Impacts of Hong Kong Trawling Ban on Chinese White Dolphins (*Sousa chinensis*)

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ABSTRACT

The Chinese white dolphin population in Hong Kong has been decreasing rapidly, declining by 26% in the past four years. This decline is partly due to fishing boat related mortalities. In the past, this population of dolphins has often followed fishing boats as a source of food. To analyze the affect of the trawling ban on dolphin feeding behavior I used vessel-based population survey data from 2010 to 2015. I compared the number of sightings of dolphin-fishing boat feeding associations before and after the 2012 trawling ban. Additionally, using land-based survey data from 2011-2016 I evaluated how the percentage of dolphin sightings associated with fishing boats changed around the economically important village of Tai O after the trawling ban. I also examined the causes of death in dolphin stranding cases before and after the trawling ban. I found a significant decrease in vessel-based sightings of dolphins feeding behind all types of fishing boats and a decrease in fishing boat related dolphin deaths post-trawling ban (2013-2015) compared to pre-trawling ban (2010-2013) (P value= 0.00079).

KEYWORDS

Marine mammals, fishing regimes, bycatch, feeding association, mortality

INTRODUCTION

Human population centers have grown around estuarine areas to exploit the marine resources produced by these productive ecosystems. This growth led to the development of trade and manufacturing in these areas, but there have also been declines in estuarine ecosystem function. Pollution, boat traffic, invasive species, coastal development and overfishing have decreased biodiversity and the health of estuarine ecosystems (Lotze et al. 2006). Large vertebrates are especially vulnerable. In a subset of estuaries from North America, Australia and Europe, 93% of extinctions and 81% of depletions were large vertebrates (Lotze et al. 2006). Estuarine health decline has also occurred along the Chinese coast with many important fish species declining by over 70% in the northern South China Sea (Cheung and Pitcher 2007). This trend reduces the economic viability of fisheries and simplifies marine food webs leading to a lack of resilience against disturbance.

China's Pearl River Delta is a center of the fishing and manufacturing industry in Asia. Despite intensive industrial development, this area is also home to the estuarine ecosystem that supports a population of Chinese white dolphins (*Sousa chinensis*). Their population has declined in recent years due to habitat destruction, pollution, and harmful fishing practices (Marcotte et. al. 2015, Hung 2015, Jefferson et al. 2009). Recent coastal developments including the Hong Kong-Zhuhai-Macau Bridge and airport land reclamation have reduced the dolphins' habitat pushing the dolphin population south (Hung 2015). As a result, the dolphin population has decreased from 110 to around 60 individuals by 2014 (Hung 2015). Additionally, construction boats and ferry traffic have disturbed the dolphin populations, resulting in longer dive times in the presence of some vessels (Ng and Leung 2003). Yet, the effect of Hong Kong's fishing regime on the *S. chinensis* population has not yet been extensively studied.

Before the intensification of the fishing industry, *S. chinensis*, being top marine predators, fed on lower trophic level fish and were important for keeping populations in check (Jefferson 2000). However, by the 1970s overfishing depleted many of these fish stocks (Cheung and Sadovy 2004). One popular method of fishing was trawling, in which weighted nets were dragged along the sea floor breaking up coral and destroying habitat for demersal (bottom feeding) fish (Morton 1996). This fishing method is extremely destructive to estuarine fish habitat, and in 2012 the Hong Kong government banned trawling in order to allow the marine

ecosystem to recover (AFCD 2016). When trawling was still pervasive, the dolphins formed close feeding associations with these boats and were observed following behind the operating trawling boats to eat fish caught in the nets or stirred up by the fishing activity (Barros et al. 2004). The dolphins and trawling boats shared a common target, bottom feeding estuarine fish like the large yellow croaker (*Pseudosciaena crocea).* It is possible that the ban on trawling will allow demersal fish populations to rebound and influence dolphin-feeding behavior leading them to no longer rely on fishing boats to catch prey (Hung 2015).

Due to overfishing and habitat destruction, trawling fishing has been banned in Hong Kong and regions in Australia, New Zealand, Canada, Norway, Mediterranean Sea and Indonesia. Trawling bans can also alter the social and feeding behaviors of dolphins (Ansmann et al. 2012). Because feeding behavior is learned and taught by mothers to calves, trawling associated feeding vs. non-trawling associated feeding can determine social groups. This delineation occurs in Hong Kong dolphin populations and in other populations around the world (Jefferson, 2000). After a reduction in trawling in Australia, previously separate non-trawling associated dolphins and trawling associated dolphins began to interact frequently (Ansmann et al. 2012). In 2015, the rate of Hong Kong dolphin-fishing boat associations was at its lowest level since 1996 (Hung 2015). Not only have the dolphins stopped interacting with trawling boats, but seem to have lessened their interactions with other fishing boat types as well (Hung 2015). This situation can serve as a model of how trawling bans can alter dolphin feeding interactions with fishing boats.

The association between fishing boats and dolphins is not always beneficial. Bottom trawling is a harmful practice because the dolphins can be injured or killed when caught in their nets (Barros 2004). There have been several cases of stranded dolphins found with net marks on their bodies and other signs that fishing operations drowned them (AFCD, Hung 2015). The decrease in dolphin-fishing boat associations after the trawling ban could also reduce fishing boat related casualties in the population. It is important to understand all the causes of dolphin deaths because this is a declining population. An evaluation of the Hong Kong trawling ban could illuminate how fishing regime change has altered the cause of mortality in the vulnerable *S. chinensis* population. To understand how the trawling ban has changed *S. chinensis* feeding behavior and mortality, I ask two sub questions: first, has the rate of dolphins associating with fishing boats for feeding purposes decreased after the enactment of the trawling ban in 2012?

Second, has the number of fishing boat related dolphin deaths decreased since the trawling ban was enacted? I predict that the number of sighted dolphin fishing boat associations and the number of fishing boat related dolphin deaths per year have decreased since the trawling ban was enacted.

METHODS

Study population

My study population is the group of Chinese white dolphins (*S chinensis*) that regularly use the waters off of the western and southwestern coasts of Lantau Island, Hong Kong. They inhabit the waters on the western side of Hong Kong due to greater estuarine fish availability from the brackish outflow of the Pearl River (Jefferson 2000). Individuals from this group occasionally range into the greater Pearl River Estuary (Ling ding yang bay), which is Chinese territory, but usually remain within Hong Kong waters (Hung 2015). The dolphin's diet consists mainly of bottom feeding estuarine fish such as *Collichthys lucida* and *Johnius sp.* (Barros et al. 2004). *S. chinensis* reach physical maturity at approximately 14-17 years when their body size is 238 to 249 cm in length and can live up to 38 years of age (Jefferson et al. 2012). Their calving interval is relatively long, 5 years, and they appear to have a peak calving season from March-June (Jefferson et al. 2012). This population has high offspring mortality, with 53% of all stranded carcasses being calves less than one year old (Jefferson et al. 2006). Calf mortality may be caused by high concentrations of dichlorodiphenyltrichloroethane [DDTs] and polychlorinated biphenyl [PCBs], accumulating in the young dolphin's bodies (Jefferson et al. 2012, Wu et al. 2013).

Study site

The Pearl River Estuary is made up of three sub-estuaries: Mo dao men, Huang mao hai and Ling ding yang Bay. Ling ding yang Bay is the largest and receives 53% of the outflow of the Pearl River (He et al. 2014). In recent years the Pearl River Estuary has undergone rapid and intense development (Wu et al. 2013, Marcotte et al. 2015). These developments include the

creation of 12 km^2 of land from the ocean west of Lantau and the Hong Kong-Zhu-Hai-Macau Bridge, which will be one of the longest bridges in the world when completed (Marcotte et al. 2015). The Hong Kong *S. chinensis* population habitat is the 1800 km^2 to the north, west and south of Lantau Island (Jefferson 2000). Lantau Island is the largest island in Hong Kong at 147.16 km^2 and has mostly mountainous, unpopulated terrain with settlements along the coast. North of Lantau is the Urmston road-shipping channel (Marcotte et al. 2015). The northwestern side of the island is the site of the Hong Kong International Airport along with the growing population center of Tung Chung. South of Tung Chung along the western coast of Lantau is Tai O, a famous traditional fishing village and tourist attraction (Marcotte et al. 2015). The people of Tai O conduct S *chinensis* dolphin watching tours from small speedboats called walla wallas (Ng and Leung 2003). The dolphins are a source of income and conflict for the community since these dolphin-watching boats have been accused of injuring dolphins by accidentally running them over (Hung 2015). In the past, the waters west and south of Lantau Island were heavily used by the trawl fishing industry and dolphins often formed feeding associations with the fishing boats (Jefferson 2000).

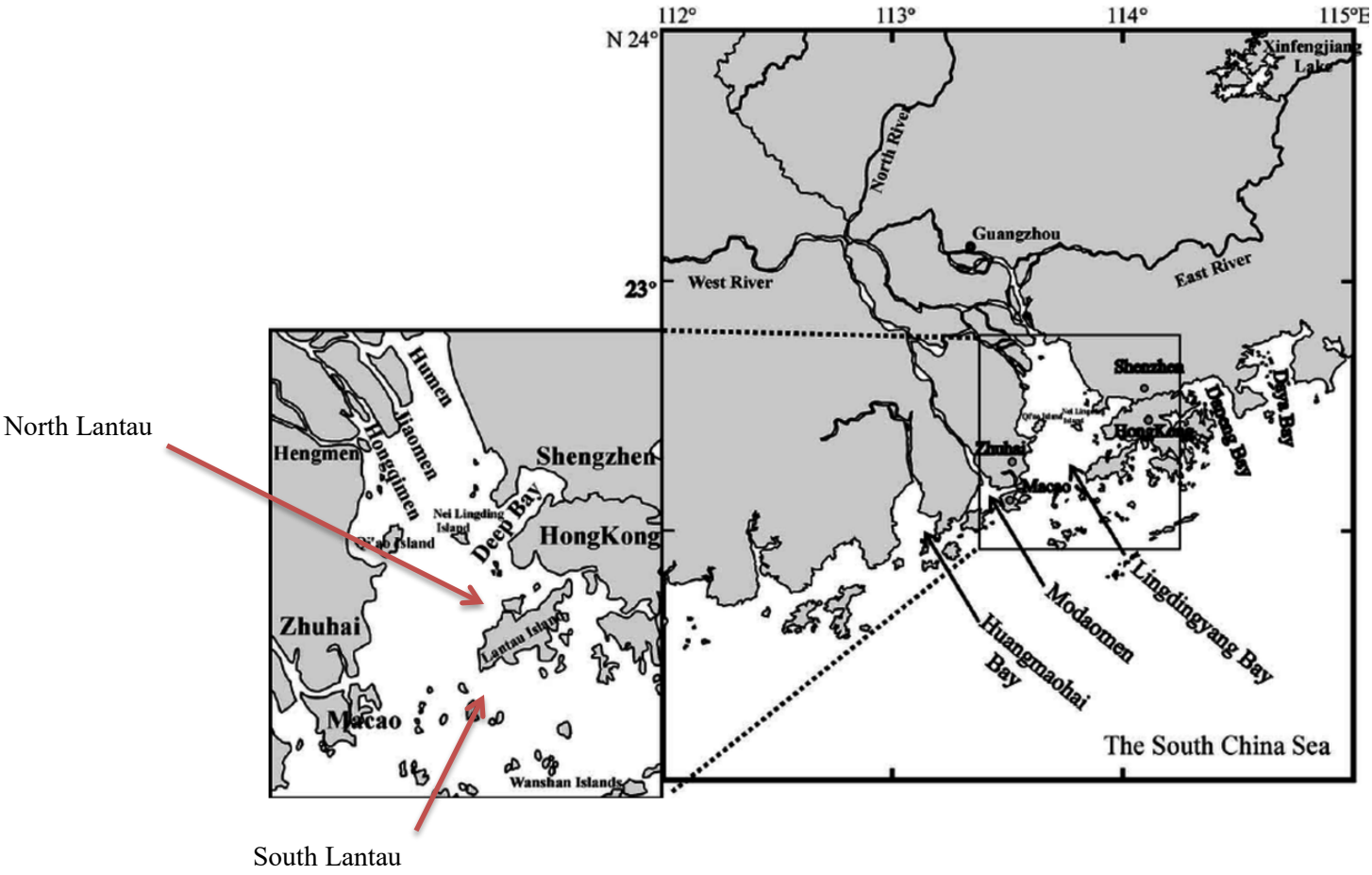

Figure 1: Map of Pearl River Estuary (Callahan et. al. 2004)

Dolphin survey

To assess the impact of the 2012 trawling ban on dolphin-fishing boat feeding associations I used vessel-based population survey data from the Hong Kong Cetacean Research Project (HKCRP). To collect this data the HKCRP conducted weekly standard line-transect surveys of 5 areas Northwest (NWL), Northeast (NEL), West (WL), Southwest (SWL) and Southeast Lantau (SEL) from 2009-2016. I did not use survey data prior to 2009 because the population difference would compromise the data. The line transects run parallel and horizontal to Lantau island along the boundary between Hong Kong and Chinese waters (Figure 2). The

area outside of the dotted line is Chinese territory. As the vessel moved at a 13-15 km/hr speed along the transect line, two observers scanned the ocean from the top deck using binoculars (Hung 2015). The vessel was stopped each time a dolphin was sighted and they noted the beaufort state (an empirical measure of wind speed at sea), GPS coordinates, sighting distance, angle from sighted animal to boat, and time. Then the survey team recorded the group size, individuals, boat presence/ fishing boat association and boat type. A dolphin-fishing boat association was recorded when the group of dolphins was actively following behind or feeding behind a fishing boat.

I also used land-based population survey data collected by the HKCRP 2011-2015 in addition to the land-based survey data that I collected in summer 2016 to compare dolphin-fishing boat association rates around Tai O village. The red arrow indicates where Tai O is located (Figure 2). The HKCRP used a theodolite, a surveying tool that measures speed and distance, to collect land-based data. The theodolite was set up at the Fu Shan peak marker in Tai O (Hung 2015). Two observers scanned the ocean with binoculars in 20 min intervals and each time a boat or dolphin was sighted the theodolite was switched on and three points were collected to characterize the objects speed and direction (Hung 2015). The type of boat, number of dolphins in a group and the boat association was noted as well (Hung 2015).

In the summer of 2016 I conducted bi-weekly land-based population surveys from the Fu Shan peak marker in Tai O. I scanned the ocean with binoculars in 20 minutes intervals. Each time my research assistant or I sighted a dolphin or boat I recorded the time, beaufort state, number of dolphins, type of boat and presence of dolphin-fishing boat association. All dolphin sightings at beaufort state above 3 were disregarded because it is hard to positively identify dolphin sightings in rough sea conditions.

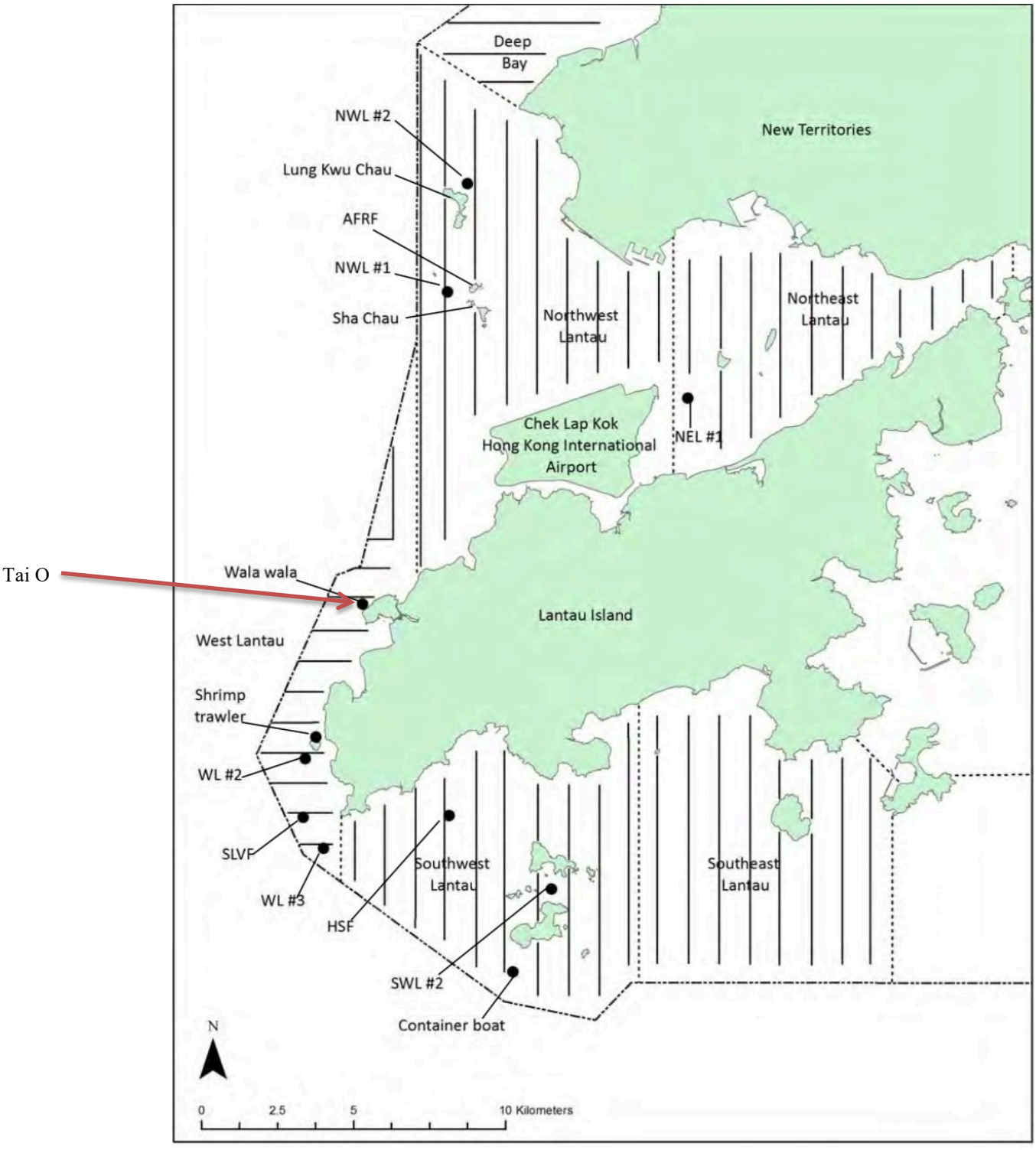

Figure 2: Map of Lantau Island Vessel Based Population Survey Line Transects

To determine whether the trawling ban in 2012 has significantly decreased dolphin fishing boat associations rates I used R commander to preform a Welch two sample t-test and regression analysis on the vessel-based survey data 2009- March 2016 (R Core Team 2013). To get the yearly association rates I divided the total sightings of dolphins feeding behind fishing boats by the number of survey kilometers in that year.

Additionally, I used the land-based survey data 2011-2016 to determine if the dolphin-fishing boat association rates have decreased significantly in the area surrounding the important fishing and tourist destination, Tai O. I divided the total yearly sighted dolphin-fishing boat associations by number of survey hours from that year and used R commander to preform a Welch two sample t-test on the average association rate before and after the ban. I also did a regression analysis on the data.

Mortality

To determine whether the trawling ban has impacted the number of fishing boat related dolphin deaths, I analyzed the cause of death data from stranding (washed up dolphin carcass) cases from 2000 to 2015. The Agriculture, Fisheries and Conservation Department (AFCD) provided data. In the 1990s the Hong Kong government started a dolphin stranding recovery program (Jefferson et al. 2006). Every time a dolphin carcass is spotted, the sighting is reported to the AFCD or HKCRP and scientists come to preform a necropsy in lab or in the field if the body is too badly decomposed (Jefferson et al. 2006). For each stranding they record biological data such as length, sex, decomposition state, location, and cause of death (Jefferson et al. 2006). Due to heavy boat traffic in the area increasing chances of spotting dolphin carcasses, this method is a fairly robust sample of dolphin cause of death data.

I used the cause of death data from stranding cases to determine if there has been a decrease in fishing boat related dolphin deaths since the trawling ban. I split the cause of death into two categories fishing boat related vs. not fishing boat related. I disregarded cases where the cause of death was undetermined. I used R commander to preform a t-test on the average amount of confirmed fishing boat-related dolphin deaths before and after the ban (R Core Team 2013).

RESULTS

Vessel based observations

I found that the rate of dolphin-fishing boat feeding associations per kilometer of vessel-based survey did significantly decrease since the enactment of the trawling ban in 2012. The mean association rate before the trawling ban was enacted (2009-2012) is 0.004386 associations/survey km (sd: 0.0005915) and the mean association rate after the trawling ban 2013- March 2016 is 0.001991 (sd: 0.000645). The association rates from years before and after the trawling ban are very different (Figure 3). The mean dolphin-fishing boat association rate after the trawling ban is lower than the rate before the trawling ban. Using a Welch two sample t-test I got a p value of $0.0007977 < .05$.

I calculated a simple linear regression for 2009-2012 and 2013-2016 to predict dolphin-fishing boat association based on the year. For 2009-2012 I found the regression equation, $Association\ rate = (0.00018 \pm 0.0003) * Year - (0.36 \pm 0.59),\ R^2 = 0.159,\ F(1,2) = 0.378, p = 0.6013$. Given the insignificant regression equation we cannot reject the null hypothesis that there is no effect of year on dolphin fishing boat association rate. For 2013-2016 I found the regression equation $Association\ rate = (0.00001 \pm 0.00035) * Year - (0.018 \pm 0.7122),\ R^2 = 0.0004,\ F(1,2) = 0.00038, p = 0.9796.$ For years 2013 to 2016 we cannot reject the null hypothesis that the year has no effect on dolphin-fishing boat association rate. However, comparing the regression equations from 2009-2012 and 2013-2016 the slopes are very different (Figure 4).

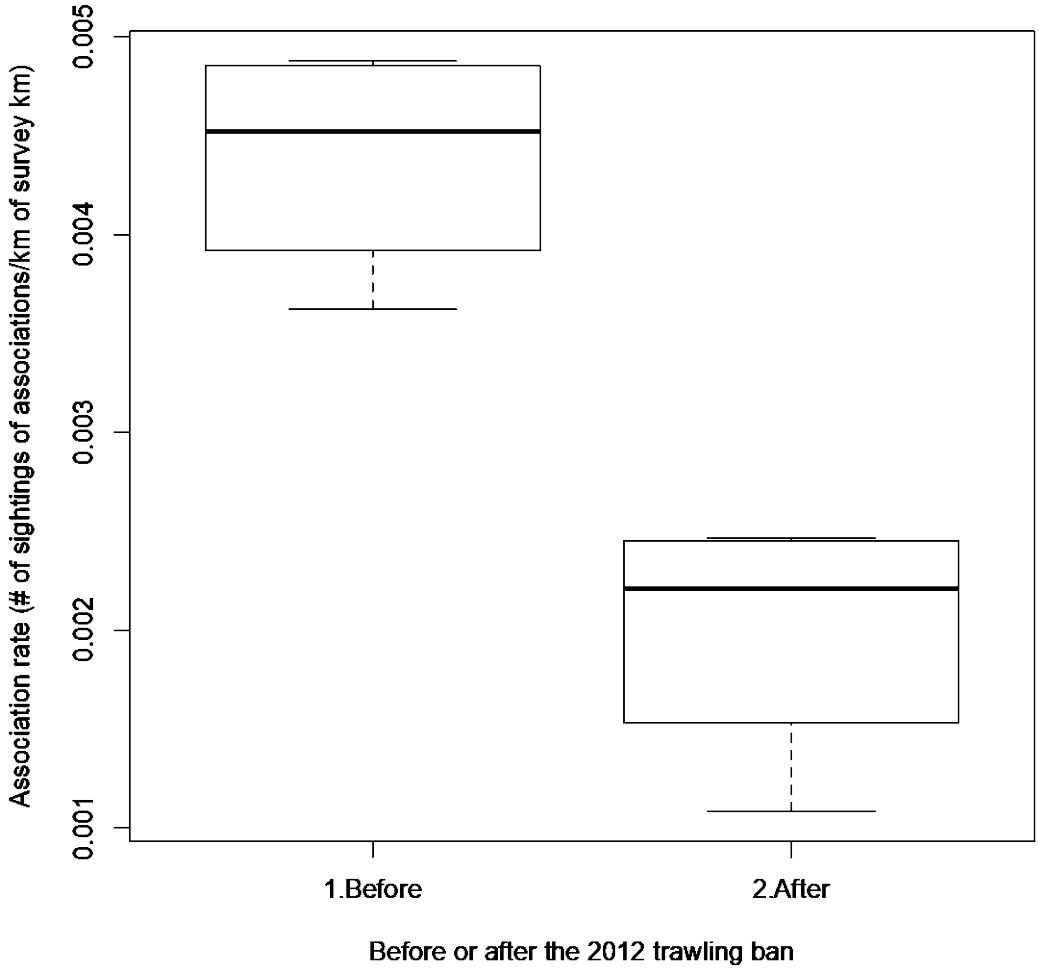

Figure 3: Dolphin-fishing boat feeding association rate before and after 2012 Trawling ban

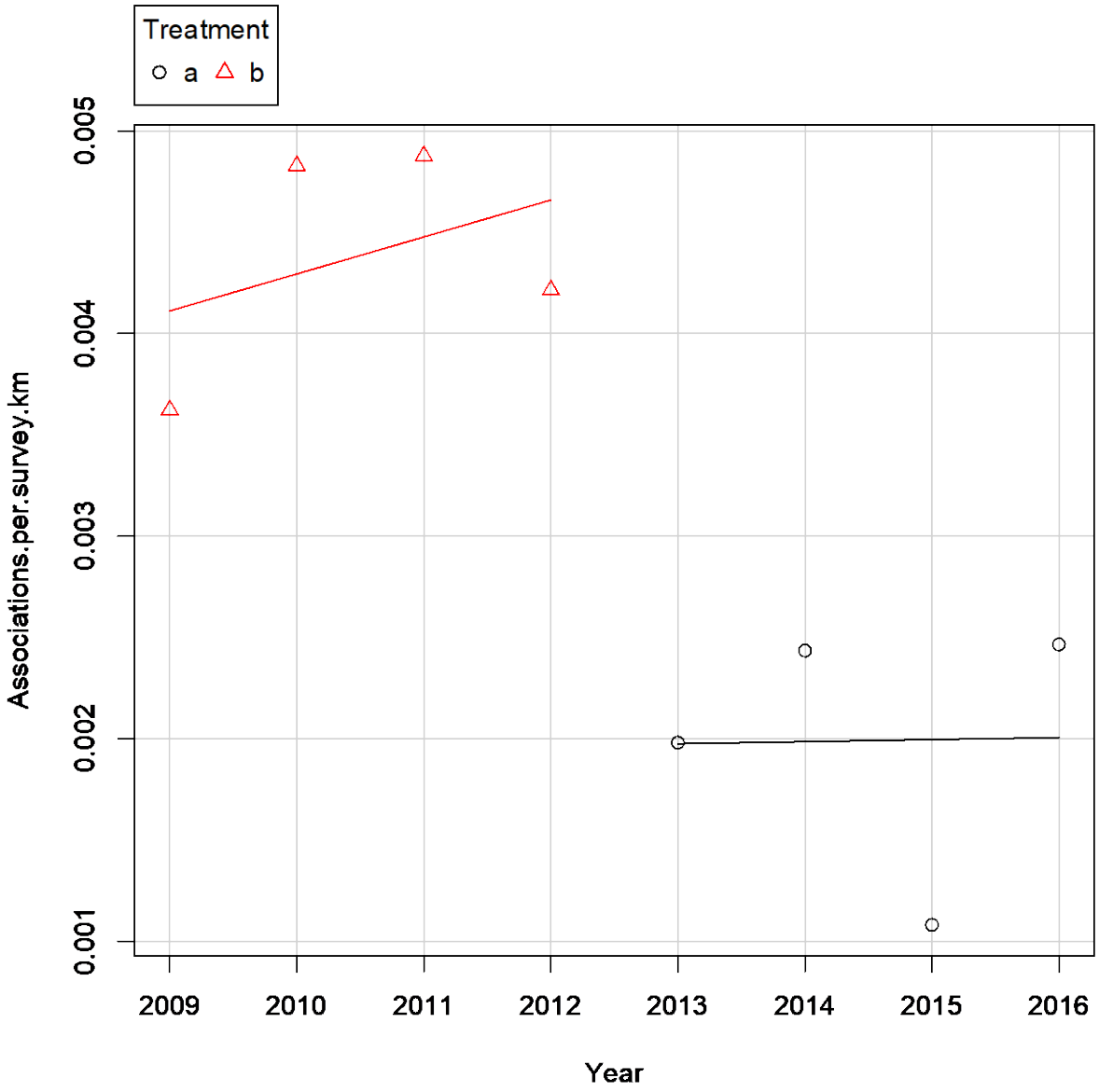

Figure 4: Vessel-Based Survey Dolphin-fishing boat associations 2009-2016 Linear Regression.

Land based observations

The amount of dolphin-fishing boat feeding associations in the Tai O area did not decrease significantly since the 2012-trawling ban. The mean association rate before the trawling ban was enacted 2011-2012 is 0.2691848 associations/survey hour (sd: 0.3806847) and the mean association rate after the trawling ban 2013-2016 is 0.1437922 associations/survey hour (sd: 0.1555941). Although I found that the mean dolphin-fishing boat association rate after the trawling ban in Tai O is lower than the rate before the trawling ban, the change in association is not significant (p-value: 0.3616). I calculated a simple linear regression for 2011-2016 to predict dolphin-fishing boat association rate based on the year. I found an insignificant regression equation $Association\,rate = (-0.0373 \pm 0.055) * Year - (75.39 \pm 111.35),\ R^2 = 0.102,$ $F(1,2) = 0.4561, p = 0.5365.$ Association rate decreased 0.0373 for each year (Figure 3).

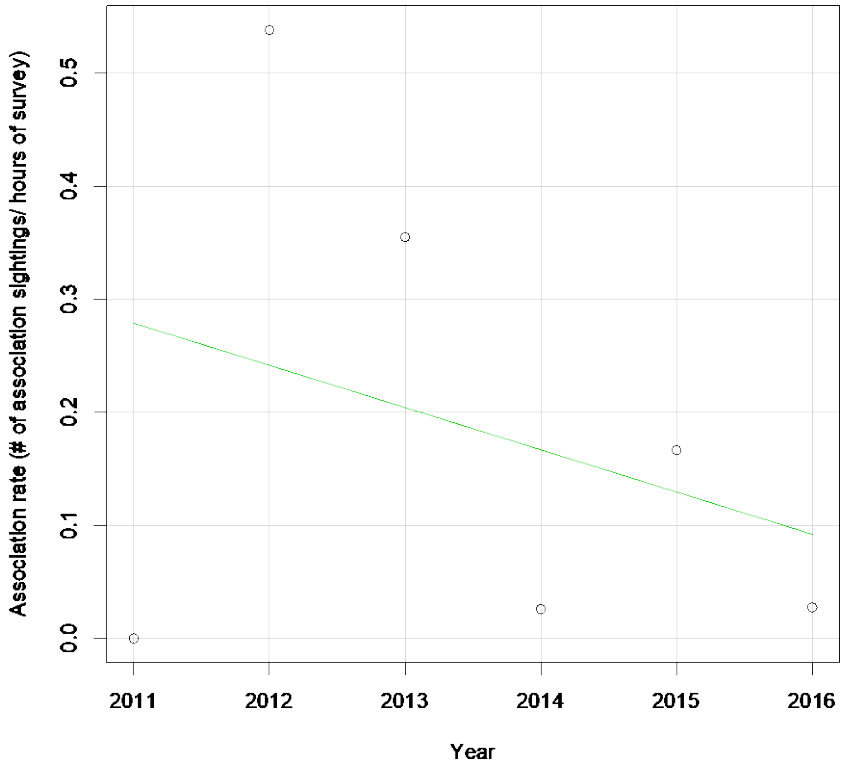

Figure 6: Tai O Land-Based Survey Dolphin-fishing boat associations 2011-2016 Linear Regression.

Dolphin Mortality Data

The percent dolphin deaths caused by fishing boats after the 2012-trawling ban did not decrease significantly. The mean percent of dolphin deaths that were caused by fishing boats before the trawling ban was enacted 2000-2012 is 0.034 % of total strandings per year (sd: 0.07270019) and the mean after the trawling ban 2013 -2015 is 0 % (sd:0). The mean percent of fishing boat related dolphin deaths after the trawling ban is lower than the rate before the trawling ban. Using a Welch two sample t-test I got a p value of 0.05817 > 0.05.

DISSCUSSION

Fishing boat-feeding associations are a source of food but also mortality in the population of *S. chinensis* in Hong Kong. Dolphins feed behind fishing boats to gain greater access to food resources while expending less energy to catch prey (Jefferson 2000). However, there are numerous cases of dolphin deaths due to entanglement in fishing nets or collision with operating fishing boats (Hung 2015, Boer 2012, Lewison et al 2004). Trawling bans increase lower trophic level marine populations, but it is unclear how they will affect marine mammal feeding behavior, social groups and mortality (Pipitone et al. 2000). After the Hong Kong trawling ban, I found that there was a significant decrease in sightings of dolphins forming feeding associations with all fishing boats per survey kilometer compared to before the trawling ban. I also found zero fishing boat related dolphin mortalities post-trawling ban. These findings may indicate that a ban on trawling reduces dolphin interaction with fishing boats and fishing boat related deaths.

Dolphin-fishing boat associations

In the 1990's to 2000's *S. chinensis* in Hong Kong were well documented feeding behind fishing boats, most commonly trawling boats (Jefferson 2000, Hung 2015, Barros 2004). After the Hong Kong government banned trawling in 2012, which took full effect in 2013, the dolphins began to associate less with all types of fishing boats as well as trawling boats. From vessel-based survey data I found a significant decrease in dolphin fishing boat association rates after the trawling ban. From land-based surveys, the rateof dolphin sightings associated with

fishing boats was lower when compared to those before the trawling ban. Since banning trawling reduces sea floor habitat destruction and alleviates fishing pressure on certain fish stocks, this change may be caused by a rebound in demersal fish populations allowing the dolphins to be less reliant on fishing boats to catch prey (Hung 2015). However, a 1991 assessment of the 1980-trawling ban in the Java Sea indicated that even 11 years after the ban the fish stocks in the Java Sea failed to recover fully (Buchary 1991). Therefore, since the Hong Kong trawling ban has only been in effect for 4 years the fish stocks may not have rebounded fully.

The dolphins' prey includes many demersal species, which get stirred up by operating trawling boats (Barros 2004). Because the boats are now using less efficient fishing methods (purse seine, gillnet and hand line) feeding behind fishing boats may no longer be rewarding for the dolphins. Furthermore, for individuals that once depended on trawling as their food source, foraging opportunities are now less reliable, thus potentially encouraging the expansion of their foraging range (Ansmann et al. 2012). Fishing boat-associated dolphins may even migrate to Chinese waters to exploit the trawling boats operating over the border. A decrease in fishing boat associations may also lead to less deadly interactions between dolphins and fishing boats.

Dolphin mortality

Fishing boat related mortality is a factor that impacts *S. chinensis* populations. In my analyses of dolphin mortality from 2000-2015, I found no fishing boat related deaths after the trawling ban 2013-2015, whereas there were 6 cases before the trawling ban. A similar change was observed off the coast of southwest England, Boer observed that significantly more short-beaked common dolphin (*Delphinus delphis*) deaths occurred around operating pair trawlers compared to areas without fishing activity (Boer 2012). In population modeling of New Zealand's hector dolphin (*Cephalorhynchus hectori*), Slooten and Dawson found that a blanket ban on trawling could produce less dolphin mortalities and increase the population (Slooten and Dawson 2012). The New Zealand ban may produce a reduction of interactions between fishing boats and therefore reduce chances of harm from fishing boats. Additionally, the remaining fishing methods, purse seine and line fishing, might be safer for the dolphins (Lewison et al. 2004). Another factor in Hong Kong that may cause less fishing boat related mortality is further awareness of dolphin population decline; fishing boat operators may be more careful now.

However, a larger sample size of dolphin stranding could give a more robust understanding of the trends in mortality.

Limitations

My results and their interpretations are limited by how recent the trawling ban went into effect. The ban went into effect in 2013; therefore my study was limited to four years of post trawling data. Before the trawling ban there is survey data from 1996 to 2012, there is a much smaller sample size of years after. Additionally, we did not have data indicating which individuals were forming feeding associations with fishing boats before and after the trawling ban. This data may help determine if dolphins are simply moving out of the study area or if the fishing boat-associated dolphins are changing their feeding behavior within Hong Kong waters.

Lastly, the mortality sampling was not a perfect measure of all causes and cases of dolphin mortality. A lot of valuable data was lost due to the inaccuracy of carcass reporting and recovery. If a dolphin dies there is a chance that it will float out of Hong Kong waters before it can be reported to and retrieved by the Hong Kong AFCD (Agriculture, Fishers and Conservation Department). Furthermore, if the carcasses are not found quickly, high decomposition may prevent determination of cause of death. The mortality study limitations are hard to correct because dolphins freely cross international borders. Due to this mobility it would be impossible to monitor all individual dolphins until their death. However, a continuation of this study would correct for the lack of post trawling ban vessel-based and land-based survey data.

Future directions

Future research is needed to fully understand the trends in dolphin-fishing boat associations and changes in other dolphin behaviors. The Hong Kong Dolphin Cetacean Research Project must continue weekly vessel-based and land based dolphin surveys and record presence of fishing boats. Additionally, the Hong Kong AFCD should require fishermen to report the composition of their by-catch to help determine how many dolphins fishing boats kill each year. This would provide more accurate dolphin mortality data. Finally, more research needs to be done to determine how fish stocks and sea floor habitat is responding to the trawling ban. This

will help in understanding how the dolphins' prey base is impacted by the trawling ban. Giving further insight into the causes of the decrease in dolphin fishing boat associations. Since it takes many years for the trawling ban to allow fish populations to recover fully, continuous monitoring of the dolphin population will allow a full assessment of the impacts of the ban.

Broader implications

Human fishing activities in marine environments can have large impacts on all organisms in marine ecosystems beyond the target fish species. Likewise, changes in fishing regimes can impact marine species that were not the main focus of the new legislation. The reduction in fishing boat associations and change in cause of mortality may indicate that the Hong Kong trawling ban will help slow the decline of the *S. chinensis* population. Fishing regulation is incredibly important to marine mammals because it decreases unnatural mortality while increasing prey stocks (Lewison et al 2004, de Juan and Lleonart 2010). My findings support the value of implementing trawling bans to prevent decline of biodiversity in marine ecosystems. This conclusion can encourage other coastal fishing industries to limit trawling in order to recover marine mammal populations. However, other threats to the population such as, coastal development projects and heavy metal pollution must also be addressed to prevent further decline in the Hong Kong *S. chinensis* population.

Just like the Hectors and Maui dolphin in New Zealand the Hong Kong people recognize the intrinsic value of the existence of Chinese white dolphins in their city. They are an important cultural icon and tourist attraction. For example, a dolphin-watching trip is a component of the Lantau Island Ngong Ping 360 tourist package and the Chinese white dolphin was chosen as the mascot for the 1997 handover of Hong Kong back to China. The existence of this population not only has ecological value as a top marine predator but also has economic value. Appreciation of the dolphins has developed into a large dolphin-watching tourist industry in Tai O. When managed and monitored correctly the fishing industry can coexist with a healthy marine ecosystem with stable marine mammal populations.

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