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Short Note

Influence of Vessel Traffic on Movements of Indo-Pacific Humpback Dolphins (*Sousa chinensis*) Off Lantau Island, Hong Kong

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Marine mammals with near-shore distributions are susceptible to human-related recreation and commercial disturbances, particularly near densely populated and industrialized coastal communities (Würsig, 1989; Jefferson et al., 2009). A single population of over 2,500 individual Indo-Pacific humpback dolphins (*Sousa chinensis*) occurs year-round in near-shore waters off Lantau Island, Hong Kong, ranging throughout the Pearl River Estuary (PRE) and southern China (Hung & Jefferson, 2004; Jefferson & Hung, 2004; Hung, 2008; Jefferson et al., 2009; Chen et al., 2010). Here, they are subjected to potentially adverse cumulative anthropogenic effects, including vessel disturbance, fisheries interactions, and boat-based tourism. This is an important foraging area for *S. chinensis* (herein referred to as dolphins) where these generalist feeders consume a variety of demersal and mid-water shoaling fishes supported by the PRE (Barros et al., 2004). While dolphins also engage in other biologically important activities in these waters, including socializing and resting, feeding appears to dominate daytime behavior (Hung, 2008). Increasing levels of vessel traffic and other anthropogenic activity off Lantau Island, including associated underwater noises that overlap with the dolphins' vocalizations (Sims et al., 2012), are of concern to the welfare of the Hong Kong coastal population of this "Near Threatened" species (Reeves et al., 2008; Jefferson et al., 2009).

Studies of other delphinid species, including *Tursiops* sp., *Delphinus* sp., *Lagenorhynchus obscurus*, *Grampus griseus*, and *Orcinus orca*, have demonstrated that vessel disturbance can result in short-term behavioral changes, including alterations in linearity (i.e., swimming direction) (Nowacek et al., 2001; Williams et al., 2002; Lusseau, 2006; Stensland & Berggren, 2007; Dans et al., 2008); changes in swimming speed (Nowacek et al., 2001; Williams et al., 2002; Lundquist, 2012); and reduced or disrupted foraging, resting, and/or socializing bouts (Constantine et al., 2004; Williams et al., 2006; Dans et al., 2008; Stockin et al., 2008; Lusseau et al., 2009; Christiansen et al., 2010; Visser et al., 2011). These short-term behavioral changes can cause shifts in habitat use, temporary displacement, or reduced energy consumption; and without proper management, there may be long-term consequences such as changes in survival or population size (Bejder et al., 2006a). A decline in local abundance of bottlenose dolphins (*Tursiops* sp.) occurred in a tourism area concomitant with a small increase in vessel-based tourism from one to two boats over a 9-y period (Bejder et al., 2006b). Although this decline in abundance did not have a directly devastating outcome for the large and genetically diverse study population, Bejder et al. (2006b) state that a similar decline may have devastating consequences for small or resident cetacean populations in which animals are repeatedly targeted for encounters. Because bottlenose dolphins are closely related to Indo-Pacific humpback dolphins (Parra & Ross, 2008), similar behavioral reactions to vessel-based tourism disturbance may be expected.

In Hong Kong, dolphins are protected under the Wild Animals Protection Ordinance (Cap. 170), and a code of conduct for vessels approaching and viewing marine mammals is in place. Suggested vessel operations include maintaining a slow and steady speed of less than 10 kts, a minimum viewing distance of 100 m, a maximum viewing time of 30 min, and a maximum of one dolphin-watching vessel within 500 m of a dolphin group; however, this voluntary code may be ineffective in providing adequate protection to the dolphins. A preliminary land-based study in 2004 also revealed that several dolphin tourism boats failed to comply with code recommendations, exceeding both the the recommended maximum number of boats present near dolphin groups and the recommended observation time (Hung, 2004). Moreover, heavy vessel traffic off Lantau Island includes high-speed ferries, marine police vessels, sand barges, container ships, speedboats, dolphin tour boats, and commercial fishing trawlers (for characteristics of these anthropogenic noises, see Würsig & Greene, 2002). There is presently insufficient scientific evidence of vessel disturbance effects on dolphins in Hong Kong waters; however, anecdotal evidence and observations point to at least short-term changes in activity patterns and movements relative to traffic and other anthropogenic noise (pers. obs.). More data are necessary to better understand and manage interactions between anthropogenic influences and dolphins.

The purpose of this research was twofold: (1) to describe the extent of overlap between vessel movement and dolphin habitats off Lantau Island, and (2) to determine whether dolphin movement patterns and other behaviors (e.g., speed, reorientation rate, behavior states) change relative to vessel type and speed. We used a land-based digital theodolite to record precise geographic coordinates of dolphins and vessels and to provide an accurate overview of habitat overlap and movement patterns that were previously unavailable from this location (Würsig et al., 1991; Gailey & Ortega-Ortiz, 2002). This approach allowed for a remote, non-invasive method of describing the movement patterns of dolphins without influencing or altering the animals' behavior. Several previous land-based studies were conducted from Lantau Island to assess dolphin behavior in the presence of various vessel types, including dolphin-watching, passenger, fishing, high-speed, and cargo vessels (Ng & Leung, 2003; Hung, 2004); however, to our knowledge, there are no peer-review published data evaluating dolphin and vessel overlap with the use of a precision digital theodolite. An analysis of dolphin movements from an island just to the north of Lantau Island (Sha Chau and Lung Kwu Chau Marine Park) showed that dolphins increased speed during percussive piling operations during pier construction (Würsig et al., 2000). Thus, these dolphins may respond similarly to vessel activities.

Three shore-based theodolite stations (Fan Lau, Sham Wat, and Tai O) were used along the north- and southwest coasts of Lantau Island, Hong Kong, to study the behavioral response of dolphins to vessel traffic (Figure 1). Stations were selected based on height above sea level (> 20 m) (Würsig et al., 1991), close proximity to shore, and relatively unobstructed views of dolphin habitat (Table 1). To maximize observation time, research was typically conducted from one station per day so that valuable daylight hours were not spent travelling among sites.

A digital theodolite (Sokkia/Sokkisha Model DT5) with 30-power magnification and 5-s precision was used to obtain the vertical and horizontal angle of each dolphin and vessel position. Angles were converted to geographic coordinates (latitude and longitude), and data were recorded using *Pythagoras* software, Version 1.2 (Gailey & Ortega-Ortiz, 2002). This method delivers precise positions of multiple spatially distant targets in

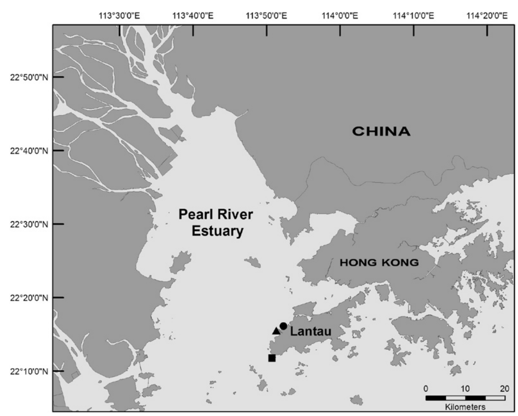

Figure 1. Locations of shore-based stations (Fan Lau ■, Sham Wat ●, Tai O ▲) along the north- and southwest coasts of Lantau Island, Hong Kong; dark grey areas portray land, and light grey areas portray water. (Map shapefile courtesy of the Hong Kong Government)

Table 1. Shore-based observation stations on Lantau Island, Hong Kong

Station name	Latitude (N)	Longitude (E)	Station height (m) at mean low water	Approx. distance from shore (m)
Fan Lau	22° 11' 45"	113° 50' 45"	28.94	20
Sham Wat	22° 16' 06"	113° 52' 19"	55.70	66
Tai O	22° 15' 30"	113° 51' 20"	73.36	85

a short amount of time, which are not as easily acquired from boat-based work.

Observers searched for dolphins using the unaided eye and handheld binoculars (7 × 50). A theodolite tracking session was initiated when an individual dolphin or group of dolphins was located. When possible, we selected a distinguishable individual, based on coloration, within the group. The focal individual was then continuously tracked via theodolite, with a position recorded each time the dolphin surfaced when possible. If an individual could not be positively distinguished from other members, we tracked the group by recording positions based on a central point within the group whenever dolphins surfaced (Bejder, 2005; Martinez, 2010). Tracking continued until animals were lost from view, moved beyond the range of reliable visibility (> 5 km), or environmental conditions obstructed visibility (e.g., intense haze, Beaufort sea state > 5, or sunset) in which case the research effort was terminated. In addition to the tracking of dolphins, all vessels that moved within 5 km of shore were tracked. An effort was made to obtain at least two positions for each vessel. Additional positions where acquired when vessels changed course or speed.

Theodolite tracks obtained from April through September 2011 were filtered to include only data obtained by experienced theodolite operators and to exclude potentially erroneous recordings identified by visual inspection of tracklines. We were unable to obtain a complete distribution of dolphins in Hong Kong waters via shore-based methods due to inherent limitations in sighting distance. The limit at which consistent observations and reliable recordings could be made was within 5 km of the stations. Lack of dolphin and vessel tracks between sites is an artifact of limited land-based sighting distance. Usable data totaled 95.67 h of tracking (Table 2). Effort was greatest at the Tai O location due to accessibility of station sites. Dolphin and vessel positions were plotted and overlaid on a map to visually examine habitat overlap. Data were then evaluated for dolphin leg speed and bearing changes in the presence of different vessel types. The leg speed of dolphins was calculated by dividing the distance travelled by the duration between two consecutive positions (Gailey et al., 2007). Reorientation rate quantifies the change in bearing along individual tracklines relative to linear movement. This rate was calculated by adding all bearing changes in degrees along a trackline and dividing by total duration in minutes of that trackline (Smultea & Würsig, 1995).

Table 2. Shore-based tracking data collected from April through September 2011 from Lantau Island, Hong Kong

Station name	Number of days	Research effort (hh:mm)
Fan Lau	4	11:35
Sham Wat	5	13:41
Tai O	22	70:24
Total	**31**	**95:40**

It is not possible to record two subjects (e.g., a dolphin and a vessel) simultaneously with one theodolite (therefore obtaining the position of a dolphin and a vessel at precisely the same time), although two subjects can be recorded in succession relatively quickly regardless of the distance between them. Vessel positions were interpolated *post hoc* based on dolphin position times, allowing for a more precise estimation of vessel distances from dolphins. For this analysis, a vessel was considered present if it was within 1 km of the focal dolphin position. Tracklines of dolphins with no vessels present (reference) and tracklines of dolphins with one vessel type within the 1 km threshold (treatment) were included in this analysis. Individual tracking sessions varied in duration; therefore, all tracks that met the above criteria were separated into approximately 10-min sections for analysis. One 10-min section per dolphin trackline was selected at random for analysis to reduce the risk of oversampling and pseudoreplication (Gailey et al., 2007; Lundquist et al., 2008). Tracklines less than 10 min in duration were excluded from analysis.

ArcMap, Version 9.3.1, was used to plot dolphin and vessel positions to visually evaluate spatial habitat overlap; Microsoft *Excel 2010* was used to conduct computational analysis of leg speed and reorientation rate; *R* statistical software was used to conduct power analysis; and *JMP* statistical software, Version 10.0.0, was used to perform descriptive statistics, goodness-of-fit normality tests, and one-way analysis of variance.

In waters off Lantau, vessels that overlapped with dolphin habitat included high-speed ferries, marine police vessels, research boats, sand barges, container ships, speedboats, dolphin tour boats, and commercial fishing trawlers (Figure 2).

Mean leg speed and reorientation rate of dolphins varied in the presence of some of these vessel types. Only dolphin movements in the absence of boats ($n = 8$) and in the presence of tour boats ($n = 13$) or trawlers ($n = 15$) were compared because sample sizes for other vessel types were too small ($n < 4$) to consider. Tour boats vary slightly; they are approximately 5 to 8 m in length, with fiberglass body construction and outboard motors. Trawlers (hang trawlers and shrimp trawlers) are larger vessels, approximately 20 to 25 m in length with inboard motors. One-way analysis of variance was

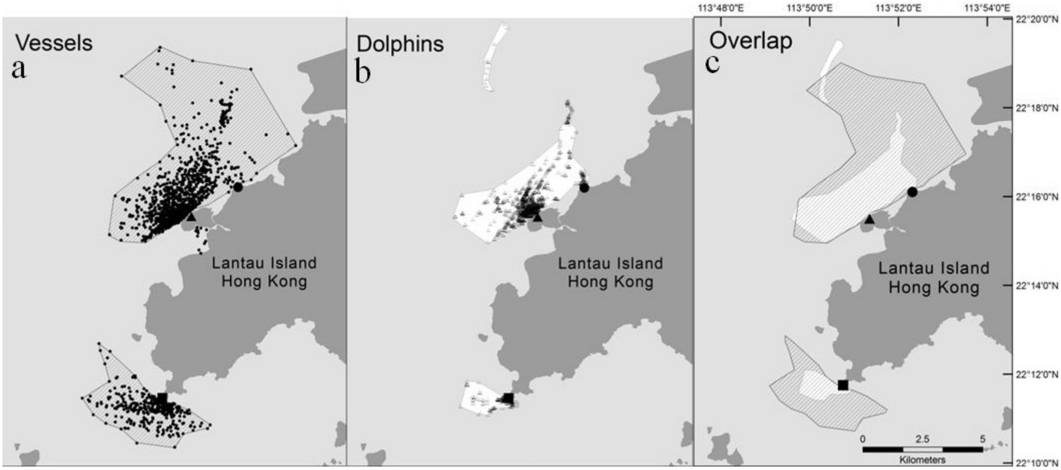

Figure 2. (a) Geographic coordinates (black dots) and polygon outlines (diagonal lines) of vessel positions, (b) geographic coordinates (black triangles) and polygon outlines (solid white) of *S. chinensis* positions, and (c) polygon outlines of (a) and (b) superimposed to evaluate habitat overlap (Map shapefile courtesy of the Hong Kong Government)

applied to determine if there was a significant difference among the means of no vessels present and the presence of tour boats vs trawlers. There was a significant difference in mean leg speed of dolphins ($p = 0.0469$), with the highest mean speed in the presence of trawlers (Figure 3). Although the mean reorientation rate was marginally higher in the presence of tour boats (Figure 4), this difference was not statistically significant ($p = 0.4709$). Shapiro-Wilk goodness-of-fit normality tests (Shapiro & Wilk, 1965) showed that data were not normally distributed for reorientation rate or leg speed, indicating that more data are necessary to run robust statistical analyses.

Field observations were consistent with preliminary results: dolphin behavior appeared to be affected by the presence of vessels and differed based on vessel type. Commercial fishing trawlers did not target dolphins directly, but dolphins changed course and increased speed to follow and forage behind and around them. Dolphin leg speed in the absence of vessels may be overestimated at times if approaching trawlers were detected by dolphins before moving within observer view. For example, a small portion of waters at the southwest corner of Tai O is obstructed by a hilltop, which potentially delayed detection of some vessels by observers. The mean reorientation rate of dolphins was lowest when trawlers were present, possibly because trawlers generally operate in a linear manner. Although trawlers likely concentrate prey items of dolphins, certain risks are associated

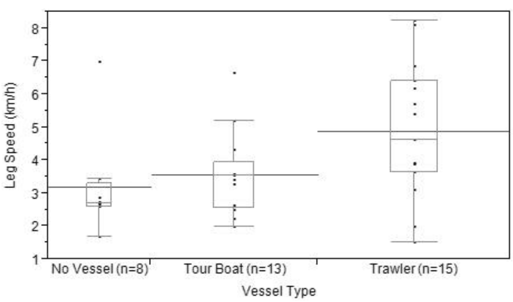

Figure 3. Leg speed of *S. chinensis* in the presence of different vessel types off Lantau Island, Hong Kong; boxes represent the 25th to 75th percentiles, short horizontal lines within the boxes represent the 50th percentile, long horizontal lines represent the means for one-way analysis of variance, and whiskers represent the 10th and 90th percentiles. There was a significant difference in mean leg speed of dolphins in the presence of trawlers ($p = 0.0469$).

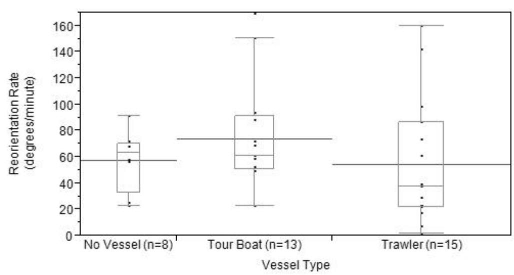

Figure 4. Reorientation rate of *S. chinensis* in the presence of different vessel types off Lantau Island, Hong Kong; boxes represent the 25th to 75th percentiles, short horizontal lines within the boxes represent the 50th percentile, long horizontal lines represent the means for one-way analysis of variance, and whiskers represent the 10th and 90th percentiles. There were no statistically significant differences in mean reorientation rate.

with this type of behavior. Direct interactions, such as propeller wounds, bycatch, and drowning, have been observed (Fertl & Leatherwood, 1997; Chilvers et al., 2003; Reeves, 2003). Less obvious impacts, including behavioral changes and shifts in social structure, have also been documented (Fertl & Leatherwood, 1997; Chilvers et al., 2003). At least 15 different species of odontocetes are known to feed on fishes associated with commercial trawlers worldwide, as reviewed by Fertl & Leatherwood (1997). Barros et al. (2004) suggested that dolphins may feed on fishes caught in the nets of trawlers or stirred up by trawler activity in Hong Kong waters. Interactions with trawlers in Hong Kong waters potentially present increased risks of vessel collision with, or net entanglement of, dolphins.

Tour boats that targeted dolphins remained in areas of dolphin habitat for short periods; however, they entered and departed abruptly and at high speeds (leg speeds up to 41 km/h). Reorientation rates were not statistically significant in this analysis, perhaps due to small sample sizes. However, field observations indicated that dolphins appeared to change direction more often when tour boats were present vs when they were absent, possibly to avoid unpredictable, fast moving objects. Several studies support the concept that predictable vessel movement results in less impact on dolphin behavior and is thus an important component of responsible vessel operation near odontocetes (Williams et al., 2002; Constantine et al., 2004; Lusseau, 2006). As such, this aspect should be considered when establishing vessel guidelines in marine mammal habitat.

Our preliminary data suggest that short-term changes in dolphin movement occur in the presence of different vessel types in Hong Kong waters, but more information is needed for rigorous statistical analyses. We conducted a power analysis based on a balanced one-way analysis of variance using *R* statistical software. We selected an effect size of 0.3, a significance level of 0.05, and a power of 0.9. Based on these conservative values, increasing our sample size to $\geq$ 48 will increase our power to detect moderate trends. Data collection continues in an effort to further evaluate these objectives in addition to other long-term objectives, including assessing dolphin movement patterns relative to the quantity, type, and distance of vessels present. Longitudinal research is necessary to evaluate potential long-term biological effects of vessel traffic on Indo-Pacific humpback dolphins in Hong Kong, and to make meaningful recommendations to policymakers.

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