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# Rapid changes in environmental factors could affect the distribution of Taiwanese humpback dolphins (*Sousa chinensis taiwanensis*) off the coast of Yunlin, Taiwan

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ABSTRACT: A small population of fewer than 80 *Sousa chinensis taiwanensis* inhabits the western coast of Taiwan. To explore the relationship between environmental factors (water depth, temperature, salinity, turbidity, and pH) and distribution patterns of dolphins, this study was conducted in Yunlin, which has been one of the population's core areas despite being subject to heavy industrial development. 242 day-surveys were conducted along four parallel transect lines between 2008 to 2018, during which sightings of 274 dolphin groups of this species were recorded. The standardized dolphin sighting rate (groups/100km) was used as an index for comparison. Contrasting to the roughly steady distribution in east-west gradient, the north-south gradient exhibited substantial and varied temporospatial changes among three sections (north, middle, and south) off the coast of Yunlin and among three periods. Dolphin sighting rate during spring-summer was significantly higher than that during Autumn-winter. Taking data from inshore surveys for long term comparison, we found that sighting rates at the middle section remained high and relatively stable (around 2-4.6), whereas the rates in the other two sections exhibited opposite trend with high fluctuations, e.g. drastically fluctuated between 0-3.4 in the northern section, while from 3.36 declined to 0.35 in the southern section. We further discovered that rapid changes in three environmental factors, including turbidity, pH, water depth and construction disturbance, could play key roles on dolphin distribution patterns, and can serve as good indicators for habitat suitability for this vulnerable subspecies.

KEY WORDS: distribution, environmental factors, pH, turbidity, *Sousa chinensis taiwanensis*, Taiwanese humpback dolphins.

## INTRODUCTION

Indo-Pacific Humpback Dolphins have been considered to occur in shallow, coastal waters from central China (the northernmost records near the estuary of the Yangtze River) in the east, southward throughout Southeast Asia, and westward around the coastal rim of the Bay of Bengal to at least the Orissa coast of eastern India. Due to the uncertain taxonomic status of humpback dolphins from Bangladesh, eastern India and Sri Lanka, at this time the confirmed range of *S. chinensis* should only be considered to extend west to the Bangladesh/Myanmar border. (Jefferson *et al*., 2017). Initially sighted in Chinese waters and described by Pehr Osbeck in 1765 (Flower, 1870; Jefferson and Karczmarski, 2001), humpback dolphins between southeastern Africa and China are thought to belong to a single species, *Sousa chinensis*. So far, eight Indo-Pacific humpback dolphin populations have been claimed and are distributed from east to west as, Eastern Taiwan Strait [ETS] population by Wang *et al*. (2004, 2007); Ningde population by Chen *et al*. 2012; Xiamen population by Liu and Huang (2000); Chen *et al*. (2008, 2011); Chou *et al*. (2013); Shantou population by Wu (2010); Pearl River Estuary [PRE] population by Jefferson (2000) and Hung (2008); Zhanjiang population by Xu *et al*. (2012, 2015); Sanya population by Dong *et al*. (2017); and the northern Beibu Gulf population with 2 subgroups by Chen *et al*. (2009, 2016). Furthermore, the ETS population is believed to have a more spotted pigmentation than the populations of Xiamen and PRE (Wang *et al*. 2008), and was thus defined as a new subspecies of Indo-Pacific humpback dolphin (*S. chinensis taiwanensis*) (Wang *et al*. 2015). Being a small and diminishing population that faces numerous threats, this population was designated as "critically endangered" by the Red List of Threatened Species of the IUCN in 2018 (Wang *et al*.,2018).

In Taiwan, the population of *S. chinensis taiwanensis* is distributed along a continuous but narrow coastal strip from Longfeng Port in Miaoli to Jiangjun Port in Tainan, on the west coast of Taiwan. Less than 80 individual dolphins are distributed in shallow waters up to a depth of 15 m, within 3 km from the shore at depths of 7-8 m. In terms of the dolphins' distribution within different offshore areas, they occur at a mean offshore distance of 1.4 km, generally closer to shore in the northern and southern extents of their range and at a greater distance from shore in the middle of their range. Their entire range spans approximately 200 km from north to south (Chou *et al*., 2015). Estuarine prey species dominate the diet of this species (Barros *et al*., 2004). Despite the high human density and extensive industrial and agricultural development in the area, the dolphins have remained in this habitat. Therefore, this population is at a high risk of extirpation, and faces being impacted by some major anthropogenic threats including fisheries bycatch, chemical and biological pollution, noise and habitat loss and degradation (Wang *et al*., 2004b, 2007; Reeves *et al*., 2008b).

The coastal waters of Yunlin are one of Taiwan's most important habitats for this sub-species but there are increasing pressures on this population in this area (Dares *et al*., 2017； Chou *et al*., 2018). Following extensive land reclamation, the first industrial port was constructed in Yunlin in 1992, and the resulting changes in the coastal terrain and increases in shipping activity impacted several species of wildlife. Since the Mailiao Power Plant began operation in 1999, new problems have arisen; flue-gas desulfurization during the electricity production process and subsequent water discharge has caused acidification of the surrounding waters. The dilution of sulfide during the sludge-activation process has caused an overall increased in pH. Additionally, the industrial district is located next to the Zhuoshui River, which is well known for its highly fluctuating turbidity and high organic input to coastal waters. The drastic changes in environmental factors in the estuarine area may also affect the distribution of dolphins. The combined natural and human factors make it difficult for this population to thrive in this area. This study explores the associations between environmental factors and dolphin distribution patterns in this heavily impacted area.

## MATERIALS AND METHODS

### *Board Surveys*

The survey area extended from the north of Zhuoshui River (23°52'N) to the south of Taizhicun (23°34'N) in Yunlin, Taiwan (Fig. 1). Each year, a predetermined series of transect lines was defined. However, the survey design varied between years. During the first year (2008) of pilot study, only one "inshore route" was conducted. In 2009, the scope of the survey was expanded to include additional areas, further away from the shore. Different surveys were designated as the "inshore route" and three "offshore routes" (distributed in parallel to the inshore routes and separated by 0.5 nautical miles) (Fig. 1). Thus, each day-survey consisted of the inshore route and one of the 3 offshore routes (one trip for each route). The order of routes was determined randomly, and each route was 36.9 km long. During surveys, a handheld GPS satellite positioning system (GPSMap 64ST, Garmin Corp., Taiwan) was used to plan and log the route. The survey effort "on effort" was defined on the transect line and as the survey period when the sea states were Beaufort 4 or better (according to Beaufort Wind Scale). The "off effort" was defined as a Beaufort Sea state was worse with visibility less than 1km (poor), or when survey route was interrupted by sighting, boat issues, or other unplanned events causing the vessel to leave the survey route. Surveys were largely conducted between early April and early October from 2008 to 2018, which are generally the calmest weather and sea state months.

The surveys were conducted from a 11m–long fishing boat traveling at speeds that varied between 4 and 9 knots. At least four observers were onboard for each survey, and rotated through 3 positions; two using binoculars and observing areas from the bow to the port and starboard (8× and 10× magnification) and one using the unaided eye to observe the area immediately in front of the boat. Observers were positioned on a high viewing platform and observed the area from 090 degrees' port to 090 degrees starboard. The observers alternated positions every 20 minutes to avoid fatigue. After an hour's duty, each observer had a 20 minutes' rest period.

### *Environmental data*

The research area spanned 19 minutes of latitude (23°34'-23°52'), thus environment factors were recorded at 19 stations, with distance interval of one-minute latitude. YSI pro1030 (YSI, USA) was used to measure the water temperature, salinity, and water hydrogen ion concentration (pH). The HACA 2100Q (HACH, U.S.A) was used to measure the water turbidity and depth was recorded using a fish finder (Koden cvs-126, Koden Electronics corp., Japan). When dolphins were encountered, the sighting location was recorded using the GPS. The distance to the location of dolphin was sighted was determined using the Taiwan Blue Chart v5 map (Garmin Corp., Taiwan) in addition to distance the dolphins was sighted from the ship. During each dolphin encounter, water temperature, salinity, pH, water depth, and turbidity were also recorded, in addition to the group size estimate. A digital monocular camera or video recorder was used to capture images of the dolphins for later photo identification analysis. When the dolphins vanished from the observers' field of vision, the observers waited for 10 minutes before confirming the end of the encounter and restarting survey effort.

### *Survey data analysis*

#### Sighting rate

The north-south area of Yunlin Coast contains three distinct zones, the northern one with intense industrial development, the middle one is a modified estuary and the southern one has low development. These are located to the north, middle and south of Yunlin County. Mailiao Harbor (23°47'N) is located between the north and middle sections and Santiaolun Harbor (23°40'N) is located between the middle and south sections. These sections are referred to as:

(1) YLN, 23°52'–23°47'N, the north section of Yunlin County,

(2) YLM, 23°47'–23°40'N, the middle section of Yunlin County,

(3) YLS, 23°40'–23°34'N, the south section of Yunlin County (Fig. 1).

The survey data were pooled according to different sections and different routes. The dolphin sighting rate,

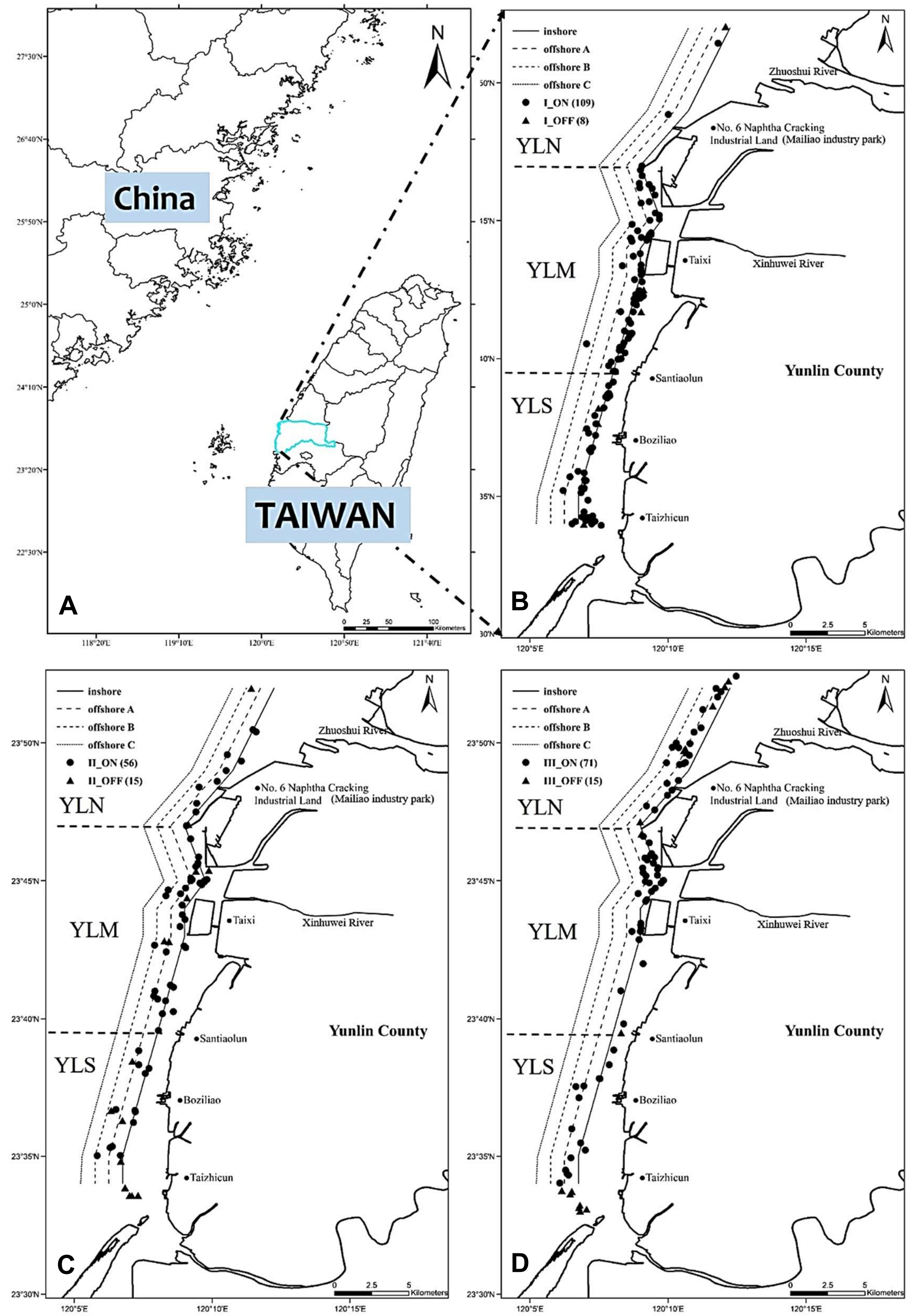


**Fig. 1. A**. Four parallel transect lines were established for regular surveys. The "inshore route" (solid line) is the nearest to shore, and the other three lines (dashed lines) are the "offshore routes," labeled A, B, and C in descending order of distance from the shore. The distance between each line is 0.5 nautical miles. Spatial distribution of dolphin sightings (with or without a mother–calf pair) during three periods (**B**. period I: 2008–2010, **C**. period II: 2012–2014, **D**. period III: 2016–2018). The circle represents on-effort sightings of groups, and the triangle represents off-effort sightings of groups.

spatial distribution and environmental factors were plotted. In order to explore inter-annual variation, 2008-2010 is defined as the first period, 2012-2014 as the second period and 2016-2018 as the third period. Data from 2011 and 2015 are not included due to the low effort conducted in these years (fewer than 10 surveys).

To facilitate comparisons between different time points and locations, a standardized sighting rate was calculated:

$$Sighting\ Rate = \frac{number\ of\ sighting}{effective\ effort}\ \text{(groups/100 km)}$$

* only "on effort" data area used for this calculation
* only the inshore route data used for comparisons.

Seawater temperature recorded at weather stations by the Central Weather Bureau in Fenzi, Yunlin County was used to differentiate seasons, with an average sea surface temperature (SST) of 20 °C as the change point. Temperatures below 20 °C indicate winter; December through March are winter months because the minimum temperature in these months can drop below 14 °C. On average, the SST is higher than 28 °C in summer, and June through September are summer months and the maximum temperature in these months can exceed 32 °C. Thus, the seasons can be defined as April-May (spring), and June-September (summer), October-November (autumn), and January-February (winter).

### *Data analysis*

The Kruskal-Wallis test was used for statistical data analysis to determine whether the sighting rate differed significantly between seasons, and the Mann-Whitney test was employed to determine which seasons exhibited significant differences. The statistical analysis performed in R (https://www.r-project.org/) (version 3.1.1).

## RESULTS

### *Survey effort*

From April 2008 to October 2018, a total of 242 surveys were conducted. In 2008, surveys were conducted only on the inshore line. From 2009, surveys transect lines varied in numbers; 4 transect lines (2009), 3 transect lines (2011-2014), and 2 transect lines (2016-18). There were very few offshore dolphin sightings so the survey area was rescued to focus nearer the coast. In total, 274 dolphin groups were recorded (only one species), with 202, 61, 11, and 0 sightings on the inshore routes and three offshore routes, respectively (Table 1).

The results demonstrate that the distribution of Taiwan humpback dolphins is concentrated in a relatively narrow strip along the coast of Yunlin County but density varied between the three sections. The fewest sightings were made in YLN but with a markedly increasing trend: 2, 12, and 28 groups in periods I, II, and III, respectively. By contrast, in both YLS and YLM, sightings decreased from period I to II; with 67, 26 and 29 groups in periods I, II and III, respectively (YLS) and 47, 32 and 31 groups in periods I, II, and III, respectively (YLM) (Table 1).

**Table 1.** Number of dolphin groups sighted either "on effort" or "off effort" during 484 survey trips (242 conducting days) along four transect lines during 2008 to 2018.

| | Inshore | Offshore A | Offshore B | offshore C |
|---|---|---|---|---|
| Year | *On/Off (Trips) | *On/Off (Trips) | *On/Off (Trips) | *On/Off (Trips) |
| 2008 | 47/1 (80) | NA | NA | NA |
| 2009 | 27/3 (33) | 3/1 (11) | 2/0 (12) | 0/0 (10) |
| 2010 | 24/3 (28) | 5/0 (14) | 1/0 (14) | NA |
| 2012 | 15/2 (24) | 3/2 (12) | 3/2 (12) | NA |
| 2013 | 13/2 (24) | 5/1 (12) | 1/1 (12) | NA |
| 2014 | 9/2 (24) | 7/2 (12) | 0/1 (12) | NA |
| 2016 | 16/2 (22) | 6/1 (11) | 0/0 (11) | NA |
| 2017 | 22/5 (24) | 15/5 (24) | NA | NA |
| 2018 | 7/2 (21) | 5/0 (21) | NA | NA |

*On: on effort; Off: off effort; NA: not available

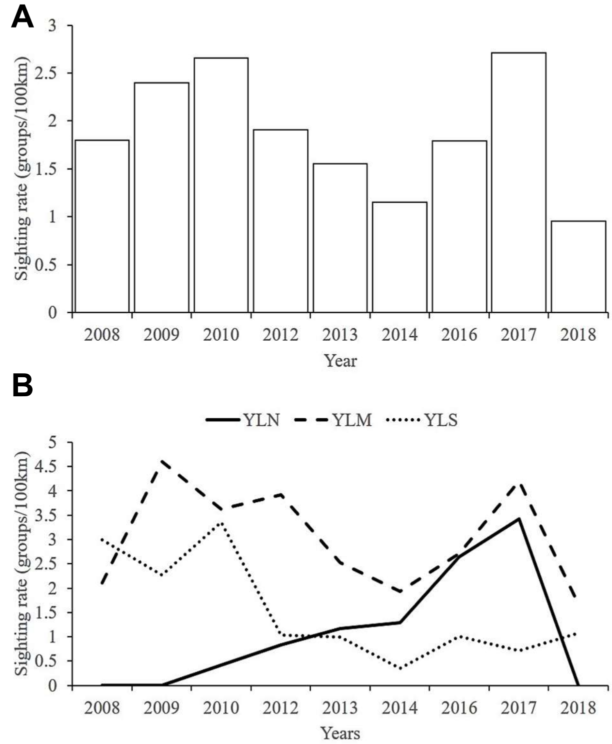


**Fig. 2.** Yearly variation in the dolphin sighting rate of the inshore transect lines **A**. for the whole county coastal line and **B**. separated by three sections.

### *Temporospatial variations in the sighting rate on inshore routes*

Comparison of the standard sighting rates (sightings per unit of 100-km survey effort) in the inshore area, the annual dolphin sighting rate appeared to exhibit a cyclic variation among the years, with two peaks in 2010 and 2017 (with rates of 2.66 and 2.71, respectively), and two

**Table 2.** On-line survey effort (km), number of sighted dolphin groups, and sighting rate (SR) for the "inshore route" among three sections during 2008 to 2018. YLN: northern section, YLM: middle section, and YLS: southern section.

| | Total | | YLN | | YLM | | YLS | |
|---|---|---|---|---|---|---|---|---|
| Year | Effort (Groups) | SR | Effort (Groups) | SR | Effort (Groups) | SR | Effort (Groups) | SR |
| 2008 | 2616.01 (47) | 1.80 | 723.85 (0) | 0.00 | 1090.90 (23) | 2.11 | 801.25 (24) | 3.00 |
| 2009 | 1126.41 (27) | 2.40 | 315.98 (0) | 0.00 | 368.91 (17) | 4.61 | 441.61 (10) | 2.26 |
| 2010 | 902.421 (24) | 2.66 | 241.35 (1) | 0.41 | 303.63 (11) | 3.62 | 357.44 (12) | 3.36 |
| 2012 | 785.801 (15) | 1.91 | 239.91 (2) | 0.83 | 255.54 (7) | 2.74 | 290.36 (6) | 2.07 |
| 2013 | 836.971 (13) | 1.55 | 256.28 (3) | 1.17 | 277.14 (7) | 2.53 | 303.55 (3) | 0.99 |
| 2014 | 780.091 (9) | 1.15 | 231.69 (3) | 1.29 | 258.58 (5) | 1.93 | 289.82 (1) | 0.35 |
| 2016 | 781.861 (14) | 1.79 | 227.30 (6) | 2.64 | 258.08 (5) | 1.94 | 296.48 (3) | 1.01 |
| 2017 | 775.091 (21) | 2.71 | 234.22 (8) | 3.42 | 262.01 (7) | 2.67 | 278.86 (6) | 2.17 |
| 2018 | 735.281 (7) | 0.95 | 215.98 (0) | 0.00 | 238.76 (5) | 3.00 | 280.55 (2) | 1.25 |
| | | 1.88±0.21 | 298.51±48.87 (2.56±0.85) | 1.09±0.37 | 368.17±82.55 (9.67±1.91) | 2.79±0.27 | 371.1±51.15 (7.44±2.17) | 1.83±0.3 |

troughs, in 2014 and 2018 (with rates of 1.15 and 0.95, respectively) (Fig. 2a). Furthermore, annual variation was different between the three sections. The sighting rate in the YLM section remained the highest, with an average of 2.79 groups/100 km (variation of 1.93-4.61 groups/100 km), however, the opposite was observed in the YLS and YLN sections. The sighting rate at YLS was high for the first 3 years (2.26-3.36 groups/100 km) years and then continually decreased until it reached the lowest rate of 0.35 groups/100 km in 2014. By contrast, the sighting rate at section YLN increased from zero in the first 3 years to 3.42 groups/100 km in 2017 before declining again to zero again in 2018 (Fig. 2b; Table 2).

### *Seasonal variations in seasonal sighting rates in the inshore area*

Survey effort varied between seasons (due to weather restrictions). The number of dolphin sightings and the number of survey trips in each season were 26 groups and 42 day trips in spring, 111 groups and 173 day trips in summer, 2 groups and 11 day trips in autumn, and 3 groups and 10 day trips in winter, respectively. The Kruskal-Wallis test results revealed a significant difference in the sighting rate among the four seasons ($p< 0.05$). The Mann-Whitney test was employed for matched-pair comparison and indicated no significant differences between spring and summer or between autumn and winter. However, the matched-pair comparison revealed significant differences between spring and autumn or winter ($p= 0.02$, $p= 0.03$) and between summer and autumn or winter ($p= 0.01$, $p= 0.01$), indicating the presence of two distinctive seasonal distributions (e.g., spring-summer vs autumn-winter) (Fig. 3).

### *Environmental factors*

Environmental parameters were collected both during a dolphin sighting and from fixed stations along the transect lines. The means, standard errors and medians of the five environmental factors at each sighting location were: water surface temperature: 29.16 ± 0.13 (29.7) (°C), water surface salinity: 32.55 ± 0.12 (33.2) (⁰/₀₀), pH: 8.11 ± 0.01(8.13), turbidity: 8.76 ± 0.67 (6.85) (NTU), and water depth: 7.98 ± 0.28 (7.5) (M) (Table 3). At the fixed stations, water surface temperature: 28.8 ± 0.03 (30.3) (°C), water surface salinity: 32.28 ± 0.0.03 (33.9) (⁰/₀₀), pH: 8.09 ± 0.001 (8.15), turbidity: 13.92 ± 0.50 (10.1) (NTU), and water depth: 10.02 ± 0.07 (8.5) (M) (Table 3). There were significant differences in 2 factors, depth and turbidity, between dolphin location site conditions and overall survey conditions (t-test, ps< 0.05). Although no significant difference in total mean pH values between the dolphin locations and overall site conditions, the pH measured in the period I and II at YLN were significantly lower than that for dolphin locations (t-test, ps< 0.01).

By further comparing the temporal changes at each section, only three environmental parameters exhibited significant changes between time periods in 2 sections, i.e. significantly increased pH-value, significantly decreased

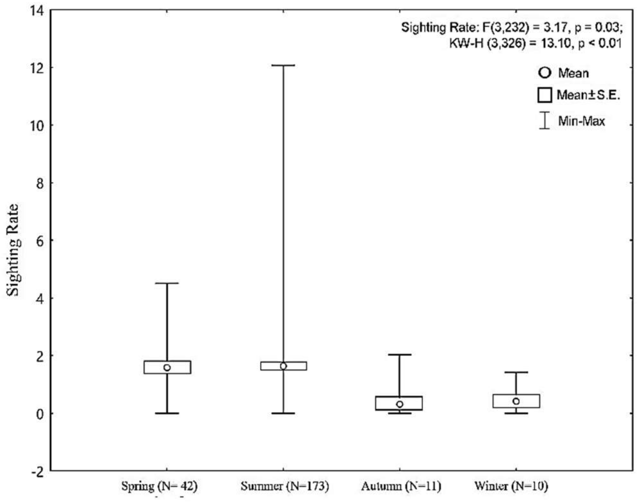


**Fig. 3.** The difference in dolphin sighting rate was significant among the four seasons (Kruskal–Wallis test, p < 0.01). Further pair comparison revealed that significant differences were observed for spring–autumn and spring–winter pairs (Mann–Whitney test, p = 0.02, p = 0.03) and for summer–autumn and summer–winter pairs (Mann–Whitney test, p = 0.01, p = 0.01).

**Table 3.** Measurements of five environmental factors (temperature, salinity, depth, pH, turbidity) collected at measuring stations at three sections (YLN, YLM, YLS) during three periods (I, II, and III) and the dolphin sighting location (S).

| | | Temperature(°C) | | Salinity ($^0/_{00}$) | | Depth (M) | | pH | | Turbidity (NTU) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | mean ± SE (median, min-max) | N | mean ± SE (median, min-max) | N | mean ± SE (median, min-max) | N | mean ± SE (median, min-max) | N | mean ± SE (median, min-max) |
| YLN | I | 590 | 29.5±0.07 (29.8, 20.8-33.7) | 568 | 32.55±0.08 (32.8, 17.5-34.5) | 589 | **13.45±0.37 (11.8, 1.3-38)** | 417 | **7.89±0.008 (8.06, 7.31-8.28)** | | NA |
| | II | 628 | 29.0±0.09 (29.3, 14.8-33.8) | 585 | 31.85±0.11 (32.6, 15-34.9) | 581 | 9.32±0.3 (6.4, 1.2-32) | 517 | **7.99±0.008 (8.04, 7.3-8.28)** | 508 | **22.96±2.77 (10.7, 1.04-928)** |
| | III | 762 | 28.77±0.10 (29.6, 17.2-33.9) | 720 | 32.68±0.11 (33.6, 5.4-34.9) | 750 | 9.89±0.24 (8, 0.5-36) | 742 | 8.1±0.04 (8.13, 7.53-8.28) | 762 | **16.15±1.45 (8.6, 0.24-783)** |
| YLM | I | 658 | 29.2±0.08 (29.6, 20.5-32.0) | 631 | 32.62±0.07 (32.8, 26.8-34.9) | 662 | 12.44±0.18 (12, 1.7-29.6) | 469 | 8.1±0.003 (8.11, 7.6-8.29) | | NA |
| | II | 664 | 28.4±0.09 (28.7, 18.7-32.7) | 623 | 32.43±0.05 (32.6, 23.9-34.9) | 629 | 12.0±0.16 (12.5, 3.6-29.6) | 543 | 8.09±0.003 (8.1, 7.65-8.28) | 538 | 9.41±0.28 (7.85, 1.06-57.9) |
| | III | 809 | 28.4±0.10 (29, 17.1-32) | 771 | 32.90±0.05 (33.4, 22.9-34.9) | 804 | 11.5±0.11 (12.3, 3.1-27.8) | 790 | 8.14±0.002 (8.15, 7.8-8.29) | 807 | 9.06±0.29 (6.74, 1.55-81.1) |
| YLS | I | 792 | 29.5±0.07 (29.9, 20.3-32.6) | 762 | 31.85±0.08 (32.2, 18.9-34.9) | 791 | 7.32±0.13 (6.5, 0.8-19.2) | 543 | 8.10±0.004 (8.11, 7.8-8.29) | | NA |
| | II | 762 | 28.6±0.10 (29.3, 18.2-33.7) | 717 | 31.66±0.06 (31.8, 25.5-34.6) | 733 | 7.91±0.13 (8.2, 1.4-21) | 615 | 8.09±0.003 (8.09, 7.74-8.29) | 617 | 13.22±0.55 (10.4, 0.7-262) |
| | III | 927 | 28.6±0.10 (29.3, 17-33) | 906 | 32.11±0.06 (32.7, 24.4-34.9) | 926 | 8.42±0.09 (8.85, 1.7-21) | 899 | 8.13±0.003 (8.14, 7.63-8.29) | 929 | 12.72±0.45 (8.89, 2.07-206) |
| Total | | 6592 | 28.8±0.03 (30.3, 14.8-33.9) | 6283 | 32.28±0.03 (33.9, 5.4-34.9) | 6465 | 10.02±0.07 (8.5, 0.5-38) | 5535 | 8.09±0.001 (8.15, 7.3-8.29) | 4161 | 13.92±0.50 (10.1, 0.24-928) |
| S | | 248 | 29.2±0.13 (29.7, 18.8-33.9) | 242 | 32.55±0.12 (33.2, 25.5-34.9) | 242 | **7.98±0.28 (7.5, 1.6-32.2)** | 176 | **8.11±0.01 (8.13, 7.6-8.37)** | 113 | **8.76±0.67 (6.85, 2.23-51)** |

NA: not available, turbidity measurements began in period II.

turbidity, and slightly decreased depth in YLN; while slightly increased water depth in YLS. In YLN, significant differences between the three time periods were observed for pH (Krustal-Wallis test, df = 2, chi-squared = 227.68, $p < 0.01$) and turbidity (df= 1, chi-squared = 23.92, $p< 0.01$). Furthermore, the Mann-Whitney pairing test results revealed significant differences in pH between periods II and III ($p< 0.01$) and between periods I-III ($p< 0.01$). This result suggested that a significant increase in the lower-range pH value (approximately 7.3 to 7.6) occurred after period I. Turbidity was significantly diminished between periods II and III ($p< 0.01$). By contrast, the only parameter in YLS that exhibited any significant difference was water depth (i.e., the depth in periods II and III was significantly greater than that in period I (Table 3).

## DISCUSSION

With such a small population size (less than 80 individuals, Chou *et. al*., 2018), sighting opportunities were low which led, in turn to high variability in sighting rates. Therefore, greater survey effort is required to achieve more accurate information. It is often challenging to balance budget between the survey area to be covered and survey replications. This study focused on conducting surveys over with greatest area and with a higher effort when compared to previous studies in this area. The results demonstrate that sighting rates fluctuate greatly annually as well as between the three survey sections, i.e., with a steady increase in period I, decrease in period II and increase again in period III although with a decrease in 2018.

Environmental variables (e.g., temperature, turbidity, salinity, and pH) considerably influence the inshore distribution of cetaceans that are restricted to a relatively small range (Forcada, 2009). Salinity and temperature are major determinants of coastal and estuarine community structure, partially because of salinity tolerance and the adaptive ability of associated flora and fauna (Day *et al.*, 1989). For some inshore dolphins, the habitat characteristics, i.e., sea water temperature, water depth, and water clarity, were significantly correlated to occurrence, e.g., Hector's dolphins (*Cephalorhynchus hectori*) (Brager *et al.*, 2003). This study included turbidity and pH measurements and observed drastic changes in these variables coincided with the dolphins temporarily abandoning their usual habitat.

YLN was located at the mouth of the Zhuoshui estuary, and was influenced by several factors besides the Mailiao industry park. The Zhuoshui river is the longest river in Taiwan, with an average annual rainfall of approximately 2,459 mm and an average annual flow of approximately $6.095 \times 10^9$ $m^3$, mainly from heavy rainfall during May to October (Pai *et al.*, 2013). This heavy rainfall can transport large amounts of debris and organic matter downstream, causing extremely high variation in turbidity that potentially affects seawater turbidity and other factors, such as phytoplankton density which, in turn, can lead to changes in the structure and productivity of food webs. Because of its proximity to the Zhuoshui estuary, YLN is quickly encroached by turbid fresh water after typhoons, the southwesterly monsoon and rain, thus causing drastic variation in turbidity (0.24-928 NTU in this study). Based on the results of food web model research, it can be inferred that fish resources are an important factor affecting the distribution of dolphins (Pan *et al.,* 2016). Thus, turbidity driven changes to the food web (includes dolphin prey), can alter dolphin distribution.

There is no significant difference in the environmental factors in YLS, except for a minor increase in depth, however, the depth range was still within that preferred range by this species. The dolphin sighting rate, however, was in continuous decline over the survey period. In 2017, a submarine cable was laid from Penghu to southern Yunlin and it is speculated that related construction activities may have led to the dolphins abandoning the habitat by 2018. It is not known yet if the dolphins will return.

Another influencing factor is ocean acidification. The surface pH of seawater in a typical ocean is generally 8.0-8.3. When discussing global warming, scientists define ocean acidification as an average drop of approximately 0.1 in oceanic pH (Gattuso and Hansson, 2011), which demonstrates that even such a small drop of pH has a profound impact. The Conservation Working Group, Channel Island National Marine Sanctuary Advisory Council (2008) reported that decreases in seawater pH reduces the degree of $CO_3^{2-}$ saturation of seawater, which can alter ocean chemistry and substantially affect the physiology of marine life. In this study, a small area (<1km from the exit of drainage) of increased acidification was observed in YLN and was caused by the desulfurization of seawater by Mailiao power plants. The desulfurization process during electricity production produces acidified wastewater, the discharge of likely led to the decrease in the pH value of waters in YLN. Field measurements indicated that the pH value was low (average value = 7.89, min 7.31-max 8.28) during period I when no or very few dolphins were sighted. In 2014, the Formosa company constructed an aeration basin that diluted the sulfide emitted during the sludge-activation process. Subsequently, the pH value increased and as did the dolphin sighting rate. Chen *et al.* (2016) conducted a long-term monitoring task in the southwestern waters of Taiwan between 1993 and 2010 and discovered that when the pH value was under 7.8, the quantities of zooplankton, phytoplankton, shrimp larvae, crab larvae, fish egg and fish larvae significantly dropped. This is a strong indication that the discharged water should have a pH value above 7.8, to reduce negative impacts on marine zooplankton biodiversity and abundance. Different organisms have different pH tolerance ranges, and changes in pH affect organisms in every part of the food chain (Haines, 1987). It has been suggested that changes in environmental factors can be directly observed in lower order organisms in the food chain rather than be apparent in high-level predators, such as cetaceans, so it is changes in prey distribution that drives the spatial distribution of dolphins.

YLM exhibited high dolphin sighting rates for all 3 periods. This section contains a hot spot for dolphins, centered at the Xinhuwei estuary. Estuaries are major habitats for the genus *Sousa,* populations of which typically occur in shallow coastal water (depth < 20 m) (Wang *et al.*, 2016, Wang *et al.*, 2004a, Jefferson 2000). Estuaries are nurseries for juvenile fish and invertebrate species, and this increase in prey density likely drives the preference of some species of dolphins for estuarine areas (Ballance, 1992; Grigg and Markowitz, 1997; Harzen, 1998). Regarding the association between dolphin density (indicated by the sighting rate) and the food web, Pan *et al.* (2016) constructed an Ecopath trophic model for three food webs, namely those at the Zhuoshui River estuary, a power plant discharge exit, and the Hsinhuwei River estuary (an area of high dolphin density). It was shown that the high density of dolphins at the Hsinhuwei River estuary can be attributed to higher levels of phytoplankton production and the greater biomass of benthic invertebrates and fish compared with those at the other two sites. The tropical/subtropical estuary environment is usually characterized by copious amounts of organic debris, transported from mangrove forests. This can stratify the water column, which in turn can enhance productivity in and form these nursery areas for fish (Robertson and Duke, 1987; Hobbie, 2000). The available data suggest Taiwan dolphins are opportunistic-generalist predators, consuming a wide variety of coastal, estuarine, and nearshore reef-associated fishes (Heinsohn, 1979, Barros *et al.*, 2004). Effects on the environment may cause shortages in food resources and influence the distribution of cetaceans.

For opportunistic-generalist predators, such as cetaceans, temporal-spatial distribution is usually related to prey resources. Based on the results of the food web model research, it can be inferred that fish resources are an important factor affecting the distribution of dolphins in Yunlin (Pan *et al.,* 2016). As there have only been a few stranding cases, and these have had empty stomachs, the diet of these dolphins in Taiwan is poorly understood. According to research in the nearby waters of Hong Kong, this species has a diet comprised almost exclusively of fish, which is consistent with Liu *et al*. (2015) that identified the Taiwanese population was an exclusive fish eater based on the isotope analysis of two dolphin samples. Barros *et al.* (2004) reported the croaker (*Johnius* sp.) as the most frequent prey item for the *Sousa* population in Hong Kong, and the fish families

Sciaenidae, Engraulidae, Trichiuridae and Clupeidae accounted for over 93% of all prey consumed. Most of these are common in estuarine waters and often occur in large shoals. This study provides evidence that the distribution pattern of *S. chinensis taiwanensis* is influenced by the common rapid changes in local environmental factors. As the Taiwan dolphin population is very small, any slight change could lead to substantial impacts on this population and even lead to its extinction. Protection policies are required that focus on habitat health in order to conserve this critically endangered subspecies.

## CONCLUSIONS

The considerable variation in the temporospatial distribution pattern of *S. chinensis taiwanensis* off of the Yunlin County coast was shown to be associated with concomitant changes in local environmental factors, including turbidity and pH, as well as by construction activities. High turbidity and low pH value in YLN may have caused changes in the food web system that prompted the dolphins to leave. In addition, the submarine cable construction at YLS could have disturbed the dolphins sufficiently to cause them to abandon this habitat. Whether the dolphins will return to their original habitat after the environment has recovered, been restored or anthropogenic influences have decreased will depend on their resilience. This plays a crucial role for the conservation of such a small population. Therefore, the dynamic nature environment factors can serve as an index for dolphins' habitat suitability. Continual monitoring and understanding of the long-term dynamics of the habitat, especially the quantity and quality of food resources, can provide a foundation for good decision-making for the conservation of *S. chinensis taiwanensis* in Taiwan.

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