國立臺灣大學生命科學院生態學與演化生物學研究所

碩士論文

Institute of Ecology and Evolutionary Biology

College of Life Science

National Taiwan University

Master Thesis

中華白海豚在台灣之分布預測與活動模式

Distribution Prediction and Ranging Pattern of Indo-Pacific Humpback Dolphins *(Sousa chinensis)* in Taiwan

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中華民國 100 年 6 月

June, 2011

謝辭

出海在海上漂漂盪盪，第一次心中想的不是回去分析怎麼做，而是編排著誌謝的順序，好開心！心裡也閃過很多畫面。回想研究所的畢業典禮，比大學的時候多好大一份感動，因為做這些研究的每個過程不是像每堂課以成績衡量，可以摸魚的空間就更小了，投注的心力也更多。很感謝我的兩位指導老師，周蓮香與李培芬教授，選擇相信我可以做得到。總是在我摸索出方向後，忍受著我帶著一堆亂七八糟的圖討論，耐心、一針見血、又不忘記挫一下我銳氣地一起討論。老師的觀點總是有我考慮不到的方向，永遠值得學習。還有謝謝為我口試的丁宗蘇、林雨德、姚秋如老師們，不僅百忙中抽空，也給我好多珍貴的見解。

最大的核心，是實驗室一群一起出海的夥伴，沒有他們就沒有這篇論文。陸海空(重量級)章魚、飛龍、象哥，海綿寶寶 Emily 王，劉三敵，阿貘，林子皓，余欣怡，黃祥麟，王俊傑，張維倫，柯孟辰，林明慶，陳遠寧，辜以舒，謝嘉煌，林思瑩，郭毓璞，吳彥頡，王達勉，黃柏倫，吳彩豔，翁霈琪；深深地感謝大家在海上一起努力追尋著白海豚，創造好多珍貴的畫面，其中應該不少人在我暈船的時候 cover 過我。還有西岸的船長及大哥們，謝謝你們與我們分享海與海豚。

一開始踏入研究的世界難免有些徬徨，我很感謝當時地理系的朱健銘助教，帶我認識的 GIS，都是課堂上學不到的。最重要的是實驗室的夥伴們，給我精神上的支持及研究上的想法。往往都非常貼切，不論是我的思路的盲點或心情需要被鼓舞的部分。在口試預講的那晚大家仍以海豚同胞愛跟無限的耐心，給了我五個小時的建議跟回饋，太感謝！也特別謝謝陳小班學姐，努力的了解我的寫作模式還有融入第二章的內容，在很短的時間給了我很多意見，實在了不起也很辛苦。

這三年其實不太輕鬆，謝謝我身邊的朋友們在我皺眉頭說好忙後，從來不放棄一起吃飯走走放鬆；謝謝我的姐妹們在每個禮拜二鍥而不捨邀我一起聚，妳們是我強大的後盾，充分讓我體會到充電的感覺。很謝謝陳昱翔在每個時刻支持著我，聽我說所有的事，就算只是討論哪種分析方法好這類的嚴肅話題；跟你一起，周圍的事都有他們獨一無二的意義。還有感謝我的家人，在我奮鬥的時候，連生態池的薑母鴨怎麼不見了(其實他都在)這種小問題還先忍住不問，太可愛了！

以上，獻給每位我真心感謝的人。

中文摘要

中華白海豚多出沒於 25 米水深以內，由於與人類活動區域高度重疊，白海豚遭受許多人為活動的干擾等威脅。台灣西海岸的族群目前僅剩不到一百隻，已於 2008 年由 IUCN 紅皮書列為「嚴重瀕危」的保育等級。本研究的目的為透過分析 2006-2010 年海上調查所得資料，了解其空間分布，棲地特徵及活動模式，分為兩大部分進行。

第一部份是由族群的層級來探討影響台灣中華白海豚分布的因子，並進一步預測其分布模式。在 ArcGIS 9 的操作平台上建立調查區域環境因子的網格資料及白海豚目擊的點位資料，分別以三個預測模式運算：廣義累加模式 Generalized Additive Models (GAMs)，最大熵物種分布模式(Maximum Entropy Model, MaxEnt)及遺傳演算法(Genetic Algorithm for Rule-set Prediction, GARP)，篩選出能顯著區分白海豚出沒與否的因子組合及合適的推估模式。結果顯示網格內水深的最大值及標準差、鹽度標準差及離岸距離為影響海豚分布的關鍵因子。三種模式疊合分析後，預測在調查區域內中華白海豚的適合棲地僅侷限於沿岸水域，而在此棲地內，以苗栗縣南至大肚溪口(北)、雲林縣至外傘頂洲沿岸(南)之出現機率較高，另目擊率資料顯示為台灣中華白海豚兩個密度熱區。

第二部分由個體的層級比較於各年齡層(少、青、成、老年)及育幼與否於活動模式上的差異，包括範圍大小及棲地忠誠性兩個方面的探討。由已辨識出的 71 隻中華白海豚中篩選目擊十次以上之個體 57 隻，以最小多邊形法(Minimum Convex Polygon, MCP)計算海豚的活動範圍大小，平均 MCP 範圍為 192.6 km^2，另範圍平均南北長為 69.1km。於各年齡層及個體育幼與否皆無顯著差異，然老年個體使用的 MCP 範圍偏小。棲地忠誠性方面，使用群集分析區分不同地域的使用者，發現分別有只侷限在兩個熱區的居留者，以及往返南北的遷徙者。計算個體於兩個熱區內的月目擊率，發現居留者與遷徙者於目擊率上的分隔不明顯；又以南區遷徙者的目擊率與居留者的差異不顯著—多數的個體傾向為密集使用此區但偶爾離開此區活動的遷徙者。相較之下，利用北區的個體傾向為當地的居留者或是偶爾拜訪的遷徙者。此外，曾育幼之個體有較高的區域目擊率。

結合空間分布預測及個體的棲地忠誠性分析得知中華白海豚在台灣西海岸有

南北兩個主要分布的區域，為海豚所密集利用，確為台灣中華白海豚之重要棲地；另外曾育幼的個體對於這兩個區域的忠誠性也較高。未來應加入棲地利用的詳細研究，以對海豚於棲地內各區的偏好及其功能有更清楚的了解。

關鍵字：中華白海豚、空間分布、廣義累加模式、最大熵物種分布模式、遺傳演算法、活動模式、棲地忠誠性

ABSTRACT

Indo-Pacific humpback dolphins (hereafter Chinese White dolphins) inhabit in shallow coastal waters, almost within 25 m depth. Due to the proximity to areas of human activity, Chinese white dolphins have encountered tremendous threats caused by many anthropogenic activities. In Taiwan, the population size is no more than 100 individuals and the population has been listed as "Critically Endangered" (CR) by IUCN since 2008. With a view to providing practical information to conservation management, the purpose of this research is to identify critical regions within habitat, including finding key factors that influenced the distribution pattern in population level and investigating differences in ranging patterns among age classes and breeding statuses in individual level as described in the following two parts.

In the first part, habitat modeling techniques were applied to build prediction models. The environmental raster data within 2006-2010 survey coverage and occurrence of dolphins including sighting and tracking positions (n=2289) were input to ArcGIS 9. Three models were applied, including Generalized Additive Models (GAMs), MaxEnt (Maximum Entropy Modeling) and GARP (Genetic Algorithm for Rule-set Prediction). The appropriate models were selected, containing key factors including maximum water depth, standard deviation water depth, standard deviation salinity and distance to shore. An ensemble models was generated by overlaying these three models to obtain map of suitable areas for Chinese white dolphins in Taiwan. Predicted suitable areas were limited inshore, with the probability of occurrence was higher in coastal area of southern Miaoli County to Dadu River and coastal area of Yunlin County to Waisanding Sandbar.

In the second part, individual ranging pattern was investigated and comparisons were made between age classes and breeding statuses. For the range estimate, 57 individuals with more than ten sightings were selected from 71 identified dolphins. Minimum Convex Polygon (MCP) method and latitudinal length were the two estimators for the range size. The average MCP size was 192.6 km^2, and the average latitudinal length was 69.1km. Old individuals tended to have smaller ranges despite non-significant result.

As for site fidelity, individuals were divided into residents and transients to north and south region respectively based on cluster analysis in range use, but the monthly sighting rate didn't show clear stratification. Sighting rates of transients were close to those of residents in southern region, where most individuals tended to utilize as intensively as residents, but visited other areas on occasion. On the other hand, many dolphins tended to be either residents or transients that visited other areas frequently. In addition, females who have been observed calving have significantly higher sighting rates.

To sum up, the result of distribution prediction, ranging patterns and site fidelity revealed two suitable areas that were occupied by residents. Moreover, dolphins who used to be mothers used these regions more frequently. Specific research in habitat use should be carried out in future to obtain detailed information about habitat preference and possible functions of regions within habitat.

Key words: Chinese white dolphins, distribution pattern, GAMs, MaxEnt, GARP, ranging pattern, site fidelity

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Chapter 1 General Introduction

Indo–Pacific Humpback Dolphin

Indo-Pacific humpback dolphins (hereafter Chinese white dolphins) inhabited inshore waters of western Taiwan. According to studies conducted by Wang et al. (2004, 2007), Chinese white dolphins were distributed across the inshore waters from Tongxiao (通霄) to Taixi (台西), where the length of the coast was approximately 100 km; and the dolphins occurred within about 2 km from the shore. The estimated population size was small and no more than 100 (Wang et al. 2004, 2007, Yu et al. 2010).

Despite the ecological knowledge of this population was primitive, the conservation concerns for the survival of this small, limited-distributed population had been aroused. Prior to proposing conservation plans such as delineation of protected areas and suggestion of associated management, it is critical to understand the relationship between Chinese white dolphins and their habitats in Taiwan. Therefore, one of the goals of this study was investigate how environmental factors shaped the distribution pattern, which would be the theme of Chapter Two. Using habitat modeling approach, characteristics of suitable habitats could be identified and predictions for suitable habitats would be made.

Another aspect was the individual ranging pattern, which was the complex of ecological and demographic factors. The investigation of ranging patterns allowed understanding of individual range use and provided insights to essential microhabitats. In

Chapter Three, major themes included the estimation of individual range and evaluation of site fidelity of regions. To sum up, Chapter Two was aimed to offer interpretation about habitat selection from the aspects of environmental factors. However, ranging pattern was investigated to understand the differences of space use among individuals in Chapter Three.

Taxonomic status

Two species of humpback dolphins belonging to the genus *Sousa* are currently recognized by the IUCN (International Union of Conservation of Nature) and IWC (International Whaling Commission): the Atlantic humpback dolphin *S. teuszii* (Kükenthal, 1892), found in the coastal waters of western Africa, and the Indo-Pacific humpback dolphin *S. chinensis* (Osbeck 1765), found off the coasts of South Africa, India, the Indo-Malay Archipelago, northern Australia and southern China (IWC 2006, Reeves et al. 2008a). A previous morphological study conducted by Jefferson and Van Waerebeek (2004) suggested that three groups existed, based on patterns of cranial variation: *S. teuszii*, *chinensis*, and *plumbea*, but evidence for the distinction between *plumbea* and *chinensis* at the species level was not clear. However, phylogeographic studies found different results. Using mtDNA control region sequences (338-bp), Frère et al. (2008) found that humpback dolphins from Hong Kong (*S. chinensis*) and South Africa (*S.

plumbea) formed a clade strongly supported by *S. teuszii*, which excluded dolphins from eastern Australia (*S. chinensis*). This suggested the Australian humpback dolphins could be an evolutionarily significant unit. Similar result was discovered by Chen et al. (2010) using mtDNA control region sequences (287-bp). Moreover, their result proved that only one species (*S. chinensis*) of humpback dolphin resided in Chinese coastal waters. Regarding the *Sousa* population in Taiwan, Chou (2006) has reported the lack of genetic differentiation between dolphins from China (n=4) and the Taiwan Strait (n=4), but more evidence would be needed to support this result due to the insufficient sample size. In sum, Chinese white dolphin populations from the Pearl River estuary, Xiamen, Leizhou Bay, Beibuwan Gulf and Western Taiwan are all currently labeled *Sousa chinensis* (Chen et al. 2008, 2009, Liu and Huang 2000, Wang et al. 2004, Zhou et al. 2007) despite the unresolved taxonomy of Indo-Pacific humpback dolphins.

Distribution and Habitat Preference

Indo-Pacific humpback dolphins (hereafter Chinese white dolphins) are commonly distributed in areas of relatively shallow water depth. Karczmarski et al. (2000) proposed water depth was a factor limiting the distribution, and 25 m isobath was suggested as the critical depth, above which the presence of dolphin(s) could barely be found. Water depths reported by other studies were almost no greater than this depth (Atkins et al. 2004, Parra et al. 2006, Zhai 2006, Wang et al. 2007). Moreover, studies conducted in the northern section of the Great Barrier Reef Marine Park, Australia and Algoa Bay, South Africa found the greatest occurrences of Chinese white dolphins in waters less than 15 m in depth (Karczmarski et al. 2000, Parra 2006).

Researchers have found that Chinese white dolphins inhabit shallow coastal waters (Chen et al. 2008, Jefferson 2000, Karczmarski et al. 2000, Parra et al. 2004, Wang et al. 2004), of which several habitat types are found to be preferred by the dolphins. In Hong Kong, denser populations of dolphins (dolphins/100 km^2) were found near the Pearl River Estuary (Jefferson 2000). At Richards Bay, South Africa, Atkins et al. (2004) calculated an encounter-to-search ratio (*i.e.*, the number of times that dolphins were encountered/total time spent in particular sector) and discovered that the ratios were highest at the estuary and harbor mouth. In Cleveland Bay, Australia, randomization tests using a distance-based method (Perkins and Conner 2004) were applied to examine the preference of Chinese white dolphins and Snubfin dolphins to coastal zones, river mouths, sea grass, reefs and dredged channels (Parra et al. 2006b, Parra 2006). Preference was identified if the means of the empirical values were significantly smaller than random values. Chinese white dolphins were found to prefer inshore areas, river mouths and dredged waters less than 15 meters in depth.

Estuaries and harbors were suggested as important locations for prey aggregation to

Chinese white dolphins (Atkins et al. 2004, Parra 2006). Chinese white dolphins were observed spending more time feeding at these areas in Richards Bay (Atkins et al. 2004). In Algoa Bay, South Africa, the Area Use index (*i.e.*, the proportion of time spent at a particular area) and Activity Index (*i.e.*, the proportion of time engaged in a particular behavior) indicated rocky reefs as a primary feeding ground (Karczmarski et al. 2000).

Aside from the physical characteristics, hydrological factors of the habitats of Chinese white dolphins have also been investigated. In Hong Kong waters, Hung (2008) found that monthly dolphin density was negatively correlated with sea surface temperature and salinity. Also, a negative correlation between dolphin sighting rate and salinity was observed in waters near Brother's Island (Jefferson 2000). In Algoa Bay, the distribution and group size of Chinese white dolphins were found to have fluctuated with seasonal changes in sea surface temperature (Karczmarski et al. 1999a). The changing temperature and salinity were suggested to have direct influence on the distribution of prey, rather than dolphins (Karczmarski et al. 1999a, Hung 2008). Another factor, Secchi disc depth (i.e., water clarity), was also investigated, but the results were not consistent among studies (preferred turbid water: Durham 1994, no relation: Karczmarski et al. 2000, preferred clear water: Hung 2008). Karczmarski et al. (2000) suggested that preference for turbid water was a secondary result of the distribution of prey, which was agreed by Hung (2008).

Range studies

Few studies of Indo-Pacific humpback dolphins (hereafter Chinese white dolphins) have investigated individual ranging patterns and site fidelity. First, to study their ranging patterns, Hung (2008) used minimum convex polygon (MCP) and the kernel method with 95%, 50% and 25% UD (*i.e.*, utilized distribution) to calculate the range sizes of 16 Chinese white dolphins in Hong Kong. For these individuals, the average MCP size was 135.0 km^2. The average kernel ranges in 95% UD (*i.e.*, utilized distribution), 50% UD and 25% UD were 145.4km^2, 23.1km^2 and 7.9km^2 respectively. No significant difference between the MCP and kernel was found, and the range sizes of most individuals ranged from 100–200 km^2. Chen (2007) estimated the MCP and the length of linear movement of 20 Chinese white dolphins in Xiamen; the average MCP of these individuals was 52.88km^2, and the average distance of linear movement was 17.58km. Parra (2005) calculated yearly and monthly sighting rate for 22 identified individuals, along with the MCP and the length of MCP for nine individuals in Cleveland Bay, Queensland. The average MCP was 69.1km^2, and the average length of MCP was 27.4 km. The yearly sighting rates were generally high compared with monthly sighting rates. Therefore, he concluded that most dolphins used this area as part of their home ranges and were occasional visitors.

Threats and status of Chinese white dolphins in Taiwan

Studies have revealed that some of the populations of Chinese white dolphin were discrete and distributed discontinuously. Researchers have suggested that inhabiting coastal waters could have lowered the probability of interaction between local populations (Karczmarski 2000, Baldwin et al. 2004). The population sizes of Chinese white dolphins estimated by previous studies are summarized in Table 1, and typically the sizes were not large (Durham 1994, Corkeron et al. 1997, Karczmarski et al. 1999b, Jefferson and Karczmarski 2001, Guissamulo and Cockcroft 2004, Jefferson and Hung 2004, Sutaria and Jefferson 2004, Parra et al. 2006a, Stensland et al. 2006, Wang et al. 2007, Zhou et al. 2007, Chen et al. 2008, 2009, Cagnazzi et al. 2009, Chen et al. 2010b, Jaroensutasinee et al. 2010, Yu et al. 2010). In addition, the inshore distribution has put this species at risk from anthropogenic impacts including pollution, noise, habitat degradation or loss, fishing pressure and bycatch. Since 2008, the IUCN has listed *S. chinensis* in the Red List as "Near Threatened"(NT). For Chinese white dolphins in Taiwan, population levels have even reached "Critically Endangered" (CR) (Reeves et al. 2008b).

The criteria "CR" was suggested mainly based on the research conducted by Wang et al. (2007), who estimated the population size to be approximately 99 individuals by using line–transect method. Although the survey design didn't conform to the assumptions of a transect-line survey, and the CV(51.6%) was high, it revealed the limited population size and thus raised concerns about the conservation of Chinese white dolphins in Taiwan. Yu et al. (2010) applied the mark-recapture method with closed population criteria; the result also revealed a relatively small population size, with 80 individuals (95% CI: 74-86) in 2007–2008, and 75 individuals (95% CI: 69–81) in 2009. Since the vulnerabilities resulting from a small population size and greater likelihood of isolation have been noticed in studies of coastal dolphins (D'agrosa et al. 2000, Thompson et al. 2000, Brager et al. 2002), effective conservation strategies for Chinese white dolphins in Taiwan is needed.

Habitat modeling and distribution prediction

Modeling purpose and application

The development of models comes from the accumulation of knowledge about the target species, and modeling purposes are usually meant to build up mathematical relationship between ecogeographic variables (EGVs) and response (*e.g*, species occurrence, group size, behavior), and to forecast the response at particular areas. The latter involved the establishment of prediction maps, which points out the habitat selection and suitable habitats for animals.

At the beginning stage of habitat modeling, descriptive statistical methods are often applied to find the correlation between animal occurrence and environmental variables (Redfern et al. 2006). For example, Cañadas et al. (2002) applied chi-square test to examine the habitat preference of several dolphin species in the Mediterranean Sea. They found the preference to shallow waters for short-beaked common dolphins *Delphinus delphis*. This finding raised the conservation concerns at inshore areas where the fishing pressure and pollution were serious. The goal of research shifted to understand how this species responded to environmental factors. As the survey and environmental data accumulated, Cañadas et al. (2005) used generalized linear models (GLMs) to build prediction models inclusive of more environmental and geographical variables. In 2008, generalized additive models (GAMs) were applied to predict responses such as interannual and seasonal variation of abundance, mix species, behavioral states and groups with calves (Cañadas and Hammond 2008). Highest relative density was predicted at coastal areas, where were also preferred by nursing and feeding groups. The results enhanced the importance and indicated functions of coastal areas, allowing researchers to promote that coastal areas should serve as primary areas for conservation of common dolphins (Cañadas et al. 2005, Cañadas and Hammond 2008).

Above, modeling is oriented from the need to explain the relationship between the environment and a species, and it turns into prediction and identification of critical regions. As it often requires plenty of time for data collection in cetacean studies, habitat modeling is particularly important to the designation of conservation strategies.

Types of models

The way a model operates is heavily influenced by the data which typically can be divided into two types: presence–absence and presence–only models. The study mentioned before (Cañadas et al. 2005) is a case of presence–absence modeling, in which both presence and absence data were obtained during survey. However, “true” absence data is almost impossible to obtain in marine research (MacLeod et al. 2008), and sometimes only the presence of an animal could be recorded such as whale watching data. As a result, some studies also applied presence–only modeling techniques to compensate for the limitations of data acquisition. Common presence−absence models included GLMs (Nelder and Wedderburn 1972) and GAMs (Hastie and Tibshirani 1987). For presence−only models, Genetic Algorithm for Rule-set Prediction (GARP) (Anderson et al. 2002), and Maximum Entropy model (MaxEnt) (Phillips et al. 2006) were more frequently applied.

GLMs and GAMs are both statistical models. They explain the relationships between ecogeographical variables (EGVs) and a response mathematically. When combined with spatial tools (*e.g.*, ArcGIS), predictive maps could be generated with the application of these mathematical relationships. Since it would be unrealistic to analyze lots of ecological phenomenon with parametric statistical models such as simple linear regression, models dealing with non-parametric relationships such as GLMs and GAMs have become practical and popular. According to the review by Guisan et al. (2002), major breakthroughs in GLMs allowed large numbers of variables and non-normally distributed variables to be modeled. For GAMs, more progress was achieved. A smoothing function was involved to enable direct analyzation of nonlinear or polynomial variables, rather than advance identification and transformation. GAMs also improved flexibility with the application of smoothers, and penalized regression splines were proposed by Wood and Augustin (2002) to permit efficient model selection. In order to select appropriate and significant predictors (*i.e.*, variables), the choice of smoothing parameters (*i.e.*, effective degree of freedom) is quite important. Wood (2006) offered a set of criteria for choosing appropriate smoothing parameters. An ideal smoother will be able to strike a balance between reasonable model fitting and computation efficiency.

On the other hand, MaxEnt and GARP belong to presence-only models that use the presence of one or multiple species of interest as the response variable for prediction. Presence–only models are free from such limitations as different survey methods and unavailable absence data (*e.g.*, records from museum or herbarium) (Anderson et al. 2002), and they have been proven to produce accurate predictions on the distribution of rare species and open-ocean species (rare species in California: Hernandez et al. 2006, Olive Ridley Sea Turtles: Peavey 2010). Therefore, they serve as powerful predictive tools. Both of these models work iteratively and required machine-learning procedure.

The basic concept of MaxEnt is that the best approximation that fits into an unknown distribution should involve every constraint, maximizing the entropy (Phillips et al. 2006). The advantages of MaxEnt include the regularization to prevent from overfitting and the capability of dealing with small sample sizes (Phillips et al. 2006). The result returned by MaxEnt is a series of continuous probabilities. For GARP, it operated in a different way. The model involved a set of rules considering stochasticity, and the rules were selected based on predictive significance (Anderson et al. 2003, Phillips et al. 2006). The results returned by GARP would be a binary prediction that comprised either a “0” or “1” (*i.e.*, absence and presence).

Model evaluation

A threshold-independent method, Receiver Operating Characteristic (ROC) analysis, is a predominant tool that has been widely-used in model evaluation. It was originally used in radiology (Hanley and McNeil 1982, Swets 1988) and clinical medicine (Zweig and Campbell 1993) to evaluate the performance of treatments or examinations. A better performance was considered to maximize the sensitivity (*e.g.*, diagnosis succeed in detecting the disease when patient has condition) and specificity (*e.g.*, diagnosis succeed in excluding the existence of disease for healthy patient). Similarly, for model evaluation, excellent models should be able to predict presence and absence correctly (*i.e.*, true positive and true negative). ROC analysis estimates the overall predictive success of a model; the advantage of this method is its simplicity in interpretation and free from prevalence (Manel et al. 2001, Phillips et al. 2006).

ROC analysis includes the ROC curve and AUC calculation. The ROC curve is produced by plotting the sensitivity against 1-specificity (*i.e.*, false positive), and it exhibits the changing of the model's performance with various thresholds. The indicator of a model's performance is the AUC (Area Under Curve). The AUC value ranges from zero to one; 0.5 indicates a random classifier below which the discriminative capacity of the model is poor, and the closer to one, the better the model is (Manel et al. 2001, Elith et al. 2006).

Ranging pattern and site fidelity

Home range estimate

According to Burt (1943), the home range is the area supporting the normal activities, including foraging, mating and nursing offspring, of an animal. This definition has been widely-used in studies of terrestrial and marine animals. He proposed that home range size may differ depending on age, body size or season. Lindstedt et al. (1986) reviewed and analyzed data from previous studies; he confirmed that body mass was related to home range size for both carnivores and herbivores. That is, animals with a larger body size would use a larger range size to meet their energy needs; however, this positive correlation was applicable only during critical biological times (*e.g.*, gestation).

A ranging pattern might be a complex of various factors. Home range study of macropods (*i.e.*, marsupials, *Macropodidae* and *Potoroidae*) conducted by Fisher and Owens (2000) found that, instead of body size, the home range sizes were influenced by climate which promoted the differences in social organization. In regions with larger amount of rainfall, range sizes of female marsupials were small because of abundant and predictable resources, and males often had larger ranges overlapping with several females. Body sizes of males and females were similar and the reproductive strategy was that males searching for receptive females. However, the situation in arid regions was opposite. Due to fluctuating distribution of resources, males were incapable of defending the whole range, resulting in a similar range size in both sexes. Sexual dimorphism of body sizes was obvious; males were larger than females and they competed against each other to get the mating opportunities.

Study in male bottlenose dolphins *Tursiops truncatus* in Sarasota Bay also found the influence of social organization to home ranges. According to Owen et al. (2002), males formed pair bonds commonly, and the ranges of paired males were larger than unpaired males. They suggested the formation of pair bonding was beneficial to the defense of predator and prevented harassments by other males, thus allowing members to range farther, the advantage of which would be the increase of mating opportunities with female dolphins.

From the aspect of energy requirement, females were considered to rely on stable food resource, especially in the reproductive stage. The concept that the availability of resource played a deterministic role in females' range and habitat use has been widely accepted (Austin et al. 2004, Lin and Batzli 2004, Henry et al. 2005, McSweeney et al. 2007). Henry et al. (2005) found a smaller range size for reproductive female red foxes (*Vulpes vulpes*); he proposed these females might exclude other females from food patches with the best quality. Studies of the movements of prairie voles (*Microtus ochrogaster*) and grey seals (*Halichoerus grypus*) revealed that the ranging pattern of females was related to stable supplement of food (Austin et al. 2004, Lin and Batzli 2004).

The range of female Cheetahs (*Acinonyx jubatus*) in Kruger National Park were found associated with the distribution of impala *Aepyceros melampus*, which was their main prey.

In sum, the range size of animals was a reflection of environmental and biological processes according to previous studies; therefore, understanding range size and ranging patterns could provide insight into the characteristics of a species in ecological, demographical and evolutionary ways. To estimate home range, popular methods include the Minimum Convex Polygon (MCP) method (Mohr 1947) and kernel method (Van Winkle 1975). The former concerns the extent of range only, while the latter provides the intensity of usage additionally (Worton 1987). Despite that the kernel method is able to provide detailed information such as the level of habitat selection based on probabilistic distribution, it requires up to 50 observations to minimize bias and variance (Seaman et al. 1999). Common estimations applied in studies were MCP, kernel method and linear distance (Gubbins and Cook 2002, Flores and Bazzalo 2004, Wedekin et al. 2007, Silva et al. 2008, Rayment et al. 2009).

Besides home range, another concept interested by researchers is core area, which is usually important to the survival of animals in some aspects because it contains critical resources such as food or shelter. The definitions of core area varied in studies due to different methodologies. However, a general principle for core areas suggested by

Samuel et al. (1985) referred to the disproportionate use of range within home range and was accepted by many studies (Worton 1987, Kenward et al. 2001, Barg et al. 2004, Hauser et al. 2007). For the MCP method, Larivière and Messier (1998) calculated a 50% MCP as the core area for the Striped Skunk (*Mephitis mephiti*), but it was on the basis that all individuals had only one center of activity. Considering that the cores of range might be multinuclear, estimate of outlier-exclusive cores (OECs) using cluster analysis was proposed by Kenward et al. (2001). For the kernel method, 50% utilized distribution (UD) or 25% UD were commonly used, and some studies used both of these two (Gubbins and Cook 2002, Owen et al. 2002, Heupel et al. 2006, Hung 2008, Rayment et al. 2009)

Site fidelity

Besides range estimates, site fidelity has been another focus in range studies. Generally, studies would involve the idea of residents, transients or visitors based on different site fidelity. However, the criteria evaluating site fidelity varied case by case. A study conducted at two estuaries in Australia used the proportion of surveys and number of seasons that recorded dolphin as estimators (Fury and Harrison 2008); Brager et al. (2002) calculated the proportion of summers that dolphins showed up; in a study of Rough-toothed dolphins (*Steno bredanensis*) in Hawaii, high resighting rates of resighted groups composed 75% of the distinguishable individuals were described as higher site fidelity (Baird et al. 2008).

Resource availability and sex were found to have related to degrees of site fidelity. For resource availability, site fidelity studies for cetaceans in the Hawaii Archipelago revealed higher fidelity in island waters, and the availability of limited resources such as resting areas (for spinner dolphins *Stenella longirostris*) and foraging areas were proposed to have influenced the fidelity of animals (McSweeney et al. 2007, Baird et al. 2008, Andrews et al. 2010). Also, bottlenose dolphins in South Carolina and the Gulf of Mexico revealed different site fidelities separately, and the predictable concentrations of resource were inferred as a main possible reason (Ballance 1992, Gubbins and Cook 2002).

Female animals were usually found to have higher site fidelity based on resource and shelter concerns. Long-term records of adult female beaked whales (Cuvier's, *Ziphius cavirostris*; Blainville's, *Mesoplodon densirostris*) and bottlenose whales (northern bottlenose whales, *Hyperoodon ampullatus*) at particular areas with higher productivity were suggested (Wimmer and Whitehead 2004, McSweeney et al. 2007). On the other hand, the concern of shelters included prevention of male harassment, occurrence of infanticide and predation. Nursing groups of Dusky's dolphins (*Lagenorhynchus obscurits*) off Kaikoura significantly preferred shallow waters (*i.e.*, ≦20m), where they were kept as refuge from males and from commercial boats (Weir et al. 2008). The frequent occurrence of female botos (*Inia geoffrensis*) and calves at areas remote from rivers and with permanent shallow lakes, was associated with the protection from aggressive males during reproductive seasons and also energy demands for both a mother and calf (Martin and Da Silva 2004).

Table 1. Summary of estimated population size of Chinese white dolphins.

Region	Location	Method	Population size	Reference
Indian Ocean				
Algoa Bay	South Africa	mark-recapture	466	Karczmarski et al. 1999c
KwaZulu-Natal	South Africa	mark-recapture	160–165	Durham 1994, Jefferson and Karczmarski 2001
Maputo Bay	Mozambique	mark-recapture	105	Guissamulo and Cockcroft 2004
south coast of Zanzibar	Tanzania	mark-recapture	63	Stensland et al. 2006
Arabian Sea				
Gulf of Kachchh	India	line-transect	78	Sutaria and Jefferson 2004
coast of Goa	India	line-transect	842	Sutaria and Jefferson 2004
Great Barrier Reef region				
Moreton Bay	Australia	mark-recapture	119–163	Corkeron et al. 1997
Sandy Strait	Australia	mark-recapture	137–162	Cagnazzi et al. 2009
Cleveland Bay	Australia	mark-recapture	34–54	Parra et al. 2006a

Table 1 (continued). Summary of estimated population size of Chinese white dolphins.

South China Sea				
Khanom	Thailand	mark-recapture	49	Jaroensutasinee et al. 2010
Hong Kong& east Pearl River Estuary	China	line-transect & mark-recapture	800 (1504&753)	Jefferson and Hung 2004
Pearl River Estuary	China	line-transect	2517–2555	Chen, T. et al. 2010
Xiamen	China	line-transect	87	Chen, B. Y. et al. 2008
Xiamen	China	mark-recapture	76	Chen, B. Y. et al. 2009
Hepu	China	line-transect	39	Chen, B. Y. et al. 2009
Dafengjang estuary	China	line-transect	114	Chen, B. Y. et al. 2009
Leizhou Bay	China	mark-recapture	237	Zhou et al. 2007
Taiwan Strait	Taiwan	line-transect	99	Wang et al. 2007
	Taiwan	mark-recapture	75–80	Yu et al. 2010

Chapter 2 Distribution prediction models of Chinese white dolphins in Taiwan

Introduction

Common habitat characteristic of Chinese white dolphin (*Sousa chinensis*) found by researchers is the shallow water. Chinese white dolphins inhabit in coastal waters of western Pacific and Indian Ocean. Studies conducted in northern section of Great Barrier Reef Marine Park, Australia and Algoa Bay, South Africa both found most occurrences of Chinese white dolphins were within waters less than 15 meters in depth (Karczmarski et al. 2000, Parra 2006). Karczmarski et al. (2000) proposed water depth was a factor limiting the distribution, and 25 m isobath was suggested as the critical depth, above which the presence of dolphin(s) could barely be found. Water depths reported by other studies were almost no greater than this depth (Atkins et al. 2004, Parra et al. 2006, Zhai 2006, Wang et al. 2007), except for records found in dredged channels where the water depths were about 30 m (Hung 2008). In addition to water depth, nearest distance to shore was a factor related to distribution of Chinese white dolphins (Karczmarski et al. 2000, Parra et al. 2006b).

Aside from physical factors, hydrological factors of the habitats of Chinese white dolphins have also been investigated. In Hong Kong waters, Hung (2008) found that monthly dolphin density was negatively correlated with sea surface temperature and salinity. Also, a negative correlation between dolphin sighting rate and salinity was observed in waters near Brother's Island (Jefferson 2000). In Algoa Bay, the distribution and group size of Chinese white dolphins were found to have fluctuated with seasonal changes in sea surface temperature (Karczmarski et al. 1999a). The changing temperature and salinity were suggested to have direct influence on the distribution of prey, rather than dolphins (Karczmarski et al. 1999a, Hung 2008). Another factor, Secchi disc depth (i.e., water clarity), was also investigated, but the results were not consistent among studies (preferred turbid water: Durham 1994, no relation: Karczmarski et al. 2000, preferred clear water: Hung 2008). Karczmarski et al. (2000) suggested that preference for turbid water was a secondary result of the distribution of prey, which was agreed by Hung (2008).

In inshore waters, several habitat types are found to be preferred by the dolphins. In Hong Kong, higher dolphin density was observed in region near Pearl River Estuary (Jefferson 2000); in Cleveland Bay of Australia, the habitat use/habitat availability ratio revealed preference to river mouth and dredged waters less than 15 meters depth (Parra 2006). Estuaries and harbors were suggested as important locations for prey aggregation to Chinese white dolphins (Atkins et al. 2004, Parra 2006). Chinese white dolphins were observed spending more time feeding at these areas in Richards Bay (Atkins et al. 2004). In Algoa Bay, South Africa, the Area Use index (*i.e.*, the proportion of time spent at a particular area) and Activity Index (*i.e.*, the proportion of time engaged in a particular behavior) indicated rocky reefs as a primary feeding ground (Karczmarski et al. 2000).

The inshore distribution has risked Chinese white dolphins in anthropogenic impacts. The conservation status of population in Taiwan has been listed as “Critically Endangered”(CR) (Reeves et al. 2008), and there is an urgent need of conservation management. To start with, there is a necessity to understand how habitat characteristics influence the distribution pattern of dolphins, and prediction models were employed to construct mathematical relationships and maps of suitable habitats. For example, prediction models were applied in a series of studies of short-beaked common dolphins *Delphinus delphis* in Mediterranean Sea; the results enhanced the importance of some coastal areas which were heavily exploited by humans (Cañadas et al. 2002, 2005, Cañadas and Hammond 2008). However, similar techniques were never been used in other studies of habitats of Chinese white dolphins.

The fundamental question drawn in this chapter was how the physical variables would influence the distribution of Chinese white dolphins in Taiwan. The purpose was to build a predictive distribution model which appropriately contained influential environmental factors that were able to identify suitable habitats for Chinese white dolphins. I applied GAMs, MaxEnt and GARP models that are commonly used to generate the spatial models, among which the best models would be selected to derive an ensemble model.

Since those dolphins in Taiwan were endangered and demanded a protected area, this chapter was anticipated to provide an insight into practical conservation plans.

Method

Study area

Shipboard surveys were conducted by LS Chou's team from March 2005 to April 2010. The map of survey coverage and corresponding geographic names was shown and labeled at Fig. 1 and 2. Pilot surveys were conducted from March 2005 to May 2006. The decision of the survey area was mainly based on results from fishermen questionnaires. Pilot surveys were excluded from following analyses because for each region, the survey was conducted only once and the effort was poor. Therefore, for the following parts, the study area referred to the survey coverage from May 2006 to April 2010.

Underwater topography

The water depth of the study area was usually less than 17 m except the area around two artificial ports, Taichung Port and Mailiao Port. However, the underwater topography varied greatly throughout the survey area. Fig. 3 showed contours among regions. Topography with steep slopes could be recognized by densely-arrayed contours, while loose contours denoted shallow regions. From Miaoli County to Wuqi of Taichung City, the underwater topography was relatively steeper (Fig. 3A). Topography of coastal area from Wuqi to northern Mailiao of Yunlin County became flat, and a broad tidal zone could be found between Fangyuan and Dacheng of Changhua County (Fig. 3B). In addition, the river mouths of the two major rivers in western Taiwan, i.e., Dadu and Zhuoshui, was located in this area. Further southward, several sandbars located between coastal area from Mailiao to Beimen of Tainan City; Waisanding sandbar was the one held the largest terrain area (Fig. 3C, D). Characterized by shallow sandy bottom and constant warm current, oyster mariculture has been a major type of fishery among this region. At the southern end of study area, the underwater topography of coastal area from Beimen to Jiangjun of Tainan City grew precipitously but with a relatively shallower region offshore.

Terrestrial topography and coastal type

The majority of topographic features at western Taiwan are hills, plateaus and plains, with several rivers flow into the Taiwan Strait. The western Taiwan seashore is intermingled with manmade and natural coastal types. There are seven major artificial facilities strewed the coast, including two coal-fired power plants at Tongsiao of Miaoli County and Taichung of Taichung City, ports at Taichung and Mailiao, and Changhua Coastal Industrial Park.

Data collection

Dolphin occurrence

Most surveys (92.62%) were carried out during summer (April to September) while the weather was under steady condition for field work. Survey routes and methods differed or modified among years based on various mission of funding agency. During 2006 and 2007, the field surveys were conducted only in inshore area since the primary interests were to explore the distribution of dolphins, and subsequently, between 2008 and 2010, offshore surveys were added to explore the outer boundary of distribution. During the survey period, ship followed approximately 4-7 meters depth (*i.e.*, inshore) along the coastline at speed of 6-9 knots and; as for offshore surveys, routes were designed either by distance to inshore lines or by water depth in ascending level.

Surveys were performed generally from 6 am to 3 pm. Beaufort sea states ≦3 and visibility ≧1km were regarded as conditions for effective observation (*i.e.*, on–effort). Observers, at least three, were assigned to search dolphins by unaided eyes and with 7 × 50 binoculars. Environmental factors including water depth, surface temperature, salinity and pH value were recorded at each GPS coordinate station. When dolphins were sighted, the initial emerged position, environmental factors, numbers of dolphins, presence and number of mother-calf pairs, age class and behavior would be recorded. The record of dolphin group position would be updated every three minutes; the record would be terminated once the trace of dolphins was lost for more than 10 minutes.

Environmental Data

Considering the water depth data estimated from boat survey was influenced by tidal status and there was no satisfactory correction method available, nautical charts designed by Taiwan Navy (Naval Meteorologic and Oceanographic Office. 1994 to 2005) were applied to acquire standardized water depth (*i.e.*, depth during ebb tide). Digitalization of point features was performed in ArcGIS 9.3; Kriging method for interpolation and surface analysis for slope from Spatial Analyst toolbox were applied to construct grids with depth and slope data. Later on, zonal statistics was performed to calculate maximum (*e.g.*, $depth_{max}$ and $slope_{max}$) and standard deviation (*e.g.*, $depth_{sd}$ and $slope_{sd}$) value for each grid in 1 × 1 nautical mile (nm) cell size. Using Hawth's Raster Tools (Beyer 2004), these rasters were cut by a survey coverage polygon which was a 1 km buffer of on-effort survey routes.

The above rasters were used as template to generate the following rasters. Salinity data obtained from shipboard surveys was converted into rasters with mean and standard deviation value respectively (e.g., $salinity_{mean}$ and $salinity_{sd}$). As for the distance to shore and the distance to river mouth data, the distance from center point of each grid to nearest coast and river mouth were calculated and converted into two rasters (e.g., *dist_shore* and *distRV*).

Data analysis

GIS was employed to generate geometric features and perform raster calculations, and also served as interface that allowed Marine Geospatial Ecology Tools (MGET), performed in R syntax, to function. For presence-absence model, Generalized Additive Models (GAMs) were applied using MGET for calculation. GAMs were selected to model nonlinear relationship between environmental variables and response variable. Lots of cetacean studies (Hastie et al. 2005, Certain et al. 2008, Torres et al. 2008, Cañadas and Hammond 2008, Redfern et al. 2008, Scott et al. 2010) applied GAM to conduct habitat modeling, for its smoothing function that allowed nonlinearity to be captured.

Two presence-only models, i.e., Maximum Entropy model (MaxEnt) (Phillips et al. 2006) and Genetic Algorithm for Rule-set Prediction (GARP) (Anderson et al. 2002), were employed. These two models both accomplish the prediction with iterative progress and acquired machine-learning. The basic concept of MaxEnt is the best approximation that fitted into unknown distribution should involve every constraint, that is, maximize the entropy (Phillips et al. 2006). Another important feature of MaxEnt is its regularization to prevent from overfitting and allows important terms to stand out (Phillips et al. 2006). The result returned by MaxEnt would be a series of continuous probability. In contrast, GARP operates in a different way. The model involves a set of rules considered stochasticity, and the rules are selected based on predictive significance (Anderson et al. 2003, Phillips et al. 2006). The result returned by GARP would be binary prediction that comprised absence or presence of prediction.

As for model evaluation, threshold-independent method, Receiver Operating Characteristic (ROC) analysis, was applied. It has been used originally in radiology (Hanley and McNeil 1982, Swets 1988) and clinical medicine (Zweig and Campbell 1993) to evaluate the performance of treatment or examination. ROC analysis has been employed in evaluation of predictive models recently to estimate an overall predictive success of model; the advantage of this method was its simplicity in interpretation and free from prevalence (Manel et al. 2001, Phillips et al. 2006).

Survey sighting rate estimate

Sighting rate was defined as the ratio of number of sightings divided by survey kilometers, and only on-effort survey should be included. Considering the coherence and similarity of survey method, data collected during 2006-2010 were used, including 304 surveys and 249 on-effort sightings. Features denoted survey route and sighting points were intersected with 1 nm ×1 nm grid and sighting rate (groups/100km) was calculated in GIS. However, in order to prevent unrealistic results, such as extremely high sighting rate caused by insufficient effort or coverage in grid, grids with effort less than 2.619 km (*i.e.*, diagonal length) and less than 80% coverage were deleted from analysis.

Prediction models

(1). Presence–absence model

Tracks were randomly chosen and the widths between them were measured; the average width stood for the width for buffer zone. Using analysis tools in ArcGIS, a 500 m buffer of merged sighting and tracking points (n=2289) was generated as area with dolphin presence. This buffer zone served as clip feature that divided survey route into two parts, presence and absence. Three hundred random points were generated along survey routes with dolphin presence and absence respectively, with the minimum allowed distance of 1 km (*i.e.*, distance should be at least 1km between each point). Marine Geospatial Ecology Tools (MGET, Roberts et al. 2010) were applied to the following analyses.

First, environmental raster values (*i.e.*, depth, slope, salinity and distance rasters) were sampled to points, and bilinear resampling method was chosen due to the continuous raster surfaces. Second, the distribution of variables was observed from density histograms drawn by MGET. Third, a binomial GAM was used to perform model fitting in MGET, which invoked R package mgcv to calculate and select key variables for dolphin occurrence by using penalized regression spline, which caused unimportant terms to shrink (Wood 2006). The formula applied in R expression syntax was:

P_A ~ s(depth_max, k = 5) + s(depth_sd, k = 6) + s(sal_mean, k = 3) + log(sal_sd) +

log(dist_shore) + s(dist_RV, k = 3)

where "P_A" was the presence-absence variable, and "k" parameters allowed terms being smoothed with appropriate degree of freedom which stroke a balance between reasonable model fitting and computation efficiency (Wood 2006). The result was used in model prediction, including probability of occurrence and binary response. At the final stage, the model was evaluated in MGET, which invoked R package rocr to calculate AUC (Area Under Curve) (Swets 1988)(Hanley and McNeil 1982) and cutoff value for binary classification (Sing et al. 2005). Based on AUC criterion, the value is between 0 and 1. The closer to 1, the better discriminability of the model; while the value 0.5 means the discriminability of the model is no better than random prediction (Fawcett 2006).

(2). Presence–only models

Since presence-absence models would be influenced by the detectability of targeted species and the accurate absence data is almost impossible especially in marine research (MacLeod et al. 2008), presence-only models, such as MaxEnt (Phillips et al. 2006) and GARP (Anderson et al. 2002), were therefore applied to compromise this limitation. The data points of dolphin presence were randomly divided into a four-fifth for training data set and one-fifth for testing data set. One hundred runs were set for both models. MaxEnt calculated probability of occurrence ranged from 0-1 for each grid, while GARP returned either 0 or 1 (*i.e.*, absence or presence). For MaxEnt, jackknife and permutation were applied to measure variable importance. The final model was composed of the average predicted probability. For GARP, different combinations of layers were performed to determine which layers were important to the species. Optimal models were selected based on the decision procedure recommended by Anderson et al. (2003). To soften variations among models, the composite model combining optimal ones was served as the final model (Anderson et al. 2002). The probability of occurrence of each grid was calculated as the number of presence (*i.e.*, “1”) divided by number of models being combined. In addition, for both MaxEnt and GARP, final models were evaluated based on ROC analysis by a web-based ROC calculator (Eng 2007), and the models with the best performance (*i.e.*, highest AUC) would be selected (Peterson et al. 2007) for further analyses.

(3). Ensemble model

The ensemble model was the combination of best models selected from GAM, MaxEnt and GARP, and binary classification was required. Binary predictions were performed in MGET for GAMs, and MaxEnt and GARP models, the scenario of expected value was applied for binary classification. According to Buckland and Elston (1993), expected value could be calculated as the sum of probability of occurrence; the probability represented the threshold for presence should be at the rank similar to the expected value. After the binary classifications were made, these binary models were compiled together and became a composite model of which the value ranged from 0 (*i.e.*, absence) to 3 (*i.e.*, predicted presence by all three models). Grids predicted with dolphin presence by at least two models (*i.e.*, value $\geqq$ 2) were regarded as suitable habitats for Chinese white dolphins in the west coast of Taiwan based on analysis of the observed data.

Results

Survey sighting rate estimate

The number of sighting positions from 2006 to 2010 April were 268, in addition, two positions recorded in 2005 were also included in the map, and most of sighting locations were inshore to 20 meter isobaths (Fig. 4). Movement tracks (tracked for up to 30 minutes, *n*=133) showed the movement directions of dolphins were usually between north and south rather between inshore and offshore (Fig. 5). Efforts in inshore areas were higher than those in offshore (Fig. 6). For inshore areas, the effort was particularly high and dense in waters from Taichung City to Waisanding sandbar. On the contrary, effort was low along coastal areas of Miaoli County, because the survey had started in 2009. Effort at coastal area of Chiayi County was low, too. Regular survey was conducted in 2008 only, with few at 2006–2007.

The sighting rates in two coastal areas, from Baishatun to north of Taichung Port and south of Mailiao Harbor to Waisanding sandbar, were particularly high among study area (Fig. 7). In addition, sighting rate in a small proportion of Dongshi coastal area was also high. However, overall sighting rate in Chiayi coastal area was low. Conversely, sighting rate decreased gradually from coastal areas of Taichung Port to Changhua County, where the lowest sighting rate was found near Zhoushui river mouth.

Prediction models

GAMs

Density histograms of each variable were shown in Fig. 8A-H. As being left-skewed, variables including *dist_shore*, $slope_{sd}$ and $salinity_{sd}$ were log-transformed to acquire more even distribution. Distinct distribution of presence and absence data was expected; it represented the capability of separating presence and absence of particular variable. The overlap was obvious in $salinity_{mean}$ (Fig. 8E) and log–transformed $slope_{sd}$ (Fig. 8D). For variable $depth_{max}$, both presence and absence data were bimodal distributed, and notably, the density of presence became zero when $depth_{max}$ was about 25m (Fig. 8A). Similar situation could be found in the chart of $slope_{max}$ (Fig. 8C). For variables $depth_{sd}$ (Fig. 8B), *dist_RV* (Fig. 8H) and log-transformed $salinity_{sd}$ (Fig. 8F), on the other hand, the distinctive distribution were not obvious. However, density distribution of presence and absence was much more distinct in log-transformed variable *dist_shore* (Fig. 8G).

Variables $slope_{max}$ and $slope_{sd}$ were excluded from the following modeling process because they were highly correlated to each other (correlation coefficient: 0.90) and therefore might affect accuracy of model prediction. Smoothing was applied to keep the complexity of characteristics of those variables showed bimodal or multimodal distribution, that is, $depth_{max}$, $depth_{sd}$, *dist_RV* and $salinity_{mean}$.

The result indicated $depth_{sd}$, $salinity_{sd}$ and *dist_shore* were significantly associated with the occurrence of dolphins ($p<0.001$). Also, since penalized regression splines were perform, unimportant terms could be identified for their zero-enclosed confidence interval and flat shape in Fig. 9A, C, F. For $depth_{sd}$, dolphin occurrence was indicated within 1-3m and positively correlated within about 1-2m (Fig 9B). For $salinity_{sd}$, dolphin occurrence was positively correlated at 1 ppt $salinity_{sd}$ up (Fig 9D). For *dist_shore*, the occurrence was within 1km distance to shore and negatively correlated to the increase of distance (Fig 9E).

With an unbiased risk estimator (UBRE) score of -0.07, the model explained 35.5% of the null deviance. The AUC value was 0.87, suggesting a practical model. The predicted probability of occurrence was high at coastal waters of southern Miaoli County, northern Changhua County and southern Chiayi County, along the edge of Taichung and Mailiao Harbor, and along offshore edges of sandbars (Fig. 10). In addition to these regions, coastal areas of north Taichung were classified as areas with dolphin presence (Fig. 11). On the other hand, at regions close to the two river mouths, Dadu and Zhoushui, the probability of occurrence was medium to low (Fig. 10). Standard deviation of probability of these areas was at medium level, indicating there were no huge differences among prediction results of each runs (Fig. 12). In comparison, standard deviation of probability along coastal areas of Miaoli to Taichung City and areas near passages of Taichung and Mialiao Harbor was higher (Fig. 12).

MaxEnt and GARP

Using MaxEnt, the best model to predict the dolphin distribution contained three variables: $depth_{max}$, *dist_shore* and $salinity_{sd}$ with the highest AUC equals 0.68. The responses curves accounting only one particular variable and together with other variables were shown in Fig. 13A, C, E and Fig. 13B, D, F respectively. The pattern of single variables was similar to that of GAMs, however, the shape of response curve of $salinity_{sd}$ changed and the probability of occurrence decreased after one ppt of standard deviation when other variables were included (Fig. 13F).

The best GARP model had AUC equals 0.89, same variables were also included. MaxEnt model predicted that dolphins would most likely to occur along coastal areas within the survey region (Fig. 14), and GARP tended to predict a wider region (Fig. 17). The pattern of standard deviation for occurrence probability in MaxEnt was different from what in GAM: the highest standard deviation was observed in regions close to river mouths of Dadu and Zhoushui Rivers (Fig. 15). For binary predictions, unlike GAM, both

MaxEnt and GARP suggested dolphins would occur in the most of coastal areas (Fig. 16), and again, with GARP, the areas were wider (Fig. 18).

An ensemble model

The predicted pattern of dolphin occurrence was generally consistent with empirical observation (Fig. 19), suggesting the environmental variables included in model simulations did reflect the distribution of Chinese white dolphins in the west coast of Taiwan, and that ensemble model derived from multiple models was able to predict the distribution pattern more accurately.

The result of model predictions should be viewed as the potential distribution for the Chinese white dolphin. Using the ensemble approach, waters with potential distribution were regarded as suitable for targeted species. Consider regions predicted presence by at least two models, predictive suitable areas for the Chinese white dolphin included two larger regions, coastal areas of Baishatun to Taichung Port and off Waisanding sandbar, and other smaller, patchy coastal areas such as the margin of Changbin and Liuqing Industry Parks, coastal areas of Longfeng, Wanggong to Fangyuan and Budai, and along sandbar of Santiaolun to Boziliao (Fig. 20).

Discussion

Sighting rate estimate

Sighting rate of inshore was higher than offshore, suggesting the preference to inshore. Similar parameter, the encounter–to–search ratio (*i.e.*, the number of sighting group/time spent in particular sector), was used by Atkins et al. (2004). They also found the ratio decreased as the increasing distance from land. Our data confirmed that the Chinese white dolphins in Taiwan used inshore areas extensively. However, since offshore surveys have not been conducted at coastal area of Miaoli County, the pattern that offshore with lower sighting rate was not obvious. Future studies should undergo surveys offshore to complete the boundary that Chinese white dolphins most likely to occur.

Uneven sighting rate in inshore was observed, and sighting rates at Zhoushui river mouths were low. Deposition of mud in this estuary is predominant, forming broad and flat tidal zone. Such topography is reported to have been avoided by Chinese white dolphins in Hong Kong, because it may cause stranding of dolphins during low tide (Hung 2008). Since dolphins will adjust their behavior following tidal cycle, it is possible that the influence of low tide at estuary was actually the change of prey distribution (Mendes et al. 2002, Akamatsu et al. 2010). The observations (n=2) made at Zhoushui River mouth were during high tide while dolphins traveled fast. More observations are needed to understand the situation in Taiwan.

Prediction models

Key environmental factors

The nearest distance to shore (*i.e.*, *dist_shore*) was the most influential factor in all the models, coherent to the fact that Chinese white dolphins were distributed exclusively inshore in the western coast of Taiwan. Similar results were found in Great Barrier Reef Marine Park, Australia (Parra et al. 2006) and Algoa Bay, South Africa (Karczmarski et al. 2000), indicating that it is the species' nature to prefer a shallow habitat. Factors that characterizing to shallow waters, such as the maximum depth ($depth_{max}$) examined in this study, is also one of the important factors associated with presence of dolphins. The bathymetry of coast in Great Barrier Reef Marine Park, Algoa Bay and western Taiwan are alike. However, other known habitats for Chinese white dolphins, such as shallow waters of Xiamen and Hong Kong, are located at the large river mouth of Jiulong and Pearl River, where the topography are different from open-stretch coasts such as Taiwan. Therefore, distribution pattern found at Xiamen (Zhai 2006) and Hong Kong (Jefferson 2000) are not linearly along the coast, and didn't recognize the nearest distance to shore as key factor to distribution.

Irregular underwater topography, which could be represented by standard deviation of depth (*i.e.*, $depth_{sd}$) in models, a 1-3 meters range was associated to dolphin presence. Irregular underwater topography enhances the efficacy of foraging through the aggregation of prey species (Atkins et al. 2004, Parra 2006, Zhai 2006), inhibition of prey escape (Allen et al. 2001) and occurrence of regional eddies, fronts or upwellings promoting environmental productivity (Cañadas et al. 2002, Bailey and Thompson 2010). Some studies (Hastie et al. (2003, 2004) suggested that deep water served as favorable condition for foraging due to the increase of potential search volume and limited refuge of prey. This might be the reason that some of marginal rasters with greater water depth at Taichung and Mailiao Port were predicted as suitable habitats, since dolphins were observed feeding with deep dives near southern embankment of Taichung Port and of Mailiao Port.

The influence of standard deviation of salinity ($salinity_{sd}$) varied under different circumstances. When only $salinity_{sd}$ itself was analyzed, the response curves produced by GAMs and MaxEnt were similar; however, when it was analyzed with *dist_shore* and $depth_{max}$, the response curve showed an opposite pattern. When taking other variables into account, those associated with underwater topography were found to influence the positive correlation of occurrence and one ppt $salinity_{sd}$ significantly. The scenario is that the more proximity to the river mouth, the greater variation in salinity, and the waters become much shallower with flat bottom; therefore, the environment become unfavorable to dolphins. This could be the possible explanation for why the probability of occurrence right at the opening of Dadu and Zhoushui river mouths was lower than their peripheral areas. In addition, considering foraging strategy, that is to maximize energy intake and minimize the cost of pursuit, may influence the habitat use of dolphins, dolphins may prefer to forage at the margin of estuary for adult fishes more than at shallow estuaries where are usually nursery grounds and refuge for juvenile fishes (Allen et al. 2001).

Prediction interpretation

Despite the common regions predicted presence of dolphins were generally similar for all models, standard deviation of predicted probability by GAMs and MaxEnt showed different patterns, which represented different ways of data processing. For GAMs, the results were influenced by the distribution of presence and absence points. Despite dolphins did not occur at offshore areas, they used waters off ports where the water depths were also relatively deep. Therefore, standard deviation of probability was largest at waters off ports; in addition, it was the reason why *depth_max* was not one of the factors that influenced the occurrence of dolphins in the selected GAM model. As for MaxEnt, the environmental features corresponding to presence points were influential. For the most of cases, dolphins occurred at shallow waters, and *depth_max* was selected as one of the influential factors. However, dolphin presence was rare near river mouth where the water was also shallow, which resulted in the largest standard deviation of probability near river mouths.

Two areas with higher sighting rates were included in predicted suitable habitats from the ensemble model, which suggested the environmental features were favorable for habitat utilization by dolphins. On the other hand, the suitability and sighting rate at Zhoushui River mouth were neither satisfactory (*i.e.*, predicted present by at least two models) nor high, corresponding to the previous finding that dolphins were expected to occur at peripheral areas rather than right at the opening based on the response curve of $salinity_{sd}$ considering interaction of factors.

Despite the prediction model captures the species' niche requirement, the predicted potential distribution range will be typically larger than the realized one due to other possible factors such as insufficient effort, historical restriction, geographical barriers preventing dispersal and human activities that alter the environment (Anderson et al. 2002, Arntzen and Espregueira Themudo 2008, Martínez-Meyer et al. 2007, Phillips et al. 2006). Likewise, the ensemble model predicted some regions, such as coastal waters of Budai and northern Liuqing Industry Park, where the current occurrence records show absence.

Survey efforts were few at Budai with most of them were carried out within one year, and it was possible that the empirical result didn't fit the prediction which represented an overall pattern. Besides, there was one sighting recorded at Jiangjun in 2005, suggesting the necessity of passing coastal areas of Chiayi for Chinese white dolphins and remote possibility of existence of natural barrier. Although sighting rate in coastal areas of Chiayi County was low in general, about 43% rasters were predicted as suitable habitats (*i.e.*, predicted presence in the ensemble model). Therefore, future efforts should be invested to ensure the difference of prediction and observation was caused by sparse effort or by other factors such as boat traffic at Budai Port. Coastal areas of Chiayi should be viewed as part of potential habitat and the designation of further strategies of habitat restoration is needed if the probability of encountering dolphins is still low in future.

There might be other environmental factors that influence the distribution of dolphins but yet included in this study. For instance, dolphin presence was not observed in northern Liuqing Industry Park, and sighting rates of neighboring areas were low, but it was predicted as suitable area. Survey efforts were quite sufficient (97.9 km), one possible explanation is the unexamined environmental factors. The pH value of sea waters could be one possible missing factor: the monitoring of pH values was just started in 2009 so that it was not included in the analysis, but the pH value of northern Liuqing Industry Park was lower than those of surrounding areas due to the water emission of Liuqing Industry Park (Fig 21). Low pH value of the sea waters had been found to affect marine calcifiers physiologically, such as shifting energy metabolism pathways of oysters (Lannig et al. 2010), and the decrease of calcification rate of bivalves in post-larval stage (Waldbusser et al. 2010). For mobile animals such as fishes, review of studies included some species indicated the egg and larvae were more susceptible than adults, and despite the exposure of low pH was tolerable, the alter of metabolism may have negative effect in population level since the reduction of growth and reproductive success (Guinotte and Fabry 2008, Ishimatsu et al. 2004, Pörtner et al. 2004). The pH effect on marine mammals has not been evaluated yet, but Lawler et al. (2007) did suggest the influence on foraging which caused by adverse effect on prey distribution. Therefore, the influence of lower pH on Chinese white dolphins in this area might need a careful investigation.

Conclusion

This study identified key environmental factors that influenced the distribution pattern of Chinese white dolphin in Taiwan. These variables included water depth (maximum and standard deviation), salinity (standard deviation) and distance the nearest to shore. The characters of suitable areas were shallow water with irregular topography and waters off sandbars. The pattern of sighting rate confirmed the inshore preference of Chinese white dolphins, and two regions with higher sighting rate were enclosed in prediction map, suggested relative importance of these regions which should be regarded as the priority of protected areas. In addition, prediction model disclosed suitable areas at two ends of study area, where the effort were not so frequent. Further investigation within those regions should be taken to fully understand the dolphin distribution, and habitat restoration would be probably needed.

Figure 1. Map of Taiwan and the study area of Chinese white dolphins. The study area is located at western coast, including inshore waters of Taoyuan County to Tainan City. The gray region denotes the survey coverage from May 2006 to April 2010, and the regions enclosed by dash lines denote the coverage of pilot surveys.

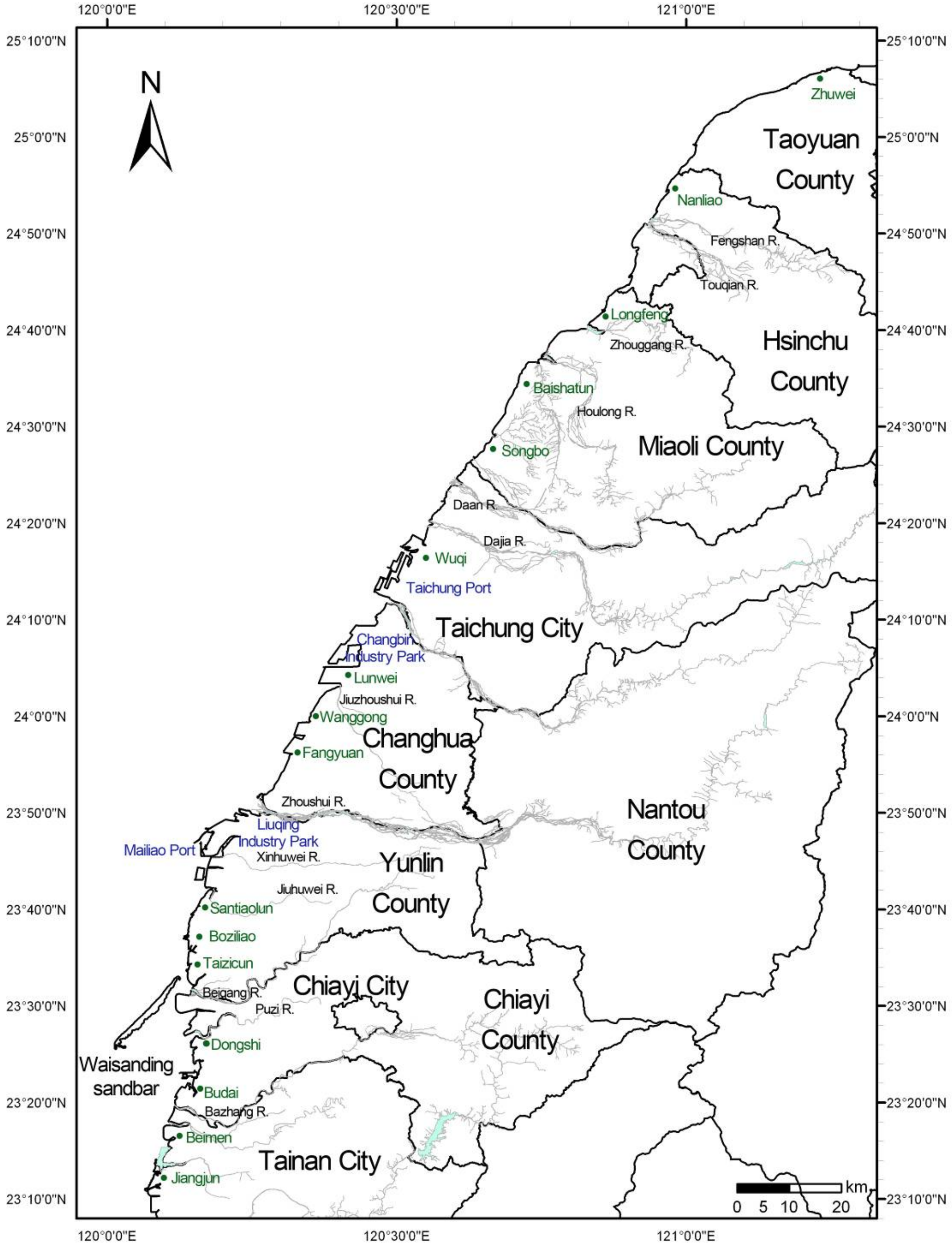


Figure 2. Study area at west coast of Taiwan. The geographic names of different classes of places were labeled.

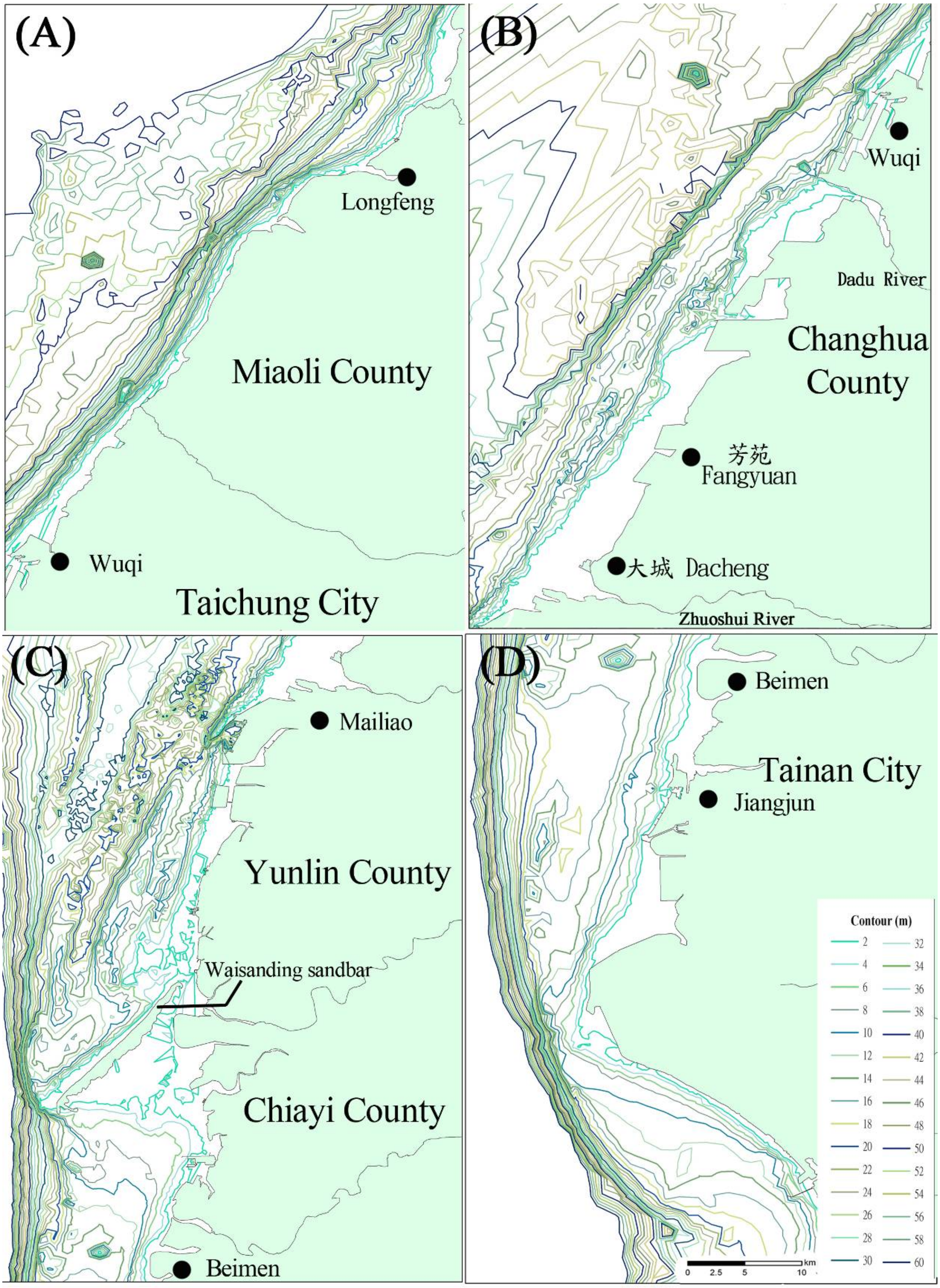


Figure 3. Penal (A)-(D) shows the benthic topography with contours. Different water depths were represented by different colors.

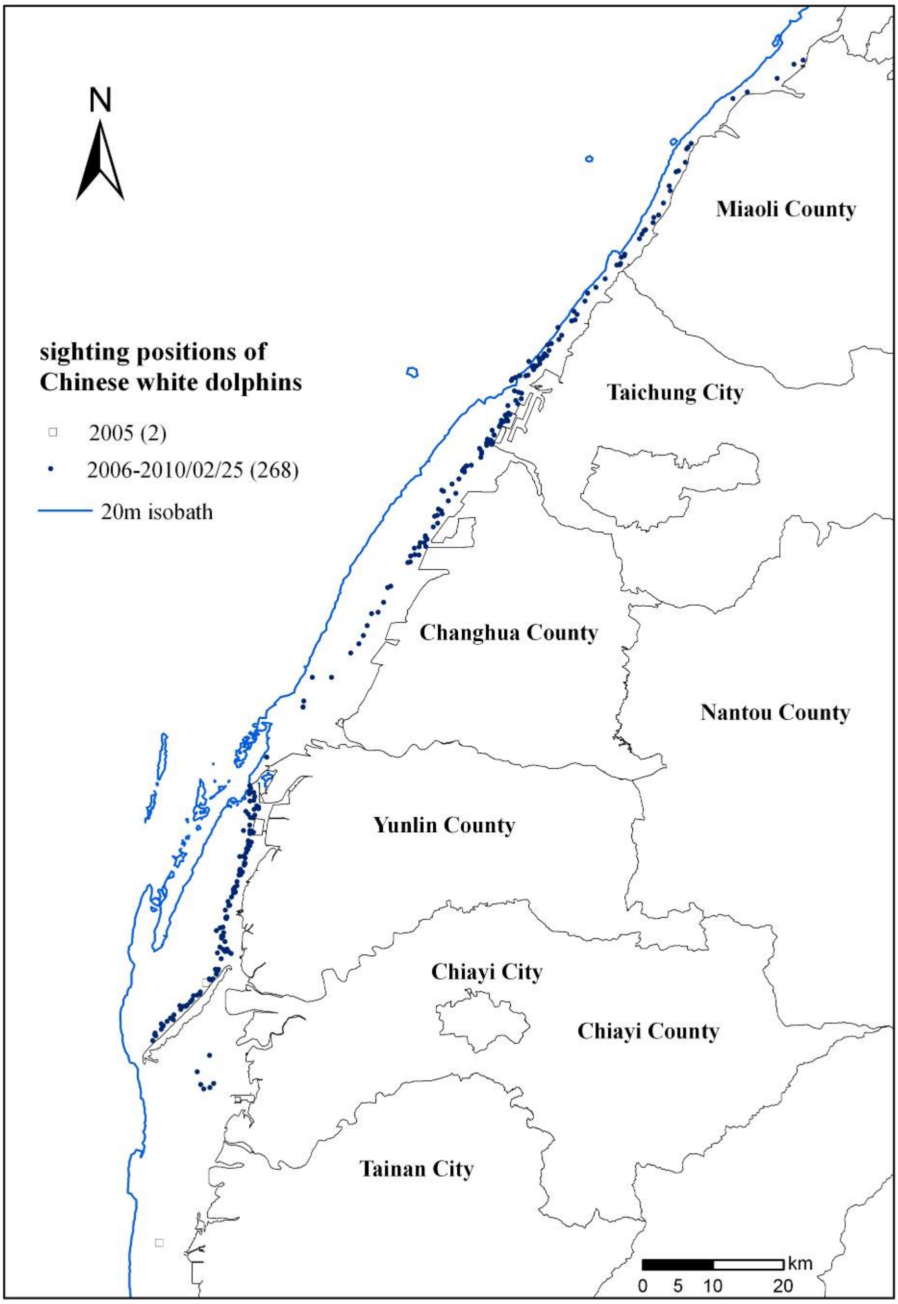


Figure 4. Sightings (soild dots, n=268) of Chinese white dolphins based on field surveys conducted from 2006 to 2010. Two points (open square) during pilot surveys in 2005 were added. Most of the sightings were within the waters with depth less than 20 m (blue line).

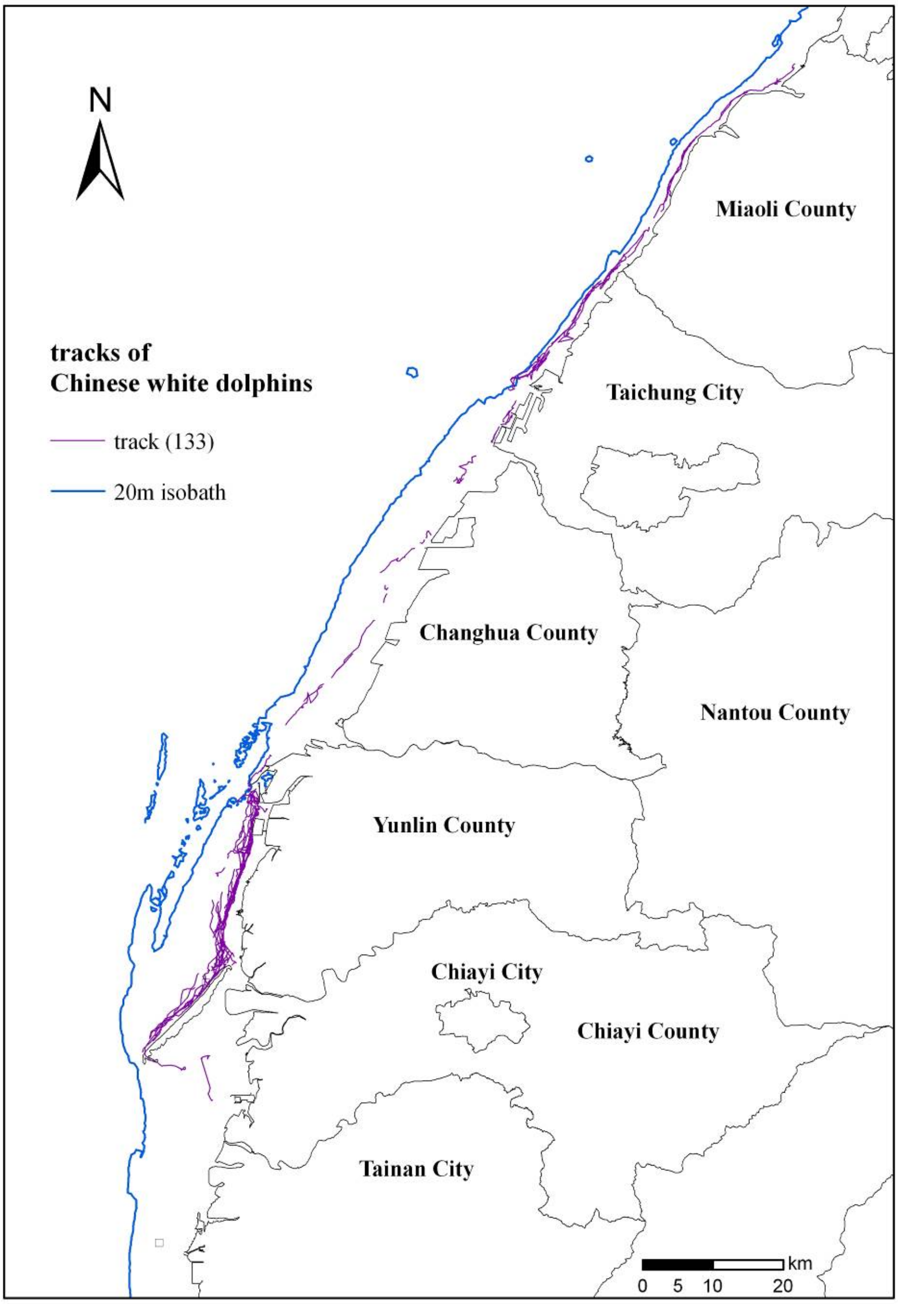


Figure 5. Movement tracks of Chinese white dolphins (purple lines, n=133). Directions of most of the tracks were between north and south, suggesting movement parallel to shore line.

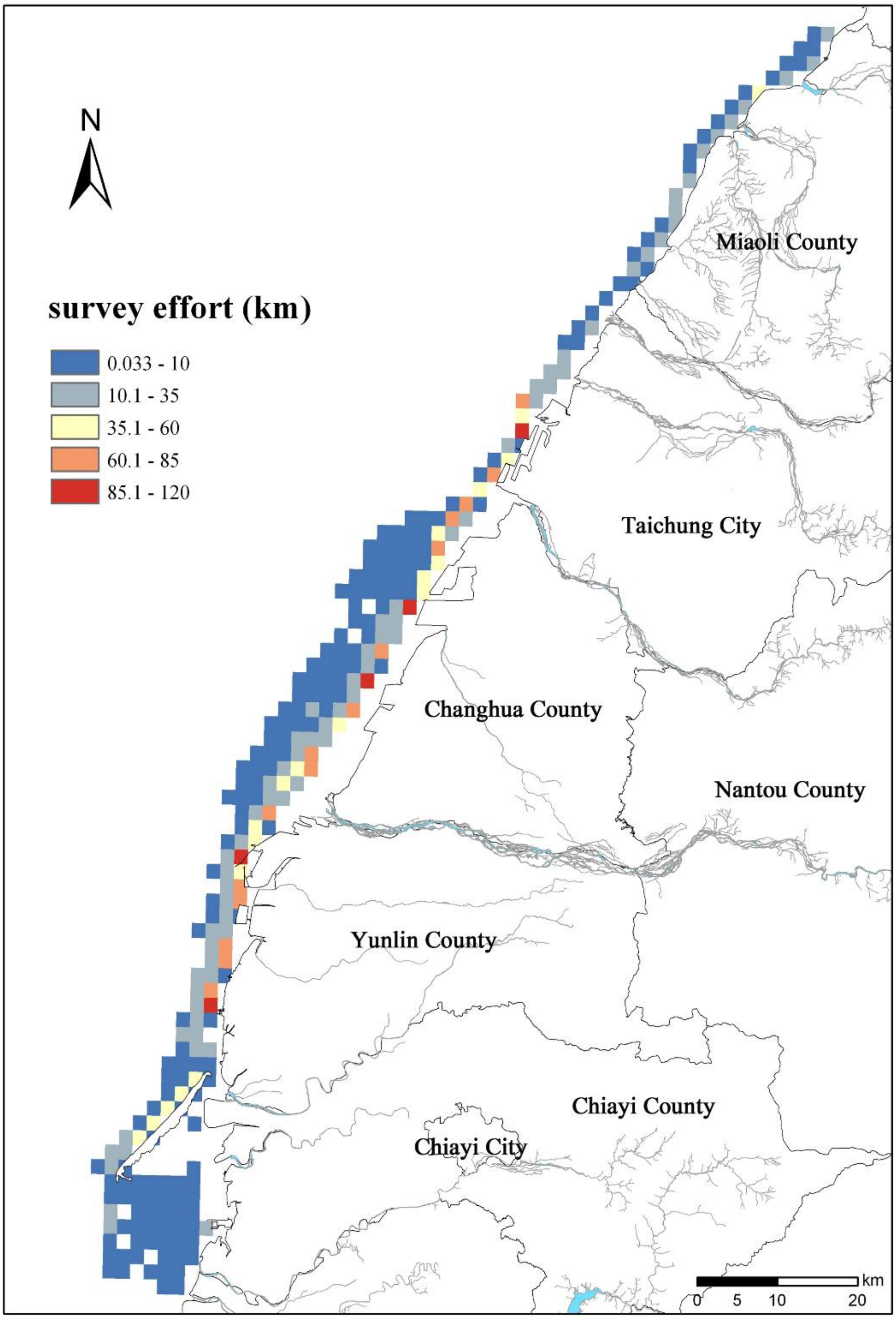


Figure 6. Distribution of survey effort throughout the study area between 2006 and 2010. The greatest effort was made through the inshore areas from Taichung City to Waisanding sandbar of Yunlin and Chiayi counties.

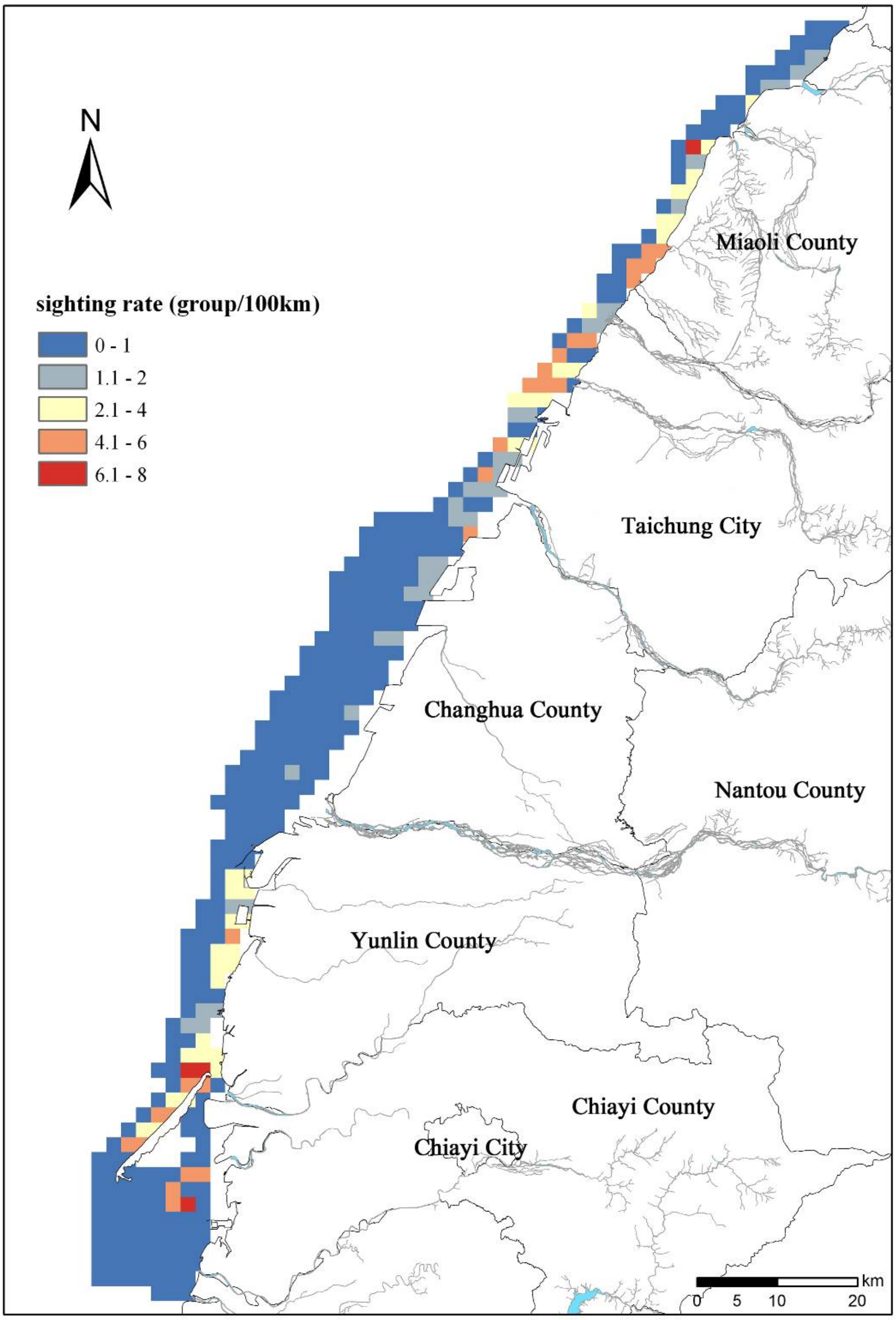


Figure 7. Distribution of dolphin sighting rate in the study area. The highest sighting rate was found at the coast from Baishatun to Wuqi and from south of Liuqing Industry Park to Waisanding sandbar.

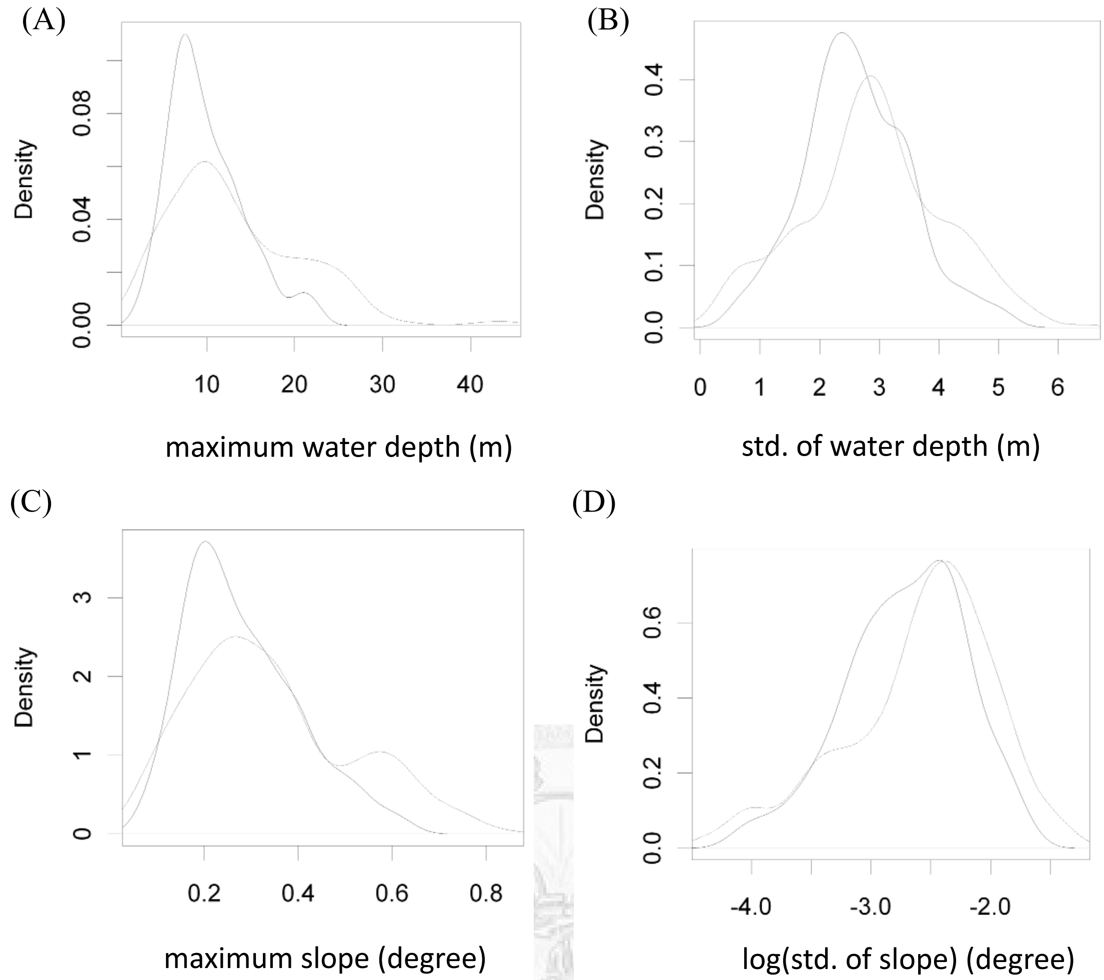


Figure 8. Density histograms for environmental variables responding to the presence (dash line) or absence (dot line) of Chinese white dolphin based on the sighting records: (A) the maximum water depth (m), $depth_{max}$; (B) standard deviation of water depth, $depth_{sd}$; (C) maximum slope (degree) ,$\mathrm{slope}_{\mathrm{max}}$; (D) the standard deviation of slope, $slope_{sd}$; (E) mean salinity (ppt), $salinity_{mean}$; (F) standard deviation of salinity, $\mathrm{salinity}_{\mathrm{sd}}$; (G) distance to nearest shore (km), *dist_shore*; (H) distance to nearest river mouth (km), *dist_RV*. The variables of *dist_shore*, $slope_{sd}$ and $salinity_{sd}$ were log-transformed.

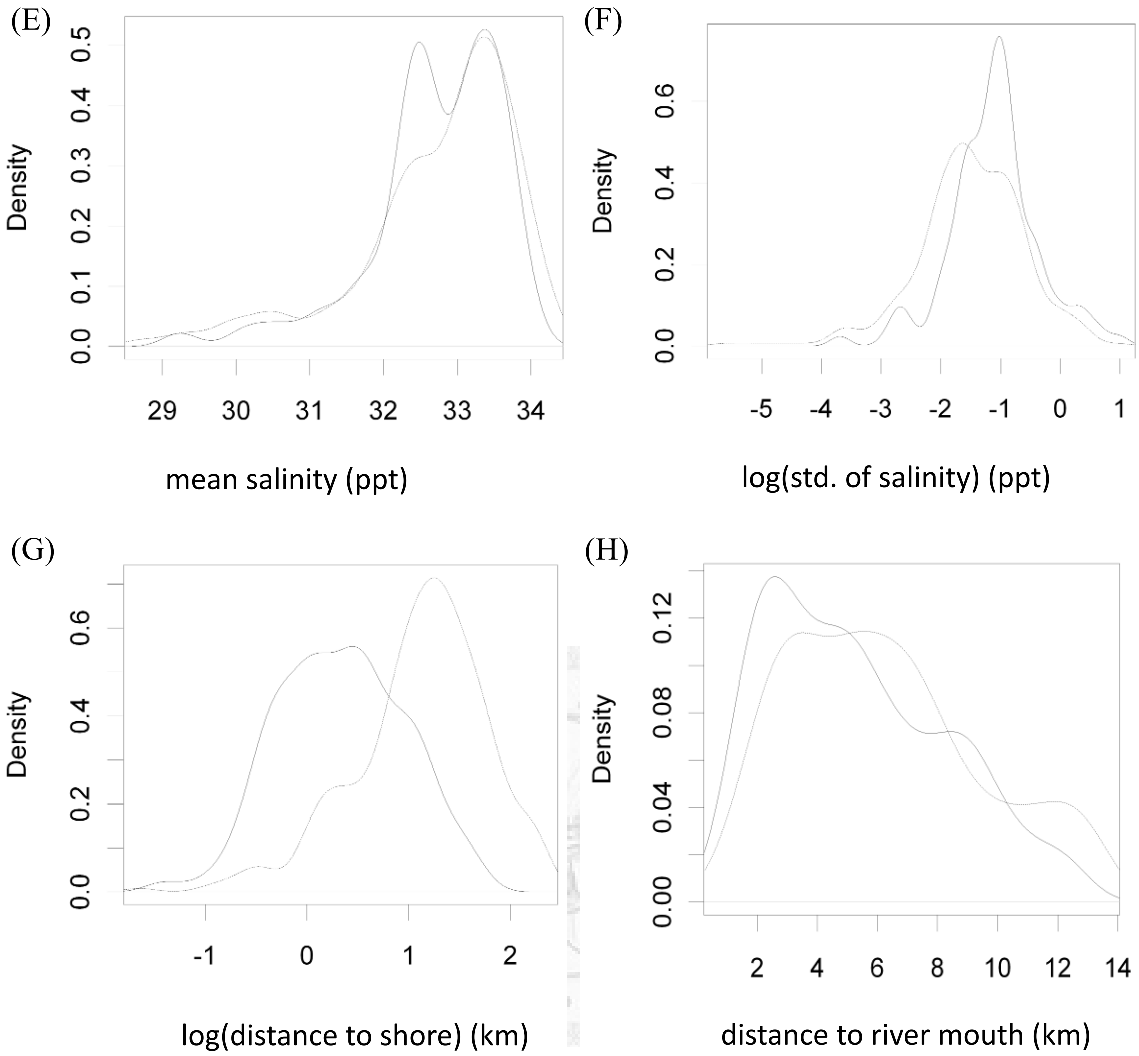


Figure 8 (continued).

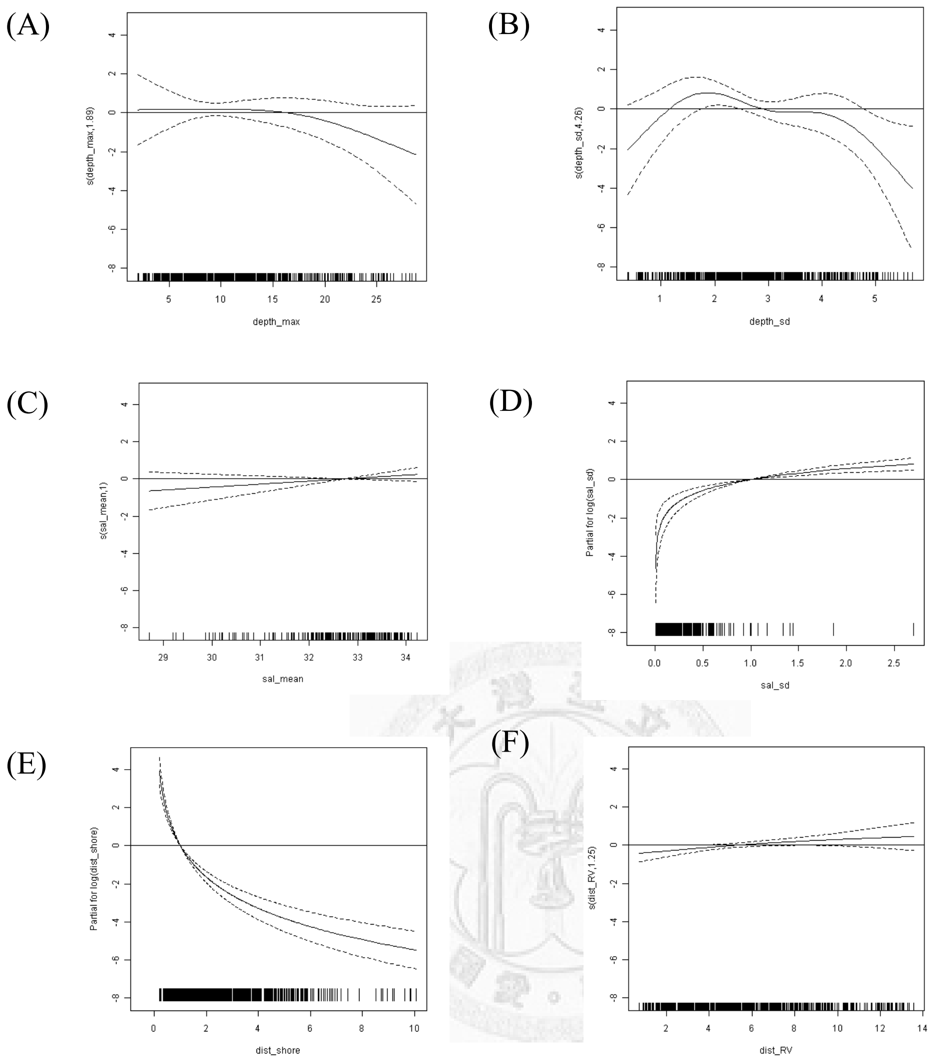


Figure 9. Response curves for environmental variables used in generalized additive model (GAM). Zero in y axis with horizontal line separates presence (above line) and absence (below line). Unimportant terms are characterized by zero-enclosed confidence intervals with flat shape (*e.g.*, A, C, F). Variables selected by GAM are: (B) standard deviation of water depth, the occurrence of dolphins is positively correlated; (D) standard deviation of salinity, which is positively correlated when the value is above one ppt; (E) distance to nearest shore, which is negatively correlated.

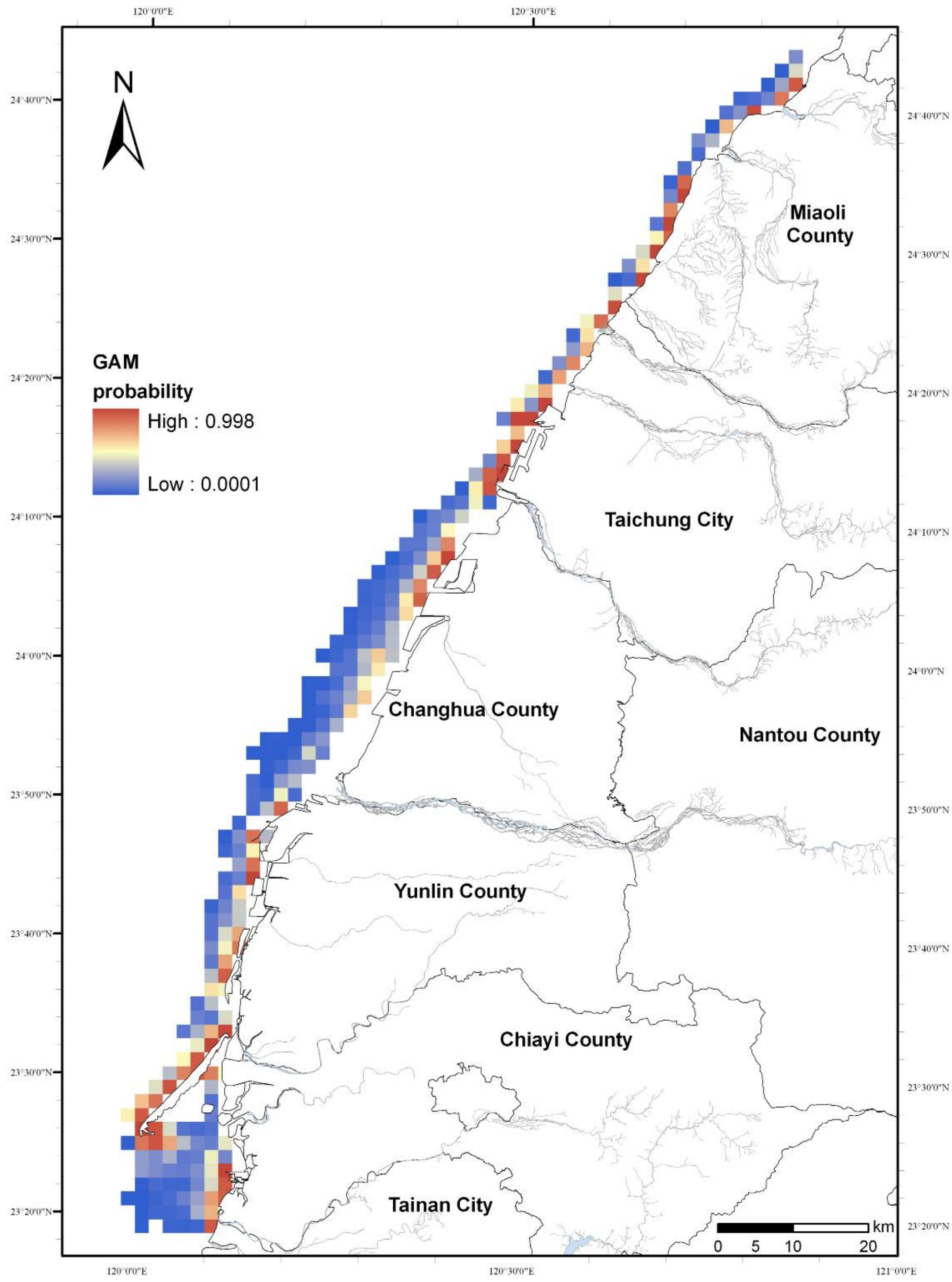


Figure 10. Predicted probability of Chinese white dolphin occurrence by GAM. Except Dadu, Zhoushui river mouths and waters off southern Changhua County, the probability of occurrence was generally medium to high (yellow to red on color ramp).

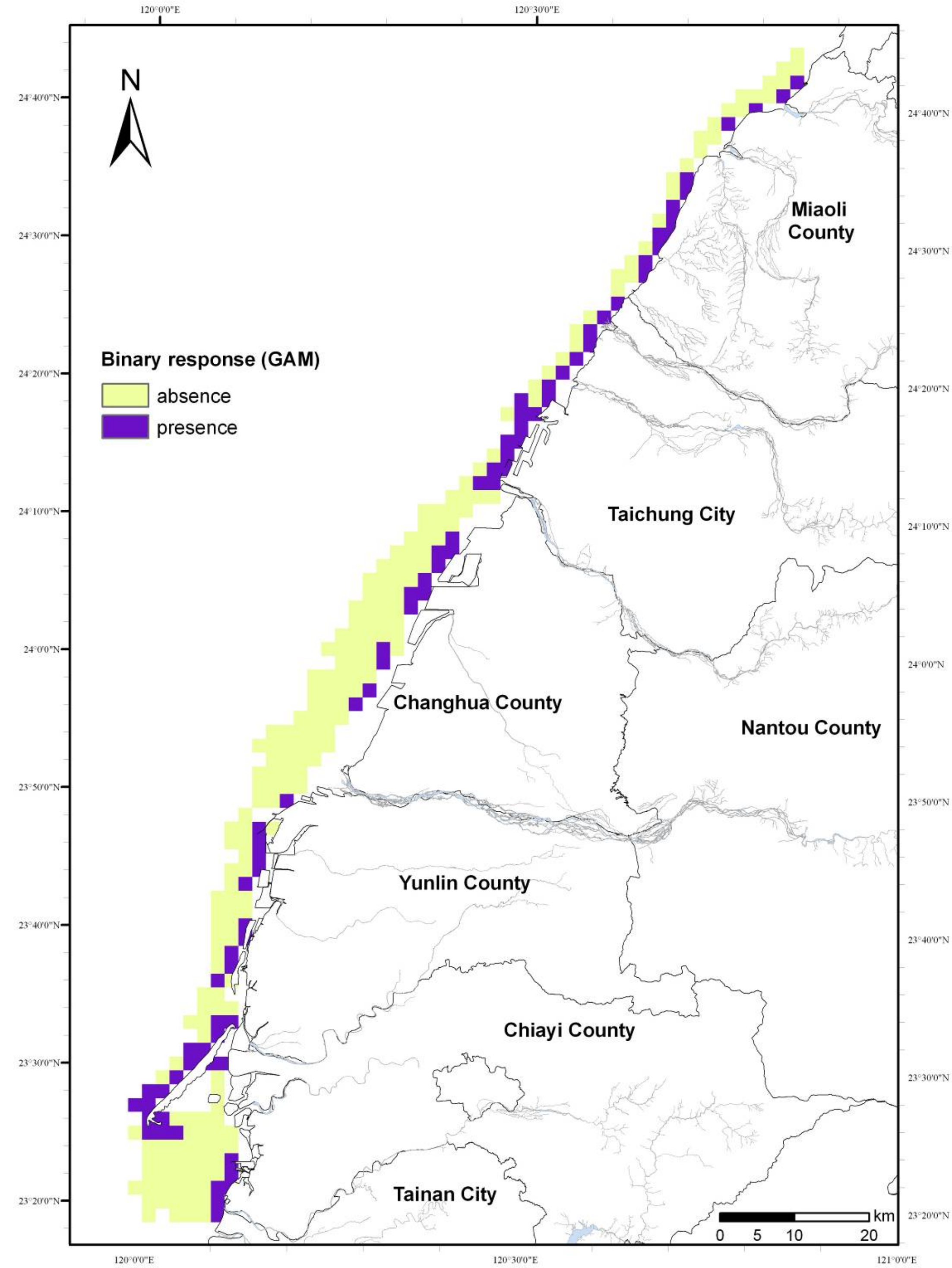


Figure 11. Binary classification of Chinese white dolphin occurrence in Taiwan predicted by GAM.

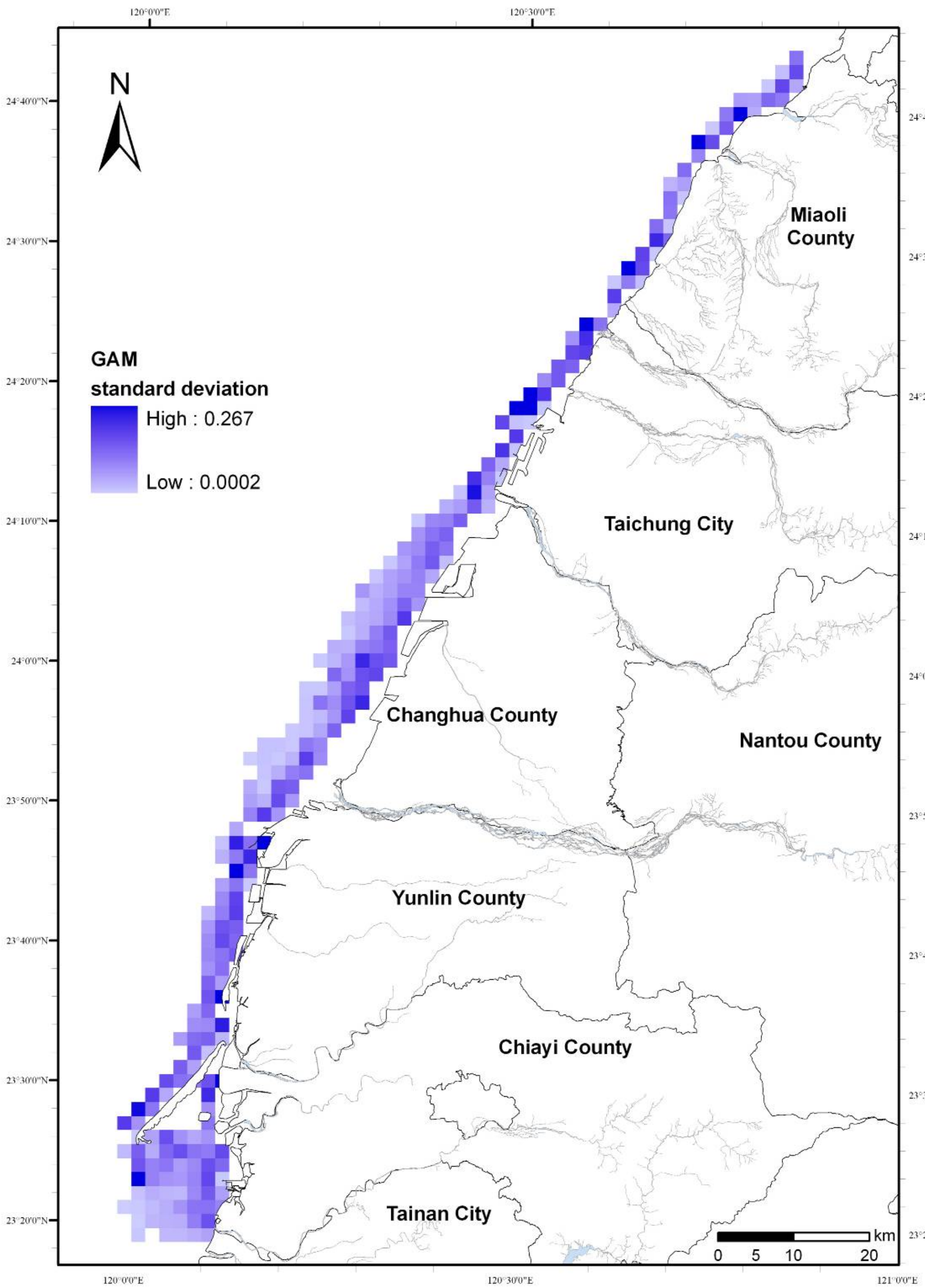


Figure 12. Standard deviation of predicted Chinese white dolphin occurrence probability by GAM. Darker color represents larger standard deviation, such as coastal area from Miaoli to Taichung City and areas near passages of Taichung and Mialiao Harbor.

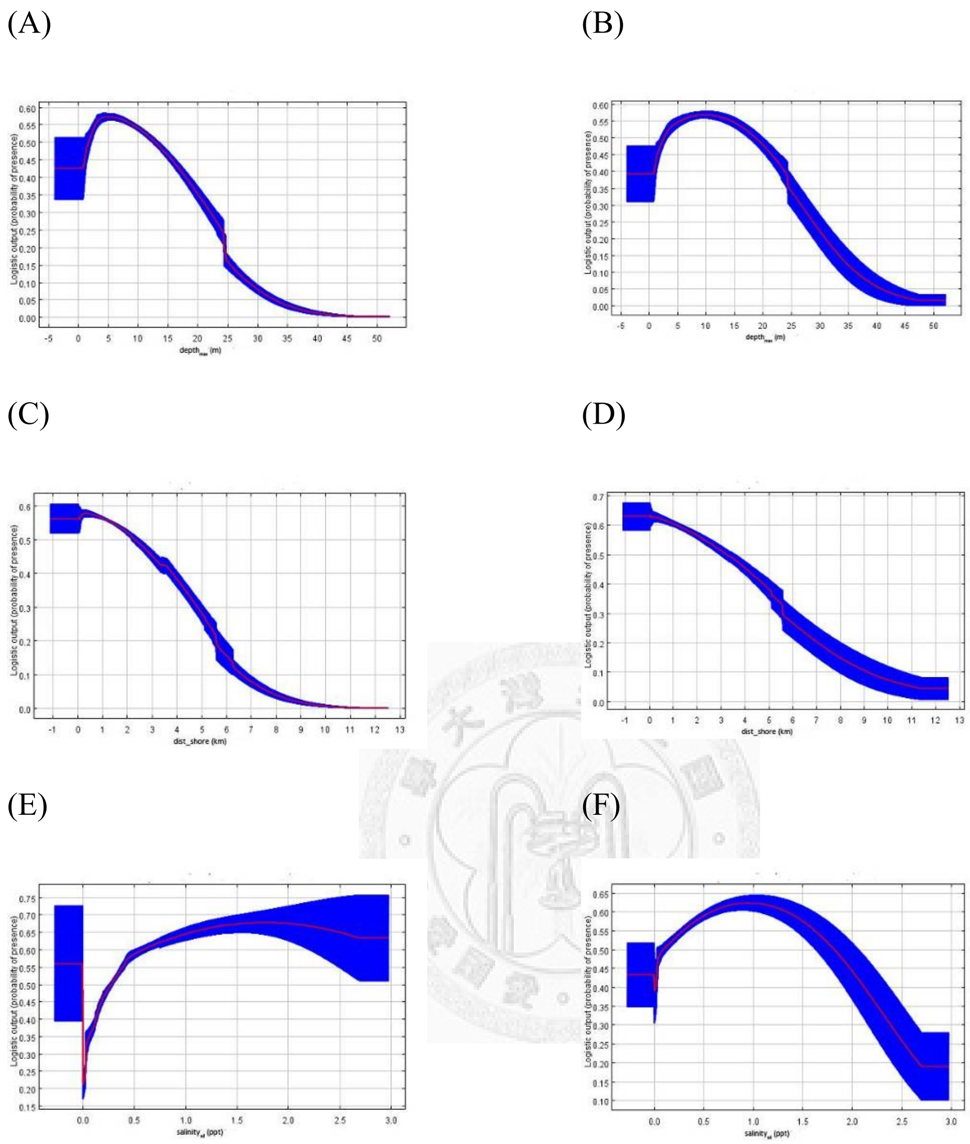


Figure 13. Response curves for variables in MaxEnt. Left panels (A, C, E) represent the response of variables independently, while right penals (B, D, F) represent the response of variables under interaction with others. The figures showed three variables influential to occurrence of dolphins, including *depthmax* (A, B), *dist_shore* (C, D) and *salinitysd* (E, F). Note the shape in (E) and (F) are different, since (F) considered response of *salinitysd* with other variables included.

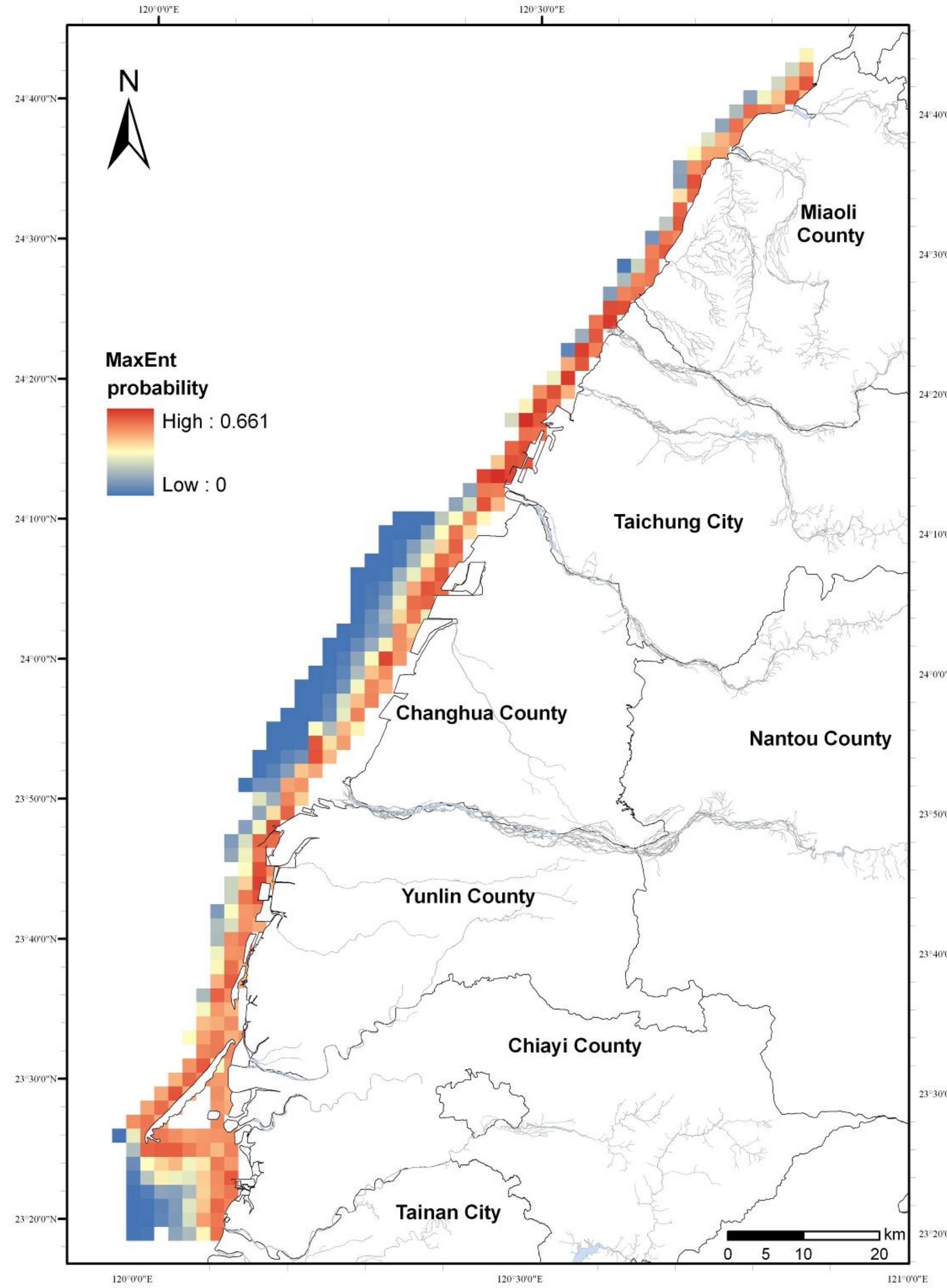


Figure 14. Predicted probability of Chinese white dolphin occurrence by MaxEnt model. The highest probability (red grids) was predicted at almost inshore side among study area.

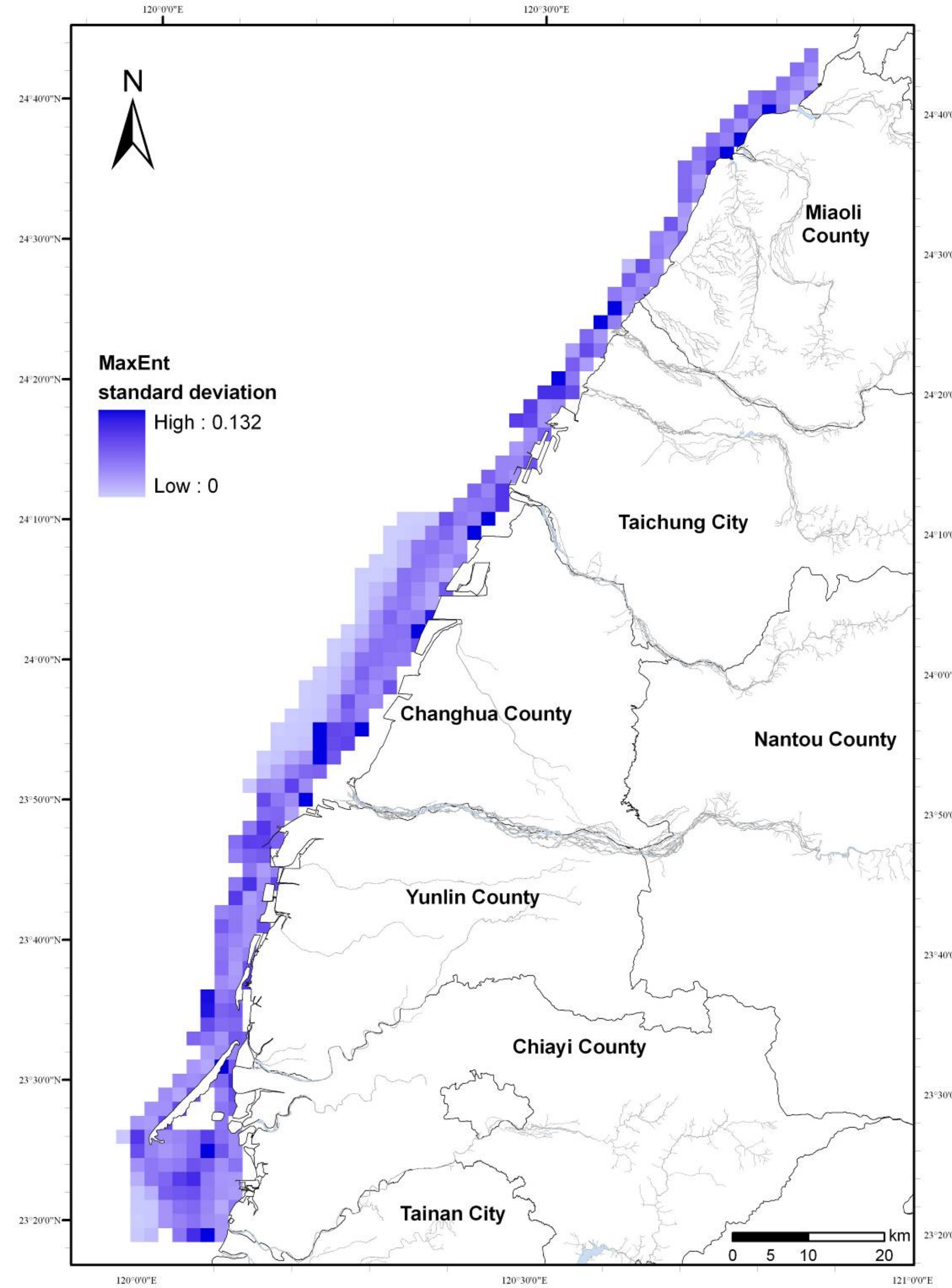


Figure 15. The distribution of standard deviation for predicted probability by MaxEnt model. Darker color represents larger standard deviation, such as regions close to river mouths of Dadu and Zhoushui.

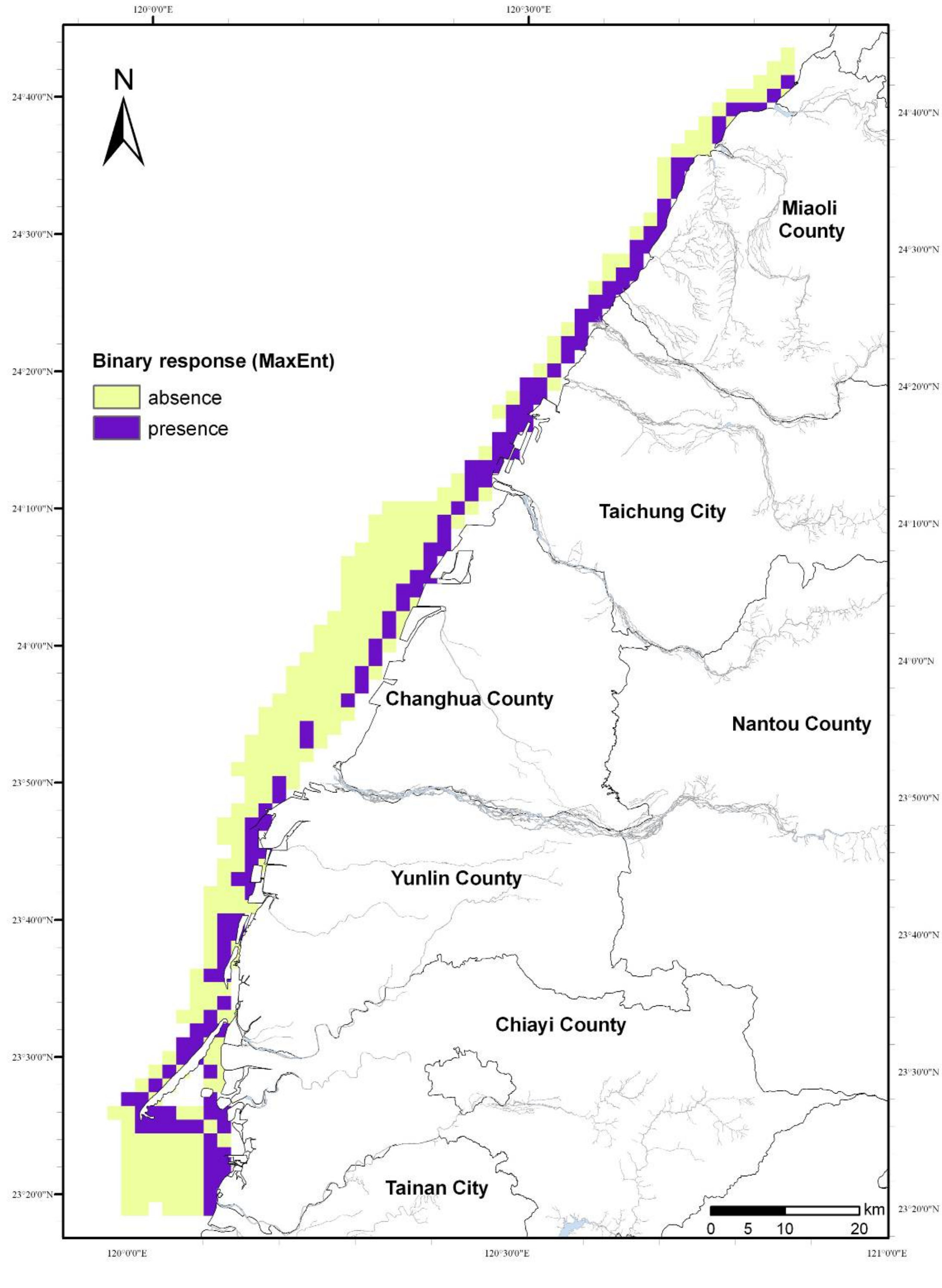


Figure 16. Binary classification of Chinese white dolphin occurrence in Taiwan predicted by MaxEnt model.

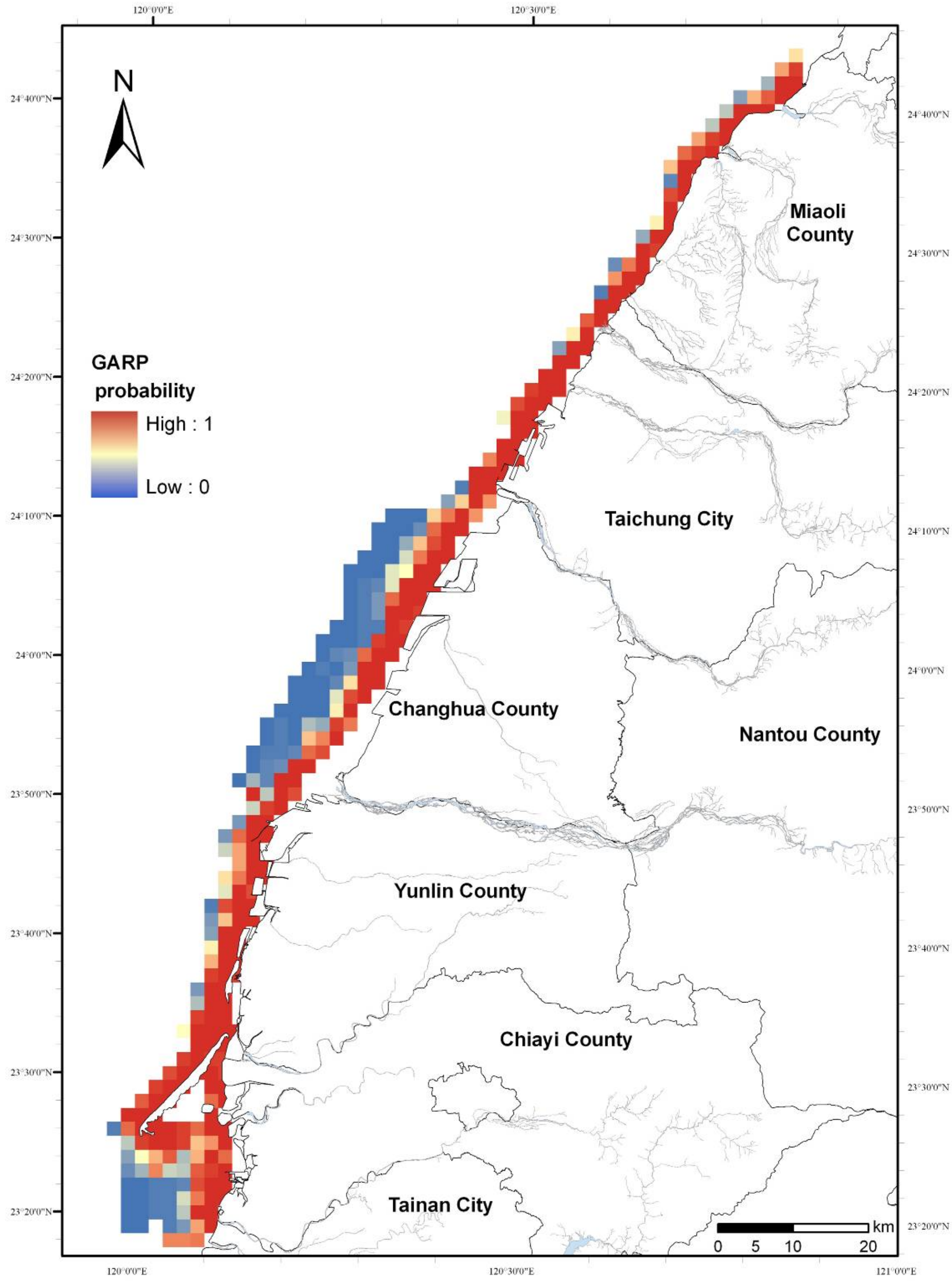


Figure 17. Predicted probability of Chinese white dolphin occurrence by GARP model. Overall probability at inshore was high and close to one.

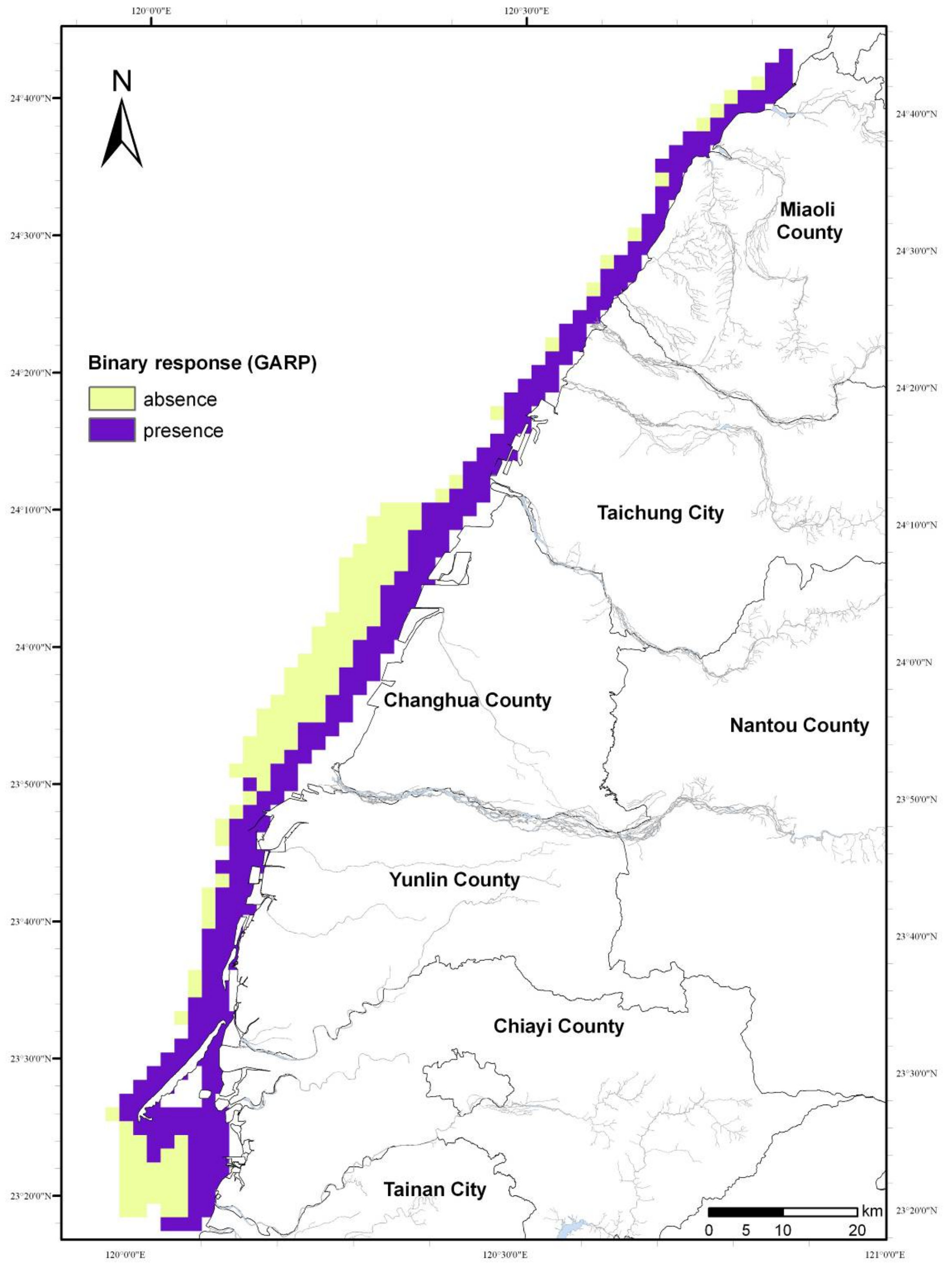


Figure 18. Binary classification of Chinese white dolphin occurrence in Taiwan predicted by GARP model.

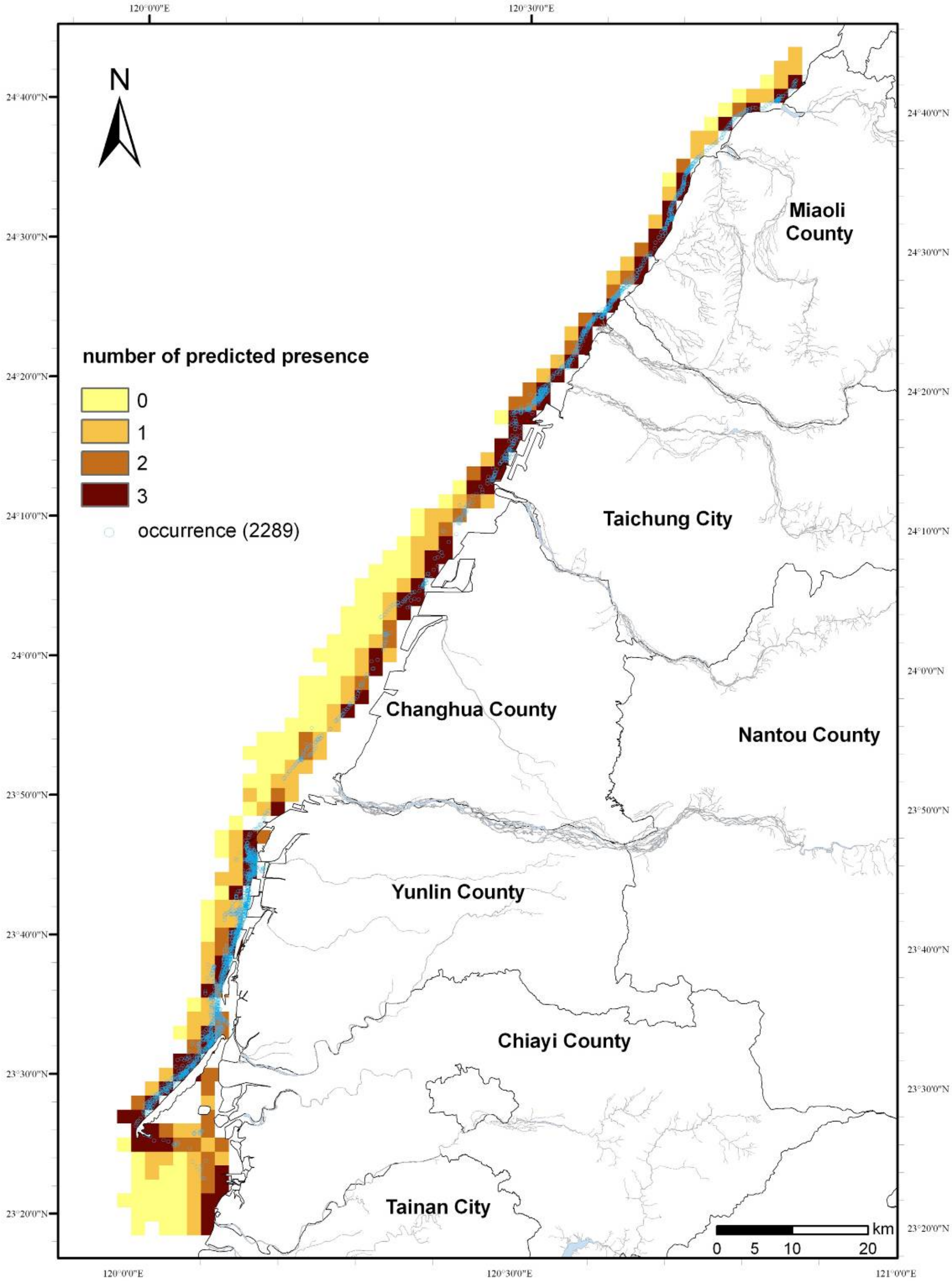


Figure 19. The ensemble model combined binary predictions from GAM, MaxEnt and GARP. The observed occurrence (*i.e.*, sighting and tracking points) was denoted by hollow circles.

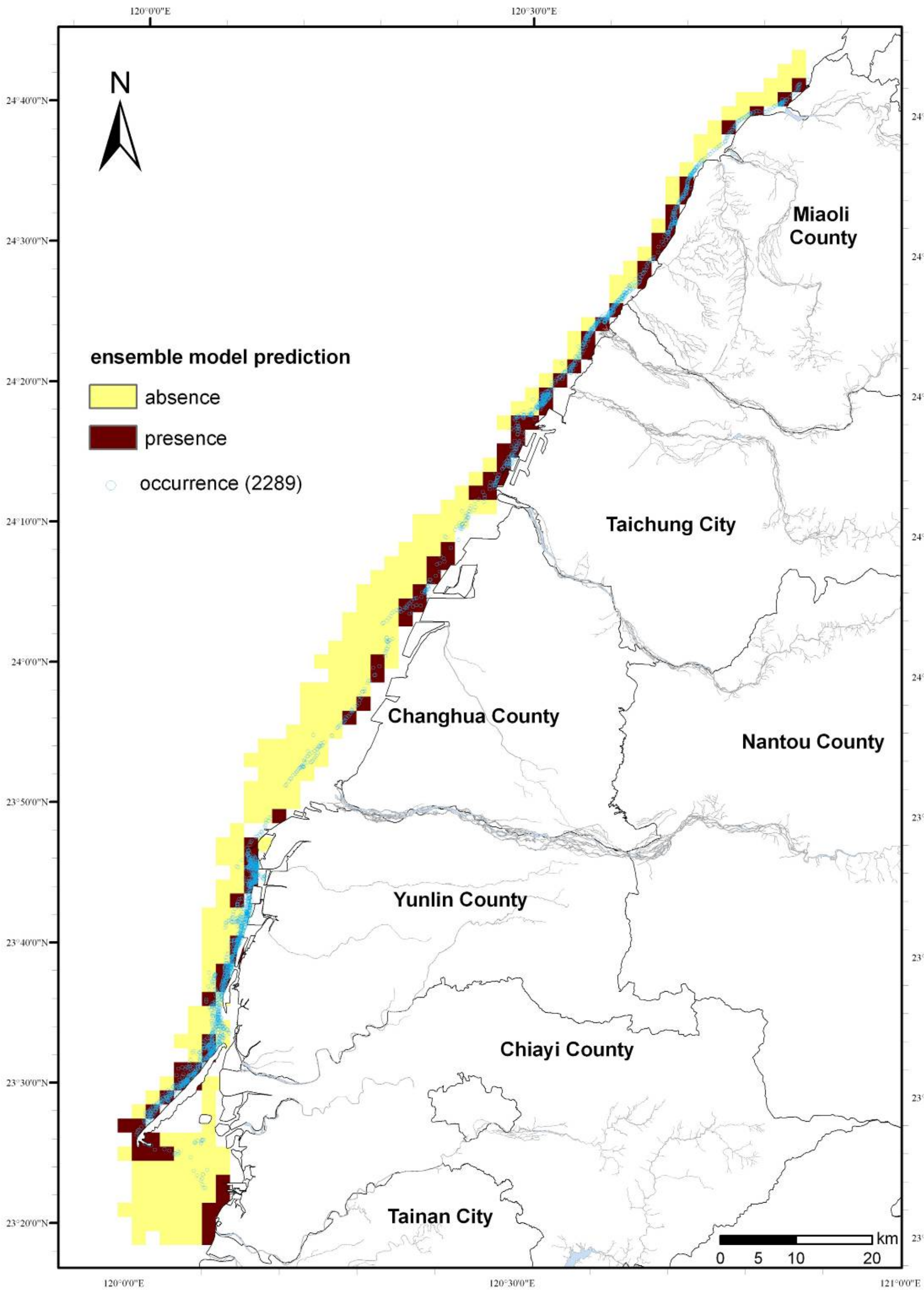


Figure 20. Final predictive distribution model of Chinese white dolphin based on an ensemble model. Grids predicted with dolphin presence were determined by at least two models.

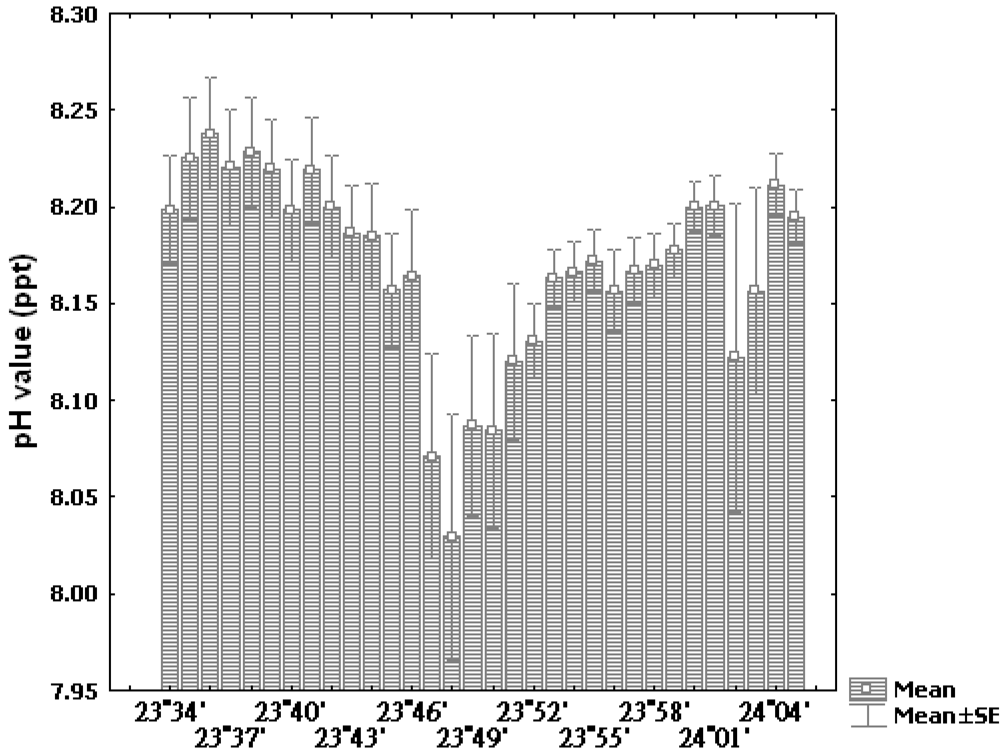


Figure 21. The pH value recorded in coastal waters from Lunwei (崙尾, 24o05') to Taizicun (台子村, 23o34') June 2009 to April 2010, where the record of pH was more than ten days. The lowest pH was found at stations near northern Liuqing Industry Park (23°47'– 23°48').

Chapter 3 Ranging pattern and site fidelity

Introduction

A home range is defined as the area supporting an animal's normal activities, including foraging, mating and the nursing of offspring (Burt (1943). These ranges are shaped by various abiotic (*e.g.*, accessibility to water, shelter) and biotic factors (*e.g.*, body mass, reproductive status) (Lindstedt et al. 1986, Karczmarski 1999, Brito 2003). For example, Lindstedt et al. (1986) confirmed a positive correlation between body mass and home range size, but, it was applicable only during critical biological times (*e.g.*, gestation). However, a study of macropods (i.e., marsupials, *Macropodidae* and *Potoroidae*) found that instead of body size, the home range sizes were influenced by climate which promoted the differences in social organization. (Fisher and Owens 2000). Study of male bottlenose dolphins *Tursiops truncatus* in Sarasota Bay also found the influence of social organization to home ranges. Males formed pair bonds commonly, and the ranges of paired males were larger than unpaired males (Owen et al. 2002). The authors suggested the advantages of forming alliances would be the prevention of harassment by predators or other males and increasing mating opportunities.

From the aspect of energy requirement, quantity and quality of resources was found to be closely related to the ranging pattern of animals. Studies of the ranges of bottlenose dolphins revealed an obvious pattern: range sizes in nutrient–rich regions (*e.g.*, estuaries) were smaller, while the sizes were larger in oligotrophic regions (*e.g.*, open ocean) (Ballance 1992, Wells and Scott 1999, Gubbins and Cook 2002, Silva et al. 2008). Moreover, females were considered to rely more on stable food resources, especially during the reproductive stage. The theory that availability of resources play a deterministic role in female ranging patterns and habitat use has been widely accepted (Austin et al. 2004, Lin and Batzli 2004, Henry et al. 2005, McSweeney et al. 2007). Reproductive female red foxes (*Vulpes vulpes*) were found to have smaller range sizes by Henry et al. (2005), and he suggested that these females might exclude other females from food sources of better quality. Studies of the movements of prairie voles (*Microtus ochrogaster*) and grey seals (*Halichoerus grypus*) revealed that the ranging pattern of females were related to a stable supply of food (Austin et al. 2004, Lin and Batzli 2004). The ranges of female cheetahs (*Acinonyx jubatus*) in Kruger National Park were found to be associated with the distribution of impala *Aepyceros melampus*, which was their main prey (Broomhall et al. 2004).

In sum, the range size of animals was a reflection of the environment and biological processes according to previous studies; therefore, understanding range sizes and ranging patterns could provide insight into the characteristics of a species in ecological, demographical and evolutionary ways. To estimate the home range, popular methods include the Minimum Convex Polygon (MCP) method (Mohr 1947) and the kernel method (Van Winkle 1975). Suppose an animal was found at several positions; the home range estimated by MCP would enclose the external positions, while the kernel method estimated the distribution density to delineate home range (*e.g.*, 95% kernel range). The advantage of MCP is its simplicity, but it is prone to emphasize the effect of spatial outliers. The kernel method concerns not only the extent of the range but also the intensity of activity (Worton 1987). However, while the kernel method is able to provide detailed information such as the level of habitat selection based on probabilistic distributions, it requires up to 50 observations to minimize bias and variance (Seaman et al. 1999).

Besides home range, another concept used by researchers is core area. Definitions of core area varied between studies due to the different methods applied in home range estimation. However, the general principle suggested by Samuel et al. (1985) for core areas referred to disproportionate use of a range within the home range and was accepted by many studies (Worton 1987, Kenward et al. 2001, Barg et al. 2004, Hauser et al. 2007). For the MCP method, Larivière and Messier (1998) calculated 50% MCP as the core area, but it was on the basis that all individuals had only one center of activity. Considering that the cores of a range might be multinuclear, estimates of outlier-exclusive cores (OECs) using cluster analysis was proposed by Kenward et al. (2001). For the kernel method, 50% utilized distribution (UD) or 25% UD were commonly used, and some studies used both (Gubbins and Cook 2002, Owen et al. 2002, Heupel et al. 2006, Hung 2008, Rayment et al. 2009).

Site fidelity has been another focus in range studies. Since animals use their space unevenly, areas with high fidelity become relatively important to their survival. However, the definitions of site fidelity also varied between studies. A study conducted at two estuaries in Australia used the proportion of surveys and number of seasons that recorded dolphin as estimators (Fury and Harrison 2008); Brager et al. (2002) calculated the proportion of summers that dolphins showed up; in a study of Rough-toothed dolphins in Hawaii, high resighting rates of resighted groups composed 75% of the distinguishable individuals were described as higher site fidelity (Baird et al. 2008).

Few studies of Indo-Pacific humpback dolphins (hereafter Chinese white dolphins) have investigated individual ranging patterns and site fidelity (Table 1). First, Hung (2008) used the MCP and kernel methods to calculate range size of Chinese white dolphins in Hong Kong to determine ranging patterns. For 16 individuals, the average MCP size was 135.0 km^2. The average kernel ranges for 95% UD (*i.e.*, utilized distribution), 50%UD and 25% UD were 145.4km^2, 23.1km^2 and 7.9km^2 respectively. No significant difference between the MCP and kernel was found and the range sizes of most individuals ranged from 100–200km^2. Chen (2007) estimated the MCP and linear movement of 20 Chinese white dolphins in Xiamen; the average MCP for these individuals was 52.88km^2, and the average distance of linear movement was 17.58km. Parra (2005) calculated the site fidelity for 22 identified individuals, along with the MCP and the length of range for nine individuals. He concluded that most dolphins observed in Cleveland Bay, northeast Queensland were occasional visitors, for the relatively higher yearly sighting rate compared with the monthly sighting rate. The average MCP was 69.1km^2, and the average length of range was 27.4 km.

Individual ranging patterns and site fidelity allow for a better understanding of the habitat use of a targeted species. While we can infer possible functions of a particular area from behavioral data, range studies provide insight into the importance of a particular area frequently occupied by animals. Since this kind of information is valuable for conservation and the population of Chinese white dolphins in Taiwan has been listed as “critically endangered” (Reeves et al. 2008) by the IUCN, individual ranges should be investigated to offer practical information for conservation management.

Method

Home range estimate

Because the distribution of Chinese white dolphins in Taiwan was limited inshore, and sighting rates were low at two ends of the study area (see chapter 2), the term “home range” was applied in this study. Except calves, each individual dolphin with clear mark or body color pattern was photo-identified and categorized by Weilung Chang of Chou’s research team. The individuals with more than 10 sightings were used for range estimation and site fidelity analysis. During May 2006–Sep 2010, 370 surveys were conducted and 64,109 photographs were taken. Seventy one individuals were identified from 225 groups of Chinese white dolphins sighted during boat surveys, and were cataloged by their sighting positions, date, age classes defined by coloration stage of the dolphin's skin, and breeding status (*i.e.*, recorded calving or not). For data analysis, in order to prevent pseudo-replication, only one sighting record per day was included (Owen et al. 2002). The number of sighting records of individuals ranged from 3 to 37 and recorded in a histogram (Fig. 1).

Due to limited sample size of resightings, the Minimum Convex Polygon (MCP) method (Mohr 1947, Hayne 1949) was applied to estimate the range size of the dolphins. Also, this measure permitted comparisons with other studies of Chinese white dolphins in Australia and Hong Kong. Before range estimation, an effective sample size was chosen to permit realistic range estimates. Because the MCP size tended to be influenced by spatial outliers, a resampling method was needed to minimize the effect of outliers. To do this, 1000 bootstrap iterations were conducted to observe the relation between the increase of sightings and MCP size. Package "adehabitat" written in the R program (Calenge 2006) was employed for the analysis. In most simulations, the cumulative area achieved asymptotes around 90% of the MCP size; therefore, this percentage was considered to be qualified to represent the realistic size. For most individuals, ten sightings were enough to reach 90% of the MCP. Fifty-seven individuals with $\geqq$ 10 sightings were thus included in the range estimate.

First, for the home range estimate, unpeeled (*i.e.*, 100%) MCPs with landmasses and oyster grounds subtracted were calculated using Hawth's Animal movement tools (Beyer 2004). Second, considering some dolphin individuals may have more than one center of core area, MCP core areas were performed for individuals by home range clustering with the R "adehabitat" package (Kenward et al. 2001, Calenge 2006). This method would produce outlier-excluded cores (OECs) used extensively by the animals. Core areas were then converted into shapefiles for ArcGIS 9. A 500m*500m grid was generated to calculate the overlap of core areas. Third, considering the shortage of MCP that weighted high and low degrees of utilization equally, the latitudinal length (i.e. range of minimum to maximum latitudinal degree) for the MCP of each dolphin was also estimated as an alternative index.

To compare the differences in range size between age classes or breeding status, nonparametric statistics including Kruskal-Wallis test and Mann-Whitney U test were used. The numbers of individuals for the four age classes were 19 mottled skin (MT, i.e. teenage), 24 speckled skin (SK, i.e. young), 11 spotted skin (SA, i.e. adult) and three unspotted skin (UA, i.e. elder). Grouping the dolphins by breeding status, 22 individuals occurring with calves were regarded as mothers, while the rest did not.

Site fidelity

Site fidelity can be evaluated from the spatial aspect as the sighting position distributions, as well as from the temporal aspect as the frequency of sightings over the surveyed months. From the spatial aspect, because dolphins were discovered to have unequal range extents during the mapping of MCP, it was hypothesized that some of the ranges were limited in particular region, which was so-called "subarea", and for those individuals, they could be regarded as "resident" to that subarea. On the contrary, if dolphins whose ranges were not limited in subarea(s), they should be regarded as "transients". In order to understand the spatial range use by individual dolphins according to sighting position distributions, 3 parameters of the spatial features (i.e. median, minimum and maximum latitudinal degree of sighting positions) were calculated for each dolphin using spatial statistic tools in GIS. Then, cluster analysis with Ward's method was conducted to distinguish the range use pattern of individuals.

As for the temporal indicator of site fidelity, the monthly sighting rate was calculated for subareas inhabited by resident dolphins to understand whether residents and transients showed any difference in the intensity of space use. The monthly sighting rate was defined as the number of months that a dolphin was discovered divided by the total number of survey months. Sighting rates of residents and transients as well as different age classes and breeding statuses were compared through nonparametric statistics including Kruskal-Wallis (K-W) test and Mann-Whitney (M-W) U test.

Result

Home range estimate

From the histogram of resightings of individuals (Fig. 1), most dolphins have 10-20 records and the median number of resightings was 16. The limited sample size didn’t permit the kernel estimates; therefore, MCP and linear measurement were the applicable methods for range estimation of Chinese white dolphins in Taiwan.

The MCP shapes for Chinese white dolphins were stripes. The mean MCP size of the 57 individuals was 192.56± S.E.13.32km^2 (range: 60.75–389.62), and the mean latitudinal length was 69.10± S.E.3.03km (range: 33.18–122.61). The MCPs and core areas of 57 dolphins of each dolphin were illustrated at Fig. 2. Out of 57 individuals, 16 dolphins have more than one distinct core areas, while the others have single core area within the home range. The overlap of core areas was heavy in the shallow waters of Taichung City (台中市), Yunlin County (雲林縣), and off the west side of the Waisanding sandbar (外傘頂洲) (Fig. 3).

The average MCP size and latitudinal length for each age class and breeding status (mother role) is summarized in Table 2. There was a significant difference in MCP range sizes among the four age classes (K-W test, $H_{3,57}$=12.56, p=0.006) in general. However, in terms of pair-comparisons, except for unspotted adults, the MCP size segregation among other age classes was not obvious. The quartile ranges (*i.e.*, 25%-75%) of the other three categories overlapped (Fig. 4). However, from the indicator of latitudinal length, the difference among the 4 age groups was not significant (K-W test, $H_{3,57}$=4.56, p=0.21)(Fig. 5). In addition, for the comparison between the 2 breeding groups (with calf or not), the differences were not significant in either the MCP or latitudinal length (M-W U test, p=0.13, for both) (Fig. 6,7).

Site fidelity

According to the 57 dolphins' home range parameters (*i.e.*, minimum, median and maximum latitude degree), the cluster analysis revealed four distinct clusters (Fig. 8,9). The medians of the ranges of dolphins concentrated into northern and southern groups. For these two groups, dolphins with their ranges limited to either the north or south could be classified as residents, while transients could be defined as the others covering both north and south. The geographical boundary of the northern region was from Songbo to Lunwei, and from south of Mailiao Port to the Waisanding sandbar for the southern region. Therefore, the four clusters could be named as northern residents (n=17), southern residents (n=8), northern transients (n=6) and southern transients (n=26) respectively.

In terms of the sighting rate, estimates within corresponding regions showed unclear stratifications of the degree of fidelity between local residents and transients for both regions (Fig. 10,11). The differences in sighting rate between residents and transients was not significant for the southern region (M-W U test, p=0.007) but was significant for the northern region (M-W U test, $p<0.00$).

For the comparison of age classes and breeding statuses, differences in sighting rates was not significant (K-W test, $H_{3,57}$=1.35, p=0.37) among age classes, but was significant

(M-W U test, p=0.02) between the two breeding groups (being mother or not). This plot was shown in Fig. 12.

Discussion

Home range estimate

The striped MCP shape suggested that Chinese white dolphins mostly acted within a linear range in Taiwan. This pattern was similar to that of Algoa Bay, where the water depth was shallow and contours were parallel to the coastline. The topographies of these two places were similar, and they might lead to linear movements for such inshore-distributed dolphins. If this was the case, the comparison between the MCP and latitudinal length should have no difference. However, since dolphins were also found along Waisanding sandbar, which was more distant from land, ranges estimated by the MCP method might cover areas rarely being utilized. One case that might relate to MCP overestimation was the different results across age classes; significant differences were found in the MCP, while differences in latitudinal length were insignificant. For species that uses linear range, the accuracy of range estimation was prone to be influenced by overestimation and spatial autocorrelation (particular to kernel estimation); it was proposed that linear estimator should be applied (Blundell et al. 2001). In this case, latitudinal range would be the parameter free from overestimation compared with MCP and was the better estimator for Chinese white dolphins in Taiwan.

The average MCP size (192.56km^2) was larger than in other studies of Chinese white dolphins (Hong Kong: 135km^2, Xiamen: 52.88km^2, Australia: 69.1km^2). One of the possible reasons is the survey coverage. Since evidence showed that Chinese white dolphins normally do not go to areas other than western coast of Taiwan, the study area covered almost all of the range used by the dolphins regularly. On the other hand, in Hong Kong, Chen et al. (2010) indicated that the western PRE (*i.e.*, Pearl River Estuary) shared the same population with the eastern PRE, where a previous study of dolphin range was conducted. Both the studies in Xiamen and Australia suggested that their study areas were part of the home range of the Chinese white dolphins recorded (Parra et al. 2006a, Chen et al. 2008). Therefore, range studies in those regions might obtain smaller range sizes. Another explanation is the availability of resource patches. Populations of Chinese white dolphins displayed seasonal immigration and emigration in Algoa Bay(Karczmarski et al. 1999b), and seasonal movement following the variation of prey was suggested by Karczmarski (1999a); he proposed that resource fluctuations might force these dolphins to use larger areas to forage. Also, Bottlenose dolphins in the Azores were found to have a larger range size (average MCP: 182.0km^2, 95%UD: 437.2km^2) (Silva et al. 2008) compared with those in an estuary of South Carolina (average MCP: 40.8km^2, 95%UD: 51.2km^2) (Gubbins and Cook 2002). Since the open ocean is oligotrophic and oceanic islands usually serve at patches with higher productivity (Doty and Oguri 1956, Sander and Steven 1973), larger range size is a consequence of a patchy distribution of resources.

Core areas were related to important resources such as shelter and reliable sources of food (Samuel et al. 1985, Hanski et al. 2000, Silva et al. 2008, Rayment et al. 2009). The heavy overlap of core areas was found in the coastal waters of Taichung City and Yunlin County, indicating that the resources of these areas might be predictable and abundant. For the case of Hector's dolphins (*Cephalorhynchus hectori*), which were alongshore-distributed, distinct cores were found and critical habitats were recommended by Rayment et al. (2009). As a coastal species which is susceptible to disturbances caused by human activities, the two regions highly overlapped by individual cores should be regarded as critical areas for Chinese white dolphins in Taiwan. Although possible reasons that contributed to the intensive use by dolphins in these regions haven't been confirmed, analyses of behavioral data could help in understanding the functions of the two regions and might serve as supportive evidence for a hypothesis such as food availability.

Although the differences were not significant, range sizes across age classes showed a decreasing trend. A study had found that young Chinese white dolphins in Xiamen (*i.e.*, MT and SK) used larger ranges than adult ones (*i.e.*, SA and UA), which corroborated by the result of this study. According to Lindstedt et al. (1986), larger areas used by younger animals could be attributed to social organization and the behavior of the species. Because younger individuals have not developed territories and were possibly excluded by predominant individuals occupying particular ranges, they were prone to be found in peripheral regions. Also, the demand of energy and poor foraging skills could drive young animals to live in a larger range. However, the overlap of core areas and ranges among individuals in this study suggested minor territoriality of Chinese white dolphins in Taiwan. Therefore, the latter is more likely to account for the large ranges of juvenile and young dolphins.

However, the result of a range estimate in Hong Kong conducted by Hung and Jefferson (2004) was different, where adult dolphins had larger ranges. A special case found only in Hong Kong was that some adult dolphins would follow trawlers, which often occurred at marginal areas of the range. Ranges of dolphins with rarer associations with fishing boats were significantly smaller than those who associated frequently, and more than half of the dolphins were observed frequently associated with fishing boats. This might be one of the reasons for the larger range size of adults. Nonetheless, boat-associated behavior was rarely observed in Chinese white dolphins in Taiwan, and dolphins were never recorded to have followed fishing boats to the margins of their range.

Previous studies found limited ranges used by mothers (Austin et al. 2004, Henry et al. 2005). In this study, however, 14 out of 22 mothers were transients who moved through almost all of the study area, and there was no significant difference in range size between different breeding statuses. Since the ranges of mothers were influenced by the growth stage of the calves (Karczmarski 1999), comparisons between ranges under normal circumstances and during the calving interval may help to clarify this question. However, due to the limited sample size per individual, this approach was not included in the present study. Also, the fluctuation of resources is a possible explanation; it might force mothers to range further for food. Since the main prey items of Chinese white dolphins were estuarine and benthic fishes distributed inshore (Parra and Jedensjö 2009), coastal environments with dynamic change might lead to the unstable distribution and abundance of prey (Defran et al. 1999).

Site fidelity

Previous studies estimated site fidelity in various ways and parameters, most of which considered the time scale only. This is the first study that combined spatial and temporal investigations to provide more detailed information about site fidelity. The northern and southern regions gathered by medians of animal localities and inhabited by resident dolphins suggested important regions which were heavily utilized by Chinese white dolphins.

An inconsistent residency exhibited in range use and sighting rate was found. Sighting rates of some transients were as high as those of residents, indicating that those transients used a particular region as intensively as residents did, although they were occasionally recorded outside of that region. These occasional records were spatial outliers that might lead to such a conflict. Ten southern transients were recorded ranging outside the core only once; these outliers were in individuals to be classified into transients rather than residents in cluster analysis.

Despite unclear stratifications of sighting rates of residents and transients at both regions, a significant difference was found in northern region. Out of 28 transients in northern region, 22 of them exhibited low sighting rate; it caused significantly lower sighting rate of transients. While out of 31 transients in southern region, only 5 of them exhibited low sighting rate; it indicated most transients found at southern region were as loyal to the ground as residents did. Moreover, considering the proportion of resident, it was larger in northern region (17 out of 45, 37.8%) than in southern region (8 out of 39, 20.5%). The above suggested dolphins of northern region were prone to be either residents or transients visiting occasionally, and most dolphins of southern region were likely to be transients using this place frequently but moving outside occasionally.

Sighting rates of mothers were significantly high. As indicated by many studies, higher site fidelity of nursing female was expected due to the need of energy supplied by stable resources and concern of shelters to prevent male harassment and predators. Long-term record of adult female beaked whales (Cuvier's, *Ziphius cavirostris*; Blainville's, *Mesoplodon densirostris*) and bottlenose whales (northern bottlenose whales, *Hyperoodon ampullatus*) at particular areas with higher productivity were founded (Wimmer and Whitehead 2004, McSweeney et al. 2007). Nursing groups of Dusky's dolphins (*Lagenorhynchus obscurits*) off Kaikoura significantly preferred shallow waters (*i.e.*, ≦20m), which were proven to be refuges from males and commercial boats (Weir et al. 2008). In this study, however, only calving dolphins could be recognized as females. Neither the genders of the rest of dolphins nor the quantity and quality of the resources in these two regions were unknown. Since areas preferred by females are potentially crucial for nursing offspring, the importance of the two regions should be highlighted and further studies are recommended to investigate the prey availability within habitats and the gender composition of Chinese white dolphins in Taiwan.

Conclusion

The average range size of 57 dolphins was 192.6km^2 for MCP and 69.1km for latitudinal length. The average MCP size was larger than those in other regions, which might be due to the survey coverage and resource fluctuation. Core areas within the ranges, as well as the existence of residents of the northern and southern regions, were found. The study has highlighted the importance of these areas to the survival of this population, since core areas are related to crucial resources such as shelters or reliable sources of food, and regions inhabited by residents suggested there might be no substitution for them. However, it is note-worthy that the data were collected mainly during summer; therefore, more surveys would be needed in future to investigate the differences of ranging patterns among seasons. In addition, sighting rates of mothers within the northern and southern regions were significantly higher, suggesting the importance of these regions for nursery.

Table 1. Summary of range studies on Chinese white dolphins. Note that 95% UD was the estimator in the kernel method.

Location	sample size	mean MCP (km^2)	MCP shape	95% UD (km^2)	linear distance (km)	reference
Cleveland Bay	22	74.8	polygon	–	25.2	Parra (2005)
Xiamen	20	52.88	polygon	–	17.58	Chen (2007)
Hong Kong & PRE	16	135	polygon	145.4	–	Hung (2008)

* PRE: Pearl River Estuary

Table 2. Summary of range estimates including the MCP size and latitudinal length by age class and breeding status.

Age (coloration stage)	sample size	MCP size (km^2)	latitudinal length (km)
	n	mean± s.e	
mottled stage (MT)	19	236.26±19.80	74.17±4.89
speckled stage (SK)	24	192.99±20.34	70.02±4.46
spotted adult (SA)	11	150.84±30.09	65.40±8.22
unspotted adult (UA)	3	65.26±3.67	43.30±1.72
breeding status			
mother	22	220.88±20.39	23.97±5.11
not mother	35	174.76±17.03	65.63±3.68

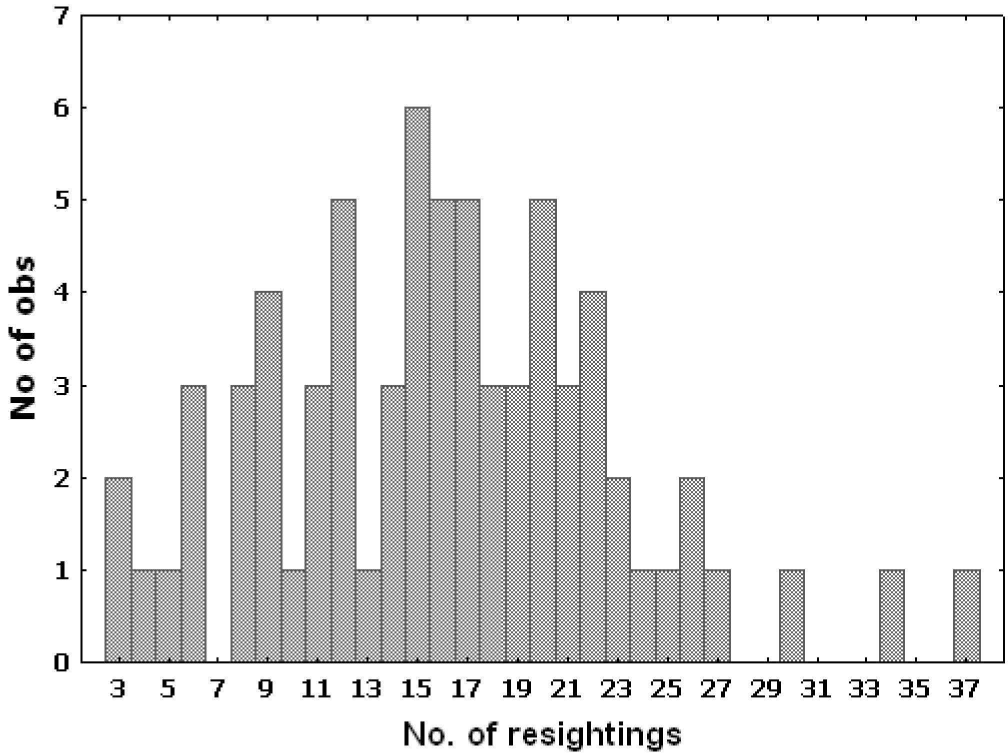


Figure 1. histogram of resightings (*i.e.*, number of sighting points) of 71 dolphins. Most of dolphins have 10–20 resightings.

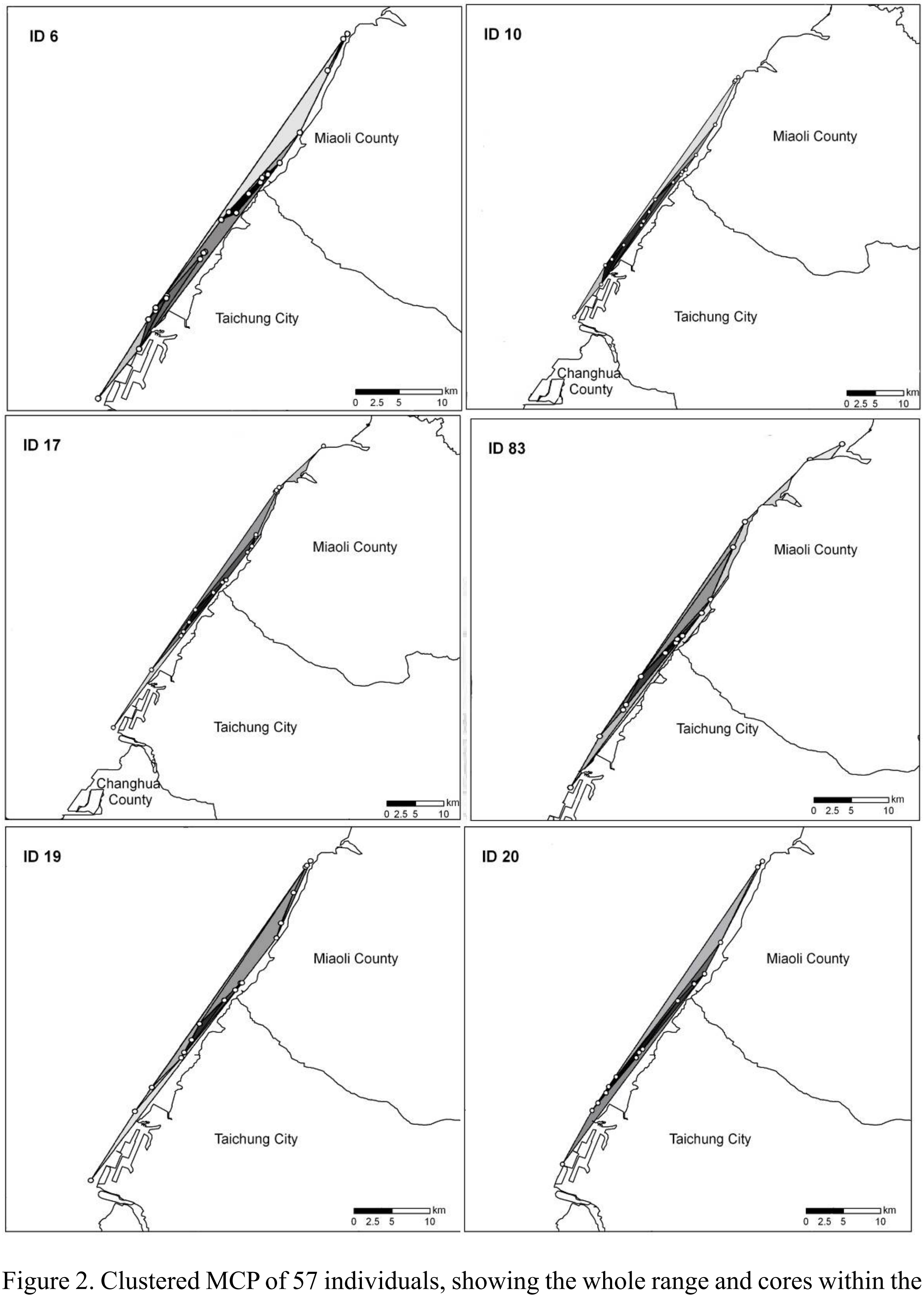


Figure 2. Clustered MCP of 57 individuals, showing the whole range and cores within the range. The outermost boundary represents 100% MCP. Internal polygons represent the cores under different percentage MCP. The darker the polygon, the more intense use of this area.

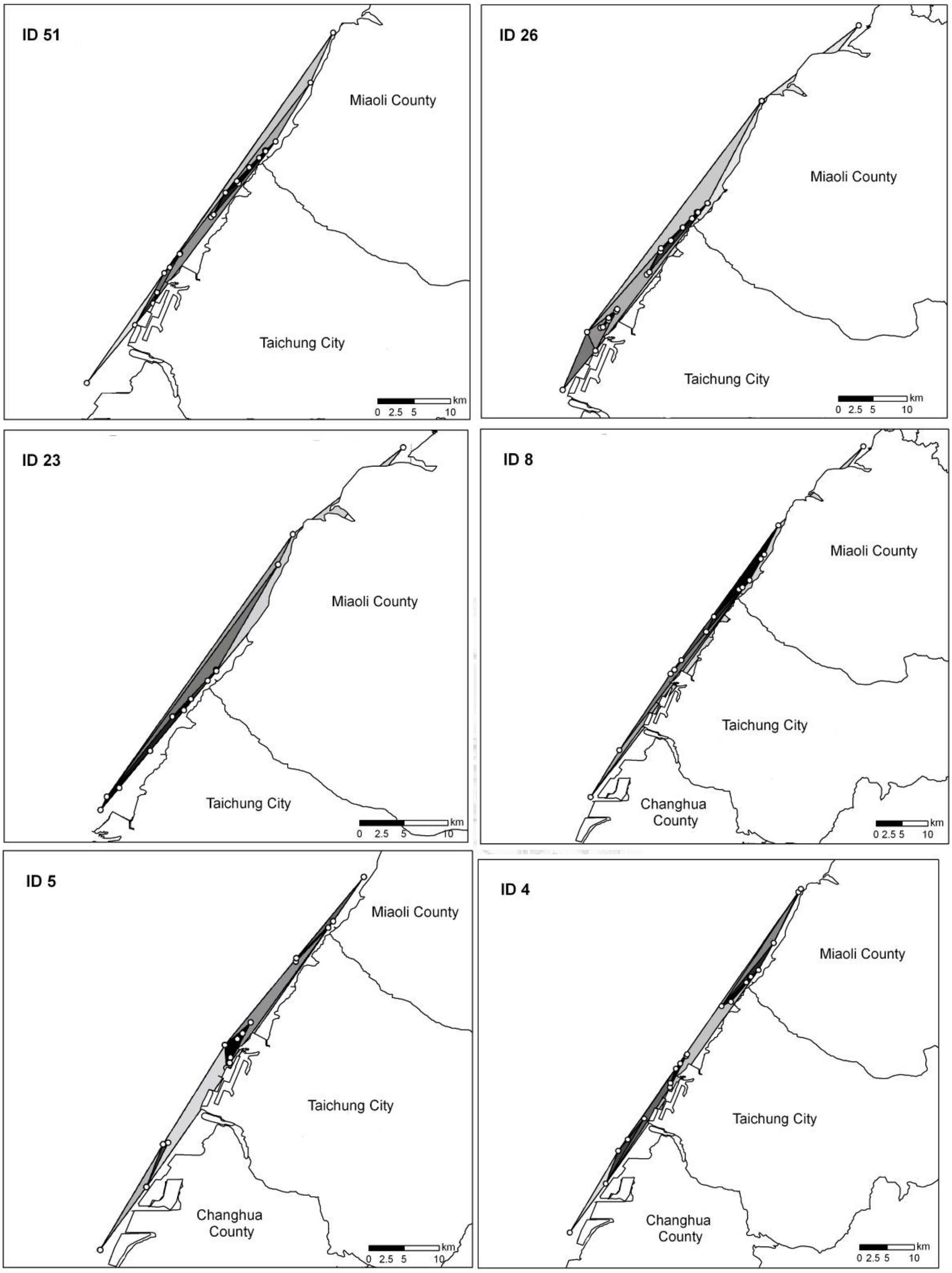


Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.

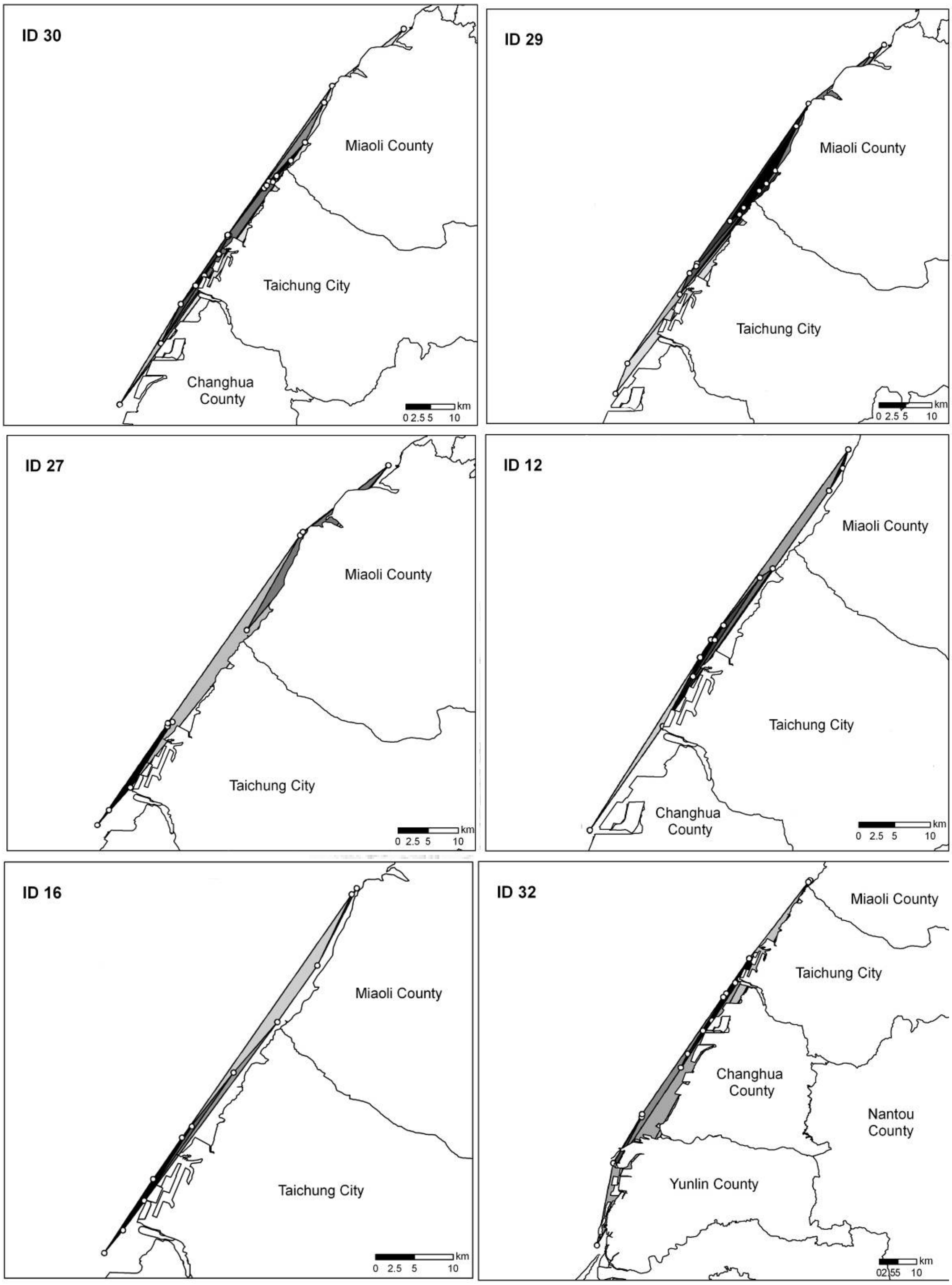


Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.

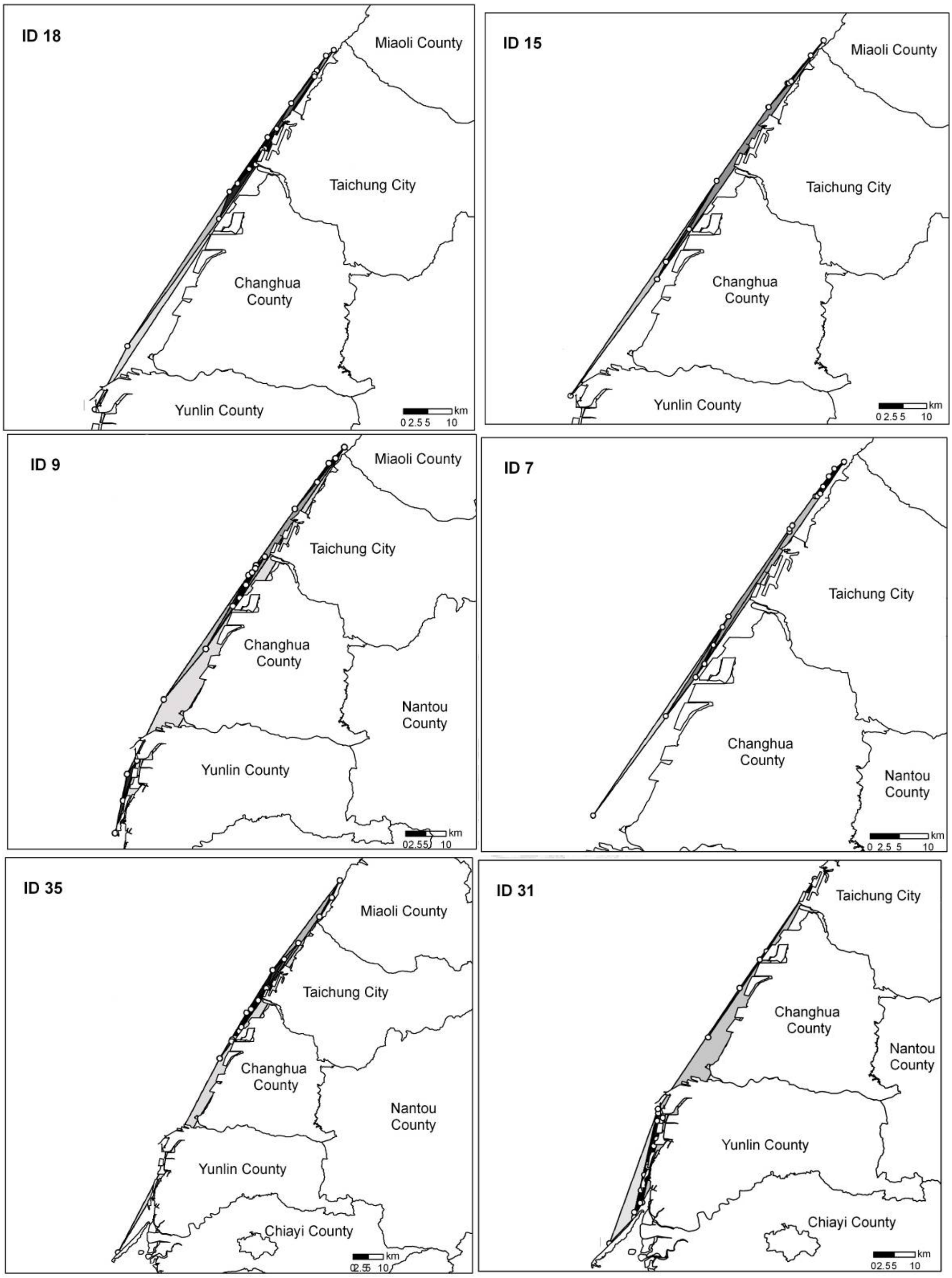


Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.

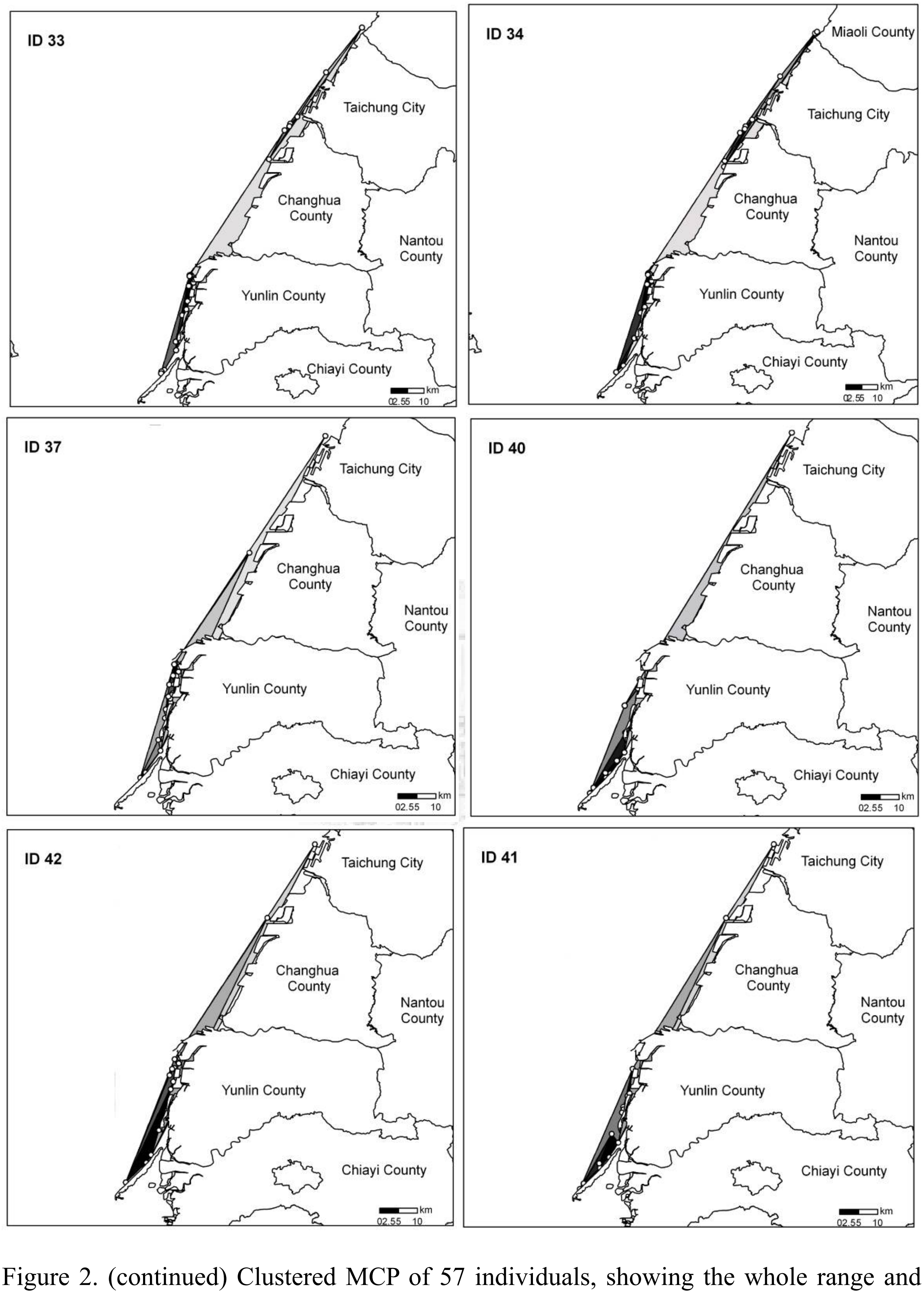


Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.

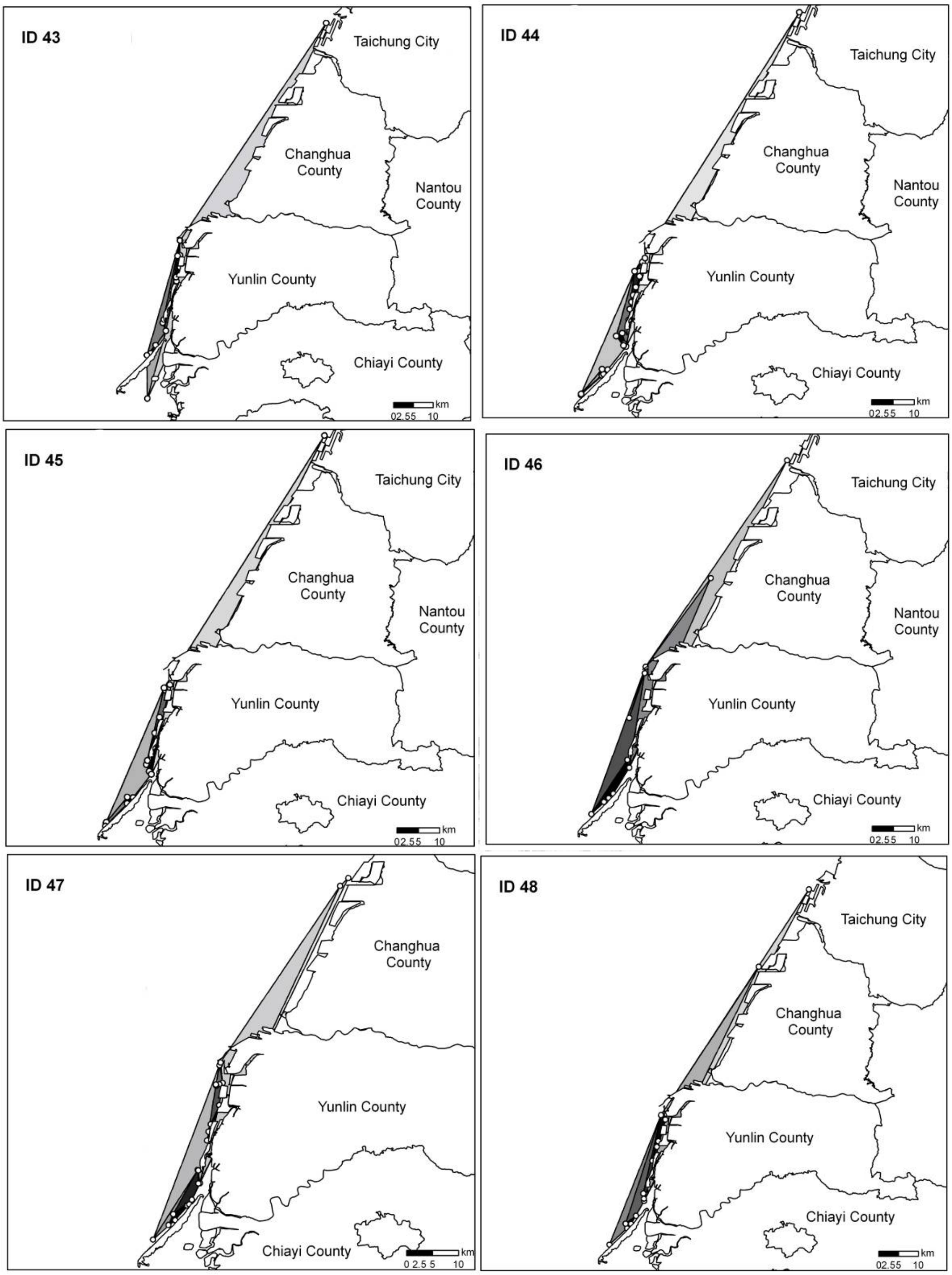


Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.

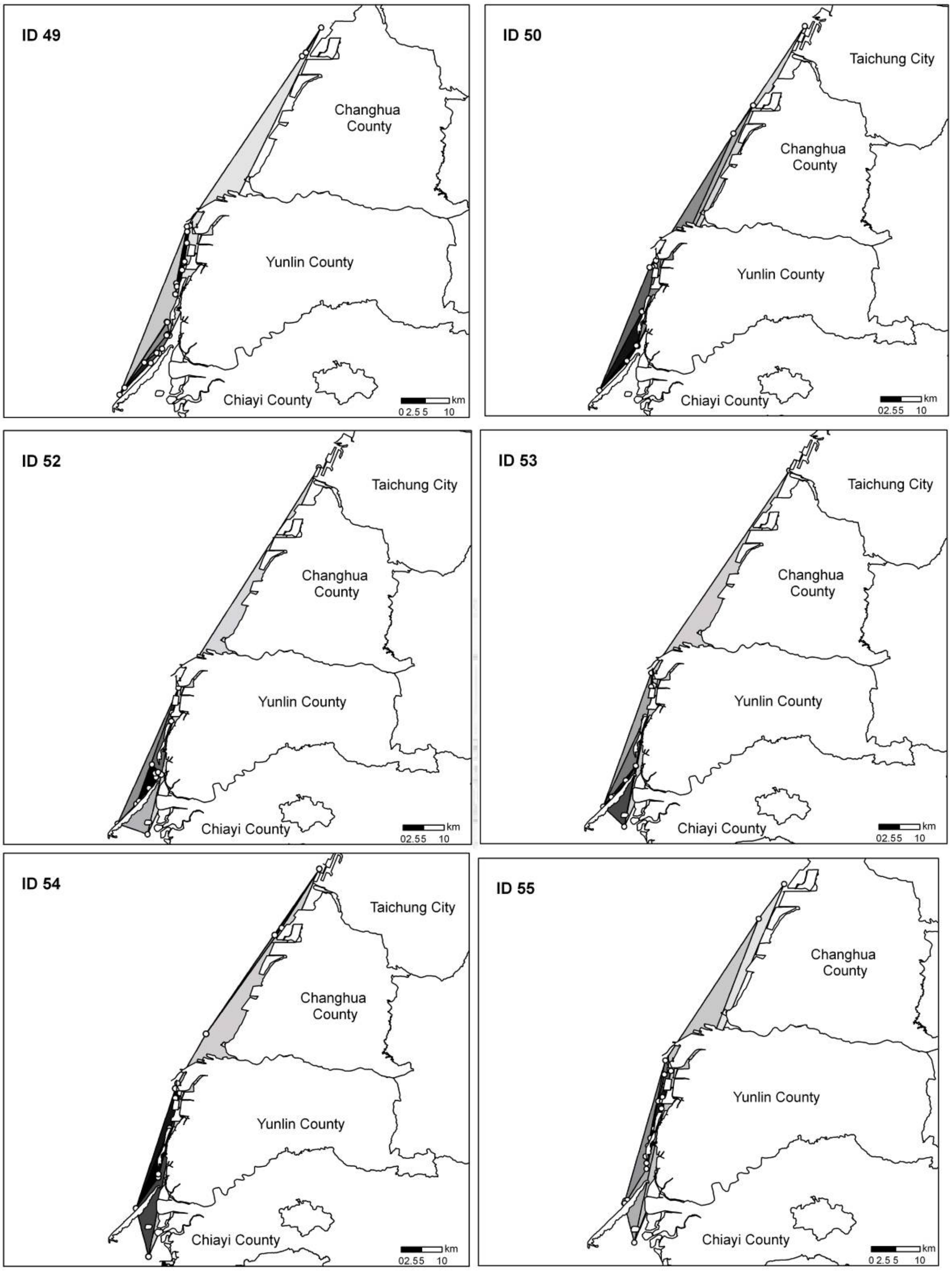
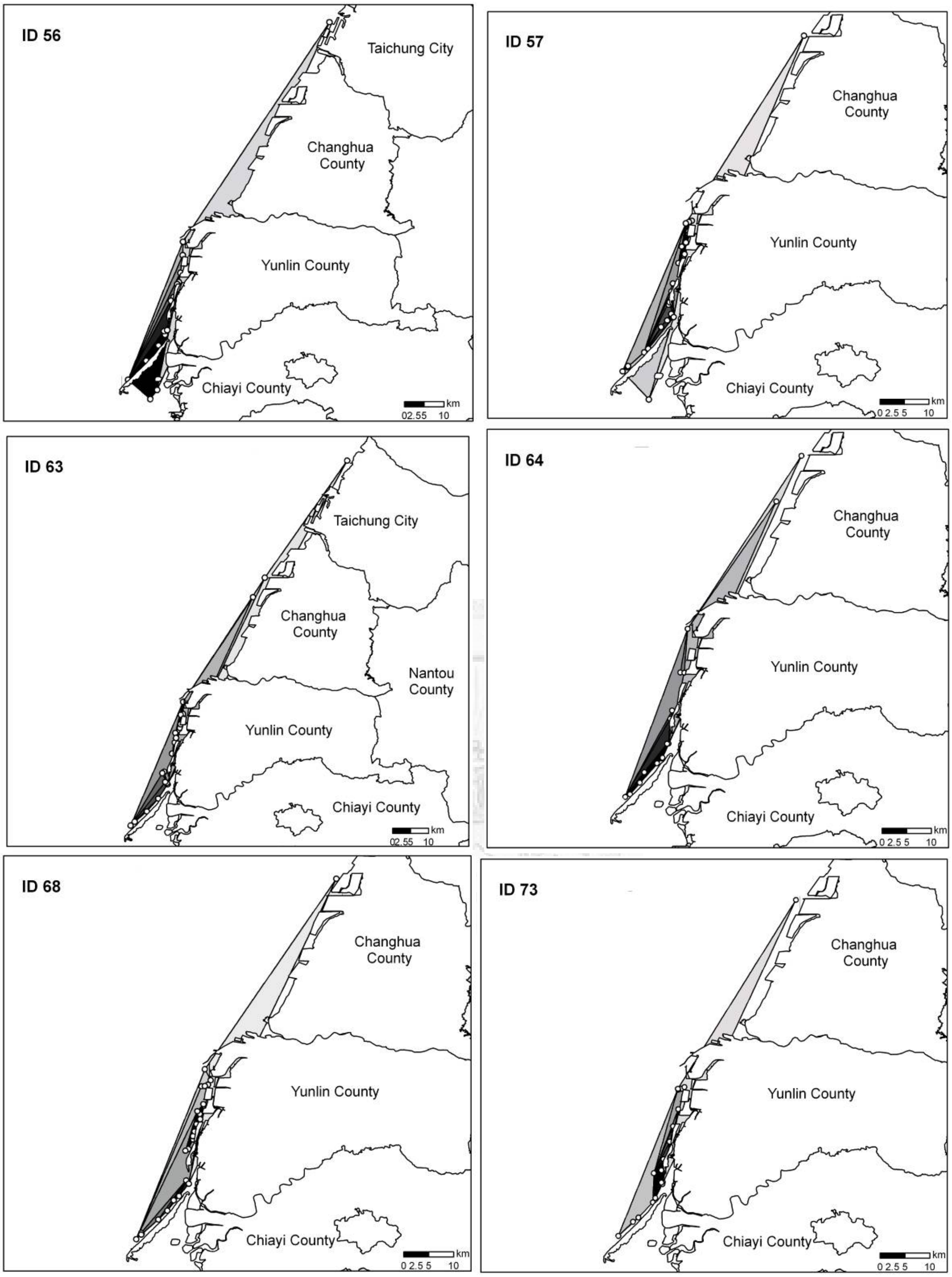


Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.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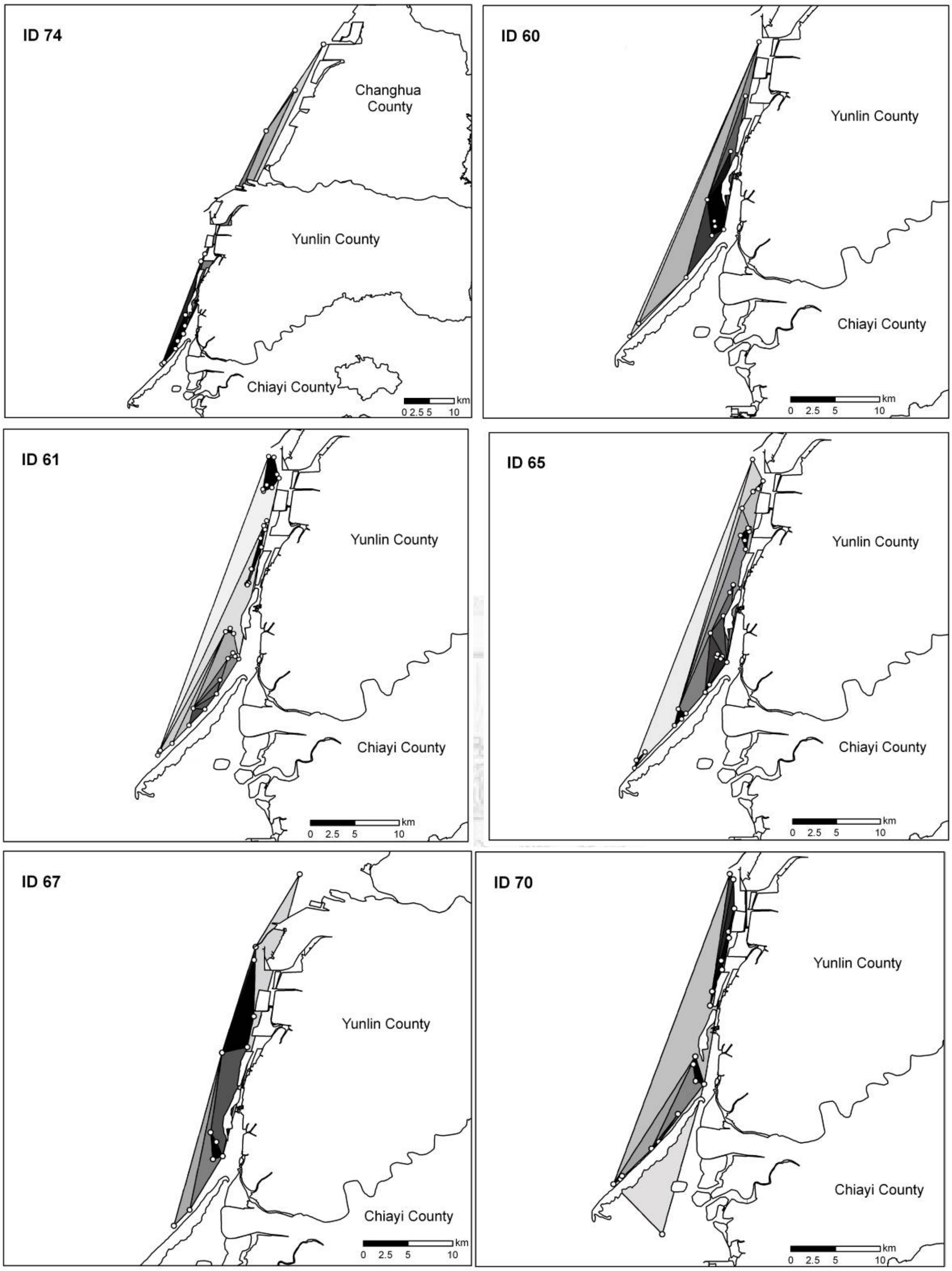

Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.

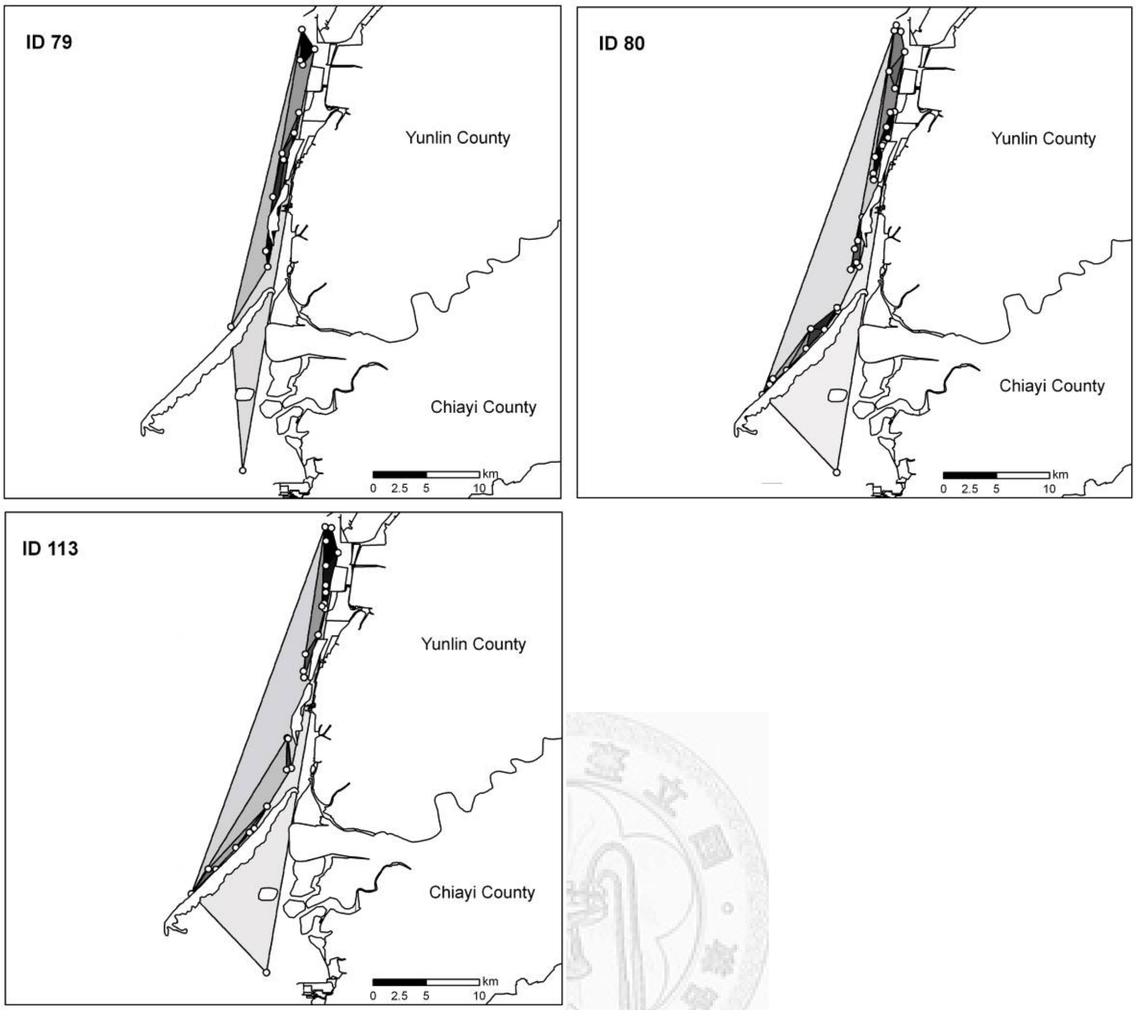

Figure 2. (continued) Clustered MCP of 57 individuals, showing the whole range and cores within the range.

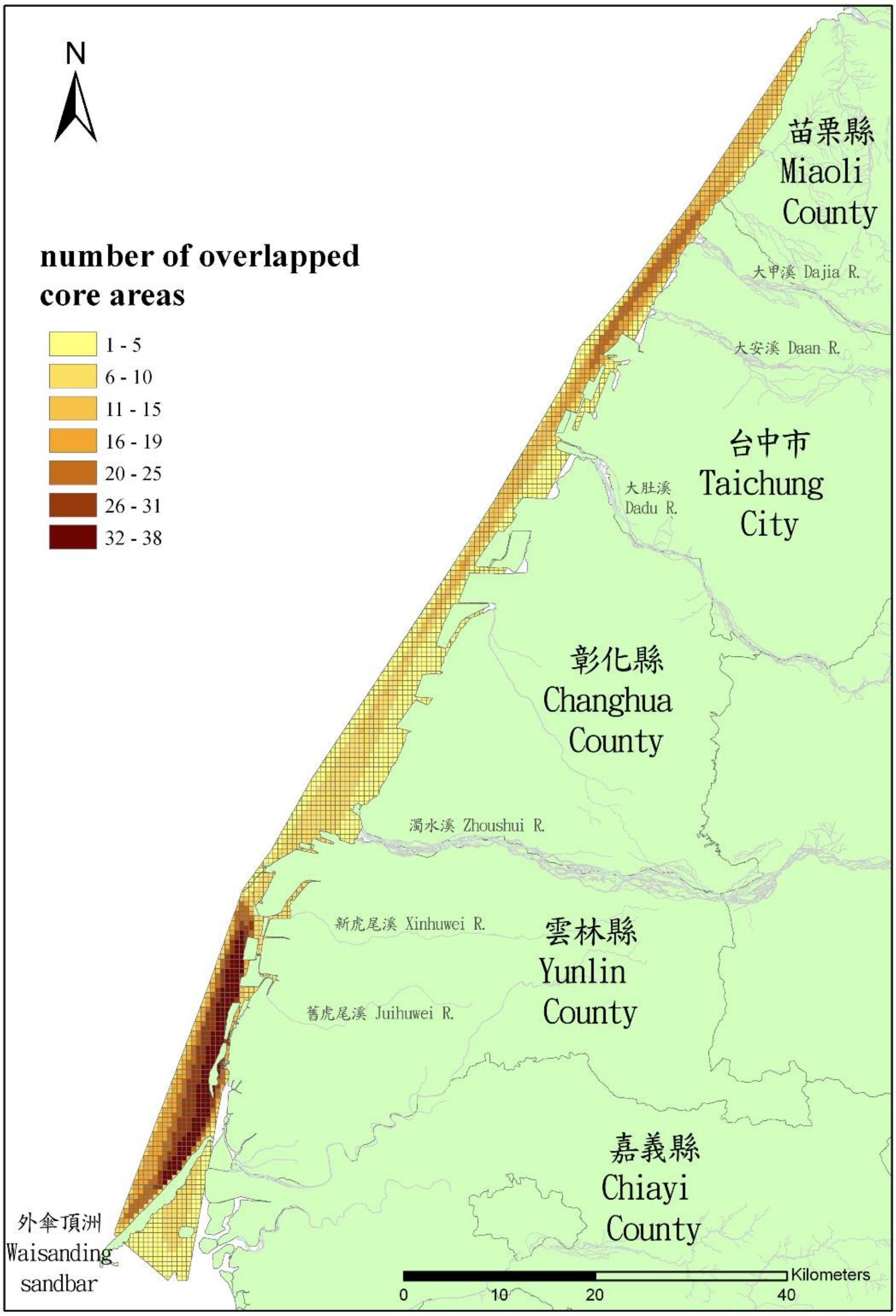

Figure 3. Merged core areas of 57 individuals. The color of the grid represents the degree of core area overlap. The overlap was dense in the coastal waters of Taichung City and from Yunlin County to the Waisanding sandbar.

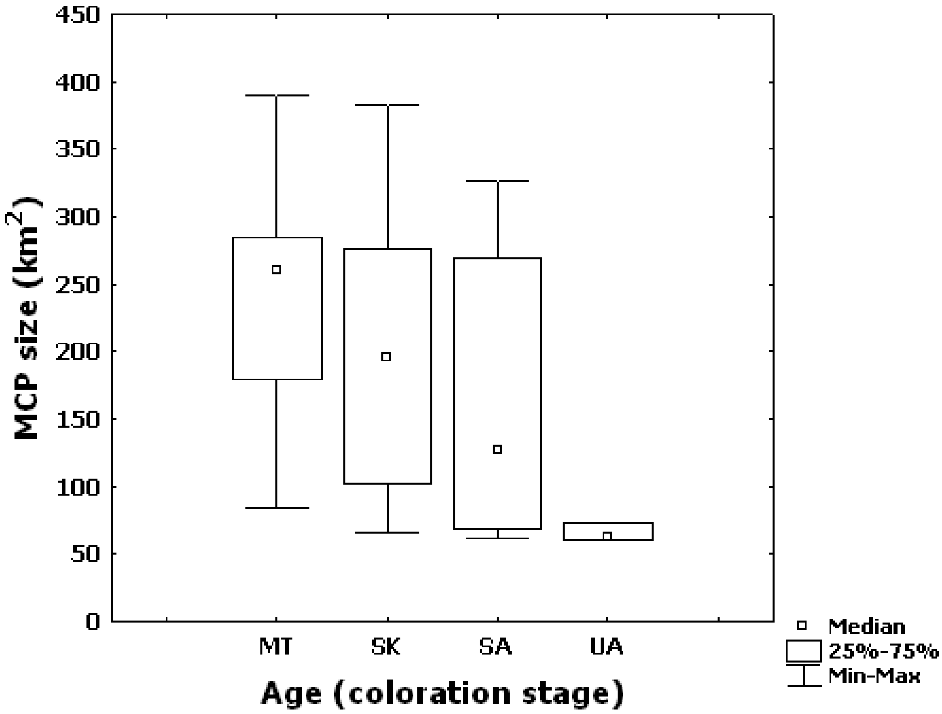

Figure 4. Box plot of MCP size by coloration stage. MT=mottled dolphins (n=19), SK=speckled (n=24), SA=spotted adults (n=11), and UA= unspotted adults (n=3).

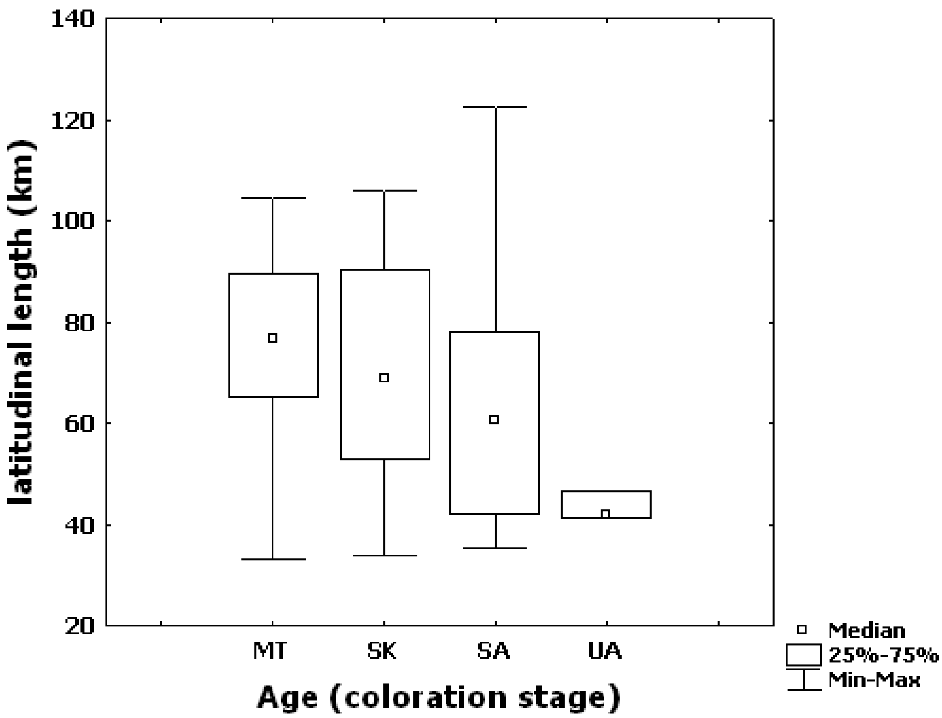

Figure 5. Box plot of latitudinal length by coloration stage.

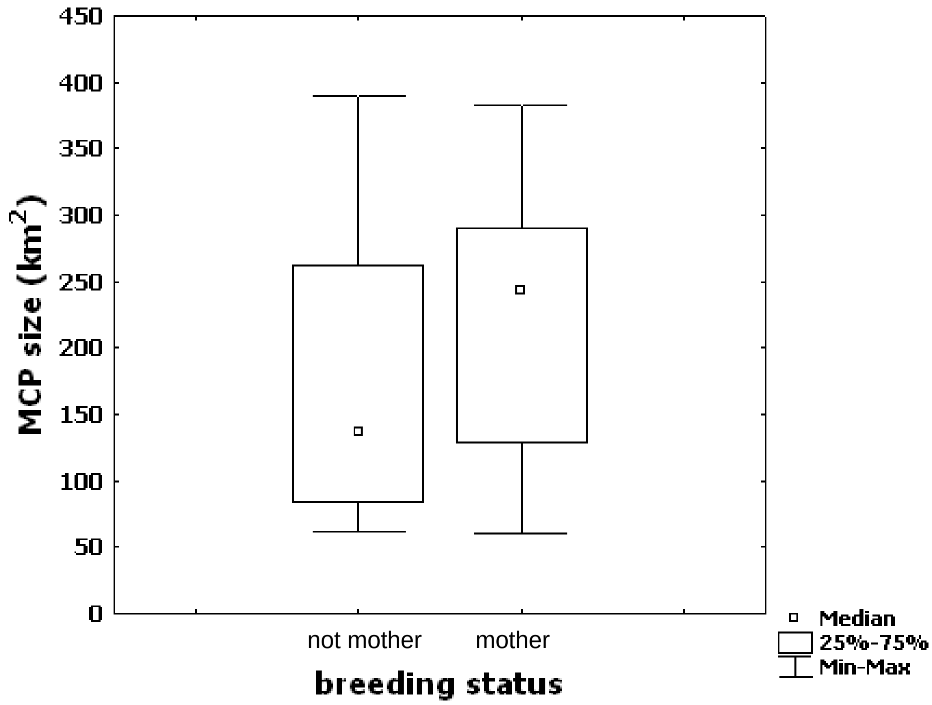

Figure 6. Box plot of MCP size by breeding statuses. Zero "0' means not recorded as calving, while one "1" means being recorded as calving.

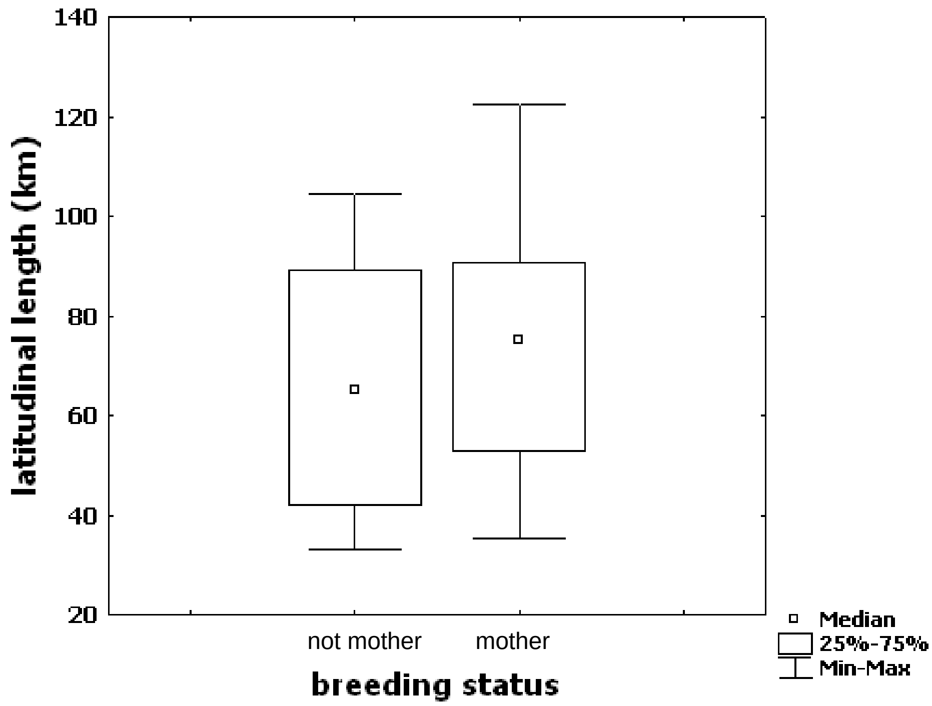

Figure 7. Box plot of latitudinal length by breeding statuses.

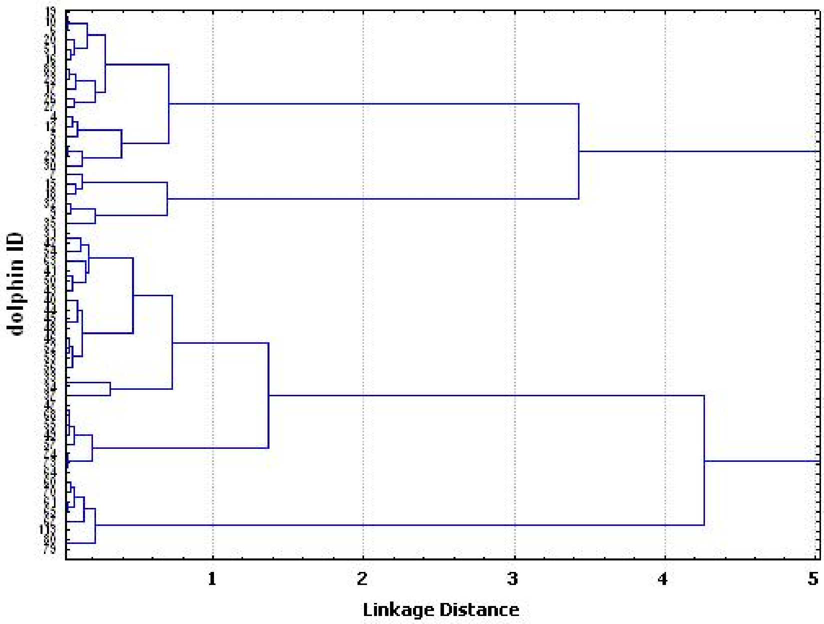

Figure 8. Dendrogram of cluster analysis, showing two major clusters with four subgoups. The vertical axis is the ID of each dolphin.

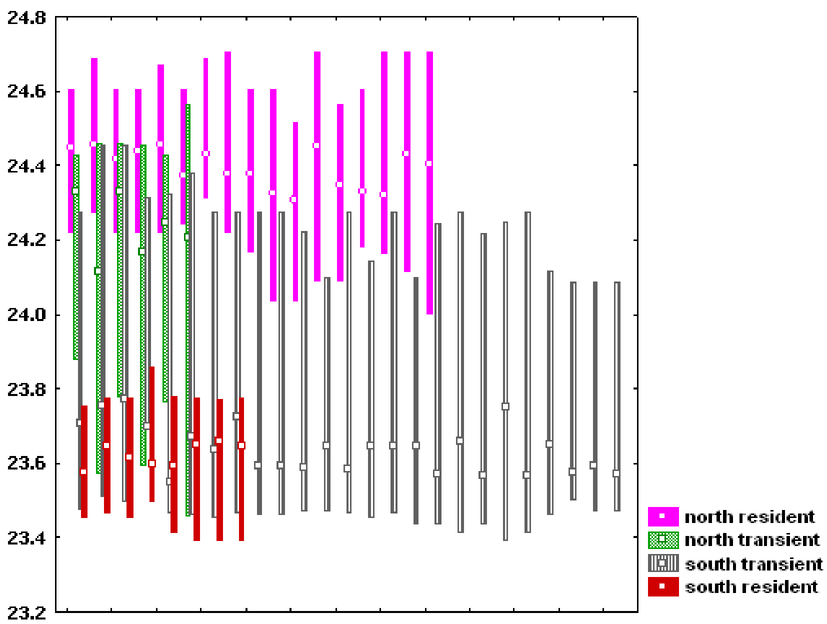

Figure 9. Latitudinal extent of four clusters from the cluster analysis. The hollow square denotes the median, and the two sides of the column denote the minimum and maximum. The pink and red columns represent the northern and southern residents, and the green and grey columns represent transients whose medians were close to the northern or southern region.

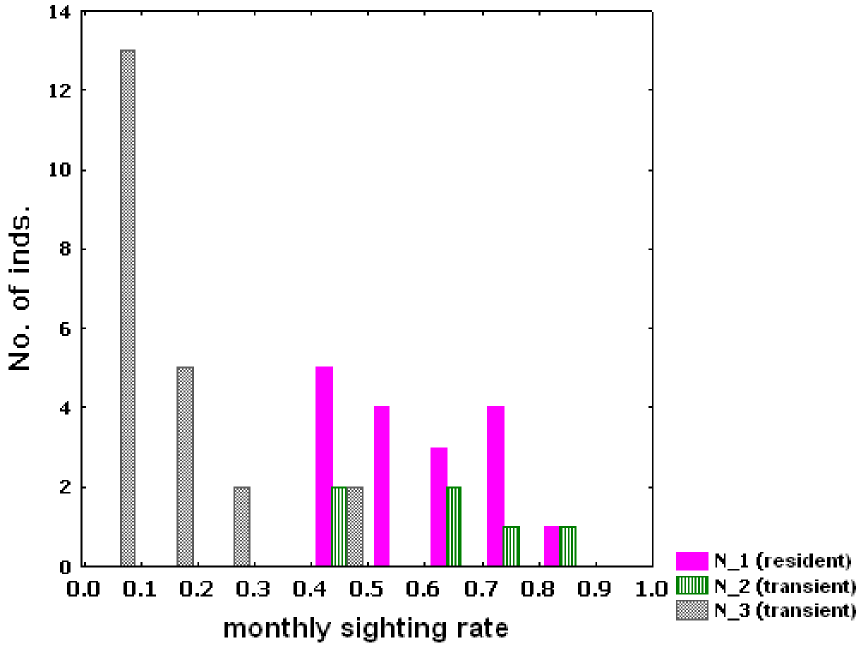

Figure 10. Histogram of monthly sighting rate among cluster members in the northern region. Pink columns denote northern residents, green columns denote northern transients (cluster 2) and grey columns denote southern transients (cluster 3).

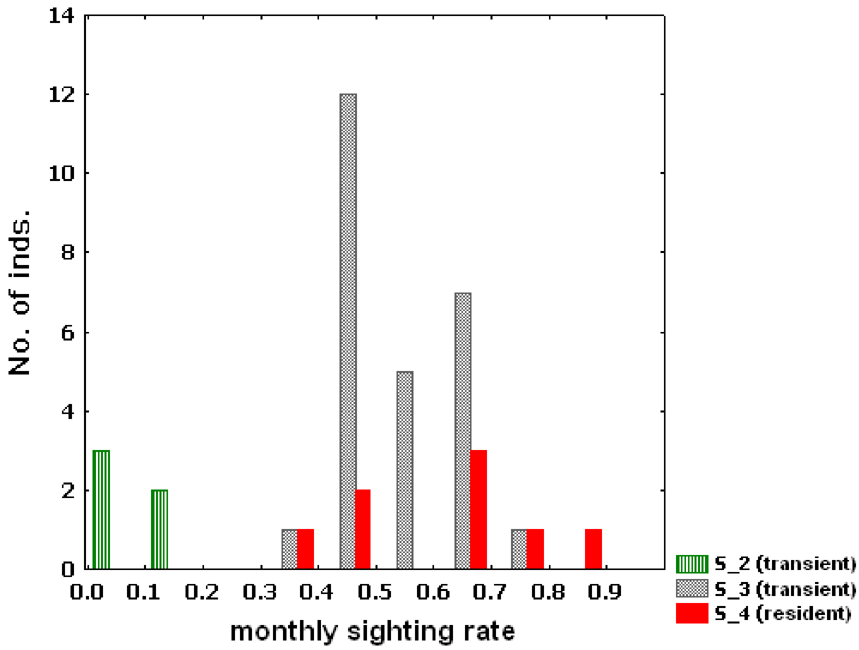

Figure 11. Histogram of monthly sighting rate among cluster members in the southern region. Red columns denote southern residents, green columns denote northern transients and grey columns denote southern transients. columns denote south transients.

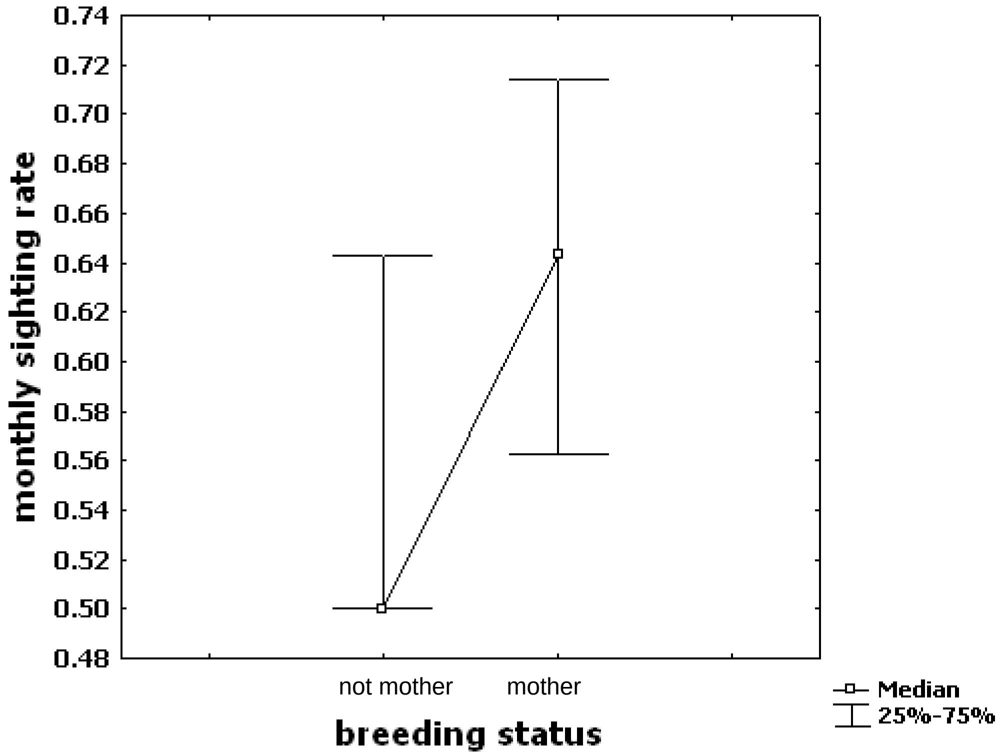

Figure 12. Sighting rate difference between breeding statuses. Plot showing the differences in quartile range and median (hollow square) by mother role, as individuals recorded calving display higher sighting rates (p=0.02).

Chapter 4 Summary

Distribution prediction models

Through distribution prediction performed by habitat modeling, including one presence-absence model (GAMs) and two presence-only models (MaxEnt and GARP), key environmental factors that related to distribution pattern of Chinese white dolphins in Taiwan were recognized, including water depth (maximum and standard deviation), salinity (standard deviation) and distance nearest to shore. The characters of suitable habitats were waters with irregular topography and off sandbars. According to the ensemble model, coastal waters that predicted as suitable habitats were discontinuous, including shallow waters off Longfeng (龍鳳), from Baishatun (白沙屯) to Taichung Port (台中港), from Wanggong (王功) to Fangyuan (芳苑), from Santiaolun (三條崙) to Boziliao (箔子寮), off Waisanding sandbar (外傘頂洲), off Budai (布袋), and marginal waters of Changbin and Liuqing Industry Parks (彰濱工業區，六輕工業區).

Within the range of suitable habitats, two areas with higher sighting rates were indicated, suggesting the importance of these areas. However, two predicted suitable areas were lack of occurrence. This inconsistency might be due to insufficient effort and unexamined factors. In addition, prediction model disclosed suitable areas at two ends of study area (*i.e.*, Zhunan and Budai), where the effort were less. Further investigation within those regions should be taken to understand more about the dolphin distribution. The result is noteworthy for delineating the protected areas and sketching the associated conservation strategies for Chinese white dolphins in Taiwan, for it highlights the priority of particular areas as well as indicates areas with potential distribution where may request further investigation or habitat restoration.

Ranging pattern and site fidelity

In this chapter, range size and site fidelity to subareas within distribution range were analyzed, and the differences between age classes and breeding status (mother role) were compared using nonparametric statistics. For range size estimation, Minimum Convex Polygon (MCP) method and latitudinal length were employed. Out of 71 identified individuals, 57 were included to the analyses due to sufficient resightings. The average MCP size of Chinese white dolphins was 192.6km^2, and the average latitudinal length was 69.1km. The average MCP size was larger than those in other countries. Possible reasons for this were the survey coverage and resource fluctuation. The shape of MCP was stripe; it was suggested topography might play an important role in shaping the range and movement of Chinese white dolphins in Taiwan. Considering topography, latitudinal length would be a better estimator of range size for Chinese white dolphins in Taiwan.

Core areas of each individuals ranged from shallow waters of Baishatun (白沙屯) to Dongshi (東石), with waters off Taichung City (台中市), Yunlin County (雲林縣), and off west side of Waisanding sandbar (外傘頂洲) heavily overlapped. The overlapped core regions were suggested to be critical to the survival of these animals, because they were related to important or even limited resources such as shelter or reliable source of food

Site fidelity analyses were performed based on spatial and temporal aspects. Cluster analysis of spatial parameters revealed two regions, waters from Songbo (松柏) to Lunwei (崙尾) and from south of Mailiao Port (麥寮港) to Waisanding sandbar, were gathered by range centers. Within these regions, residents and transients could be recognized from their range extent. In addition, sighting rates of mothers (*i.e.*, females recorded calving) within these regions were significantly high. The finding of residents and intensively use by mothers suggested these region might be unique and unsubstitutable.

Conservation Implication

Since it is a time-consuming process for establishment of protected area, progressive goals and priority habitats should be set and decided. Baishatun (白沙屯) to Lunwei (崙尾) and from southern Mailiao Port (麥寮港) to Waisanding sandbar were predicted as suitable habitats and were intensively used by resident dolphins and mother dolphins; it is suggested that these regions should be considered priority habitats for protected area for Chinese white dolphins in Taiwan. Although information such as benthic resource abundance and function of these regions were not complete, it was plain to see that these areas were disproportionately used by the whole population.

Discontinuous core regions were observed in other coastal dolphin species, and the endurance of small population to stochasticity was relatively low (Pichler et al. 1998, Hastie et al. 2003, Rayment et al. 2009). Since the primary goal of protected area is to ensure the survival of this vulnerable population, the coastal area between Lunwei and Mailiao will be the next candidate to include in protected area. Meanwhile, it is recommended to invest more effort on marginal distribution range such as Longfeng and Budai, where the survey effort were low but predicted as suitable habitats. With an aid of field survey data, the status of habitat and dolphin preference to these areas could be fully understood.

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