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# DISTRIBUTION AND ABUNDANCE OF FINLESS PORPOISES IN HONG KONG AND ADJACENT WATERS OF CHINA

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***ABSTRACT.*** – We studied the distribution and abundance of finless porpoises (*Neophocaena phocaenoides*) in Hong Kong and adjacent waters of China's Guangdong Province between September 1995 and November 2000. Vessel (50,194 km) and helicopter (2,696 km) surveys were used to assess distribution patterns, and estimates of abundance were calculated using line transect methods. Acoustic detection data from a towed porpoise click detector (POD) were used to make an estimate of the trackline detection probability [g(0)] for ship surveys, and surface and dive time data were used for correcting helicopter survey estimates. Porpoises occurred in Hong Kong and adjacent waters year-round, but showed evidence of seasonal movements, with porpoises largely vacating most of Hong Kong's southwestern waters in summer and autumn. Seasonal changes in overall abundance were also evident. The peak season within Hong Kong waters was spring, in which an estimated 152 porpoises inhabited territorial waters. The peak estimates for all areas combined (217 porpoises in spring and summer) can be viewed as a minimum estimate of the size of the local population. Examination of potential violations of line transect assumptions indicate that the techniques used were well-suited, with no evidence of serious biases. However, because the distribution clearly extends beyond the study area and the exact range limits are unknown, further work is needed to assess overall population size.

***KEY WORDS.*** – Finless porpoise, *Neophocaena phocaenoides*, Hong Kong, China, abundance, distribution, population size, line transect.

## INTRODUCTION

Great advances have been made recently in our knowledge about some species of small cetaceans. The finless porpoise (*Neophocaena phocaenoides*), however, remains one of the most poorly-known of all cetacean species (see Reeves et al., 1997; Kasuya, 1999). In particular, there have been very few directed ecological studies on this species, partly because it is restricted to Asian waters where, until recently, little marine mammal research had been conducted. The major exception has been in Japan, where a number of studies have documented the distribution, occurrence, and abundance of this species (Kasuya & Kureha, 1979; Shirakihara et al., 1994; Yoshida et al., 1997, 1998). Research on distribution and abundance has also been conducted on the population of finless porpoises that occurs in the Yangtze River of the People's Republic of China (PRC), the only known wholly-freshwater population of the species (Zhang et al., 1993; Zhou et al., 1998, 2000; Wang et al., 2000). The latter work has been done largely as a by-product of studies directed towards understanding the biology and conservation status of the baiji (*Lipotes vexillifer*), the world's most endangered cetacean.

Very little is known about the finless porpoise in the rest of its range, with the exception of the Indus River delta and surrounding areas of Pakistan, where Pilleri and colleagues (Pilleri & Gihr, 1972; Pilleri, 1973; Pilleri & Pilleri, 1979) conducted some work on distribution and occurrence. The above-mentioned studies in Japan (Kasuya & Kureha, 1979; Shirakihara et al., 1994; Yoshida et al., 1997, 1998) still present the only statistically-defensible abundance estimates available. Despite its known occurrence in marine waters along most of the coast of mainland China and Taiwan (see Zhou et al., 1995), no studies have investigated the population ecology of this species in this area.

The purpose of this paper is to report on the distribution and abundance of the finless porpoise population that inhabits the waters of the Hong Kong Special Administrative Region

(SAR) and adjacent areas situated along the coast of southern China, in the PRC's Guangdong Province. This paper presents results of a five-year study on small cetaceans in Hong Kong, conducted from September 1995 to November 2000. The study is ongoing, and we hope to conduct further, more detailed analyses in the future.

## STUDY AREA AND METHODS

***Study Period, Area, and Survey Design.*** – Finless porpoise survey data were collected during a directed study on Indo-Pacific humpback dolphins (*Sousa chinensis*) between September 1995 and April 1998 (see Jefferson & Leatherwood, 1997; Jefferson, 2000). After a 2-month period of little survey effort, dedicated surveys for finless porpoises began in July 1998 and continued through November 2000. Data collection procedures were similar throughout, but during some parts of the dolphin study period, there was comparatively little survey effort in areas inhabited by porpoises.

The Hong Kong study area consists of largely-inshore marine waters, comprising about 1,800 km$^2$. They are mostly shallow, with the majority less than 40 m deep. The study area was divided into nine survey subareas, each of which could be surveyed in a single day (Table 1; Fig. 1). In addition, adjacent Chinese waters to the west and southwest of Hong Kong were also surveyed (Table 1). These latter areas are part of, or adjacent to, the Pearl River (Zhujiang) Estuary. The Pearl is China's second-largest river (Dudgeon, 1995).

Survey lines were designed to cover each survey area evenly; no reference was made to porpoise distribution patterns when designing survey lines (Fig. 1). The primary lines were parallel and ran perpendicular to the shoreline; spacing for most survey lines was 2-3 km apart. Between November 1995 and November 2000, 50,194 km of vessel-based survey effort data were collected, with 79% of it obtained during calm conditions of Beaufort 0-3. In the same period, 2,696 km of helicopter survey effort data were collected, 78% of it in Beaufort 0-3 conditions.

***Vessel Surveys.*** – Vessel surveys were conducted from several 12-15 m inboard vessels when weather permitted (Beaufort 0-5, no heavy rain, and visibility $\geq$ 1,200 m). Twelve different vessels were used over the course of the study. All vessels had the same basic configuration, with open upper decks affording relatively unrestricted visibility. The observer team conducted searches and observations from the flying bridge area, 4-5 m eye height above the water's surface. Two observers made up the on-effort survey team. As the vessel transited the survey lines at a relatively constant speed of 13-15 km/hr, the primary observer searched for porpoises continuously through 7 X 35 Fujinon marine binoculars. The data recorder searched with unaided eye and filled-out data sheets. Both observers searched ahead of the vessel, between 270° and 90° (in relation to the bow, which was defined as 0°). Observers rotated positions every 30 minutes, and on most surveys, there were 1-3 additional observers on the boat, who would rotate into position to give observers a rest after each hour of search effort, thereby minimizing fatigue. All observers were experienced in small cetacean survey techniques and in identification of local cetacean species. Most had undergone at least one 3-day training program, including a day of at-sea training.

Effort data collected during on-effort survey periods included time and position for the start and end of effort, vessel speed, sea state (Beaufort scale), visibility, and distance traveled in each series (a continuous period of search effort). When porpoises were sighted, the data recorder filled out a sighting sheet, and generally the team was taken off-effort and the vessel diverted from its course to approach the porpoise group for group size and behavioral observations. The sighting sheet included information on sighting angle and distance, position of initial sighting, sea state, group size and composition, and behavior, such as response to the survey vessel and associations with vessels. Position, distance traveled, and vessel speed were obtained from a hand-held Global Positioning System (most commonly a Magellan Colortrack GPS unit).

We attempted to use reticles in the binoculars to more accurately estimate distances (see Kinzey & Gerrodette, 2001). However, due to the fact that most survey areas were surrounded by land, we could not generally see the horizon, making use of reticles impossible. Observers were trained in distance estimation, by asking them to make distance estimates to various objects (e.g., other boats, specific points on shore, floating debris, etc.). Simultaneously, a distance reading was taken with a pair of laser rangefinder binoculars (Leica Geovid or Bushnell Yardage Pro 800 models). Plots of measured vs. estimated distance were shown to observers occasionally, so they could see if they needed to refine their distance estimates.

***Helicopter Surveys.*** – Helicopter transects were used to survey the Mirs Bay survey area, which was relatively difficult to cover by boat because of its remoteness and large size (Fig. 1). The surveys followed the same basic pattern as the vessel surveys, with the following exceptions. The helicopter flew at a speed of approximately 185 km/hr and an altitude of 100 m. The survey team consisted of 3-4 observers. The two primary observers were seated in back-to-back seats, one on each side, and looked out the open side doors of the helicopter. The navigator also searched for porpoises, assisted the pilot in following the survey lines, and recorded the data from the co-pilot's seat. On all except a few surveys, an additional person was stationed in the back compartment to assist the primary observers in looking for porpoises. Although the navigator could generally see along the trackline, the trackline directly below the aircraft could not be seen by the observers in the back compartment; thus, some animals on the trackline may have been missed.

We experimented with the use of a clinometer to assist in determining sighting distances to porpoise groups, by taking a vertical angle to the sighting position. However, we found

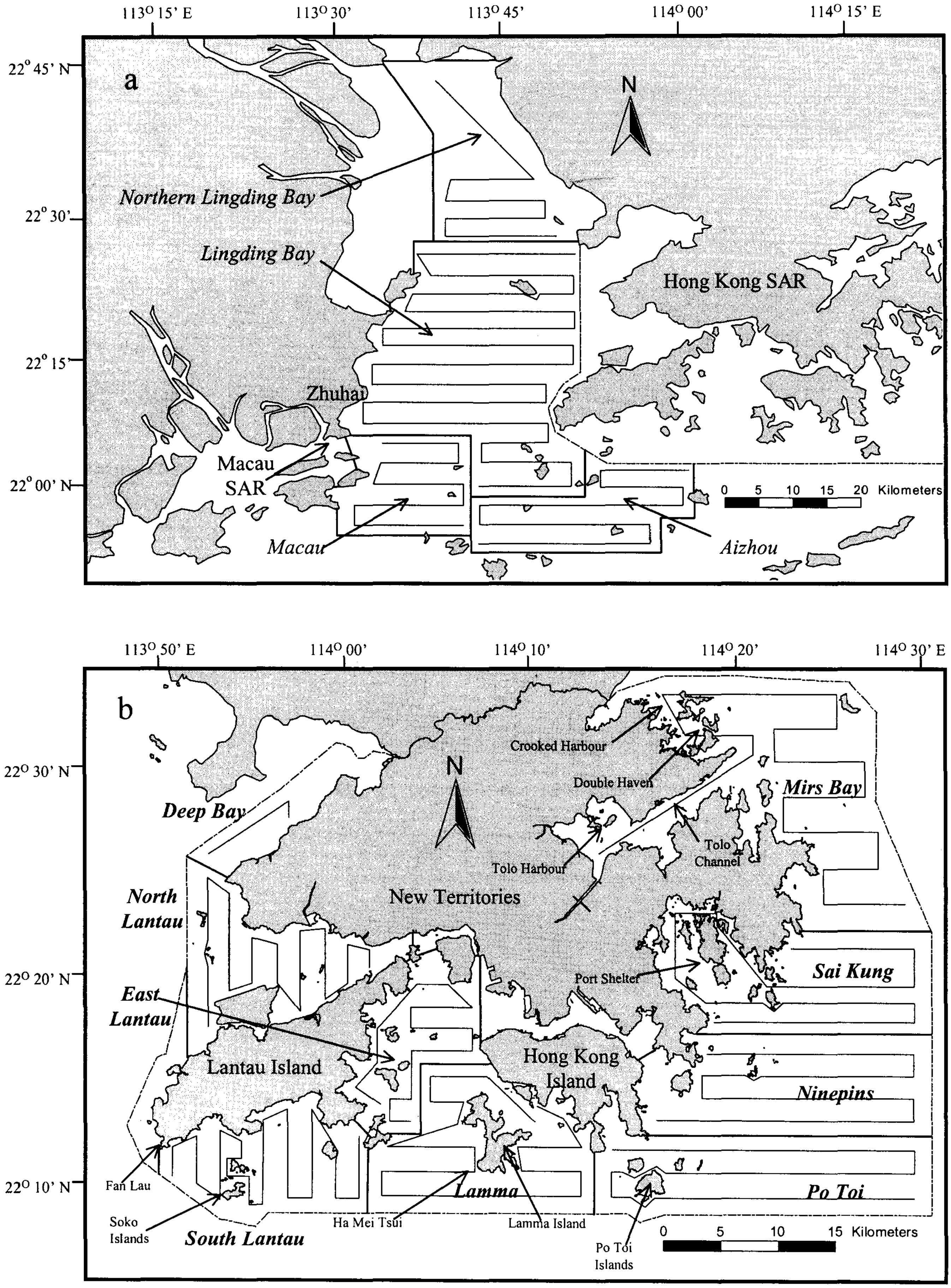


Fig. 1. Map of the study area, showing the survey sub-areas and transect lines: Chinese waters of Guangdong Province (a), Hong Kong SAR (b).

Table 1. Summary of characteristics of the nine survey subareas in Hong Kong, and the four in and around the Pearl River Estuary in China.

| Survey Area | Area ($km^2$) | Survey Effort (km)# | Description | Vessel Traffic | Pollution Level | Fishing Activity |
|---|---|---|---|---|---|---|
| | | | **HONG KONG** | | | |
| Deep Bay (DB) | 60 | 611 | Very shallow enclosed bay with extensive mudflats and mangroves; influenced by the Pearl River (high turbidity) | Moderate | Heavy | Significant area for gillnetting only |
| North Lantau (NL) | 141 | 17,868 | Strong estuarine influence, especially in western area; under heavy development; major shipping lanes and site of Hong Kong's new airport at Chek Lap Kok | Heavy | Heavy | Major area for shrimp trawling; significant area for hang trawling and gillnetting; pair trawling is common in western waters in autumn through spring months |
| East Lantau (EL) | 109 | 4,134 | Weak seasonal influence of the Pearl River; heavy shipping and major anchorage area; site of future theme park (Hong Kong Disneyland) | Heavy | Heavy | Major area for shrimp trawling; significant area for hang trawling |
| South Lantau (SL) | 129 | 3,462 | Seasonally influenced by the Pearl River; very little development, but major ferry lanes to Macau | Moderate | Low | Major area for pair and shrimp trawling; significant area for hang trawling; some purse seining and mixed gear fishing |
| Lamma (LA) | 174 | 6,744 | Largely marine influence; heavy shipping along some routes; site of large power plant | Heavy | Moderate | Major area for shrimp trawling; some stern trawling and purse seining |
| Po Toi (PT) | 189 | 3,750 | Relatively deep marine waters with little shoreline; heavily influenced by oceanic forces | Low | Low | Important area for mixed gear fishing |
| Ninepins (NP) | 213 | 1,836 | Relatively deep marine waters with little shoreline; heavily influenced by oceanic forces | Low | Low | Important area for mixed gear fishing |
| Sai Kung (SK) | 191 | 1,914 | Rocky, heavily indented shoreline; marine influence; light development | Low | Low | Major area for stern trawling; some pair trawling in northern part |
| Mirs Bay (MB) | 341 | 2,459* | Rocky shoreline; marine influence with coral communities; light development | Low | Low | Major area for pair trawling (including Tolo Channel and Harbour); significant area for stern trawling and purse seining |
| | | | **CHINA** | | | |
| Northern Lingding Bay (NLB) | 541 | 823 | Upper estuary of Pearl River; some deeper channels used as major shipping lanes | Moderate | Heavy | Important area for many types of fishing, especially pair and shrimp trawling |
| Lingding Bay (LB) | 1,090 | 6,887 | Large, estuarine system; some deeper channels used as major shipping lanes; receives run-off from heavily-populated Guangdong Province | Moderate | Moderate | Important area for many types of fishing, especially pair and shrimp trawling |
| Macau (MU) | 312 | 876 | Area to the east of Macau; influenced by the Pearl River; major ferry lanes between Macau and Hong Kong run through area | Moderate | Moderate | Moderately extensive areas for fishing, especially trawling |
| Aizhou (AZ) | 366 | 1,288 | Offshore area directly south of western Hong Kong | Moderate | Moderate | Relatively low fishing pressure |

\# Total survey effort is presented here, but the survey effort (L) presented in Table 2 is only that used in calculation of the abundance estimates (i.e., Beaufort 0-3 data).

* Primary survey effort in Mirs Bay was conducted by helicopter. However, in addition, we conducted 112 km of vessel survey effort in Mirs Bay.

the use of the device impractical from the fast-moving helicopter flying at low altitude. Subsequently, sighting distances were estimated by eye (distance estimation training specific to helicopter surveys was not attempted).

***Collection of Acoustic Data.*** – To determine the proportion of groups missed on and near the transect line (i.e., the trackline detection probability or g[0]), we used an automatic porpoise detector (POD - see Tregenza & Northridge, 1999) on a subset of the vessel surveys. The POD only became available late in the study, so the sample of data from it is small. However, the POD was deployed whenever possible during this period. The POD is a self-contained acoustic spectrum analyzer housed in a polypropylene cylinder (45 x 13 cm). A microprocessor in the POD compares the output of four bandpass filters centered between 132 kHz and 25 kHz, and times the duration of every event in which the energy from any of the three highest filters exceeds that from the two nearest filters by ratios that are set before deployment. The number of such events is stored for each second during deployment, with the highest frequencies counted in three duration classes. Mean noise levels at each filter frequency are also logged. The POD is battery powered and is activated by an immersion switch.

Although the POD was originally developed for static use in fisheries (Tregenza & Northridge, 1999), we developed a method of towing the unit at 13-15 km/h behind the survey vessel on a polypropylene line (Fig. 2). The positively-buoyant POD was kept about 2 m below the surface using a streamlined float (made from a recreational knee board) and a small hydroplane designed for use with recreational troll fishing gear (a Nekton Z-Wing 500). The float was rigged asymmetrically so that the POD was towed just outside the starboard edge of the vessel's bubble wake. It proved easy to deploy and retrieve and a data file from each deployment could then be downloaded to a PC via a serial port.

***Data Analysis.*** – Density and abundance estimates were calculated from sighting and effort data collected during conditions of Beaufort 0-3 (see below), using line transect methods (Buckland et al., 1993). The estimates were made using the computer program DISTANCE Version 2.1 (Laake et al., 1994). The following formulae were used to estimate density, abundance, and their associated coefficients of variation:

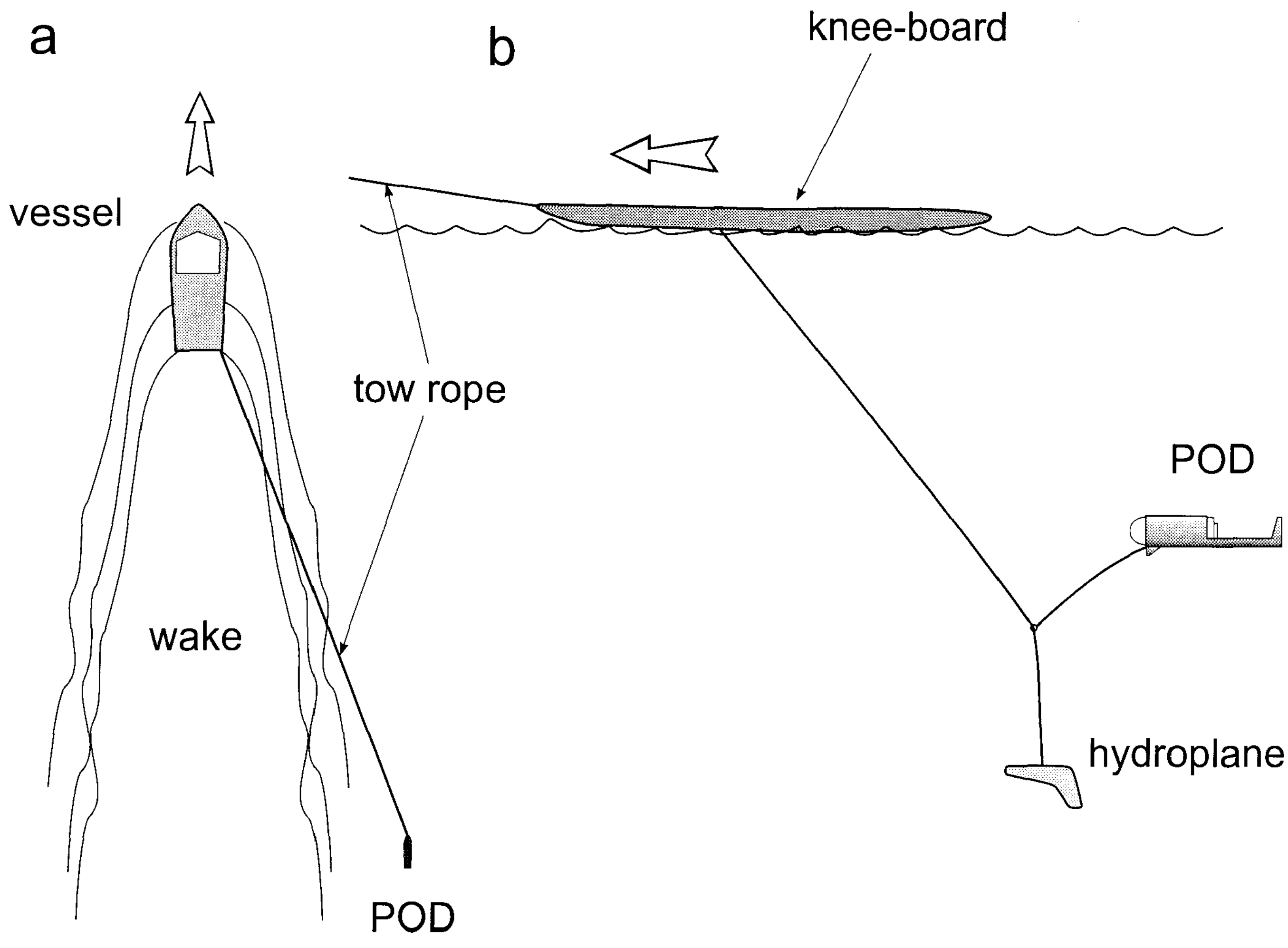


Fig. 2. Schematic diagram of set-up of the POD, viewed from above (left) and from the side (right).

$$\hat{D} = \frac{n\,\hat{f}(0)\,\hat{E}(s)}{2\,L\,\hat{g}(0)}$$

$$\hat{N} = \frac{n\,\hat{f}(0)\,\hat{E}(s)\,A}{2\,L\,\hat{g}(0)}$$

$$C\hat{V} = \sqrt{\frac{\hat{var}(n)}{n^2} + \frac{\hat{var}[\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\hat{var}[\hat{E}(s)]}{[\hat{E}(s)]^2} + \frac{\hat{var}[\hat{g}(0)]}{[\hat{g}(0)]^2}}$$

where D = density (of individuals),
n = number of on-effort sightings,
f(0) = trackline probability density,
E(s) = unbiased estimate of average group size,
L = length of transect lines surveyed on effort,
g(0) = trackline detection probability,
N = abundance,
A = size of the survey area,
CV = coefficient of variation, and
var = variance.

The parameter f(0), the trackline probability density, is central to the calculation of line transect estimates. Estimates made using small or biased samples can lead to great inaccuracies in the resulting abundance estimates; however, improper pooling can also introduce biases (see Buckland et al., 1993). We attempted to strike a balance between potential problems resulting from using small sample sizes and the potential introduction of inaccuracies from overpooling. For each survey area, we pooled data from all four seasons to calculate a single estimate of f(0) for each area. We feel this approach is justified, because the same vessels, observers, and sighting protocols were used in all seasons. This estimate [f(0)'] was then used in calculating separate seasonal estimates of density and abundance for that survey area. Besides this, and pooling for calculating the detection probability (see below), the estimates were fully-stratified by area and season. The theoretical estimation of the variance of f(0) was used. All other variance factors were estimated empirically. A feature of DISTANCE was used that calculated a size bias-corrected estimate of group size by regressing the natural logarithm of group size against detection probability (Laake et al., 1994), and this estimate was used in the calculation of density and abundance.

Acoustic data were downloaded to a desktop PC via a cable that plugged directly into the top of the POD (after removing the top). Preliminary adjustment trials of the POD showed that non-porpoise clicks in the highest frequency band were few, and scattered in time. Porpoise contacts often produced large numbers of high frequency clicks, with those over 100 microseconds duration being highly specific to the animals. Indo-Pacific humpback dolphin contacts produced small numbers of high frequency clicks of shorter duration associated with clicks at lower frequencies. Some working trawlers and large cargo vessels also produced high frequency clicks, but always with clicks at lower frequencies as well. A simple set of detection criteria was added to the POD software to define porpoise detections by a minimum number of high frequency clicks and a maximum number of associated clicks at lower frequencies. In this preliminary study, maximum click rates detected did not appear to rise with group size, despite the fact that larger groups would be expected to be associated with a higher number of total clicks.

The trackline detection probability for vessel surveys was estimated using the following formula:

$$\hat{g}(0) = \frac{n(0)_v}{n_a\,\hat{p} + n(0)_v}$$

where $n(0)_v$ = number of visual detections on and near the transect line,
$n_a$ = number of acoustic (POD) detections not seen by the visual observers, and
p = proportion of acoustic detections on and near the transect line.

For the purposes of this study, we defined 'on and near the trackline' to be within 125 m on either side of the transect line, based on the drop-off in sightings between 125 and 150 m perpendicular distance (see Fig. 3).

Since it was specific to vessel surveys, we could not use the POD data for estimation of the trackline detection probability for helicopter surveys. Instead, we followed the approach suggested by Laake et al. (1997). To do this, we obtained data on the time in which the porpoises are available to be detected by aerial observers, which was approximated by the time spent 'at or near' the surface (see Beasley & Jefferson, 2002). In that study, the time 'at or near' the surface was approximated by the surface time, which was defined as those periods in which at least one porpoise in the group was present at the surface, or in which all porpoises were underwater, but with dives no longer than 29 sec. The dive time (when porpoises were considered to be unavailable to be detected) corresponded to those periods in which the entire group of porpoises was underwater for 30 sec. or longer. The terms surface time and dive time correspond to Laake et al.'s (1997) surface/surfacing interval and dive interval, respectively. We then estimated the trackline

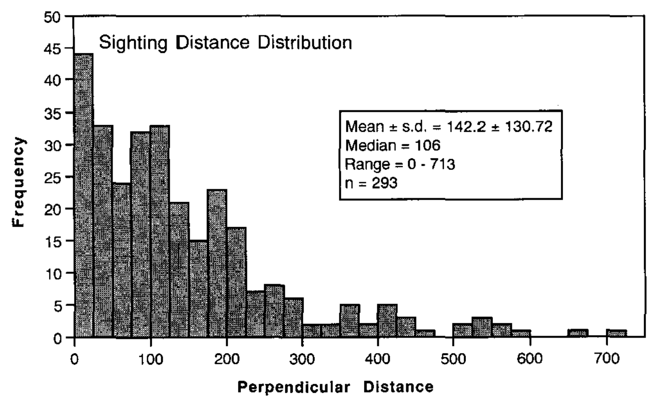


Fig. 3. Histogram of finless porpoise perpendicular sighting distance estimates.

detection probability for helicopter surveys from a modified version of Equation 5 in Laake et al. (1997):

$$\hat{g}(0) = \frac{st}{st + dt} + \frac{r/v}{st + dt}$$

where st = average surface time,
dt = average dive time,
r = radius of search area, and
v = aircraft survey speed.

Radius of search area was determined, based on the most distant sighting from the helicopter (520 m perpendicular distance). For more details on surface and dive time analysis, and details on how the data were collected, see Beasley and Jefferson (2002).

## RESULTS

***Distribution.*** – Finless porpoise sightings occurred in all of the southern and eastern waters of Hong Kong (South Lantau, East Lantau, Lamma, Po Toi, Ninepins, Sai Kung, and Mirs Bay study areas - Fig. 4). Porpoises were also sighted in the Aizhou area, which is directly south of South Lantau, in Chinese waters.

No sightings occurred in the northwestern areas of North Lantau and Deep Bay, despite extensive survey effort in all seasons (17,868 km in North Lantau; and 611 km of vessel effort and 237 km of helicopter effort in Deep Bay). Similarly, the Lingding Bay, Northern Lingding Bay, and Macau areas directly to the west of Hong Kong (part of the Pearl River Estuary in Chinese waters) were surveyed extensively (a combined total of over 8,586 km), and only one porpoise sighting was made (at the very southern end, far away from the major area of freshwater input, and near the Hong Kong boundary). Thus it is clear that areas heavily influenced by the freshwater contribution of the Pearl River were not used by finless porpoises. Even in South Lantau (which is only seasonally influenced by the river), porpoises occurred almost exclusively in the seasons of low freshwater input (winter and spring).

In contrast, the remaining waters of Hong Kong (which are not strongly influenced by the river flow) were all used, although not to the same extent. The southern waters (South Lantau, Lamma, and Po Toi areas) were clearly all important habitat for finless porpoises in Hong Kong, although there were seasonal differences in their use. The eastern survey areas (Ninepins, Sai Kung, and Mirs Bay) appeared to be used throughout the year, but the inshore portions of Port Shelter, Tolo Channel and Harbour, Double Haven, and Crooked Harbour did not appear to be used by porpoises.

Due to the uneven survey coverage in different areas and seasons, seasonal differences in porpoise distribution patterns are best understood by examining seasonal density and abundance estimates (see below).

***Abundance Estimates.*** – Finless porpoise groups, although somewhat cryptic and difficult to detect in poor weather, appeared to be appropriate subjects for visual line transect surveys. Sightings were made out to an estimated perpendicular distance of 713 m from the vessel, although the majority of sightings were estimated to be less than 300 m distant (Fig. 3). The POD detected most sightings that were visually detected within 250 m perpendicular distance (Fig. 5). Both sightings more distant than 350 m were not detected by the POD. It thus appears that the range of the POD is between 250 and 350 m. An estimate of the trackline detection probability for vessel surveys was made using data from four surveys with nearly complete transect line coverage and calm sighting conditions (Beaufort 0-3). The estimates ranged from 0.58 to 1.0, with a mean of 0.72. The estimate of the trackline detection probability for helicopter surveys was 0.65.

Hong Kong Waters - Abundance estimates were calculated for all areas in which there were adequate data (Fig. 6, Table

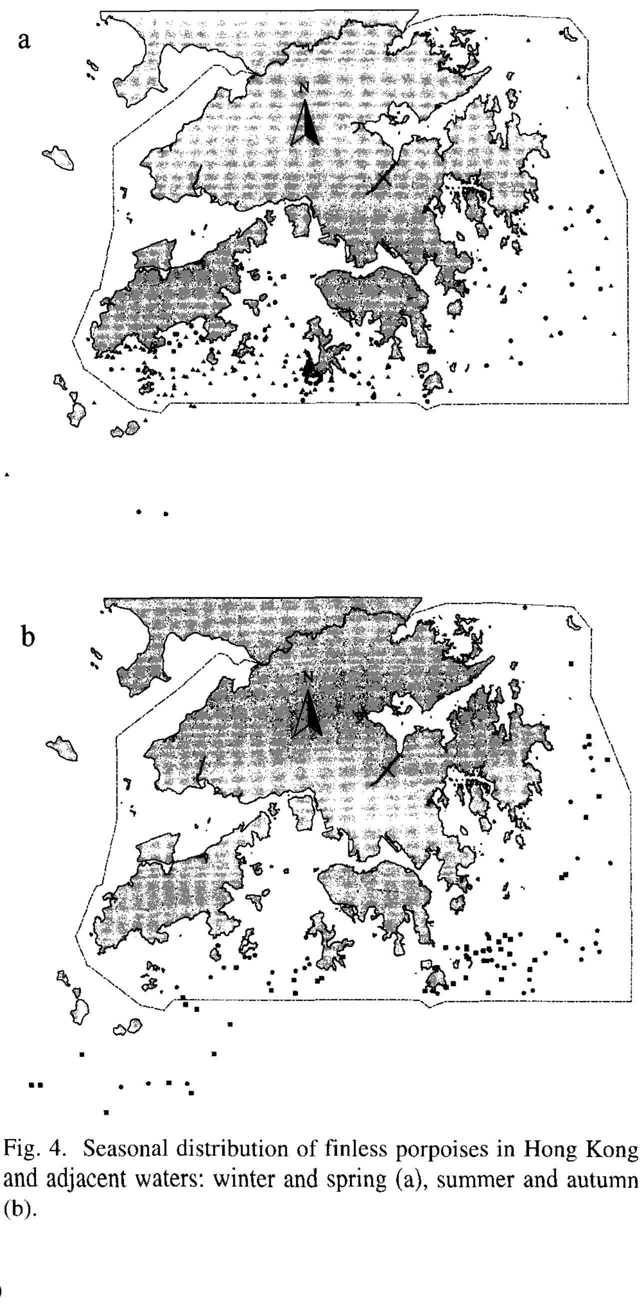


Fig. 4. Seasonal distribution of finless porpoises in Hong Kong and adjacent waters: winter and spring (a), summer and autumn (b).

2). Overall, abundance in Hong Kong appeared to peak in spring (with an estimated 152 animals present), and the low season was autumn (with an estimated 55 porpoises). The autumn season estimate corresponds to only 36% of the peak season estimate for spring, indicating that a large portion of animals are outside of Hong Kong waters in autumn. However, it should be emphasized that many of the seasonal estimates have high coefficients of variation (more than half are higher than 50%) and should, therefore, be viewed as preliminary.

In winter, porpoises appeared to be mostly present in the central and western survey areas of South Lantau, East Lantau, and Lamma. Abundance remained high in these areas in spring, but numbers appeared to be supplemented by movements into some of the more eastern waters at this time of year. Summer resulted in a dramatic decrease in abundance in South Lantau and Lamma, but abundance in some southeastern areas (e.g., Po Toi and Ninepins) increased. Finally, in autumn abundance decreased everywhere and was low in most areas, except Po Toi and, to a lesser extent, Ninepins.

Aizhou Area - The Aizhou area had substantial numbers of porpoises in all seasons, with summer having the highest (Fig. 6). The general pattern appeared to result more from shifting of animals among different areas and movements of porpoises across the Hong Kong/China border, rather than from mass migrations into and out of the study area. The combined peak estimate for all areas (217 porpoises in spring and summer) can be viewed as a preliminary minimum population size. Most of these animals (an estimated 147 out of 217 porpoises, or 68%) are outside of Hong Kong waters in summer.

## DISCUSSION

***Distribution Patterns.*** – Four general points are readily apparent from examination of the winter/spring and summer/autumn distribution maps (Fig. 4):

(1) Finless porpoises do not appear to occur in the northwestern waters of Hong Kong and most of Lingding Bay. These areas are all heavily influenced by the Pearl River and are estuarine in nature. They are also major habitat for Indo-Pacific humpback dolphins.

(2) Porpoises occur in all of the southern and eastern waters of Hong Kong, and in all of the waters that have so far been surveyed south of the Hong Kong border (e.g., Aizhou). These areas are only seasonally and weakly, if at all, influenced by the Pearl River.

(3) There are no migrations (i.e., there is no evidence that porpoises vacate large portions of their range in different seasons).

(4) Seasonal movements, or shifts in abundance, do occur. There appears to be a general shift in the main clusters of sightings from the west and inshore in winter and spring, to the east and offshore (and therefore outside of the SAR boundary) in the summer and autumn seasons. Shifts back into Hong Kong waters begin in winter and continue through spring.

The reasons for the apparent seasonal shifts in abundance of finless porpoises in Hong Kong and adjacent waters are not known with any degree of certainty at this point. There are a number of possible explanations, any number of which may be involved. The most likely factor has to do with the seasonal patterns of freshwater output of the Pearl River. The higher density seasons for porpoises (winter and spring) occur during the dry months and the lower density seasons (summer and autumn) coincide with the summer monsoon rains. This pattern may be linked, either directly or indirectly through corresponding effects on prey, to the seasonal movements exhibited by these animals. Predation and competition with humpback dolphins (see discussion below) are other possible factors.

***Potential Biases in Abundance Estimates.*** – Some of the factors that may cause bias in this study have been investigated with preliminary data, by critically examining several of the line transect assumptions. Bias in estimates of group size is one factor that may have a significant effect,

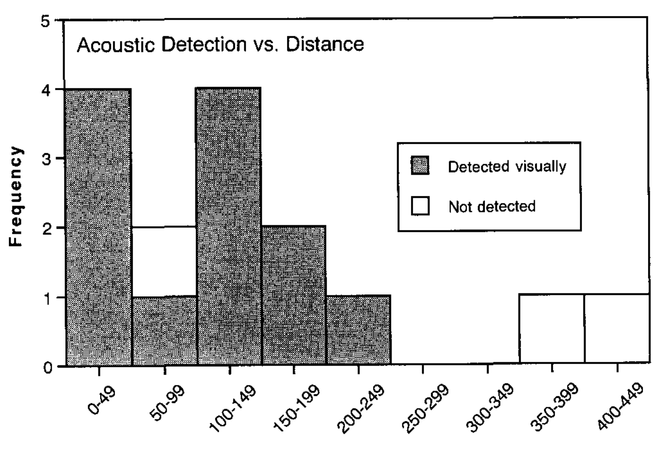


Fig. 5. Histogram of estimated distances of porpoise sightings in relation to whether or not they were detected acoustically with the POD.

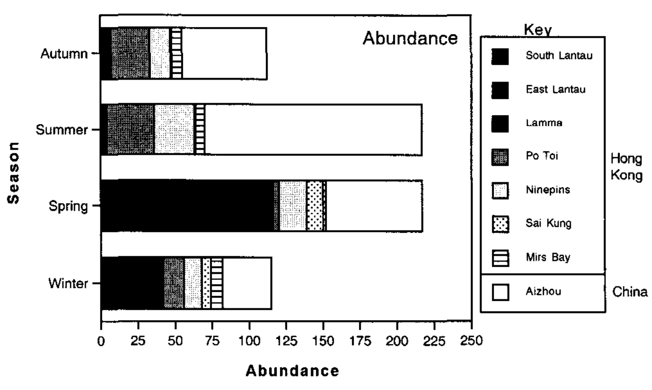


Fig. 6. Estimates of abundance of finless porpoises in Hong Kong and adjacent waters. Western areas of Hong Kong are represented by dark shading, eastern areas by lighter shading and hatching, and areas outside of Hong Kong (Guangdong Province) by open bars.

Table 2. Components of the line transect equation, and estimates of density (D) and abundance (N) for finless porpoises in Hong Kong and adjacent waters of Guangdong Province, China. The trackline probability density stratified by season is denoted by f(0) in the fourth column, and that pooled across seasons is denoted by f(0)' in the fifth column. Measures are in the following units: $km^{-1}$ for f(0) and f(0)', km for L, and individuals/100km² for D. The size of the survey areas is given in Table 1.

| Area | Season | n | f(0)* | f(0)' | E(s) | L | D | N | %CV |
|---|---|---|---|---|---|---|---|---|---|
| South Lantau | Winter | 10 | 2.86 | 4.02 | 2.5 | 523 | 13.31 | 18 | 45 |
| | Spring | 19 | 4.77 | 4.02 | 2.1 | 546 | 19.35 | 25 | 37 |
| | Summer | 0 | - | - | - | 590 | 0 | 0 | - |
| | Autumn | 1 | 2.86 | 4.02 | 1.0 | 993 | 0.28 | 0$ | 150& |
| East Lantau | Winter | 3 | 4.56 | 1.82 | 8.2 | 468 | 6.64 | 7 | 122& |
| | Spring | 2 | 1.82 | 1.82 | 1.5 | 668 | 0.57 | 1 | 72& |
| | Summer | 0 | - | - | - | 726 | 0 | 0 | - |
| | Autumn | 0 | - | - | - | 1,515 | 0 | 0 | - |
| Lamma | Winter | 17 | 6.10 | 4.08 | 2.4 | 1,173 | 9.85 | 17 | 32 |
| | Spring | 35 | 3.75 | 4.08 | 5.9 | 1,126 | 51.96 | 90 | 32 |
| | Summer | 4 | 3.75 | 4.08 | 2.0 | 1,007 | 2.25 | 4 | 50 |
| | Autumn | 12 | 3.84 | 4.08 | 1.6 | 1,283 | 4.24 | 7 | 32 |
| Po Toi | Winter | 6 | 7.68 | 5.00 | 1.3 | 400 | 6.93 | 14 | 63& |
| | Spring | 3 | 79.47 | 5.00 | 1.7 | 962 | 1.82 | 4 | 60& |
| | Summer | 18 | 5.50 | 5.00 | 2.8 | 940 | 16.51 | 32 | 36 |
| | Autumn | 16 | 4.65 | 5.00 | 2.0 | 667 | 14.45 | 26 | 36 |
| Ninepins | Winter | 2 | 6.37 | 4.61 | 2.0 | 225 | 5.69 | 12 | 62& |
| | Spring | 5 | 9.72 | 4.61 | 2.0 | 363 | 8.82 | 19 | 48 |
| | Summer | 6 | 1.67 | 4.61 | 3.7 | 556 | 12.78 | 27 | 99& |
| | Autumn | 2 | - | 4.61 | 4.0 | 379 | 6.76 | 14 | 65& |
| Sai Kung | Winter | 4 | 2.47 | 2.47 | 1.0 | 244 | 2.91 | 6 | 43 |
| | Spring | 3 | 3.68 | 2.47 | 4.0 | 363 | 5.86 | 11 | 71& |
| | Summer | 2 | 3.45 | 2.47 | 1.0 | 477 | 0.52 | 1 | 57& |
| | Autumn | 1 | 2.82 | 2.47 | 1.0 | 494 | 0.64 | 1 | 70& |
| Mirs Bay# | Winter | 2 | 3.64 | 3.51 | 1.5 | 290 | 2.36 | 8 | 102& |
| | Spring | 1 | 4.00 | 3.51 | 1.0 | 369 | 0.71 | 2 | 112& |
| | Summer@ | 3 | 3.51 | 3.51 | 1.5 | 660 | 1.75 | 6 | 65& |
| | Autumn | 1 | 5.99 | 3.51 | 5.0 | 598 | 2.15 | 7 | 97& |
| Aizhou | Winter | 2 | 10.53 | 7.58 | 1.5 | 177 | 8.86 | 33 | 21 |
| | Spring | 4 | 7.58 | 7.58 | 2.0 | 238 | 17.84 | 65 | 61& |
| | Summer | 8 | 8.47 | 7.58 | 3.0 | 316 | 40.00 | 147 | 62& |
| | Autumn | 2 | 15.39 | 7.58 | 2.5 | 170 | 15.51 | 57 | 66& |

* Truncation distances used for estimation of f(0)' = 550 m (South Lantau), 675 m (Lamma), 400 m (Po Toi), and 600 m (Ninepins). There was no truncation for the other areas.

$ It may seem enigmatic to have an abundance estimate of zero resulting from a set of surveys in which one porpoise was seen. However, this results from the practice of presenting all abundance estimates as whole numbers; the low density resulted in an abundance of less than 0.5 porpoise, which was consequently rounded to zero.

& These estimates have very high CVs of over 50%, and should thus be viewed as highly preliminary.

\# The Mirs Bay area was surveyed by helicopter (see text).

@ The summer estimate for Mirs Bay would have been highly influenced by a sighting of a large aggregation of 35 finless porpoises. This group size was considered an outlier, as it was far larger than any other group observed in the area. Therefore, we deleted this group size when estimating abundance for this area in summer.

although this is generally more of concern for species of dolphins that occur in large schools. A plot of porpoise group size vs. perpendicular sighting distance shows that overall group size estimates do not appear to be significantly biased by sighting distance (Fig. 7). While there is more scatter in group sizes for closer sightings, this is partially due to the larger sample size of close sightings. This indicates that group size bias should not be a major factor in the accuracy of abundance estimation for finless porpoises in Hong Kong.

Distance estimation bias can be another factor that has an influence on abundance estimates. Throughout the study, we have used laser rangefinder binoculars to test the accuracy of distance estimates of observers (see Jefferson, 2000).

While there are differences in estimating distances to stationary objects vs. surfacing porpoises, we believe that this experiment has improved our ability to obtain accurate sighting distance data. Figure 8 shows the actual (measured) distance associated with each estimate made by an observer during the distance-estimation experiment, along with a regression line fit to the data and another (theoretical) line showing no bias. Although there is scatter about the line, the regression line falls nearly on top of the theoretical line associated with no bias. Thus, there appear to be no major problems in distance estimation capabilities of the observers, and this factor should not bias the accuracy of abundance estimation. Despite this, two other issues are apparent from the analysis. First, at great distances (> 700 m), distance estimates are almost always negatively biased (although, in general, these distant sightings will have little effect on the resulting abundance estimates). Second, variance of the estimates increased with increasing distance (but was relatively low at 0-200 m).

Perhaps one of the most important factors in estimating abundance of many cetaceans is the bias introduced by using data collected during poor sighting conditions, generally high Beaufort sea states (although there are other factors, such as swells, glare, etc.). This can cause a downward bias in abundance estimation, due to animals missed on and near the trackline. This would be expected to be a particularly significant issue for finless porpoises, which have no dorsal fin, are small, dark in colour, and do not approach vessels, nor have showy behavior. Clearly, finless porpoise groups are more difficult to detect in poor sighting conditions, with the average sighting distance dropping-off linearly with increasing sea states (Fig. 9). However, line transect analysis has the capability to compensate for animals missed due to poor sighting conditions, at least to some extent (see Jefferson and Leatherwood, 1997).

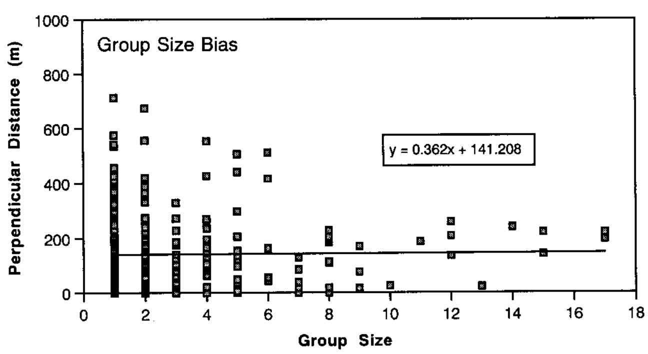


Fig. 7. Assessment of group size bias in relation to estimated perpendicular sighting distance. This graph makes use of on-effort sighting data only.

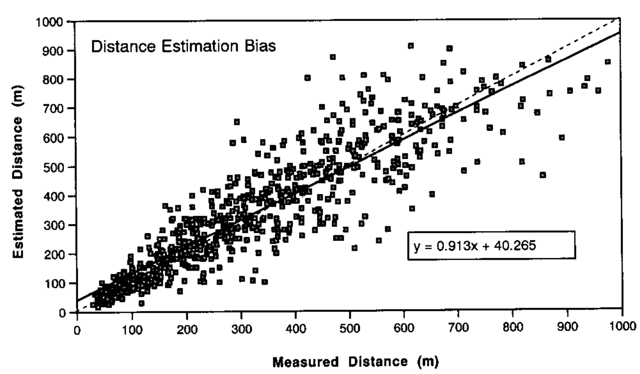


Fig. 8. Assessment of distance estimation bias from observer calibration experiments using laser rangefinder binoculars. Regression line fit to empirical data is indicated by a solid line and theoretical line with no bias by a dashed line.

To determine if the above caused bias in abundance estimates for the present study, we stratified the effort and sighting data by Beaufort sea state (Beaufort 0-3 in one category, and Beaufort 4-5 in the other - we could not further stratify due to small sample sizes). Estimates of sighting rate, f(0) (the trackline probability density), and abundance were then calculated using the stratified data (Fig. 10). The results showed that:

(1) The sighting rate dropped off in the higher sea states (although not dramatically),

(2) The f(0) for the higher sea states was greater, thereby compensating, to a certain extent, for the lower sighting rate, and

(3) The overall estimate of abundance (a product of both sighting rate and f(0)) was lower by 42% for the higher sea states.

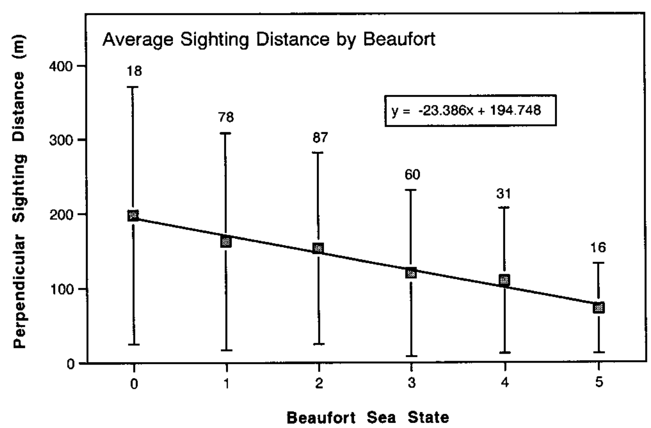


Fig. 9. Effect of sighting conditions, as indicated by Beaufort sea state, on the average estimated perpendicular sighting distance for finless porpoise groups. Point estimates are indicated by filled dots, ± 1 standard deviation by vertical bars, and sample sizes by numbers above bars.

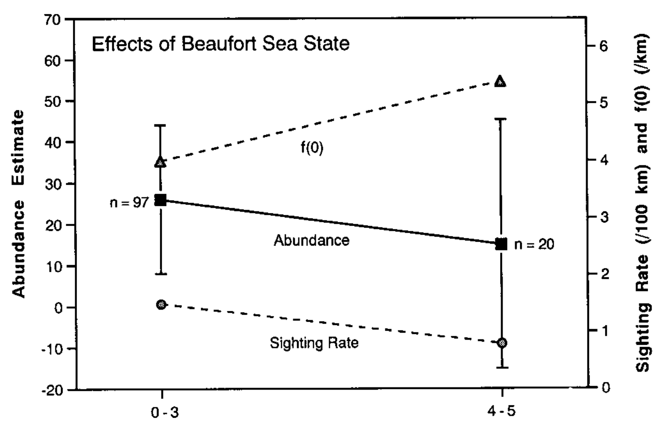


Fig. 10. Assessment of the effects of Beaufort sea state on estimates of sighting rate, f(0), and abundance of finless porpoises.

Taken together, these results suggest the following. First, porpoises are more difficult to detect in rougher sea conditions (this is obvious). Second, line transect is an appropriate method of abundance estimation for this species, in that its built-in compensating mechanism can correct for lower sighting rates in poorer sighting conditions (as long as the assumption detection unity along the trackline, and other primary assumptions are satisfied). Finally, despite the previous fact, using data collected in Beaufort 4-5 conditions would still result in estimates of abundance that are biased low (this is presumably due to missing more animals on the transect line in those conditions). This is the reason that density and abundance estimates were made using only Beaufort 0-3 data in this study.

It should be noted that our estimate of g(0) for the vessel surveys, calculated with the assistance of the POD, is subject to a positive bias. This is due to the fact that some unknown proportion of porpoises will not be seen, but will also not be detected acoustically (the latter mostly due to the absence of detectable vocalizations as the vessel passes). In addition, we have indications that porpoise detectability differs among survey areas (suggested by the large variation in estimates of f[0]). Our g(0) estimate for vessel surveys was made using a small sample of data and it ignores these apparent differences, both of which may have a serious effect on the accuracy of the resulting abundance estimates. Despite these remaining problems, we feel our use of the POD to estimate the trackline detection probability represents a significant improvement over the traditional practice of assuming that g(0) = 1.0. Further, we hope to refine our abilities to estimate trackline detection probability with continued research in the future.

For comparative purposes, we also calculated an estimate of g(0) for vessel surveys from the surface/dive time data. The resulting estimate was 0.55, compared to an estimate of 0.72 made from the POD data. The two estimates are broadly similar, and we would expect the estimate from the POD to be higher because it also incorporates animals missed as a result of perception bias (the surface/dive time estimate only accounts for availability bias). We feel that the good agreement of these two estimates lends confidence to the validity of the g(0) estimates we used in this study, despite the potential problems indicated above.

The helicopter surveys suffered from some additional potential biases. These include the potential for missing some animals on the trackline, due to the inability of the primary observers to see directly below the aircraft. This problem should be minimized by the fact that the navigator could see along the trackline ahead of the aircraft. Also, the survey team varied in size from 3-4 people, and was thus not 100% consistent. However, this should have only a minor effect on abundance estimates, since in practice almost all sightings were made by the primary observers or the navigator (which were present on all surveys). In any event, this factor would only affect the estimates for Mirs Bay.

Any future attempt to examine the data for abundance trends is susceptible to an additional potential bias, due to the fact that the study area does not contain a closed population of animals. Porpoises can, and apparently do, move freely among this area and adjacent areas that were not surveyed. Fishermen report sightings and captures of finless porpoises in Chinese waters south and offshore of Hong Kong (Torey, 2000). Therefore, any trends observed in the estimates, even if real, may simply reflect local movements of animals and not necessarily changes in overall abundance of the population (e.g., the "redistribution" factor). Because of this, we have not attempted a trends analysis. However, the study is ongoing and we are working to collect additional survey data in adjacent areas. We hope to be able to conduct a trends analysis at some point in the future, when the present shortcomings are addressed.

***Comparisons with Other Studies.*** – The avoidance by finless porpoises of brackish waters of the Pearl River Estuary is interesting, as it is in contrast to what might be expected. It might be suggested that this is a result of human impact on the area, as the estuarine waters are used extensively for shipping, fishing, and other commercial activities. However, this would not explain the seasonal patterns that we see (such as heavy use of South Lantau in winter/spring, and near-absence in summer/autumn). A more likely explanation is that there is some sort of ecological competition or niche separation between finless porpoises and humpback dolphins, as suggested by Parsons (1998). The latter species is found only in the western Pearl River-influenced waters, and has peaks in abundance in summer/autumn, and lows in spring (Jefferson & Leatherwood, 1997; Jefferson, 2000). The distribution patterns of the two species are almost exactly opposite. We have never seen any aggressive behavior between the two, and in fact, we have rarely seen the two species in the same area at the same time. While it is not possible to evaluate this hypothesis further at this time, it is intriguing to speculate. Further work on both species in the area may shed light on their relationships.

Previous studies in Japan, China, and Pakistan have found a seasonal pattern of distribution for finless porpoises (Pilleri & Gihr, 1972; Kasuya & Kureha, 1979; Zhang et al., 1993; Shirakihara et al., 1994; Yoshida et al., 1998). This has also been suggested previously for Hong Kong waters (Parsons, 1998; Parsons & Wang, 1998; Jefferson & Braulik, 1999). It thus appears that seasonal movements may be the norm for most finless porpoise populations. Some studies have indicated a much higher density of finless porpoises very near the shoreline (within a few hundreds of meters) (Kasuya & Kureha, 1979; Zhang et al., 1993). We did not find much evidence of this in Hong Kong, where sightings occurred just as commonly in some areas several kilometers from shore as they did nearshore (although still in relatively shallow water). However, density is also influenced by group size, and if group sizes are larger near shore, the overall density may still be higher nearshore.

The only previous estimates of abundance for finless porpoises in Hong Kong are those of Jefferson & Braulik (1999), made from preliminary data of this study. The overall pattern of seasonal abundance was similar, with a peak in the spring and a low in the autumn. The spring peak season estimate of this paper (152) is similar to the previous estimate (about 150 animals), despite some differences in analytical methods. The estimate of this paper is likely to be more accurate, because of the larger sample of data, as well as the practices of seasonal pooling for estimation of f(0) and incorporation of the trackline detection probability into the line transect equation (which were not followed in the Jefferson & Braulik study). The higher precision of the current estimates is reflected in the lower CVs associated with the component estimates (see Table 2).

Finless porpoise densities reported in this paper (0.28-51.96 individuals/100 km$^2$) are broadly similar to those reported by Kasuya & Kureha (1979) for the Inland Sea of Japan (11-34 /100 km$^2$). However, densities in most other studies in Japanese coastal waters have been higher (60 /100 km$^2$ in Omura Bay - Yoshida et al., 1998; 30-229 /100 km$^2$ in the coastal waters of western Kyushu - Shirakihara et al., 1994; and 120-140 /100 km$^2$ in Araike Sound and Tachibana Bay - Yoshida et al., 1997). It thus appears that Hong Kong does not represent a particularly high density area for finless porpoises. However, these studies used many different methods, and some of the apparent differences may be artifacts of methodological differences.

***Implications for Conservation and Management.*** – The highest density found in this study was for the spring season in the Lamma survey area. During this time of year, when there are many newborn calves, large numbers of finless porpoises are found in the waters around Lamma Island (especially off the southwest coast). Therefore, this area would appear to be a good candidate as a protected area for finless porpoise conservation. In fact, the Hong Kong SAR Government is currently designating the south Lamma area as a marine park, and we strongly support this and further recommend that stringent measures be put in place to prevent this area from becoming further degraded by human activities.

One of the most important pieces of information that is needed for sound conservation and management is an accurate estimate of the overall size of the affected stock. Although we can use our peak season abundance estimate (about 220 animals) as a minimum population estimate until better information is available, it is clear that the actual size of the population is somewhat higher, for the reasons outlined in Jefferson & Braulik (1999). Until we are able to obtain survey data in additional waters to the south and east of Hong Kong and determine the entire range, we will not be able to determine how many animals the population contains.

If the population is indeed not much larger than the spring/summer estimates of 217 porpoises, then its conservation status would be of immediate concern. Generally, populations of well over 100 animals (from a genetic perspective, at least 500-5000) are considered to be necessary to ensure viability (see Lande & Barrowclough, 1987; Lande, 1995; Rosel & Reeves, 2000). Of course, if the distribution extends far beyond Hong Kong, then the population may be much larger. In any event, it will be important to provide adequate protection to the animals in Hong Kong to ensure that their abundance does not decrease. At the same time, we must work to obtain survey data for Chinese waters inhabited by porpoises of the same population, and to further elucidate stock structure.

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