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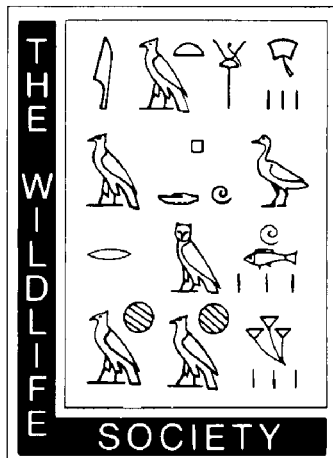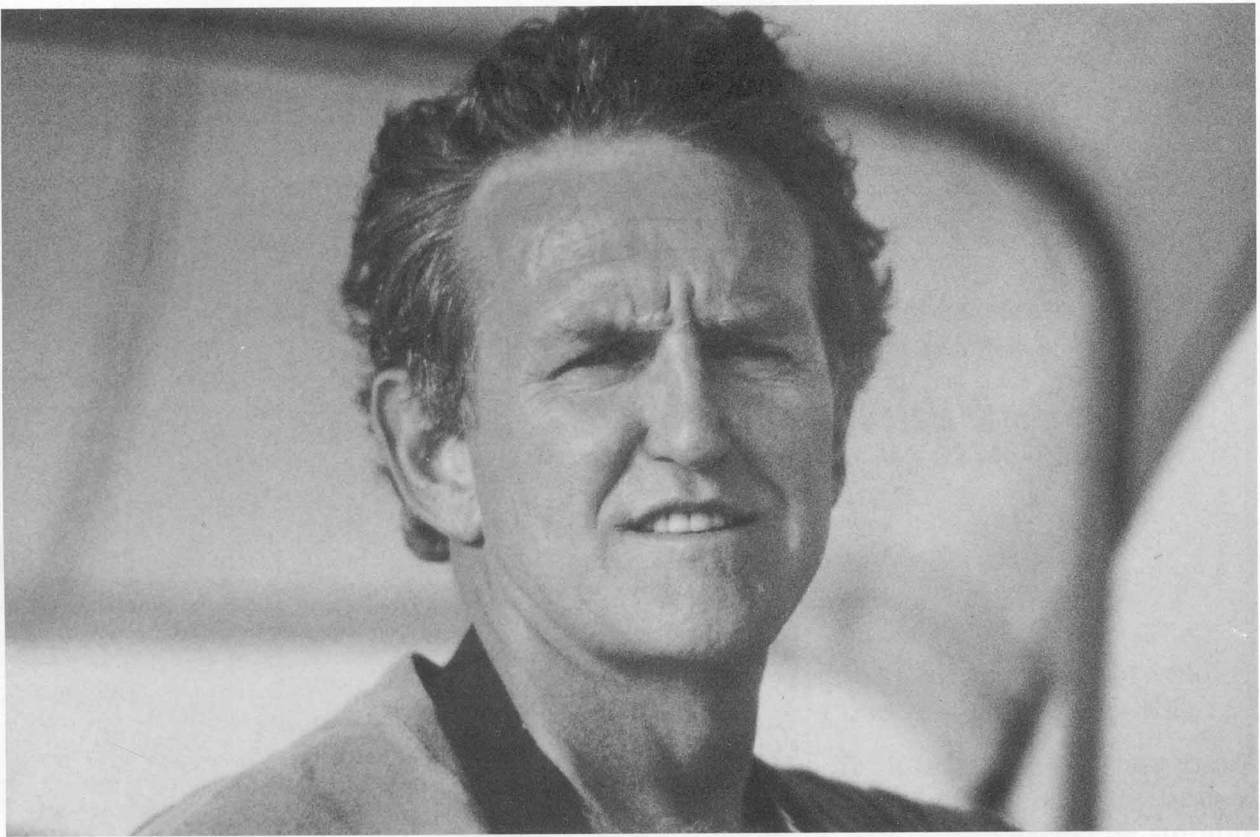
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POPULATION BIOLOGY OF THE INDO-PACIFIC HUMP-BACKED DOLPHIN IN HONG KONG WATERS

by

THOMAS A. JEFFERSON

FRONTICEPIECE. This monograph is dedicated to the memory of the late Dr. Stephen Leatherwood (top). Steve was integrally involved in the initial stages of this work, and his shining example of fine science, good will, and caring compassion for the subjects of his work will always be a source of inspiration. The "Chinese white dolphins" of Hong Kong (bottom) made fascinating research subjects, and I hope that these animals will always be found frolicking in the murky waters of Lantau Island.

POPULATION BIOLOGY OF THE INDO-PACIFIC HUMP-BACKED DOLPHIN IN HONG KONG WATERS

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Abstract: The Indo-Pacific hump-backed dolphin (*Sousa chinensis* Osbeck, 1765) is found throughout the western Pacific and Indian oceans, from southern China and northern Australia in the east to South Africa in the west. Throughout most of its range it has not been well studied, and in southern China very little is known of its biology. The goal of the present study was to provide scientific information needed for the long-term conservation and management of the population that occurs in Hong Kong waters. From September 1995 to November 1998, 38,105 km of systematic line transect surveys were conducted throughout marine waters of the Hong Kong Special Administrative Region (SAR) of the People's Republic of China (PRC) and adjacent waters to provide data on distribution and abundance. Photo-identification of individual dolphins allowed for examination of movement patterns, home ranges, and social organization. Collection of stranded dolphin carcasses and detailed necropsies provided information on causes of death as well as samples for life history studies, such as feeding habits, growth and reproduction, ecotoxicology, and stock structure.

The dolphin population appears to be centered around the Pearl River Estuary, and Hong Kong waters represent the eastern portion of the range, which extends far into mainland Chinese waters (Lingding Bay) and covers at least 1,800 km². Within Hong Kong, dolphins only occur in western waters around Lantau Island. The area north of Lantau Island is heavily used throughout the year and represents by far the most important habitat in Hong Kong. Line transect analyses indicate that between 88 (spring) and 145 (summer) dolphins occur in Hong Kong. Based on 27,600 photographs taken, 213 individual dolphins were identified. The total size of the Pearl River breeding population is unknown, but is estimated to consist of at least 1,028 dolphins, based on line transect analysis. An apparent decline in the number of dolphins in the North Lantau area over the period from 1996–1998 was not statistically significant. Individual dolphins have overlapping home ranges of about 30–400 km² in different sections of the population's overall range. Groups of dolphins in Hong Kong number up to 23 animals, with an average group size of 3.8 ± s.d. 3.63 animals. There is no significant seasonal variation in group size, but groups feeding behind pair trawl fishing vessels (mean = 9.6 ± s.d. 5.37) are significantly larger than other groups, and groups in Lingding Bay, in Chinese waters west of Hong Kong (mean = 8.3 ± s.d. 7.84) are significantly larger than those in Hong Kong. Groups are very fluid and change composition frequently, with association indices ranging from 0–0.333. Behavioral patterns are similar to those of other coastal dolphins, but Hong Kong hump-backed dolphins only rarely ride bow waves. Following pair trawlers represents an important feeding strategy for some individuals. Construction work on an airport fuel facility in the dolphins' main habitat appears to have caused some disturbance (indicated by increased swimming speeds) and possibly temporary evacuation of the surrounding area.

There is a great deal of developmental variation in the color pattern of southern Chinese hump-backed dolphins, with a general lightening from newborn to adult stages. Males appear to retain more spots in adulthood than females. Length at birth appears to be about 100 cm, and postnatal development is characterized by rapid growth in the first year and a levelling-off of the growth curve after reaching adulthood. Asymptotic length is reached at around 243 cm. Length and weight are related exponentially, with the maximum weight about 250 kg. Calving occurs throughout the year, but most young are born from January through August, with a peak in spring/summer. Scant evidence suggests that sexual maturity in females is reached at about 9–10 years of age. Dolphins feed mainly on several demersal and pelagic fish species that are often associated with estuaries. There is a lack of evidence for long-distance movements (on the order of hundreds of linear kilometers), and this presumably results in isolation of groups around major Chinese river mouths. Thus it appears that there may be at least 8 separate populations of hump-backed dolphins along the coast of southern China. The Pearl River Estuary, including Hong Kong, is apparently inhabited by one of these populations, although preliminary genetic work has shown only equivocal evidence of population separation from dolphins in the Xiamen area. Human-related causes of mortality include entanglement in fishing nets and vessel collisions. Some environmental contaminants (especially the heavy metal mercury and the pesticide DDT) were found in high levels in some dolphins, and preliminary evidence suggests that these may be affecting the health of the animals.

A series of recommendations for management and for further research have been made to aid in the conservation of these animals. Principles for the conservation of wild living resources should be followed, and

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information from both the natural and social sciences are needed for proper management. Research and long-term monitoring of the population must continue for management strategies to be evaluated and refined. Overall, the population of hump-backed dolphins that occurs in Hong Kong waters appears to be viable and should be able to survive with appropriate conservation efforts.

CONTENTS

INTRODUCTION

Project Background

The Indo-Pacific hump-backed dolphin (*Sousa chinensis* Osbeck, 1765) is distrib-

uted throughout shallow, coastal waters of the Indian and western Pacific oceans, from South Africa in the west to northern Australia and southern China in the east (Ross et al. 1994). Throughout most of its range, the species has been completely un-

studied. The only dedicated, long-term research on these animals has been in South Africa, where studies of behavioral ecology (Saayman and Tayler 1973, 1979; Karczmarski 1996) and population biology (Ross 1984; Cockcroft 1989, 1990, 1991; Durham 1994; Karczmarski et al. 1999) have been conducted, and northeastern Australia, where Corkeron (1990) and Corkeron et al. (1997) have done some work on social ecology. This nearshore species inhabits waters that are being heavily modified for human use. Fishing, vessel traffic, pollution, and various forms of coastal development are affecting hump-backed dolphins and their habitats, both directly and indirectly. It was primarily these concerns that led to recent calls for studies of the status of populations of this species (Perrin 1989, Reeves and Leatherwood 1994).

One such population of this species occurs, at least partially, in waters of Hong Kong (Parsons et al. 1995). Hong Kong[2] is a rapidly-developing region along the southwestern coast of China. As one of the wealthiest societies in southeast Asia, Hong Kong has enjoyed the benefits of economic development, but the natural environment has suffered accordingly (see Leatherwood and Jefferson 1997, Liu and Hills 1997).

In the late 1980s, environmentalists began to call attention to the hump-backed dolphins that occur in western waters of Hong Kong, which until then had been largely ignored. When plans for construction of Hong Kong's new international airport in the middle of the dolphins' range became widely-known in the early 1990s, concern quickly grew about the effects that this large project might have on the dolphin population (see review in Leatherwood and Jefferson 1997).

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[2] On 1 July 1997, the British Dependent Territory of Hong Kong became a Special Administrative Region (SAR) within the People's Republic of China (PRC). Despite this, Hong Kong still retains a high degree of autonomy, and the boundary remains a political barrier to dolphin research efforts. For these reasons, Hong Kong is treated in this report as a region separate from mainland China.

The present project was undertaken to address the need for reliable information to properly manage and conserve the dolphin population. The principal aims of the study were to examine the distribution and abundance of the population and to determine trends in numbers. In addition, information on stock discreteness, behavioral ecology, movement patterns, life history, and threats to the population also was collected. Preliminary results of the distribution and abundance analyses have previously been published (Jefferson and Leatherwood 1997).

Status of Knowledge on *Sousa chinensis* in Southern China

Taxonomy and Systematics.—The first scholarly description of a hump-backed dolphin, albeit brief, was made from observations of live animals in the Canton (Pearl) River, in mainland Chinese waters just west of Hong Kong, by Pehr Osbeck in 1757. He described the animals as "*Delphinus chinensis*," but no type specimen was collected, as this was one year before Linnaeus' taxonomic system was published in 1758. Thus, by the Law of Priority, Osbeck's (1765) German translation must be used for taxonomic purposes as the original description.

Flower (1870) provided a detailed description of the skeleton of a specimen of the "Chinese white dolphin" collected at Quemoy (Chinmen) Island in the Taiwan Strait, thereby solving the problem of lack of a type specimen. Unfortunately, this skeleton was destroyed during a bombing raid in World War II (Pilleri 1979).

At least four other species of hump-backed dolphins (genus *Sousa*) have since been described: *Sousa plumbea* (G. Cuvier, 1829), *S. lentigenosa* (Owen, 1866), *S. teuszii* (Kükenthal, 1892), and *S. borneensis* (Lydekker, 1901). Currently, in most official lists all hump-backed dolphins in the Indo-Pacific region are classified as a single species, *Sousa chinensis*, with Atlantic (West African) animals considered a separate species, *S. teuszii*. However, the taxonomy of this group is somewhat contro-

versial (Ross et al. 1994). Some workers have suggested that three of the five nominal species are valid (Zhou et al. 1980, Ross et al. 1994, Rice 1998). In this scenario, *Sousa chinensis* and *S. borneensis* are synonymous. However, recent morphological and genetic work in progress has been unable to find strong justification for more than a single, highly variable species (Ross et al. 1995, Cockcroft et al. 1997). The final story is not yet in, and both genetic and morphological data will ultimately play an important role in resolving the taxonomy of this group. The current classification of the species (following Rice 1998) is as follows:

Class Mammalia (mammals)
    Order Cetacea (whales, dolphins, and porpoises)
        Suborder Odontoceti (toothed whales and dolphins)
        Superfamily Delphinoidea (dolphins and porpoises)
        Family Delphinidae (dolphins)
        Genus *Sousa* (hump-backed dolphins)
            Sousa chinensis (Osbeck, 1765) (Indo-Pacific hump-backed dolphin).

Traditionally, *Sousa* has been considered to be most closely related to the genera *Sotalia* (the tucuxi of coastal and riverine waters of South America) and *Steno* (the rough-toothed dolphin of oceanic waters of all oceans). Due to morphological similarities, these three genera have been united in the subfamily Steninae (for instance, see Reeves and Leatherwood 1994). However, recent molecular studies of the entire family Delphinidae suggest that *Sousa* shares no particular affinities with *Sotalia* or *Steno* and may actually be more closely related to several oceanic dolphin genera of the tropical regions (i.e., *Tursiops, Stenella, Delphinus,* and *Lagenodelphis*) (LeDuc et al. 1999).

Physical Description.—The most striking external characteristic of *Sousa chinensis* in southern China is the color of adults, which differs radically from that of conspecifics in the western part of the species' range (Ross et al. 1994). Most adults are brilliant white, often with small irregularly-shaped spots and flecks (Zhou et al. 1980). The eyes are surrounded by many black blotches, and the body often has a pinkish hue (Wang and Sun 1982). There is much variation in the color pattern of animals, depending on growth stage; young are generally gray in color, with a lighter belly (Wang 1965, 1995; Jefferson and Leatherwood 1997). Wang and Sun (1982) reported some fetuses that were white or pink in color.

Indo-Pacific hump-backed dolphins tend to be rather robust in body shape, with large, broad flippers and flukes (Fig. 1). There is not a distinct crease between the beak and melon, as there is in most other species of long-beaked dolphins (Ross et al. 1994). Indo-Pacific hump-backed dolphins in China reach lengths of at least 250 cm and weights of up to 240 kg, with females apparently growing somewhat larger than males (Wang 1965, 1995; Wang and Sun 1982). The beak is slender and very long and represents about 6–10% of the total length (Wang 1965, 1995; Wang and Sun 1982). The edges of the flukes fold over each other at the deep fluke notch (Zhou et al. 1980). Although the dorsal fin sits on a broad-based hump of connective tissue in hump-backed dolphins from the Atlantic and western Indian oceans, there is little or no evidence of this hump in animals from southern China, where the dorsal fin is low, broad at the base, and slightly recurved.

The skull of *Sousa chinensis* is heavily built and the rostrum is stout compared to that of most oceanic dolphins. Condylobasal length of Chinese specimens reaches at least 543 mm (Wang and Sun 1982). Tooth counts are 30–36 in the upper jaws and 24–34 in the lower jaws (Wang 1995), but tooth counts as high as 37 have been reported (Wang and Sun 1982). The mandibles are concave when viewed from above, and the mandibular symphysis is long, about 25% of the mandible length (Wang and Sun 1982). The skull of *Sousa chinensis* is characterized by widely-separated pterygoids and a long rostrum that is wide at the base and tapers towards the
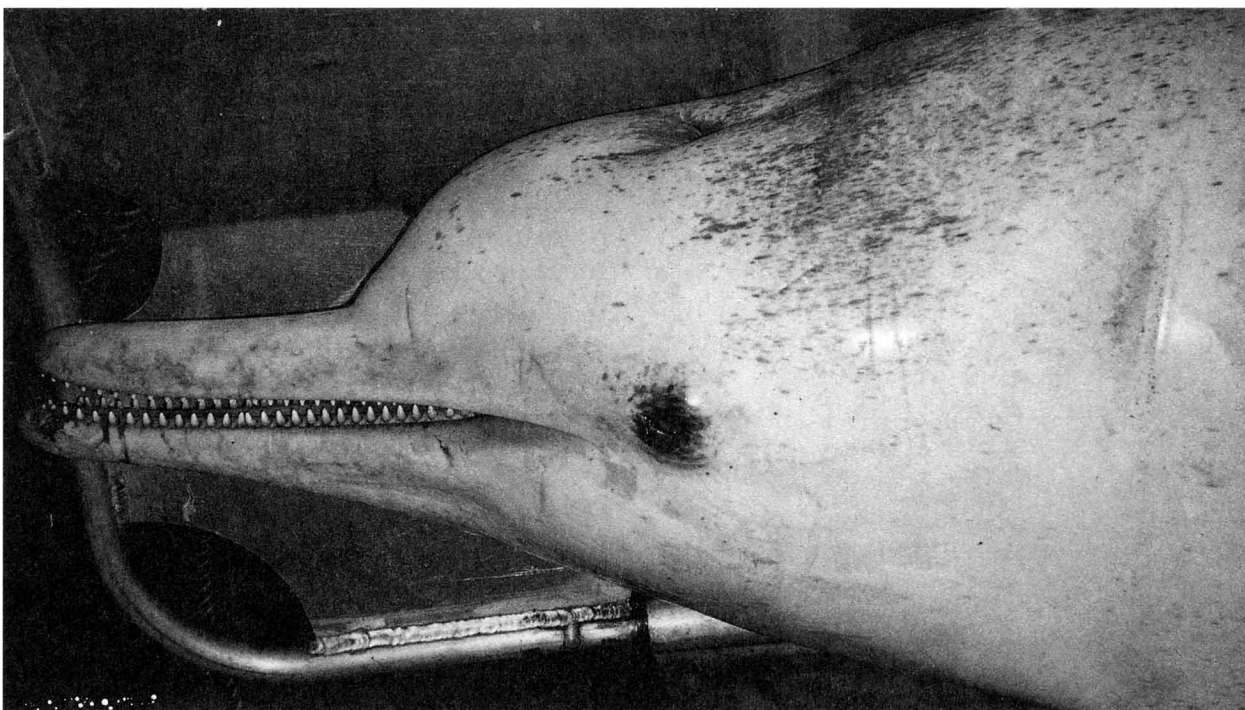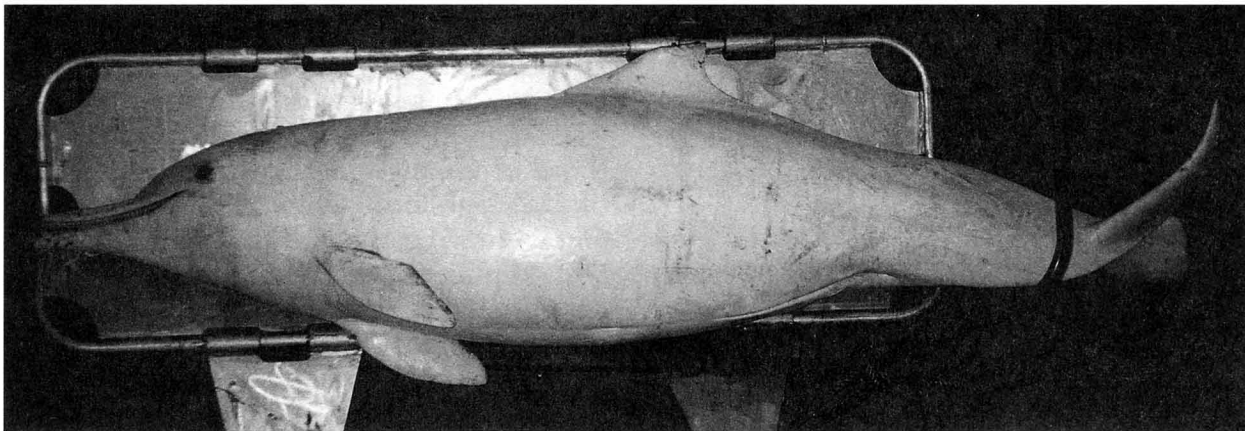
Fig. 1. External appearance of a young (age = 9.5 years) mature female hump-backed dolphin from Hong Kong (SC97-31/05-B). Photos by D. Choi (Agriculture and Fisheries Department).

tip (Flower 1870). The ear bones of newborn animals are about the same size as those of adults (Liu et al. 1999a).

In general there are less vertebrae than in other dolphins, each one is longer, and the transverse processes are broader and shorter (Flower 1870). The typical vertebral formula is about $C_7 + T_{12} + L_{10} + Ca_{22}$, for a total of about 51 (Wang and Sun 1982). Wang and Sun (1982) reported the phalangeal formula to be $I_2 + II_7 + III_{5+} + IV_3 + V_2$. The skull and post-cranial skeleton of dolphins from China were described in detail by Flower (1870),

Huang et al. (1978), Zhou et al. (1980), and Wang and Sun (1982).

Distribution and Abundance.—The known worldwide distribution of *Sousa chinensis* was summarized and figured by Ross et al. (1994). This species occurs in nearshore, shallow waters from the tip of South Africa eastwards along the rim of the Indian Ocean, including the Red Sea and Persian Gulf areas. In the western Pacific they are found at some locations in the Indo-Malay archipelago and from the Gulf of Thailand east to southern China. Off Australia they occur along the north-
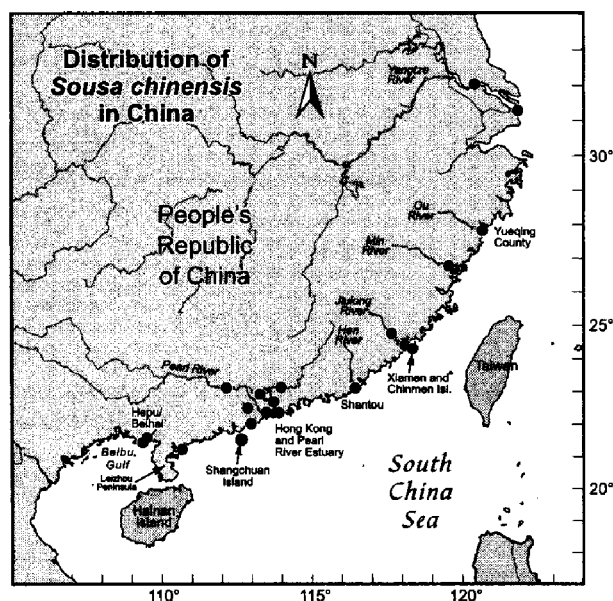
Fig. 2. Distribution of reliable records of Indo-Pacific hump-backed dolphins in Chinese waters (see details in Appendix 1).

ern, tropical coasts, down as far as about 35°S along the east coast (Corkeron et al. 1997). Overall, the distribution is poorly known, and they may be found in several areas for which there are no current records. Hump-backed dolphins generally appear to occur in small to moderate populations, often localized around river mouths and estuaries.

Huang (1997) reported hump-backed dolphins from many areas along the southern China coast, extending from the Yangtze River mouth to the Vietnam border, but the reliability of some of these records is questionable. Records that I consider to be reliable (i.e., those in which identifications were supported by detailed descriptions, photos, voucher specimens, or were confirmed by a marine mammal identification expert) are shown in Appendix 1 and Figure 2. From the map (Fig. 2), it can be seen that most of the reliable records are centered around the mouths of large rivers (such as the Yangtze, Ou, Min, Jiulong, Han, and Pearl [Zhujiang] rivers). Hump-backed dolphins are seen in every month at the mouth of the Jiulong River in the Xiamen area, but May and June are reported to be the months of peak occurrence (Huang and Chou 1995, Huang 1997).

One of the best-known populations is centered around the mouth of the Pearl River (Zhujiang) and inhabits waters of Macau and the Hong Kong SAR as well as those of Guangdong Province of the People's Republic of China (PRC). Yang and Chen (1996) estimated that there are 300–500 dolphins in this area, but this estimate appears to be simply a guess. In the Pearl River, dolphins have been reported to go many tens of kilometers up some of the smaller tributaries, but again the reliability of these records is unknown (Yang and Chen 1996).

Records along most of the Chinese coast are sporadic and were collected opportunistically. Except for the above-mentioned areas, and the Gulf of Tonkin (Beibu Gulf), which appear to have year-round populations (Wang and Sun 1982), the seasonal occurrence patterns of hump-backed dolphins in southern China are not known.

Ecology.—Hump-backed dolphins in China have not been reported to occur in mixed groups with other dolphin species. No records of shark or killer whale (*Orcinus orca*) predation are known from Chinese waters, but both of these predators could take dolphins, at least occasionally.

There has been very little anatomical or physiological work done on hump-backed dolphins from China. Blubber thickness in Xiamen dolphins varies throughout the year and is greatest during the cold weather months (Wang 1995). The tongue and entire digestive system were described in detail by Ping (1927) and Tang and Huang (1940), respectively.

Chinese hump-backed dolphins have been reported to feed on a variety of fishes, squids, and shrimps (Huang et al. 1978). Thirteen species of fishes were recorded from stomach contents of 36 dolphins killed in Xiamen waters in the early 1960s (Wang 1965, 1995). The fish genera *Mugil, Ilisha,* and *Calia* were dominant; no squid were found (Wang 1995). An animal stranded 60 km up the Jiulong River had fed on a number of freshwater fish species (Zhou et al. 1980). Stomachs of specimens from Beihai and the Gulf of Tonkin contained several fish species, including at

least one that normally occurs in deep water (Wang and Sun 1982). Dolphins stranded in Hong Kong fed on over 10 taxa (species, genera, or families) of pelagic and demersal fishes, as well as small numbers of crustaceans and cephalopods (Parsons 1997). The predominant fish groups were sciaenids (croakers) and mugilids (mullet), both estuarine fishes. Tang and Huang (1940) reported algae from the digestive tract of one animal, but this was probably ingested incidentally.

The parasites and pathology of hump-backed dolphins along the Chinese coast have apparently not been studied in any detail. The only report in the published literature appears to be a record of the nematode *Anisakis alexandri* from the stomach of a Chinese hump-backed dolphin (Hsu and Hoeppli 1934). Some parasites have been noted during necropsies of dolphins stranded in Hong Kong, including the lungworm *Halocercus* sp. (Parsons 1997). Also, unidentified trematodes have been discovered in the orbits of a stranded dolphin (Parsons 1997). Some Hong Kong dolphins have been observed with orange-brown encrustations, especially around skin lacerations, and these may be mycotic in nature (Parsons 1997). However, it is also possible that these are simply diatom infestations, and only sampling and analysis will resolve this issue. Sewage-born bacteria have been identified in stranded dolphin carcasses from Hong Kong, but what health effects these may have caused are not yet known (Parsons 1997).

Contaminant levels only have been published for 11 dolphins stranded in Hong Kong (Parsons 1997, Parsons and Chan 1998). In general, heavy metal levels were not particularly high, but some (such as mercury) existed in quantities that may have caused health problems. Organochlorine levels were highly variable, but some individuals showed very high levels of some organic compounds. In particular, DDT levels were very high in some individuals, and there was evidence to suggest that the source of much of the DDT was

from across the boundary in mainland China (Parsons and Chan 1998).

Behavior and Life History.—Chinese hump-backed dolphins occur in relatively small groups. Sizes of herds in the Xiamen area reportedly range from 1 to 9 individuals (Huang and Chou 1995), and those following fishing boats in the Pearl River reportedly contain 3 to 10 individuals (Wu and Chen 1996). In Hong Kong, the average group size was reported to be about three individuals, with groups ranging from singles to aggregations of up to 21 (Jefferson and Leatherwood 1997, Parsons 1998a).

Swimming speeds have been reported to be about 15 km/hr and up to 12 knots (22 km/hr), but how these records were obtained is not known (Wang 1995, Yang and Chen 1996). Timed dives of individual Hong Kong dolphins lasted from 2–434 seconds with a mean of about 40–50 seconds (Parsons 1997). Dives of as long as 4–5 minutes have been reported (Yang and Chen 1996). Huang et al. (1978) stated that hump-backed dolphins will assist injured members of the group, and at least one anecdotal record of this is known from Hong Kong (B. Leverett in Parsons 1998a). Cases of adults supporting dead calves also have been observed in Hong Kong (Parsons 1998a). Although foraging was the predominant activity observed in Hong Kong, a variety of behaviors were described for hump-backed dolphins there, based on land-based observations (Parsons 1998a). Social behavior was observed most commonly between August and November (Parsons 1998a).

In Hong Kong, hump-backed dolphins appear to occur south of Lantau Island primarily during summer and are replaced in this area in winter by finless porpoises *Neophocaena phocaenoides* (Parsons 1997, 1998a). Hump-backed dolphins in Xiamen, Hong Kong, and the Pearl River Estuary were reported to follow fishing boats, primarily trawlers (Wang and Sun 1982, Wang 1995, Wu and Chen 1996, Parsons 1998a). In Xiamen, this apparently occurred primarily in summer and autumn

(Wang 1995), but trawling is now illegal in the Xiamen area.

Life history has not been well studied. Three sexually mature females from several locations in China ranged in length from 237 to 250 cm (Zhou et al. 1980, Wang and Sun 1982, Zhou 1991). The only detailed study on reproductive biology of Chinese *Sousa* that used multiple specimens was that done on 36 Xiamen specimens by Wang (1965, 1995). He found that gestation lasted 10–12 months, and the main mating season was April to June. Wang and Sun (1982) found that most calves were born from March to May, but apparently some calves were born outside this season, and they suggested that calving could take place over a protracted period of about 6 months. Wang (1965, 1995) suggested that adult females were 200–250 cm in length (the pregnant ones ranged from 230 to 250 cm) and adult males 190–240 cm, but he did not use histological or statistical techniques to calculate length at sexual maturity, nor did he age the specimens. Based on the lengths of fetuses, newborns appear to be about 100–110 cm long (Wang and Sun 1982). Pregnant females made up about 60% of adult females from Xiamen examined by Wang and Sun (1982).

Conservation Status.—*Sousa chinensis* is listed as Insufficiently Known in the IUCN Red Data book (Reeves and Leatherwood 1994), and is classified in CITES Appendix I (Klinowska 1991). In mainland China it is listed as a "Grade 1 National Key Protected Species" (Huang 1997, Parsons 1997). In Hong Kong protection from hunting, possession, and trade is provided by the Wild Animals Protection Ordinance (Cap. 170) and the Animals and Plants (Protection of Endangered Species) Ordinance (Cap. 187).

In the Xiamen area the following threats have been identified: (1) Development and coastal engineering, (2) Port development and shipping, (3) Pollution, (4) Directed and incidental catches, and (5) Prey reduction from fisheries (Lin and Wang 1997). Studies on hump-backed dolphins in the area of Xiamen Harbour suggest that dolphin numbers there have declined since the 1960s; however, there are no statistically-defensible estimates of abundance or trends (Wang 1965, 1995; He and Huang 1995; Huang and Chou 1995). In the Gulf of Tonkin (Beibu Gulf), dolphins have apparently been seen for sale in local fish markets (Wang and Han 1996).

The same general categories of threat exist for Hong Kong and the Pearl River Estuary. At least three dolphins have been incidentally caught in fishing nets in mainland Chinese waters in recent years (Wu and Chen 1996). Parsons (1997) suggested that overfishing in Hong Kong may not have reduced available prey so much as changed its composition. High levels of organochlorines, especially DDT, in dolphin tissues may explain the high incidence of neonate strandings in Hong Kong in recent years (Parsons 1997, Parsons and Chan 1998). Preliminary research in Hong Kong waters indicated that about 90–155 dolphins occur in the area north of Lantau Island in any one season (Jefferson and Leatherwood 1997), but there are fears that the population may have declined in recent years (Parsons et al. 1995, Yang and Chen 1996, Parsons 1998b). The total number of animals that use Hong Kong waters was estimated to be at least 246, but the total breeding population in the Pearl River Estuary is probably significantly higher (Jefferson and Leatherwood 1997).

Although in the past several authors recommended that dolphins be killed in the Xiamen area to reduce competitive effects on fisheries (Wang 1965, Huang et al. 1978), dolphin conservation zones have been established recently for the Xiamen and Pearl River Estuary areas (Lin and Wang 1997, Yang and Chen 1996). A 12-hectare marine park, managed by the Hong Kong Agriculture and Fisheries Department (AFD), came into effect on 22 November 1996 around the islands of Sha Chau and Lung Kwu Chau in Hong Kong waters, largely for the protection of hump-backed dolphins (Leatherwood and Jefferson 1997, Wong 1997). This marine park

has been the subject of some criticism within the environmental community in Hong Kong (Liu and Hills 1997). A Marine Mammal Conservation Working Group (MMCWG), consisting of people from many different backgrounds and perspectives, was established by the AFD to aid in management of the park. The proposal for Xiamen has also been pursued, and a large area to the west and north of Xiamen Island was established as a "dolphin sanctuary" in 1997 (Lin and Wang 1997). The effectiveness of this so-called sanctuary remains to be seen, and my observations suggest that enforcement of regulations is lax. Finally, a large area of the Pearl River Estuary, west of Hong Kong in PRC waters, has recently been established as a dolphin conservation zone (D. Choi, pers. comm.).

Human overpopulation, along with its attendant problems, appears to present the greatest threat to hump-backed dolphins in China. It is clear that these animals need effective protection if they are to survive in the long term. However, despite some recent, rather gloomy predictions (e.g., Morton 1996, Liu and Hills 1997, Porter 1998), the species appears to be moderately abundant along at least some parts of the coast, and there is currently no reason to believe that the species is doomed in China (Wang and Han 1996). However, to ensure their protection, we need to learn much more about their biology. In addition, long-term population monitoring is needed, with realistic conservation plans set in place to mitigate effects of deleterious human activities.

Goals and Objectives of the Study

The overall goal of this project was to provide scientific information that is needed for the long-term conservation and management of the population of Indo-Pacific hump-backed dolphins that occurs in Hong Kong waters. The specific objectives of the study were as follows:

(a) To estimate the abundance and pop-

ulation size, and establish trends in abundance of the population,

(b) To strengthen the recovery of stranded dolphins by establishing a stranding program and network for reporting and archiving dolphin stranding data,

(c) To conduct complete necropsies on all recovered carcasses in order to establish causes and rates of mortality,

(d) To make detailed assessment of movement patterns and home ranges of Indo-Pacific hump-backed dolphins in and around Hong Kong waters by means of systematic surveys and photo-identification techniques,

(e) To estimate life history parameters of the population by gonads/teeth analysis;

(f) To study the feeding habits of the dolphins through stomach contents analysis;

(g) To examine the stock structure of Hong Kong hump-backed dolphins using cranial morphometrics and molecular genetic techniques, and

(h) To monitor and audit the effectiveness of measures that have been drawn-up to mitigate the cumulative impacts arising from various projects on the dolphins, and to propose further mitigation measures, if necessary.

STUDY AREA AND METHODS

Study Area

Hong Kong is situated along the southern coast of the People's Republic of China, and is surrounded on three sides by Guangdong Province (Fig. 2, 3). It lies
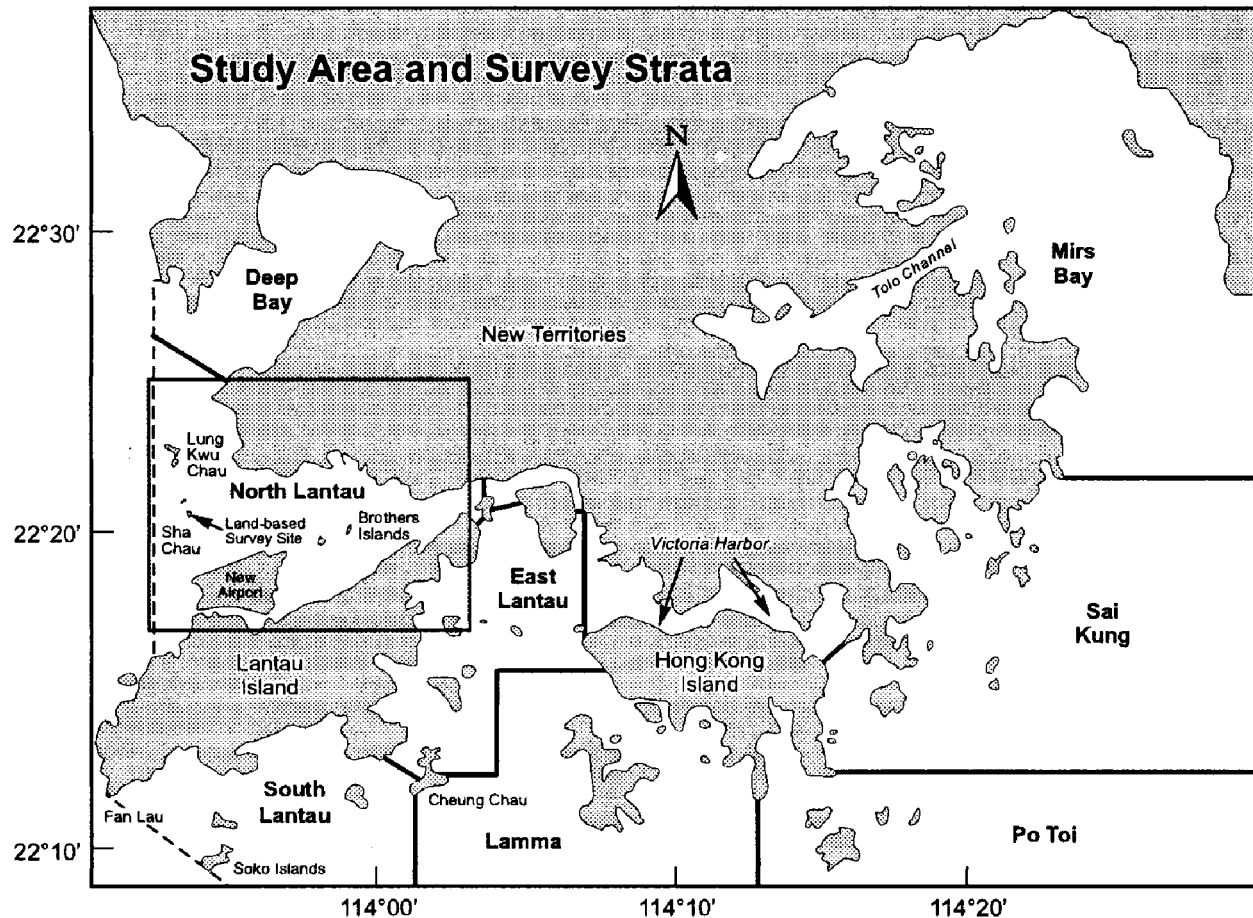
Fig. 3. Map of the Hong Kong study area, showing the primary place names mentioned in the text and the survey strata. Also shown is the location of the land-based survey station at Sha Chau. The border shown is that in effect before mid-1997, when the majority of data for the study were collected; the boundary has been modified slightly since then. The Lingding Bay study area, which is part of China's Guangdong Province, lies directly to the west of the Hong Kong/China boundary (dashed line).

along the eastern border of the mouth of the Pearl River (Zhujiang). By volume of discharge (336×10^9 m^3), the 2,214 km-long Pearl River is China's second largest river, and the largest in southern China (Xiong et al. 1989, Dudgeon 1995, Kot and Hu 1997). Thus, much of Hong Kong's western waters are estuarine, at least seasonally. The region is largely marine, with about 1,800 km^2 of territorial waters (63% of the total area). There are 235 islands and about 800 km of coastline. Much of the coastline is not natural, about 20% results from so-called seabed reclamation. Although technically in the tropics, the climate is not strictly tropical, and distinct seasons are evident (for a review of Hong Kong's natural environment see Morton 1996).

The cold North China Coast Water (Tai-wan Current) influences Hong Kong in winter, bringing cool waters from the northeast, and the South China Sea Water (Hainan Current) brings warm water from the southwest in summer (Morton 1996). Air temperatures fluctuate predictably throughout the year, with highs in the summer months. Rainfall also peaks in summer, and Hong Kong's winters tend to be relatively dry. The pattern of discharge of fresh water from the Pearl River mimics that of rainfall, peaking in summer months. Wind speed varies throughout the year, with lows in spring and summer and highs in autumn, although there is not a great deal of variability in average Beaufort sea state for North Lantau, the primary survey area for this project. Environmental parameters are summarized on a monthly basis in Figure 4. For the purposes of this
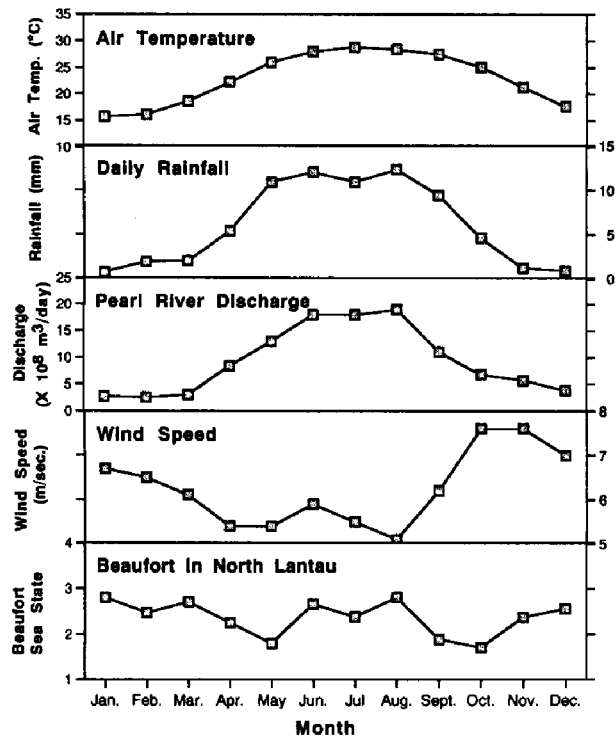
Fig. 4. Monthly averages for various environmental parameters in Hong Kong. Data on air temperature, rainfall, and wind speed are from Ip (1996), data on Pearl River discharge are from Broom and Ng (1996), and data on Beaufort in North Lantau were collected during this study.

report, seasons are defined as follows: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November).

The human inhabitants of Hong Kong occur in some of the highest densities known on the planet (one district, Mong Kok, has the world's highest human population density, 116,500 people/km^2). Overall, the region has about 6.5 million people, and that number is growing, largely through immigration from mainland China.

The waters of Hong Kong were divided into 8 survey areas, each of which could be surveyed in a single day (Fig. 3 and Table 1). The primary survey area was North Lantau, where the dolphins were considered to be most common and where Hong Kong's new airport at Chek Lap Kok was being built. A set of transect lines was designed for each survey area. The lines were intended to sample each area evenly and were drawn-up with no reference to dolphin distribution. For logistical reasons,

the primary lines were oriented either north/south or east/west and generally ran perpendicular to the shoreline. Spacing between the lines was 1 km in the western and southern survey areas and 2–3 km in the larger eastern survey areas of Sai Kung and Mirs Bay. Survey lines for North Lantau were shown in Jefferson and Leatherwood (1997: Fig. 2).

West of the main study area in Hong Kong, a 12-month study of dolphin distribution and abundance in Chinese waters of Lingding Bay was conducted from November 1997 to November 1998. This project was part of an Environmental Impact Assessment study, commissioned by the Civil Engineering Department[1] of the Hong Kong SAR Government, to examine the potential effects of the construction of a major dredged shipping channel (the Tonggu Waterway) in waters west of Lantau Island. Survey work, conducted by workers from the South China Sea Fisheries Institute (SCSFI) after suitable training by the author, followed the same procedures as that in the Hong Kong study. Although outside the main study area of this paper, these surveys represent a significant source of information on dolphins in mainland Chinese waters west of Hong Kong, so data from these surveys are presented in this report.

Survey Methods

Vessel Surveys.—A short pilot study was conducted from September 1995 to mid-November 1995 to establish data collection protocols and train observers. Between November 1995 and November 1998, surveys for the main project were conducted from 10–15 m vessels, most commonly the *Sea Horse* (operated by Ocean Park Corporation), *Lady Muriel* (operated by China Light and Power), or *Harbour Front* No. 13 (operated by Wing Yip Shipping and Transportation Company Ltd.) (Fig. 5). All boats had open upper decks, allowing for observer eye heights of 4–5 m above water level. When on-effort, the boat travelled along the survey lines at a speed of about 7–8 knots (13–15 km/hr).

Table 1. Summary of characteristics of the 8 survey areas in Hong Kong and the Pearl River Estuary in China.

Survey area	Area (km²)	Transect length (km)	Description	Vessel traffic	Pollution	Fishing activity
Deep Bay (DB)	97	90 (44)[a]	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)	146	94	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)	106	90	Weak seasonal influence of the Pearl River; heavy shipping and major anchorage area; site of future Disney theme park	Heavy	Heavy	Major area for shrimp trawling; significant area for hang trawling
South Lantau (SL)	117	105	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)	181	106	Largely marine influence; heavy shipping along some routes	Heavy	Moderate	Major area for shrimp trawling; some stem trawling and purse seining
Po Toi (PT)	189	109	Relatively deep marine waters with little shoreline; heavily influenced by oceanic forces	Low	Low	Important area for mixed gear fishing
Sai Kung (SK)	396	132	Rocky, heavily indented shoreline; marine influence; light development	Low	Low	Major area for stem trawling; some pair trawling in northern part
Mirs Bay (MB)	424	122 (86)[a]	Rocky shoreline; marine influence with coral communities; light development	Low	Low	Major area for pair trawling (including Tolo Channel and Harbour); significant area for stem trawling and purse seining
Lingding Bay (LB)	856	299	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 fishing, especially pair and shrimp trawling

[a] Due to previous disagreement between Hong Kong and the People's Republic of China about the placement of the border in these areas, it was not always possible to survey the entire set of transect lines. So, an alternate set of transect lines was drawn up to avoid such conflicts.

Fig. 5. The *Sea Horse,* the primary survey vessel used in the study. Searching was carried out from the upper deck area (flying bridge). Other research vessels were of a similar size and configuration.

The direction of the survey was alternated on different days to avoid possible biases related to the timing of survey coverage.

Observers from several organizations collected survey data (Table 2). Observers had undergone varying levels of training, and some had previous experience with dolphin surveys in Hong Kong. The main observers generally underwent a 3-day training program covering line transect and mark/recapture analyses, survey protocol, equipment use, data sheet completion, and species identification, followed by at-sea training. A pair of Leica Geovid laser rangefinder binoculars was used for observer distance calibration. Observers practiced with the laser binoculars, and this resulted in increased accuracy of distance estimation. Also, I periodically collected data on observers' distance estima-

Table 2. Sources of survey data for line transect and photo-identification analyses.

Organization conducting survey	Time period	Frequency	Areas surveyed
Ocean Park Conservation Foundation	November 1995 to November 1998	4–8 days/month	All Hong Kong survey areas
ERM-Hong Kong	January 1996 to November 1997	3–10 days/month	North Lantau, East Lantau, South Lantau, Lamma, and Po Toi
Airport Authority	May 1996 to March 1998	2–3 days/month	North Lantau
South China Sea Fisheries Institute	November 1997 to November 1998	8–10 days/month	Lingding Bay (PRC) - Tonggu Waterway study area
Ecosystems Ltd.	March 1998 to November 1998	1 day/month	Deep Bay
CES (Asia) Ltd./Maunsel	July 1998 to November 1998	5 days/month	North Lantau

tion capabilities to ensure that distance data were accurate (see Jefferson and Leatherwood 1997).

The on-effort survey team consisted of two people stationed on the flying bridge (affording them unobstructed forward visibility). The primary observer searched for dolphins continuously with Fujinon 7 × 50 marine binoculars (with built-in compass), scanning the search path ahead of the boat (from 270° to 90° in relation to the bow as 0°). The data recorder filled out the data sheets and searched for dolphins in the search path with the naked eye, emphasizing the area near the vessel. While on-effort, observers were instructed to ignore potential sighting cues that could bias the sighting distance distribution (e.g., pair trawl fishing vessels, see below). Binoculars (7× or 12×) were used by the data recorder for occasional quick scans, and to check out possible sighting cues. In an attempt to minimize fatigue, observers rotated positions every 30 min and generally had at least 30 min off after each hour of on-effort time.

Vessel speed, course, and position were obtained from a Garmin 75 handheld Global Positioning System (GPS) unit (and other similar units on some surveys), which operated continuously during surveys. The above data, as well as information on sighting conditions (Beaufort sea state and visibility), were obtained periodically (generally at least every 15 minutes). When dolphins were sighted, time, position, sighting angle and radial distance, group size, and various behavioral data were collected. Sighting angle was generally obtained from successive compass bearings taken on the dolphins' detection location (i.e., the center of the group at first detection) and the track of the survey vessel. Sighting, or radial, distance was estimated by eye.

To calculate a value for the detection function [g(0)] (see below), an independent observer collected data on trackline groups missed by the main survey team on a portion of the cruises (for a total of 71.8 hours). In these cases, an observer rotated to the independent observer position for

30 min after completing the two main positions. This was generally only done when there were at least 4 observers on board, so that there was still at least a 30 min rest period before each on-effort shift.

The independent observer searched for groups of dolphins on and near the trackline. This person was stationed at the stern of the vessel on the lower deck, so that there could be no communication between the independent observer and the main survey team. The independent observer scanned the area behind the vessel from 90° to 270° (relative to the bow as 0°) with the naked eye, only using binoculars to confirm sightings. Glare and other factors that could affect visibility were similar for the independent observer and the main survey team. Because the vessel diverted course and all observers went off-effort when a sighting was made, any sightings seen by the main team were unavailable for detection by the independent observer. The concept behind this was that the independent observer data would be used to determine what proportion of trackline groups was missed by the main survey team, either due to availability bias (dolphins not surfacing within the main survey team's field of view) or perception bias (dolphins that were available to be seen, but were missed due to other factors) (see Marsh and Sinclair 1989 for a description of the differences between these two types of bias). For the lower platform of the independent observer, there may have been more of a problem with distance estimation bias because I conducted no distance estimation training specific to that perspective.

Photo-Identification.—When dolphins were sighted the observers typically went off-effort, and the vessel approached the dolphin group for accurate estimation of group size and for photo-identification (Fig. 6). About 27,600 frames were taken of dolphins in this study for the purpose of photo-identification. Photographs were taken with Nikon or Canon autofocus cameras (primarily Canon EOS 5, 50, and 100QD models). All cameras were equipped with databacks, and day of the
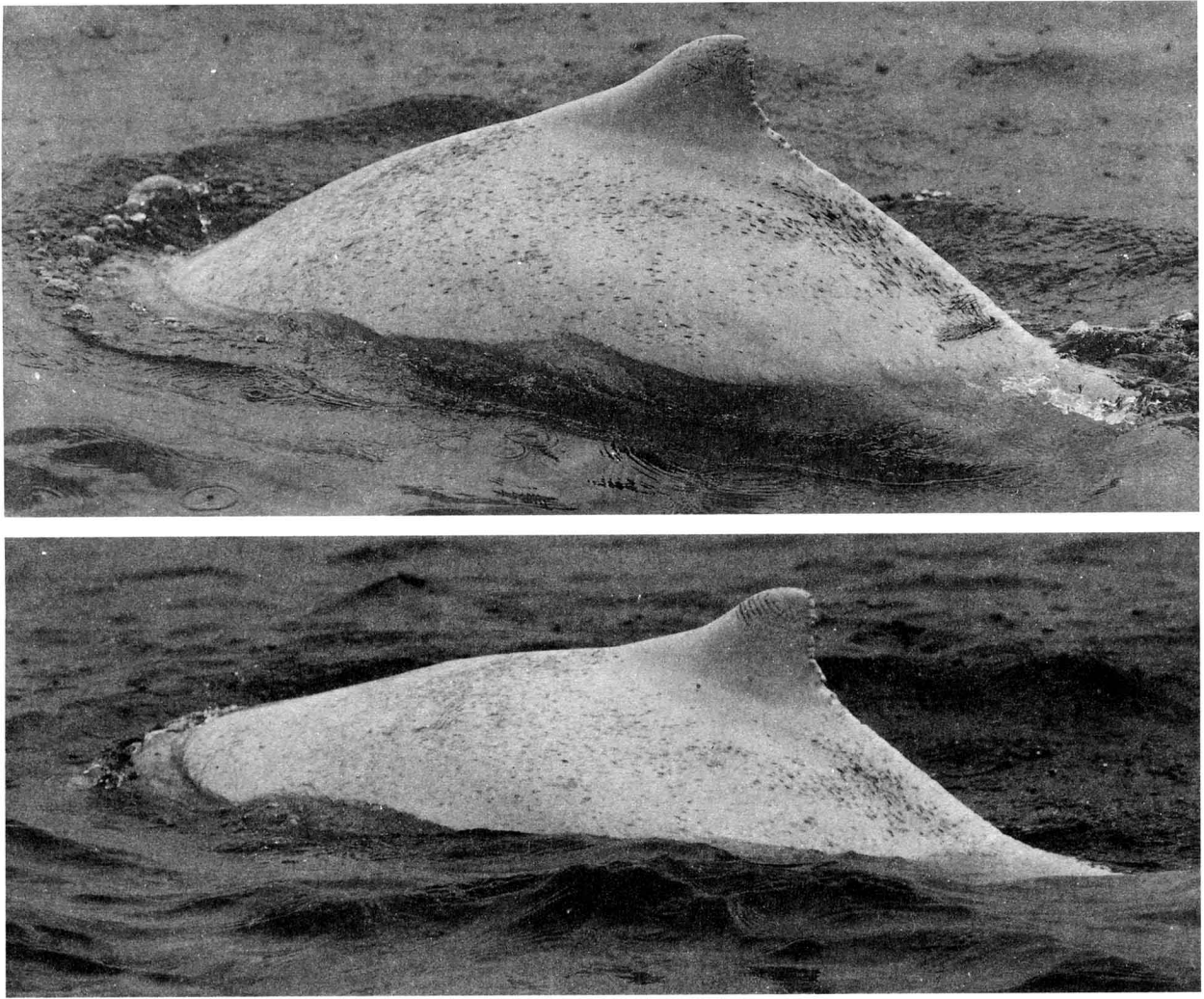
Fig. 6. Two photos of the same individual dolphin (EL05), taken 12 months apart, showing the features used in photo-identification.

month and time were imprinted on each frame, allowing frames to be correlated with a particular sighting. Two lenses, a Canon L series 35–350 mm/f5.6 zoom and a Canon L series 300 mm/f2.8 telephoto, were used to take most photographs. Generally, the 300 mm lens was used with a 1.4 teleconverter, effectively making it a 420 mm/f4.0 lens.

Slide (transparency) film was shot for all photo-identification work. Fujichrome Provia 100 ISO, Sensia 100 ISO, Astia 100 ISO, and Velvia 50 ISO film were used most commonly. Occasionally, when lighting conditions were very poor, the photographer switched to Sensia 200 ISO film. The preferred film was Velvia; the extremely fine grain of this film resulted in very sharp photos, ideal for identification

of individuals. However, this film could only be used with the fast f2.8 telephoto lens on days with good lighting.

Ideally, dolphin groups were approached slowly from the side and behind (see Würsig and Jefferson 1990). Maneuvering the boat to within 30–50 m, directly alongside a moving group of dolphins, resulted in the best shots. Every attempt was made to photograph each dolphin in the group, even those that appeared to have no unique markings.

Aerial Surveys.—Eighteen aerial surveys were conducted from helicopters for a total of 24.5 hours flight time. Generally, there was no attempt to use aerial surveys to collect systematic transect data; instead, they were used primarily to collect distributional data, especially in areas of the re-

gion that were difficult to survey by vessel. Although there were no strict transect lines, one of three general survey routes was followed on each flight. The most common one covered waters of the entire region and lasted 1.5–2.0 hours.

Surveys were flown at an altitude of 150–330 m and a speed of 110–175 km/hr. Three or more observers searched on both sides of the aircraft for dolphins. When dolphins were sighted, the helicopter either circled or hovered overhead (but off to the side) and data on position, group size, and behavior were noted. These surveys provided the majority of information that was available to assess dolphin occurrence patterns in the northeastern survey area of Mirs Bay.

Land-Based Surveys.—To obtain unbiased data on dolphin behavior, land-based surveys were carried out on 74 days from an observation station on the southern part of the small island of Sha Chau (Fig. 3). The observation station was 56.5 m above mean water level, and was located at the base of a radar station built for the new airport. It provided unobstructed views to the east for about 8 km, over much of the main vessel survey area. Two observers alternated searching for dolphins, and when a sighting was made, both observers worked together to collect behavioral data. Dolphin groups were observed with Fujinon 15 × 80 tripod-mounted binoculars, and their movements were tracked with a Leica Wild TC500 surveyor's theodolite (see Würsig et al. 1991). Theodolite data were converted into grid references and analyzed using the computer program T-TRACK (courtesy F. Cipriano). Tracks of dolphin movements in relation to other objects were produced and swimming speeds were calculated. In addition, land-based observers collected group dive-time data to assist in examining the validity of line transect assumptions. Dives of entire groups of dolphins that lasted over 10 seconds were timed with a stopwatch.

Carcass Analysis Methods

Through a publicity program (involving the publication of a poster and fact sheet,

as well as inter-departmental memos), appropriate government departments and the public were asked to report cetacean strandings. Carcasses of stranded or incidentally-caught dolphins were examined in an attempt to determine cause of death and to provide data and samples for biological studies. Each carcass was classified as to its level of decomposition based on the 5 codes summarized by Geraci and Lounsbury (1993). Briefly, the codes are: 1 (alive), 2 (freshly-dead), 3 (moderately-decomposed), 4 (badly-decomposed), and 5 (dessicated or skeletal remains only). The level of detail of each necropsy was determined by the stage of decomposition as well as by various logistical considerations, such as location and difficulty of transport. When possible, fresh carcasses (code 2 or early code 3) were transported back to a necropsy lab at Ocean Park or the AFD Castle Peak Laboratory and the examination was done in conjunction with a veterinarian trained in pathology.

For most carcasses, the following basic data and samples were collected:

(1) Date, location, and circumstances of stranding,
(2) Sex, length, and decomposition code of specimen,
(3) Photographs and standard measurements (only those that were considered reliable),
(4) Skin samples (in 20% dimethyl sulfoxide [DMSO], for stock structure studies),
(5) Blubber, liver, and kidney samples (frozen, for ecotoxicology),
(6) Stomach (frozen, for feeding habits analysis),
(7) Reproductive organs (in formalin, for life history studies),
(8) Skull (frozen, for voucher specimens and for stock structure studies), and
(9) Teeth (in alcohol or water, for age determination).

Fresh carcasses were also classified into one of the 6 age classes described by Jefferson and Leatherwood (1997) for Hong Kong hump-backed dolphins.

Age Determination

Age determination, based on counting dentinal growth layer groups (GLGs) in teeth, was conducted at the Southwest Fisheries Science Center, La Jolla, California, USA, generally following the techniques outlined by Myrick et al. (1983). Large teeth, most often from the middle of the lower jaw, were chosen for aging. After cleaning, teeth were decalcified in RDO (a commercially-available rapid decalcifying acid). Decalcification times were generally much longer than those presented by Myrick et al. (1983) for *Stenella* spp. because hump-backed dolphins have much larger teeth. To reduce decalcification times, some larger teeth were wafered before decalcification. For wafering, sections approximately 2–3 mm thick were cut from the center of the tooth using an Isomet low-speed saw equipped with a diamond-edged blade.

Each tooth was sectioned after freezing onto the stage of a sledge-type microtome. Longitudinal sections 24 μm thick, from the center of the tooth and encompassing the entire pulp cavity, were selected for mounting. The chosen sections were stained using Mayer's hematoxylin and blued in ammonia and, after drying, mounted on microscope slides (Fig. 7).

Mounted sections were examined by myself and K. Robertson (Southwest Fisheries Science Center, La Jolla, California, USA) under a dissecting microscope. Counts of dentinal GLGs were made without reference to length or other biological data from the specimen and were independent of counts made by the other reader. Final estimates of age were then made by consensus, and if no consensus was reached, the estimate made by the more experienced reader was used. For some older animals, dentinal counts could only be used to provide a minimum age. For these specimens, cemental GLG counts were used.

Feeding Habits Analysis

After tying off both ends, stomachs were removed intact from stranded specimens
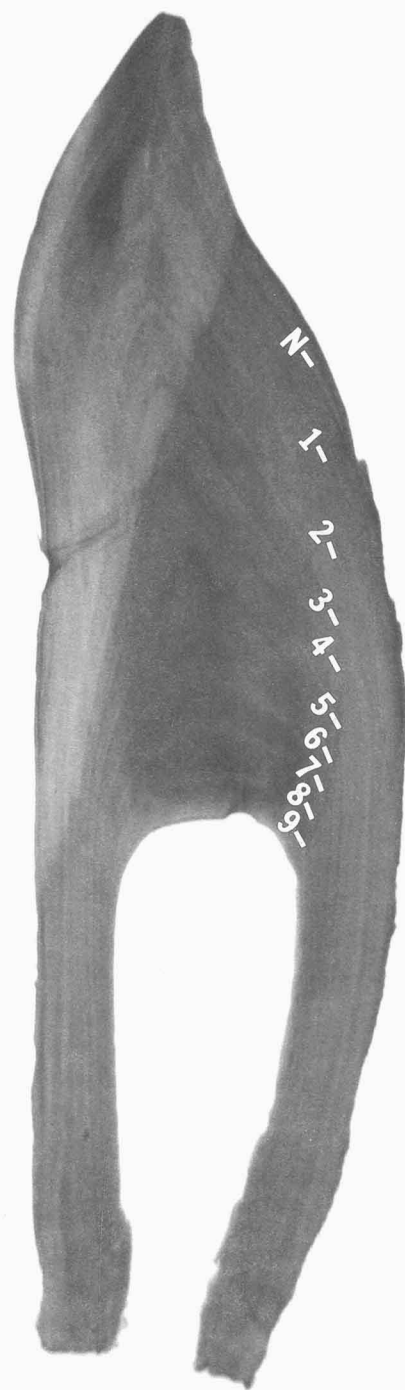
Fig. 7. Tooth section of a young adult female dolphin (SC97-31/05-B), showing growth layer groups (GLGs) in the teeth. The neonatal line (N) and the GLG boundaries are indicated by white lines. This specimen was aged at 9.5 GLGs.

and examined in the laboratory for the presence of food remains. Stomach contents analysis was conducted by N. B. Barros (Hubbs/Sea World Research Institute,

Orlando, Florida, USA). Stomach contents were washed and strained in a sieve, and wet weight was recorded. Fork lengths of undigested fish were measured with a tape measure. Hard structures, such as fish otoliths and squid beaks, were identified based on comparison to a preliminary reference collection assembled from visits to local fish markets, as well as from literature references. Fish bones other than otoliths were not considered to be diagnostic enough to be used in species identification. Fish otoliths were sorted into left and right categories, and squid beaks into upper and lower, and the highest number of each category was taken to indicate the total number of individuals consumed of each particular prey species. Otoliths collected during a previous study of the same dolphin population (Parsons 1997) were reanalyzed and incorporated into the present results.

Molecular Genetic Analysis

Tissue samples (skin or muscle stored in a solution of saturated NaCl in 20% [v/v] DMSO) were collected from 26 stranded dolphins (16 from Hong Kong, 1 from Lingding Bay west of Hong Kong, and 9 from Xiamen). Genetic analyses were performed by L. Garrison and B. E. Curry (Southwest Fisheries Science Center, La Jolla, California, USA). Mitochondrial DNA sequence analysis was used as a preliminary means of examining population differentiation among samples from Hong Kong and other areas of southern China. A procedure incorporating lithium chloride (LiCl) and chloroform extraction with ethanol precipitation was used to isolate total genomic DNA from tissue samples (Gemmell and Akiyama 1996).

Polymerase Chain Reaction (PCR; Saiki et al. 1988) procedures were performed using 50 microliter reactions. The two primers used to amplify a portion of the hypervariable control region I were L15926 5′ ACACCAGTCTTGTAAACC-3′ (modified from Kocher et al. 1989) and H000345′-TACCAAATGTATGAAACCT-

CAG-3′ (Rosel et al. 1994). Automated sequencing techniques (Applied Biosystems Inc., ABI 377 DNA Sequencer) were used. QIAquick PCR purification (Qiagen Inc.) was used to clean the PCR product. Each strand of the product was sequenced with dye-labelled terminators using standard protocols, and both of the strands were read to safeguard against sequencing errors (Applied Biosystems, Inc. 1992). Primers used for automated sequencing were H16498 5′-CCTGAAGTAAGAAC-CAGATG-3′ and L15926. Sequences were edited and aligned with the Sequencher 3.1 software program (Applied Biosystems Inc. 1992).

The computer software MEGA (Kumar et al. 1993) was used to generate UPGA-MA and Neighbor-Joining trees (Saitou and Nei 1987). Computations were based on distances calculated using Tamura-Nei gamma distances (alpha = 0.5). Five-hundred bootstrap replicates were implemented to compute standard error confidence probabilities. The delphinid species *Delphinus delphis*, *Stenella coeruleoalba*, and *Tursiops truncatus* (*aduncus*-type) were specified as outgroups in some Neighbor-Joining analyses.

Analysis of Chemical Contaminants

Samples of liver and kidney were collected for analysis of heavy metals and other trace elements, and blubber samples were collected for examination of levels of organochlorines and organotins (butyltins) in dolphin tissues. Laboratory analysis of chemical contaminants in dolphin tissues was conducted by S. Tanabe and colleagues (Ehime University, Matsuyama, Japan).

Heavy metal analysis followed the method of Kannan et al. (1993). Briefly, samples were dried and digested to produce a transparent solution. The solutions were diluted with distilled water, and concentrations were measured by atomic absorption/flame emission spectrophotometer. The method used for organochlorine analysis is described in detail in Tanabe et al.

(1994a). After Soxhlet extraction, fat was removed by elution through a florisil packed glass column. Gas chromatography was used for quantificiation of pesticide levels. PCB concentrations were obtained using a fused silica capillary column. Detection and quantification methods used for butyltin compounds are given in detail in Iwata et al. (1994). After homogenizing about 1–2 g of the blubber sample, a gas chromatograph-flame photometric detector was used for quantification of BTCs.

Data Analysis Methods

Abundance Estimation by Line Transect Analysis.—Survey data were analyzed using line transect methods, which uses information on the amount of survey effort and the distribution of perpendicular distances of sighted objects to estimate density and abundance (Buckland et al. 1993). The distance surveyed was calculated for each sample (defined as one survey day), and for each dolphin sighting the group size and perpendicular distance were determined. Perpendicular distance was calculated from radial distance and sighting angle using the following formula:

$$y = r \sin \phi$$

where

y = perpendicular distance,
r = radial distance, and
ϕ = sighting angle.

Density and abundance, and their associated coefficient of variation, were estimated with the following formulae:

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

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

$$\widehat{CV} = \left\{ \frac{\widehat{var}(n)}{n^2} + \frac{\widehat{var}[(\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\widehat{var}[\hat{E}(s)]}{[\hat{E}(s)]^2} + \frac{\widehat{var}[\hat{g}(0)]}{[\hat{g}(0)]^2} \right\}^{1/2}$$

where

D = density of individuals,
n = number of on-effort sightings,
f(0) = probability density function at zero perpendicular distance,
E(s) = unbiased mean group size,
L = length of transect surveyed,
g(0) = detection function,
N = abundance,
A = size of survey area,
CV = coefficient of variation, and
var = variance.

Calculation of most of the parameters of these equations is quite straightforward. However, calculation of f(0) involves complex calculus and statistical modelling. The DOS computer program DISTANCE (Laake et al. 1994) was used to estimate f(0) and to develop the estimates of density and abundance, using a stratified analysis. However, because of concerns over using small samples to model distribution data (see Buckland et al. 1993), the f(0) for the appropriate season for North Lantau was used to estimate density and abundance in those strata in which $n \leq 10$. This is considered to be valid because of the fact that all survey areas in which dolphins were seen had similar sighting conditions.

The most distant sightings were truncated to remove outliers and accommodate modelling, as recommended by Buckland et al. (1993). Truncation distances for different areas ranged from 450–1,200 m. Because previous examination of data from Hong Kong hump-backed dolphins suggested that there might be a slight bias in the estimation of average group size, a component of DISTANCE was invoked to calculate a size bias-corrected estimate of group size by regressing the natural logarithm of group size against detection probability. This estimate was used by the program if it was significantly different from the arithmetic mean group size (Laake et al. 1994).

DISTANCE used three statistical models (uniform, half normal with a hermite polynomial adjustment, and hazard rate) to fit curves to the data. The model with the lowest value of Akaike's Information Cri-

terion (AIC) was chosen as the best and was then used in calculation of density and abundance. For most estimates, the Hazard Rate model with a Cosine Adjustment was chosen for estimating f(0) (Buckland et al. 1993).

I intended to use the methods outlined in the appendix of Barlow (1995) to calculate a value for the detection function g(0). However, there were no sightings made by the independent observer "on or near the transect line" (see definition below) with which to model a value for the independent observer's probability density function $f(0)_2$. Therefore, a more simple approach was used, and the detection function was estimated using the following formula:

$$\hat{g}(0) = 1 - \frac{n(0)_i}{n(0)_m}$$

where

g(0) = detection function,
$n(0)_i$ = number of sightings on and near transect line detected by the independent observer, and
$n(0)_m$ = number of sightings on and near transect line detected by the main survey team while the independent observer was on-effort.

Based on the drop-off of sightings with distance, "on and near the transect line" was defined as within 50 m perpendicular distance for the purposes of this study. The variance of the detection function was estimated empirically.

To estimate the trend in the population, the study period was divided into 6 sampling periods, each lasting 6 months. An estimate of abundance for the North Lantau area was calculated for each period using a fully-stratified analysis. Because of low sample sizes and uneven sampling in other areas, only North Lantau data were used to examine trends in abundance. Regression techniques were then used to fit a curve to the point estimates, and the trend was determined by the slope of the fitted line. Power analysis, with the aid of program TRENDS, was used to determine

the statistical power to detect certain levels of population decline (Gerrodette 1987, 1993). The power of detecting a decreasing trend is expressed by Gerrodette (1991):

$$1 - \beta = \Phi\left[t(\alpha, n - 2) - \frac{b}{\sigma_b} \right]$$

where

$1 - \beta$ = statistical power,
Φ = theoretical distribution function,
$t(\alpha,n-2)$ = value of non-central t distribution,
b = expected value of the true slope of the regression line, and
σ_b = standard deviation of b.

Analysis of Identification Photos.—Dolphin photos were examined after processing, and useless photos (those in which the dolphin surfacing was missed, or was badly out of focus) were discarded. The remaining photos were filed in archival slide sheets and separated by date and sighting number. Then, each slide was examined carefully with an 8× loupe, and those showing a distinctive individual were selected. Each distinctive animal was then compared to the existing photo-identification catalog (and supporting photos) to determine if it was a new individual or a resighting. Dolphins were identified by general dorsal fin shape and markings on the back and dorsal fin such as nicks and cuts on the dorsal fin, body scars, and deformities and injuries (Fig. 6). Spot patterns were not used as the primary basis for identification because they appear to change over time (see Jefferson and Leatherwood 1997). However, spots and coloration were used in conjunction with other, more permanent, marks to aid in identification. This approach is similar to the 'matrix photo-identification technique' described by Karczmarski and Cockcroft (1998).

Photographs of each individual dolphin were kept in separate slide file sheets, in chronological order, so that comparisons

could be made easily, and any changes in markings could be tracked over time. A computer database was kept, using the bibliographic software ENDNOTE®. Each dolphin was given its own record within the database, which included the catalog number, name, date and location first identified, resightings, associated individuals, distinctive features, sex (if known), age class, and comments. A print catalog was also kept for easy comparison. There was a single print of each dolphin (either right or left side), and the highest quality photograph was chosen for the print catalog. The print catalog was updated periodically.

Association Patterns.—Photo-identification data provide a very good way of looking at the patterns of association between different individuals in a population, as well as social structure. Simple Ratio Association Indices for pairs of individuals were calculated using the following formula (Karczmarski 1996):

$$AI = \frac{j}{(a + b) - j}$$

where

AI = association index for a pair of individuals, A and B,
j = number of joint sightings of individuals A and B,
a = number of sightings of A, and
b = number of sightings of B.

Association Index values were only calculated for pairs in which both individuals were sighted at least 3 times. An association index of 0 means that two individuals were never seen together, and an index of 1.0 indicates that they occurred together all the time.

DISTRIBUTION AND HABITAT USE
Seasonal Distribution

Lingding Bay.—The Pearl River Estuary is a large system with a complex mixing of freshwater and saltwater over a large area (Kot and Hu 1997). There are 8 outlets, and the eastern 4 exits empty into Lingding Bay, which is usually what is referred to as the Pearl River Estuary. However, it is important to remember that the actual estuary extends to the west of Macau as well, and there are 4 additional exits in this western section. Although it is likely that dolphins also occur in the western estuary (west of Macau), there is currently no information available on the distribution of dolphins there, and the following discussion refers to dolphin distribution only in Lingding Bay (i.e., the eastern section of the Pearl River Estuary).

Indo-Pacific hump-backed dolphins occur in Lingding Bay in high to moderate numbers in all seasons. As noted previously (Jefferson and Leatherwood 1997), dolphin sightings were spread fairly evenly throughout the area in winter (Fig. 8). In spring, a similar pattern was seen, although dolphin sightings tended to be more concentrated along the eastern side of Lingding Bay (Fig. 8). In summer months, sighting locations shifted dramatically south, and sightings were rare in the area of Neilingding Island (an area which had been identified as a "hot spot" in winter and spring) (Fig. 8). During autumn months, sightings of dolphins in the area were somewhat more evenly spread out than in summer, with the greatest density of sightings in the region west of Lantau Island (Fig. 8). The pattern was rather similar to that in spring.

Despite the seasonality of distribution noted above, some general trends in distribution extended across all seasons. First, some dolphins were seen in most parts of Lingding Bay in every season. This indicates that the seasonal movements do not represent migrations *per se*, but rather shifts in density at different times of the year. Second, the eastern portion of the Estuary near the Hong Kong boundary appears to be more heavily used than the western portion near Macau. Finally, and very importantly, dolphin sightings were made frequently near the borders of the survey area in all seasons (see Fig. 3). The latter fact indicates that dolphins extend beyond the borders of the Lingding Bay
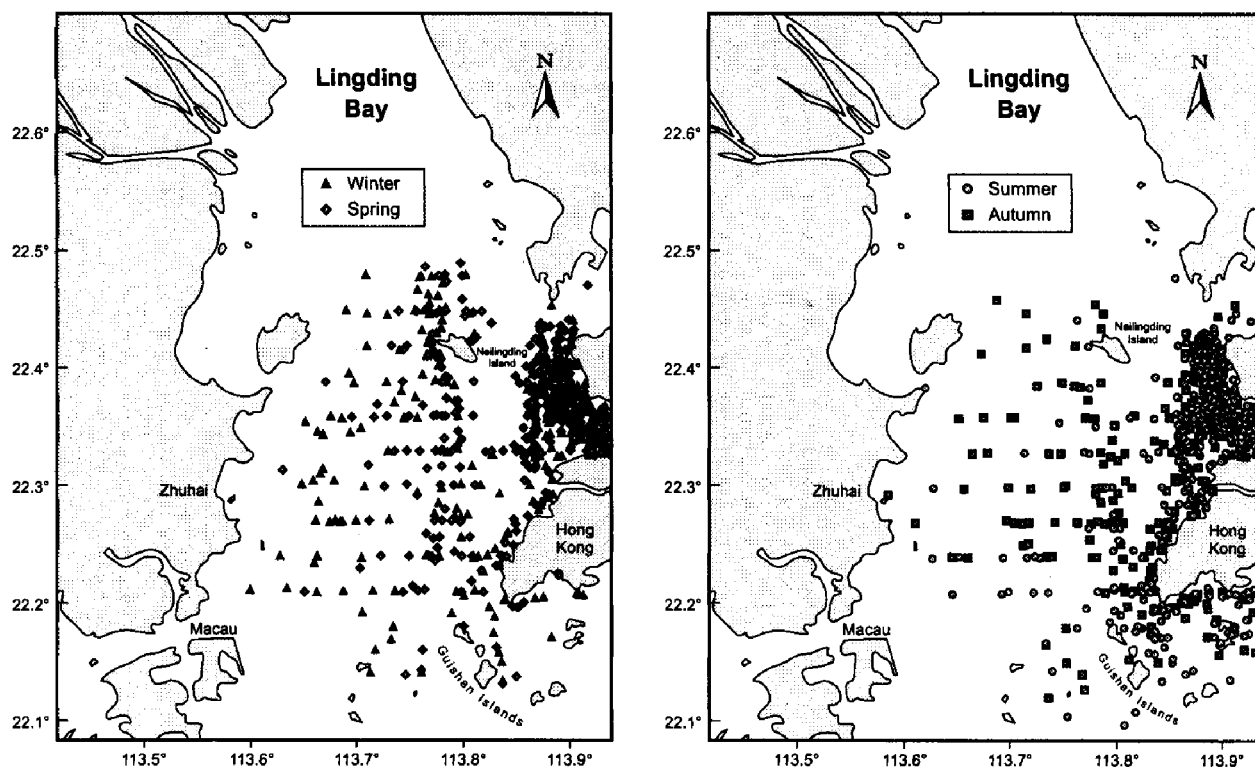
Fig. 8. Maps of Lingding Bay, showing locations of sightings of dolphins in Chinese waters to the west of Hong Kong. These maps are intended to show seasonal distribution. Because there were differences in the amount of survey effort conducted in different areas, relative densities among survey areas should not be inferred from these maps. Survey area boundaries are shown in Fig. 3.

study area (although we still do not know how far).

Hong Kong Waters.—Sightings of hump-backed dolphins were recorded in all the western waters of Hong Kong: Deep Bay, North Lantau, East Lantau, South Lantau, and Lamma (Fig. 9). No sightings were recorded in the eastern survey areas of Po Toi, Sai Kung, and Mirs Bay, despite moderate survey effort (3,208 km in Beau 0–3 conditions) in those waters. However, finless porpoises were commonly seen in these latter areas (Jefferson and Braulik 1999). All of the areas in which dolphins were commonly seen were affected by fresh water from the Pearl River. Hump-backed dolphins in South Africa also appear to be most densely distributed in areas near river mouths (Durham 1994). A brief summary of distribution in the different survey areas is given below; North Lantau is treated in greater detail in the next section.

The mouth of Deep Bay was used by dolphins, especially in summer and autumn months, but dolphins were not observed in the shallow northern portions of the bay. Dolphins were sighted in the waters of East Lantau in all 4 seasons, but most sightings were in autumn and winter months. The majority of sightings in the East Lantau area were made very near the northern Lantau Island coastline; dolphins were only rarely sighted south of Peng Chau or near the Hong Kong Island shore. There appears to be some internannual variation in use of the East Lantau area. While dolphin sightings there were relatively common in autumn and winter of 1996/97, there were no sightings in the same area in autumn and winter of 1997/98.

With the exception of a few sightings very close to Fan Lau in other seasons, most of the observations of dolphins in the South Lantau area occurred in summer
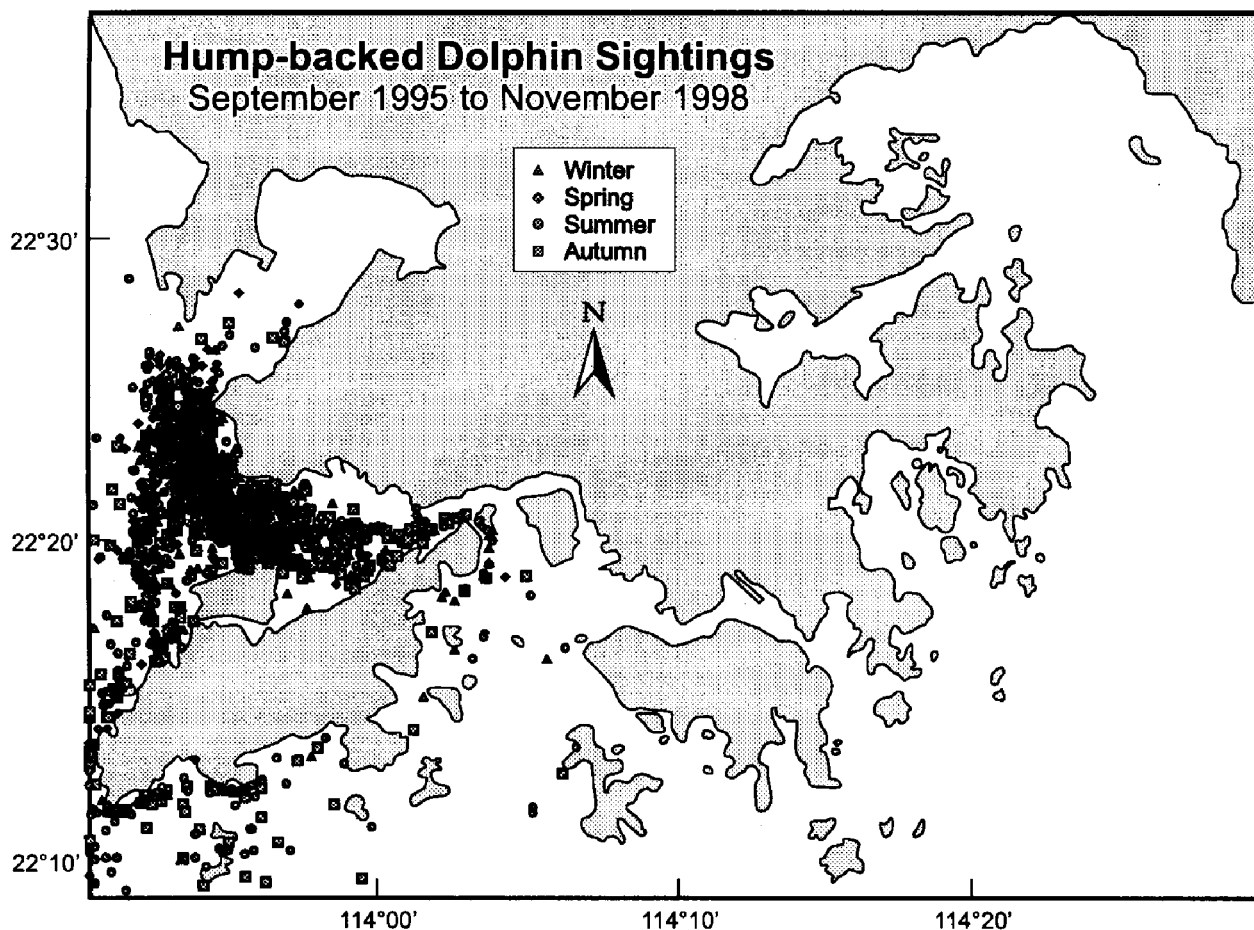
Fig. 9. Map of Hong Kong, showing distribution of sightings within the SAR regional boundaries. Because there were differences in the amount of survey effort conducted in different areas, relative densities among survey areas should not be inferred from this map. Survey area boundaries are shown in Figure 3.

and autumn months, when finless porpoises move out of the area and dolphins apparently move in (Jefferson and Braulik 1999). The western part of this area, near the Soko Islands and Fan Lau, appears to be used more heavily than the eastern area, near Cheung Chau. Several dolphin sightings were recorded in the Lamma area during summer and autumn of 1997; all of these were to the west side of Lamma Island, with two very close to the Lamma shoreline.

North Lantau Waters.—North Lantau represents the major area of distribution of dolphins in Hong Kong waters, and is the only place in Hong Kong where dolphins can be found reliably all year. This part of Hong Kong is heavily influenced by the Pearl River (Kot and Hu 1997).

Dolphins occurred throughout almost the entire area, with the greatest number of sightings in the area between Pillar Point, the northeastern corner of Chek Lap Kok, Lung Kwu Chau, and Black Point (Fig. 10). There were 2 regions in which sightings were quite rare: along the entire New Territories coastline from Kap Shui Mun to Pillar Point, and the region just east of the airport platform. Also, the area to the west and northwest of the airport platform had a relative paucity of sightings.

There were seasonal differences in the distribution of dolphins within the North Lantau area. In winter and spring months dolphin sightings were common in the western North Lantau area, but sightings from the Brothers' Islands and eastward were relatively infrequent. The distribu-
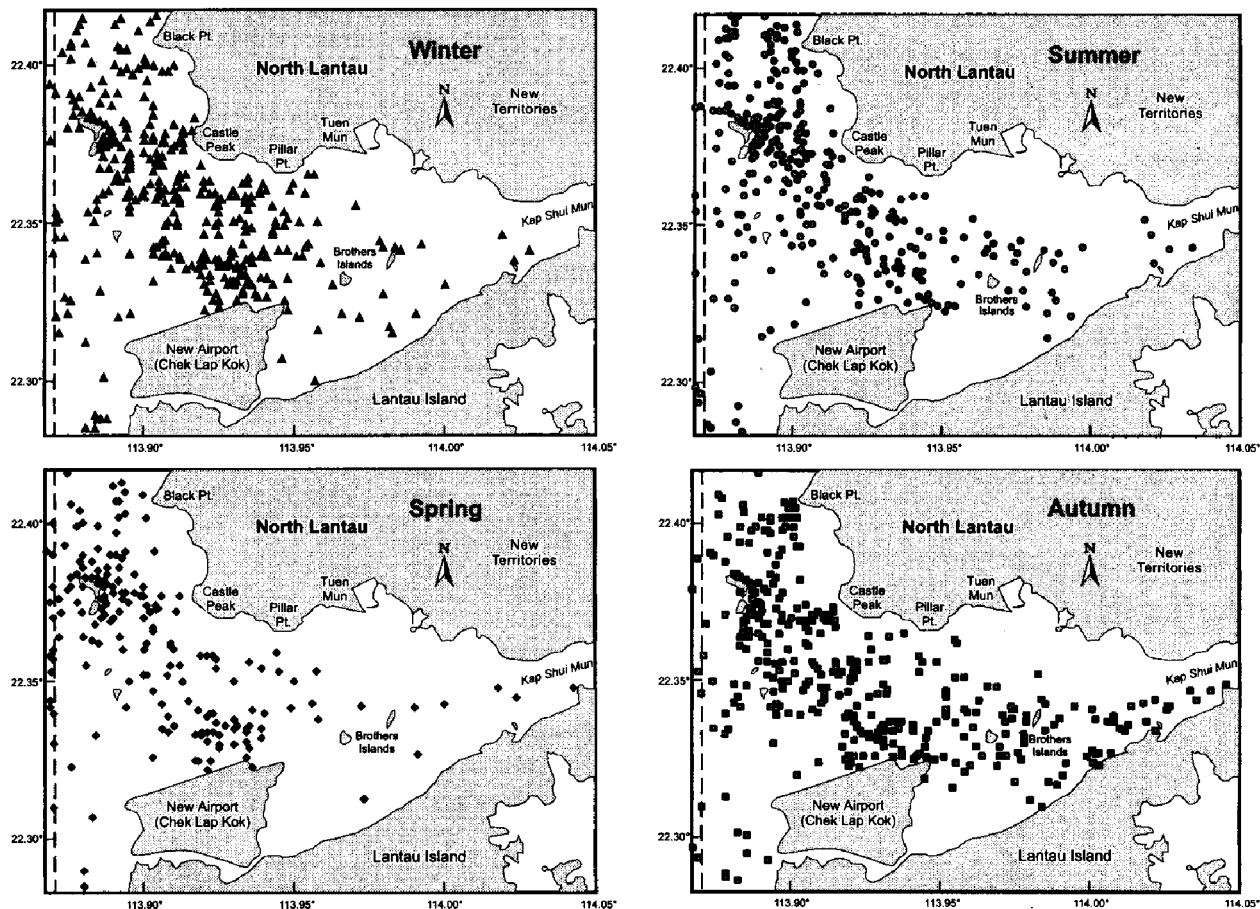
Fig. 10.   Maps of the main survey area of North Lantau, showing seasonal distribution of dolphin sightings.

tion in summer and autumn months was much more nearly uniform, and there were many sightings in the area of the Brothers' and eastward to the Kap Shui Mun channel.

Fig. 11.   Estimates of individual density of dolphins in different survey areas by season, an indicator of their relative importance as dolphin habitat in Hong Kong.

Habitat Use

Different parts of the habitat were not used evenly by the dolphins. There were, in particular, seasonal differences in the extent to which dolphins used different geographic areas of Hong Kong, as indicated by seasonal densities (see below) in those areas (Fig. 11). In winter months, use of North Lantau waters was high, and the East and South Lantau areas were used only lightly. In spring months, significant numbers of dolphins only occurred in North Lantau and Deep Bay waters. Summer appeared to bring an influx of animals in from mainland Chinese waters, and dolphins in this season appeared to use most of their range in Hong Kong (Deep Bay, North and South Lantau, and Lamma areas). Although Deep Bay was used more heavily at this time of year, dolphins only occurred in the area near the

mouth of the bay. This trend appeared to continue in autumn, as moderate to heavy use of both North Lantau and Deep Bay persisted, and dolphins still used the East and South Lantau areas. North Lantau was by far the most heavily used area in Hong Kong during all seasons.

All of the areas used by the dolphins are influenced, at least seasonally, by freshwater input from the Pearl River (see Broom and Ng 1996, Kot and Hu 1997). For those areas that are used seasonally (e.g., South Lantau and Lamma), the seasons of dolphin use are those in which fresh water from the river influences the area. The areas in which no dolphin sightings were made (Po Toi, Sai Kung, and Mirs Bay) are far enough away from the Pearl River mouth that there is little or no freshwater influence, even during years with heavy rains and correspondingly heavy river discharge (such as summer of 1997). Thus, the estuarine habitat preference of this species in the southern China area appears to be very strong. Some high-density areas appeared to be associated with deeper-water channels (e.g., Urmston Road and Fanshi Channel).

The changes in North Lantau distribution noted above may result from increased freshwater input from the Pearl River during summer and autumn, which could result in increased feeding opportunities for the animals. In general, there is an increase in the number of species and biomass of fish in this area in summer months (Ni 1997). This scenario is supported by the fact that there is an inverse relationship between dolphin sighting rates and salinity in the Brothers' Islands area (Fig. 12). In addition, during late autumn through spring, pair trawlers used the area of western North Lantau, but rarely ventured as far east as the Brothers'. This influence may be more important than hydrological factors for some individuals, which use pair trawlers as their major feeding strategy (see below under Behavior and Social Organization).

There does not appear to be any obvious habitat separation in terms of particular areas being used specifically for cer-
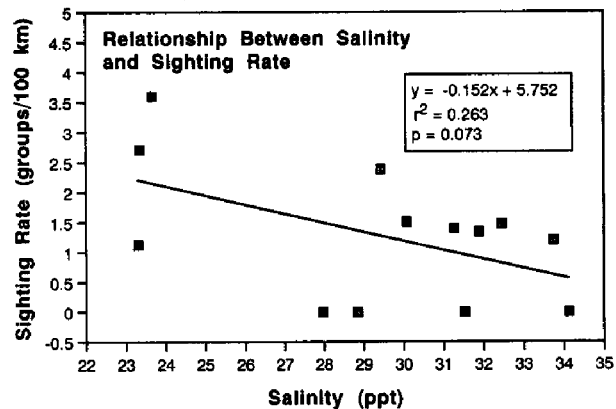
Fig. 12. Relationship between salinity and sighting rates of dolphin groups in the eastern part of the North Lantau survey area, around the Brothers' Islands. Salinity data courtesy of the Environmental Protection Department.

tain activities such as breeding or feeding. From observations to date, it appears that dolphins in each of these areas engage in the full range of activities.

ABUNDANCE AND POPULATION TRENDS

Abundance Estimates

The size of the photo-identification catalog as of December 1998 is 213 individuals (however, two of these individuals are known to have died). Therefore, the minimum population size is 211 individuals. New individual dolphins were identified in most months in which at least 10 rolls of film were taken, and were added to the photo-identification catalog throughout the duration of the study. At the end of the study a plateau had still not been reached (Fig. 13). This can be interpreted to mean that not all identifiable animals in the population have been photo-identified. Although some individuals were identified up to 36 times, most dolphins were only seen only once or a few times (Fig. 14). A mark-recapture analysis (Otis et al. 1978) of the photo-identification data to estimate overall population size will be attempted once all the identifiable individuals in the population have been identified.
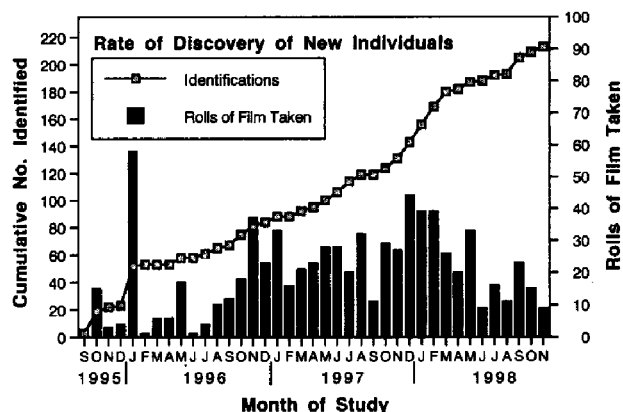
Fig. 13. Rate of discovery of new individual dolphins in Hong Kong and Lingding Bay. Also shown is the number of rolls of 36-exp. film taken per month, an index of photographic sampling effort.

Fig. 14. Histogram showing number of sightings per individual dolphin in the OPCF photo-identification catalog.

A total of 38,105 linear km of transect line was surveyed in Hong Kong and adjacent waters during the study period. Because of previous indications that estimates using data collected during sea states of Beaufort 4 or greater would be biased (Jefferson and Leatherwood 1997), only data collected in Beaufort conditions of 0 to 3 were used for abundance estimation. This left 30,423 km, which is 80% of the total.

Estimates of abundance varied by survey area and season (Table 3). For all seasons, abundance in Hong Kong was highest in the North Lantau area (Fig. 15). In winter months, an estimated total of 91 dolphins occurred in Hong Kong waters, most of these in North Lantau, but with small numbers in the East and South Lantau areas. Spring resulted in a slight reduction in abundance in Hong Kong to 88 dolphins and an absence of dolphins in significant numbers in other survey areas outside of North Lantau (except for a small number in Deep Bay). In summer, numbers in North Lantau increased to about 105, and small numbers of dolphins occurred in the Deep Bay, South Lantau, and Lamma areas, bringing the total to 145. In autumn there were similar numbers to summer in North Lantau, as well as other survey areas (Deep Bay, East Lantau, and South Lantau). The total number of dolphins in Hong Kong waters in au-

tumn was estimated to be 140 animals. The peak seasons for dolphin abundance in Hong Kong appear to be summer and autumn, and the higher number of dolphins in the North Lantau area at this time of year is probably related to higher diversity and abundance of fish in the area at the same time of year (Ni 1997).

The coefficients of variation (CVs) of the estimates should be taken into account when evaluating abundance estimates. The CVs for the seasonal estimates for North Lantau are all <20%, indicating relatively high levels of statistical precision. These estimates are thus considered reliable and can serve as good bases for examining potential trends in abundance in the future. However, the abundance estimates for all other areas have relatively low levels of precision, with CVs ranging from 21% to 86%. This indicates that these estimates should be viewed as preliminary. More work needs to be done to refine these estimates to be used as starting points for comparison of potential changes in abundance.

For the Lingding Bay study area, the season with the highest estimate of abundance was winter (N = 937), and the season with the lowest was summer (N = 293; Table 3). Estimates for spring and autumn were intermediate (N = 670 and N = 585, respectively). The estimates have associated coefficients of variations ranging from 21% to 42%, indicating moderate levels of statistical precision.

A minimum estimate of the size of the Pearl River Estuary population can be

Table 3. Estimates of abundance and associated parameters for hump-backed dolphins in different survey areas of Hong Kong and the Pearl River Estuary. Because a value for the probability density function [f(0)] cannot be calculated based on a single sighting, density and abundance have not been estimated for cases in which n = 1, and are assumed to be 0 in these cases. Symbols used: L, total length of transect surveyed; n, number of on-effort sightings; ESW, effective strip width; n/L, group sighting rate; D, individual density; N, individual abundance; and CV, coefficient of variation.

Survey area	Survey days	L (km)	n	ESW[a] (m)	n/L (100 km⁻¹)	D (100 km⁻²)	N	CV (%)
Deep Bay[b]								
Winter	3	58	1	--	1.72	0	0	-
Spring[c]	6	119	2	163	1.68	10.32	9	70
Summer[c]	6	147	4	154	2.71	12.08	12	56
Autumn[c]	5	133	3	223	2.26	12.77	13	74
North Lantau								
Winter	71	3,210	246	205	7.66	57.26	84	15
Spring	52	2,809	156	163	5.55	54.03	79	18
Summer	75	4,141	257	154	6.21	71.68	105	17
Autumn	47	2,225	203	223	9.12	71.16	104	18
East Lantau								
Winter[c]	7	378	3	205	0.79	4.50	4	61
Spring	12	575	1	-	0.17	0	0	-
Summer	14	670	1	-	0.15	0	0	-
Autumn	51	2,507	13	250	0.52	5.21	6	52
South Lantau								
Winter[c]	8	283	2	205	0.71	3.46	3	86
Spring	9	412	0	-	0	0	0	-
Summer	10	392	13	441	3.06	16.71	20	66
Autumn	22	776	15	207	1.80	14.57	17	41
Lamma								
Winter	23	963	0	-	0	0	0	-
Spring	23	940	0	-	0	0	0	-
Summer[c]	16	803	2	154	0.25	4.03	8	82
Autumn	26	1,090	1	-	0.09	0	0	-
Lingding Bay (PRC)								
Winter	25	1,044	44	131	4.22	109.48	937	42
Spring	21	1,450	67	190	4.62	78.28	670	21
Summer	20	1,078	27	153	2.50	34.26	293	34
Autumn	18	1,269	52	165	4.10	68.39	585	24

Total Pearl River Estuary

Winter	1,028
Spring	758
Summer	438
Autumn	725

[a] The ESW is an intuitive interpretation of f(0), expressed as the inverse of f(0).
[b] Because dolphins are only distributed in the southern half of Deep Bay, the density and abundance estimates were divided in half.
[c] Because of a sample size of less than 10 on-effort sightings for these strata, f(0) (and the ESW) for the appropriate season for North Lantau was used in the line transect equation to estimate density and abundance.

made by adding the present estimates to estimates for Hong Kong waters for each season (Table 3). The peak estimate of 1,028 dolphins can be viewed as the best available estimate of the total population size. However, it should be noted that there are still extensive areas of the estuary south and north of the Lingding Bay study area and another region west of Macau that have not been surveyed. If these areas are also inhabited by dolphins from the same population, then the above estimate will likely underestimate the true population size.
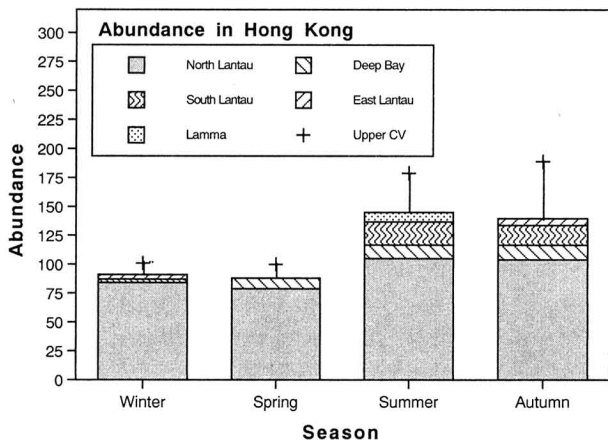
Fig. 15.   Seasonal abundance estimates for different survey areas of Hong Kong. The vertical bars represent the CV for that season's estimate, calculated by averaging the CVs of the component estimates, weighted in proportion to the point estimate of abundance.

Fig. 16.   Trend in abundance estimates of dolphins in North Lantau waters, as indicated by a least squares regression line fit to the point estimates. The vertical bars represent log-normal 95% confidence intervals of the estimates.

Trends in Abundance

North Lantau abundance estimates for the 3 years of the study showed a decreasing trend (Fig. 16). The third estimate was below all of the others, both before and after it. It appears that dolphin numbers in the main survey area dropped dramatically during winter and spring 1996/1997, a period corresponding to the phase immediately following the intensive percussive piling work on the Aviation Fuel Receiving Facility (AFRF) for the new airport. It is probable that dolphins may have avoided this area because of the loud noise associated with the piling work (see below), thereby resulting in an overall decline in the number of dolphins in the North Lantau area. However, there appears to have been a large influx of dolphins back into the area during the next time period (summer and autumn 1997), after the piling work had been completed.

Least squares regression fit of an exponential curve to the point estimates resulted in a nearly linear curve (Fig. 16). The natural logarithm of abundance was regressed against the time scale to determine the slope, which was -0.166, indicating a 16.6% rate of decline. Three of the point estimates fell outside the 95% confidence interval for the first estimate, but the observed decline is not statistically significant (t-test, $p > 0.05$). It is important to consider the statistical power of the analysis to detect trends in abundance (see Taylor and Gerrodette 1993). Using the program TRENDS, the power of the current analysis to detect the indicated level of change is 0.94, or 94%. This is quite high, and it suggests that the non-significant result of the trends analysis is indeed meaningful (i.e., that the decline may not be real).

If we assume that the estimated decline is real, there is still some uncertainty as to the cause. Such a result could be indicative of an actual decrease in the population size of hump-backed dolphins in the area due to levels of mortality exceeding recruitment. However, the area for which the trends analysis was done is only a very small proportion of the population's overall range (less than 12%). Therefore, it is also possible that the decline could result from the movement of dolphins out of the survey area of North Lantau, either permanently or temporarily. The fact that the third abundance estimate was so low and the fourth increased dramatically suggests that this may be at least a partial explanation. To reflect a real population decline, the population would have had to decrease by more than half and then double in a one-year period, which is biologically impossible. It seems likely that some portion of the potential decline may result from temporary movement of dolphins outside the main survey area and into surrounding waters, presumably those in mainland Chi-
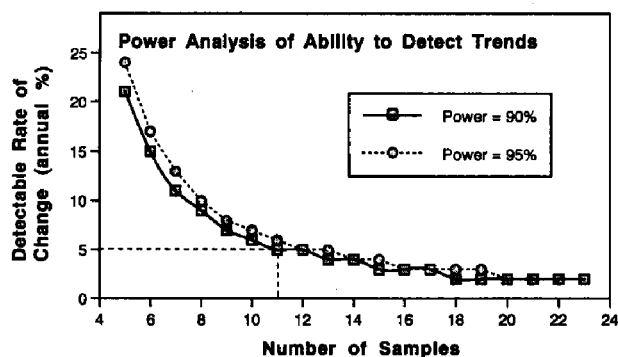
Fig. 17. Relationship between statistical power to detect certain rates of population change and number of samples (6-month survey periods). For example, the dashed box indicates that more than 10 samples (5 years) would be required to detect a 5% decline with 90% statistical power.

nese waters west of Hong Kong. However, this scenario is uncertain, and we need to have data from a longer time period and a larger proportion of the population's range to determine the trend in population size accurately.

Because of the short time period (3 years) and small number of samples (6) of the present study, the statistical power of the present analysis to detect anything but very large population declines is not high. In addition, the seasonal differences in abundance demonstrated above may confound this analysis somewhat. Continuing the time series of abundance estimates into the future would allow for a much more reliable analysis of small rates of change (Fig. 17). For instance, detecting a decline as small as 5% with high statistical power (90%) would require 5.5 years (Fig. 17). This would require extending the surveys for 2.5 years beyond the present study. To detect a decline of 2% with the same power would necessitate 18 samples, or 6 more years of study. This demonstrates that long-term monitoring is essential for the effective conservation of this population.

Potential Biases in Abundance Estimation

In order to determine if there were any significant biases in the resulting line transect abundance estimates, six assumptions were examined and tested with empirical

data. The first three are considered to be critical assumptions of line transect sampling (Buckland et al. 1993), and the last three, while not considered critical by Buckland et al. (1993), do have the potential to cause significant bias in line transect estimates (see Palka 1993). In particular, the first two assumptions are violated in many marine mammal studies, but with proper work to develop correction factors, reliable abundance estimates have still been obtained (e.g., Barlow 1995, Palka 1995, Turnock et al. 1995). The assumptions are:

(1) Objects on the transect line are detected with certainty (i.e., the detection function, $g(0) = 1$),

(2) Objects are detected at their initial location, prior to any movements in response to the survey platform,

(3) Distances and angles are measured accurately,

(4) Repeated detections of the same object within the same sampling unit are not common,

(5) Variability in environmental conditions does not significantly affect point estimates, and

(6) The probability of detection is not strongly affected by factors other than perpendicular distance.

Several of these assumptions were already examined by Jefferson and Leatherwood (1997), who found no evidence for significant bias in the abundance estimates. However, each is reconsidered below, some for the first time with empirical data and all with larger sample sizes.

Data have been collected to examine the validity of the assumption that all dolphins on and near the transect line at the time of passage of the research vessel are detected (Assumption 1). As part of this exercise, dive times for groups of humpbacked dolphins were recorded from the shore-based station at Sha Chau. Groups, rather than individuals, were used in this analysis, because groups (not individuals) are the targets of the survey. The resulting data indicate that the vast majority of group dives are of less than 1 min in du-
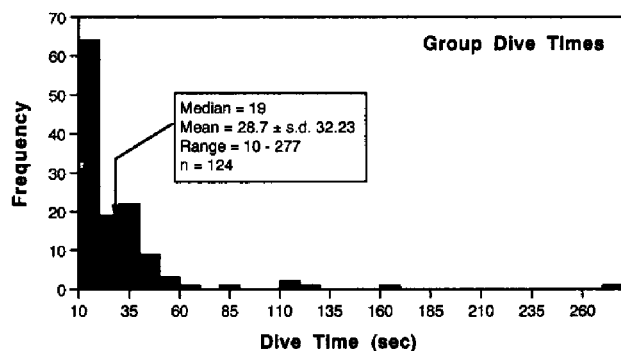
Fig. 18. Histogram of group dive times, based on data collected from the land-based station at Sha Chau.

Fig. 19. Histograms of perpendicular distances, showing effect of use of the laser rangefinder binoculars (pre-Geovid refers to the period before the laser binoculars were used, and post-Geovid to after).

ration (Fig. 18). Groups of dolphins are within the visual range of the observers for much greater than 1 minute, and therefore should surface at least once in the detection time interval. This strongly suggests that availability bias (see Marsh and Sinclair 1989 for a description of the distinction between availability bias and perception bias) is likely to be insignificant. In other words, it will be rare that dolphin groups near the boat are missed due to being on a dive as the vessel passes. Of course, this does not properly take into account the potential for responsive movements in relation to the survey vessel.

It is likely that some groups of dolphins near the transect line will avoid detection by the main survey team due to perception bias. However, the independent observer would be expected to detect most of these groups behind the vessel. My approach, of empirically estimating a value for the detection function and factoring it into the line transect equation, is intended to correct for missed groups on and near the transect line.

In the 71.8 hrs of independent observer data collected, only 10 sightings were made by the independent observer, and all of these were outside the 100-m strip defined as "on and near the transect line" (mean perpendicular distance = 210.3 ± s.d. 103.79 m, range = 56–340 m). For comparison, during the same period, the main survey team made a total of 48 on-effort sightings. A value of 1.0 has therefore been estimated for the detection function. However, the estimate will only

be unbiased if g(0) is the same for the main observer team and the independent observer, and there is no responsive movement within the 50-m strip before the independent observer has a chance to see the group. While neither of these assumptions is likely to be strictly true, the approach taken allows for a preliminary estimate of g(0) to be made, rather than the usual approach of just assuming it to be 1.0. It is possible that some groups on or near the transect line will be missed by both the main survey team and by the independent observer, but group dive time data suggest that this is probably not common. Therefore, I consider that Assumption 1 has been addressed adequately for now (i.e., until a better estimate of the detection function can be made).

Assumption 2 has to do with responsive movements by the animals before detection. Histograms of sighting distance showed no evidence of evasive movements by the animals before detection (Fig. 19). These generally take the form of a 'valley' in the distance histogram near the origin (see Buckland et al. 1993). However, it is difficult to rule out attraction to the survey
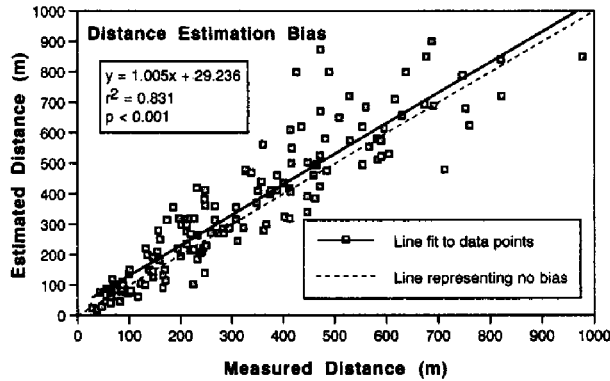
Fig. 20. Scatterplot showing bias in distance estimation capabilities of observers. The solid line was fit to the data using least squares linear regression techniques. For comparison, the dotted line is a theoretical line representing the situation of no bias.

vessel from examination of such histograms, but unlike many species of small cetaceans (Würsig et al. 1998), hump-backed dolphins in Hong Kong do not routinely approach vessels to ride bow waves. In a sample of 1,532 sightings, we have observed bow-riding behavior only 3 times (0.2%), and in these instances the animals approached the boat long after first detection by the observers. Despite this, attraction to the vessel does occasionally occur. In 189 sightings in which the dolphins' response to the survey vessel could be clearly discerned, only 4 sightings (2.1%) were classified as attraction, and a further 4 (2.1%) were classified as avoidance. The remaining 181 sightings (95.8%) were classified as no response. Therefore, Assumption 2 is considered to be satisfied.

Jefferson and Leatherwood (1997) used a pair of laser rangefinder binoculars to examine for problems in distance estimation and found some evidence of problems near the beginning of this study (see Fig. 19). However, the use of the laser binoculars allowed biased distance estimates to be 'corrected,' and later data showed no evidence of significant bias. Data collected since those of Jefferson and Leatherwood (1997) also show scatter about the line but no significant bias problems (Fig. 20). Angles are calculated from successive compass bearings on the dolphin group and the vessel's track, leaving little opportunity for estimation bias to become a factor.

Thus, there is evidence that Assumption 3 is not violated.

From examination of photo-identification data, repeat detections of the same individual on the same day were uncommon (this relates to Assumption 4). When these did occur, they were almost always on separate survey lines. On several occasions repeated sightings of the same individual occurred, but one of the sightings was off-effort, thus causing no bias in the abundance estimates. There was only one case in which a dolphin was identified twice on-effort on the same survey line; in this case, the second sighting was 43 minutes after the previous detection. Estimates of group size were 8 and 9 for the two sightings, suggesting that they may have been the same group of dolphins. This was the exception, however; repeat detections were extremely rare, and are thus not considered to cause significant bias in estimates. Therefore, Assumption 4 does not appear to have been significantly violated.

Jefferson and Leatherwood (1997) examined in detail the effects of various Beaufort sea states on the estimation of abundance. Their results showed that effort data collected in Beaufort sea states of 0–3 were not biased, but those of Beaufort 4–5 were. In this study, estimates of abundance were made using only data collected in Beaufort 0–3 conditions. Several other environmental features, such as swell height, glare, and poor visibility, can also affect sighting rates and thus potentially line transect estimates (see Holt and Cologne 1987). However, swells of over 0.5 m were almost never encountered in areas inhabited by hump-backed dolphins. Glare also was generally not a problem, as surveys were not conducted near dusk or dawn, and low sea states and land masses surrounding the survey areas generally prevented serious glare problems from developing. Also, the transect lines were short, and frequent direction changes (usually < 30 min.) prevented any glare from remaining in the same part of the search path for long. Visibility could be poor in the study area, but only effort data
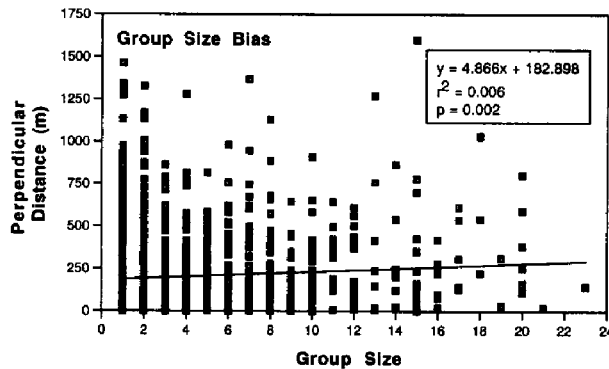
Fig. 21. Scatterplot showing probable bias in group size estimates in relation to distance from the survey vessel.

in which visibility was at least 1,200 m were used in estimating abundance. These considerations indicate that Assumption 5 was adequately satisfied.

Assumption 6 is related to conditions that could affect detection probability. Group size is the major factor, other than environmental conditions, likely to affect detection probability. Estimates can be inaccurate if there is bias in the estimation of average group size. There was a slight increase in estimated group size with increasing perpendicular sighting distance (Fig. 21). This was presumably caused by the fact that almost all groups, regardless of size, were detected near the vessel. However, small groups were difficult to detect at great distances, resulting in a positive bias in estimation of group size by using the arithmetic mean. However, this problem was handled during the analysis. Program DISTANCE was used to compute a size-bias corrected estimate of group size using linear regression techniques (Laake et al. 1994). Then, this unbiased group size estimate was used in place of the biased arithmetic mean in the line transect equation, thereby solving the problem of violation of Assumption 6.

In summary, information is presented indicating that line transect assumptions are either satisfied or corrected, and most potential biases are not likely to be of consequence in the use of line transect sampling to study hump-backed dolphin density and abundance in Hong Kong waters. However, the assumption of detection of

all trackline animals should be examined further.

SOCIAL ORGANIZATION AND BEHAVIOR

Individual Movements and Home Ranges

Because a disproportionate amount of research effort so far has been conducted in the small portion of the population's range in Hong Kong, evaluations of the total home range size of these dolphins must be considered tentative. From the currently available data, however, it is possible to get some idea of home range size and extent of individual movements.

Most individuals seen in Hong Kong had home ranges that included the North Lantau area, and some animals appeared to be resident to the North Lantau area (e.g., NL24 was seen 41 times, NL35 and NL57 each seen 22 times; Appendix 2). All of the sightings of these individuals occurred in the North Lantau area or nearby waters, although they were sometimes not seen in North Lantau for several months at a time. There was no obvious seasonality to patterns of occurrence in North Lantau. Some dolphins also used the East Lantau area (e.g., NL22 seen 23 times in North Lantau and 4 times in East Lantau). No animals were only seen in East Lantau, and it is unlikely that any individuals use East Lantau exclusively. In fact, at most times there appear to be no dolphins present in the East Lantau area. One individual (EL07) appeared to range at the margins of the population's range; it was seen 5 times in East Lantau, then once in Lamma, and finally 8 times in the North Lantau area, mostly east of the Brothers' Islands.

A few animals appeared to be more far-ranging, such as NL02, which was seen 23 times in areas ranging from East Lantau to south of Tai O, but still mostly in North Lantau. Many dolphins have been confirmed to move between Hong Kong waters and those of Lingding Bay, west of Hong Kong. In particular, the area around

Neilingding Island appears to be heavily used by several of these individuals, which also come into Hong Kong waters on occasion. However, many individuals identified in Lingding Bay have not been sighted in Hong Kong, and it appears that many members of the population may not use Hong Kong waters at all (or only very rarely).

Six individuals first seen in South Lantau were later seen in Lingding Bay, and one was later seen in North Lantau. However, most individuals observed in South Lantau were not seen in other parts of Hong Kong. It is likely that these are mainly animals that occur further west in Lingding Bay waters for most of the year, only moving into South Lantau on occasion, mostly in summer and autumn. Of 119 animals seen more than once, 66 (55%) were seen only in Hong Kong, 25 (21%) were seen only in Lingding Bay, and 28 (24%) were seen in both Hong Kong and Lingding Bay. This is a biased sample (a very large percentage of survey effort has been in Hong Kong), but it nevertheless indicates that cross-boundary movements are common. With further research effort other animals may be found with similar home ranges. The above observations provide evidence that, contrary to previous claims (Porter 1998), there is overlap (and presumably interbreeding) between dolphins that use the North Lantau and South Lantau areas.

Hung (2000) conducted an analysis of home range size and patterns, and the factors that affect them. He used photo-identification data from this study, and analyzed only individuals with at least 10 sightings (n = 27), which was found to be suitable to provide a valid estimate of the overall home range size for most individuals. His analysis suggests that home range size extends from about 29 to 395 km² in Hong Kong and Pearl River Estuary hump-backed dolphins (Hung 2000). This indicates that an individual's range includes only some portion of the population's overall range of over 1,800 km². Most home ranges are irregularly-shaped polygons with linear dimensions of only
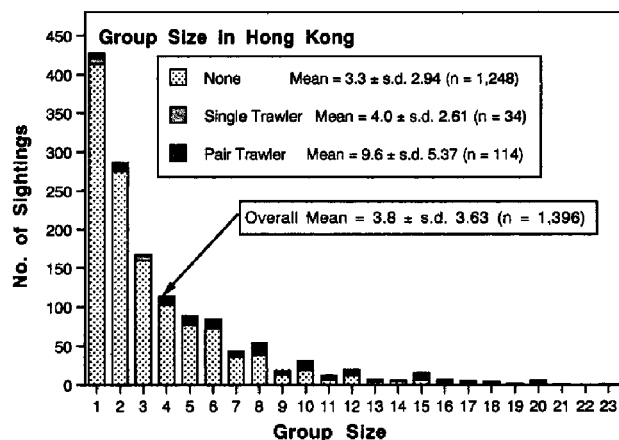
Fig. 22. Group size distribution and summary statistics for groups with different types of vessel association.

tens of kilometers, rather than narrow strips along the coast with linear ranges of a few hundred kilometers, as appears to be the case in hump-backed dolphins from the Algoa Bay region of South Africa (Karcmarski 1996). Therefore, Chinese animals may range over shorter linear distances than animals of the same species from South Africa. Also, there appears to be some age and sex-related variation in the size of the home range, and seasonal variation within the home range of individual Chinese hump-backed dolphins. Additional details can be found in Hung (2000).

Social Organization

Group Size and Composition.—Indo-Pacific hump-backed dolphins in Hong Kong occur as singles or in small groups ranging up to 23 animals (Fig. 22). Solitary dolphins and pairs are most common, and the overall mean group size is 3.8 ± s.d. 3.63. Groups of dolphins associated with pair trawlers (the largest type of fishing gear used in Hong Kong) were significantly larger than those associated with single trawlers or with no vessel association (ANOVA, F = 201.0, total df = 1,395, p < 0.001), and groups of greater than 10 dolphins were usually associated with pair trawlers. There was no significant variation in the average group size throughout the year (Fig. 23). Also, there was little variation in average group size among different
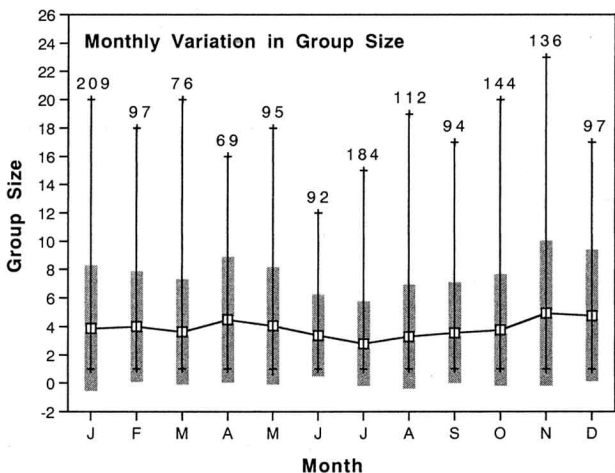
Fig. 23. Monthly variation in average group size. The white points are the means, the shaded bars are the standard deviations, the thin bars are the ranges, and the numbers are the sample sizes.

Fig. 25. Variation in composition of groups by survey area.

areas in Hong Kong (Fig. 24), with averages of about 3–4 dolphins. However, regions in China appear to have significantly larger group sizes (ANOVA, F = 37.13, total df = 1,532, p < 0.001; Fig. 24) . Tukey's pairwise comparisons indicated that Lingding Bay groups (ranging in size up to 44 animals) were larger than all others except those in Xiamen; Xiamen groups were significantly larger than North Lantau groups.

Although based on small sample sizes, there are geographic differences in group composition from the overall average composition for the following survey areas: South Lantau (X^2 = 13.48, df = 4, p <

0.01), East Lantau (X^2 = 20.57, df = 4, p < 0.001), North Lantau (X^2 = 12.79, df = 4, p < 0.05), and Deep Bay (X^2 = 27.95, df = 4, p < 0.001). There was no significant difference for the Lingding Bay area (Chi-square, p > 0.05; Fig. 25). The most obvious difference is the high proportion of juveniles in the South Lantau and Deep Bay areas. East Lantau had a high proportion of animals in the mottled age class (see below). It is possible that some younger members of the population are restricted to more peripheral parts of the population's range. The composition of groups throughout the seasons did not appear to change dramatically, except that during winter months few calves were seen (Fig. 26). Differences in group composition among seasons were not statistically significant (Chi-square, p > 0.05).

Individual Associations.—Calculation of association indices between pairs of dolphins showed that most pairs of dolphins

Fig. 24. Variation in average group size by survey area. Display as in Fig. 23.
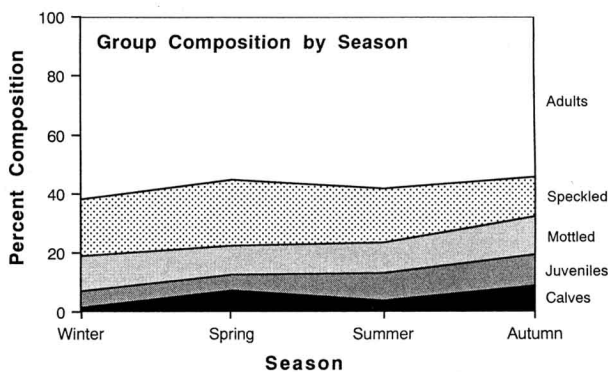
Fig. 26. Variation in composition of groups by season. Adults includes both Spotted Adults and Unspotted Adults.
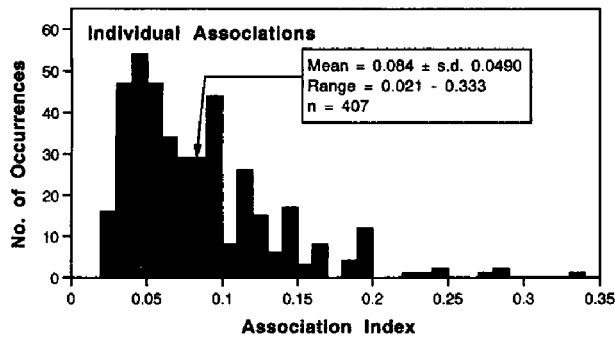
Fig. 27. Histogram of association indices for pairs of individuals that were seen together. For most possible pairs of dolphins, the association index = 0 (see text for explanation)

never or only rarely occurred in the same group, with a range of association indices for pairs that did associate from 0.021–0.333 (Fig. 27). The average association index for these pairs was 0.084 ± s.d. 0.0490. Most individuals did not associate (association index = 0). Incorporating these data resulted in an average index of 0.0023. This indicates that, on average, two individuals only spend about 0.23% of their time together. With the exception of mothers and their young calves (which are closely associated in all mammal species), there was a lack of evidence for stable associations between pairs or among groups of individuals. This is in stark contrast to the report of Porter (1998), who suggested that stable subgroups were seen repeatedly in Hong Kong. However, little supporting evidence was given for her claim, and she made no attempt to quantitatively evaluate association patterns.

The average association index is low, but it is in good agreement with what is known of hump-backed dolphins in South Africa (Karczmarski 1996) and of other species of coastal small cetaceans, which generally appear to have a very fluid social structure, such as bottlenose dolphins (*Tursiops truncatus*) (Shane et al. 1986). Some larger delphinids, such as killer whales and short-finned pilot whales (*Globicephala macrorhynchus*), have much higher levels of association and much more stable social systems (Bigg et al. 1990, Heimlich-Boran 1993). Hump-backed dolphins in Hong Kong, however, appear to have a social system more similar to the "fission/fusion" so-

cieties of some primates, such as chimpanzees (*Pan troglodytes*) (see Würsig 1978). Groups would often change composition during the course of a sighting as new individuals joined a group and others left.

Behavioral Observations

General Behavior.—Although detailed behavioral sampling was not conducted in this study, some general observations on behavioral patterns were recorded. As is true for the species in South Africa (Karczmarski et al. 1997), the behavior of hump-backed dolphins in Hong Kong and southern China is broadly similar to that of other species of coastal dolphins, such as bottlenose dolphins. A variety of activities and aerial behavior patterns were noted by Parsons (1998a). Aerial behaviors, such as breaching and spy-hopping, appeared to be more common in late summer to autumn months. Based on the seasonality of calving (see Life History below), this would coincide with a hypothesized peak in socio-sexual activity.

Behavior of individual dolphins in a group was often not cohesive or consistent (as it often seems to be in schools of oceanic dolphin genera, such as *Stenella*, *Delphinus*, and *Lagenorhynchus*; TAJ pers. observ.). Dolphin activity patterns often changed during the course of a sighting, and it was not uncommon to see several individuals in a group behaving quite differently from each other.

Wave-riding behavior was not commonly seen. Unlike many other species of dolphins, hump-backed dolphins do not appear to be active bow riders (Karczmarski et al. 1997). Behavior that could be called bow riding was observed only 3 times, and was generally engaged in only by certain members of the group (most often small juveniles) and for short periods. Occasionally, dolphins would ride the wakes of passing vessels for short periods of time. However, unlike hump-backed dolphins in South Africa (Karczmarski et al. 1997), Hong Kong dolphins did not always avoid vessels. Many groups of dolphins appeared to be undisturbed by nearby vessels. It was

not uncommon for groups of dolphins to approach the research vessel and even to orient toward it as it lay idle for periods of an hour or more.

Associations with Fishing Vessels.— Hump-backed dolphins in Hong Kong and Lingding Bay often associate with fishing vessels. Short-term associations were observed with shrimp trawlers and other small trawlers. However, the most important interactions appeared to occur between the dolphins and pair trawl fishing vessels (see ERM-Hong Kong 1998 for a description of this and other fishing methods used in Hong Kong). Of the total of 1,532 sightings analyzed, 12.1% (186) were associated with pair trawlers, and 3.2% (49) were with other types of fishing vessels (mostly shrimp trawlers).

The pair trawler interaction occurs over a large area, as the 2 vessels pull a single large trawl net, which extends some 500–800 m behind the boats. The end of the net is indicated by a marker buoy, and the dolphins are usually seen about 100–200 m in front of the buoy. Dolphins have been observed following these vessels for over 2 hours, and it is relatively uncommon to see a group of dolphins leave the net while it is actively fishing. Generally, the dolphins slowly mill in the area when the net is pulled in, and if the vessels do not soon begin fishing again, the dolphins eventually disperse. Because the catch is sold to fish farms as cheap feed, there is little to no discarded bycatch in this fishery.

Dolphins often gathered behind fishing pair trawlers in large numbers, and in fact the largest groups seen were usually associated with pair trawlers (Fig. 22). Dolphins often appeared to actively approach pair trawlers, and in one instance dolphins were observed swimming at high speed from well over 1 kilometer away to follow a set of pair trawlers. When the vessels are moving quickly, the dolphins often leap clear of the water as they surface in an apparent attempt to take a quick breath and quickly go back down (presumably to feed near the net at depth). Dolphins generally move in a straight line while follow-

ing the trawlers. They move at a consistently high speed as measured by theodolite tracking from the shore-based station at Sha Chau. Average swimming speed of pair trawler-associated dolphins (1.99 ± s.d. 1.101 m/sec) was higher than for other groups (1.06 ± s.d. 0.671 m/sec) (t-test, p < 0.001). Conversely, the average extent of direction change was significantly less for pair trawler dolphins (57.1 ± s.d. 50.12°) than for others (93.1 ± s.d. 62.12°) (t-test, p < 0.001). The movement patterns of dolphins were thus very predictable at these times, and excellent identification photos could be taken of groups behind pair trawlers. All age classes, from neonates through large adults, were seen following behind these vessels.

Although many Hong Kong-based pair trawlers fish mainly in Guangdong waters across the boundary, pair trawling is still common in some of Hong Kong's waters (e.g., Mirs Bay, Tolo Harbour/Channel, South Lantau, and the western portion of North Lantau) (ERM-Hong Kong 1998). A large percentage of those pair trawlers fishing within the range of the dolphins in Hong Kong's western waters and adjacent areas had dolphins feeding behind them (38 of 40, or 95.0% for North Lantau; 8 of 41, or 19.5% for South Lantau; and 11 of 13, or 84.6% for Lingding Bay waters). None of the 3 pairs of trawlers seen fishing in East Lantau was associated with dolphins, and similarly none of 12 seen fishing in Mirs Bay and Tolo Harbour/Channel had dolphins associated.

There appear to be great individual differences in the tendency of particular dolphins to feed behind pair trawlers. Most frequently-seen individuals associated with pair trawlers during some proportion of their sightings (e.g., NL24 was seen 21 times with trawlers and 15 times without). However, some commonly-seen dolphins rarely or never were seen to feed behind pair trawlers (e.g., NL37 seen a total of 19 times, never with pair trawlers; and NL 58 with only 1 of 12 sightings associated with pair trawlers). Yet other dolphins were associated with pair trawlers in all or nearly all sightings (e.g., NL11 with 16 of 21

sightings with pair trawlers; and NL28 with 6 of 7 sightings with trawlers). These latter dolphins were termed 'pair trawler junkies,' and they may use this as their primary feeding method. Although I think this general conclusion is valid, it should be mentioned that these data probably suffer from some bias related to the fact that dolphins are generally easier to find and photograph when they are following trawlers.

Interactions between cetaceans and trawling activities are not uncommon; at least 12 odontocete species have been documented to feed behind trawlers (Fertl and Leatherwood 1997). In reviewing the literature on cetacean/trawler interactions, Fertl and Leatherwood (1997) suggested that cetaceans are often attracted to trawling activities, because such behavior makes it easier to exploit a highly-concentrated food source. They also suggested that the offspring of individuals that commonly feed behind trawlers might learn this feeding technique at an early age and thus may be more inclined to use it themselves. One point that emerged from their review was that even though the dolphins may gain some short-term benefit from this readily-available source of food, the costs (e.g., increased risks of net entanglement and persecution by the fishermen, potential damage to the dolphins' ecosystem, and possible increased exposure to suspended sediments laden in toxic compounds) may outweigh the benefits. In the long term, the population may suffer as a result. Further study is thus needed to determine the exact nature and consequences of the interactions between dolphins and pair trawlers in Hong Kong waters.

Interactions between single trawlers (most often shrimp trawlers, but sometimes stern trawlers) are much less common than those with pair trawlers, and the group sizes involved are more similar to those of groups not associated with fishing vessels (Fig. 22). However, there appears to be some interannual variability. In autumn and winter 1996/1997, only 5 of 328 groups (1.5%) were associated with single trawlers. In 1997/1998, single trawler interactions were much more common, occurring in 25 of 355 groups (7.0%), which is highly significant ($X^2 = 81.1$, df = 1, p < 0.001). The reasons for this difference are not known, but are probably linked with yearly variations in environmental conditions, which would presumably affect distribution of both fishing effort and dolphin feeding opportunities.

Interactions with gillnetters were not commonly seen, and all observations of interactions with this type of fishing gear appeared to be opportunistic and short-term. However, an interesting interaction was observed between a gillnet boat and a group of dolphins just under the Tsing Ma Bridge on 2 January 1997 (Fig. 28). A group of eight dolphins was moving northwest through the Kap Shui Mun Channel, and two fishermen in a small skiff were pulling in a gillnet by hand just under the bridge. As the dolphins approached, they moved directly toward the boat, and several dolphins surfaced less than 1–2 m from the boat. Just after surfacing they created splashes and moved quickly away, as if startled or perhaps chasing something. About 20 seconds later the fishermen pulled up a section of gillnet with a large fish (about 1 m long). This is the largest fish that I have ever observed being caught in Hong Kong, and it seems unlikely that this was just a coincidence. The dolphins may have been using the net as a barrier to facilitate prey capture, and thus inadvertently scared the fish into the net.

Effects of Human Activities.—There are many human activities occurring in the dolphins' range, especially in North Lantau waters. Several major development projects, in particular the construction of Hong Kong's new international airport at Chek Lap Kok, were taking place during the study (see Leatherwood and Jefferson 1997). Vessel traffic is heavy, and there is a major shipping channel (the Urmston Road) that runs through prime dolphin habitat in North Lantau waters. High-speed hovercraft, turbocat, and hydrofoil ferries to Macau and various cities in mainland China use the area frequently.

Fig. 28. A group of dolphins approaching a gillnet vessel during net haul operations (see text for description).

There are a number of sewage outfalls that empty into the waters of North Lantau, most discharging sewage with only minimal treatment. The area southeast of the island of Sha Chau is a dumping site for mud that is contaminated with heavy metals. Other forms of pollution (including heavy metals and organochlorines) abound in the area (Morton 1989), and there are several floating dry docks, which represent a potential source of organotins used in anti-fouling paints. Besides these potential threats originating in Hong Kong, the Pearl River drains a vast area with a large human population and productive agricultural lands; these facts suggest that pollution from outside of Hong Kong could contribute greatly to the potential for ecotoxicology problems for the dolphins.

One development of particular concern occurred during the course of the study. As part of the airport construction project, an Aviation Fuel Receiving Facility (AFRF) was built adjacent to the northern island of Sha Chau. Construction took place from February 1996 to early 1998. Because this project was taking place in an area that had previously been identified as a "hot spot" for dolphins, special attention was paid to the potential effects of construction of the AFRF on the dolphins (see Leatherwood and Jefferson 1997). Percussive pile-driving was used in the early stages of jetty construction, and a "bubble curtain" was designed and implemented as a mitigation measure to reduce the potential for noise damage and disturbance to the dolphins (see Würsig et al. 2000). The bubble curtain was shown to be effective in reducing the noise levels in the water surrounding the piling operation (Würsig et al. 2000).

In addition to the use of the bubble curtain, three other mitigation measures were implemented during AFRF construction (based largely on recommendations in Richardson et al. 1995):

(1) *Exclusion Area*—the area within a radius of 250 m around the piling barge was to be thoroughly checked for dolphins previous to the initiation of each piling episode, and piling delayed until any dolphins that were spotted left the area.

(2) *Warning Sounds*—If dolphins were seen in the general vicinity of the piling operation when piling was to begin, loud (but non-hazardous) sounds were to be used to provide a warning that the piling hammer was about to begin operation.

(3) *Acoustic Decoupling*—Air compressors used during the operation were separated from the steel decks of the barges by air-inflated rubber tires, thereby reducing the amount of noise transmitted through the barge hull into the water.

Due to a lack of adequate personnel, there were not frequent checks to see that these measures were actually implemented, and the contractor was largely trusted to carry them out. However, some spot checks and occasional land-based observers were able to confirm that the bubble curtain was used consistently during periods of active piling.

Despite the use of the bubble curtain and other mitigation measures, there may have been some temporary abandonment of the area by dolphins after the period of piling for the AFRF (see above under Abundance and Population Trends, Würsig et al. 2000). In order to determine whether there was any behavioral disturbance or harassment caused by the noisy piling activity, theodolite tracking data were examined. It has been found that killer whales and bowhead whales (*Balaena mysticetus*) increase their swimming speeds when faced with sources of acoustic disturbance, and it was hypothesized that hump-backed dolphins may do the same (see Richardson et al. 1985, Kruse 1991).

There was no significant difference in the average amount of direction change for dolphins theodolite-tracked during piling operations (92.4 ± s.d. 63.21°) vs. those tracked at times when piling was not occurring (93.0 ± s.d. 62.12°) (t-test, p > 0.05). However, the average speed of dolphin groups tracked by theodolite during the period of active piling for the AFRF (2.3 ± s.d. 1.78 m/sec) was over twice as fast as for other periods (1.1 ± s.d 0.67 m/sec) (t-test, p < 0.001). This suggests that, despite the use of the bubble curtain, dolphins may still have experienced some level of disturbance and stress during piling activity.

LIFE HISTORY

Detailed studies of the life history of *Sousa chinensis* using large samples of fresh specimens have yet to be published. The most detailed study so far was that done by Cockcroft (1989), using samples collected from hump-backed dolphins caught in anti-shark nets in South Africa. However, it should be noted that the populations of this species in southern China appear to differ greatly, both morphologically and ecologically, from those studied in South Africa (Ross et al. 1994). The possibility of subspecific differences between these geographic forms has been recognized (Cockcroft et al. 1997). Perrin and Reilly (1984) pointed out that because of this type of extensive morphological variability one must be very careful in applying information obtained from one geographical form to another.

The primary source of material for the study of life history of hump-backed dolphins in Hong Kong was from stranded specimens. This is somewhat unfortunate, because strandings are relatively uncommon events, carcasses are often badly decomposed when examined, and the age/sex composition of a stranding sample may be biased. As a result, the sample of usable material was small, and therefore conclusions drawn from this study should be considered tentative.

Age and Growth

Color Pattern Development.—There is a great deal of developmental variation in the color pattern of hump-backed dolphins from southern China (see Jefferson and Leatherwood 1997). However, the exact sequence of this development still remains to be worked out by study of large samples

of fresh specimens of known age and length.

To conduct a preliminary evaluation of color-pattern variation, data from strandings in Hong Kong and Xiamen, as well as literature records (Zhou et al. 1980, Wang and Sun 1982, Zhou 1991, Parsons et al. 1995, Huang et al. 1997) were examined. Fresh carcasses of known length (and in some cases known age) were classified into one of the six age classes proposed by Jefferson and Leatherwood (1997). It should be noted that the Spotted Juvenile phase of Jefferson and Leatherwood (1997) has been renamed Mottled, and the Spotted Subadult phase has been renamed Speckled, due to indications that these phases may not be reliably correlated with the juvenile and subadult age classes, respectively.

The 9 Unspotted Calves ranged from 102 to 130 cm and included both males and females. The two that were aged from teeth were both estimated to be not more than 1 month old; all were clearly young of the year. Only 2 Unspotted Juveniles were identified, a 180-cm male and a 142-cm female. Three Mottled animals ranged from 204 to 234 cm in length and from 8.5 to 9 years in age. Two were males and the third was of unknown sex. There were 7 Speckled-stage animals ranging from 207 to 265 cm and from 4 to 32.5 years in age. All six of known sex were males. Finally, there were 3 specimens in the Spotted Adult and 3 in the Unspotted Adult stages; all were females ranging from 235 to 254 cm. The three that were aged were 9.5, 23, and 31 years old (all adults), and two others were known to be sexually mature as well.

A tentative scenario of color pattern development can be inferred from the above information. Newborn hump-backed dolphins of both sexes in southern China are generally dark gray, almost black, and begin to lighten within a few months following birth. They probably go from the Unspotted Calf to the Unspotted Juvenile stage late in their first year and are presumably several years old before they lose

their gray background color and attain the white ground color of adults.

The question of whether or not there is sexual dimorphism in the color pattern of subadult and adult hump-backed dolphins remains open. However, from the above analysis it appears that large males may retain moderately heavy spotting, and many adult males appear to be in the Mottled age class. Adult females, on the other hand, appear to lose most or all of their spotting, thereby reaching the Spotted Adult and Unspotted Adult age classes. It is unclear if females go through the Speckled age class, or if all of these animals are all young males.

The lightly-colored areas on the bodies of animals often appear pink; however, this is not thought to be related to red pigments in the skin. Instead, it appears that the pink color results from flushing of blood to the body surface. This phenomenon is related to thermoregulation and is well-known in other dolphin species. In particular, the boto or Amazon River dolphin (*Inia geoffrensis*), shows a similar pinkish hue caused by circulation just under the skin (Layne 1958). This was particularly clear during the necropsy of one fresh adult specimen, in which the skin areas that were diffused with blood appeared pink and the areas lacking diffusion were closer to white in color. Examination of identification photos of individual dolphins taken on different occasions showed that the amount of pinkish coloration varied greatly from sighting to sighting. It appeared that animals engaged in vigorous activity, such as fast swimming or repeated leaping, showed the greatest amount of pink flushing.

Length at Birth, Gestation Period, and Fetal Growth.—Length at birth is most reliably estimated by the quantitative method termed "50% interpolation" by Perrin and Reilly (1984). However, this method requires a moderately large sample of fetuses and neonates in overlapping length categories. Unfortunately, data of this sort were not available for Chinese hump-backed dolphins. Thus, a qualitative estimate was made. The largest hump-backed
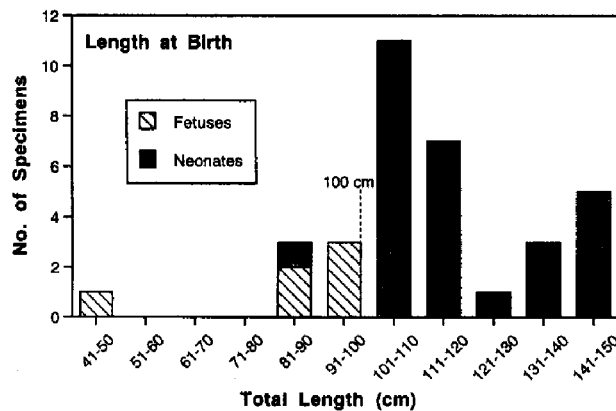
Fig. 29. Distribution of lengths of fetuses and neonates, showing derivation of the estimate of length at birth.

Fig. 30. Age vs. length graph for hump-backed dolphins from southern China. The fitted line uses a Gompertz model.

dolphin fetus from Chinese waters was 100 cm in length, and the smallest neonate was 90 cm (Fig. 29). However, the latter specimen may have been incorrectly measured, as it was examined by inexperienced observers prior to this study. The next smallest neonate was 101 cm long. Thus, the length at birth is assumed to be about 100 cm.

Hugget and Widdas (1951) and Laws (1959) found that during gestation fetal growth of cetaceans is characterized by two phases: a short curvilinear phase, t_0 (generally lasting 7–15% of the total gestation period, t_g), followed by an extended linear phase. There were insufficient data to reliably estimate the gestation period or fetal growth rate for *Sousa chinensis*; however, values were assumed by analogy with the striped dolphin *Stenella coeruleoalba* from Japan, which also has a length at birth of 100 cm. In this population, the gestation period has been estimated to be 12 months (Kasuya 1972) and the fetal growth rate 0.29 cm/day (= 8.82 cm/mo.) (Miyazaki 1984). However, most small delphinids have gestation periods of slightly less than 12 months (see Perrin and Reilly 1984). Based on gestation periods that have been determined for most other species, I presume that a gestation period of 11 months is a better estimate for *Sousa chinensis*. I recommend that the above values be used as default values until more data are available to estimate these parameters empirically. Cockcroft (1989) derived similar estimates of length at birth and

gestation period for South African hump-backed dolphins.

Postnatal Growth.—A preliminary growth curve was constructed based on ages determined from 34 stranded hump-backed dolphins from Hong Kong and Xiamen (see Liu et al. 1999b) (Fig. 30). The assumption was made that 1 GLG is equivalent to 1 year. The oldest dolphin in the present sample was aged at 33 GLGs. Cockcroft (1989) found evidence that longevity for South African *Sousa* can be over 40 years.

A Gompertz model was used to fit a growth curve to the data (Fitzhugh 1975). This model is widely used in studies of odontocete growth (see Read et al. 1993), and it appeared to provide a good fit to the data. As is generally true for all delphinids, growth in the first year is rapid, and thereafter begins to level off. Asymptotic length appears to be reached at about 243 cm, at an age of about 16 years. Unlike in South African *Sousa* (see Cockcroft 1989), there is little evidence of sexual dimorphism (although the sample size is still small).

Length/Weight Relationships.—The relationship between length and weight for 38 post-natal hump-backed dolphins and 5 fetuses from southern China was examined using data from specimens stranded in Hong Kong and data from the literature (the latter primarily from Xiamen specimens published in Wang 1965, 1995). Weight increased exponentially to a maximum of just under 250 kg for the largest specimens of about 260 cm total length (Fig. 31). No evidence of significant sexual
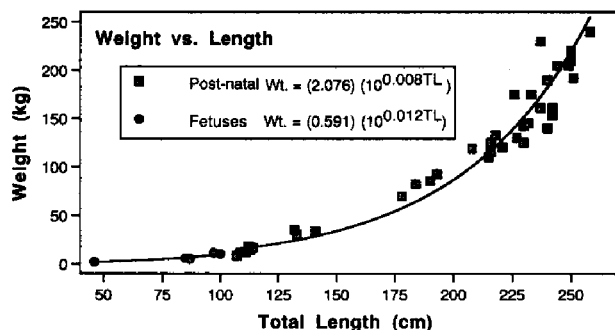
Fig. 31. Relationship between length and body weight for hump-backed dolphins from southern China. The fitted lines use an exponential model. Separate lines are shown for fetuses and post-natal specimens.

Fig. 32. Distribution of estimated months of birth for neonates and fetuses, showing seasonality in calving.

dimorphism was observed, but it should be pointed out that the sample size is quite small. If it turns out to be true that there is little or no dimorphism, then it is in contrast to hump-backed dolphins in South Africa, in which males are significantly longer and heavier than females (Cockcroft 1989).

Reproduction

Calving Seasonality.—Seasonality of calving was examined by calculating dates of birth for fetuses and calves based on the presumed fetal growth rate and first year postnatal growth rate. Again, because of a lack of data for *Sousa*, analogous values obtained from studies of reproduction in *Stenella coeruleoalba* from Japanese waters were used: fetal growth = 8.82 cm/mo. and postnatal growth = 5.5 cm/mo. (Miyazaki 1984).

Using these values, projected dates of birth were calculated (Fig. 32). The results indicated that some births occurred throughout the year. Within this protracted period, most births occurred in the early part of the year, with 92% occurring in the first two-thirds of the year (January through August). This is significantly more than would be expected (X^2 = 29.45, df = 1, p < 0.001). There appeared to be a slight overall peak from late spring through summer, or perhaps two peaks, one in April/May and one in August.

Although there is evidence of seasonality, some births were presumed to occur

in every month of the year. The seasonality of sightings of newborn calves also agrees quite well with the above results. Young calves were rarely seen in winter months (see Fig. 26). This pattern is broadly similar to patterns in calving of hump-backed dolphins in South Africa (Cockcroft 1989, Karczmarski 1996).

Attainment of Sexual Maturity.—Because of the advanced level of decomposition of most stranded specimens, very little data were available on attainment of sexual maturity for hump-backed dolphins from southern China. However, a 254-cm female (SC98-03/06) was recovered in a fresh state west of Lantau Island. A necropsy showed that the specimen was pregnant with a near-term fetus (98 cm female), and the mother was aged at 23 GLGs. Unfortunately, the ovaries were not collected. A second large female specimen (SC97-31/5-B) also was obtained in a very fresh state. This animal was 235 cm in length and had 9.5 GLGs in its teeth. Examination of the ovaries showed one *corpus luteum*, measuring 14 × 22 mm at its largest diameter. This apparently represented the first ovulation and pregnancy for this individual, and is suggestive that females reach sexual maturity at 9–10 years of age. This is similar to hump-backed dolphins from southern Africa, which mature at 10–11 years (Cockcroft 1989).

Two large, fresh male hump-backed dolphins were examined. The first (SC96-31/05) was 207 cm long and was aged at 5 GLGs. This animal had testes (without epididymes) weighing 19.8 and 22.4 g. The

second specimen (SC97-10/02) was also 207 cm long with an age of 8.5 GLGs. Only one testis was collected and it weighed 23.2 g. With testes weighing much less than 50 g, both of these specimens appear to have been immature. This conclusion is based on information from striped and *aduncus*-type bottlenose dolphins with similar growth and reproductive characteristics (see Miyazaki 1984, Cockcroft and Ross 1990). Male humpbacked dolphins from southern Africa mature 2–3 years later than females, at approximately 12–14 years of age (Cockcroft 1989).

Feeding Habits

Stomachs of 12 dolphins were examined for food remains. Four were empty; however, 3 of these were from neonates ranging in size from 102–107 cm. Stomachs of the remaining 8 animals (ranging in size from 144–247 cm) contained food remains. The wet weight of stomach contents ranged from <10 to 764 g. Most of these specimens (7 of 8) had only fish remains in the stomach; one dolphin also had squid remains. Most specimens had multiple prey taxa in the stomach (mean = 6.3 ± s.d. 3.28, range = 1–10), possibly indicating opportunistic feeding, or at least the selection of a wide range of prey. The number of individual prey items per stomach ranged from 1–261 (mean = 104.9 ± s.d. 86.20).

A minimum of 20 fish species in 13 families were identified as prey (Fig. 33). The most important families in numerical terms were Engraulidae, Sciaenidae, and Clupeidae, which together accounted for over 81% of all fish taken. The most commonly taken, and numerically important, prey species was the lionhead (*Collichthys lucida*), followed by various croakers (*Johnius* spp.), and anchovies (*Thryssa* spp.). Most of the undigested fish (*Trichiurus* sp., *Thryssa* sp., and *Collichthys lucida*) were retrieved from a single stomach (SC96-31/05), and ranged from 9–31 cm in length.

The three most important families of
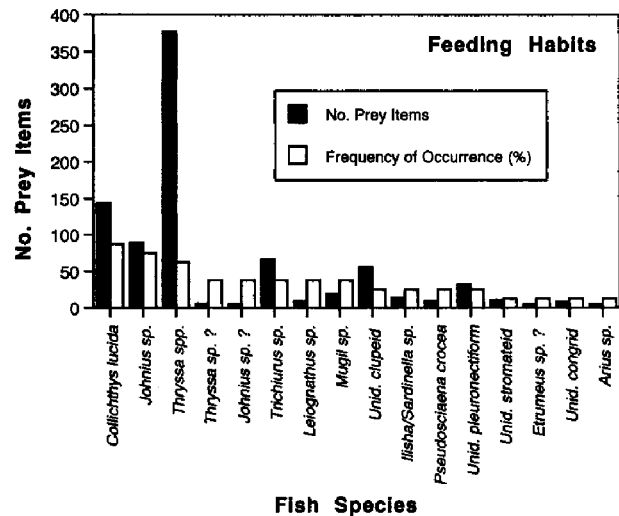
Fig. 33. Most common fish prey items from Hong Kong hump-backed dolphins. Only prey species represented by at least 5 individuals are presented.

fish preyed on by the dolphins were also among the most important families of fish caught by pair trawlers in Hong Kong, as indicated both by interview surveys and onboard observation of catches (ERM-Hong Kong 1998). This is not surprising, considering the apparent importance of following behind pair trawlers as a feeding technique for these dolphins (see under Social Organization and Behavior above).

Based on the present study, humpbacked dolphins appear to rely almost solely on fish for food in Hong Kong waters. The most important prey species include demersal species (such as croakers, Sciaenidae), as well as several pelagic groups (engraulids, clupeids, and trichiurids). From the small sample available, cephalopods and crustaceans do not appear to be important prey items. Many of the fish prey items are typically associated with estuaries (e.g., mullets and most sciaenids). Anchovies (*Thryssa* spp.) are generally found in large schools in bays and estuaries (van der Elst 1981), and these animals were present in large numbers in 5 of the 8 stomachs with prey remains. This is not surprising, considering the apparent preference for freshwater-influenced waters demonstrated by humpbacked dolphins in Hong Kong and surrounding waters (see above).

The only other location in southeast

Asia for which we have dietary information for hump-backed dolphins is Xiamen, also in southern China (Wang 1965, 1995). Although many of the individual prey species were different, Wang found a broadly similar pattern to that seen here. Estuarine fish also predominated in Xiamen, and there were some genera in common between the Hong Kong and Xiamen studies (e.g., *Mugil*, *Ilisha*, and *Johnius*). Hump-backed dolphins in South African waters also showed similar results, preying primarily upon estuarine-associated fish species (Barros and Cockcroft 1991). However, preliminary results suggest that squid and octopus may be more important for South African dolphins than they are for Chinese *Sousa chinensis*. This possibility will be examined further when more detailed analyses based on larger sample sizes are possible for both areas.

POPULATION/STOCK STRUCTURE

Long Distance Movements

Movements of individual dolphins can tell us something about the population discreteness of dolphins from different areas. Photo-identification of individuals provides a good way of getting this kind of information without the risk of injury to the animals being studied.

In Hong Kong and Lingding Bay, 213 individual dolphins were identified by natural and acquired scars and markings on the body (see above). Preliminary dolphin surveys in Xiamen, about 500 km northeast of Hong Kong, have resulted in the identification of 11 individuals there, and several of these animals were resighted as many as 5 times in Xiamen (Jefferson and Huang Zongguo, unpublished data). Comparisons were made between individuals from the Hong Kong/Pearl River and Xiamen catalogs, and no matches were found between them. Although not conclusive, this is consistent with the idea that dolphins in the Pearl River area and the Xiamen area form two separate populations with no mixing. Further examination of
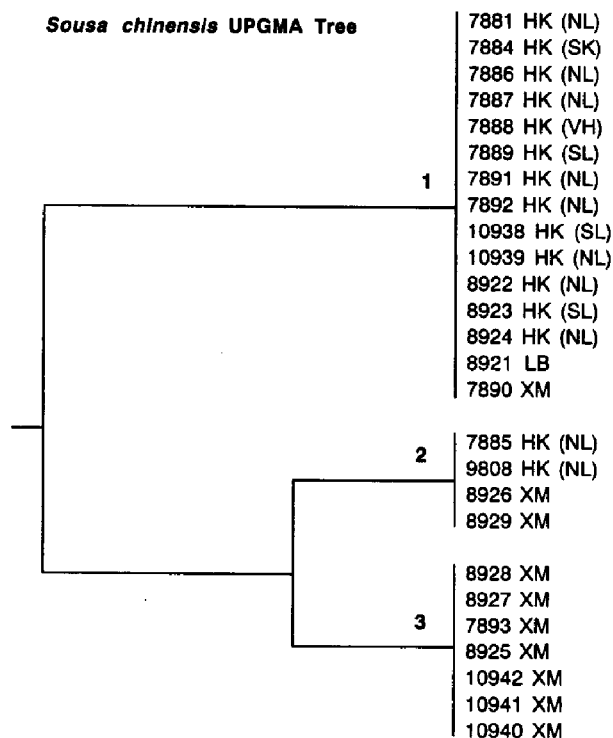
Fig. 34. UPGMA tree for 26 *Sousa chinensis* specimens from Hong Kong (HK), Lingding Bay (LB), and Xiamen (XM), based on 500 bootstrap replicates using standard error confidence probabilities. The stranding localities of Hong Kong samples are indicated: NL, North Lantau; SL, South Lantau; VH, Victoria Harbor; and SK, Sai Kung.

this hypothesis using molecular genetic techniques is described below.

Molecular Genetics

All 26 Indo-Pacific hump-backed dolphin tissue samples currently available for genetic analysis were successfully sequenced and analyzed using UPGMA and Neighbor-Joining methods. A total of 446 base pairs were sequenced for all samples. There were 3 distinct genetic haplotypes among the 26 individuals sampled. There were 6 variable sites, all of which were phylogenetically informative. Informative sites differed by 5 transitions and one insertion/deletion event. Of the 5 transitions, 3 were G/A and 2 were C/T substitutions.

Distance-based UPGMA and Neighbor-Joining analyses produced similar results (Fig. 34). A genetic distance of 1.14% separated samples in group 1 from those in group 2, and samples in group 2 were separated from those in group 3 by a genetic

distance of 0.5%. In this analysis, nucleotide diversity of Indo-Pacific hump-backed dolphin sequences ranged from 0 to 1.1%. Cockcroft et al. (1997) reported an average distance of 7% among hump-backed dolphins from a much larger area throughout the species' range, including Hong Kong, South Africa, and Australia.

These results provide some indication of population subdivision between the animals sampled from Hong Kong and those from Xiamen. However, this must be examined further, as there is not complete geographic concordance among samples from the two main geographic regions sampled.

Porter (1998) suggested that there is population subdivision within Hong Kong, with no genetic mixing between animals south and north of Lantau Island, but I found no evidence for this hypothesis. The 3 samples from South Lantau in my analysis clustered with many others from North Lantau in group 1 (Fig. 34). Only 11 samples were available to Porter (1998); thus it is difficult to make any conclusions based on such a small sample. As noted from photo-identification data (see Individual Movements and Home Ranges), although most South Lantau individuals were not observed in North Lantau, there is still overlap in distribution between South and North Lantau animals. Thus, the preliminary genetic evidence of the present study, the close physical proximity (5–10 km), and photo-identification matches between animals from North and South Lantau all strongly suggest that they are from the same population.

Additional genetic analyses of mtDNA data will be possible as increased sample sizes become available, and analyses of nuclear markers should provide further information on population structure of Indo-Pacific hump-backed dolphins in Chinese waters.

Discussion

When larger sample sizes of skull morphometric data become available (currently, morphometric data are available from only 8 skulls from Hong Kong and 5 from Xiamen), it may be possible to use this technique to assist in definition of stocks. However, currently only molecular genetic studies and information from photo-identification are available to shed light on stock structure. Both datasets have been examined to ascertain whether dolphins from the Pearl River Estuary and from Xiamen form separate populations. Both are inconclusive at the present time but are consistent with the hypothesis of population-level differences between the areas.

Photo-identification work in Hong Kong and Xiamen suggests that most hump-backed dolphins in China are resident in areas around large river mouths, and that movements of tens of kilometers linear distance are common. Movements on the order of hundreds of kilometers have not yet been documented and, based on residency patterns of known individuals, it appears unlikely that such movements are anything more than rare occurrences. From these points, along with information on the distribution of reliable records of hump-backed dolphins in China (Fig. 2), I hypothesize that there are about 8 populations of this species in Chinese waters localized around the mouths of at least the Chiangjiang (Yangtze River), Oujiang (Ou River), Minjiang (Min River), Jiulongjiang (Jiulong River), Hanjiang (Han River), Zhujiang (Pearl River), Jianjiang (Jian River), and Nanliujiang (Nanliu River). These represent 8 of the 12 largest rivers in southern China, based on discharge volume (Xiong et al. 1989). If this hypothesis is eventually found to be true, it has important implications for conservation and management, as it means that the possibility of depleting these small, localized populations is much greater than for a larger, more far-ranging stock. Further work to test this hypothesis should be considered a matter of high priority for future conservation efforts on hump-backed dolphins in Chinese waters.

MORTALITY RATES AND CAUSES

Almost all information on mortality of dolphins in Hong Kong comes from a
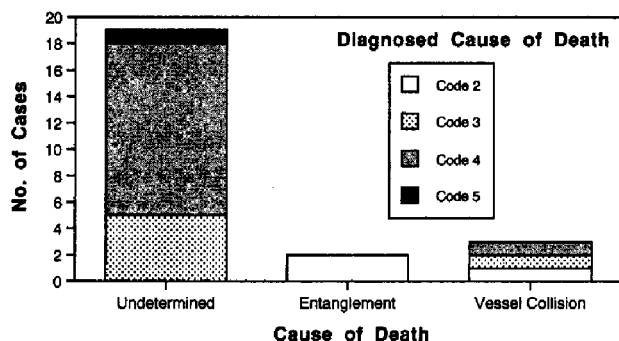
Fig. 35.   Bar graph showing causes of death for hump-backed dolphins stranded in Hong Kong waters. In addition to the specimens indicated here, there were several others in which the carcass was not recovered, and therefore no cause of death could be determined. See text for explanation of decompostion codes.

stranding recovery program. Hump-backed dolphin stranding events in Hong Kong peak in the summer months (Parsons 1998b). Although the reason for this is not known, it is probably at least partially related to the fact that there is more human activity along the beaches of Hong Kong in summer, and therefore more reports of strandings. The use of stranding data, which is generally reliant on reports of stranding events from the public and government officials, has a number of such associated biases. These should be kept in mind when interpreting the data presented below.

Causes of Mortality and Morbidity

During necropsy of stranded specimens, attempts were made to determine the cause of death. However, for most strandings (n = 19) this was not possible, due to the advanced level of decomposition displayed by the specimens (Fig. 35). Two code 2 specimens showed strong evidence of incidental capture in fishing nets (they were otherwise healthy, had obvious net cuts on the head and appendages, and frothy fluid in the lungs; see Kuiken 1996). One of these specimens (SC96-31/05) had abundant undigested fish remains in the stomach, indicating it had fed not long before death. Also, it had healed rope scars around the bases of the flippers, suggestive of a past non-fatal encounter with a net made of heavy line. The other animal

(SC97-31/05-B) was photo-identified several times before being found floating dead in an area of frequent pair trawling, and in 5 of the 8 sightings it was associated with pair trawlers. Based on this circumstantial evidence, it appears probable that both animals were caught in pair trawl nets.

Three other specimens (decompostion codes 2, 3, and 4) showed evidence of death from vessel collision, although the possibility that the animals died from some other cause and were struck by boats while floating after death can not be totally discounted for two of them. All of the other specimens were classified as cause of death unknown.

Evidence of non-fatal encounters with fishing nets and vessels can be seen in many live animals in the photo-identification catalog. Of the total of 213 animals currently in the catalog, at least 5 (2.3%) show what appear to be net scars and a further 6 (2.8%) show unmistakable evidence of propeller cuts on the body, apparently resulting from previous vessel collisions. Several others clearly had injuries from one or the other of these causes, suggesting that at least 8.9% of Pearl River Estuary dolphins have survived injurious encounters with human activities.

During necropsies of fresh specimens, evidence of parasitic infestation appeared to be much less prevalent than in the other local species of small cetacean studied, the finless porpoise (see Jefferson and Braulik 1999). This may be an indication that hump-backed dolphins are less susceptible to parasites than are porpoises, and this will be investigated further. Similarly, no evidence was found to indicate that predation was a factor in the deaths of Hong Kong hump-backed dolphins. However, for the finless porpoise, at least one stranding appeared to have been caused by shark attack (Jefferson and Braulik 1999). At first, the lack of evidence for shark predation on hump-backed dolphins may seem a bit surprising when one considers the fact that sharks represent a significant threat to animals of the same species in South Africa (Cockcroft 1991). Although

bull sharks (*Carcharhinus leucas*) can inhabit brackish waters and have been found near Tuen Mun in the North Lantau area (see Parsons 1998a), Hong Kong hump-backed dolphins spend nearly all of their time in the relatively turbid, estuarine waters of the Pearl River Estuary, and this is an area in which one would not expect to find many large sharks.

There are certainly other causes of death than those mentioned above. For instance, the introduction of pathogenic bacteria from the release of large amounts of sewage into Hong Kong's coastal waters is an issue of great concern in relation to the dolphin population (see Montgomery Watson 1998, Parsons 1997). Although potentially harmful bacteria have been found in areas inhabited by Hong Kong dolphins, there is very little information available on the effects of sewage outfalls on wild dolphin populations (Montgomery Watson 1998, Parsons 1997). This is an issue that must be studied further.

Based on the results of this study, incidental catch and vessel collision appear to be two of the most significant human-related mortality factors. Another factor is probably poisoning and immunosuppression caused by accumulation of environmental contaminants, such as heavy metals and organic compounds. However, the health implications of this latter factor are much more difficult to demonstrate (but see below).

Toxicology

Heavy Metals.—Levels of 22 different trace elements and heavy metals (Al, Ti, V, Cr, Mn, Co, Cu, Zn, Ga, Se, Sr, Zr, Mo, Ag, Cd, Cs, Ba, W, Hg, Tl, Pb, and Bi) were analyzed based on samples from 13 specimens of *Sousa chinensis* stranded in Hong Kong. Concentrations of some toxic compounds were high in relation to those found in other species of marine mammals from different geographic areas. Mean concentrations of mercury (Hg) and cadmium (Cd) in liver tissue were 92.8 ± s.d. 183.55 (range = <0.01–630) and 0.52 ± s.d. 0.789 (range = <0.001–2.8), respec-

tively. Both of these compounds showed evidence of increasing levels in larger, older individuals.

The only previous information on heavy metal levels in hump-backed dolphins from Hong Kong came from the study of Parsons (1998c), who analyzed trace metal levels in 11 stranded hump-backed dolphins (including some of the same specimens as in this study). He found that levels of most compounds were similar to those reported from marine mammals in other industrialized areas of the world, and his results were similar to those of the present study. However, mercury levels were very high in some older individuals. Parsons (1998c) also estimated daily intake values for different trace metals and compared concentrations in prey with those found in dolphin tissues. He found that while some compounds existed in lower concentrations in the dolphin tissues, others (such as mercury and zinc) showed evidence of biomagnification through the food web.

Concentrations of mercury and cadmium from the present study were somewhat lower than those found by Parsons (1998c) for the same population, but the levels of mercury were still high enough to warrant concern, considering the known damaging effects that this heavy metal can exhibit in dolphins (see Rawson et al. 1993). In view of this information, levels of mercury, cadmium, and some other toxic heavy metals may be high enough to combine with other factors to compromise the health of dolphins in Hong Kong. Further work correlating metal levels with pathological conditions is now needed to determine if this is indeed the case.

Organochlorines.—Organochlorine levels in the blubber were analyzed for 11 hump-backed dolphin specimens (for more details, see Minh et al. 1999). Mean concentrations (ΣHCHs, ΣDDTs, and ΣPCBs) were 2.1 ± s.d. 2.24 (range = 0.0086–4.9), 101.6 ± s.d. 74.00 (range = 9.4–200), and 55.4 ± s.d. 42.63 (range = 6–160) μg/g lipid weight, respectively. Similar to the results of a previous study by Parsons and Chan (1998), the levels of many organochlorines were overall very
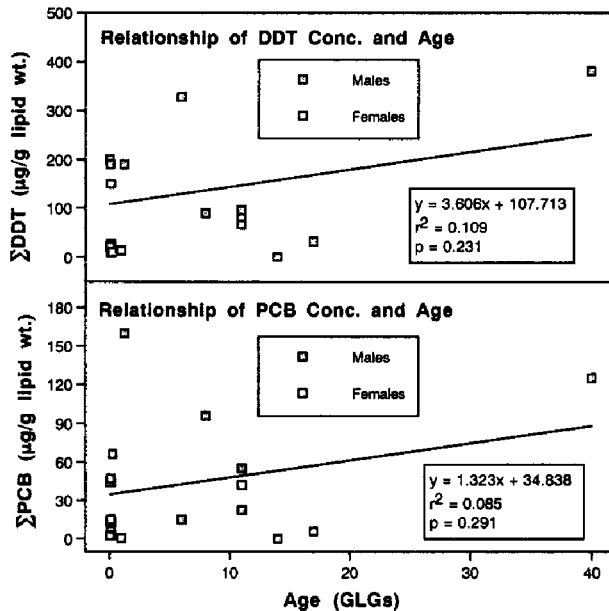
Fig. 36. Relationship of organochlorine concentrations and dolphin age.

high, even in many newborn animals. The high levels of DDT, PCBs, and HCHs in nursing calves that have not yet taken solid food indicate that organochlorines are being transferred tranplacentally to the calf during gestation and during lactation through the mother's milk (see Tanabe et al. 1982, Cockcroft et al. 1989). Transfer during lactation is also supported by the finding of high concentrations (similar to those in the animal's blubber) of PCBs in milk from the stomach of a young calf (Parsons and Chan 1998). Concentrations of both DDT and PCBs appear to increase somewhat with age, at least in male dolphins, although some neonates appear to have very high organochlorine levels even at an early age (Fig. 36).

Organochlorines are well known for their persistency in the marine environment,. Marine mammals appear to be especially vulnerable to their toxic effects, partly due to a low capacity to metabolize these compounds (see Tanabe and Tatsukawa 1991, Tanabe et al. 1994b). The damaging effects that these compounds can have on marine mammal populations in highly-contaminated areas is well illustrated by the St. Lawrence population of beluga whales (*Delphinapterus leucas*). This population remains at a low level and

has not recovered from heavy hunting in the early part of this century. Stranded individuals show a very high incidence of pathological conditions, with the highest rates of cancerous tumors known among any marine mammal population (Beland et al. 1993, Martineau et al. 1994, De Guise et al. 1995). All of these conditions have been linked to the immunosuppressive qualities of very high levels of some organochlorines, especially PCBs, in the tissues of the animals.

Hong Kong hump-backed dolphins would appear to be highly vulnerable to a similar situation. The apparent residency of the population in the Pearl River Estuary means that the animals are not likely to move out of the area to a less polluted one. Although a direct link has not yet been established, a causal relationship between the high organochlorine levels and the high incidence of neonate hump-backed dolphin strandings in Hong Kong (see below) appears likely (see also Parsons and Chan 1998). Further, the ratio of DDE/DDT indicates that the source of the DDT has been relatively recent, and thus it seems likely that this pesticide may still be used in some parts of the Pearl River Estuary (Parsons and Chan 1998). Although it is very difficult to prove conclusively, it appears likely that dolphins in Hong Kong are suffering negative effects from organochlorines, and investigating this should be a high priority for future research on the population status of these animals.

It should be mentioned that the suitability of using samples from stranded dolphins to examine levels of organochlorines in animals in the population has been questioned in a number of cases. Aguilar and Borrell (1994) outlined the reasons why such samples may be problematic:

(1) Because there are often strong sex and age biases in stranded specimens, the samples may not be representative of the population as a whole. This definitely appears to be the case in Hong Kong, where young of the year and

males appear to predominate among strandings (see below).

(2) Stranded dolphins are often suffering from disease that may impair their ability to metabolize and excrete organochlorines, thereby biasing information on pollutant levels upwards. It is currently unknown if this is an issue in Hong Kong.

(3) Decomposition of tissues may result in altered concentrations of organochlorine residues, and this does not always occur in a predictable manner. Most strandings in Hong Kong are very badly decayed when examined, and therefore this is likely to be a significant issue.

Based on the above considerations, Aguilar and Borrell (1994) recommended the use of biopsy samples from live animals, consisting of a small plug of skin and blubber, for obtaining reliable, representative data on organochlorine levels in populations of wild cetaceans. A biopsy collection program can be easily tailored to eliminate any of the above issues affecting the quality of the data obtained, and the technology and expertise now exist to obtain biopsy samples relatively safely, without needing to capture the animals.

Organotins.—Organotin (butyltin) levels have only recently been examined in cetaceans. These highly toxic compounds are used in antifouling paints for vessel hulls and other marine uses. Butyltin levels (ΣBT) have been determined for only 3 neonate hump-backed dolphins so far; levels ranged from 170–650 ng/g wet weight. These are lower than levels from finless porpoises in Japan and bottlenose dolphins in the United States (Iwata et al. 1997), but it should be remembered that the sample size is still small and biased toward young animals. Since organotins are bioaccumulated (Iwata et al. 1997), older individuals would presumably have much higher levels than calves. Further analysis of organotin levels, based on an additional 8 specimens, is currently in progress. The same limitations listed above for organochlorine analysis based on stranded speci-

mens apply to organotin analysis, favoring the use of biopsy sample collection for obtaining high-quality data (Aguilar and Borrell 1994).

Levels of Mortality

Adequate data to examine mortality rates in relation to population size do not currently exist for this population. Instead, we can only make inferences from stranding and photo-identification records. Both sources of data have shortcomings, and there are many uncertainties involved in their use. Thus, the assessments below should be considered highly tentative.

A high proportion of all the hump-backed dolphin strandings in Hong Kong have been of young-of-the-year. Of the total of 26 hump-backed dolphins stranded in Hong Kong between January 1996 and November 1998, 54% (14) have been newborns less than 150 cm in length. This appears high, but it is unknown if this is the result of a naturally-high neonatal mortality rate or human-related factors.

To get a better idea of neonatal mortality, photo-identification records of known individuals with calves were examined. Of 11 calves born to known mothers, at least 7 appeared to have survived to 6 months, and at least 6 to the age of 12 months. The status of the remaining individuals could not be determined, generally because the mothers were not seen again. Calves that are born and die before they are first photo-identified with their mothers are not included, so the above analysis probably overestimates survival.

Using the method of Wells and Scott (1990), recruitment to the age of one year was estimated to be 0.047. However, it should be noted that this number includes several uncertainties that could easily cause either underestimation or overestimation of the true value, and is therefore tentative. Despite this, the value falls within the range of yearly values calculated for an apparently stable population of bottlenose dolphins in Sarasota Bay, Florida (Wells and Scott 1990), and is very close to the value estimated for South African

hump-backed dolphins in an area of relatively light exploitation (Karczmarski 1996). This analysis indicates that, despite the high incidence of newborn strandings, some calves are still surviving at least until the age of one year. It is generally impossible to track their status after they no longer associate closely with the mother (probably before around 1.5 years of age), because most have not yet developed unique markings of their own. This makes calculation of recruitment to older age classes even more difficult.

Attempts to determine mortality rates for this population of dolphin are fraught with difficulties. First, we do not have good data on actual mortality levels. The only data we have come from strandings, and because not all strandings are likely to be discovered, we can only obtain minimum mortality levels from this source. Second, the total population size is not yet known, although we have good seasonal estimates of abundance for much of the Pearl River Estuary (including Hong Kong and Lingding Bay).

If we assume that Hong Kong is a closed system (this is an unreasonable assumption, and I will make it here only for the sake of discussion), we can evaluate minimum mortality from strandings in relation to estimated abundance. The total number of confirmed hump-backed dolphins strandings in Hong Kong for 1996 was similar to that for 1997 (11 and 10 dolphins, respectively), but was lower in 1998 (6 dolphins). The total reported hump-backed dolphin strandings for the two previous years were similar (9 in 1994 and 10 in 1995; see Parsons 1998b). Thus, despite increased promotion of the stranding recovery program each year, the annual number of strandings appears to be somewhat constant. The annual average of 9.2 strandings represents 7.9% of the average seasonal estimate of the number of dolphins in Hong Kong but only 0.9% of the current best estimate of the total size of the Pearl River population. Based on the fact that all diagnosed causes of death so far have been human-related (Fig. 35), presumably most of the stranded dolphins

represent human-caused mortality. Maximum rates of increase for most dolphin populations are probably around 4–5%, and non-natural mortality levels higher than this might be unsustainable (see Reilly and Barlow 1986, Slooten and Lad 1991). So, depending on which estimate we use, the current level of mortality may or may not be high enough to cause a population decline.

However, we must remember that the actual situation is much more complicated than the simplified scenario described above. The total population size appears to be over 1,000 animals, and from this a mortality of 9 animals per year could be insignificant from a population perspective. It is also true that strandings that occur in mainland Chinese waters are not generally reported, so the mortality could be much higher than indicated. These are just some of the uncertainties involved in this type of analysis. Taking a conservative approach, there is some evidence to suggest that the current level of mortality that this population is experiencing may be unsustainable. Considering how difficult it is to demonstrate population trends and mortality rates, we should endeavor to better protect the animals' habitat, and not wait for incontrovertible evidence of unsustainable mortality or a population decline to take action (i.e., we should invoke the "Precautionary Principle").

RECOMMENDATIONS AND CONCLUSIONS

Summary of Findings

1) Indo-Pacific hump-backed dolphins are distributed widely in the eastern Pearl River Estuary, from the western waters of Hong Kong to at least the Zhuhai and Macau areas of Lingding Bay. There is much intermixing throughout this area, suggesting that a single population is involved.

2) In the large area of Lingding Bay, west of Hong Kong, dolphins appear to be more concentrated in the northern area around Neilingding Island in

winter and more offshore and further south in the estuary in summer.

3) Within the Hong Kong SAR, dolphins only occur regularly to the north and west of Lantau Island. However, the Deep Bay, East and South Lantau, and Lamma areas are used seasonally and to a lesser extent.

4) In winter and spring months, dolphins in Hong Kong use mostly waters of North Lantau. However, in summer and autumn when freshwater input increases, there is an influx of animals into other western waters of Hong Kong.

5) There are seasonal changes in the distribution patterns of dolphins in the North Lantau area. In winter and spring, dolphins are mostly seen west of the Brothers' Islands, but in summer and autumn they are more continuously distributed throughout the entire area.

6) Abundance of dolphins in Hong Kong (based on line transect analysis) ranges from a low of about 88 animals in spring to a high of about 145 dolphins in summer. There appear to be over 900 animals in the mainland Chinese waters of Lingding Bay in winter, and currently the best available estimate of the total Pearl River population size is 1,028 dolphins.

7) Analysis of trends in abundance showed some evidence of a declining trend in North Lantau. However, the trend is not statistically significant, and even if real, it is uncertain if it is the result of a decrease in total population size, movements of dolphins out of the main survey area of North Lantau, or both.

8) Potential biases in abundance estimates were evaluated by empirically examining the validity of theoretical line transect assumptions. Based on this, line transect estimates were considered to be reliable, but further work is needed to estimate an unbiased value for the detection function.

9) Most individual dolphins appear to have home ranges of about 30–400

km², which is much smaller than the population's overall range of at least 1,800 km². Many dolphins have been found to move between Hong Kong and Chinese waters to the west of the boundary with Guangdong Province.

10) Groups of up to 23 dolphins are seen in Hong Kong, with an overall average group size of 3.8 dolphins. Groups in Lingding Bay are significantly larger, ranging up to 44 animals. There appears to be no significant seasonal variation in average group size. Calves make up only a small proportion of groups observed in winter months.

11) Composition of groups is highly fluid, with groups often changing membership over periods of hours or even minutes. Association indices for most pairs of individuals were quite low, indicating that on average any two individuals spend less than 1% of their time together.

12) General behavior patterns are similar to those of other species of coastal dolphins, although wave riding behavior is uncommon.

13) Dolphins associate with a number of types of fishing vessels, although pair trawlers are by far the most common and important. Dolphins often gather in large groups behind active pair trawlers and feed on prey stirred up by the nets. Individual dolphins show different tendencies to feed behind pair trawlers.

14) There are many human development activities occurring in the area that may be having an effect on the dolphins' behavior. The construction of an Aviation Fuel Receiving Facility in the range of the dolphins around the island of Sha Chau appears to have caused some short-term disturbance and temporary movement out of the adjacent area.

15) There is a great deal of developmental variation in the color pattern. Newborns are dark gray, and they lighten in the juvenile stage. Young subadults continue to lighten and the dark color gives way to dark spots on a light

background. Adult females are pink-ish-white in color with few or no spots. There may be some sexual dimorphism, with males retaining more spotting in the adult stage.

16) Length at birth is estimated to be about 100 cm, and the fetal growth rate appears to be about 8.8 cm/month.

17) Post-natal growth is rapid during the first year and then begins to level off. Asymptotic length is reached at a length of about 243 cm and an age of about 16 GLGs.

18) The length/weight relationship shows an exponential pattern, reaching a maximum of about 250 kg for animals of 260 cm total length.

19) Although some young are clearly born throughout the year, most calving occurs in the early part of the year (January–August). Calving peaks from late spring through summer. Sexual maturity in females appears to occur at about 9–10 years of age.

20) Feeding appears to be mainly on several species of demersal and pelagic fish species, which are generally associated with estuaries. Neither cephalopods nor shrimps appear to be important prey items.

21) Preliminary mitochondrial DNA analysis between Hong Kong and Xiamen dolphins suggests that population-level differences may exist between the two areas. Also, there have been no photo-identification matches between Hong Kong and Xiamen dolphins, and this is consistent with the above.

22) Several causes of death were diagnosed for stranded dolphins, including incidental entanglement in fishing gear and vessel collisions. However, because of the advanced level of decomposition of most strandings, cause of death could not be determined for most animals.

23) Toxicological analysis shows that some dolphins have very high levels of environmental contaminants in their bodies (especially mercury and DDT). What effects these are having on the

animals' survival and reproduction are unknown, but a high incidence of neonate strandings may be related to organochlorine poisoning.

24) Levels of mortality in relation to population size cannot be accurately assessed at this time. Extirpation is not likely in the immediate future, and the population is still moderately large and appears to be viable. However, based on the many serious threats facing it, there appears to be cause for concern over the future status of the population.

Recommendations

General Management Recommendations.—General recommendations for management are based on the 7 principles for the conservation of wild living resources that resulted from a workshop organized by the U.S. Marine Mammal Commission in March 1994 (Mangel et al. 1996, Meffe et al. 1999):

(1) *Maintenance of a healthy wildlife population is inconsistent with unlimited growth of human population pressures.* The fact that human overpopulation is at the root of the problems facing the dolphin population must be recognized. An effective long-term program of human population stabilization and reduction is needed to alleviate the pressures facing this and other wildlife species.

(2) *The goal of conservation should be to maintain biological diversity at all levels.* An understanding of the genetic uniqueness of the population in Hong Kong waters is essential for proper conservation. Because the Pearl River Estuary and the Xiamen area each appear to contain a unique stock of dolphins, these animals should be fully protected and managed separately in each area.

(3) *Environmental assessment should precede use of/impacts on the resource.* Currently, in Hong Kong the Environmental Impact Assessment (EIA) pro-

cess is used to evaluate impacts of development projects on wildlife and to suggest mitigation measures after the fact. It should become something more, and it ideally should be used as a decision-making tool preceding development to determine whether or not a particular project should be allowed (see Liu and Hills 1997).

(4) *Regulation of the use of the resource must be based on understanding of the ecosystem and its various ecological and sociological influences.* Research on the Hong Kong environment has provided a good base of knowledge on various elements of the dolphins' ecosystem. More work is needed to fill knowledge gaps, and in particular, the relationship of dolphins and pair trawler fishermen should be studied in detail using both natural and social science techniques.

(5) *The full range of knowledge from the natural and social sciences must be brought to bear on the issue.* In addition to the expertise of natural scientists, input from relevant social scientists should be sought in the decision-making process. This could most easily be achieved by adding appropriate social scientists to the membership of the Marine Mammal Conservation Working Group (MMCWG).

(6) *Effective conservation requires evaluating and incorporating the interests of all users and stakeholders, but not by simply averaging their positions.* The MMCWG provides a good way of doing this. However, a better relationship with local fishermen should be sought. Public meetings and more direct contact between AFD staff and fishermen are needed.

(7) *Effective conservation requires communication that is interactive, reciprocal, and continuous.* A long-term conservation strategy for the dolphin population should be developed between Hong Kong SAR and Guangdong authorities. This should include an action response plan, to be set in motion if critical levels are exceeded

(e.g., maximum allowable rates of population decline). Long-term, cooperative population monitoring is needed for this to work properly. To be effective, the conservation strategy should not just be an internal AFD document. Key elements in the conservation strategy must be integrated into future government development policies for the Hong Kong SAR and Guangdong Province.

Specific Management Recommendations.—There are several specific recommendations for management that would help to ensure effective conservation of the dolphin population:

(1) A large-scale public awareness campaign should be launched to inform Hong Kong people of the need for environmental conservation. This would ideally include an aggressive advertising campaign using dolphins as a prominent symbol of a healthy Hong Kong.

(2) A major effort should be made to clean up local waters and otherwise improve water quality. Sources of toxic illegal substances, such as DDT, should be investigated and eliminated. Cooperation with appropriate Guangdong government authorities will be required.

(3) Due to the likelihood that high levels of pathogenic bacteria would cause health problems for the dolphins, existing and future sewage outfalls in the dolphins' range should be upgraded or designed to include both primary (or secondary) chemical treatment and disinfection (see Montgomery Watson 1998).

(4) To obtain reliable, quantitative information on bycatch rates and dolphin/fishery interactions, an onboard fishery observer program should be initiated, at least for the pair trawl fishery.

(5) A management strategy should be pursued with respect to mortality from incidental catches, vessel collisions, and other human-caused deaths. This should make use of the concept of Po-

tential Biological Removal (PBR). The PBR is a conservative and simple estimate of the number of animals that can safely be removed from a population, which incorporates uncertainty in parameter estimates (see Barlow et al. 1995, Wade 1998).

(6) Mitigation measures, such as monitored exclusion areas and the use of a bubble curtain to muffle potentially damaging piling noise levels (see Würsig et al. 2000), should be required for development and construction projects that will occur within important habitat areas for the dolphin population.

(7) Additional dolphin habitat should be protected. The relatively undeveloped area along the west coast of Lantau Island (and perhaps part of the South Lantau area around Fan Lau and the Soko Islands) should be considered for marine park or marine reserve status.

(8) The conservation and management of hump-backed dolphins (as well as finless porpoises) should be seen as an integral part of a multi-disciplinary coastal zone management (CZM) strategy. This would be an official, government-sanctioned program to efficiently integrate competing uses of the coastal zone, with an established policy for settling disputes among different user groups. Long-term planning for such a strategy is essential for a healthy balance between environmental conservation and further economic development of Hong Kong.

Recommendations for Further Research.—Although much has been learned in recent years about *Sousa chinensis* in Hong Kong waters and some of the surrounding waters of southern China, many aspects of the biology of these animals are still not known. Information on several of these unknown aspects is essential for sound conservation and management of these animals. This study has identified a number of these important and promising avenues for further research, and recom-

mendations for such study are given below:

(1) Line transect monitoring, using the same techniques as in this study, should continue in Hong Kong and Lingding Bay over the long term. This would allow for tracking of population trends with a high degree of statistical power. Also, in order to determine the size of the total population, currently unsurveyed areas of the Pearl River Estuary should be studied.

(2) Programs involving vessel surveys of distribution and abundance and recovery of stranded animals, such as those now established in Hong Kong, the Pearl River Estuary, and Xiamen, should be extended to other areas along the coast of southern China (perhaps starting with the area of the Beibu Gulf or Gulf of Tonkin). Only by doing so, can we put the situation of the local population into the larger context.

(3) Recovery of stranded and salvaged carcasses should be strengthened, with particular emphasis on increasing access to fresh specimens. Additional emphasis should be placed on detailed pathological examination of fresh carcasses to determine mortality and morbidity factors. In order to determine empirically what effect different environmental pollutants are having on the animals, indices of health of specific individuals should be correlated with levels of various toxic contaminants.

(4) To obtain accurate data, representative of the population as a whole, organochlorine levels of live dolphins should be evaluated. This would involve the development of a small-scale, trial program aimed at collection of small biopsy samples of skin and blubber from live specimens in at least the Hong Kong/Pearl River Estuary. Further collection of biopsies should only proceed if adequate wound healing can be documented.

(5) Because knowledge of stock structure

is such an important management issue, population discreteness along the southern China coast should be examined further using molecular, morphometric, and other techniques. Collection of skin samples from biopsies would greatly facilitate this.

(6) We still have little information on the critical issue of life history parameters. Therefore, the reproductive biology and life history of the population occurring in Hong Kong waters should be further examined. In particular, parameters such as age and length at sexual maturity, length of stages in the female reproductive cycle, and reproductive rates should be studied.

(7) Due to the fact that there has been almost no research conducted on the acoustic behavior of and noise disturbance factors for Indo-Pacific humpbacked dolphins, a study to characterize the predominant sounds made by the animals should be conducted. This should also include an evaluation of potential acoustic disturbance from human-caused sound sources in the dolphins' environment.

Conclusions

Until recently, within Hong Kong there was a general perception that the local population of hump-backed dolphins numbered less than 100 animals, was declining rapidly, and would be extinct by the year 2000 or soon thereafter (see Liu and Hills 1997). This perception was based on an uncritical acceptance of subjective impressions gained from preliminary study of the animals, and was disseminated in the mass media (for a review see Leatherwood and Jefferson 1997). Further detailed study using quantitative analysis of systematic surveys has provided little evidence to support the above conclusions. Surely, the dolphin population is under great threat from the degradation of its habitat brought about by intensive economic development in Hong Kong and other parts of the Pearl River Estuary. However, the population appears to number over 1,000 animals,

and all indications are that it is still viable. Although there is some evidence for a declining population trend in North Lantau, any such trend presumably could be stabilized and even reversed, and there is currently no reason to think that the population is doomed.

The government of the Hong Kong SAR has committed itself to an ambitious program of research and management of these animals. It has the economic resources to ensure not only proper study of these animals, but also to use the resulting information to wisely conserve this invaluable "natural resource." All that is needed is the political will by senior government officials and support for such a policy by members of the Hong Kong public. Environmental conservation is not currently among the highest priorities for either group, but the current trend is toward increasing levels of sympathy for nature conservation. This study strongly indicates that the local dolphin population can still be saved. Only the future will tell if efforts to do so have been too little or too late.

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Appendix 1. Reliable records of *Sousa chinensis* in Chinese waters.

Location	Record type	Date	Source(s)
Guangxi Province			
Hepu	1 specimen collected 5 dolphins found	December 1976 August 1995	Huang et al. (1978); Wang and Han (1996) Huang (1997)
Behai City	1 adult female collected 1 specimen collected 1 specimen collected	June 1980 December 1982 March 1985	Wang and Sun (1982) Wang and Han (1996) Wang and Han (1996)
Beibu Wan (Gulf of Tonkin)	Sightings	1970s	Huang et al. (1978); Wang and Sun (1982)
Guangdong Province			
Leizhou Peninsula	3 sightings and 1 capture by fishermen	August 1981	W. J. F. Mörzer Bruyns (unpublished data, courtesy P. J. H. Van Bree and D. Kreb)
Shangchuan lsl., Taishan Cty.	1 specimen stranded	March 1991	Wang and Han (1996)
Hong Kong	38 strandings and many sightings 2 sightings	1973–1994 January–February 1976	Parsons et al. (1995) Melville (1976)
	Several sightings	June–October 1980/81	Hammond and Leatherwood (1984)
	Over 1,200 sightings and stranding records	1995–1997	Leatherwood and Jefferson (1997); Jefferson and Leatherwood (1997)

Appendix 1. Continued.

Location	Record type	Date	Source(s)
Pearl River (P.R.C. waters)	Sightings	July 1637	Carnac-Temple (1919)
	Sighting (type description)	1751	Osbeck (1765)
	Sighting and 1 specimen collected	Mid-1950s	Zhou et al. (1997)
	Sightings near Guangzhou	September 1983	Zhou (1991)
	Several sightings and incidental captures	1986–1996	Yang and Chen (1996)
	1 specimen incidentally caught at Wai Ling Ding Island	September 1989	Wu and Chen (1996)
	1 animal sighted near Hua Dao City	Early 1990s	Wu and Chen (1996)
	1 adult male killed at Zhaoqing, Xijiang	September 1990	Wang and Han (1996)
	1 specimen caught at Dongguan	June 1991	Yang and Chen (1996)
	1 adult female stranded at Dongguan	January 1992	Wang and Han (1996)
	1 adult male incidentally caught	December 1992	Wang and Han (1996)
	1 adult male collected at Guangzhou	January 1993	Wang and Han (1996)
	1 adult female specimen collected at Shekou	March 1993	Wang and Han (1996)
	2 specimens found	February 1993	Yang and Chen (1996)
	1 specimen stranded at Tanjiang, Kaiping City	April 1993	Yang and Chen (1996)
	Several dolphins killed by blasting at Zhuhai	December 1993	Yang and Chen (1996)
	1 dolphin found at Jinsha Town, Nanhai City	August 1994	Yang and Chen (1996)
	1 juvenile male collected	January 1995	Wang and Han (1996)
	1 calf incidentally caught at Neilingding Island	October 1995	Wu and Chen (1996); Yang and Chen (1996)
	Sightings	Pre-1996	Wu and Chen (1996)
	1 specimen incidentally caught at Guangzhou	January 1996	Wu and Chen (1996)
	2 specimens found at Chikan Town, Kaiping City	April 1996	Yang and Chen (1996)
	1 specimen found alive; died later	August 1997	D. Yang (pers. comm.)
Macau	Sightings	1990s	Zhou et al. (1995)
Shantou	Sightings	1900s	Huang (1997)

Appendix 1. Continued.

Location	Record type	Date	Source(s)
		Fujian Province	
Xiamen	Sightings	Pre-1858	Swinhoe (1858)
	1 specimen sent to Royal College of Surgeons	1867	Flower (1870)
	1 stranded specimen	Pre-1927	Ping (1927)
	1 specimen collected in harbor	Pre-1936	Tang and Huang (1940)
	36 specimens collected	1960–1962, 1964	Wang (1965, 1995)
	Sightings (from vessels)	January 1994–March 1995	He and Huang (1995)
	Sightings (from shore)	April 1994–July 1995	Chou et al. (1996); Huang and Chou (1995)
	Sightings (from shore)	January–July 1996	Huang et al. (1997)
	4 stranded specimens	1997	Huang et al. (1997)
	Many sightings	1997–1998	T. A. Jefferson and Huang Zongguo (unpubl.)
Jiulong River	2 animals observed (1 adult female stranded 60 km upriver)	March 1978	Zhou et al. (1980)
Min River	Sightings	Pre-1982	Wang and Sun (1982)
	2 specimens caught 45 km up Min River	May 1983	Huang (1997)
	Sightings	1990s	Huang (1997)
		Taiwan	
Chinmen Island	1 specimen sent to Royal College of Surgeons (type specimen)	1867	Flower (1870)
	1 adult live-stranded	March 1995	Chou et al. (1996)
	Second-hand sightings	1995	Chou et al. (1996)
		Zhejiang Province	
Yueqing County	1 female stranded	February 1995	Zhou et al. (1995)
		Jiangsu Province	
Yangtze River	1 male captured (Hengsha Isl.)	September 1982	Huang and Fu (1984)
	1 adult female stranded (Rugao Cty.)	February 1987	Zhou (1991); Zhou et al. (1997)

Appendix 2. Matrix of occurrence of the 25 most-commonly sighted individual dolphins during the study, September 1995 to November 1998. Area abbreviations: N, North Lantau; C, Chinese waters west of Hong Kong; E, East Lantau; S, South Lantau; and L, Lamma.

No.	1995				1996												1997												1998										
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
NL02		N			N										N					CN	CN		E			N	N	N	N	N				N				CN	N	N
NL11		N			N										N	N								N		N	N						C				N		
NL12		N			N										N		N		N					S		N				C							C		
NL16		N	N						N							EN				EN			E	N			N	N									N		
NL17			N		N				N				N	N	N	E																			N	N			
NL18			N		N							N			N		N					N				N								N	N				
NL20					N			N							N							NS		N	N	N				C				N					C
NL22		E			NE							N			EN		N	N			E	N		N		N	N						N		N	N			
NL23					N	N					N			N		N	N	N		N			N								N	N			N	CN			
NL24		N			N				N	N		N			N	N	N	N	N				C		N	N	N	N	C	NC	NC			N				N	
NL33					N										N	N	N	N						N	N								N	N					
NL35					N			N	N		N			N	N			N	N	N																			
NL37									N	E			N	N		N		N		N	N	N		N	N	N							N	N					
NL40					N				C				C		C	C		C				C	C																
NL41					N			N			N	C		N		N		N		N	N				N		N			C									N
NL57					N				N		N	N		N	N	N	N		N		N	N		N															
NL58							N		N		N			N			N	N					N			N	N												
NL59							N													N				C	C		C	C	C	C			C	C					
NL60							N										N	N				C	C				NC	C		N									
NL89															N		N	N	N	N			C	C					N										
EL01				EN	N								E	E	E	EN				B	N				N														
EL07													E			E		E		N	N				N								N	N					
CH06													C		S					C	C	C	C	SC		C	C												
CH24													C					C	C	C	C	C	C		C	C												
CH50															C		C			C	C	C																
Month	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N