

CASE STUDIES AND REVIEWS

Averting the baiji syndrome: conserving habitat for critically endangered dolphins in Eastern Taiwan Strait

PETER S. ROSS^{a,*}, SARAH Z. DUNGAN^b, SAMUEL K. HUNG^c, THOMAS A. JEFFERSON^d,
CHRISTINA MACFARQUHAR^e, WILLIAM F. PERRIN^d, KIMBERLY N. RIEHL^b, ELISABETH SLOOTEN^f,
JOHN TSAI^g, JOHN Y. WANG^{b,h,i}, BRADLEY N. WHITE^b, BERND WÜRSIG^j, SHIH CHU YANG^j and
RANDALL R. REEVES^k

^a*Institute of Ocean Sciences, Fisheries and Oceans Canada, Canada*

^b*Department of Biology, Trent University, Canada*

^c*Hong Kong Cetacean Research Project, Hong Kong*

^d*Cetos Research Organization, USA*

^e*Wild at Heart Legal Defense Association, Taiwan*

^f*Otago University, New Zealand*

^g*Changhua Environmental Protection Union, Taiwan*

^h*National Museum of Marine Biology and Aquarium, Taiwan*

ⁱ*Formosa Cetus Research and Conservation Group, Taiwan/Canada*

^j*Texas A&M University, USA*

^k*Okapi Wildlife Associates, Canada*

ABSTRACT

1. Numbering no more than 100 individuals and facing many threats, the geographically isolated Eastern Taiwan Strait population of Indo-Pacific humpback dolphins (*Sousa chinensis*) is in peril. The estuarine and coastal waters of central-western Taiwan have historically provided prime habitat for these dolphins, but environmental conditions today bear little resemblance to what they were in the past.

2. The humpback dolphins must share their habitat with thousands of fishing vessels and numerous factories built upon thousands of hectares of reclaimed land.

3. They are exposed to chemicals and sewage released from adjacent terrestrial activities. Noise and disturbance associated with construction, vessel traffic and military activities are features of everyday life for these animals.

4. Measures to slow the pace of habitat deterioration and reduce the many risks to the dolphins are urgently needed. As one practical step in this direction, this paper describes the habitat needs of these small cetaceans so that decision makers will be better equipped to define 'priority habitat' and implement much needed protection measures under the terms of local legislation.

5. The preferred habitat of these dolphins in Taiwan consists of shallow (<30 m), near-shore marine waters with regular freshwater inputs.

6. For such a small, isolated and threatened population, 'priority habitat' should not be limited to areas of particularly intensive dolphin use or high dolphin density, but rather it should encompass the entire area where the animals have been observed (their current 'habitat'), as well as additional coastal areas with similar bio-physical features ('suitable habitat'). Such a precautionary approach is warranted because the loss of only a few individuals could have serious population-level consequences.

7. While conventional socio-economic analysis might suggest that implementing protection measures over an area stretching ~350 km north–south along Taiwan's west coast and ~3 km out to sea would be too 'costly', the loss of this charismatic species from Taiwan's waters would send a troubling message regarding our collective ability to reconcile human activities with environmental sustainability.

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*Correspondence to: P. S. Ross, Institute of Ocean Sciences, Fisheries and Oceans Canada, PO Box 6000, Sidney BC V8L 4B2, Canada
E-mail: peter.s.ross@dfo-mpo.gc.ca

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INTRODUCTION

Recent news of the likely extinction of the baiji, or Yangtze River dolphin (*Lipotes vexillifer*), has created a sense of urgency about other critically endangered cetaceans. The scientists who undertook a futile range-wide search in late 2006 concluded that the baiji's disappearance had not been caused by 'active persecution' but rather that it was due to environmental degradation by humans on a massive scale (Turvey *et al.*, 2007). The baiji had long enjoyed legal protection from hunting and other types of deliberate harm, but such protection was inadequate; a poorly understood combination of unintended insults sealed the fate of this 'goddess of the Yangtze' (Zhou and Zhang, 1991). Some of those insults, such as pollution, disturbance, and reduced quality of the prey base, were chronic and insidious; others, such as mortality from entanglement in fishing gear and boat strikes, were acutely lethal.

There are many similarities between the situation faced by the baiji in the late 20th century and the circumstances now confronting a small, isolated population of Indo-Pacific humpback dolphins (*Sousa chinensis*; Figure 1) found in near-shore waters along the west coast of Taiwan. This marine and estuarine area is, like the Yangtze River, intensively used by humans for fishing, sand extraction, land reclamation, transportation and recreation, and it receives large quantities of industrial and municipal runoff (Wang *et al.*, 2007c). Also, just as structures built in the outlets of Yangtze tributary lakes and streams deprived the baiji of access to formerly prime habitat and compromised its prey resources, the upstream diversion of water for industrial, agricultural and municipal uses in Taiwan has led to reduced freshwater and sediment discharge that shape the estuarine and nearshore habitat on which humpback dolphins rely.

The Eastern Taiwan Strait (ETS) population of humpback dolphins (also known in the region as 'Matsu's fish' or 'Chinese white dolphins') is one of many small, naturally



Figure 1. An Indo-Pacific humpback dolphin leaps in coastal waters adjacent to the Dadu River estuary off western Taiwan, 26 July 2007 (© 2007 S.C. Yang).

isolated populations of small cetaceans that are in trouble across the planet. The vaquita (*Phocoena sinus*) of the northern Gulf of California in Mexico is critically endangered because of accidental entanglement in fishing nets (Jaramillo-Legorreta *et al.*, 2007). Several populations of Irrawaddy dolphins (*Orcaella brevirostris*), which occur in both freshwater and estuarine habitats, are on the brink of extinction largely due to entanglement in bottom-set and drifting gillnets, restrictions on their movements by fishing gear and habitat degradation (Smith and Beasley, 2004; Smith and Braulik, 2004; Beasley *et al.*, 2007). Some populations of Ganges dolphins (*Platanista gangetica*) have been fragmented by dams and are declining as a result of an array of other threats including entanglement, pollution and habitat degradation (Smith and Braulik, 2009). Coastal bottlenose dolphins (*Tursiops truncatus*) in some parts of the world are at risk. For example, a largely isolated population in Amvrakikos Gulf, Greece, faces growing threats from agrochemical pollution and eutrophication, such that this population is considered threatened despite its present high density (Bearzi *et al.*, 2008). Bottlenose dolphins in Doubtful Sound (Fiordland, New Zealand), also isolated from adjacent areas, are declining; for them, the main threats include disturbance from vessel traffic and changes in surface water temperature stemming from an upstream hydroelectric power project (Currey *et al.*, 2009).

A major factor which renders many populations of riverine and coastal small cetaceans vulnerable is that they occur in limited ranges and are isolated or nearly isolated from other populations (Reeves *et al.*, 2003). In some cases, the anthropogenic threats are multiple and systemic, such as with Ganges and Irrawaddy dolphins (and the baiji). In other cases, the threats are fewer in number, but still significant, as with the vaquita and the Amvrakikos Gulf and Doubtful Sound populations of bottlenose dolphins.

Intense competition exists between various sectors of society in Taiwan for space (both on land and in nearshore waters), fresh water from rivers draining into the Taiwan Strait and fisheries resources (Chen and Liu, 2004; Hsieh *et al.*, 2004; Feng, 2007). As one important step towards safeguarding the ETS humpback dolphins, and as an immediate aid to decision makers and planners, we focus here on the dolphins' habitat. The intent is to provide:

- background information on the biology of Indo-Pacific humpback dolphins;
- brief summaries of major threats to the ETS population;
- general and ETS-specific features of humpback dolphin habitat; and
- a science-based description of 'priority habitat' for the ETS population of humpback dolphins.

BACKGROUND ON *SOUSA CHINENSIS*

The ETS population of humpback dolphins was first reported scientifically as a result of dedicated cetacean surveys of the

waters along the western coast of Taiwan carried out in 2002 (Wang *et al.*, 2004a). Before this, two strandings, a few photographs and anecdotal reports constituted the only available evidence that the species was present in these waters. Since 2002, increased survey effort has documented the presence of humpback dolphins in the nearshore waters of Tongshiao (Miaoli County) in the north, and extending to at least Jianggyun (Tainan County) in the south (Wang *et al.*, 2007a,c).

While humpback dolphin populations exist elsewhere in the world, the ETS population is morphologically distinct and geographically isolated. Clear differences in pigmentation patterns indicate that ETS dolphins are genetically discrete from populations in the Pearl River and Jiulong River estuaries of the Chinese mainland (Wang *et al.*, 2008). Geographically, the ETS population appears to be well isolated from its nearest neighbours on the mainland coast of China (Figure 2). The Taiwan Strait is 140–200 km wide, with relatively expansive areas (i.e. the Wuchu and Kuanyin depressions) that are much deeper than the maximum water depth in which humpback dolphins have been recorded in other parts of Asia (Jefferson and Karczmarski, 2001). Despite both nearshore and offshore surveys, humpback dolphins have not been observed in waters deeper than 30 m in Taiwan (Wang *et al.*, 2008). Together with other ocean features (e.g. currents), water depth apparently constrains the exchange of humpback dolphins between Taiwan and mainland China.

The only published estimate of population size for ETS humpback dolphins is 99 (CV = 51.6%; 95% CI = 37 to 266), based on line-transect data from 2002 to 2004 (Wang *et al.*, 2007a). As a result of its geographical isolation, small population size and presumed ongoing decline due to existing

and anticipated threats, the ETS population is red-listed by IUCN as 'Critically Endangered' (Reeves *et al.*, 2008b).

Globally, Indo-Pacific humpback dolphins inhabit tropical and subtropical near-shore waters from southern Africa, around the rim of the Indian Ocean, southwards to central Australia and northwards to southern mainland China, Hong Kong and Taiwan (Parra and Ross, 2009). Initially described in Chinese waters by Pehr Osbeck in 1765 (Flower, 1870; Jefferson and Karczmarski, 2001), the humpback dolphins between south-eastern Africa and China are thought to belong to a single species, *Sousa chinensis*. The species is red-listed by IUCN as 'Near Threatened', based on an inferred global reduction in the number of mature individuals of close to 30% over three generations (~60 years), driven primarily by 'heavy fishing pressure (incidental mortality) and habitat loss in coastal and estuarine areas' (Reeves *et al.*, 2008a).

In China, the species occurs from the Vietnam border to the Yellow Sea, although records from the Yangtze River and further north are considered extra-limital (Wang and Han, 1996; Zhou *et al.*, 1997; Han *et al.*, 2003). At least eight populations are thought to exist along the coasts of mainland China, Hong Kong and Taiwan, separated by areas of absence or low animal density (Jefferson, 2000; Jefferson and Hung, 2004). These populations tend to be centred at the mouths of large rivers. Three of the populations have been relatively well studied: the Pearl River Estuary/Hong Kong population, numbering ~2500 (Chen *et al.*, 2010), the Jiulong River Estuary/Xiamen population, numbering ~75–80 (Chen *et al.*, 2008) and the ETS population, numbering fewer than 100 (Wang *et al.*, 2007c). Additional populations numbering 100–250 individuals have been confirmed in the Beibu Gulf (also known as the Gulf of Tonkin) (Chen *et al.*, 2009, 2010) and Leizhou Bay (Zhou *et al.*, 2007).

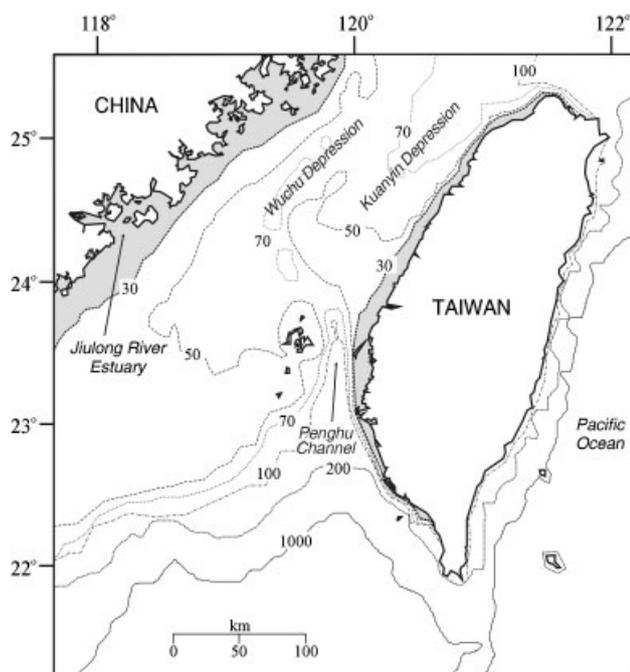


Figure 2. Indo-Pacific humpback dolphins in Taiwan have not been observed in waters deeper than 30 m, probably helping to explain their geographic isolation from mainland populations. The Taiwan Strait (between China and Taiwan) is 140 to 200 km across, can reach depths up to 200 m, and has currents and other oceanographic properties which may impede movement of these estuarine cetaceans across the Strait.

THREATS TO *SOUSA CHINENSIS* IN THE EASTERN TAIWAN STRAIT

The coastal plains of western Taiwan are an area of both high human population density (approximately 90% of Taiwan's 23 million people live in counties that border the west coast of Taiwan) and extensive industrial and agricultural development (Figure 3). While the very small humpback dolphin population heightens the risk of extirpation from the ETS, five major types of anthropogenic threat to the ETS dolphin population have been identified (Wang *et al.*, 2004b, 2007c; Reeves *et al.*, 2008b). The severity of these threats underscores the need for habitat characterization and the implementation of protection measures (Figure 4).

Fisheries mortality (bycatch)

The greatest threat to small cetaceans globally is entanglement in fishing gear (Read *et al.*, 2006). Types of fishing gear that pose the greatest threat include gillnets and trammel nets. Dolphin entanglements in fishing net often result in injuries or death. Thousands of vessels fish with gillnets and trammel nets in waters used by humpback dolphins along the west coast of Taiwan (Wang *et al.*, 2004b). Entanglement certainly occurs, but because the species is legally protected, fishermen are unlikely to report bycatch events (Chou, 2006; Wu, 2007). More than 30% of the ETS dolphin population bear serious

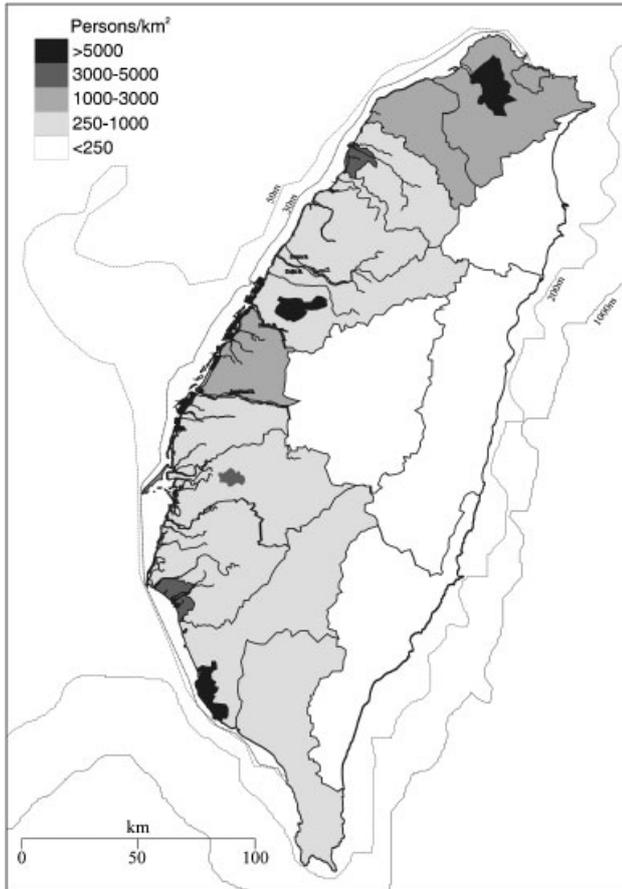


Figure 3. Taiwan's land mass covers approximately 36,000 km², with a rugged eastern coastline that drops off rapidly into deep ocean waters. The western coastline is much different, typified by gently sloping watersheds and coastal plains that drain Taiwan's major rivers onto a shallow coastal shelf. With more than 23 million people, Taiwan is densely populated (637 persons km⁻²) with over 90% of the population living within the counties bordering the west coast of the island, which is also intensively cultivated and developed for industry and commerce. The black polygons along the coast of western Taiwan represent land reclamation areas for industrial purposes.

wounds or scars, at least some of which are almost certainly from encounters with fishing gear (Figure 4) (Wang *et al.*, 2007c). In September 2007, a dolphin was photographed with a rope, probably from fishing gear, wrapped around its torso, and in September 2009, a known individual died with lesions that were probably caused by a gillnet (J.Y. Wang, unpublished data).

The bycatch removal of even a few dolphins annually from such a small population would be unsustainable and probably lead eventually to extirpation of the species from Taiwan's waters. A similar situation exists for the vaquita in Mexico: bycatches by the hundreds of gillnet boats operating in the northern Gulf of California are rare events. The probability that an individual fisherman will catch or even see a vaquita is low, but the number of vaquitas taken in the fishery as a whole is unsustainable (Rojas-Bracho *et al.*, 2006; Jaramillo-Legorreta *et al.*, 2007). The recommended solution is to ban all gillnet fishing throughout the range of the vaquita's core habitat, and the Mexican Government has taken initial steps to bring this about (International Whaling Commission, 2000, 2010).

Watershed alteration and freshwater diversion

Virtually all of the rivers in western Taiwan and their watersheds have been altered for the purposes of municipal/residential use, flood control, agriculture, aquaculture and industrial development (Wang *et al.*, 2004b, 2007c). A number of the island's major westward-flowing rivers have already been dammed and/or diverted (Chen and Liu, 2004; Hsieh *et al.*, 2004; Huang *et al.*, 2009) and further diversions and impoundments have been proposed for the high-technology, manufacturing, petrochemical and power-production sectors. For example, the discharge of the longest river in Taiwan, the Zhuoshuei River, has been greatly reduced as a result of upstream dams constructed to divert water for agriculture, municipalities and industry. The construction of the Hushan Dam as well as a number of proposed water diversion projects to supply water to the petrochemical industry, science parks, and other industrial development sites will further reduce the flow of this important river system. These plans threaten to further deplete freshwater resources and heighten competition from other users including municipalities, farmers and aquaculturists. The extent to which the receiving estuary (where humpback dolphins are found) has already been affected, and will be further affected, is unclear but the impacts are likely profound.

Most studies on the effects of reduced freshwater flow on cetaceans have focused on river dolphins (Chen and Hua, 1989; Reeves and Leatherwood, 1994; Dudgeon, 2000; Smith *et al.*, 2009). The effects on estuary-dependent marine species, such as humpback dolphins, may be less apparent but significant nonetheless. Freshwater diversions alter the physical, chemical and biological features that support the rich arrays of species that inhabit typically productive estuarine ecosystems. The reduction of freshwater input into the estuarine habitat of humpback dolphins alters the character and productivity of their food web, and hence the availability of suitable prey. Reduced freshwater flow also alters the structural characteristics of the mudflats and sandbars that appear to represent key features of suitable habitat for the dolphins. Finally, reduced freshwater flow is likely to lead to heightened contaminant concentrations in the remaining water.

Chemical and biological pollution

A variety of toxic chemicals have been detected in cetaceans in Taiwan, although only a single humpback dolphin has been examined for contaminants (Chou *et al.*, 2004). While there is some direct exposure to toxic films at the surface microlayer and to air pollutants, the primary exposure route in dolphins is expected to be through the ingestion of contaminated prey. Mercury (Hg), in its organic (methylated) form, can accumulate to worrisome concentrations in humpback dolphins (Hung *et al.*, 2004). However, other inorganic elements do not typically bioaccumulate in food webs and thus are unlikely to represent a major health risk for *Sousa chinensis* (Chen *et al.*, 2002). Contaminants that are persistent, bioaccumulative and toxic can occur in high concentrations in some cetaceans. Such contaminants preferentially partition into fat, resist degradation and are readily amplified in aquatic food webs. For example, polychlorinated biphenyls (PCBs) have been associated with the disruption of reproductive, immune and endocrine systems of seals and whales (Reijnders,



Figure 4. Indo-Pacific humpback dolphins in Taiwanese waters face a number of threats, including habitat destruction and fisheries and vessel interactions. Top left: a few members of a group of humpback dolphins observed in waters off Mailiao Industrial Park of the Formosa Plastics Group, Yunlin County, Taiwan, 25 July 2007 (© 2007 J.Y. Wang). Top right: an individual humpback dolphin observed in waters off Chiayi County, Taiwan (12 April 2010), scarred, probably as a result of a fishery or vessel interaction (© 2010 J.Y. Wang). Bottom left: a humpback dolphin in Taiwanese waters entangled with rope, likely due to an interaction with local trammel net operations (off Mailiao Industrial Park, Yunlin County, Taiwan, 07 September 2008) (© 2008 J.Y. Wang). Bottom right: one of two trammel nets that were being deployed on either side of a pair of humpback dolphins in waters off Chiayi County, Taiwan, 12 April 2010 (© 2010 S.C. Yang).

1986; De Guise *et al.*, 1995; Ross, 2000). The concentrations of PCBs and DDT in some stranded and biopsied humpback dolphins in Hong Kong exceeded established effects thresholds demonstrated in marine mammals (Parsons, 2004; Jefferson *et al.*, 2006), suggesting that these persistent organic pollutants (POPs) are a concern for ETS dolphins. Despite regulatory steps to eliminate many POPs in Taiwan and around the world, some are still widely used (e.g. polybrominated diphenyl ethers or PBDEs) while others (e.g. PCBs) continue to represent health risks to wildlife as a result of their environmental persistence (Ross, 2006; Ross *et al.*, 2009).

Chemical pollution is a well documented threat to marine mammals but biological pollution is increasingly viewed as an additional major wildlife health concern in some coastal areas. Agricultural runoff and the discharge of sewage effluent introduce vast quantities of bacteria, protozoa and viruses into coastal areas, where they may profoundly affect the health of marine mammal populations (Miller *et al.*, 2002). The proximity of humpback dolphins to Taiwan's dense human population centres puts this population at risk of pathogen exposure, as observed in the humpback dolphins in Hong Kong (Parsons and Jefferson, 2000). International maritime trade and species invasions deliver new biological agents to previously naïve marine mammals, something that also may be facilitated by climate change (Harvell *et al.*, 1999; Ross, 2002). For example, the tropical *Cryptococcus* fungus caused the recent deaths of a number of harbour porpoises (*Phocoena phocoena*) in the north-eastern Pacific Ocean (Stephen *et al.*, 2002).

Noise

Humpback dolphins produce sounds largely in the range 0.9 kHz to well above 22 kHz (Van Parijs and Corkeron, 2001b) and it is inferred that their hearing has a similarly broadband nature,

probably from as low as 50 Hz to as high as 150 kHz (Richardson *et al.*, 1995; Janik, 2009). Humpback dolphins alter their behaviour in the presence of vessels (Ng and Leung, 2003), including changing their acoustic signalling (Van Parijs and Corkeron, 2001a). There is increasing evidence that short-term responses to human presence can have deleterious long-term consequences for dolphins (Lusseau and Bejder, 2007).

Humpback dolphins are likely to be affected by a suite of anthropogenic sounds, including those from ships and boats, military exercises, seismic research and near-shore percussive pile driving. Intense or chronic noise exposure can cause temporary or permanent hearing threshold shifts (Mooney *et al.*, 2009), thus reducing the efficiency of echolocation, passive sound detection of certain prey and inter-animal communication. Noise can also cause physiological stress and mask biologically significant sound, thus affecting the dolphins' health and impairing their ability to communicate (Wartzok *et al.*, 2004; Nowacek *et al.*, 2007).

Other forms of habitat degradation and loss

Approximately 60% of the world's human population resides within 100 km of a coastline, and 20% of coastal ecosystems, including estuaries and wetlands, have been lost to industrialization (e.g. filling, dredging, shoreline reclamation), agriculture, aquaculture and the diversion or damming of rivers (Burke *et al.*, 2000). Land reclamation for ports, industrial zones, power plants and wastewater discharge channels has already altered the morphology of the coastline of Taiwan, with only 20% of the west coast considered 'natural' (Wang *et al.*, 2007a). Along the west coast of Taiwan, the construction of new large-scale manufacturing facilities and additional water diversions are planned. For example, a proposed offshore petrochemical plant in Changhua County in

central western Taiwan would involve the construction of a 4000 ha artificial platform extending several kilometres seaward from the existing shoreline; this falls in the central portion of the known current distribution of the ETS humpback dolphins and would remove a substantial part of their habitat.

For some coastal species, inaccessible or non-preferred (i.e. inhospitable) habitat can become an ecological, physical or behavioural barrier. It has been argued in the case of humpback dolphins off southern Africa that the loss of preferred habitat through shoreline alteration and reef destruction restricts the animals to even smaller areas within an already limited distribution (Karczmarski, 2000). Indeed, the disturbance and resultant changes associated with urbanization and industrialization are bound to have significant effects on the ETS dolphins, linked as these animals are to shoreline features and near-shore ecological conditions.

GENERAL CHARACTERISTICS OF HUMPBACK DOLPHIN HABITAT

In global terms, Indo-Pacific humpback dolphins generally occur in a wide variety of coastal habitats, including those characterized by sandy beaches, enclosed bays, coastal lagoons, mangrove channels, seagrass meadows, rocky and coral reefs and turbid estuaries (Ross *et al.*, 1994; Jefferson and Karczmarski, 2001). Typically, humpback dolphins occupy coastal waters less than 20 m deep (Corkeron, 1990; Karczmarski *et al.*, 1998; Jefferson, 2000; Karczmarski, 2000). Water properties including temperature and salinity appear to be important drivers of humpback dolphin habitat, possibly due to influences on prey productivity and/or availability (Karczmarski *et al.*, 1998, 1999; Guissamulo and Cockcroft, 2004).

In the coastal waters of China, humpback dolphins are usually associated with estuarine habitat (Zhou *et al.*, 1995; Jefferson and Hung, 2004). In the Pearl River Estuary, they occur only in areas influenced by the river's freshwater plume (Jefferson, 2000; Hung, 2009). This association probably relates to the distribution of their prey, as these are species often linked to the productive waters of estuaries (Barros *et al.*, 2004; Hung, 2009). In Hong Kong, areas with higher fishery yields had higher densities of humpback dolphins (Hung, 2009). Monthly dolphin densities were significantly correlated with several hydrological parameters, including surface water temperature, salinity and water clarity, all of which could directly influence the distribution of prey. Humpback dolphins showed clear preferences for waters 20–30-m deep along steep benthic slopes (Hung, 2009). Dolphin densities were also significantly higher along rocky shorelines than along sandy or artificial shorelines, and habitat use was negatively affected by anthropogenic factors, including vessel traffic, coastal reclamation and dredging and filling activities (Hung, 2009).

'PRIORITY HABITAT' FOR HUMPBACK DOLPHINS IN THE EASTERN TAIWAN STRAIT

Dedicated legislation protecting species at risk in many jurisdictions requires the identification of particularly important habitat areas and features as a basis for enhanced protection measures. Such areas are known as critical, core, important or major habitat, depending on the jurisdiction.

To avoid confusion with legal terms used in Taiwan ('important habitat') and elsewhere, we define here the habitat necessary for the recovery or survival of a species as 'priority habitat', and hope that this delineation of such priority habitat for ETS humpback dolphins will be considered for designation as legally binding 'important habitat' in Taiwan.

While recent advances in research and monitoring technology have contributed to understanding the habitat needs of cetaceans, scientists and managers alike continue to struggle with the problem of how to define and delineate priority habitat. Much of the difficulty in formulating a science-based approach for marine mammals comes from their highly mobile nature and the fact that they live in an aquatic (fluid) environment (Gregs and Bodtker, 2007). In addition, their life histories vary, as do their feeding preferences, migratory patterns and ways of using habitat. The difficulty of delineating priority habitat is often compounded by the desire on the part of government managers to protect only what is considered particularly important or essential habitat, and this typically necessitates an awkward compromise between scientific and socio-economic considerations.

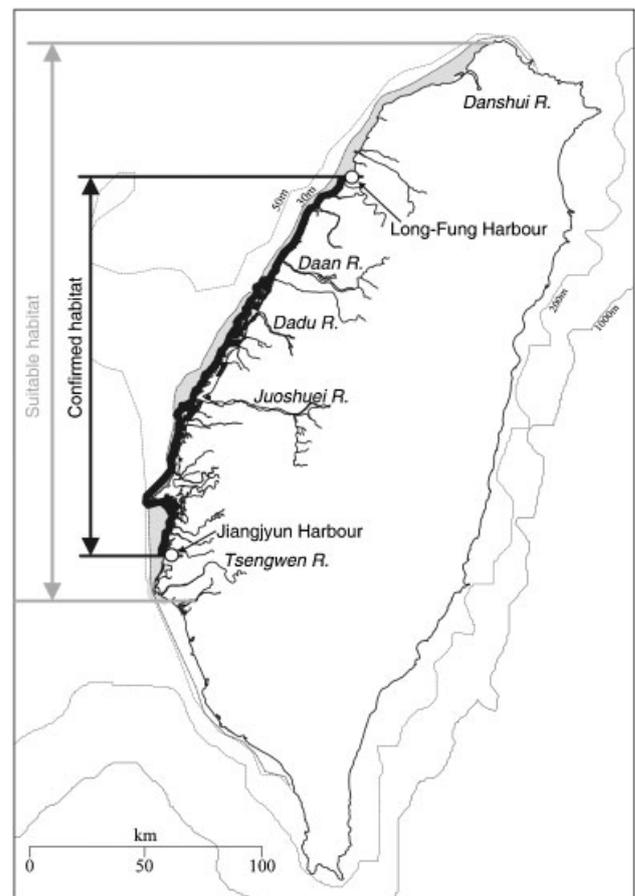


Figure 5. The proposed priority habitat for Eastern Taiwan Strait humpback dolphins encompasses the entire geographic range of confirmed sightings (= 'confirmed habitat'), in addition to areas outside that range judged to contain habitat suitable for this species, based on the biophysical features found in the existing range of this population and others (= 'suitable habitat'). The black polygons along the coast of western Taiwan represent land reclamation areas for industrial purposes. This image underscores the vulnerability of this small, isolated population that inhabits shallow, nearshore waters immediately adjacent to a heavily urbanised and industrialised shoreline.

Presence alone provides a starting point for characterizing habitat preferences. Based on all available sightings and range data, the current distribution of ETS humpback dolphins extends from Long-Fung Harbour (24°41'N, 120°51'E; Miaoli County) to Jiangjyun fishing port (23°12'N, 120°05'E; Tainan County; Figure 5) (Chou, 2006; Wang *et al.*, 2007a). Sightings have been made throughout that distribution and individual minimum ranges covering more than 60% of the total population range have been documented through individual photo-identification. Additional sightings and strandings have been reported to the north and south of these boundaries (Wang *et al.*, 2004a; Wang, 2005), suggesting that the areas up to and including the coastal waters influenced by the Danshui (a.k.a. Tamsui) and Tsengwen rivers in the north and south, respectively, provide suitable habitat for humpback dolphins. This is consistent with the habitat currently used by humpback dolphins in Taiwan and elsewhere, and it is therefore inferred that these areas are part of the historic range. As such, they are potentially part of the future range of the ETS population, and could be essential for their recovery.

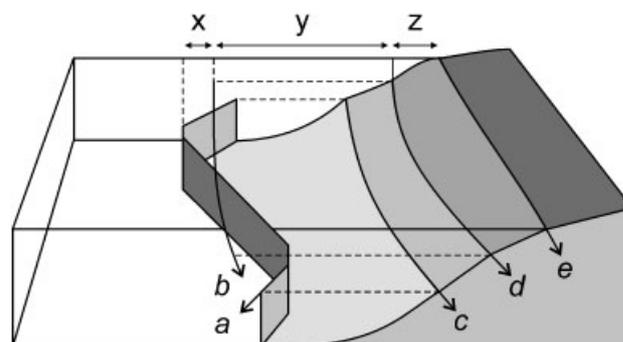
Water depth appears to be the primary factor governing the range and movements of humpback dolphins. These animals are among the most coastally inclined of all marine cetaceans, and their habit of staying in shallow, near-shore waters likely helps explain the geographic isolation of the ETS population (Wang *et al.*, 2008). Indeed, the southern boundary of what we infer to be suitable habitat off Taiwan is characterized by a change in depth contours, with much deeper water close to shore and without the marsh and mudflat features typical of areas in the central part of western Taiwan.

The best available data support an offshore habitat boundary of 30 m water depth relative to the lowest low tide of the year, or 3 km from the shoreline, whichever is farther offshore (Figure 6) (Chou, 2006; Wang *et al.*, 2007a). We define 'shoreline' as any land that is dry at the lowest high tide of the year (including sandbars, tidal flats, reclaimed land, sea walls, diversion structures and concrete block walls) (Wang *et al.*, 2007a). Also, all areas within this range that are submerged at high tide should be included in the dolphins' habitat, even if they are inshore of the 'shoreline' as defined above. Further research may improve our understanding of the habitat needs of the animals, allowing refinement of these boundaries (e.g. taking into account seasonal and diurnal differences in habitat use).

Based on sightings data, the key physical characteristics that defines habitat of ETS humpback dolphins is relatively shallow, near-shore water influenced by rivers, ranging from estuarine to marine with sandy, silty or muddy substrates. Fine-scaled bathymetric features such as channels and changing depth contours appear to be important. All of these features probably contribute in some way to foraging success for the dolphins, either by supporting the food web (e.g. enhancing primary or secondary production) or by making preferred prey easier to catch (e.g. concentrating, entraining or trapping organisms).

There are four specific reasons for considering the entire range currently occupied in the Eastern Taiwan Strait as priority habitat, quite apart from the biophysical characteristics. These are:

- (1) the very small size of the population (<100 individuals);



a = 30 m isobath (relative to the lowest low tide of the year)
 b = 3 km offshore line (measured from the shoreline)
 c = Lowest low tide of the year
 d = Shoreline (i.e. any land dry during the lowest high tide of the year)
 e = Waterline (at any given time)
 x = 3 km offshore line to 30 m isobath
 y = Shoreline to 3 km offshore line
 z = Waterline to shoreline
 x + y + z = Offshore boundary of priority habitat

Figure 6. Schematic representation of the proposed offshore boundaries of priority habitat for the Eastern Taiwan Strait population of Indo-Pacific humpback dolphins.

- (2) the smallness of the population range, which is narrow, short and linear, and may be shrinking;
- (3) the variety and intensity of anthropogenic threats facing the population; and
- (4) the lack of evidence to suggest that any portion of the range is of greater or lesser importance to the population (e.g. for feeding, reproduction, rearing of offspring or movement).

Adjacent coastal areas with physical and biological features similar to those of the current range should also be included as priority habitat, even if there are no confirmed reports of humpback dolphins in such areas. In this manner, priority habitat would be the sum total of the 'confirmed habitat' and the adjacent 'suitable habitat' (Figure 5). The geographical extent and quality of the confirmed habitat may not be sufficient to sustain or allow recovery of the population, and therefore measures to reduce threats throughout the priority habitat are urgently needed. Experience with other endangered small cetaceans (Rojas-Bracho *et al.*, 2006; Rayment *et al.*, 2009) indicates that protection measures in only part of the range can lead to ineffective management due to population fragmentation and displacement of threats from one area to another. Worse yet, the designation of small areas under varying degrees of protection may heighten the vulnerability of a wildlife population by creating a false sense of confidence in protection measures (Rayment *et al.*, 2009; Williams *et al.*, 2009).

CONCLUSIONS

This paper provides a basis for identifying and recognizing priority habitat as the entire current range of the ETS humpback dolphin population, along with adjacent coastal areas with similar physical features. Given the severity of existing anthropogenic threats to this very small population, legal protection of this priority habitat would facilitate mitigation through land- and water-use decision-making

processes. Taiwan's Wildlife Conservation Act, under which the humpback dolphin is listed as a Level One Protected Species (generally equivalent to an 'Endangered' classification in other contexts, and the highest level of legal protection in Taiwan), provides a legal framework for the delineation and management of species-specific 'important habitat' and for related designations of 'habitat refuges'. Subject to the discretion of the Council of Agriculture, environmental impact assessments and environmental enhancement plans may be required for existing facilities and human activities within 'important habitat'. The establishment of 'habitat refuges' may involve the development of conservation plans, expropriation and management of land by the state and/or specific requirements of owners or users to provide suitable habitat or to modify or eliminate activities deemed harmful to wildlife.

The types of protection measures that need to be implemented 'immediately' in priority habitat were specified in an action plan published several years ago (Wang *et al.*, 2007b). This should begin with a formal declaration of 'important habitat' by the government, which can then use that declaration to reinforce the need for transparent, rigorous reviews of proposed development projects and for appropriate mitigation. Formal recognition of priority habitat would also facilitate other measures for protection of the dolphins and the resources upon which they depend, including a prohibition on the use of gill nets and trammel nets in all waters inhabited by ETS humpback dolphins, and restrictions on vessel-based dolphin-watching tourism in favour of land-based observation platforms. Another benefit is that funding and other resources would be more readily available to support conservation and enforcement (Wang *et al.*, 2007b).

Our hope is that the rationale for, and delineation of, priority habitat for humpback dolphins as proposed here will prove useful to decision makers and planners in Taiwan as they seek to address difficult issues of reconciling the socio-economic aspirations of people with the habitat needs of the dolphins. We hasten to emphasize that any improvement in the quantity and quality of humpback dolphin habitat is bound to bring with it major, long-term benefits for humans and a host of other organisms.

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