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ENDANGERED SPECIES RESEARCH
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Impacts of fisheries on the Critically Endangered humpback dolphin *Sousa chinensis* population in the eastern Taiwan Strait

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ABSTRACT: Biological and fisheries data were analysed to assess the impact of fisheries mortality on a Critically Endangered subpopulation of <100 humpback dolphins *Sousa chinensis* in the eastern Taiwan Strait (ETS). Substantial interactions between ETS *S. chinensis* (hereafter *Sousa*) and fishing gear are known to cause dolphin mortality. In 2009, a total of 6318 motorised fishing vessels were operating from ports within *Sousa* habitats. An average of 32 fishing craft per kilometre was observed along a 200 km stretch of *Sousa* habitat. Based on a photo-identification catalogue, >30% of the ETS *Sousa* subpopulation exhibited injuries caused by fishing gear. Three individuals were photographed with fishing gear attached to their bodies, and 1 dolphin was found dead with fresh injuries caused by fishing gear. To ensure recovery of ETS *Sousa*, mortality due to human causes should be reduced to <1 individual every 7 yr. Fisheries bycatch is the most serious threat to these dolphins and needs to be eliminated as soon as possible to avoid extinction. Preventing the use of trammel nets, other gillnets and trawling throughout their habitat would be the single most effective conservation measure for ETS *Sousa* in the short term. Other fishing methods are available, and using the most selective, sustainable fishing methods available will benefit not only dolphins but also fish stocks, seabirds and other species, as well as the fishing industry, which depends on these species for its long-term viability. However, in the short term, there are costs associated with switching to more selective fishing gear.

KEY WORDS: Fisheries impacts · Eastern Taiwan Strait · Critically Endangered · Bycatch · Indo-Pacific humpback dolphins

INTRODUCTION

A narrow, shallow band of water of approximately 200 km in length along the west coast of Taiwan (Fig. 1) is home to an isolated and Critically Endangered (Reeves et al. 2008) subpopulation of <100 Indo-Pacific humpback dolphins *Sousa chinensis* (Wang et al. 2007a). Frequenting shallow inshore

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waters (<30 m deep; Wang et al. 2007a), these dolphins inhabit some of the most industrialised coastal areas in the world (Ross et al. 2010). The 23 million people of Taiwan live in an area of just over 36 000 km^2 (Taiwan Yearbook 2012 www.gio.gov.tw/taiwan-website/5-gp/yearbook/), giving an average population density of >637 people km^{-2}; 90% live in counties that border the west coast (Ross et al. 2010, Taiwan Yearbook 2012, www.gio.gov.tw/taiwan-website/5-gp/yearbook/). Dolphins relying exclusively on this nearshore environment are highly vulnerable to impacts associated with human activities.

The very small population size, coupled with a growing recognition of its vulnerability to anthropogenic threats, culminated in a 2008 listing of eastern Taiwan Strait (ETS) *Sousa chinensis* (hereafter *Sousa*) as 'Critically Endangered' by the IUCN Red List of Threatened Species (Reeves et al. 2008). This literally means that they are 'facing an extremely high risk of extinction' (IUCN 2001). Five major threats underscore the conservation imperative for these dolphins; these are discussed in more detail elsewhere (Wang et al. 2004, 2007b, Ross et al. 2010, Dungan et al. 2011). Briefly, habitat loss has taken the form of land reclamation for industrial, aquaculture and agricultural development. Industrial, urban and agricultural pollution introduces countless chemical and biological agents into coastal waters, where they may affect the dolphins directly, as well as the quantity and/or quality of dolphin prey and their habitats. Freshwater flow into the estuaries that comprise important dolphin habitat along the coast has decreased by as much as 80% (Ross et al. 2010). Noise and disturbance associated with ongoing shipping, fishing, coastal construction/development, and seismic and military activities permeate the water column. Finally, fishing nets (including gillnets, trammel nets and trawl nets) employed by an active fisheries sector threaten dolphins with injuries and mortality caused by entanglement, and may also deplete prey resources.

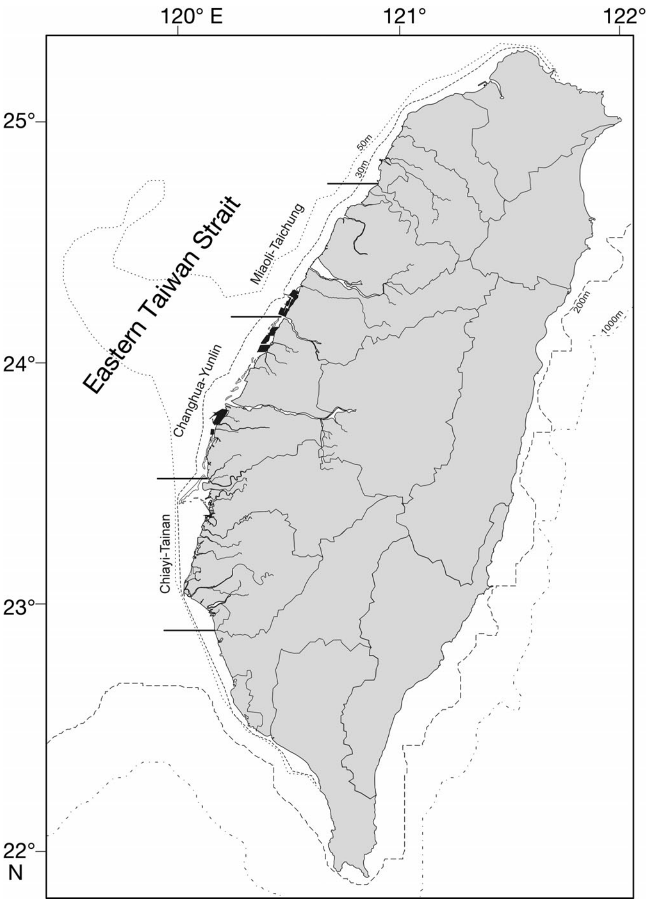

Fig. 1. Eastern Taiwan Strait (ETS) humpback dolphins *Sousa chinensis* (hereafter *Sousa*) are found in waters <30 m deep, offshore of the counties indicated on the map: Taichung in the north to Tainan in the south. Three survey areas, each comprising 2 counties, are indicated on the map

While the steady erosion of habitat quality through human activities is pervasive and complex, the threats posed by fishing activities are more evident, immediate and comparatively easier to manage. Globally, bycatch of cetaceans in fishing nets has been estimated at >300 000 individuals yr^{-1} (Burns & Wandesforde-Smith 2002, Read et al. 2006). While indirect impacts of fishing are more difficult to characterise, fishing can also affect dolphins by depleting their prey and altering the habitat upon which the dolphins and their prey rely. Reports on the Taiwan ocean fisheries sector in general, beyond the Taiwan Strait, indicate that entanglement in fishing nets causes 1000s of deaths of several species of small cetaceans (see Perrin et al. 2005, Chou 2006).

The direct link between fishing activities and dolphin bycatch provides decision-makers with clear management options that will contribute to the recovery of the Critically Endangered ETS *Sousa*. We conducted a review of fishing practices in Taiwan to evaluate the implications for these dolphins, many of which have scars indicative of net-related injuries.

DIRECT EFFECTS OF FISHING

Risks from different fishing techniques

We reviewed humpback dolphin bycatch internationally and found that incidental catches in fishing gear have been documented virtually everywhere humpback dolphins have been studied (e.g. Harwood & Hembree 1987, Parsons & Jefferson 2000, Baldwin et al. 2004, Jefferson & Hung 2004, Van Waerebeek et al. 2004, Kiszka et al. 2008, Jaaman et al. 2009). The primary types of gear involved are gill or trammel nets (both set and drifting) and trawls, although several other fishing techniques have also been suggested to cause mortality (Fig. 2).

Gillnets (including trammel nets) pose the highest risk in terms of humpback dolphin entanglement. A standard gillnet consists of a single layer of netting, usually made of monofilament (sometimes multifilament) nylon line. Target fish are caught after they swim through the mesh of the net and become snared by the gill covers when they try to back out of the net. Gillnets also catch many other animals, including larger fish, dolphins and whales.

Trammel nets are made of multiple (usually 3) layers of monofilament netting, with the intention of entangling organisms rather than catching them by the gill covers. Two layers of netting on either side of the middle layer are usually of a larger mesh size and looser than the middle layer. The greater 'slack' in trammel nets increases their ability to entangle fish and other animals. However, many simple gillnets used in Taiwan are also relatively loosely hung and act more like an entangling net (i.e. similar to a trammel net). Both gillnets and trammel nets can be secured to the seafloor with anchors or weights and are then often called set gillnets, bottom-set gillnets, or setnets. Alternatively, they can be left drifting near the water surface and are then called drifting gillnets or driftnets.

Gillnets and trammel nets affect virtually every group of marine mammals, with some types of dolphins and porpoises being particularly vulnerable (Jefferson & Curry 1994, Young & Iudicello 2007). They are responsible for the majority of marine mammal fishery mortality in the USA (Read et al. 2006) and probably worldwide. Major bycatch issues have been documented for humpback dolphins in anti-shark gillnets deployed in South Africa and Australia to protect bathers (Bannister 1977, Cockroft 1990, Cockroft & Krohn 1994, Gribble et al. 1998), and, at least in South Africa, these have endangered local dolphin populations (Cockroft 1990).

Trawl nets are considered a medium risk. Although trawls affect a large number of different species of marine mammals, they generally have a lower level of impact than gillnets (see Fertl & Leatherwood 1997). However, in certain situations they can be a major problem. For instance, most of the mortality and injuries associated with net entanglement in Hong Kong, where humpback dolphins have been extensively studied, are thought to be related to trawlers (Jefferson 2000, Jefferson et al. 2006). In Hong Kong waters, dolphins follow trawlers to feed on discarded fish bycatch (Jefferson 2000), but, in some other areas, including Taiwan, such trawler associations (and thus entanglement) have not been observed to date. However, there is 1 anecdotal report of an ETS *Sousa* caught in a trawl net.

Longlines and other hook-and-line methods are considered the lowest risk for ETS *Sousa*. In general, these fishing techniques only have significant impacts on populations of species that are known to actively remove fish and/or bait from the hooks, such as sperm whales *Physeter macrocephalus*, killer whales *Orcinus orca*, pilot whales *Globicephala* spp. and false killer whales *Pseudorca crassidens* (Gilman et al. 2006, Garrison 2007, Forney et al. 2011). There is currently no evidence that humpback dolphins do this, and, in any case, longlines are most often used in waters deeper than the most typical depth range in which humpback dolphins are found.

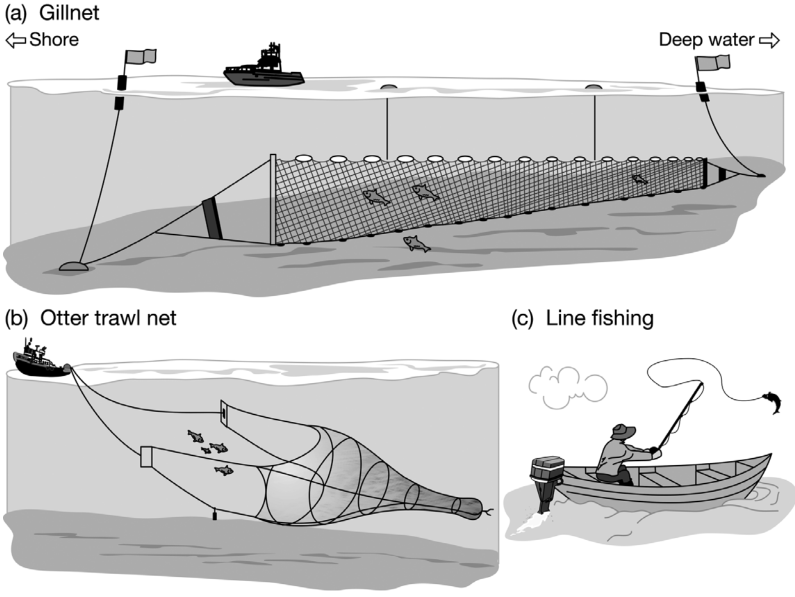

Fig. 2. Fishing gear types and their risk level in terms of dolphin entanglement. (a) High risk: trammel nets (not shown) and gillnets; (b) medium risk: trawling; (c) low risk: hook-and-line/pole fishing; figures redrawn from Nedelec & Prado (1990)

Finally, there is no evidence that purse seines, which have major impacts on some populations of oceanic dolphins, are a serious problem for humpback dolphin populations. Large-scale purse seines are not known to operate in inshore waters along western Taiwan. Aquaculture activities may be problematic for humpback dolphin populations in some areas, both through entanglement in lines and nets and in terms of habitat loss and pollution. This needs to be investigated further.

Scant information is available on cetacean bycatch in Taiwanese waters, but 1 report based on surveys of fishers estimated that 560 cetaceans are captured annually from the eastern fishing port of Shihti Harbour and 2210 from Chengkung Harbour (Chou 2006), so just for these 2 ports, the total cetacean catch was estimated to be almost 2800 cetaceans yr^{-1}. Estimates for the western coastal region (where ETS *Sousa* is found) are unavailable, but given the similar approach to fisheries management and conservation by the local fisheries authorities cetacean bycatch along western Taiwan is concerning.

Overlap between *Sousa chinensis* and fisheries

There is considerable overlap between ETS *Sousa* habitat and the use of types of fishing gear known to cause dolphin mortality, including gillnets and trammel nets (Ross et al. 2010, Dungan et al. 2011). Trammel nets are by far the most prevalent kind of entangling net used in the inshore waters along western Taiwan, while single-mesh gillnets are used less frequently.

Fishers using gill and trammel type nets in the waters along western Taiwan number in the 1000s and are found in almost every fishing port along western Taiwan (see Tables 1 & 2). Most of these fishers operate from small rafts made of polyvinyl chloride (PVC) pipes. However, larger vessels up to at least 'CT3' boats (20 to 50 t) have also been seen setting trammel nets in inshore waters.

Trawl fisheries also pose threats to dolphins. There is at least 1 report of a humpback dolphin that was killed by a trawler fishing along western Taiwan, and trawl nets are known to kill this species elsewhere (e.g. Jefferson 2000, Jefferson et al. 2006). Various types of trawls are used within the habitat of ETS *Sousa*, including pair trawls, otter trawls, larval fish ('bulah') trawls and beam trawls.

Set traps are also known to capture coastal small cetaceans, including harbour porpoises *Phocoena phocoena* in the Bay of Fundy (Smith et al. 1983), while stow nets have captured dolphins and finless porpoises in mainland Chinese waters (Zhou & Wang 1994, Yang et al. 1999, 2000). The only known set trap found in the priority habitat of ETS *Sousa* (see Ross et al. 2010) was in Hsinchu County. Other species of dolphin have been reported caught in this trap, and therefore such traps also pose a threat to ETS *Sousa*.

Finally, non-net fisheries are also found throughout the distribution of ETS *Sousa* and may pose additional threats. Many fishers use hook-and-line methods, which are less harmful to dolphins and other marine life, including fish stocks. However, more effort is needed to encourage proper, onshore disposal of fishing-related trash (used lines, hooks, plastic packaging, etc.). Fishing lines (especially the new, low diameter, low-stretch braided, or fusion lines) left discarded in the water can entangle dolphins and other marine life, resulting in severe injuries and death (e.g. Barco et al. 2010). Lines and trash can also accumulate on structures within aquaculture beds, increasing the risk of injury associated with such facilities.

Data sources

We analysed 2 sources of information on fishing effort within ETS *Sousa* habitat: (1) data collected by researchers from the *FormosaCetus* Research and Conservation Group and (2) data available from the Taiwan Fisheries Statistical Yearbook (Fisheries Agency 2010).

First, fisheries data from the *FormosaCetus* Research and Conservation Group, collected from 2007 to 2010 as part of its cetacean survey protocol, were collated and analysed. In addition to recording dolphin sightings and other standard survey information (e.g. weather conditions), all fishing vessels and gear within approximately 1 km of the survey boat were recorded, including floats and markers attached to set fishing nets. We assumed that fishing floats with flags (high flyers) marked trammel nets and that a single trammel net would be represented by 2 high flyers.

The surveyed area was partitioned into 3 blocks (comprising waters of 2 counties each; Fig. 1). An estimated 0.013 trammel nets were seen per kilometre of survey effort in the northern block (waters of Miaoli & Taichung counties), and 0.056 in the central block (waters of Changhua & Yunlin counties) (Table 1). No data on fishing activity were available for the southern block (Chiayi & Tainan counties). These levels of

Table 1. Data from boat surveys for *Sousa chinensis* (*Sousa*) and fishing gear off western Taiwan, carried out by *FormosaCetus* Research and Conservation Group from 2007 to 2010. Data on high flyers were not collected systematically during the surveys in Chiayi and Tainan counties (NA: not available). Survey effort refers to the length of the survey transects. The number of sightings and number of eastern Taiwan Strait (ETS) *Sousa* include multiple resightings of individuals during the 4 yr period

Counties	Survey effort (km)	No. of sightings	Sightings (km^{-1})	Total no. of ETS *Sousa*	ETS *Sousa* km^{-1}	Total no. of high flyers	High flyers km^{-1}	Trammel nets km^{-1}
Miaoli & Taichung	1875	42	0.022	225	0.120	50	0.027	0.013
Changhua & Yunlin	4136	85	0.021	693	0.168	463	0.112	0.056
Chiayi & Tainan	70	3	0.043	9	0.129	NA	NA	NA
All	6081	130	0.021	927	0.152	513	0.084	0.042

fishing effort were similar to, or greater than, those observed in other parts of the world where bycatch has caused population declines in cetacean populations (e.g. Hector's dolphin *Cephalorhynchus hectori*; Slooten et al. 2000, Slooten & Dawson 2010, Slooten & Davies 2012; harbour porpoise *Phocoena phocoena* in California, USA; Forney et al. 2001). Insufficient data from Taiwan were available on trawlers and other fisheries for similar analyses to be meaningful.

Table 2. Total number of motorised fishing craft capable of gillnet/trammel net fishing based in the major harbours of the 6 counties adjacent to *Sousa chinensis* habitat (Fisheries Agency 2010)

County	Trawlers	Gillnetters	Rafts	Sampans	Total
Miaoli	1	19	592	88	700
Taichung	40	125	669	103	937
Changhua	1	123	313	139	576
Yunlin	0	22	1557	47	1626
Chiayi	1	53	1485	117	1656
Tainan	4	114	555	150	823
Totals	47	456	5171	644	6318

Secondly, data gathered by Taiwan's Fisheries Agency (2010) showed that a total of 6318 motorised fishing vessels, including sampans, rafts and other motorised fishing craft, operated from ports in the 6 coastal counties included in the dolphins' habitat in 2009. All of these vessels are capable of deploying gill and/or trammel nets that can kill or injure dolphins (Table 2, Fig. 3), and 45% are described as engaging in 'coastal' fishing within 12 nautical miles (n miles) from shore. Within the 200 km from northern Miaoli to southern Tainan (*Sousa* habitat), the number of fishing craft capable of using gillnets averaged 32 km^{-1}.

It is clear from the data on the number of fishing vessels and number of gillnets and trammel nets per kilometre that there is a very high risk of fisheries mortality for ETS *Sousa*, especially given the very small size of the population, its restricted distribution and its limited ability to withstand human impacts (see 'Consequences of fisheries mortality for conservation'). More detailed and accurate fishing effort data, in particular regarding fishing effort with gillnets, trammel nets and trawling, in *Sousa* habitat are urgently needed, to inform and guide conservation and management efforts

Fig. 3. Trammel nets and eastern Taiwan Strait *Sousa*, clearly showing the high flyer flags used on floats attached to trammel nets. Note the piece of fishing gear (rope) attached to the dolphin in the lower panel. Photographs by J. Y. Wang, *FormosaCetus* Research and Conservation Group

in Taiwan. Additional data would help to refine solutions to the problem. However, the currently available data clearly indicate that bycatch of ETS *Sousa* is a serious threat to this small population (see 'Consequences of fisheries mortality for conservation'), and protection of this species needs to be improved immediately to avoid its extinction.

Direct evidence of entanglement

Fisheries have been known to lead to serious injury or mortality in many marine mammal species worldwide (Angliss & DeMaster 1998, Read & Murray 2000, Andersen et al. 2008, Wells et al. 2008, Thiele 2010). To characterise the risk of entanglement to the ETS *Sousa* population, we used data from a photo-identification project that has been ongoing since 2002. Surveys were carried out in the coastal waters of western Taiwan, mainly in the summer months (April to August) with 3 winter surveys conducted over 4 mo in 2008/2009 (Wang et al. 2007a, 2012, Wang & Yang 2011). We examined photographs from this study for evidence of fisheries-related injuries. Only scars and disfigurements that are most likely due to interactions with fisheries, such as those from fishing lines or nets, were included in this examination (Fig. 4). Injuries sustained from blunt force trauma, vessel propellers, or uncertain causes were not included as they may have been due to non-fishing vessels. Where photographic evidence made it possible, we examined the entire body of individual dolphins over a number of years. Images were classified in a manner similar to that used by Thiele (2010), although our categories were developed to focus more on fisheries-related injuries: (1) no markings indicative of human interaction, (2) markings of clear anthropogenic origin and (3) distinctive markings from line and net entanglements. We examined photographs for markings considered diagnostic of net injuries as described by Angliss & DeMaster (1998).

Gillnet injuries are often associated with long, linear lacerations, but can also be identified by marks on the leading edges of flukes, pectoral fins and/or dorsal fins; gillnet marks on the body (such as those found on the beak of a freshly dead ETS *Sousa* that stranded on 25 September 2009); and deep grooves in the caudal peduncle and the loss of whole or partial appendages (e.g. tail, dorsal fin, pectoral fin; Fig. 4). Similar injuries, such as cleanly amputated appendages, can also be attributed to interactions with other types of gear, such as fishing line (Kuiken 1996).

Markings consistent with constrictive line wraps around the body were categorised as fisheries-related injuries (Wells et al. 2008). One individual was photographed in 2008 with constrictive fishing gear wrapped around its torso, but has since shed the gear and appears to be in good physical condi-

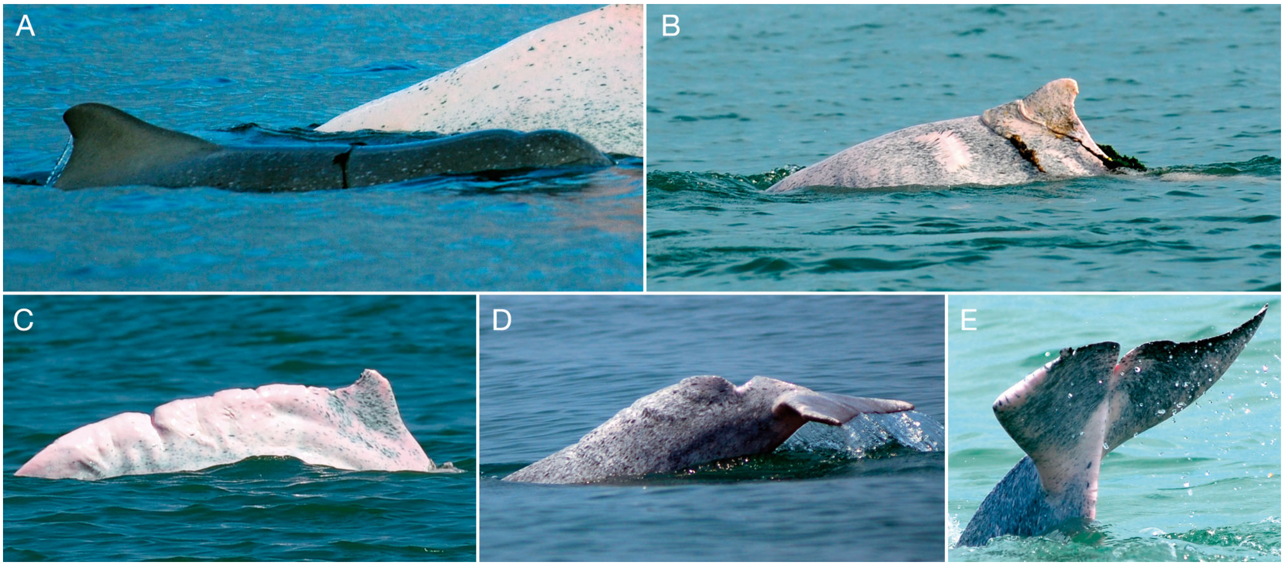

Fig. 4. *Sousa chinensis*. (A,B) Eastern Taiwan Strait *Sousa* entangled in fishing gear or (C,D,E) bearing injuries caused by fishing gear entanglement. These include adults (B,C), an individual between 2 and 4 yr old (A) and individuals of intermediate age (D,E). One individual (E) has lost half of the left lobe of the tail fluke. In all cases, the fishing gear appears to be monofilament line, likely from trammel nets or gillnets. Photographs by J. Y. Wang, *FormosaCetus* Research and Conservation Group

tion (see Fig. 3 in Ross et al. 2010). Our results indicate that of 93 individuals identified since 2002, 1 died as a result of net entanglement and 49 (52.7%) exhibited evidence of human-caused injury. We carefully examined these injuries and concluded that over half (59.2%) originated from fisheries interactions, with 29 of the 93 (31.2%) identifiable individuals having fisheries-related wounds. Photographs of the entire body were not available for all individuals, so fisheries-related injuries are likely under-represented in our analysis. Furthermore, identification of all individuals in every year was not feasible, and any injuries sustained in a year without available photographs would have gone undetected.

The strongly human-modified nature of the west coast of Taiwan (e.g. concrete seawalls and breakwaters) reduces the likelihood of a dead dolphin stranding. Therefore, non-lethal fisheries injuries are more likely to be detected, while the proportion of fisheries interactions that results in mortality is likely to be underestimated. In addition, external morphology does not allow us to characterise the proportion of individuals that may have ingested fishing gear, which can also lead to death (Wells et al. 2008). Therefore, our analysis provides a conservative risk assessment with respect to fisheries-related injuries for ETS *Sousa*. Given the high percentage of identified dolphins with fisheries-related injuries, it is clear that the risk of entanglement in fishing gear is high for these small coastal dolphins. The stranded individual from 25 September 2009 (TW-03) was the only fresh specimen of 3 confirmed *Sousa* stranding events between August 2000 and September 2009 along western Taiwan that could be examined for fishery-related injuries, and this individual exhibited clear signs of gillnet entanglement. In 2012, 2 more dolphins were observed with constrictive fishing gear wrapped around their torsos, and 2 lines that were slowly slicing into the dorsal fin at 2 different locations (both had been seen without fishing gear the previous year) (Fig. 4).

INDIRECT EFFECTS OF FISHING

Aside from direct contact between dolphins and fishing gear, fishing activity in dolphin habitat may have indirect effects on the health of individuals and populations. These effects include: depletion of prey resources, pollution, noise disturbance, altered behavioural responses to prey aggregation in fishing gear and potential changes to social structure arising from the deaths of individuals caused by fisheries activity.

Depletion of prey resources

In recent years, individual ETS *Sousa* have been observed in poor body condition (emaciated; Fig. 5), indicating that nutritional stress and/or subsequent disease may be a problem. In some other marine mammal species, poor body condition has been linked to reduced prey availability or quality (Lockyer 1986, Read 1990, Haug et al. 2002), and, in some cases, this has been linked to fishing activity (e.g. Steller sea lions *Eumetopias jubatus*; Trites & Donnelly 2003, Hennen 2006).

Fisheries can deplete prey resources directly by removing prey species from the habitat. For example, in the eastern Ionian Sea, the rapid decline of short-beaked common dolphins *Delphinus delphis* has been caused in major part by resource overlap between dolphins and purse-seine fisheries (Bearzi et al. 2006, 2008). Fisheries on the Taiwanese west coast are unlikely to target dolphin prey species directly, because these species (e.g. *Johnius* spp. [Barros et al. 2004] and clupeids) are too small, low in abundance and of little commercial value. However, most non-target fish caught by gillnets and trawlers are retained and sold in markets or used for producing fish-meal for aquaculture feed. These prey resources may also be shared with other predatory fish. Over-exploitation of smaller species can thus put stress on multiple predator populations and reduce the catch rates of fisheries that target larger, more commercially valuable species. For example, in the eastern Ionian Sea, over-fishing of small species, including sardines and anchovies, by purse-seiners has likely contributed to the decline in encounter and catch-rates of tuna and swordfish (Bearzi et al. 2006).

Better enforcement of the existing 3 n mile trawling ban in the inshore waters off western Taiwan would help to reduce fishing impacts on ETS *Sousa* and the fish populations with which they share their habitat. However, this would not be sufficient by itself to reduce fisheries impacts on the dolphins to sustainable levels. Over-fishing has caused the alteration or collapse of coastal ecosystems in several parts of the world (Jackson et al. 2001, Pauly et al. 2002, Tillin et al. 2006, Shephard et al. 2010). Strictly managing fisheries so that they are sustainable for all species caught can help restore ecosystems to pre-exploitation levels of productivity (Pitcher 2001) and, in Taiwan's case, would benefit both dolphins and fisheries in the long term.

Pollution in the fisheries sector

Pollution caused by fisheries may also indirectly affect dolphin populations by reducing habitat quality and creating health risks. Discarded or lost fishing gear, which persists for a long time in the marine environment and can travel over long distances, poses a significant hazard that can injure or kill marine mammals within and outside of active fishing areas (Kaiser et al. 1996). Pollutants released into the marine environment during fishing activities (e.g. oil discharge, trash, boat exhaust, discarded near-empty paint cans) also contribute to the contaminant load within the food-web. Anti-fouling paints are also a concern, given the high level of butyltins found in the Indo-Pacific humpback dolphin population of the

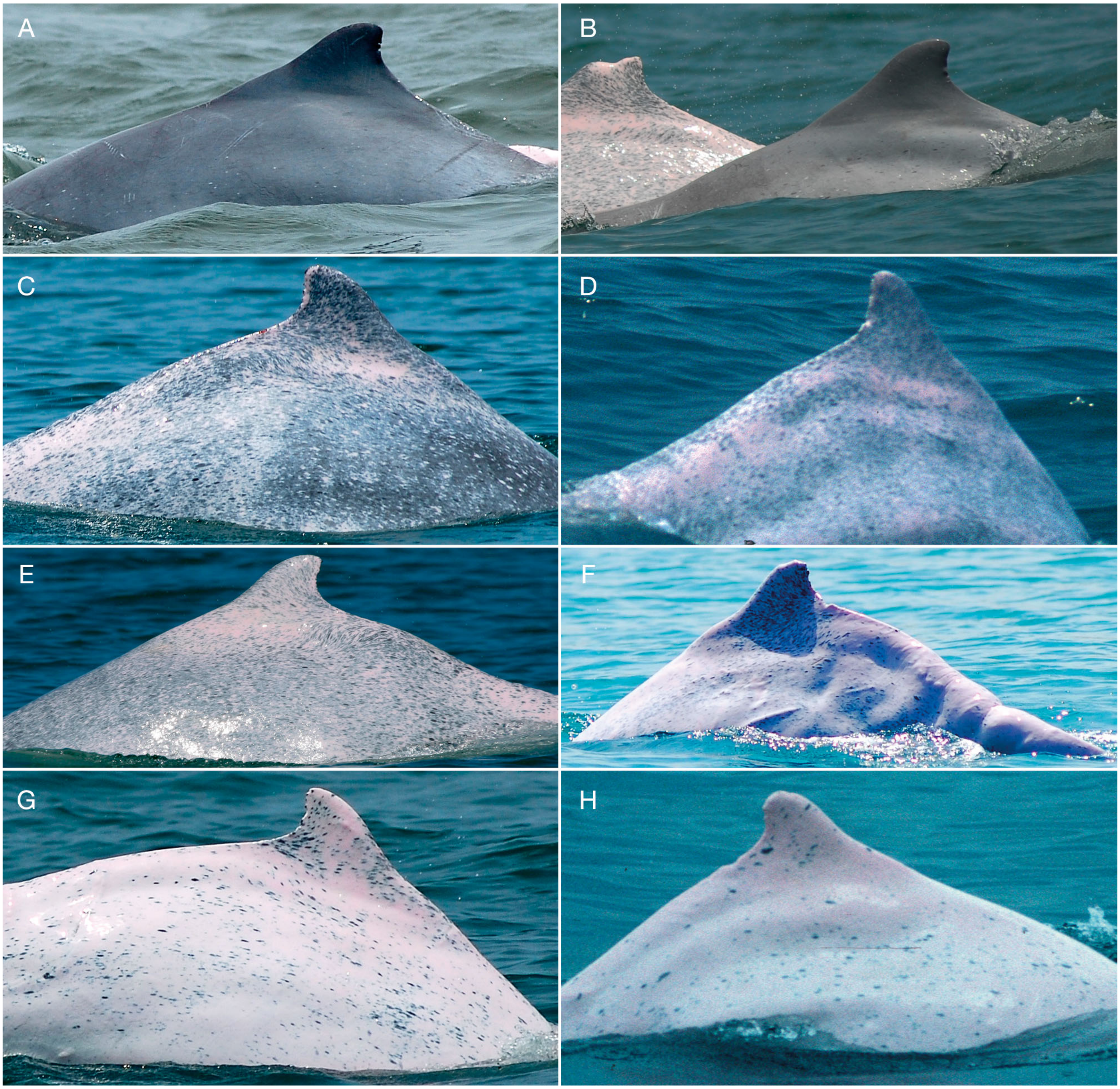

Fig. 5. *Sousa chinensis*. Eastern Taiwan Strait *Sousa* in (A,C,E,G) good and (B,D,F,H) poor body condition for different pigmentation (and likely relative age) classes. Photographs by J. Y. Wang, *FormosaCetus* Research and Conservation Group (A,B,C,F,G,H) and S. C. Yang, *FormosaCetus* Research and Conservation Group (D,E)

Pearl River Estuary (PRE) (Lawler & Aldrich 1987, Takahashi et al. 2000).

Bottom-trawling and other disturbances of the seafloor (e.g. by bottom-set nets) can re-suspend the upper layers of sediment, re-mobilising previously settled contaminants in the process (Kaiser et al. 2001). Some of these contaminants can accumulate in the tissues of fish and other marine species, reaching very high concentrations in top predators, such as cetaceans (Ross et al. 2000), and in some humans (Corsolini et al. 2005). In the case of persistent organic pollutants, including PCBs, such bioaccumulation in marine mammals can alter normal growth and development, cause cancer, reduce immune function and affect reproductive health (DeLong et al. 1973, Helle et al. 1976, Reijnders 1986, Mortensen et al. 1992, Ross et al. 1996, Ylitalo et al. 2005). There is very little information on contaminant levels in ETS *Sousa*, but high levels of persistent organic pollutants in PRE *Sousa* are considered as risks to their health (Minh et al. 1999, Parsons 2004, Leung et al. 2005, Jefferson et al. 2006). High rates of neonatal mortality in the PRE *Sousa* may be caused by exposure of breeding females to environmental contaminants (Jefferson et al. 2012).

Behavioural responses to prey aggregation

Some fishing activities have the potential to attract dolphins due to the aggregation of prey in fishing nets (e.g. gillnets, trammel nets and trawl nets). This has been documented, for example, for Hector's dolphins (Rayment & Webster 2009) and PRE *Sousa*, which are known to follow trawlers in unusually large groups (Jefferson 2000). Mothers with calves may be particularly drawn to fishing operations because they have higher energetic demands, putting them and especially their calves at greater risk of entanglement (Fertl & Leatherwood 1997). A disproportionate preference by mothers for feeding in association with pair trawlers is suspected for PRE *Sousa* (Jefferson 2000, Hung 2008). Females with calves tend to prefer areas of high prey density (e.g. Weir et al. 2008), which can result in greater overlap of habitat use by fisheries and mother–calf groups than other individuals. Over the long term, behavioural habituation to feeding in association with fishing activities can result in permanent social structure changes because calves learn foraging behaviours from their mothers (e.g. Shane et al. 1986). For example, in Moreton Bay, Australia, Chilvers & Corkeron (2001) described 2 sympatric bottlenose dolphin social units; one had a preference for feeding in association with trawlers, making it more exposed to harmful fisheries interaction than the other. The authors suggested that the 2 social units might have formed in response to trawling activity.

General behavioural consequences arising from individual deaths

The death of a single individual may have a disproportionate impact on a population because of the differing social roles among individuals. Cetaceans, and especially delphinids, often have a highly complex social structure (e.g. Connor et al. 1998). Specific individuals or classes of individuals (e.g. juvenile female killer whales; Williams & Lusseau 2006) may have disproportionately important roles in foraging, rearing of offspring and the transmission of functionally important behaviours within and between generations (Whitehead et al. 2004). For example, foraging efficiency of bottlenose dolphins in Doubtful Sound, New Zealand, depends on the knowledge possessed by a few key individuals (Lusseau & Conradt 2009). The removal of such individuals from their social network would reduce the speed of information transfer through the population (Lusseau 2003), potentially diminishing the population's ability to rapidly adapt to changing environments (Rendell & Whitehead 2001).

Specific individuals can also act as repositories of socially learned, functionally important survival or reproduction-related information. Among mammals with complex social structures, including cetaceans, this role has been particularly emphasised for matriarchs (Boran & Heimlich 1999, Yurk et al. 2002). Killer whale calves without adequate training by experienced mothers were less proficient when foraging and had lower catch-rates than calves that received more maternal training (Guinet & Bouvier 1995).

Matrilineal social structure has not been conclusively demonstrated for humpback dolphins, but post-reproductive female longevity (a hallmark of matrilineal societies; McAuliffe & Whitehead 2005) is suspected in both the PRE (Jefferson et al. 2012) and ETS populations (Dungan 2011). Breeding females appear to have important social network positions in ETS *Sousa*. As such, the loss of 1 breeding female from the ETS population to fisheries could be important, not only from a purely demographic perspective, but could also reduce the survival or reproductive success of other individuals. For example, in another delphinid species post-reproductive females have been shown to substantially improve the survival of their offspring, even many years after birth (Foster et al. 2012).

CONSEQUENCES OF FISHERIES MORTALITY FOR CONSERVATION

Like other small cetaceans, *Sousa* is a long-lived animal with a slow reproductive rate. Maximum population growth rates for dolphins are on the order of 2 to 4 % yr^{-1} (e.g. Perrin & Reilly 1984). This means that even a low level of fisheries mortality poses a serious risk to the small ETS *Sousa* population. We used a standard, internationally recognised assessment method (potential biological removal or PBR; Wade 1998, Taylor et al. 2000) to evaluate the sustainability of human impacts on the ETS *Sousa* population. PBR is an estimate of the maximum number of individuals, not including natural mortality, that may be removed while allowing the population to recover toward or maintain its optimum sustainable population size. The calculation of PBR explicitly takes into account the population's status and uncertainty in the available data.

Accurate knowledge of population structure is crucial for the PBR method, and most other methods of assessing sustainable levels of human impact (e.g. Wade 1998, Wang 2009). For example, under the US Marine Mammal Protection Act, it is recognised that the first step in managing marine mammal populations is to correctly identify the appropriate unit to conserve, or 'stock' (Taylor 1997) — either a demographically isolated population or a portion of the species' range where impacts (e.g. bycatch) are concentrated (NMFS 2005). Demographic isolation results when a group's population dynamics are more strongly determined by births and deaths within the group than by immigration or emigration. In such a case, immigration would not be sufficient to prevent a population from potentially declining in the face of anthropogenic impacts, and the group of animals should be considered a separate stock for management purposes. Many types of information can be used to identify stocks of a species: distribution gaps; movement patterns of individual animals; morphological differences including colouration, size, or shape; differences in life history or genetic markers; population trends; patterns of contaminant, parasite and natural isotope loads; and habitat differences (see Wang 2009).

Impacts of fisheries mortality and other human activities must be addressed with respect to the size of the population in the coastal waters of Taiwan. A preliminary study comparing mtDNA of 1 ETS *Sousa* with a small number of individuals from other populations failed to find evidence for genetic differences between ETS *Sousa* and other *Sousa* populations (see Chou 2006). Of course, a lack of evidence for genetic distinctiveness does not mean evidence for 1 panmictic population. Reasons for failing to detect population differences include inadequate sample size and therefore statistical power, inappropriate choice of marker(s) and insufficient time since divergence to allow differences to develop (see Taylor & Dizon 1999, Reeves et al. 2004, Wang 2009, Taylor et al. 2010). However, there is ample other evidence that ETS *Sousa* represents a demographically isolated population, including its limited and discrete geographic range, lack of movements of individuals to other areas inhabited by *Sousa*, a marked habitat discontinuity between shallow coastal water areas of western Taiwan and coastal mainland China and phenotypic differences. Colouration has been used as an important phenotypic character in cetacean taxonomy (Perrin 2009). The pigmentation of ETS *Sousa* is markedly different from *Sousa* inhabiting the shallow coastal and estuarine-influenced waters of mainland China (Wang et al. 2008), indicating genetic and demographic isolation.

Photo-identification studies have not documented any movement of individuals among 3 locations, despite substantial catalogues (~35 ETS, ~400 PRE and ~10 JRE [Jiulong River Estuary] individuals; Wang et al. 2008) that were systematically compared to identify matches. The ETS and PRE catalogues have since grown to >90 and 700 individuals, respectively, yet still there are no individuals that are common to both locations. The species has not been reported in waters deeper than about 30 m (Jefferson & Karczmarski 2001), while the depth of the main body of the Taiwan Strait is mostly >50 m (up to 70 m) and appears to be an effective oceanographic barrier against movement of the species across the strait. There is also direct evidence for year-round residency of ETS *Sousa* in the waters off western Taiwan, with no indication of seasonal changes in distribution (Wang & Yang 2011). Thus, multiple lines of evidence indicate that ETS *Sousa* represents a distinct and demographically isolated population, and it is recognised as a distinct, critically endangered, subpopulation in the IUCN Red List (Reeves et al. 2008).

Having determined that it is appropriate to calculate a PBR for the ETS *Sousa* population, we used the following standard formula (Wade 1998):

PBR = $N_{\text{min}} \times ½\ R_{\text{max}} \times F_{\text{r}}$ where N_{min} is the minimum population size (the 20th percentile of a statistically based population estimate or an actual count of distinct individuals), R_{max} is the maximum net population growth rate, and F_{r} is a recovery factor that allocates part of the population's growth to recovery and/or allows for uncertainty in population status. The assessment method provides default values of R_{max} based on taxonomic grouping (e.g. cetaceans, pinnipeds) when estimates are not available. Further, guidelines have been established for setting recovery factors based on population status, trends and designation as threatened or endangered (Taylor et al. 2000).

Two population estimates are available for ETS *Sousa*. A 2002 to 2004 line-transect survey resulted in a population estimate of 99 individuals (CV = 0.516; Wang et al. 2007a) and an N_{min} of 66 individuals. A recent mark-recapture study resulted in an estimate of 74 individuals (CV = 0.04; Wang et al. 2012), with an N_{min} of 71. No estimate of the maximum annual population growth rate is available for ETS *Sousa*. Therefore, we used the cetacean default value of 0.04. Given the Critically Endangered status of this population, the recovery factor F_{r} is 0.1 (Wade 1998, Slooten & Dawson 2008). Using the 2 abundance estimates, this resulted in a PBR of 0.13 or 0.14 ind. yr^{-1}, or no more than 1 human-caused dolphin death every 7 to 7.6 yr. If we assumed the population status was unknown, rather than Critically Endangered, the recovery factor of 0.5 would result in a PBR of 0.66 or 0.71 ind. yr^{-1} (i.e. still <1 dolphin yr^{-1}). Thus, our conclusion that a human-caused mortality of even 1 dolphin yr^{-1} would pose a serious threat to this population was not sensitive to assumptions about the population's threat status, the recovery factor (i.e. 0.1 or 0.5), or the population estimate used.

Importantly, the PBR model properly includes all non-natural mortality caused by fishing, pollution, ship strikes, habitat destruction and other human activities. Given the overlap between ETS *Sousa* and extremely high levels of fishing effort with gear and methods known to catch and kill dolphins wherever they are used worldwide (Perrin et al. 1994, Read et al. 2006) and the high levels of other risk factors in the Taiwan Strait, the total level of human-caused mortality almost certainly exceeds the calculated PBR. Given that a single dolphin death per year exceeds the PBR by a factor of up to 7, it is essential that all bycatch be eliminated. This is a particularly serious concern because 1 individual was documented to have been killed in fishing gear in 2009 (TW-03), despite the lack of a systematic bycatch monitoring program.

EFFECTIVE SOLUTIONS

The information reported above makes it clear that there is substantial overlap in range between ETS *Sousa* and the use of several kinds of fishing gear known to cause mortality in *Sousa* and other dolphin species. It is clear that bycatch in coastal fisheries, even in the absence of any other human-caused mortality, is a major threat to this population. Applying management, regulation and enforcement strategies to reduce the impact of fisheries on ETS *Sousa* also represents a constructive and practical means of recovering the population, since many of the other threats are much more difficult to study, quantify and/or manage.

To reduce the extremely high extinction risk for ETS *Sousa* it is important to eliminate fisheries mortality as soon as possible. Based on our extensive review of the international experience, the following measures can be considered effective for eliminating bycatch of ETS *Sousa* in fishing gear:

(1) Implement effective fishing regulations to prevent the use of trammel nets, gillnets and trawling throughout ETS *Sousa* habitat.

(2) Strictly enforce existing regulations that prohibit the use of trawlers within 3 n miles from shore, as well as all new regulations implemented in (1).

We also evaluated several other mitigation measures that have been attempted elsewhere, but unanimously concluded that the following measures would not be effective for ETS *Sousa*:

(i) Acoustic devices (pingers). These may alert cetaceans to the presence of a fishing net. The devices can reduce bycatch for some species, but they do not eliminate bycatch as will be required for ETS *Sousa* (e.g. Cox et al. 2001, 2003, 2007, Dawson et al. 1998, 2013). Further, pingers can displace or exclude small cetaceans from important portions of their habitat (e.g. important feeding areas) and therefore could cause further harm to ETS *Sousa*. If dolphins habituate to their presence, pingers may act to attract dolphins to nets (especially if the dolphins are removing fish from nets or feeding on scavengers around the nets), increasing rather than decreasing the risk of entanglement (e.g. Cox et al. 2001, 2004, 2007, Dawson et al. 1998, 2013). These concerns are particularly serious where fishing effort is substantial, as in the habitat of ETS *Sousa.*

(ii) Gillnet modification (e.g. metal oxide with barium sulphate). This has been tested with several species and has not been shown to eliminate bycatch in any cetacean population (e.g. Trippel et al. 2003, Larsen et al. 2007).

(iii) Seasonal area closures. There is insufficient knowledge about fisheries dynamics and patterns of seasonal *Sousa* bycatch and habitat use to ensure the survival of this population by applying this type of measure. The lack of obvious seasonal patterns in ETS *Sousa* distribution or abundance (e.g. Wang & Yang 2011) indicates that such closures would not be effective. Experience with other endangered dolphins shows that effective conservation and population recovery requires year-round protection within the entire area occupied by the population of concern (e.g. Rojas-Bracho et al. 2006, Slooten & Dawson 2010, Gerrodette & Rojas-Bracho 2011, Gormley et al. 2012).

Preventing the use of trammel nets, gillnets and trawling throughout their habitat would substantially reduce human impacts on ETS *Sousa*. This is likely to be the single most effective conservation measure that could be implemented for ETS *Sousa* in the short term. It is certainly important to resolve other impacts, including pollution and habitat degradation, but most of these will require intensive efforts over a long period. By contrast, bycatch of dolphins in fisheries can readily be avoided by using more selective fishing methods (e.g. selective fish traps or hook and line fisheries; see Werner et al. 2006 for a review). Impacts from fishing could be eliminated very quickly, as there are no technical or other practical obstacles to doing so. Other fishing methods are available, and using the most selective, sustainable fishing methods available will benefit not only ETS *Sousa* but also fish stocks, seabirds and other species, as well as the fishing industry that depends on these species for its long-term viability.

Need for specific targets and timelines

Given that fisheries entanglement as low as 1 dolphin yr^{-1} would pose a serious risk to ETS *Sousa*, timely action is critical. Regulations to prevent the use of trammel nets, gillnets and trawling need to be implemented immediately, effectively and throughout the full range of ETS *Sousa* habitat in order to reduce the extremely high risk of extinction.

In this context, the Taiwan Fisheries Agency has an opportunity to lead the recovery of ETS *Sousa* by immediately developing specific targets and dates for eliminating fisheries impacts on ETS *Sousa.*

COSTS AND BENEFITS OF CHANGING FISHING GEARS

There will be a short-term cost associated with changing to more selective, sustainable fishing methods. However, we emphasise that long-term solutions that benefit dolphins will also benefit fishers by making nearshore fisheries more sustainable. Long-term fish catches are likely to increase following a shift to using more selective and sustainable fishing methods. More high-valued fish species are also likely to increase and thus bring greater income to the fishers for the same amount of fishing effort.

Although the population size of ETS *Sousa* is very small, several factors indicate that recovery is likely if fishery mortality is eliminated. Most evidence has shown that marine mammals can recover from small population sizes, as shown in Table 3. Although some individuals have shown signs of poor body condition, most photographically identified ETS *Sousa* still appear in good condition, and calves are born almost every year (Wang & Yang 2011, Wang et al. 2012).

Those species of marine mammals that have failed to recover after being reduced by hunting to low levels, such as North Atlantic right whales *Eubalena glacialis*, southern sea otters *Enhydra lutris*, and western gray whales *Eschrichtius robustus*, continued to experience human-caused mortality from entanglement, ship strikes, or other causes at a sufficiently high level to prevent recovery. The same is true for species that have suffered unsustainable

Table 3. Examples of marine mammal population recovery from very small population sizes

Species	Estimate of minimum population size (approx. year)	Most recent population size estimate (year)	Source
Northern elephant seal *Mirounga angustirostris*	20–100 (1890)	>175000 (1991)	Stewart et al. (1994)
Southern sea otter *Enhydra lutris*	50 (1914)	>2100 (2002)	Bryant (1915), US Fish & Wildlife Service (2003)
Guadalupe fur seal *Arctocephalus townsendi*	<60 (1926)	>6400 (1993)	Gallo-Reynoso (1994)
Southern right whale *Eubalaena australis*	<300 (1920)	>7500 (2008)	Jackson et al. (2008)

bycatch through long periods of time in local fisheries, such as the baiji *Lipotes vexillifer* and vaquita *Phocoena sinus*. There are no known cases of cetacean extinction resulting simply from small population size if risk factors are eliminated.

Experience with other small cetaceans shows that protected areas are effective if they are sufficiently large and effectively manage the main threats (e.g. Rojas-Bracho et al. 2006, Slooten & Dawson 2010, Gerrodette & Rojas-Bracho 2011, Gormley et al. 2012). In the case of ETS *Sousa*, this will require effective protection from bycatch throughout the entire range of this population.

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