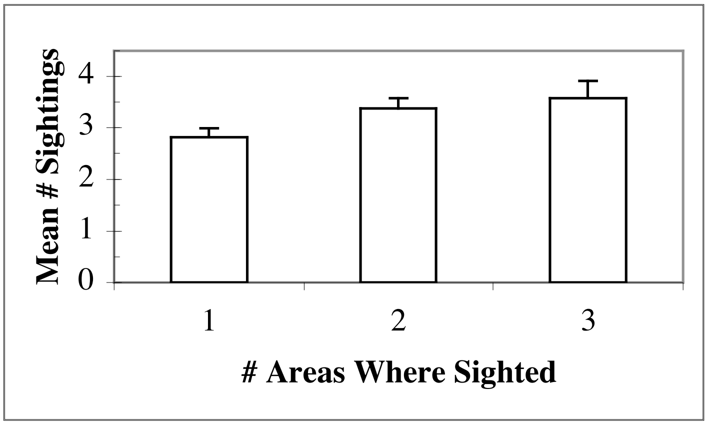

Figure 12. Number of spinner dolphins with multiple sightings identified in one or more of the four inshore study areas.

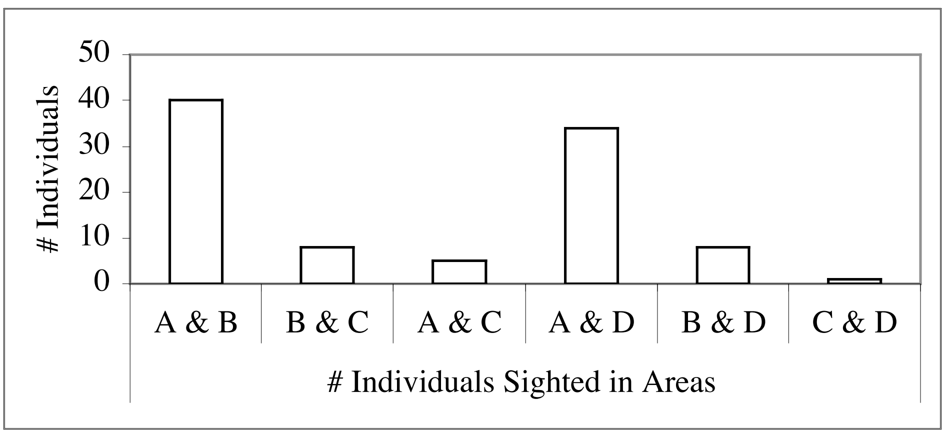

Figure 13. Number of spinner dolphins documented in different study areas.

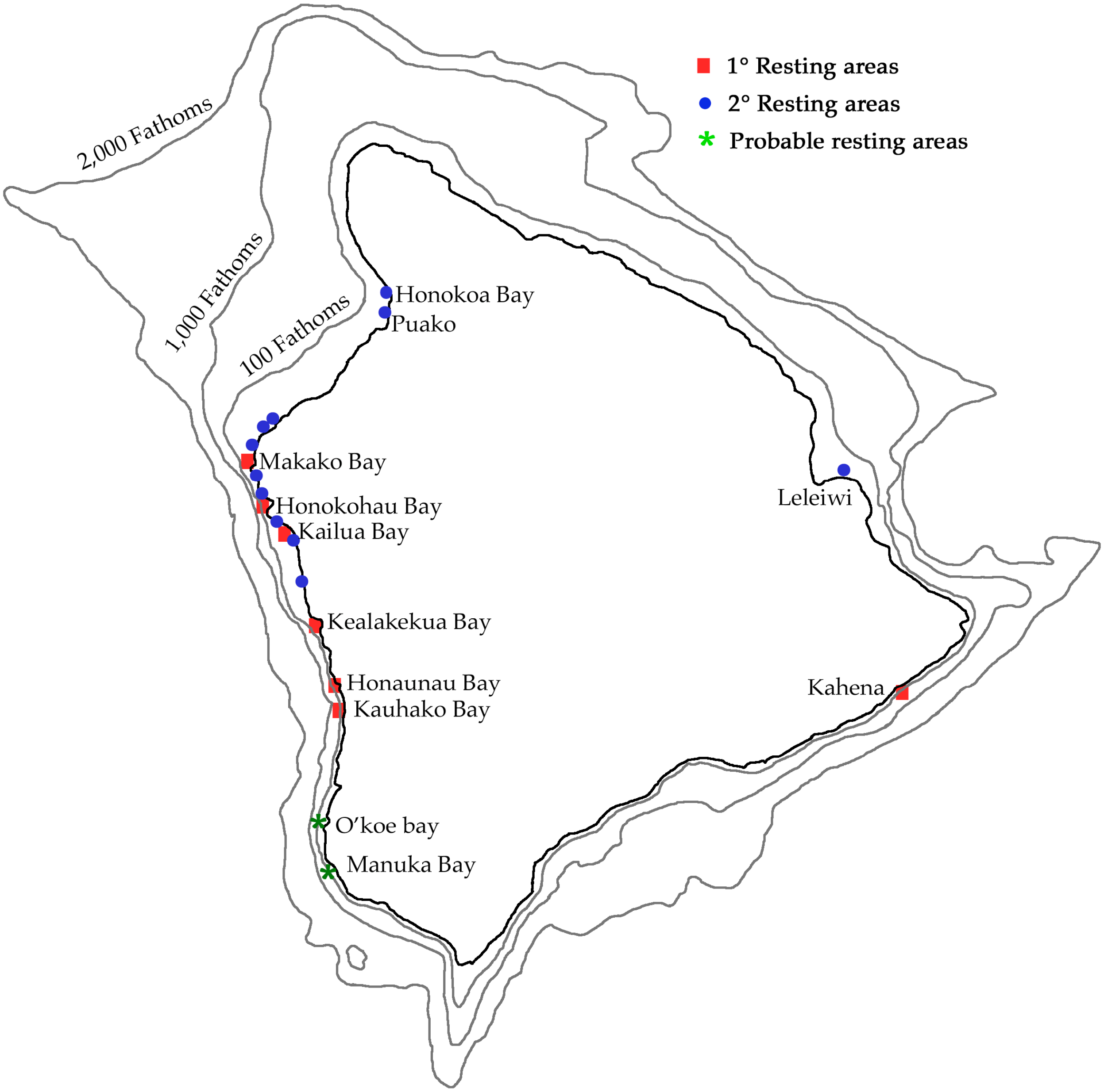

Figure 14. Distribution of known critical, secondary and probable spinner dolphin resting areas around the Island of Hawai'i.

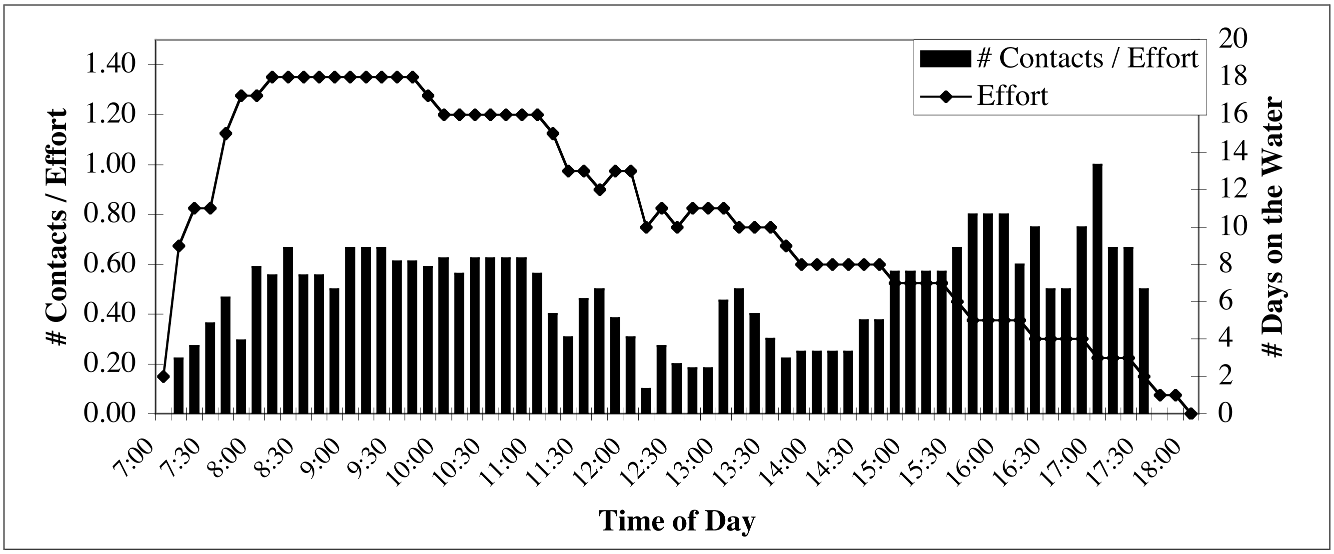

Figure 15. Total effort by time of day in 10-minute increments compared with relative amount of time on dolphins.

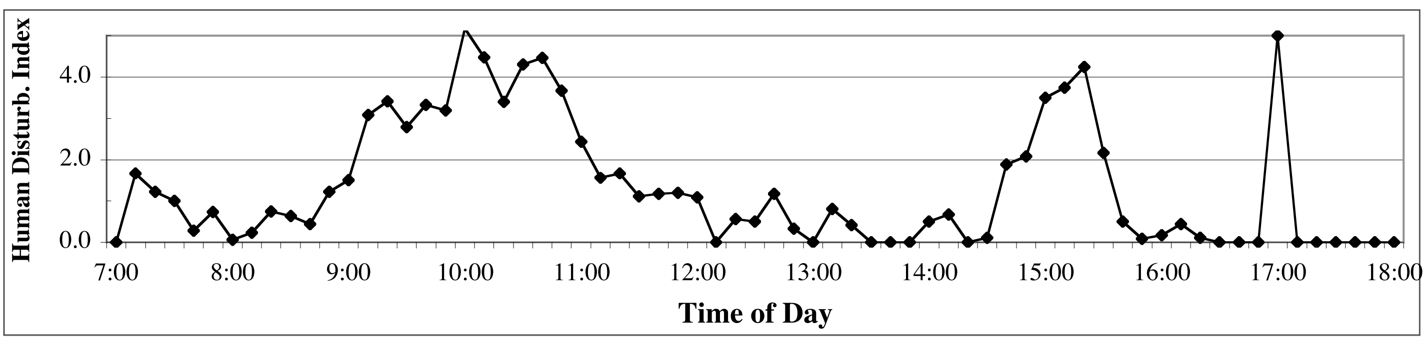

Figure 16. Human disturbance index relative to time of day.

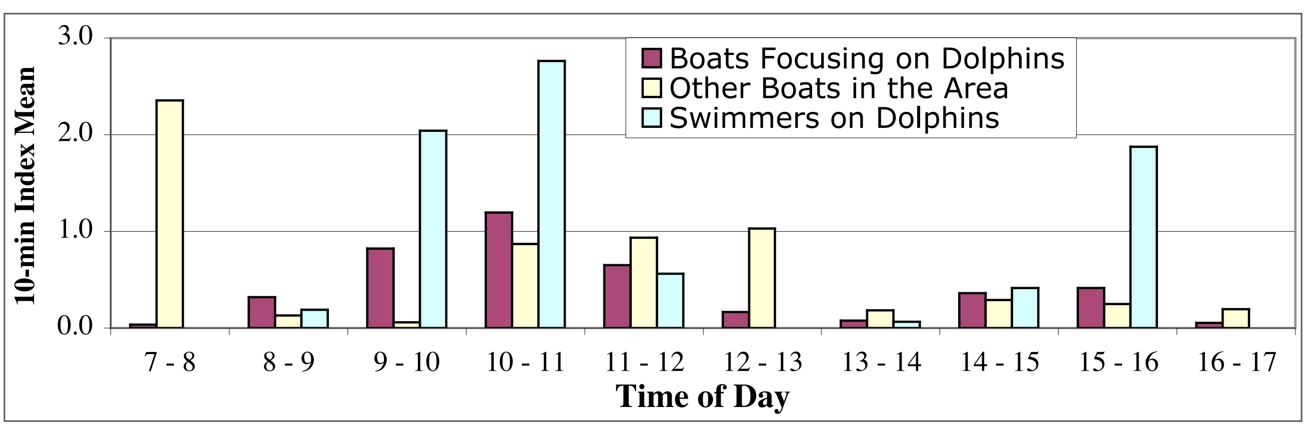

Figure 17. Amount of human disturbance by categories, in 10-min. time blocks.

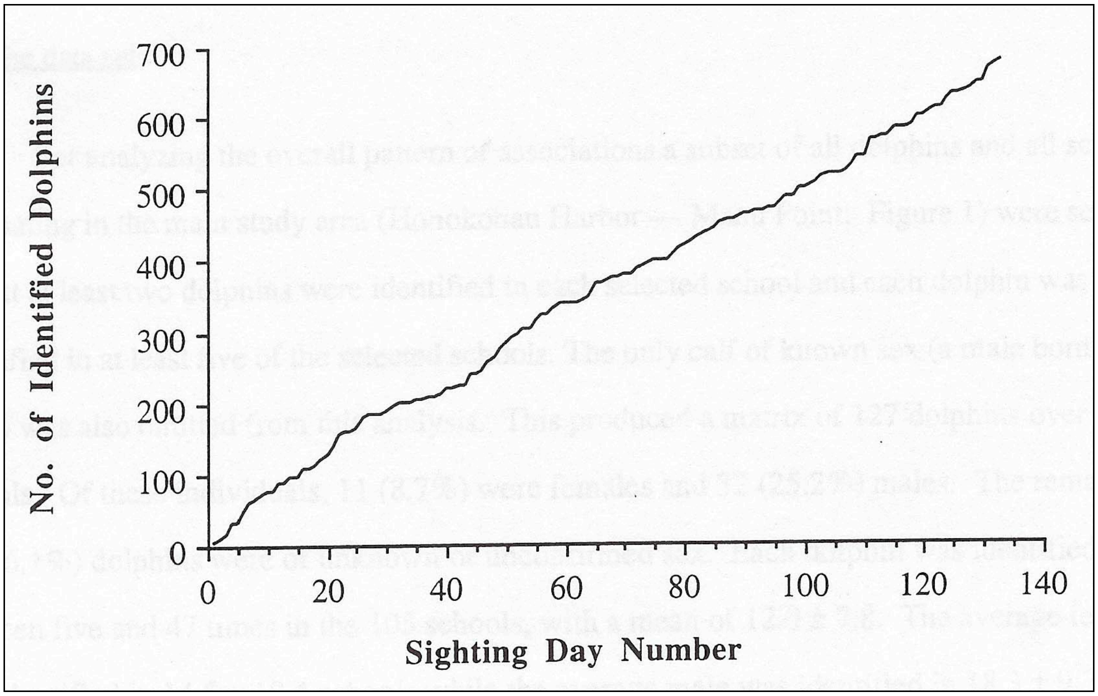

Figure 18: Cumulative number of identified spinner dolphins per sighting day during a 1989-92 study of spinner dolphins off the western coast of the Island of Hawai'i (Östman, 1994).

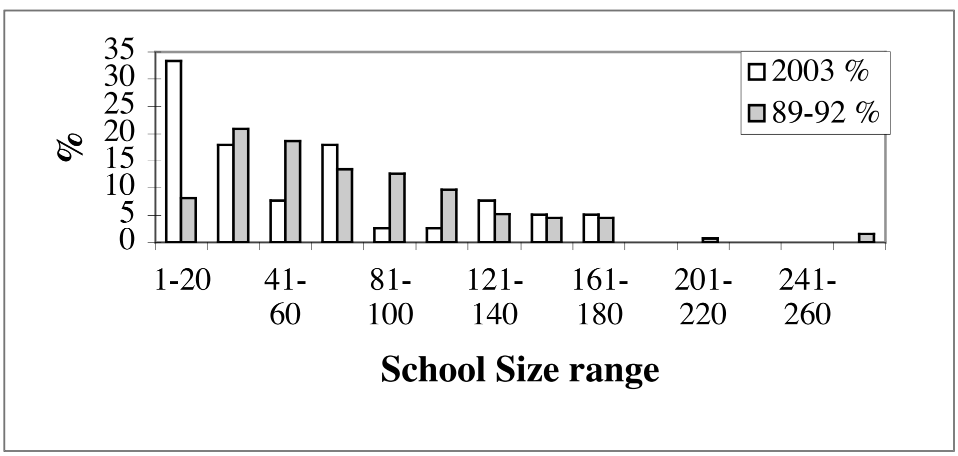

Figure 19. Comparison of school size distribution between 133 schools sighted between the summer of 1989 and the fall of 1992, and the schools sighted during this study.

Table 1. Field effort per area. The length of the coastline is indicated for each area.

Area	From – To (distance)	Field Effort (hrs)	% Effort
Inshore			
A	Honokohau – Mano Pt. (26km)	63.7	54
B	S. of Honokohau – Keawekaheaka Pt. (25km)	17.7	15
C	Kealakekua bay – Kauhako Bay (12km)	8.3	7
D	Puako – Malae Pt. (16km)	6.5	6
	Subtotal:	96.2	82
Offshore			
E	North of Kaiwi Pt. (14.8km)	4.5	4
F	South of Kaiwi Pt. (40.7km)	16.7	14
	Subtotal:	21.2	18
	Total:	**117.3**	100

Table 2. Field effort (number of days) by month. One survey day conducted in March, was divided between inshore and offshore waters.

Month	Inshore	Offshore
March	1	1
May	1	-
June	8	-
July	8	-
October	-	2
November	2	-

Table 3. Sighting information and photographic record categorized into single species and mixed species schools.

Species	# Sightings	Area(s) Sighted in	Mean School Size	# Photos
Spinner	32	A, B, C, D	47.8	2,766
Spotted	6	A, F	59.5	459
Mixed Spinner/Spotted	7	A	119.6	1,235
Bottlenose	2	A, B	2.5	72
Mixed Pilot/Pygmy Killer	1	F	-	-