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Distribution, abundance and conservation status of the eastern Taiwan Strait population of Indo-Pacific humpback dolphins, *Sousa chinensis*

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Abstract

In 2002, a small population of Indo-Pacific humpback dolphins, *Sousa chinensis*, was discovered in the coastal waters of the eastern Taiwan Strait. Serious conservation concerns about this population led to a survey of most of the coastal waters of western Taiwan to better understand the status of this population. Surveys were conducted from boats (inshore waters) and a sea-kayak or land-based platforms (littoral waters inshore of large sandbars). Humpback dolphins were sighted 35 times, all within a stretch of inshore waters approximately 100 km (linear distance) and within 2 km from shore (none were observed in littoral waters). Including consideration of other records of this species, the main distribution of these dolphins was estimated to be approximately 515 km^2 of water off central western Taiwan, where industrialization is a serious and rapidly increasing issue. The population's abundance and density were estimated to be 99 individuals (coefficient of variation 51.6%) and 19.3 individuals/100 km^2, respectively, which is quite low when compared to the Pearl River estuary population. Assessing this population using the IUCN Red List criteria resulted in a "Critically Endangered" categorization, reinforcing the urgency of the situation.

Keywords: abundance; conservation; distribution; eastern Taiwan Strait; Indo-Pacific humpback dolphin; *Sousa chinensis*.

Introduction

The Indo-Pacific humpback dolphin, *Sousa chinensis* (Osbeck, 1765), has been known to science for more than 240 years, but even basic biological information about this species has remained lacking throughout most of its distribution with few exceptions (see Jefferson and Karczmarski 2001). During an exploratory survey of the coastal waters of western Taiwan in 2002, a small and unique population of this species was discovered (Wang et al. 2004a). Although an important finding to science, there were great concerns about the future existence of this population, because massive industrialization, high human population density, intensive agriculture and aquaculture exist in the coastal areas, and harmful fishing activities in coastal waters of western Taiwan continue with little or no consideration for these dolphins (Wang et al. 2004b). The above coastal problems are not unique to Taiwan and are becoming increasingly common in other heavily-populated Asian regions that are driven by the desire for rapid economic development and growth (e.g., China, India, Southeast Asia, etc.).

The Report of the Second Workshop on the Biology and Conservation of Small Cetaceans and Dugongs of Southeast Asia (Perrin et al. 2005) recognized the potential conservation issues with the Indo-Pacific humpback dolphin, a highly coastal species whose distribution often overlaps extensively with human activities. Specifically, this report stated that "there is a need to study local coastal populations of this species wherever it occurs in SE Asia. Boat surveys are urgently needed. The populations must be assessed, and effective conservation plans must be implemented, before the populations decline to critical levels". The most recent conservation action plan for the world's cetaceans also recognized the urgent need for improving our understanding of this species (Reeves et al. 2003). In 2004, an international workshop on the conservation and research needs of the humpback dolphins of western Taiwan identified the lack of information about the population's distribution and abundance as priorities needing attention (Wang et al. 2004b).

Distribution and abundance information is important not only for improving our understanding of the biology of this species, but also for assessing its conservation status and guiding conservation actions and decisions. The main aims of this study were to gain a better understanding of the extent of the population's distribution and to generate an initial estimate of its abundance and density. Based on this information, the likely status of this population of Indo-Pacific humpback dolphins under the criteria of the IUCN Red List, the most authoritative compilation of threatened wildlife, will be examined.

Materials and methods

The coastal waters from Fuguei Cape to just north of Kaohsiung City (Figure 1) and the littoral waters of Changhua County were surveyed for cetaceans by observers onboard fishing boats, on a sea-kayak or from land-based observation sites (the latter two platforms being used mainly for surveying the littoral waters of central western Taiwan, where deep-drafted survey vessels could not be employed safely or effectively). Surveys were conducted between early April and early August in 2002 to 2006, the months when the weather and marine conditions are generally the calmest.

Shipboard surveys

The inshore and offshore waters of western Taiwan (from Fuguei Cape to just north of Kaohsiung City; Figure 1) were surveyed in 2002 (June), 2003 (April) and 2004 (May and June). The surveys were conducted from either a 16-m long fishing raft made of plastic pipes (a unique local vessel) or a 19-m long fibreglass fishing boat, travelling at a targeted speed of between 12 and 20 km/h. A minimum of two observers searched the waters using binoculars (8× and 10× magnification) and unaided eyes from sighting platforms that were 3.0–3.5 m above the sea surface (observer eyes were between approximately 4.5–5.0 m above sea level, depending on observer height and whether they were sitting or standing during the search).

Due to the distance between ports with sufficient water depth for vessels to enter and exit, the track lines of the surveys were more or less parallel to the shoreline rather than the preferred line-transect survey design of having tracks being diagonal or perpendicular to the shoreline (Buckland et al. 2001). The present design was required to allow the survey vessels to cover water between ports, while still being able to enter ports at night. Surveys were separated into "inshore" tracks (<3 km from shore) and "offshore" tracks (>3 km from shore). In general, "inshore" tracks varied from 1 to 2 km from shore, the actual distance depended upon safe water depth (and

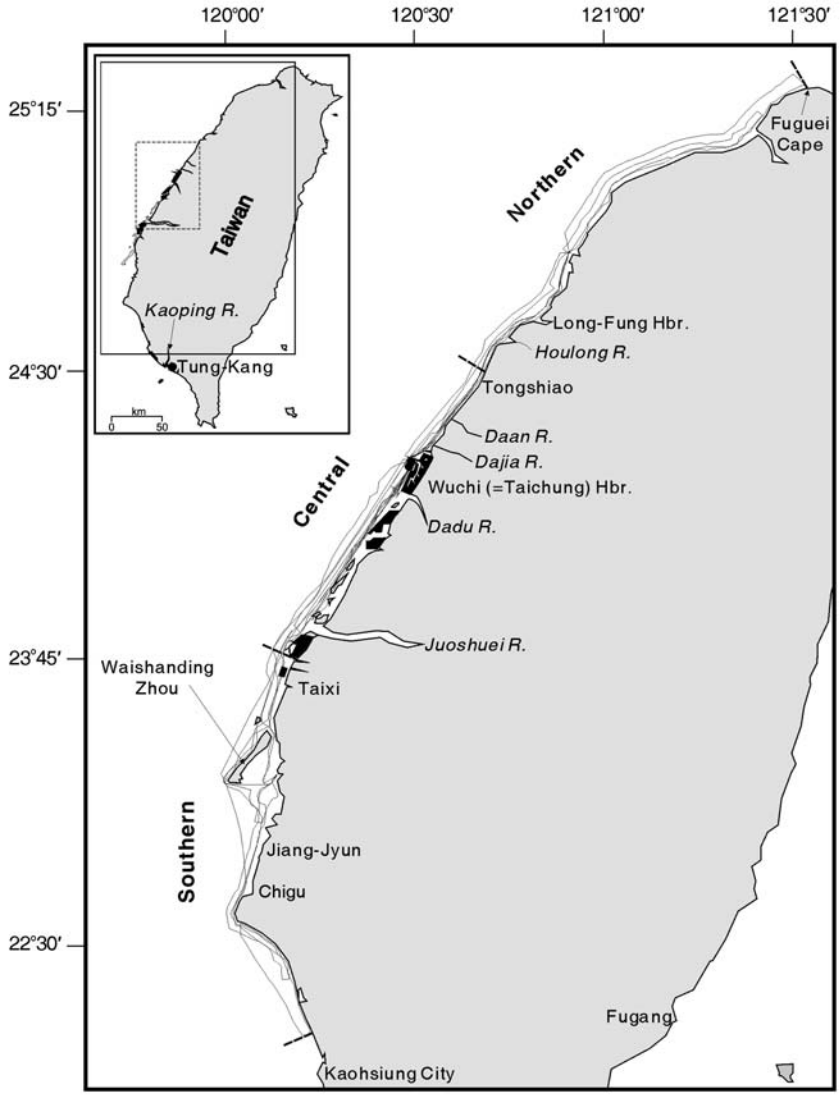

Figure 1 Map of the study area with survey track lines and area divisions. The short broken thick lines represent the boundaries of each of the northern, central and southern divisions. The inset map shows the area represented in this Figure (box with solid line) and in Figure 2 (smaller box with broken line).

thus bathymetry and tidal phase were factors) for the survey vessel.

Observers conducted the surveys with each searching a quadrant covering of 90° of arc from the centreline to the side of the boat. Observers often searched to approximately 5–10° past the centre line into the opposite quadrant and infrequently, the waters from the side to behind the boat would also be scanned quickly (however, sightings made from the side to behind the boat were not included in the abundance estimation analyses). Most of the search effort was focused on the centre line to approximately 30° of each side of the boat.

Standard survey information was recorded each time the survey vessel changed course, when dolphins, seabirds or fishing vessels and gear were observed, when marine or weather conditions changed noticeably or at approximately 20 min intervals if no events had been recorded. The information collected included: date, time, geographic positions (determined using handheld global positioning systems – Garmin GPS MAP76, Magellan GPS 2000 or Magellan Colortrak GPS), species observed, number of individuals, number of mother-calf pairs, sighting angle, distance of animals from the boat, direction and speed of travel, behaviour, sea surface temperature (when possible), water depth (when possible and using an echo-sounder), and atmospheric and marine conditions. Sighting distances were estimated by observers of which two of three observers were trained previously with laser range finders. Observers also "calibrated" distance estimates with each other and by comparing estimates with measured (using geographic positions) distances from fixed objects at sea or landmarks along the coastline (e.g., navigational markers, end of long jetties) to the boat. Sighting angles were estimated to 10° intervals with the aid of a small angle-board or protractor.

When dolphins were sighted, all data were recorded prior to departing from the track line to photograph the dolphins. Photographs were taken of as many individuals as possible, if the dolphins were approachable and tolerated our presence, before returning back to the track line to continue with on-effort search. The time spent photographing the animals was not included as on-effort search.

Surveying littoral waters

Due to the shallowness of the waters, expansive mudflats (exposed at and near low tide) and the amount of oyster mariculture structures, the littoral waters inshore of sandbars of Changhua County between Dadu and Joushuei rivers (approximately 80 km in linear distance; Figure 2) could not be surveyed using the fishing vessels above. Instead, these waters were surveyed from a sea-kayak and several land-based observation points.

Sea-kayak surveys These surveys were conducted from mid-July to early August in 2005 by two observers in a 5.5-m Seaward tandem sea-kayak and travelling between 3 and 5 km/h. Given the narrowness of the study area (width only approximately 500–2000 m at high tide and less at low tide) and the extensive oyster culturing structures present, it was not possible to preset transect lines that could be followed effectively. Instead, the kayak travelled through almost all waters where water depth permitted. The water depth was less than 1 m (often less than 0.5 m) throughout most of the study area between late ebb and early flood (note: the tidal difference between low and high tide can be over 5 m in this region).

The kayak was launched near land-based observation platforms B, D, H, N, G, J and K (Figure 2). For safety reasons, most trips were conducted during calm conditions (Beaufort Sea State <3) and when the tide was at or near low slack, so hazardous structures that are submerged during other tidal phases were visible. Between some sandbars, deeper water channels allowed passage from littoral to open inshore waters. However, breaking waves adjacent to these narrow channels generally made it dangerous to transit through, so observers in the kayak infrequently ventured beyond the sandbars.

Observers searched for dolphins using unaided eyes (observers' eyes were approximately 1 m above sea level). Standard survey information (as above) was recorded, but water depth was determined using a kayak paddle with graduation marks.

Land-based observations From 14 July to 3 August 2005 and 25 to 26 June 2006, land-based observations were also conducted to complement the sea-kayak surveys of the littoral waters, when at-sea surveys could not be conducted effectively or safely.

A total of 14 platforms, located roughly equidistant from each other (Figure 2), were selected for their view coverage of the study area. The height above sea level of the platforms varied from 2 to 10 m (depending on the tidal phase) and observers' eyes were approximately 1–1.5 m higher. For each observation period, 30 min of search time was planned, but was shortened if weather or marine conditions were poor and increased if dolphins were sighted (however, the time spent observing dolphins after they were initially detected was not included in the determination of search effort). Humpback dolphins have short dive times lasting less than 5 min and usually less than 1 min (Jefferson 2000); therefore, 30 min should have been adequate time for two observers to thoroughly search the area within 1–2 km of the platforms for dolphins. Search was only conducted in daylight hours, when the Beaufort Sea State was 3 or less, and when there was little to no rain. Observers used binoculars (8× and 10× magnification), a 20–60× magnification spotting scope mounted on a tripod and unaided eyes to search for and to observe the dolphins. Two observers searched during each observation period, with the exception of one period where there was a single observer. The data recorded included: date, time, observers, weather and marine conditions, visibility, fishing gear, the position, type and travel direction of water craft, dolphin sightings, number of dolphins, characteristics of the dolphin group and their behaviour (similar to above). The distance of the dolphins from the observation platform was based on the observers' experience and landmarks (e.g., the end of long jetties that are per-

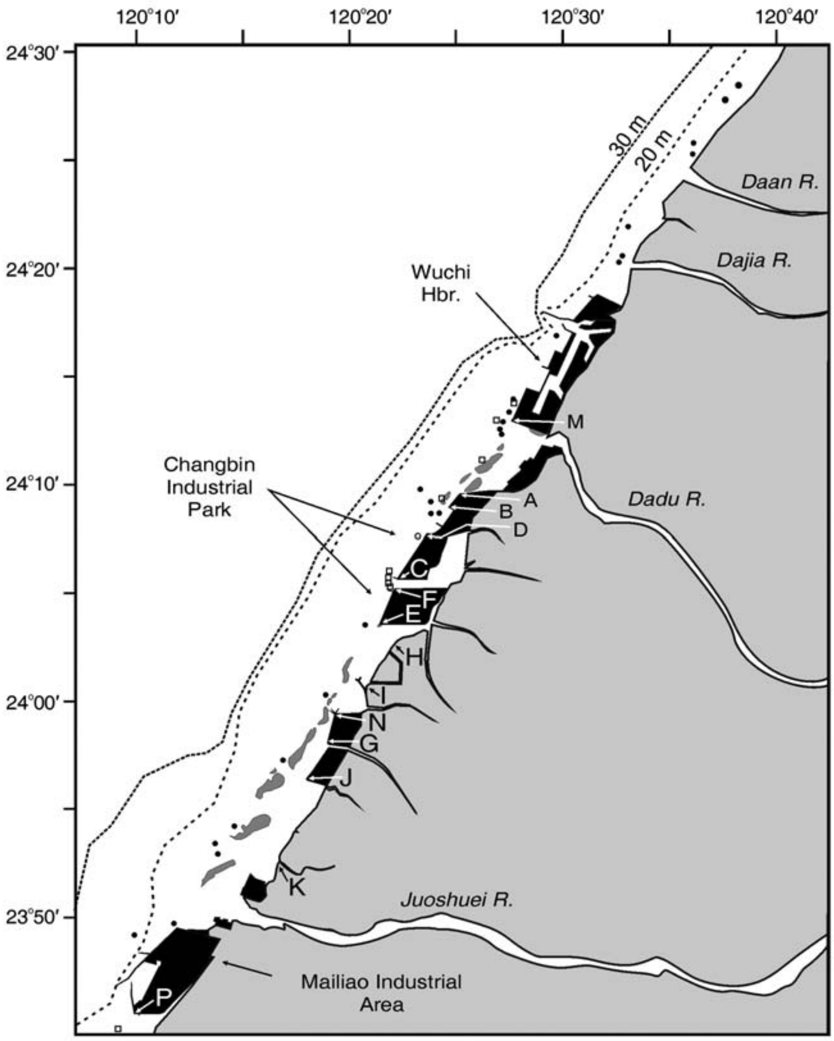

Figure 2 Close-up of the coastal waters of central western Taiwan (black polygons represent reclaimed land; dark patches in the coastal waters between Dadu and Joushuei rivers represent sandbars). Each humpback dolphin (*Sousa chinensis*) sighting is indicated by a black circle (made during shipboard surveys), open circle (made during sea-kayak surveys) or open square (made from land-based observation platforms). The location of land-based observation platforms are shown by letters.

pendicular to the shoreline, fixed structures at sea, such as buoys, etc.) with known distances from the observation platform.

It was impossible to search from sites G, H, I, J, K and N between mid ebb and mid flood, because there was little to no water inshore of sandbars during these tidal phases. Therefore, most of the search effort from land-based observation sites occurred from late flood to early ebb.

Survey data analyses

Distribution and sighting rate To determine if there was heterogeneity in the dolphins' distribution, the study area (from the northern tip of Taiwan to just north of Kaohsiung City) was divided into inshore (up to 3 km from shore) and offshore (>3 km from shore) blocks and arbitrarily into roughly equal northern, central and southern sections. The northern and central inshore and offshore blocks were approximately 85×3 km, while the inshore and offshore southern blocks were approximately 115×3 km. For the sea-kayak and land-based surveys in the waters of the central section, the area surveyed was divided into inshore and littoral (shoreward of large sandbars and is more or less dry at low tide) waters.

Abundance estimation The distances covered by on-effort search during survey trips in 2002 and 2003 were calculated from the latitude/longitude positions that were recorded. In 2004, on-effort survey distances were obtained directly from the GPS unit.

A 1 day survey effort was used as the sample for analyses. Estimates were calculated from sighting and effort data collected since 2002 during conditions of Beaufort <4 (see Jefferson and Leatherwood 1997, Jefferson 2000), using line transect methods (Buckland et al. 2001). The estimates were made using the computer program DISTANCE Version 2.1 (Laake et al. 1994). The following formulae were used to estimate density, abundance and their associated coefficients of variation (CV):

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

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

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

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

Because of the very small sample size of useable sightings available for analysis, we did not carry out any stratification. All available data from the useable sightings (from shipboard surveys only in "inshore" water as no sightings were made in the "offshore" waters; land- and kayak-based sightings were not included in these analyses) were pooled to calculate a single estimate of density and abundance for the population. Truncation distance was set at 600 m. Three models were tested to fit the perpendicular distance data, the Uniform, Hazard Rate and Half-Normal models. The most appropriate model was chosen, based on minimizing the value of Akaike's Information Criterion. We had no data available from this population to make an estimate of the detection probability of dolphin groups on the track line ([g(0)]. However, for the very closely-related humpback dolphins of the Pearl River Estuary (PRE) population, Jefferson (2000) reported group dive time data and collected 71.8 h of independent observer data, and from this estimated that the detection probability was unity for that study. We therefore made the assumption that g(0)=1.0 for the density and abundance calculations. A total of 19 (of 25) sightings that were made during shipboard surveys were used for estimating abundance.

Results

Survey effort

The total distance covered by on-effort search for dolphins during shipboard surveys was 1792.7 km (the time spent was 124.8 h). Of the distance searched, 614.9 km and 1177.8 km were conducted in offshore and inshore waters, respectively. Using a sea-kayak, eight survey trips were made, comprising 19.9 h of search time and covering 107.7 km of inshore (42.8 km) and littoral (64.9 km) waters of central western Taiwan. From land-based sites, 46 observation periods totalling 22.0 observer hours were spent searching for dolphins (14.7 observer hours and 7.3 observer hours were conducted in inshore and littoral waters, respectively).

Dolphin sightings

A total of 35 humpback dolphin sightings were recorded from fishing boats, sea-kayak and land-based observation sites and all sightings were made in the waters of the central inshore block (Figure 2). Of these, 25 sightings were made during shipboard surveys, but only 19 were during on-effort search in Beaufort Sea State <4. Only one sighting was made from the sea-kayak and it was near land-base observation site D. From land-based observation sites, nine sightings were recorded and all were in inshore waters that were not blocked from the open ocean by sandbars (none were observed in littoral waters shoreward of large sandbars).

Although the number of sightings was limited, the frequency distribution of the perpendicular distances with respect to the track line (Figure 3) was broadly similar to that for the PRE dolphins found by Jefferson (2000). This suggests that the detectability of the dolphins was similar for these two populations.

The sighting rate from shipboard surveys in the central inshore block was 0.37 sightings/10 km and 2.53 dolphins were observed per 10 km. For the sea-kayak survey, the sighting rate was 0.23 and 2.33 dolphins per 10 km (but note only a single sighting was made from the sea-kayak). From land-based observation sites, the sighting rate was 0.61 sightings per observer hour and 3.27 dolphins were observed per observer hour for the central inshore block (no dolphins were observed in littoral waters). See Tables 1 and 2 for summary of all blocks.

The distance from shore (note: for the purposes of this study, "shore" was defined as any piece of land that remained dry at high tide, so in some areas, large sandbars represented "shore") of each sighting was calculated using the initial dolphin sighting position and the position of the nearest point of shore (for at-sea sightings) or estimated directly (if sightings were made from land-based observation sites). The mean distance of the initial sighting positions of dolphins from shore was 0.9 km (SD=0.45, n=35). Dolphins were as close as 150 m from shore (swimming along a concrete breakwall) and none were observed beyond 2.0 km. However, some dolphins were observed to swim to within tens of metres from shore after the initial sighting.

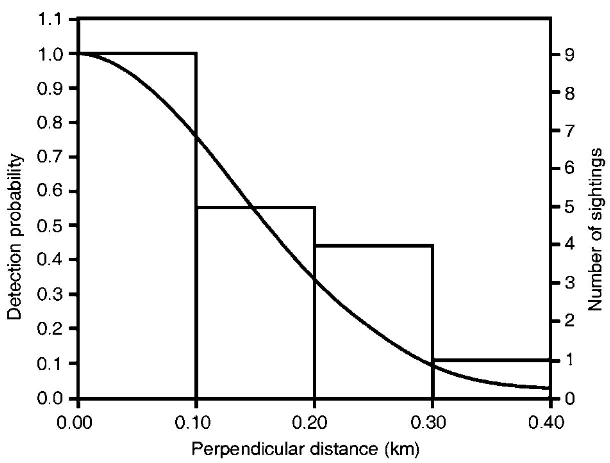

Figure 3 Frequency distribution of the perpendicular distances of sightings (relative to the track lines) for the Indo-Pacific humpback dolphins (*Sousa chinensis*) of the eastern Taiwan Strait (based on 19 sightings that were made from shipboard surveys in Beaufort Sea State 3 or less).

Table 1 For each of the northern, central and southern offshore and inshore blocks, the sightings (top value) and dolphins (middle value) per 10 km and shipboard survey effort in kilometres (bottom value) are shown.

	Offshore	Inshore
Northern	0.00	0.00
	0.00	0.00
	242.99	324.64
Central	0.00	0.37
	0.00	2.53
	220.60	489.78
Southern	0.00	0.00
	0.00	0.00
	151.26	363.38

Table 2 For the inshore and littoral waters of central western Taiwan, the sightings (top value) and dolphins (middle value) per 10 km (for sea-kayak surveys) or per observer hour (for land-based surveys) and survey effort (bottom values) are shown.

	Inshore	Littoral	Total effort
Sea-kayak surveys	0.23	0.00	
	2.33	0.00	
	42.8	64.9	107.7 km
Land-based surveys	0.61	0.00	
	3.27	0.00	
	14.7	7.3	22.0 observer hours

The survey effort for the sea-kayak surveys is measured as kilometres of water searched and for the land-based surveys, in observer hours of search time.

The sea surface temperature measured when dolphins were sighted varied from 23.9 to 29.6°C (mean=27.16°C, SD=2.15, n=10). The water depth at the location where the dolphins were first observed varied between 2.5 m and 24.8 m (mean=8.79, SD=6.05, n=20; all depths were measured using an echo-sounder). However, some dolphins entered water that was as shallow as 1.5 m.

Abundance and density estimates

Only 19 of the 25 sightings from the shipboard surveys were made on-effort and in adequate marine and weather conditions. The range of the population was estimated to be 515 km^2. This was based on the locations of the sightings made during the study and also including the Houlong River estuary, the next sizeable river system to the north and to the Waishanding Zhou sandbar (a large physical barrier to dolphin movement) to the south. It was also assumed that the dolphins could be found further from shore (possibly out to approx. 3 km), even though so far, no sightings have been made more than 2 km from shore.

Based on the distributional area above, the estimated abundance of this population was made using the Half-Normal model, with a Hermite adjustment. The resulting estimate was 99 individuals (CV=51.6%; lower and upper limits of the 95% confidence interval were 37 and 266, respectively) with a density of 19.3 dolphins per 100 km^2. Although the present estimate has low precision, because of the limited number of sightings, it is clear that the population size is small.

Discussion

Distribution

The findings of the present study support the previous notion (Wang et al. 2004a) that the distribution of the eastern Taiwan Strait population (ETS) of Indo-Pacific humpback dolphins is highly restricted. The population inhabits the shallow waters (mostly <10 m deep) within approximately 2 km from shore along a short (roughly 100 km in linear distance) stretch of coastline from Tongshiao (Miaoli County) to just north of Taixi (Yunlin County). However, the dolphins' distribution does not appear to include the littoral waters inside of large sandbars.

The main reason for the lack of dolphins in littoral waters may be the physical displacement of the dolphins by structures erected by the extensive oyster mariculture industry in the region. Becoming trapped at or near low tide, in the littoral zone inside of large sandbars, amongst the maze of mariculture structures and in a region where stranded cetaceans were, until recently, considered a protein windfall presents an obvious and direct danger to these animals. As such (and in comparison to most cetacean distributions), the distribution of the ETS population can best be described as more or less one-dimensional and resembles that of humpback dolphins off South Africa where a similar environment (small river estuaries entering a narrow stretch of shallow coastal waters along a linear coastline) exists (Saayman and Tayler 1979, Karczmarski et al. 2000). In contrast, the dolphins of the PRE population are found mainly in a single large indented river estuary (Jefferson and Hung 2004); therefore, their distribution is not linear.

The area occupied by the ETS population was estimated to be approximately 515 km^2 (assuming the "offshore" boundary to be 3 km from shore) and encompasses the estuaries of Dadu and Joushuei rivers (the two largest river systems of western Taiwan by size and water flow volume) and the outflow/harbour from the Changbin Industrial Park, which is served by several diverted smaller rivers and sewer systems. Dolphins appear to frequent these estuaries and the outflow/ harbour of the Changbin Industrial Park (Figure 2). This presumed distribution not only includes the locations of the sightings made in this study, but also the waters of the Houlong River estuary to the north and as far south as the Waishanding Zhou sandbar. The extensions beyond the locations of the sightings appeared to be reasonable buffers, given the estuarine habitat preference of humpback dolphins, the physical obstacle presented by the sandbar and some reported sightings near Long-Fung Harbour and the Houlong River mouth.

The waters from Kaohsiung City to approximately 20 km south of the Kaoping River have not been surveyed, but some limited surveys of inshore waters south of this region were conducted in 2000, with no sightings of Indo-Pacific humpback dolphins or any other species of cetaceans (Wang et al. 2001). A large portion of the coastal waters of southern Taiwan are different from those of the central region, being dominated by rocky shores, beaches of pebble, coarse sand or coral rubble, coral reefs (rather than soft substrates like fine sand and mud) and small creeks feeding into coastal waters. Also, the influence of the Kuroshio Current, which has high clarity and salinity, is greater on the waters in southern and southwest Taiwan than in the central region. In and around the Kaoping River estuary (the largest river system in southwest Taiwan), we have heard of no reports of humpback dolphins by local coastal fishermen. Tung-Kang (situated near the mouth of the Kaoping River) is one of Taiwan's largest fishing ports, so boat traffic in that area is very high. During informal interviews, many local coastal fishermen (most of who have hunted and consumed small cetaceans in the past) reported to have seen white dolphins, but invariably directed us to central western Taiwan. We believe that the waters south of Kaohsiung City are not part of the normal distribution of the ETS population. Confirmed sightings of animals near Jiang-Jyun port (Tainan County, southwest Taiwan) and Fugang (Taitung County, southeast Taiwan) were made in October and July 2005, respectively. However, given the type of marine habitat found along eastern Taiwan (very narrow shelf with deep, high salinity, oceanic water), the Fugang sighting almost certainly represented a sick, dying or vagrant individual (dead and dying humpback dolphins of the PRE population have been found outside their normal distribution – S.K. Hung, Hong Kong Cetacean Research Project, unpublished data) and should not be considered presently to represent an extension of the distribution of this species. The Jiang-Jyun sighting was of a group of approximately 20 dolphins that were observed close to the port's breakwall and then chased by local coast guards away from shore, hoping to prevent the dolphins from stranding. The waters of Tainan County appear to possess suitable habitat for the species, so it is uncertain why this was the first report of the species there (note: a highly decomposed carcass was found on a beach near Chigu, Tainan County in April 2005). It may be due to a combination of inadequate survey effort and low density and abundance of animals in the area. Clearly, more research is needed to understand the animals' distribution patterns in this area, but nevertheless, humpback dolphins do not appear to be as common in the waters of Tainan County as in the main distribution identified above.

Given the limitations of the present surveys, seasonal variations in distribution could not be examined. The present study was conducted only during spring and summer months, so it is uncertain whether some or any of the animals move out of this main area during other months. However, local recreational and commercial fishermen claim to see the animals year round, especially in and near the Dadu River estuary. In addition, the captains of our survey vessels fish for grey mullet (*Mugil cephalus*) during the winter months and report that humpback dolphins are often seen next to their nets during this season.

The limited data on water depth and sea surface temperature recorded during dolphin sightings are consistent with information in Ross et al. (1994), in that most sightings were made in water depths of 20 m or less and the water temperatures were within the reported range (some dolphins can swim into waters as shallow as 1.5 m). Only two sightings were in water deeper than 20 m. These were recorded just outside the breakwalls of the massive Formosa Plastics Group's Mailiao industrial area and the coal-fired power plant on the north shore of the Dadu River mouth, where dredging of the sea floor or physical alteration of current flow has artificially deepened the water along the shoreline in small isolated areas. Excluding these exceptions, the coastal seabed in central western Taiwan is shallow, gently sloping and consists of soft substrates. The observations of dolphins in deep water close to shore should not be considered a natural phenomenon. The impact of an artificially deepened seafloor along the shoreline on the dolphins' ability to forage on bottom-dwelling fish is unknown and needs to be examined.

Although the sea surface temperatures are consistent with previous reports, the reported range is very wide (15–36°C), and the sea surface temperatures reported in this study only represent the conditions during the months in which surveys were conducted. Clearly, much more data are needed to determine if any relationship between sea surface temperature and dolphin distribution exists.

Abundance

The preliminary abundance estimate supports previous beliefs that this population is very small. However, the present estimate is imprecise, due to the limited number of sightings [approx. 60 sightings are recommended for estimation of f(0) to obtain a relatively precise estimate (Buckland et al. 2001)]. Also, there may be some concerns related to "heaping", as a result of the 10° sighting angle intervals. More surveys within the dolphins' main distribution are required to increase the number of sightings to address these issues.

Line transect estimates can be biased if dolphins respond to the survey vessel (avoidance or attraction) before they are detected by vessel observers. This can be an issue with some species of cetaceans (Würsig et al. 1998). However, humpback dolphins generally do not ride bow waves, and Jefferson (2000) examined this potential problem in detail for the PRE humpback dolphins. He found no evidence of a significant bias, and dolphins in Taiwan appear to be very similar in their behaviour. Therefore, this is not considered to be a significant issue in this study. However, we recognize that this is an assumption not based on empirical data from the population of interest. If dolphins are, in fact, responding to the survey vessel before detection, then this would cause a bias (in either direction) in resulting density and abundance estimates. This is an issue that should be examined in more detail in the future.

Transect line placement in this study used a design with major transect lines parallel to the coast. Although this is not necessarily the most ideal design, it was required for logistical reasons. In practice, because we did not extrapolate densities from surveyed areas to other areas, and we conducted effort relatively evenly throughout the study area, any disparity of sighting rates between the inshore and offshore lines will only affect the estimates of variance (causing an overestimate) and should not bias the point estimates of abundance and density.

As is done in many line transect studies of cetaceans, we have assumed that g(0)=1 in this study. However, we have some empirical basis for doing so, based on studies of a nearby population of the same species in Hong Kong (Jefferson 2000). Nonetheless, we recognize this as a shortcoming of this study, and if dolphins are in fact being missed on the track line, this would result in an underestimation of abundance. Future work should address this issue more thoroughly.

Since 2002, 45 recognisable individuals have been photographed from this population and we estimate, roughly, that another 15–20 dolphins were observed, but did not possess distinct markings (e.g., calves and other young individuals). There is also likely to be a small, but unknown, number of dolphins that have not been photographed yet. After only three seasons of collecting such information and photographs, the number of novel, distinctly marked individuals fell below the number of recognisable individuals that had been observed in previous years, suggesting that most of the recognisable members of the population had already been identified (J.Y. Wang, FormosaCetus Research and Conservation Group, unpublished data). These data are in general agreement with the present abundance estimate based on the line transect analyses that the population is very small and is likely to be only around 100 individuals.

Capture-recapture analysis of photographically-identified individuals is another common approach to estimating abundance and this study is underway. Combined, the two approaches to estimating abundance (especially with increased datasets) should improve estimation of the population size. Nevertheless, there is little doubt that the population is small, even at the upper end of the uncertainty of the estimate.

Population comparisons

It is instructive to compare abundance and density of the ETS population to those of other known populations within Chinese waters (see Jefferson and Hung 2004). Only two others have comparable information. The closest population, geographically, is that of the Jiulong River estuary (JRE) and adjacent waters of Xiamen and the Chinmen Islands (Liu and Huang 2000). The range size of this population is not well known, but is probably several hundred square kilometres. Abundance has been preliminarily estimated at 80 individuals (CV=108%), which if correct, would put it at a similar size to the ETS population (Jefferson and Hung 2004). The JRE population also faces threats that are similar to those of the ETS population.

Further south, there is a well-studied population that inhabits the waters of Hong Kong, Macau and the PRE (see Jefferson 2000). This population inhabits an area of >1800 km^2 and numbers approximately 1500 individuals (Jefferson and Hung 2004). The ETS population distribution is estimated to be <29% of that of the PRE population, while its abundance is more than an order of magnitude less (99 vs. 1500). Most recent estimates of density in the PRE population varied from 60 to 280 individuals per 100 km^2 for high density areas, 15 to 50 in medium density regions and <10 in low density, or what are considered “marginal” habitat, areas (T.A. Jefferson, Southwest Fisheries Science Centre, unpublished data). The ETS population density of 19.3 individuals per 100 km^2 is at the lower end of the PRE medium density areas, suggesting that densities in Taiwan are fairly low.

Conservation issues

This population was unlikely to have ever been a large or widely-distributed population like the PRE population. But the extent of the historic distribution, abundance and density of the ETS population are unlikely to be known. However, given the present degraded state of the coastal and estuarine waters of western Taiwan, it is very reasonable to assume the population’s distribution, abundance and density was considerably greater prior to the heavy and rapid destruction of the coastline, increased pollution and other human activities (especially coastal fisheries) in and around these waters over the last two to three decades. The information from this study clearly confirms that initial concerns for these dolphins (Wang et al. 2004a) were warranted. High vulnerability to threats of any kind is a predisposition of any small population (especially species that are long-lived and have low reproductive output, such as these dolphins). Within the distribution of the ETS population, there is a plethora of anthropogenic threats (Wang et al. 2004b). Moreover, many new development projects (which will further degrade the inshore waters of central western Taiwan) are being proposed or have begun. However, there has been no progress in mitigating any of the existing threats to these dolphins. A panel of international experts, who met to discuss this population in 2004 stated clearly that “[in] the immediate term, it is crucial to provide as much protection as possible to the surviving animals in this population” (Wang et al. 2004c). Thus far, existing local conservation and environmental protection policies, legal protection (the highest level of protection under the Wildlife Conservation Act in Taiwan has been given to humpback dolphins) and enforcement appear to be failing this population of humpback dolphins. Economic development projects that are destructive to the environment have taken priority over the conservation of these legally-protected dolphins, other wildlife and their habitats. Continuing on this trajectory and with the present mindset will lead down the same road to imminent extinction much like the baiji or Yangtze River dolphin, *Lipotes vexillifer*. In only a little more than a decade since the baiji was estimated to be numbering approximately 100 or less (see Zhang et al. 2003, Dudgeon 2005), the species has become functionally extinct (see Turvey et al. 2007). Without effective and precautionary *in situ* conservation efforts for the ETS population of humpback dolphins, their continued existence in the coastal waters of western Taiwan is unlikely.

Applying the revised IUCN Red List criteria (IUCN 2001) to the best information available, the ETS population would satisfy the category of “Critically Endangered” under C2a (ii) [i.e., there are less than 250 mature individuals), a continuing decline in the number of mature individuals can be projected (given the continuing degradation of their habitat and a lack of mitigation of other serious threats) and at least 90% of the mature individuals are found in one population]. This category represents an extremely high risk of extinction and underscores the urgent need for effective measures to reduce the impacts of existing and impending harmful human activities to this population. A formal assessment of the Red List status of this population is underway, with the hope of conveying to local managers, officials and citizens, the precarious state of this population and the urgency of the situation.

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