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Protecting small cetaceans from coastal development: Impact assessment and mitigation experience in Hong Kong

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ABSTRACT

Since the early 1990s, there has been an active program in Hong Kong to manage and protect local populations of small cetaceans from the effects of massive development in the area. This paper reviews the progress that has been made. Only two species regularly occur there: the Indo-Pacific humpback dolphin and the finless porpoise. Because most development has occurred in the western waters of Hong Kong, where generally only the humpback dolphin occurs, most of the work has been conducted on that species. Development of large infrastructure projects (such as airports, bridges, expressways, power plants, fuel facilities, and container ports) in Hong Kong often results in land reclamation, dredging and dumping of spoils, pipe and cable laying, percussive and bored piling work, underwater blasting, large increases in vessel traffic, and other impacts. Several mitigation measures have been used with varying levels of success, including bubble curtains/jackets, exclusion zones, ramping up of piling hammers, acoustic decoupling of noisy equipment, vessel speed limits, no-dumping policies, and silt curtains. Baseline, construction-phase, and operational-phase cetacean monitoring is often conducted to evaluate the success of conservation measures put into place. The Environmental Impact Assessment process in Hong Kong has involved cetaceans to a degree perhaps higher than anywhere else in the world, and much can be learned from studying the successes and failures of this situation.

1. Introduction

Two species of small cetaceans are resident in Hong Kong, the finless porpoise (*Neophocaena phocaenoides*) and the Indo-Pacific humpback dolphin (*Sousa chinensis*) [1]. Since the early 1990s, detailed studies of Hong Kong's small cetacean populations have been conducted [2–17], and they are now some of the most thoroughly studied small cetacean populations in Asia.

Hong Kong has been developing extremely rapidly for several decades. The opening of Hong Kong's new international airport in western waters (north of Lantau Island) in 1998 has resulted in increased development pressure on this area. It has now become the focus of plans to create links with mainland cities to the west and north, and to develop tourism hubs for the surrounding Pearl River Estuary region. As a result, there is massive development in the area north of Lantau Island, which usually involves reclamation of shallow seabed to create useable land; dredging to create and maintain deep channels and basins and to create pits for dumping; building of structures, such as cargo terminals, bridges, jetties, piers; and others. These activities result in physical loss of habitat for cetaceans, and even when no net loss occurs, often there is serious degradation of the ability of the habitat to provide critical resources for cetaceans.

This is a major issue in Hong Kong at the moment, and while it remains to be seen if there are even more serious long-term threats to the population most of the government's management effort toward dolphins and porpoises is geared toward this issue. However, because development in a particular area generally does not result in direct death of dolphins or porpoises, dangers to populations are much more difficult to assess than, for instance, for fishery catches or vessel collisions. This paper provides a review of environmental impact assessment (EIA) and mitigation measures to protect small cetaceans from marine construction and development, based largely on experience in Hong Kong over the past 14 years.

2. Background

2.1. Review of small cetaceans in Hong Kong

Sixteen cetacean species have been recorded either alive or stranded dead in Hong Kong, but only the Indo-Pacific humpback

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dolphin and finless porpoise are considered year-round residents [1]. Humpback dolphins can be found in all western waters of Hong Kong and throughout the Pearl River Estuary, and display a strong preference for estuarine habitats [1,4,5]. Using systematic line-transect survey methods, the most up-to-date abundance estimate of humpback dolphins in Hong Kong ranged from 103 in spring to 193 in autumn, while the overall population size was considered to be about 1300–1500 animals in the Pearl River Estuary [18]. Analysis of trends in abundance showed that temporal patterns in abundance estimates were inconsistent across survey areas, and there was no indication of a sustained decline in overall population size [18].

Humpback dolphins in Hong Kong usually occur in small groups, ranging from singles to groups of 23 individuals [4]. Dolphins are often seen associating with fishing vessels in Hong Kong and the Pearl River Estuary [4,5]. Over 500 individual dolphins have been identified in both Hong Kong and the Pearl River Estuary since 1995. Photo-identification data revealed that individual associations were unstable, with low association indices between pairs or among groups of individuals, and the social structure was very fluid [4]. Moreover, individual home range sizes and patterns were found to vary substantially among individuals [3]. Some individuals only had ranges in a small area (about 30 km^2), while other individuals used large ranges (nearly 400 km^2), encompassing many regions within Hong Kong waters and the rest of the Pearl River Estuary [3].

Finless porpoises occur primarily in the southern and eastern waters of Hong Kong, and are also sighted in adjacent Chinese waters just south of Hong Kong [9]. They appear to avoid the western waters of Hong Kong, which are heavily influenced by freshwater input from the Pearl River [5]. Seasonal variation in distribution is evident for finless porpoises in Hong Kong [9,11,19]. Abundance estimates of finless porpoises using line-transect survey data in Hong Kong ranged from 55 porpoises in autumn to 152 porpoises in spring [9], indicating that a good portion of animals were outside of Hong Kong in autumn months. The group size of porpoises in Hong Kong tends to be small, ranging from 1 to 35 (rarely) animals per group. Analysis of stomach contents of stranded animals revealed that their prey species are primarily inshore, bottom-dwelling and mid-water species [20]. Although the diet of finless porpoises overlaps with that of humpback dolphins to some extent, the porpoises also exploit other coastal non-estuarine habitats, whereas humpback dolphins appear to focus on species that are common in estuaries.

In Hong Kong, both humpback dolphins and finless porpoises are under great pressure resulting from different types of habitat degradation from coastal development and reclamation, pollution from sewage and water treatment plants, dredging for marine fill and shipping, vessel traffic, and intensive fishing activities [4,14,21,22]. For example, high levels of environmental contaminants including heavy metals, organochlorines and organotins have been found in the blubber, liver and kidney of stranded dolphins and porpoises [4,7,13,22–24]. Although the health implications of these environmental contaminants are not fully understood, it is believed that high levels of pollutants may pose serious health hazards to them [7]. The combination of contaminants with other anthropogenic factors may also compromise the health of dolphins and porpoises in Hong Kong [4,14,22].

Vessel collision is another significant cause of death for local cetaceans. Boat traffic is intensive for trading and transportation between Hong Kong and China. Dolphins and porpoises can be struck by high-speed vessels and become seriously injured or killed [4,14]. Moreover, underwater noises generated by marine traffic and development projects such as piling works can affect the ability of dolphins and porpoises to locate their food and communicate, or in some cases could even cause injury or death to them. There are also general concerns that the problem of overfishing has resulted in a serious decline in fisheries resources in Hong Kong [25–27], which may lead to depletion of prey.

2.2. Hong Kong's protective framework and the Marine Mammal Conservation Working Group

To deal with the threats faced by local dolphins and porpoises, the Hong Kong government has established regulations to protect them and improve the quality of Hong Kong waters. The "Wild Animals Protection Ordinance" provides full protection to all dolphins, porpoises and whales in Hong Kong, under which no person is allowed to hunt or willfully disturb them. The "Animals and Plants (Protection of Endangered Species) Ordinance" strictly regulates the import, export and possession of cetaceans and their body parts. Hong Kong is also signatory to the Convention on International Trade in Endangered Species (CITES).

In 1995, under the "Marine Park Ordinance", the Sha Chau and Lung Kwu Chau marine park was established (sometimes known as the "dolphin sanctuary") [28]. This 1200 ha of sea area is frequently visited by humpback dolphins, and some regulations were set up in order to provide them a favorable habitat. These include prohibiting destructive fishing methods (e.g., no bottom trawling is allowed), and regulating the speed of boat traffic to under 10 knots inside the marine park. An additional marine park is proposed at Southwest Lantau and the Soko Islands, which is still under consideration at present. In addition, the enactment of the Environmental Impact Assessment Ordinance (EIAO) also provides some level of protection to local cetaceans against ever-increasing amounts of development pressure (see section below for details).

Since the entire Pearl River Estuary humpback dolphin population spans across the estuary from the Hong Kong Special Administrative Region (SAR) to the Macau SAR and Guangdong Province of PRC, regional cooperation between Hong Kong and Guangdong Province to protect humpback dolphins has been established, and in the past annual meetings were arranged to discuss conservation strategies to protect the entire population. The "Chinese White Dolphin National Nature Reserve" was established within the Pearl River Estuary in 2003 with the aim to provide further protection to the dolphins in Chinese waters. Unfortunately, like most such measures in the PRC, the reserve is basically a 'paper park,' providing little or no real protection to the animals. Two of the authors of this article (TAJ and SKH) have participated in systematic surveys on humpback dolphins with colleagues from the South China Sea Fisheries Research Institute Guangdong, across the boundary. Such cooperation is essential for a full understanding of the status of the entire dolphin population.

The Marine Mammal Conservation Working Group (MMCWG) was established in 1995 by the Hong Kong Government's Agriculture, Fisheries and Conservation Department. It is an interdisciplinary group of stakeholders with an interest in marine mammal issues and is designed to provide advice to the government on management of marine mammals. It holds closed-door meetings one or two times a year and attempts to achieve consensus on controversial issues by discussion and debate. Members of the MMCWG include officials from various government departments (e.g., AFCD, Environmental Protection Department, Marine Department), scientists studying marine mammals in Hong Kong, representatives from green groups (e.g., WWF Hong Kong), members of industry (e.g., Airport Authority, Ocean Park Corporation), dolphin-watching operators, academics from local universities, and representatives from fishermen's organizations. There are some other members who bring special expertise (such as veterinarians in private practice). A typical

meeting has about 25–30 attendees and translation services are provided, so that those who speak only English or Chinese are able to follow all discussions and read all papers.

The MMCWG provides an effective forum for discussion of controversial issues regarding marine mammals in Hong Kong, and has been a very useful tool to the Hong Kong Government in developing marine mammal management practices. The diverse membership assures that many different viewpoints are represented, and it gives special interest groups a chance to make their views heard in an official forum. One major shortcoming of the group is the absence of an accepted way forward when consensus cannot be reached by discussion alone. The group does not make decisions by voting, and sometimes the protests of a small segment of the group may be drowned-out by the "brute force" of the main body of the group. This is unfortunate, and the inclusion of one or more social scientists, experienced in mediation and the human dimensions of wildlife issues, would be very useful in this respect.

2.3. Hong Kong's EIA process as it relates to cetaceans

In Hong Kong, the EIAO requires all proponents of development projects to identify potential impacts of the development to ecological habitats and important species. Due to the rapid development around Lantau Island and their increasing popularity in Hong Kong, humpback dolphins are often the focal species to be assessed for potential impacts if any development project has been proposed in the western waters of Hong Kong.

In the past decade or so, a number of EIA studies have been conducted in relation to dolphins, and a few notable ones include those relating to the construction of the Chek Lap Kok Airport and its associated facilities (large-scale reclamation), River Trade Terminal (moderate-scale reclamation), Aviation Fuel Receiving Facility (percussive piling and dredging), Tonggu Waterway (large-scale dredging), a series of contaminated mud pits (dredging and dumping), Penny's Bay (Disney Theme Park and Resort) development (large-scale reclamation), LNG receiving terminal (piling, dredging, small-scale reclamation), and Hong Kong–Zhuhai–Macau Bridge and associated facilities (percussive piling, reclamation, and dredging). Through active coordination by the authors, a huge amount of systematic baseline survey data from these EIA studies has been incorporated into the long-term database of local humpback dolphins, which has significantly contributed to our understanding of humpback dolphins in the Pearl River Estuary and how development pressure has affected their abundance, behavior, and long-term survival. The EIA process and its relation to dolphins are discussed in detail below.

In Hong Kong, certain designated projects are required to apply for environmental permits through the EIA process, such as reclamation works of more than 5 ha in size, construction of container terminals, or marine dredging/dumping projects. To initiate the EIA process, the project proponent first applies for an EIA study brief for the project by submitting a project profile. Once the study brief is received from the authority, the applicant prepares a detailed EIA report in accordance to the requirements of the study brief, as well as the technical memorandum applicable to the assessment. Once the EIA report is submitted, if its assessment meets all the requirements, the entire report will be made available for public inspection for a period of 30 days on a government website to allow for transparency of the process. The report will also be circulated to different government departments, such as the Agriculture, Fisheries and Conservation Department to ensure that baseline information, impact assessment, and mitigation measures are accurate and scientifically sound. Finally, after considering comments from the public, various government departments, and the Advisory Council on the Environment (a statutory body with members made up of different experts and stakeholders), the authority will approve, approve with conditions, or reject the EIA report for the proposed project. Once a project receives approval, an environmental permit will be issued.

Notably, there have been a few cases of project rejections since the EIAO has been enacted, when the quality of EIA reports was deemed to be unsatisfactory, or the green groups strongly opposed the proposed project based on factual information (e.g., the Tonggu Waterway project segment in Hong Kong). One unfortunate fact is that several prominent green groups in Hong Kong do not cooperate with internationally-recognized experts on the animals, and base their protests on emotional pleas that are not backed-up by scientific information. They perpetuate myths about the dolphins, in order to garner sympathy and raise funds from naïve members of the public. In our opinion, their self-serving interest and lack of scientific "maturity" seriously weaken the ability to lobby effectively on behalf of the animals.

Generally, the EIA report is required to provide a detailed assessment in qualitative terms, and in quantitative terms wherever possible, of the likely environmental impacts and benefits of the project. To conduct a proper impact assessment, the EIA study would include the baseline information gathered from existing information and field surveys; the identification, evaluation, and mitigation of impacts; and an ecological monitoring and audit program. For assessment relating to potential impacts on dolphins, the baseline information needs to be sound and scientific, and the employed study methods have generally been required to be consistent with the long-term dolphin monitoring program and to use internationally recognized methods (e.g., systematic line-transect survey, photo-identification). Moreover, the dolphin field surveys usually require a study period of at least 9–12 months in order to cover all appropriate seasons of the year.

For impact identification, potential impacts on dolphins including direct, indirect, on-site, off-site, and cumulative need to be considered in detail. The evaluation of impacts usually considers the protection status and rarity of local dolphins; their distribution, density, and individual range use in the proposed work area; the size of affected habitat; as well as the duration, reversibility, and magnitude of the environmental impacts. To mitigate the potential impact, the general rule (in order of priority) is avoidance, minimization, and then compensation. For avoidance, potential impacts shall be avoided by adopting suitable alternatives, such as change of site, design and construction method, etc. In extreme cases when the assessment identified very serious impacts on dolphins that could not be mitigated (e.g., massive reclamation in a high density area for dolphins), the "no-go" alternative should be included as an option and assessed against all other options. For minimizing impacts, appropriate measures should be taken, such as confining works to specific seasons to avoid the calving season of the dolphins, or employing a bubble curtain around the working area of percussive piling. An ecological monitoring and audit program is also an important component of the process, as it can verify the accuracy of predictions of the EIA study, monitor the effectiveness of mitigation measures, and recommend action plans in response to unpredicted impacts (e.g., oil spill response plan).

The abovementioned components of the EIA process in Hong Kong have provided an effective conservation tool to eliminate or minimize impacts on local dolphins from various development pressures. As is true in every nation, the process is sometimes compromised and protection measures 'watered-down' to allow what are seen as important infrastructure developments (i.e., those involving huge amounts of money) to proceed with

little or no delay. The most serious problem, however, may very well be the lack of ability of the system to effectively address cumulative impacts of various developments that overlap in their work schedules.

3. Development activities and their impacts on cetaceans

Most of the development that is occurring in Hong Kong, besides its influence on dolphin and porpoise habitat, is also very noisy. It has the potential to cause disturbance of the cetaceans' normal activities, largely through underwater noise. While such noise can occasionally be intense and loud enough to injure or kill dolphins or porpoises (such as in blasting or percussive piling operations), the impacts are usually sublethal.

Rather than describe construction projects on a large scale (such as bridge construction, pier construction, or coastal power plant construction), an attempt has been made to classify development and construction activities into their smaller-scale components. For instance, pier construction usually involves some small-scale reclamation (for support 'islands'), percussive piling (to construct central supports), and increases in vessel traffic (for transportation of equipment and materials). These components are presented in terms of how the specific types of work involved may affect small cetaceans.

3.1. Land reclamation

Seabed 'reclamation' involves creating land areas from shallow coastal areas by dumping and filling of rock and sediment. Reclamation of shallow seabed to create land for human use is a common practice in Hong Kong. Massive reclamation has occurred on both sides of Victoria Harbor (effectively reducing the width of the harbor) for over 100 years and in recent years has been very active north and east of Lantau Island. This generally occurs by creating a perimeter around the limits of the area to be reclaimed, and then filling in the area with rock, rubble, and sand. The materials for filling are often obtained from dredge spoils, but the rockwork that is needed is also often obtained from blasting hillsides in surrounding areas.

The filling-in of marine habitats to produce land has the effect of eliminating dolphin and porpoise habitat. This is irreversible, and while the effects of construction work can be mitigated it is virtually impossible to mitigate against the effects of complete and total loss of habitat.

3.2. Percussive piling

Percussive piling generally consists of a steel pile-driving hammer that falls about 1–2 m by gravity, then detonates a fuel–air mixture to drive down the pile with extra force, creating a broad-band gun-shot like sound. Rate of pile driving varies around 1 blow/s, and each blow transmits about 90–1000 kJ of energy, depending on hammer weight, diesel charge, and other variables [29,30]. In all cases, most energy of pile driving occurs below 20 kHz, with a peak at about 200–1500 Hz ($\frac{1}{3}$ octave spectra) [30]. Pile driving can go on almost uninterrupted for days to, in some cases, several months, depending on substrate, depth, and number of piles. The lower acoustic frequencies of pile driving can be transmitted for as far as about 40 km distance in water deeper than several meters [31].

Pile driving has been used extensively in Hong Kong waters, for building piers and other structures, usually close to the shore. Pile driving was monitored in association with a temporary airport fuel receiving pier at the island of Sha Chau, north of the Hong Kong International Airport at Chek Lap Kok, in April 1996 [17]. In that case, a 6 British ton hammer created maximum blows of about 90 kJ, in 6–8 m water depth. One-octave band sound levels peaked at about 400–800 Hz and 160–170 dB re; 1 μPa at 250 m distance from the pile driver, at about 200–600 Hz and 150–160 dB re; 1 μPa at 500 m, and at about 200–300 Hz and 140–150 dB re; 1 μPa at 1000 m. However, minor energy above 120 dB was still present at all three distances to the upper limit of frequency measured, 25.6 kHz.

Because most pile driving energy tends to be below 1000 Hz, it is assumed that the activity can be particularly noxious to baleen whales that have acute-low-frequency hearing. However, there is still considerable energy into the single kHz digits, and this is where small- to mid-size toothed whales, such as bottlenose dolphins (*Tursiops* spp.) and humpback dolphins (*Sousa* spp.), for example, produce much communication sound, and are acoustically sensitive.

There is not much detailed information on reactions of marine mammals to pile driving. Harbor seals (*Phoca vitulina*) vacate areas of pile driving (for example, [32]), harbor porpoises (*Phocoena phocoena*) do so as well, possibly for quite long-term [33], and Indo-Pacific humpback dolphins did so for the period of piling (and other activity) mentioned for Hong Kong waters above, but returned once construction of the pier was finished [17]. David [31] speculated that pile driving could mask strong bottlenose dolphin vocalizations at 9 kHz within 10–15 km and weak vocalizations up to 40 km. However, he used knowledge of pile driving output and dolphin sensitivity curves for this estimation, without direct behavioral or physiological information.

3.3. Dredging and dumping of spoils

During operations of dredging and dumping of spoils, an increase in suspended solids concentration is expected. This increase may potentially influence humpback dolphins' prey, and affect the dolphins indirectly by the loss of food supply due to disturbance of the seafloor and increased sedimentation. Moreover, during dredging operations, contaminants such as heavy metals and organochlorines settled on the seabed may be stirred up and redistributed into the water column. This potential contaminant release by resuspension of environmental contaminants may increase their bioaccumulation in dolphins and porpoises through the intake of prey items in the vicinity of the work area. The potential contaminant release should be examined through hazard to health risk assessment.

3.4. Pipe- and cable-laying operations

Not much is presently known about how noise from cable- and pipe-laying activities influences dolphin behavior and physiology, or even about the frequencies and levels of noise produced by such activities. There is reason to be concerned about this issue, however, especially when one considers the vast amount of such noise in Hong Kong's western waters. The most serious concern is that disturbing noise may cause dolphins or porpoises to abandon critical habitat, and thereby reduce their survival and reproductive prospects.

3.5. Increases in vessel traffic

Increased vessel traffic at the work area can potentially increase the chance of dolphins and porpoises being killed or injured by vessel collisions. In fact, several stranded dolphins and porpoises in Hong Kong presented wounds that were consistent with blunt traumatic injury, probably caused by boat collisions

[14]. A number of dolphins in the photo-identification catalogue of known animals from the Pearl River Estuary also bear injury marks, apparently caused by propellers [4,14].

Vessel traffic can also result in acoustic disturbance to dolphins and porpoises. Small cetaceans are acoustically sensitive, and noise from vessel traffic could cause behavioral disturbance to them [34]. Since dolphins and porpoises rely on their echolocation to navigate their surroundings, detect and capture prey, and to communicate with one another, sound is vital to their survival (especially for mother–calf pairs). In fact, a land-based study on Hong Kong humpback dolphins showed changes in their diving behavior in response to heavy vessel traffic [35]. However, humpback dolphins mainly produce lower-frequency, broad-band clicks in the range of 8 to >22 kHz during foraging [36], while finless porpoises generally exhibit narrowband, high-frequency ultrasonic pulses with peak energy of 142 kHz [37]. In comparison, large vessel traffic generally produces low-frequency sounds of less than 1 kHz [38]. Therefore, the expected acoustic disturbance from large vessels is well below the primary acoustic range for humpback dolphins and finless porpoises. Nevertheless, they may still need to alter their diving and surfacing patterns to avoid collisions with marine vessels. This could result in some short-term behavioral disturbance to the dolphins and porpoises, or they may even be displaced from their preferred habitats.

3.6. Others

There are certainly other types of marine construction and development activities beyond those described above. But most such projects involve one or more of the above as the major activities of concern to dolphin and porpoise management.

4. Mitigation measures

4.1. Temporal and geographic closures

The most obvious way to reduce or eliminate the impacts of various disturbing activities is to plan those activities to occur in places or at times when the animals of interest are not present. Even when the animals are present, temporal or geographic closures that restrict the activities to lower density areas/times, or to less sensitive areas/periods may be similarly useful. Of course, such measures require that something is known about small-scale patterns of distribution, seasonal shifts in density, diurnal patterns, and/or calving seasonality. When this information is available, it is often possible to use it to reduce impacts through closures.

For instance, in Hong Kong, for many years it has been common practice to restrict potentially harmful activities (such as blasting and percussive piling operations) to periods outside the main calving season for both finless porpoises and humpback dolphins. The reasoning behind this procedure is that such time periods represent particularly sensitive ones for newborn calves and lactating females. By simply not allowing harmful activities during these sensitive periods, the risk of injury or disturbance can be reduced.

Geographic closures may be harder to implement, as most small cetaceans do not have 'nursery areas' in the sense that most fishes do (i.e., areas where only the reproductive segment of the population segregates itself to produce offspring). However, there are sometimes areas with higher densities of dolphins/porpoises, and even areas with higher densities of mother/calf pairs. Such areas can be viewed as particularly critical habitat, and when such areas have been identified they are prime candidates for geographic closures. Such measures have been used on small scales in Hong Kong waters.

4.2. Bubble curtains and jackets

Bubbles in water create an impedance mismatch, and thereby can absorb blast shocks and sound [39]. Bubble curtains have been used to protect divers and marine life, especially fishes with swim bladders that make them particularly vulnerable to loud near-field (shock, or barotrauma) effects [40].

A bubble curtain was employed in Hong Kong in 1996/97 during the construction of the temporary airport fuel receiving pier described under "percussive piling" earlier in this paper [17]. The curtain was created by forcing air from two compressors into a perforated rubber hose anchored to the sea bottom (see [17] for details), surrounding a barge with a single pile driver. In brief, the bubble curtain effectively reduced the sounds of pile driving by overall broadband reduction of 3–5 dB, but with much larger (up to 25 dB) reduction, especially between 400 Hz and 6.4 kHz. However, there was evidence that sound also propagated through the hard rock substrate under the seafloor, and that placement of the curtain relative to the piling barge was critical for greatest prophylactic effect. While the curtain reduced pile driving sound at distances between 250 and 1000 m, and was therefore deemed "a success", dolphins nevertheless used the area less than before and after construction [17].

Bubble curtains and various iterations (termed "jackets" for small curtains directly around noise-making equipment and "screens" for curtains enclosed in a foam-like mesh) have since been used in a number of industrial applications, especially to help direct fishes (for example, [41]), and to reduce sounds of percussive piling and drilling activities, largely related to construction of wind farms in Europe [42]. Such air-induced screening tends to be valuable in reducing noise towards seals, dolphins, and porpoises, especially when human-made sounds are loud and stationary in areas of important marine mammal habitat. It may eventually be possible to use bubble screening around moving industrial objects as well, as has been signaled by a US patent for reducing side-borne impulsive blasts from industrial seismic surveys for oil and gas exploration [43].

4.3. Monitored exclusion zones

When intermittent construction activities have the potential to cause serious behavioral disturbance or even physical harm to small cetaceans, monitored exclusion zones can help to reduce the chances of impacts. The idea here is that only dolphins within close range of the activity of interest are at risk, and therefore it should be possible to avoid the activity when dolphins are nearby. Exclusion zones ranging from 250 to 500 m in radius have been used in Hong Kong, depending on the activity. "Low-impact" activities such as dredging and cable-laying operations often use only a 250 m radius, while those activities that are perceived to be more harmful (e.g., underwater blasting or percussive piling) generally use a 500 m radius. The site is generally closely monitored for at least 30 min prior to the start of construction, and if dolphins or porpoises are observed within the circle construction is delayed for 30 min past the last sighting.

An important aspect of using this mitigation technique effectively is to have an independent observer (with the power to call off construction activities) to monitor the exclusion zone. Construction workers or foremen do not have the training to effectively search for dolphins or porpoises, and they may also be biased by not wanting to delay construction. The observer should be someone who is trained in dolphin and porpoise detection and

should use binoculars from an elevated platform with unobstructed visibility to aid detection. Use of passive acoustic monitoring (such as hydrophones or porpoise detectors with real-time monitoring) can also greatly increase the effectiveness of such exclusion zones, by adding another way to detect animals that may be under water or surface cryptically. Of course, adding acoustics increases the logistical complexity and expense of the monitoring, and may also require additional training in the use of the equipment by the observer.

4.4. Ramping up of piling hammers

Percussive piling activities not only have the potential to change habitat use by chasing marine mammals away from the activity, or to mask their sounds and thereby make them less effective at communication and, perhaps, finding prey by echolocation or passive listening. Percussive piling is also known to kill fishes within meters and possibly several hundred meters of piling [32], and may therefore also be dangerous to marine mammals at close range, by causing hearing damage and even trauma injury or death.

The use of "ramping up" of sounds has received widespread attention [38], but it is still unclear when and how ramping up of sounds should be practiced for maximal effect in moving animals away, rather than attracting them. Nevertheless, since percussive piling is likely to be physically dangerous to marine mammals at close range [44], the protocol should be followed of: (1) clearing the area, (2) commencing low-level percussive sound production, and (3) proceeding to full volume while continuing to monitor for marine mammals within about 500 m of the activity.

4.5. Acoustic decoupling of noisy equipment

Construction equipment is often extremely noisy. When such pieces of equipment are used on the water or in coastal areas, some of the sound may be transmitted into the water and affect small cetaceans as noise pollution. It is therefore desirable to reduce construction noise as much as possible. Construction machinery, such as compressors and generators, that are placed onto the steel hulls of barges are particular culprits. By placing such equipment on rubber or foam mats, or by using pneumatic rubber wheels under such machines, they can be 'acoustically-decoupled' to an extent.

4.6. Vessel speed limits and restrictions

As it appears that faster-moving vessels are more of a threat to dolphins and porpoises, a speed limit of 10 knots should be strictly observed within the work area. This speed limit within the boundaries of the Sha Chau and Lung Kwu Chau Marine Park appears to be effective in protecting the dolphins from vessel collisions and acoustic disturbance. All vessel captains working in the area should undergo training to educate them about local cetaceans, as well as guidelines for safe vessel operations in the presence of dolphins and porpoises. Vessels traversing through the work areas should also be required to use predefined and regular routes to reduce disturbance to cetaceans due to vessel movements.

4.7. No-dumping policies

Often, construction work involves extended work by personnel from coastal sites, reclaimed lands, anchored barges, skiffs, or other types of vessels. A no-dumping policy is simply a policy prohibiting dumping of wastes, chemicals, oil, trash, plastic, or any other substance that would potentially be harmful to dolphins and/or their habitat in the work area. Obviously, to be effective, it needs to be strictly enforced and there need to be stiff fines for infractions. Unscheduled, on-site audits are generally required.

4.8. Silt curtains

To avoid allowing suspended solid and environmental contaminants to be re-suspended back into the water column during dredging and dumping operations, silt curtains should be used around the work area wherever feasible. The intactness and effectiveness of silt contains should be regularly inspected. An effluent monitoring program should also be implemented to ensure the water quality in the vicinity of the work site meets the adopted standard.

4.9. Cetacean density monitoring

Perhaps the most important mitigation measure of all is to conduct surveys to monitor the density and behavior of the animals before, during, and after the period of the potential disturbance. This is often overlooked in mitigation plans, but it is the only way to really tell if the other mitigation measures that have been put into place have been effective in protecting the animals from disturbance and maintaining their habitat quality.

In order for such monitoring to be effective, it needs to be divided into three phases: pre-disturbance (i.e., baseline phase), disturbance (i.e., construction phase), and post-disturbance (i.e., operational phase). Survey techniques must be held constant from phase to phase, and survey equipment and personnel should ideally be the same as well. Any apparent differences in density among survey phases should be analyzed for trends, and the statistical power of the analysis to detect effects of the desired size should be tested. The software TRENDS is available free-of-charge, and can be used to easily test the *a posteriori* statistical power of the analysis [45]. It can even be used as a planning tool to determine how much effort is needed to detect a particular change in density (as long as relevant data on sighting rates are available *a priori*).

An important consideration in testing for impacts in cetacean density monitoring is to take account of any natural cycles, and pre-existing trends in densities, so that any changes can be correctly attributed to their source. Such an approach may be a challenge, and again requires some pre-existing knowledge of the population biology of the affected species. This provides a very strong argument for the need to conduct long-term monitoring of cetacean populations before major impacts from human activities are suspected. Such situations are rare, as managers and biologists are generally much better in trying to "put out fires" than we are in preventing them from breaking out in the first place. However, in Hong Kong, small cetacean monitoring has been conducted since late 1995, and therefore provides a useful baseline against which to measure current and future potential disturbances [4,9].

4.10. Others

Other measures than just those above have been proposed and used. Some examples are warning blasts and staggered charges, which are designed to have the effect of warning marine mammals of louder and/or more dangerous sounds to come, giving them the chance to leave the area voluntarily. Theoretically, this may sound reasonable. But, there is usually uncertainty as to whether animals will actually move away, and sometimes these sounds can even have the opposite effect of attracting animals (i.e., the "dinner bell" effect). Richardson et al. [38] warned of

some of these potential problems, and their use is not advocated, unless there has been extensive research indicating that they will be successful in the specific location with the particular species of interest.

5. Conclusions

Due to the large amount of coastline and extensive marine waters in Hong Kong, and the high profile of dolphins in the region (the local humpback dolphins were chosen as the official mascot of the 'handover' of Hong Kong from the UK to China in 1997), small cetaceans have received a great deal of attention in the environmental impact assessment (EIA) process. It appears that nowhere else in Asia (and perhaps the world) have small cetaceans been more heavily involved than in Hong Kong in the past 15 years. The above review provides a brief summary of what has been learned, what was found to work, and what not to work in the process. As other countries move forward with EIA work directed towards local cetacean populations, it will be instructive to examine the Hong Kong situation in detail to assist in the process. It is hoped that those involved will find this review a useful stepping stone to explore the full range of EIA work related to small cetaceans in Hong Kong.

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