Marine Pollution Bulletin 66 (2013) 117–124

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Impacts of marine debris on wild animals in the coastal area of Korea

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ARTICLE INFO

Keywords:
Marine debris
Entanglement
Ingestion
Threatened species
Recreational fishing gear

ABSTRACT

Over the last decade, marine debris has become a major factor affecting the coastal ecosystem of Korea. This study compiled information regarding how marine debris impacts wildlife in Korea. Cases of marine debris impacting wildlife were collected from experts of various fields and from local participants through an open access website from February 2010 to March 2012. A total of 21 species were affected by marine debris: 18 species of birds, 2 species of mammals, and 1 species of crustacean. Five threatened or protected species were identified: black-faced spoonbill, finless porpoise, water deer, whooper swan, and greater painted snipe. Recreational fishing gears were the types of debris that most frequently impacted wildlife, especially birds. Black tailed gulls were the most vulnerable species to recreational fishing hooks and lines. Although it was preliminary, this study revealed that recreational fishing activities should be prioritized when managing marine debris in Korea.

1. Introduction

Marine debris negatively affects marine ecosystems as well as navigational safety, beach aesthetic quality, and the economy (Balance et al., 2000; Donohue et al., 2001; Mouat et al., 2010). Marine biota such as seabirds, sea turtles, and marine mammals are especially vulnerable to floating, beached or sunken debris in the marine environment (Good et al., 2009; Jacobsen et al., 2010; Laist, 1987, 1997; Ryan, 1987). They can be injured or killed by getting entangled in marine debris and may frequently mistake it as food. This impact may become lethal (Derraik, 2002). Laist (1997) listed 267 species of marine animals that ingest debris or get entangled with debris in an extensive review he completed using available records and documents (e.g., Balazs, 1985; Day et al., 1985). Recent studies report that more species are increasingly being impacted by marine debris (Ceccarelli, 2009; Moore et al., 2009; Tourinho et al., 2010). Ingestion of indigestible materials may not directly lead to the death of an animal. Sub-lethal effects, such as a reduction in food ingestion and an obstruction in the gastrointestinal tract, however, are more likely to be long-term threats (Bjorndal et al., 1994; Ryan, 1987). Plastic ingestion and its biochemical impacts have recently become an international concern regarding the management of marine debris (Boerger et al., 2010; Denuncio et al., 2011; Murray and Cowie, 2011; van Franeker et al., 2011). The management of marine debris in Korea started in the late 1990s with a sunken debris retrieval program. The first National Plan for Marine Litter Management (2009–2013) was established in 2009 under the Marine Environment Management Act and has invested approximately 20 million US dollars annually on average to remove sunken and floating marine debris (MLTM et al., 2009). Nationwide bimonthly monitoring focusing on beach debris started in 2008. Since 2001, nongovernmental organizations have organized coastal cleanup activities and marine debris surveys (Hong et al., 2011). No efforts were made, however, to monitor and understand the impacts of marine debris on the biota in the coastal area of Korea.

Information regarding the types and intensity of marine debris impacts on wildlife is essential to gather in order to restore marine ecosystem integrity and productivity (e.g., Donohue et al., 2001; Page et al., 2004). Considering the spatial and temporal distribution of marine debris and their impacts on wildlife, it is very difficult for expert researchers to cover the entire range of cases. Participation of local stakeholders on a national scale can provide substantial amounts of data over large spatial and/or temporal extents (Conrad and Hilchey, 2011; Devictor et al., 2010).

This study aimed to identify types and sources of marine debris that affect wildlife in the coastal area of Korea. It also provides

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http://dx.doi.org/10.1016/j.marpolbul.2012.10.022

Table 1
Institutes and organizations that provided records of wild animal impacts caused by marine debris in the coastal area of Korea.

Classification	Organization	Data collected by
Wild life rescue center	Busan Wild Animal Treatment Center	Veterinarians
	Chungnam Wild Animal Rescue Center	Veterinarians
	Jeju Wildlife Rescue Center	Veterinarians
NGO	Korea Wild Bird Protection Association	Birdwatchers
	Jeju Wildlife Research Center	Birdwatchers
	PGA Wetland Ecology Institute	Scientists
	Our Sea of East Asia Network	Scientists
	Gang-hwa Citizens Coalition	Birdwatchers
Research Institute	Korea Institute of Ocean Science and Technology	Scientists
	Migratory Birds Center of National Park Research Institute	Veterinarians/ Scientists

implications for management policies based on data and information collected through an internet-based reporting system, which relied on voluntary participation of local people and experts.

2. Methods

A simple website (http://www.osean.net) was constructed to collect and share information on the cases of negative impacts on marine animals by marine debris in the coastal area of Korea. The website directed contributors to document the species affected and their conditions (e.g., injury types, dead or alive), the types of marine debris involved, the dates and places of detection, how the debris affected the animals, any treatment taken for the affected animals (e.g., released or disposed of dead animals), photographs of the animals and of the debris, etc. The website was open to anyone in the public who had information to report on their findings regarding the impacts of marine debris on wild animals. Participants could upload this information after an easy-to-use registration process. Experts from wildlife rescue centers, wild animal research groups, wetland protection groups, bird watching organizations, and marine pollution research institutes provided cases of animals affected by marine debris on a voluntary basis (Table 1). Their inputs were crucial in enhancing the quality of data collected for this study. Pictures of dissections or autoradiography provided by the experts were helpful in understanding the way in which animals were affected by the debris.

This study analyzed 45 cases from 55 reported cases that were collected through the website from February 2010 to March 2012. The affected species, the types of marine debris impacting the animal and their sources, the impact on the wildlife, and the relationship with foraging patterns or habitats of the species were analyzed. Ten cases were excluded from the analysis because wild animals were not involved or the impacts reported were not caused by marine debris. Some cases from inland areas, however, were included if they involved wild animals whose habitats also covered coastal areas. Cases that were caused by by-catches or active fishing gears were not included in the analysis.

3. Results

3.1. Spatial distribution of reported cases

A total of 45 cases of wild animals affected by marine debris spanning 10 years from September 2003 to March 2012 were collected for this study (Fig. 1). This does not include all of the cases of animals that were injured or killed by marine debris in the coastal areas of Korea during the time period. Many more cases were identified through personal communications with people who were involved in coastal conservation and wildlife management. They were not included in this analysis, however, due to the lack of robust records detailing the cases, such as associated photographs or documents.

Marine debris affected wild animals on all of the coasts of Korea, including the coasts of islands remote from the mainland. Busan, the largest Korean port city with a population of 3.6 million (MOPAS, 2011), had the highest number of reported cases ($n = 16$). Fourteen of these cases were observed in the estuary of Nakdong River, which enters the South Sea of Korea through the city. Jeju Island, the most famous tourist location in Korea, has a relatively well preserved ecosystem but had the second highest number of reported cases ($n = 9$); these cases were scattered around the island.

3.2. Species impacted by marine debris

A total of 21 animal species in 11 orders were affected by marine debris in 45 reported cases (Table 2). Birds were the most vulnerable animal to marine debris, accounting for 18 species in the reported cases. The remaining cases consisted of one terrestrial mammal, one marine mammal, and one crustacean. Five threatened species were among the impacted species: black-faced spoonbill *Platalea minor*, finless porpoise *Neophocaena phocaenoides*, water deer *Hydropotes inermis* (which are identified as an internationally threatened species on the IUCN red list), greater painted snipe *Rostratula benghalensis* and whooper swan *Cygnus cygnus* (which are protected by the Wildlife Protection Act of Korea). Black-faced spoonbills are also protected by Korean law.

3.2.1. Birds

Of the 18 bird species with reported cases that we analyzed, black-tailed gulls *Larus crassirostris* were the most frequent victims of marine debris impacts, as identified in 19 reported cases (42%). Incidents occurred nationwide. The black-tailed gulls were all affected by recreational fishing hooks and lines ($n = 19$, 100%). The birds most frequently ingested fishing hooks. Ingestion of and entanglement by hooks with monofilament lines attached was the next frequent impact (Fig. 2a and b). Only two reported cases involved entanglement of the animal by fishing lines. In one severe case, a black-tailed gull had a hook stuck in its oral cavity with attached fishing lines entwining the wings, head, and neck, preventing the animal from flying or foraging for food.

One young black-faced spoonbill *P. minor* had its legs entangled in plastic strings and was found nested in an artificial structure in the metropolitan city of Incheon (Figs. 1 and 2c). Its parents might have used plastic materials to build their nest. Another black-faced spoonbill had two hooks impaled in its neck, which was assumed to have caused starvation and weakness. It was released after the hooks were surgically removed.

Three whooper swans (*C. cygnus*) found in the Chungnam province had lead weights and other metallic debris in their stomachs (Fig. 2d). Their blood tests revealed serious lead poisoning. Lead levels in the blood of two whooper swans found dead in 2010 and 2012 were too high to measure (maximum concentration of the instrument used was 0.65 ppm). This indicates that ingestion of lead could be the direct cause of their deaths. A live whooper swan rescued in March 2012 had 0.65 ppm of lead in its blood, which is higher than the lead concentration of 0.5 ppm that is considered to be sub-lethal (US Fish and Wildlife Service, 1990). The poisoned swan was still under medical treatment after the lead weights were removed from it through endoscopy. All three reported cases showed several other metallic debris as well as lead weights in their X-rays (Fig. 2d), suggesting that heavy debris that

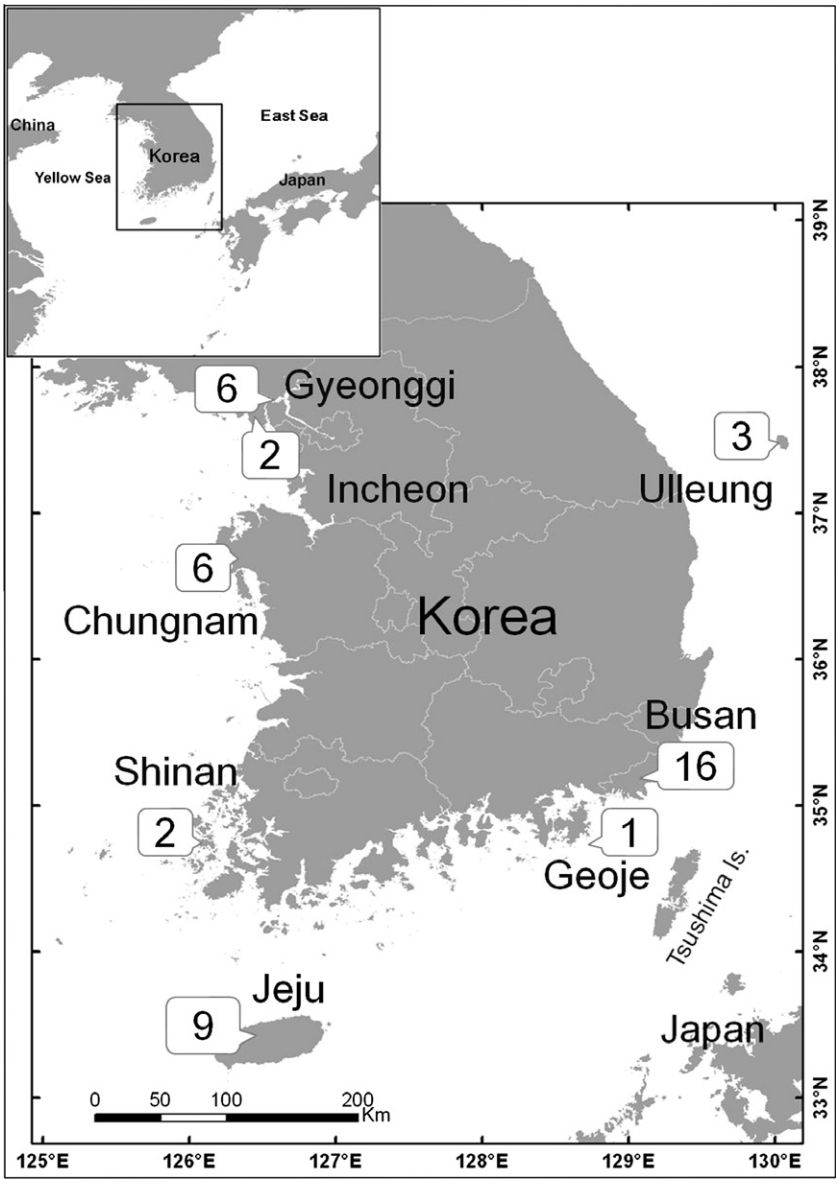

Fig. 1. Locations where wild animals were affected by marine debris in the coastal area of Korea. The numbers in the rounded squares represent the frequency of impacts and whether the impact was an entanglement or an ingestion of an item reported for each area.

has settled on the sea bottom could pose continuous threats to this natural monument species in the coastal area of Korea.

A greater painted snipe *R. benghalensis*, a protected species in Korea, was found trapped in a derelict fishing net in the Han River estuary, in the Gyeonggi province. The net was possibly installed to commercially capture crabs and eels. A serious laceration of the wing by entanglement led to its ultimate death even though it was quickly rescued.

Two cases of short-tailed shearwaters *Puffinus tenuirostris* in the order Procellariiformes were reported in Jeju Island. Examination of the carcass of a short-tailed shearwater revealed a perforated stomach ulcer that was caused by a recreational fishing hook. Another short-tailed shearwater was observed flying with a rope entangled on its wings (Fig. 2e).

A mallard *Anas platyrhynchos* was found alive in a discarded cylindrical trap, which is usually used to capture benthic organisms in the Nakdong River estuary (Fig. 2f). In the Chungnam province, two great crested grebes *Podiceps cristatus* were found tightly entangled together by a derelict fishing net, with one bird swimming on the surface and the other drowned. This was reported as one case in the analysis. Many great crested grebes were observed to construct their nests in shallow water where there was a high density of floating debris, which likely increased their risk of being impacted by marine debris.

3.2.2. Mammals

A water deer *H. inermis* was a victim of a derelict gill net in the Han River estuary in the Gyeonggi province. Its legs were entangled in the net. This led to its death because it drowned during the flood tide. A carcass of a juvenile finless porpoise *N. phocaenoides* was stranded on the shore of Shinan Island. A commercial fishing hook was found embedded in its tail fin. Impalement by the hook seemed not to be the direct cause of its death because the hook was not embedded deep within the fin.

3.2.3. Crustaceans

In a case reported for the Han River estuary in the Gyeonggi province, twenty dead De Haan's shore crabs *Sesarma dehaani* were

Table 2
Species impacted by marine debris in the coastal area of Korea. I: ingestion and E: entanglement.

Order / Species	N (%)	Marine debris (mode of impact)
Birds	42 (93.3)	
Charadriiformes		
Black-tailed gull *Larus crassirostris*	19	Recreational Fishing Hook (I, E), Recreational Fishing Hook and Line (I, E) Recreational Fishing Line (E)
Black-headed gull *Larus ridibundus*	1	Recreational Fishing Hook (I)
Slaty-backed gull *Larus schistisagus*	1	Recreational Fishing Hook (E)
Vega gull *Larus argentatus*	1	Plastic Bag (E)
Greater painted snipe *Rostratula benghalensis*[a]	1	Commercial Fishing Net (E)
Ancient murrelet *Synthliboramphus antiquus*	1	Commercial Fishing Net (E)
Pelacaniformes		
Great egret *Egretta alba (Casmerodius albus)*	2	Recreational Fishing Hook and Line (E), Plastic string (E)
Black-faced spoonbill *Platalea minor*[ab]	m	Recreational Fishing Hook (E) Plastic string (E),
Night heron *Nycticorax nycticorax*	1	Recreational Fishing Hook and Line (E)
Grey heron *Ardea cinerea*	1	Recreational Fishing Hook (E)
Temminck's cormorant *Phalacrocorax capillatus*	1	Recreational Fishing Line (E)
Anseriformes		
Whooper swan *Cygnus cygnus*[a]	3	Recreational Fishing Lead Weight and metallic gear (I)
Mallard *Anas platyrhynchos*	m	Commercial Fishing Trap (E), Commercial Fishing Net (E)
Gaviiformes		
Pacific diver *Gavia pacifica*	1	Recreational Fishing Hook (I)
Black-throated diver *Gavia arctica*	1	Recreational Fishing Hook (I)
Procellariiformes		
Short-tailed shearwater *Puffinus tenuirostris*	2	Commercial Fishing Rope (E), Recreational Fishing Hook (I)
Ciconiiformes		
Little egret *Egretta garzetta*	1	Recreational Fishing Hook (E)
Podicipediformes		
Great crested grebe *Podiceps cristatus*	1	Commercial Fishing Net (E)
Mammals	2 (4.5)	
Cetacea		
Finless porpoise *Neophocaena phocaenoides*[b]	1	Commercial Fishing Hook (E)
Artiodactyla		
Water deer *Hydropotes inermis*[b]	1	Commercial Fishing Net (E)
Crustaceans	1(2.2)	
Decopoda		
De Haan's shore crab *Sesarma dehaani*	1	Commercial Fishing Net (E)
Total (11 orders, 21 species)	45(100.0)	

[a] Protected species in Korea.
[b] Internationally threatened species (IUCN, 2011).

trapped in a derelict net. It was treated as one case of marine debris impact in this study.

3.3. Marine debris impacting wild animals

Ten types of marine debris were responsible for the negative impacts on wild animals analyzed in this study, through either ingestion or entanglement (Fig. 3). Debris from fishing activities, such as nets, hooks, ropes, lines, traps, and lead weights, was the main source of animal impacts, accounting for 93.3% (42 cases) of the reported cases. Recreational fishing contributed more to negative animal impacts ($n = 33$) than commercial fishing ($n = 9$). A total of 13 species were affected by debris from recreational fishing activities, 8 species by debris from commercial fishing, and 3 species by debris derived from packaging activities. Entanglement by debris was recorded more than ingestion of debris. Debris from recreational fishing activities was the source of all of the reported ingestion cases.

The most common item to impact wild animals was recreational fishing hooks, especially thin metal hooks smaller than 10 mm in radius (Fig. 2a and b). Recreational fishing hooks alone caused 21 reported cases, and hooks attached to monofilament lines caused 6 additional cases. Fishing lines without hooks were responsible for 3 cases, and lead weights and metallic parts of fishing gear were found in 3 cases (Figs. 2d and 3). Birds were the most frequent animals to suffer from recreational fishing hooks, with ingestion ($n = 16$) occurring more frequently than entanglement ($n = 7$) as identified by autoradiography or necropsy (Table 3). Hooks were found in various parts of birds' bodies, such as in the oral cavity ($n = 4$), the esophagus ($n = 4$), the stomach ($n = 6$), and the intestine ($n = 1$). Small hooks with bait still attached to them seemed to attract the birds to the hook for food, resulting in injuries or deaths caused by the ingestion of the hooks. Fishing lines caused entanglements in seabirds, mostly in their wings and/or legs ($n = 13$).

4. Discussion

4.1. Wild animal species affected by marine debris

More marine debris impact cases were reported in this study than previously reported, suggesting that the number of wildlife species affected by marine debris is increasing. Of the 21 species identified in this study, five bird species have already been included in previous research: black-headed gulls *Larus ridibundus* (Laist, 1997), great egrets *Egretta alba* and short-tailed shearwaters (Ceccarelli, 2009), Pacific divers *Gavia pacifica* (Moore et al., 2009), and whooper swans (Nakade et al., 2005). Our study added 16 species to the list of wildlife impacted by marine debris compiled in previous studies.

Certain species are more susceptible to being impacted by specific marine debris, which is related to their feeding or foraging

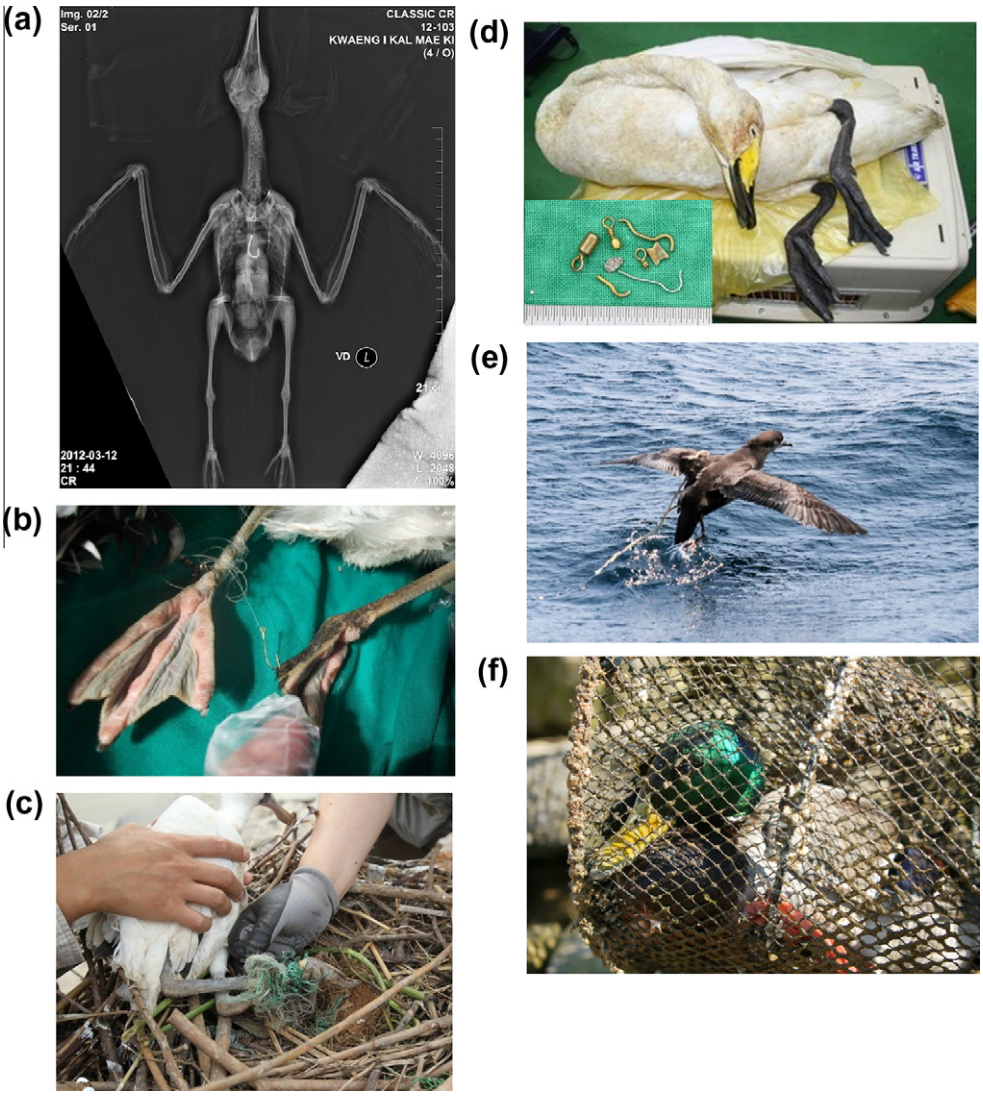

Fig. 2. Photographs of some birds damaged by marine debris in South Korea. Black-tailed gulls *Larus crassirostris* that (a) ingested a small fishing hook and (b) with a leg entwined with a monofilament line, (c) a black-faced spoonbill *Platalea minor* whose legs are tied together with plastic strings, (d) a whooper swan *Cygnus cygnus* that ingested lead weights and other metallic fishing gears (shown in the small picture), (e) a short-tailed shearwater *Puffinus tenuirostris* with a rope entangled around its body, and (f) a mallard *Anas platyrhynchos* stuck in a benthic trap.

patterns, their maturity, their body shape or their behavior (Laist, 1997; Moore et al., 2009; Stewart and Yochem, 1987). A limited number of reported cases and a lack of detailed examination of affected animals did not allow for the finding of any clear relationship between biological and ecological characteristics of animal species and types and origins of marine debris in this study. The abundance of black-tailed gulls and the intensity of recreational fishing activities on the Korean coast seem to explain the widespread distribution of impact cases regardless of season. Black-tailed gulls are only known to be distributed in Eastern Asia (Brazil, 2009) and are one of the most abundant bird species found year-round (Lee et al., 2000). As a surface-seizing and scavenging feeder, they frequently swallow bait attached to discarded hooks.

The feeding pattern of whooper swans seems to be related to lead poisoning. Whooper swans feed on tubers and stems of aquatic plants or aquatic insects (Lee, 1994) in inland reservoirs or estuarine waters. Lead weights from recreational fishing activities sink to muddy substrates where they are picked up along with tubers or stems by the birds. Lead weights dissolve in the bird's digestive track, and then lead accumulates in the animal's liver or kidneys, which can result in physiological or behavioral changes (De Francisco et al., 2003). There are many cases in which toxicity of lead weights has posed fatal threats to this species (Franson et al., 2003; O'Halloran et al., 1988).

Even though small plastics are one of the most serious marine debris found worldwide to incur ingestion-related impacts (Boerger et al., 2010; Denuncio et al., 2011; Murray and Cowie, 2011; van Franeker et al., 2011), none were found in any case analyzed in this study. This does not mean that small plastics do not impact wildlife in the coastal area of Korea. Most dead animals were examined using X-ray rather than necropsy, which may have missed the plastics. Necropsies were only performed on 4 animals. Filtering and more detailed identification of smaller-sized contents found in stomachs or intestines are needed to better understand the impacts of plastic ingestion on wild animals in the coastal area of Korea.

4.2. Management priority

The results of this study revealed that debris from recreational fishing activities could be the most important source of injury or death for wild animals, especially birds, in the coastal area of Kor-

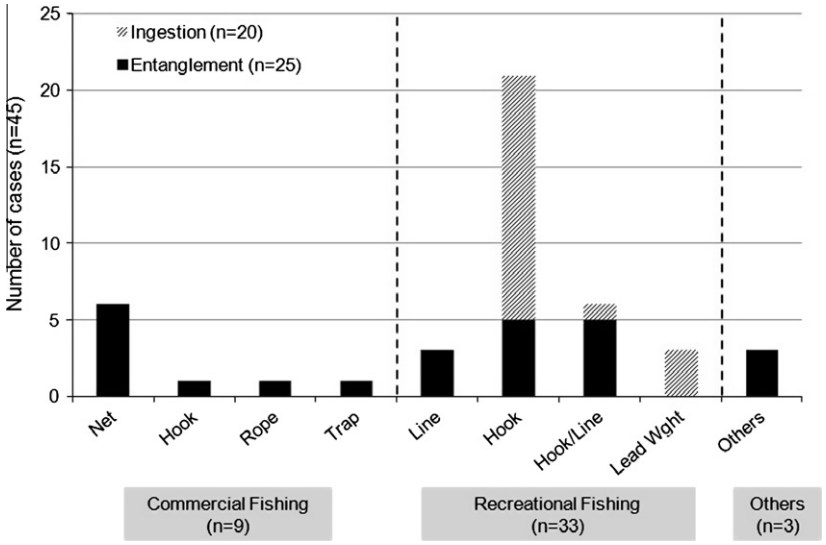

Fig. 3. Types of marine debris and their modes of impacts on wild animals in the coastal area of Korea.

Table 3
Types of impacts by recreational fishing hooks, lines, or lead weights on bird species and their body parts in the coastal area of Korea.

Debris	Species	Sections (*n*)
Hooks (*n* = 23)	Black-tailed gull *Larus crassirostris*[a]	E: bill (1), neck (1) I: oral cavity (4), esophagus (4), stomach (3), intestine (1)
	Slaty-backed gull *Larus schistisagus*[a]	E: abdomen (1)
	Black-headed gull *Larus ridibundus*	I: unknown (1)
	Black-faced spoonbill *Platalea minor*	E: neck (1)
	Short-tailed shearwater *Puffinus tenuirostris*	I: stomach (1)
	Great egret *Egretta alba*[a]	E: leg (1)
	Little egret *Egretta garzetta*	E: bill (1)
	Grey heron *Ardea cinerea*[a]	E: wing (1)
	Black-throated diver *Gavia arctica*	I: stomach (1)
	Pacific diver *Gavia pacifica*	I: stomach (1)
Lines (*n* = 16)	Black-tailed gull *Larus crassirostris*	E: bill (1), wing (6), leg (4)
	Slaty-backed gull *Larus schistisagus*	E: abdomen (1)
	Great egret *Egretta alba*	E: leg (1)
	Temminck's cormorant *Phalacrocorax capillatus*	E: wing and leg (1)
	Grey heron *Ardea cinerea*	E: wing (1)
	Night heron *Nycticorax nycticorax*	E: neck (1)
Lead weights (*n* = 3)	Whooper swan *Cygnus cygnus*	I: stomach (3)

[a] Cases from hooks attached to monofilament lines were double counted. E: entanglement and I: ingestion (*n* = frequency of occurrence).

ea. This suggests that management of recreational fishing should be given a top priority in reducing the impacts of marine debris on wild animals. Korean recreational fishers are estimated to be 3–8 million people (6–16% of the total population) (Lee, 2010). There is, however, no reliable estimation of how much fishing gears, such as small hooks and monofilament lines enter the coastal environment of Korea by the negligence of recreational fishers.

The Recreational Fishing Management Act (2011), which took effect in September 2012, may play a crucial role in managing marine debris from recreational fishing activities. The act prohibits the dumping of fishing gear and bait. It is, however, doubtful whether the act will be efficiently implemented. There are a limited number of central and local government officials in spite of a wide geographic range of recreational fishing sites and a high number of recreational fishers in Korea. In this regard, marine debris watchdogs included in the act could be used as an effective tool to fill the possible gap in the implementation of the act, together with education programs also stipulated in the act.

Three whooper swans that had very high concentrations of lead in their blood provide a strong case for the management of debris containing lead. Several countries are restricting the use of lead fishing weights in protected or ecologically sensitive areas (De Francisco et al., 2003). The Recreational Fishing Management Act prohibits the use of environmentally hazardous materials in fishing tackles but does not specify whether the use of lead weights is not permitted. Lead weights should also be restricted by this regulation, at least for use in and around protected areas. Alternatives to lead should be made available for recreational fishers, and they should be encouraged to use such alternatives.

4.3. Implications for protected species management

Marine debris needs to be considered as an important factor in managing threatened or protected species in the coastal area of Korea. Laist (1987) suggested that marine debris is one of the factors that are responsible for the decrease in the population of threatened species, even though the impacts of marine debris are difficult to measure. A total of 5 threatened or protected species were identified in the reported cases analyzed in this study (Table 2).

Current biodiversity management policies of Korea, such as the Biodiversity Conservation Act and Wildlife Protection Act, do not

treat marine debris as a significant management issue. This study has showed that impacts of marine debris on threatened or protected species should therefore be included in biodiversity management policies. Marine ecosystem monitoring programs, including coastal wetland monitoring programs, in protected areas and ecologically important sites need to be expanded to include surveys of the distribution of marine debris and to assess the potential impact on the wildlife.

4.4. Value of participatory data collection

A network of local activists and experts could be an excellent tool in monitoring and documenting the impacts of marine debris on wild animals. The online data and information collection system used for this study provided a gateway for the local activists and experts to open and share the impact cases that had not been previously widely circulated. They reported 45 cases in which 21 species of wildlife were impacted by marine debris. Considering the limited spatial and temporal coverage of expert researchers that participated in this study, this study could supply baseline information on the impacts of marine debris on wildlife in the coastal area of Korea. In-depth analysis and documents supplied by experts from various conservation and environmental research fields were essential in enhancing the quality of data and information provided by non-expert participants. For example, photographs provided by participants were used to check the accuracy of species identification, making it possible to avoid the problem of credibility, which is common in non-expert surveys (Conrad and Hilchey, 2011). This complementary interaction of various groups through an open access internet-based system will benefit both local participants and experts in conducting surveys and research on the impacts of marine debris on wildlife nationwide.

This study demonstrated a new approach in raising public awareness on the issue of marine debris in Korea. We used an online fundraising program supported by a foundation related to the biggest internet portal site in the country. The website (happy-log.naver.com/osean.do) briefly explained what marine debris is, how it is produced and how it can impact wildlife in the coastal area of Korea. It has been exposed to unspecified internet users, asking to donate money for the survey. About 9000 individuals donated approximately 3000 USD for this study. The fundraising program itself was an excellent tool in raising public awareness on the impacts of marine debris on wildlife.

Acknowledgements

This study would have been impossible without the participation of researchers, volunteers, and institutions nationwide. We appreciate all of the individuals who provided their data and their information for this study: Busan Wild Animal Treatment Center, Jeju Wildlife Rescue Center, Mr. Jongsu Choi at the Korea Wild Bird Protection Association, Mr. Namjun Ji and Mr. Heeman Kang at the Jeju Wildlife Research Center, Gang-hwa Citizens Coalition, Dr. Kee-seop Lee at the Korea Waterbirds Network, Dr. Chang Yong Choi at the East Asia Australia Flyway Partnership, and Cherwon Natural Monument Care Center. We greatly appreciate all of the donors who made this study possible, as well as the Happy Bean Foundation, who organized the fundraising program. W.J. Shim was supported by a research fund from KIOST (PE98815).

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